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RENESAS

User's Manual

CC78K0S Ver. 2.00

C Compiler

Language

Target Device
78K0S Microcontrollers

Document No. U17415EJ2V0UM00 (2nd edition)
Date Published August 2007

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INTRODUCTION

The **CC78K0S C Compiler** (hereinafter referred to as this C compiler) was developed based on **CHAPTER 2 ENVIRONMENT** and **CHAPTER 3 LANGUAGE** in the **Draft Proposed American National Standard for Information Systems — Programming Language C** (December 7, 1988). Therefore, by compiling C source programs conforming to the ANSI standard with this C compiler, applied products for the 78K0S Microcontrollers can be developed.

The **CC78K0S C Compiler Language** (this manual) has been prepared to give those who develop software by using this C compiler a correct understanding of the basic functions and language specifications of this C compiler.

This manual does not cover how to operate this C compiler. Therefore, after you have comprehended the contents of this manual, read the **CC78K0S C Compiler Operation (U17416E)**.

For the architecture of 78K0S Microcontrollers, refer to the user's manual of each product of 78K0S Microcontrollers.

[Target Devices]

Software for the 78K0S Microcontrollers can be developed with this C compiler.
Note that an optional device file corresponding to a target device is necessary.

[Readers]

Although this manual is intended for those who have read the user's manual of the microcontroller subject to software development and have experience in software programming, the readers need not necessarily have a knowledge of C compilers or C language. Discussions in this manual assume that the readers are familiar with software terminology.

[Organization]

This manual consists of the following 13 chapters and appendixes:

Chapter 1 - GENERAL
Outlines the general functions of C compilers and the performance characteristics and features of this C compiler.

Chapter 2 - CONSTRUCTS OF C LANGUAGE
Explains the constituting elements of a C source module file.

Chapter 3 - DECLARATION OF TYPES AND STORAGE CLASSES
Explains the data types and storage classes used in C and how to declare the type and storage class of a data object or function.

Chapter 4 - TYPE CONVERSIONS
Explains the conversions of data types to be automatically carried out by this C compiler.

Chapter 5 - OPERATORS AND EXPRESSIONS
Describes the operators and expressions that can be used in C and the precedence of operators.

Chapter 6 - CONTROL STRUCTURES OF C LANGUAGE
Explains the program control structures of C and the statements to be executed in C.

Chapter 7 - STRUCTURES AND UNIONS
Explains the concept of structures and unions and how to refer to structure and union members.

Chapter 8 - EXTERNAL DEFINITIONS
Describes the types of external definitions and how to use external declarations.

Chapter 9 - PREPROCESSOR DIRECTIVES (COMPILER DIRECTIVES)
Details the types of preprocessing directives and how to use each preprocessor directive.

Chapter 10 - LIBRARY FUNCTIONS
Details the types of C library functions and how to use each library function.

Chapter 11 - EXTENDED FUNCTIONS
Explains the extended functions of this C compiler to make the most of the target device.

Chapter 12 - REFERENCING THE ASSEMBLER
Describes the method of linking a C source program with a program written in Assembly language.

Chapter 13 - EFFECTIVE UTILIZATION OF COMPILER
Outlines how to effectively use this C compiler.

APPENDIXES
Contains a list of labels for **saddr** area, a list of segment names, a list of runtime libraries, a list of library stack consumption, and index for quick reference.

[How to Read This Manual]

- For those who are not familiar with C compilers or C language:
  Read from **Chapter 1**, as this manual covers from the program control structures of C to the extended functions of this C compiler. In **Chapter 1**, an example of C source program is used to show the reference part in this manual.
- For those who are familiar with C compilers or C language:
  The language specifications of this C compiler conform to the **ANSI Standard C**. Therefore, you may start from **Chapter 11** that explains the extended functions unique to this C compiler. When reading **Chapter 11**, also refer to the user's manual supplied with the target device in the 78K0S Microcontrollers if necessary.

[Related Documents]

The table below shows the documents (such as user's manuals) related to this manual. The related documents indicated in this publication may include preliminary versions. However, preliminary versions are not marked as such.

Documents related to development tools (user's manuals)

Document Name		Document No.
CC78K0S Ver. 2.00 C Compiler	Operation	U17416E
	Language	This document
RA78K0S Ver. 2.00 Assembler Package	Operation	U17391E
	Language	U17390E
	Structured assembly language	U17389E
SM+ System Simulator	Operation	U18601E
	User Open Interface	U18212E
SM78K Series Ver. 2.52 System Simulator	Operation	U16768E
PM+ Ver. 6.30 Project Manager		U18416E
ID78K0S-NS Ver. 2.52 Integrated Debugger	Operation	U16584E
ID78K0S-QB Ver. 3.00 Integrated Debugger	Operation	U17287E

[Reference]

Draft Proposed American National Standard for Information Systems - Programming Language C (December 7, 1988)

[Terms]

RTOS = **78K0 Microcontrollers Real-time OS RX78K0**

[Conventions]

The following symbols and abbreviations are used in this manual:

Symbol	**Meaning**
⋮	: Continuation (repetition) of data in the same format
" "	: Characters enclosed in a pair of double quotes must be input as is.
' '	: Characters enclosed in a pair of single quotes must be input as is.
:	: This part of the program description is omitted.
/	: Delimiter
\	: Backslash
[ ]	: Parameters in square brackets may be omitted.

[MEMO]

CONTENTS

LIST OF FIGURES

Figure No. Title , Page

LIST OF TABLES

Table No. Title , Page

CHAPTER 1 GENERAL

This chapter explains the roles of the CC78K0S at the time of system development and functional outlines of the C Compiler.

The CC78K0S Series C Compiler is a language processing program which converts a source program written in the C language for the 78K0S Series or ANSI-C into machine language. By the CC78K0S Series C compiler, object files or assembler source files for the 78K0S Series can be obtained.

1.1 C Language and Assembly Language

To have a microcontroller do its job programs and data are necessary. These programs and data must be written by a user being and stored in the memory section of the microcontroller. Programs and data that can be handled by the microcontroller are nothing but a set or combination of binary numbers that is called machine language.

An assembly language is a symbolic language characterized by one-to-one correspondence of its symbolic (mnemonic) statements with machine language instructions. Because of this one-to-one correspondence, the assembly language can provide the computer with detailed instructions (for example, to improve I/O processing speed). However, this means that the user must instruct each and every operation of the computer. For this reason, it is difficult for him or her to understand the logic structure of the program at glance and the user is likely to make errors in coding.

High-level languages were developed as substitutes for such assembly languages. The high-level languages include a language called C that allows the user to write a program without regard to the architecture of the computer.

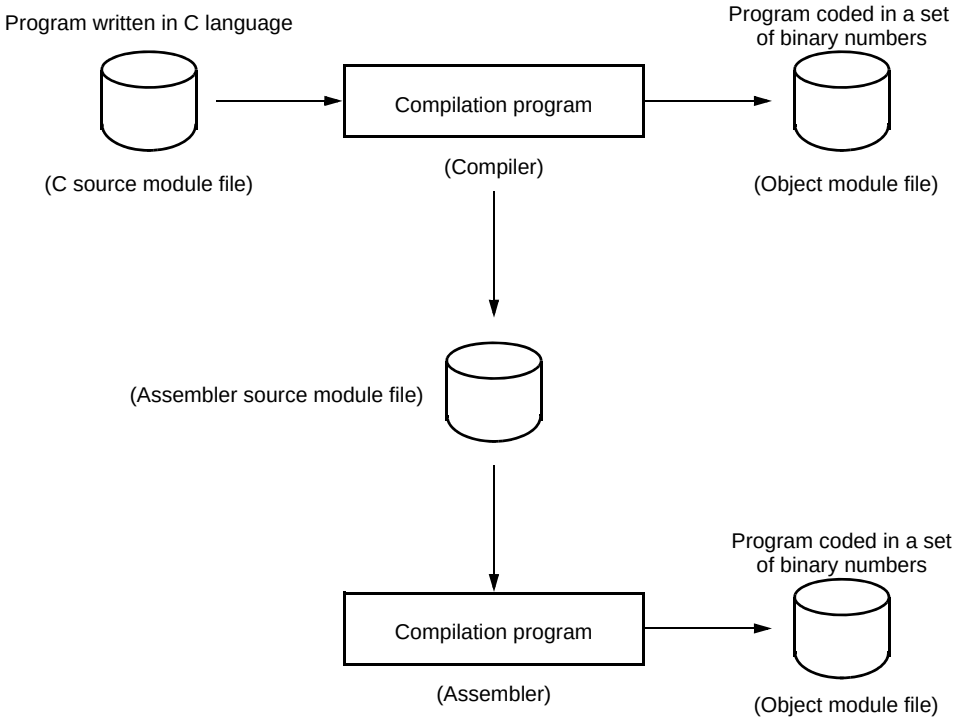
As compared with assembly language programs, it can be said that programs written in C have easy-to-understand logic structure.

C has a rich set of parts called functions for use in creating programs. In other words, the user can write a program by combining these functions.

C is characterized by its ease of understanding by user beings. However, understanding of languages by the microcontroller cannot be extended up to a program written in C. Therefore, to have the computer understand the C language program, another program is required to translate C language statements to the corresponding machine language instructions. A program that translates the C language into machine language is called a C compiler.

C compiler accepts C source modules as inputs and generates object modules or assembler source modules as outputs. Therefore, the user can write a program in C and if he or she wishes to instruct the computer up to details of program execution, the C source program can be modified in assembly language. The flow of translation by C compiler is illustrated in Figure 1-1.

Figure 1-1 Flow of Compilation



1.2 Program Development Procedure by C Compiler

Product (program) development by the C compiler requires a linker which unites together object module files created by the compiler, a librarian which creates library files, and a debugger which locates and corrects bugs (errors or mistakes) in each created C source program.

1.2.1 Software required

software requiredThe software required in connection with C compiler is shown below.

- Editor : for source module file creation
- RA78K0S assembler package

  Structured assembler preprocessor : for achieving structured programming via the assembly language
  Assembler : for converting assembly language into machine language
  Linker : for linking object module files
  for determining location address of relocatable segment
  Object converter : for conversion to HEX-format object module file
  Librarian : for creating library files
  List converter : for output of an absolute assemble list file
  PM+ : integrated development environment platform
- Integrated debugger (for 78K0S) : for debugging C source module files

1.2.2 product development procedure

The product development procedure by the C compiler is as shown below.

(1) Divide the product into functions.

(2) Creates a C source module for each function.

(3) Translates each C source module.

(4) Registers the modules to be used frequently in the library.

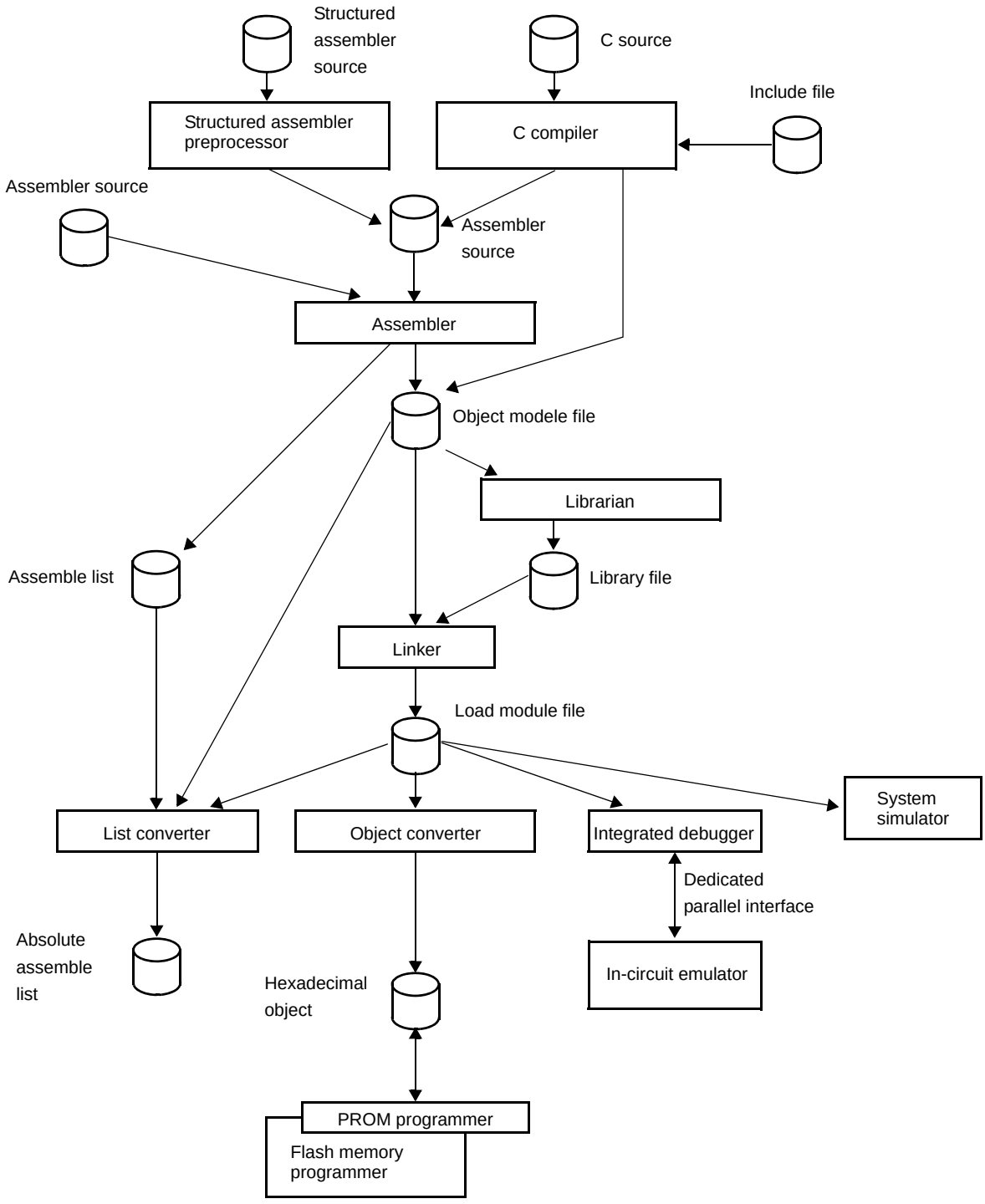
(5) Links object module files.

(6) Debugs each module.

(7) Converts object modules into HEX-format object files.

As mentioned earlier, C compiler translates (compiles) a C source module file and creates an object module file or assembler source module file. By manually optimizing the created assembler source module file and embedding it into the C source, efficient object modules can be created. This is useful when high-speed processing is a must or when modules must be made compact.

Figure 1-2 Program Development Procedure by the CC78K0S

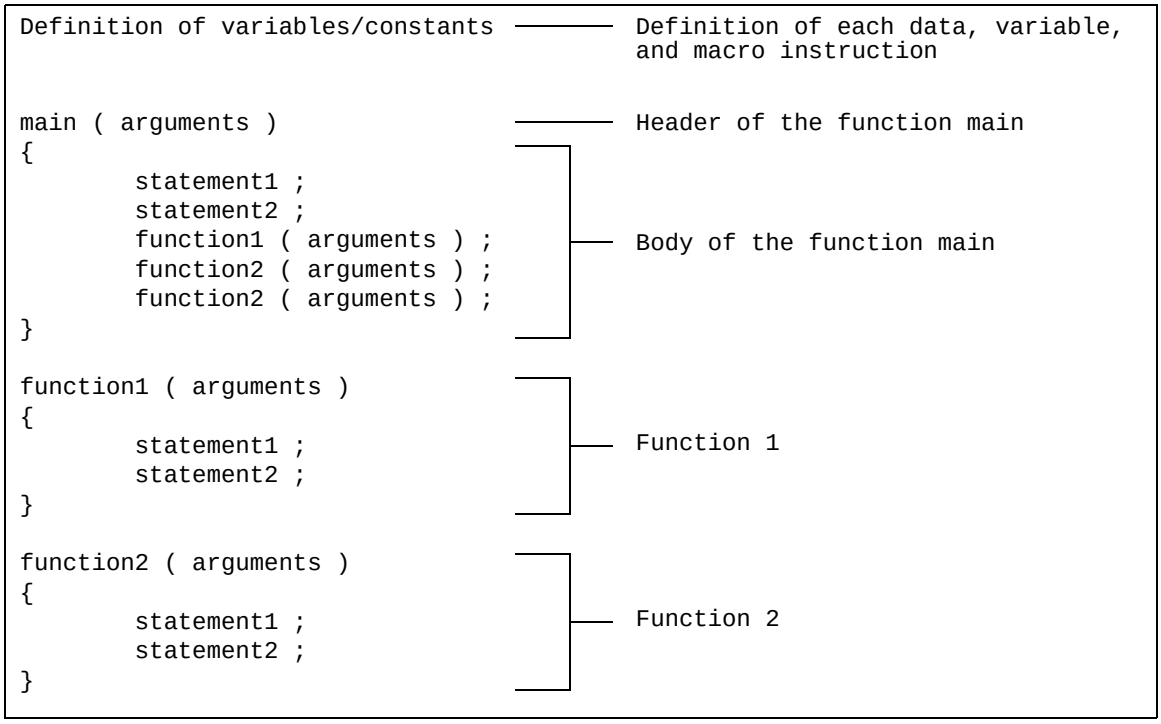


1.3 Basic Structure of C Source Program

1.3.1 Program format

A C language program is a collection of functions. These functions must be created so that they have independent special-purpose or characteristic actions. All C language programs must have a function main which becomes the main routine in C and is the first function that is called when execution begins.

Each function consists of a header part, which defines its function name and arguments, and a body part, which consists of declarations and statements. The format of C programs is shown below.



An actual C source program looks like this.

```
#define TRUE    1
#define FALSE   0          #define xxx xxx /* Preprocessor directive */
#define SIZE    200                        /* (macro definition) (6) */

void    printf ( char* , int ) ;          xxx xxxx ( xxx , xxx )
                                          /* Function prototype declarator (7) */
void    putchar ( char ) ;

char    mark [ SIZE + 1 ] ;               char xxx        /* Type declarator (1) */
                                                          /* External definition (5) */
main ( )                                  xx [ xx ]       /* Operator (2) */
{
    int     i , prime , k , count ;       int xxx   /* Type declarator (1) */

    count = 0 ;                           xx = xx   /* Operator (2) */

    for ( i = 0 ; i <= SIZE ; i ++ )        for ( xx ; xx ; xx ) xxx ;
        mark [ i ] = TRUE ;                 /* Control structure (3) */

    for ( i = 0 ; i <= SIZE ; i ++ ) {
        if ( mark [ i ] ) {
            prime = i + i + 3 ;           xxx = xxx + xxx + xxx /* Operator (2) */
            printf ( " %6d " , prime ) ;  xxx ( xxx ) ;  /* Operator (2) */

                        count ++ ;
            if ( ( count%8 ) == 0 ) putchar ( ' \n ' ) ;  if ( xxx ) xxx ;
                                                    /* Control structure (3) */
                for ( k = i + prime ; k <= SIZE ; k += prime )
                    mark [ k ] = FALSE ;
        }

    printf ( " \n%d primes found.  " , count ) ;  xxx ( xxx ) ;
                                                    /* Operator (2) */
}

void    printf ( char *s , int i )
{
    int     j ;
    char    *ss ;

    j = i ;
    ss = s ;
}

void    putchar ( char c )
{
    char    d ;
    d = c ;
}
```

(1) Declaration of type and storage class

The data type and storage class of an identifier that indicates a data object are declared. For details, see "CHAPTER 3 DECLARATION OF TYPES AND STORAGE CLASSES".

(2) Operator and expression

These are the statements, which instructs the compiler to perform an arithmetic operation, logical operation, assignment, or like. For details, see "CHAPTER 5 OPERATORS AND EXPRESSIONS".

(3) Control structure

This is a statement that specifies the program flow. C has several instructions for each of control structures such as Conditional control, Iteration, and Branch. For details, see "CHAPTER 6 CONTROL STRUCTURES OF C LANGUAGE".

(4) Structure or union

A structure or union is declared. A structure is a data object that contains several subobjects or members that may have different types. A union is defined when two or more variables share the same memory. For details, see "CHAPTER 7 STRUCTURES AND UNIONS".

(5) External definition

A function or external object is declared. A function is 1 element when a C language program is divided by a special-purpose or characteristic action. A C program is a collection of these functions. For details, see "CHAPTER 8 EXTERNAL DEFINITIONS".

(6) Preprocessor directive

This is an instruction for the compiler. #define instructs the compiler to replace a parameter which is the same as the first operand with the second operand if the parameter appears in the program. For details, see "CHAPTER 9 PREPROCESSOR DIRECTIVES (COMPILER DIRECTIVES)".

(7) Declaration of function prototype

The return value and argument type of a function are declared.

1.4 Maximum Performance Characteristics of C Compiler

Before you set your hand to the development of a program, keep in mind the points (limit values or minimum guaranteed values) summarized in Table 1-1 below.

Table 1-1 Maximum Performance Characteristics of C Compiler

Item	Limit Value/Min. Guaranteed Value
Nesting level of compound statements, looping statements, or conditional control statements	45 levels
Nesting of conditional translations	255 levels
Number of arithmetic type, structure type, pointer to qualify union type or incomplete type, array, and function declarator in a declaration (or any combination of these).	12 levels
Nesting of parentheses per expression	32 levels
Number of characters which have a meaning as a macro name	256 characters
Number of characters which have a meaning as an internal or external symbol name	249 characters
Number of symbols per source module file	1,024 symbols[Note 1]
Number of symbols which has block scope within a block	255 symbols[Note 1]
Number of macros per source module file	10,000 macros[Note 2]
Number of parameters per function definition or function call	39 parameters
Number of parameters per macro definition or macro call	31 parameters
Number of characters per logical source line	2048 characters
Number of characters within a string literal after linkage	509 characters
Size of 1 data object	65,535 bytes
Nesting of #include directives	8 levels
Number of case labels per switch statement	257 labels
Number of source lines per translation unit	Approx. 30,000 lines
Number of source lines that can be translated without temporary file creation	Approx. 300 lines
Nest of function calls	40 levels
Number of labels within a function	33 labels
Total size of code, data, and stack segments per object module	65,535 bytes
Number of members per structure or union	256 members
Number of enum constants per enumeration	255 constants
Nest of structures or unions inside a structure or union	15 levels
Nest of initializer elements	15 levels
Number of function definitions in 1 source module file	1,000

Table 1-1 Maximum Performance Characteristics of C Compiler

Item	Limit Value/Min. Guaranteed Value
Level of the nest of declarator enclosed with parentheses inside a complete declarator.	591
Nest of macros	200
Number of -i include file path specifications	64

Notes 1. This value applies when symbols can be processed with the available memory space alone without using any temporary file. When a temporary file is used because of insufficient memory space, this value must be changed according to the file size.

Notes 2. This value includes the reserved macro definitions of the C compiler.

1.5 Features of C Compiler

The CC78K0S has extended functions for CPU code generations that are not supported by the ANSI (American National Standards Institute) Standard C. The extended functions of the C compiler allow the special function registers for the 78K0S Series to be described at the C language level and thus help shorten object code and improve program execution speed.

Outlined here are the following extended functions to help shorten object code and improve execution speed :

- Functions can be called using the callt table area. : callt /__callt functions
- Variables can be allocated to registers. : Register variables
- Variables can be allocated to the saddr area. : sreg/__sreg
- sfr names can be used. : sfr area
- Functions that do not output code for stack frame formation can be created. : noauto functions, norec/__leaf functions
- An assembly language program can be described in a C source program : ASM statements
- Accessing the saddr or sfr area can be made on a bit-by-bit basis. : bit type variables, boolean/__boolean type variables
- A bit field can be specified with unsigned char type. : Bit field declaration
- The code to multiply can be directly output with inline expansion. : Multiplication function
- The code to divide can be directly output with inline expansion. : Division function
- The code to rotate can be directly output with inline expansion. : Rotate function
- Specific addresses in the memory space can be accessed. : Absolute address function
- Specific data and instructions can be directly embedded in the code area. : Data insertion function
- The used stack is corrected on the called function side. : __pascal function
- memcpy and memset are directly expanded inline and output. : Memory manipulation function

An outline of the expansion functions of the CC78K0S is shown below. For details of each expansion function, please refer to "CHAPTER 11 EXTENDED FUNCTIONS".

(1) callt functions (callt / __callt)

Functions can be called by using the callt table area. The address of each function to be called (this function is called a callt function) is stored in the callt table from which it can be called later. This makes code shorter than the ordinary call instruction and helps shorten object code.

(2) Register variables (register)

Variables declared with the register storage class specifier are allocated to the register or saddr area. Instructions to the variables allocated to the register or saddr area are shorter in code length than those to memory. This helps shorten object and improves program execution speed as well.

(3) How to use the saddr area (sreg / __sreg)

Variables declared with the keyword sreg can be allocated to the saddr area. Instructions to these sreg variables are shorter in code length than those to memory. This helps shorten object code and also improves program execution speed. Variables can be allocated to the saddr area also by option.

(4) How to use the sfr area (sfr)

By declaring use of sfr names, manipulations on the sfr area can be described at the C source file.

(5) noauto functions (noauto)

Functions declared as noauto do not output code for preprocessing and post-processing (stack frame formation). By calling a noauto function, arguments are passed via registers. This helps shorten object code and improve program execution speed as well. This function has restrictions with argument/automatic variables. For the details, refer to Section "11.5 (5) noauto functions (noauto)".

(6) norec functions (norec)

Functions declared as norec/__leaf do not output code for preprocessing and post-processing (stack frame formation). By calling a norec/__leaf function, arguments are passed via registers as much as possible. Automatic variables to be used inside a norec/__leaf function are allocated to register or the saddr area. This helps shorten object code and also improve program execution speed. This function has restrictions with argument/automatic variables and is not allowed to call a function. A function call is not performed using this function. For the details, refer to Section "11.5 (6) norec functions (norec)".

(7) bit type variables, boolean type variables (bit / boolean / __boolean)

Variables having a 1-bit storage area are generated. By using the bit type variable or boolean/__boolean type variable, the saddr area can be accessed in bit units.

The boolean/__boolean type variable is the same as the bit type variable in terms of both function and usage.

(8) ASM statements (#asm #endasm / __asm)

The assembler source program described by the user can be embedded in an assembler source file to be output by the CC78K0S.

(9) Interrupt functions (#pragma vect / #pragma interrupt)

The preprocessor directive outputs a vector table and outputs an object code corresponding to the interrupt. This directive allows programming of interrupt functions in the C source level.

(10) Interrupt function qualifier (__interrupt)

This qualifier allows the setting of a vector table and interrupt function definitions to be described in a separate file.

(11) Interrupt functions (#pragma DI, #pragma EI)

An interrupt disable instruction and an interrupt enable instruction are embedded in the object.

(12) CPU control instruction (#pragma HALT / STOP / NOP)

Each of the following instruction is embedded in the object :

- halt Instruction
- stop Instruction
- nop instruction

(13) Absolute address access function (#pragma access)

Codes that access the ordinary memory space are created through direct in-line expansion without resort to a function call, and an object file is created.

(14) Bit field declaration

By specifying a bit field to be unsigned char type, the memory can be saved, object code can be shortened, and execution speed can be improved.

(15) Changing compiler output section name (#pragma section ...)

By changing the compiler section output name, the section can be independently allocated with a linker.

(16) Binary constant (Binary constant 0bxxx)

Binary can be described in the C source.

(17) Module name changing function (#pragma name)

Object module names can be freely changed in the C source.

(18) Rotate function (#pragma rot)

The code to rotate the value of an expression to the object can be directly output with inline expansion.

(19) Multiplication function (#pragma mul)

The code to multiply the value of an expression to the object can be directly output with inline expansion. This function can shorten the object code and improve the execution speed.

(20) Division function (#pragma div)

The code to divide the value of an expression to the object can be directly output with inline expansion. This function can shorten the object code and improve the execution speed.

(21) BCD operation function (#pragma bcd)

This function uses direct inline expansion to output the code that performs a BCD operation on the operation value in an object. A BCD operation is an operation for converting each digit of a decimal number into binary and storing it in 4 bits.

(22) Data insertion function (#pragma opc)

Constant data is inserted in the current address. Specific data and instructions can be embedded in the code area without using assembler description.

(23) Static model

Specifying the -sm option during compilation enables the shortening of object codes, improvement of execution speed, realization of high-speed interrupt processing, and saving of memory space.

(24) Type modification (-zi)

By specifying the -zi option and -zl option, int/short types are regarded as char type, and long type is regarded as int type.

(25) Pascal function (__pascal)

The stack correction used for placing arguments during the function call is performed on the function callee, not on the function caller. This shortens the object code when a lot of function call appears.

(26) Automatic pascal functionization of function call interface (-zr)

By specifying the -zr option during compilation, the __pascal attribute is added to functions other than the norec/__interrupt/variable length argument functions.

(27) Method of int expansion limitation of argument/return value (-zb)

By specifying the -zb option during compilation, the object code can be shortened and execution speed can be improved.

(28) Array offset calculation simplification method (-qw2 / -qw4)

By specifying the -qw2 and -qw4 options during compilation, the offset calculation code is simplified, the object code is shortened, and the execution speed is improved.

(29) Register direct reference function (#pragma realregister)

Register access can be made easily by the C specification by coding this function in the source in the same format as the function call or by declaring the use of this register direct reference function by the #pragma realregister directive in the module.

(30) Memory manipulation function (#pragma inline)

By #pragma inline directive, an object file is generated by the output of the standard library functions memcpy and memset with direct inline expansion instead of function call. This function can improve the execution speed.

(31) Absolute address allocation specification (__directmap)

By declaring __directmap in the module in which the variable to be allocated to an absolute address is to be defined, one or more variables can be allocated to the same arbitrary address.

(32) Static model expansion specification (-zm)

By specifying the -zm option during compilation, restrictions on existing static models can be relaxed, improving descriptiveness.

(33) Temporary variables (__temp)

By specifying the -sm and -zm options during compilation and declaring __temp for arguments and automatic variables, an area for arguments and automatic variables can be reserved.

In addition, if the sections containing arguments and those containing automatic variables are clearly identified and the __temp declaration is applied to variables that do not require a guaranteed value match before and after a function call, memory can be reserved.

(34) Library supporting prologue/epilogue (-zd)

By specifying the -zd option during compilation, the prologue/epilogue code can be replaced by a library, shortening the object code.

CHAPTER 2 CONSTRUCTS OF C LANGUAGE

This chapter explains the constituting elements of a C source module file.

A C source module file consists of the following tokens (distinguishable units in a sequence of characters).

Keywords	Identifiers	Constants
String literal	Operators	Delimiters
Header name	No. of preprocesses	Comment

The tokens used in the C program description example are shown below.

```
#include    " expand.h "
extern      void    testb ( void ) ;        extern          /* Keyword */
extern      void    chgb ( void ) ;
extern      bit     data1 ;                 data1 , data2   /* Identifiers */
extern          bit     data2 ;

void    main ( )                            void            /* Keyword */
{
        data1 = 1 ;                         1               /* Constant */
        data2 = 0 ;                         0               /* Constant */

        while ( data1 ) {                   while           /* Keyword */
                data1 = data2 ;             { }             /* Delimiter */
                testb ( ) ;                 =               /* Operator */
        }
        if ( data1 && data2 ) {             if              /* Keyword */
                chgb ( ) ;                  &&              /* Operator */
        }                                   ( )             /* Operator */
}

void    lprintf ( char *s , int i )         lprintf         /* Identifiers */
{                                           char , int      /* Keyword */
        int     j ;                         s , I           /* Identifiers */
        char    *ss ;                       *               /* Operator */
        j = i ;
        ss = s ;
}
            :
```

2.1 Character Sets

2.1.1 Character sets

Character sets to be used in C programs include a source character set to be used to describe a source file and an execution character set to be interpreted in the execution environment.

The value of each character in the execution character set is represented by JIS code.

The following characters can be used in the source character set and execution character set :

Table 2-1 List of Characters that can be used in the Character Set

```
26 uppercase letters
       A  B  C  D  E  F  G  H  I  J  K  L  M
       N  O  P  Q  R  S  T  U  V  W  X  Y  Z
26 lowercase letters
       a  b  c  d  e  f  g  h  i  j  k  l  m
       n  o  p  q  r  s  t  u  v  w  x  y  z
10 decimal numbers
       0  1  2  3  4  5  6  7  8  9
29 graphic characters
       !  "  #  %  &  '  (  )  *  +  ,  -  .  /  :
       ;  <  =  >  ?  [  \  ]  ^  _  {  |  }  ~
and nonprintable control characters which indicate Space, Horizontal Tab,
Vertical Tab, Form Feed, etc. (see ESCAPE sequences below.)
```

Remark In character constants, string literal, and comment statements, characters other than above may also be used.

2.1.2 ESCAPE sequences

Nongraphic characters used for control characters as for alert, formfeed, and such are represented by ESCAPE sequences. Each ESCAPE sequence consists of the \ sign and an alphabetic character.

Nongraphic characters represented by ESCAPE sequences are shown below.

Table 2-2 List of ESCAPE Sequences

ESCAPE Sequence	Meaning	Character Code
\a	Alert	07H
\b	Backspace	08H
\f	Formfeed	0CH
\n	New Line	0AH
\r	Carriage Return	0DH
\t	Horizontal Tab	09H
\v	Vertical Tab	0BH

2.1.3 Trigraph sequences

When a source file includes a list of the 3 characters (called "trigraph sequence") shown in the left column of the table below, the list of the 3 characters is converted into the corresponding single character shown in the right column.

The trigraph sequence is enabled when the compiler option -za (the option that disables the functions which do not comply with ANSI specifications and enables a part of functions of ANSI specifications) is specified.

Table 2-3 List of Trigraph Sequence

Trigraph Sequence	Meaning
??=	#
??(	[
??/	\
??)	]
??’	^
??<	{
??!	|
??>	}
??-	~

2.2 Keywords

2.2.1 ANSI-C keywords

The following tokens are used by the C compiler as keywords and thus cannot be used as labels or variable names.

Table 2-4 List of ANSI-C Keywords

auto	break	case	char	const	continue	default
do	double	else	enum	extern	for	float
goto	if	int	long	register	return	short
signed	sizeof	static	struct	switch	typedef	union
unsigned	void	volatile	while			

2.2.2 Keywords added for the CC78K0S

In the CC78K0S the following tokens have been added as keywords to implement its expanded functions. These tokens cannot be used as labels or variable names nor can ANSI (when an uppercase character is included, the token is not regarded as a keyword).

Keywords which do not start with "__" can be made invalid by specifying the option (-za) that enables only ANSI-C language specification.

callf, __callf, rtos_interrupt, and interrupt_brk are taken as keywords for compatibility with the CC78K0.

Table 2-5 List of Keywords added for the CC78K0S

__callt / callt :	Declaration of callt function
__callf / callf :	Declaration of callf function
__sreg / sreg :	Declaration of sreg variable
noauto :	Declaration of noauto function
__leaf / norec :	Declaration of norec function
bit :	Declaration of bit type variable
__boolean / boolean :	Declaration of boolean type variable
__interrupt :	Hardware interrupt function
__interrupt_brk :	Software interrupt function
__asm :	asm statement
__rtos_interrupt :	Interrupt handler for RTOS
__pascal :	Pascal function
__flash :	Firmware ROM function
__directmap :	Absolute address allocation specification
__temp :	Temporary variable
__mxcall :	__mxcall function[Note]

Note Reserved keyword for interface with MX. This keyword must not be used by users.

2.3 Identifiers

An identifier is the name that you give to a variable such as :

Table 2-6 List of Identifiers

Function
Object
Tag of structure, union, or enumeration type
Member of structure, union, or enumeration type
typedef name
Label name
Macro name
Macro parameter

Each identifier can consist of uppercase letters, lowercase letters, or numeric characters including underscores. The following characters can be used as identifiers :

There is no restriction for the maximum length of the identifier. In the CC78K0S, however, only the first 249 characters can be identified.

Table 2-7 Numbers and Characters for Identifiers

_ (underscore)
a b c d e f g h i j k l m n o p q r s t u v w x y z
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
0 1 2 3 4 5 6 7 8 9

All identifiers must begin with other than a numerical character (namely, a letter or an underscore) and must not be the same as any keyword.

2.3.1 Scope of identifiers

The range of an identifier within which its use becomes effective is determined by the location at which the identifier is declared. The scope of identifiers is divided into the following 4 types :

- Function scope
- File scope
- Block scope
- Function prototype scope

```
extern __boolean data1 , data2 ;  data1 , data2 /* File scope */
void   testb ( int x ) ;          x             /* Function prototype scope */
void   main ( void )
{
       int     cot ;              cot           /* Block scope */
       data1 = 1 ;
       data2 = 0 ;

       while ( data1 ) {
                data1 = data2 ;
       j1 :                       j1            /* Function scope */
                testb ( cot ) ;
}
}

void    testb ( int x )           x             /* Block scope */
{
     :
}
```

(1) Function scope

Function scope refers to the entirety within a function. An identifier with function scope can be referenced from anywhere within a specified function.

Identifiers that have function scope are label names only.

(2) File scope

File scope refers to the entirety of a translation (compiling) unit. Identifiers that are declared outside a block or parameter list all have file scope. An identifier that has file scope can be referenced from anywhere within the program.

(3) Block scope

Block scope refers to the range of a block (a sequence of declarations and statements enclosed by a pair of curly braces { } which begins with the opening brace and ends with the closing brace.

Identifiers that are declared inside a block or parameter list all have block scope. An identifier that has block scope is effective until the innermost brace pair including the declaration of the identifier is closed.

(4) Function prototype scope

Function prototype scope refers to the range of a declared function from its beginning to the end. Identifiers that are declared inside a parameter list within a function prototype all have function prototype scope. An identifier that has function prototype scope is effective within a specified function.

2.3.2 Linkage of identifiers

The linkage of an identifier refers to that the same identifier declared more than once in different scopes or in the same scope can be referenced as the same object or function. An identifier by being linked is regarded to be one and the same. An identifier may be linked in the following 3 different ways : External linkage, Internal linkage and No linkage

(1) External linkage

External linkage refers to identifiers to be linked in translation (compiling) units that constitute the entire program and as a collection of libraries.

The following identifiers have external linkage examples :

- The identifier of a function declared without storage class specifier
- The identifier of an objects or function declared as extern, which has no storage class specification
- The identifier of an object which has file scope but has no storage class specification.

(2) Internal linkage

Internal linkage refers to identifiers to be linked within 1 translation (compiling) unit.

The following identifier has an internal linkage example :

- The identifier of an object or function which has file scope and contains the storage class specifier static.

(3) No linkage

An identifier that has no linkage to any other identifier is an inherent entity.

Examples of identifiers that have no linkage are as follows :

- An identifier which does not refer to a data object or function
- An identifier declared as a function parameter
- The identifier of an object which does not have storage class specifier extern inside a block

2.3.3 Name space for identifiers

All identifiers are classified into the following "name spaces" :

- Label name : Distinguished by a label declaration.
- Tag name of structure, union, or enumeration : Distinguished by the keyword struct, union or enum
- Member name of structure or union : Distinguished by the dot (.) operator or arrow (->) operator.
- Ordinary identifiers (other than above) : Declared as ordinary declarators or enumeration type constants.

2.3.4 Storage duration of objects

Each object has a "storage duration" that determines its lifetime (how long it can remain in memory). This storage duration is divided into the following 2 categories : Static storage duration and Automatic storage duration

(1) Static storage duration

Before executing an object program that has a static duration, an area is reserved for objects and values to be stored are initialized once. The objects exist throughout the execution of the entire program and retain the values last stored.

Objects which have a static storage duration are as shown below.

- Objects which have external linkage
- Objects which have internal linkage
- Objects declared by storage class specifier static

(2) Automatic storage duration

For objects that have automatic storage duration, an area is reserved when they enter a block to be declared.

If initialization is specified, the objects are initialized as they enter from the beginning of the block. In this case, if any object enters the block by jumping to a label within the block, the object will not be initialized.

For objects that have automatic storage duration, the reserved area will not be guaranteed after the execution of the declared block.

Objects that have automatic storage duration are as follows :

- Objects which have no linkage
- Objects declared inside a block without storage class specifier static

2.4 Data Types

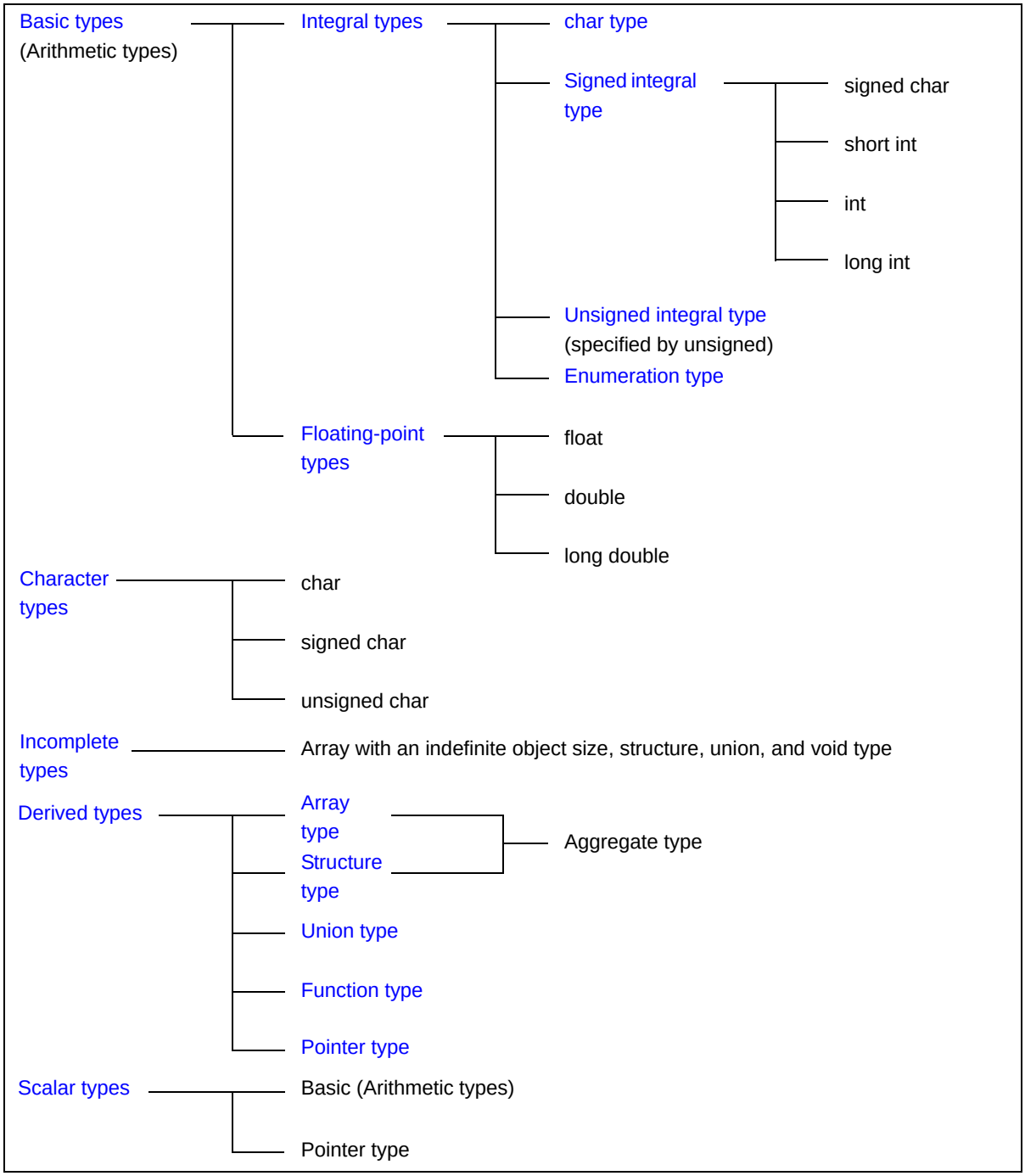
A type determines the meaning of a value to be stored in each object.

Data types are divided into the following 3 categories depending on the variable to be declared.

- Object type : Type which indicates an object with size information
- Function type : Type which indicates a function
- Incomplete type : Type which indicates an object without size information

Classification of types is shown in Figure 2-1.

Figure 2-1 Classification of Types



2.4.1 Basic types

A collection of basic data types is also referred to as "arithmetic types". The arithmetic types consist of integral types and floating-point type.

(1) Integral types

Integral data types are subdivided into 4 types. Each of these types has a value represented by the binary numbers 0 and 1.

- char type
- Signed integral type
- Unsigned integral type
- Enumeration type

(a) char type

The char type has a sufficient size to store any character in the basic execution character set. The value of a character to be stored in a char type object becomes positive. Data other than characters is handled as an unsigned integer. In this case, however, if an overflow occurs, the overflowed part will be ignored.

(b) Signed integral type

The signed integral type is subdivided into the following 4 types :

- signed char
- short int
- int
- long int

An object declared with the signed char type has an area of the same size as the char type without qualifier.

An int object without qualifier has a size natural to the CPU architecture of the execution environment.

A signed integral type data has its corresponding unsigned integral type data. Both share an area of the same size. The positive number of a signed integral type data is a partial collection of unsigned integral type data.

(c) Unsigned integral type

The unsigned integral type is a data defined with the unsigned keyword. No overflow occurs in any computation involving unsigned integral type data. This is because of that if the result of a computation involving unsigned integral type data becomes a value which cannot be represented by an integral type, the value will be divided by the maximum number which can be represented by an unsigned integral type plus 1 and substituted with the remainder in the result of the division.

(d) Enumeration type

Enumeration is a collection or list of named integer constants. An enumeration type consists of one or more sets of enumeration.

(2) Floating-point types

The floating-point types are subdivided into the 3 types.

- float
- double
- long double

In the CC78K0S, double and long double types as well as float type are supported as a floating-point expression for the single precision normalized number that is specified in ANSI/IEEE 754-1985. Thus, float, double, and long double types have the same value range.

Table 2-8 List of Basic Data Types

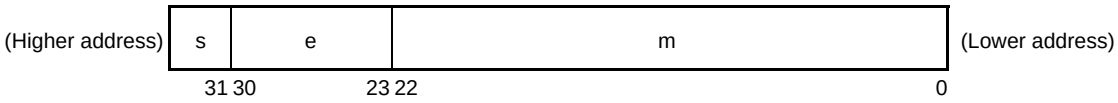
Type	Value Range
(signed) char	-128 to +127
unsigned char	0 to 255
(signed) short int	-32768 to +32767
unsigned short int	0 to 65535
(signed) int	-32768 to +32767
unsigned int	0 to 65535
(signed) long int	-2147483648 to +2147483647
unsigned long int	0 to 4294967295
float	1.17549435E-38F to 3.40282347E+38F
double	1.17549435E-38F to 3.40282347E+38F
long double	1.17549435E-38F to 3.40282347E+38F

- The signed keyword can be omitted. However, with the char type, it is judged as signed char or unsigned char depending on the condition at the compilation time.
- A short int data and an int data are handled as the data which have the same value range but are of the different types.
- A unsigned short int data and an unsigned int data are handled as the data which have the same value range but are of the different types.
- A float, double, and long double data are handled as the data which have the same value range but are of the different types.
- The value ranges for float, double, and long double types are absolute.

(a) Floating-point number (float type) specifications

- Format

The floating-point number format is shown below.



The numerical values in this format are as follows.

```
        (Value of sign)                          (Value of exponent)
( -1 )                  * (Value of mantissa) * 2
```

s : Sign (1 bit)

0 for a positive number and 1 for a negative number.

e : Exponent (8 bits)

An exponent with a base of 2 is expressed as a 1-byte integer (expressed by 2's complement in the case of a negative), and used after having a further bias of 7FH added. These relationships are shown in Table 2-9 below.

Table 2-9 Exponent Relationships

Exponent (Hexadecimal)	Value of Exponent
FE	127
:	:
81	2
80	1
7F	0
7E	-1
:	:
01	-126

m : Mantissa (23 bits)

The mantissa is expressed as an absolute value, with bit positions 22 to 0 equivalent to the 1st to 23rd places of a binary number. Except for when the value of the floating point is 0, the value of the exponent is always adjusted so that the mantissa is within the range of 1 to 2 (normalization). The result is that the position of 1 (i.e. the value of 1) is always 1, and is thus represented by omission in this format.

- Zero expression

When exponent = 0 and mantissa = 0, ±0 is expressed as follows.

```
        (Value of sign)
( -1 )                  * 0
```

- Infinity expression

  When exponent = FFH and mantissa = 0, ±∞ is expressed as follows.

```
        (Value of sign)
( -1 )                  * ∞
```

- Unnormalized value

  When exponent = 0 and mantissa ≠ 0, the unnormalized value is expressed as follows.

```
        (Value of sign)                                -126
( -1 )                  * (Value of mantissa) * 2
```

  Remark The mantissa value here is a number less than 1, so bit positions 22 to 0 of the mantissa express as is the 1st to 23rd decimal places.

- Not-a-number (NaN) expression

  When exponent = FFH and mantissa ≠ 0, NaN is expressed, regardless of the sign.

- Operation result rounding

  Numerical values are rounded down to the nearest even number. If the operation result cannot be expressed in the above floating-point format, round to the nearest expressible number.
  If there are 2 values that can express the differential of the prerounded value, round to an even number (a number whose lowest binary bit is 0).

- Operation exceptions

  There are 5 types of operation exceptions, as shown below.

Table 2-10 List of Operation Exceptions

Exception	Return Value
Underflow	Unnormalized number
Inexact	±0
Overflow	±∞
Zero division	±∞
Operation impossible	Not-a-number (NaN)

Calling the matherr function causes a warning to appear when an exception occurs.

2.4.2 Character types

The character data types include the following 3 types :

- char
- signed char
- unsigned char

2.4.3 Incomplete types

The incomplete data types include the following 4 types :

- Arrays with indefinite object size
- Structures
- Unions
- void type

2.4.4 Derived types

The derived types are divided into the following 5 categories :

- Array type
- Structure type
- Union type
- Function type
- Pointer type

(1) Array type

The array type continuously allocates a collection of member objects called the element type. Member objects all have an area of the same size. The array type specifies the number of element types and the elements of the array. It cannot create the array of incomplete type.

(2) Structure type

The structure type continuously allocates member objects each differing in size. Giving it a name can specify each member object.

The aggregate type is subdivided into 2 types :

Array type and Structure type. An aggregate type data is a collection of member objects to be taken successively.

(3) Union type

The union type is a collection of member objects that overlap each other in memory. These member objects differ in size and name and can be specified individually.

(4) Function type

The function type represents a function that has a specified return value. A function type data specifies the type of return value, the number of parameters, and the type of parameter. If the type of return value is T, the function is referred to as a function that returns T.

(5) Pointer type

The pointer type is created from a function type object type called a referenced type as well as from an incomplete type. The pointer type represents an object. The value indicated by the object is used to reference the entity of a referenced type.

A pointer type data created from the referenced type T is called a pointer to T.

2.4.5 Scalar types

The arithmetic types (basic type) and pointer type are collectively called the scalar types. The scalar types include the following data types :

- char type
- Signed integral type
- Unsigned integral type
- Enumeration type
- Floating-point type
- Pointer type

2.4.6 Compatible type

If 2 types are the same, they are said to be compatible or have compatibility. For example, if 2 structures, unions, or enumeration types that are declared in separate translation (compiling) units have the same number of members, the same member name and compatible member types, they have a compatible type. In this case, the individual members of the 2 structures or unions must be in the same order and the individual members (enumerated constants) of the 2 enumerated types must have the same values.

All declarations related to the same objects or functions must have a compatible type.

2.4.7 Composite type

A composite type is created from 2 compatible types. The following rules apply to the composite type.

- If either of the 2 types is an array of known type size, the composite type is an array of that size.
- If only one of the types is a function type which has a parameter type list (declared with a prototype), the composite type is a function prototype which has the parameter type list.
- If both types have a parameter type list (i.e., functions with prototypes), the composite type is one with a prototype consisting of all information that can be combined from the 2 prototypes.

< Example of composite type >

```
Assume that 2 declarations that have file scope are as follows :
        int f ( int ( * ) ( ) , double ( * ) [ 3 ] ) ;
        int f ( int ( * ) ( char * ) , double ( * ) [ ] ) ;
The composite type of the function in this case becomes as follows :
        int f ( int ( * ) ( char * ) , double ( * ) [ 3 ] ) ;
```

2.5 Constants

A constant is a variable, which does not change in value during the execution of the program, and its value must be set beforehand. A type for each constant is determined according to the format and value specified for the constant. The following 4 constant types are available :

- Floating-point constants
- Integer constants
- Enumeration constants
- Character constants

2.5.1 Floating-point constant

A floating-point constant consists of an effective digit part, exponent part, and floating-point suffix.

- Effective digit part : integer part, decimal point, and fraction part
- Exponent part : e or E, signed exponent
- Floating point suffix : f/F (float)
  I/L (long double)
  If omitted (double)

The signed exponent of the exponent part and the floating-point suffix can be omitted.

Either the integer part or fraction part must be included in the effective digits. Also, either the decimal point or exponent part must be included (example : 1.23F, 2e3).

2.5.2 Integer constant

An integer constant starts with a number and does not have the decimal point nor exponent part. An unsigned suffix can be added after the integer constant to indicate that the integer constant is unsigned. A long suffix can be added after the integer constant to indicate that the integer constant is long.

There are the following 3 types of integer constant.

- Decimal constant : decimal number that starts with a number other than 0
  Decimal number = 1 2 3 4 5 6 7 8 9
- Octal constant : Integer suffix 0 + octal number
  Octal number = 0 1 2 3 4 5 6 7
- Hexadecimal constant : integer suffix 0x or 0X + hexadecimal number
  Hexadecimal number = 0 1 2 3 4 5 6 7 8 9 a b c d e f A B C D E F

```
Unsigned suffix
        u  U
Long suffix
        l  L
```

(1) Decimal constant

A decimal constant is an integer value with the base (radix) of 10 and must begin with a number other than 0 followed by any numbers 0 through 9 (example : 56U).

(2) Octal constant

An octal constant is an integer value with the base of 8 and must begin with 0 followed by any numbers 0 through 7 (example : 034U).

(3) Hexadecimal constant

A hexadecimal constant is an integer value with the base of 16 and must begin with 0x or 0X followed by any numbers 0 through 9 and a through f or A through F which represent 10 through 15 (example : 0xF3).

The type of integer constant is regarded as the first of the "representable type" shown below.

In the CC78K0S, the type of the unsubscripted constant can be changed to char or unsigned char depending on the compile condition (option).

Table 2-11 Integer Constant and Representable Type

Integer constant	Representable type
Unsuffixed decimal number	int, long int, unsigned long int
Unsuffixed octal, hexadecimal number	int, unsiged int, long int, unsigned long int
Suffixed u or U	unsiged int, unsigned long int
Suffixed l or L	long int, unsigned long int
Suffixed u or U, and suffixed l or L	unsigned long int

2.5.3 Enumeration constants

Enumeration constants are used for indicating an element of an enumeration type variable, that is, the value of an enumeration type variable that can have only a specific value indicated by an identifier.

The enumeration type (enum) is whichever is the first type from the top of the list of 3 types shown below that can represent all the enumeration constants. The enumeration constant is indicated by the identifier.

- signed char
- unsigned char
- signed int

It is described as "enum enumeration type {list of enumeration constant}".

< Example >

```
enum    months { January = 1 , February , March , April , May } ;
```

When the integer is specified with =, the enumeration variable has the integer value, and the following value of enumeration variable has that integer value + 1. In the example shown above, the enumeration variable has 1, 2, 3, 4, 5, respectively. When there is not "= 1", each constant has 0, 1, 2, 3, 4, 5, respectively.

2.5.4 Character constants

A character constant is one or more character strings enclosed in a pair of single quotes as in 'X' or 'ab'.

A character constant does not include single quote', back slash (\), and line feed character (\n). To represent these characters, escape sequences are used. There are the following 3 types of escape sequences.

- Simple escape sequence : \' \" \? \\ \a \b \f \n \r \t \v
- Octal escape sequence : \octal number [octal number octal number]
  (example : \012, \0[Note 1])
- Hexadecimal escape sequence : \x hexadecimal number
  (example : \xFF[Note 2])

Notes 1. Null character

Notes 2. In the CC78K0S, \xFF represents -1. If the condition (option) that regards char as unsigned char is added, however, it represents +255.

2.6 String Literal

A string literal is a string of zero or more characters enclosed in a pair of double quotes as in "xxx" (example : "xyz").

A single quote (’) is represented by the single quotation mark itself or by ESCAPE sequence \’, whereas a double quote (") is represented by ESCAPE sequence \".

Array elements have char type string literal and are initialized by tokens given (example : char array [ ] = "abc";).

2.7 Operators

The operators are shown below.

Table 2-12 List of Operators

```
[ ]  ( )  .  ->
++  --  &  *  +  -  ~  !  sizeof
/  %  <<  >>  <  >  <=  >=  ==  !=
^  |  &&  ||
?  :
=  *=  /=  %=  +=  -=  <<=  >>=
&=  ^=  |=
,  #  ##
```

The [ ], ( ), and ?: operators must always be used in pairs.

An expression may be described in brackets "[ ]", in parentheses "( )", or between "?" and ":".

The # and ## operators are used only for defining macros in preprocessor directives. (For the description, refer to "CHAPTER 5 OPERATORS AND EXPRESSIONS".)

2.8 Delimiters

A delimiter is a symbol that has an independent syntax or meaning. However, it never generates a value.

The following delimiters are available for use in C.

```
[ ]  ( )  { }  *  , :  =  ;  ...  #
```

In brackets "[ ]", parentheses "( )", or braces "{ }", an expression declaration or statement may be described. These delimiters must always be used in pairs as shown above. The delimiter "#" is used only for preprocessor directives.

2.9 Header Name

A header name indicates the name of an external source file. This name is used only in the preprocessor directive "#include".

An example of #include instruction of a header name is shown below. For the details of each #include instruction, refer to "9.2 Source File Inclusion Directive".

```
#include        < header name >
#include        " header name "
```

2.10 Comment

A comment refers to a statement to be included in a C source module for information only. It begins with "/*" and ends with "*/". The part after "//" to the line feed can be identified as a comment statement by the -zp option.

< Example >

```
/* comment statement */
// comment statement
```

CHAPTER 3 DECLARATION OF TYPES AND STORAGE CLASSES

This chapter explains how data (variables) or functions to be used in C should be declared as well as scope for each data or function. A declaration means the specification of an interpretation or attribute for an identifier or a collection of identifiers. A declaration to reserve a storage area for an object or function named by an identifier is referred to as a "definition".

An example of a declaration is shown below.

Table 3-1 Example of Declaration of Type and Storage Classes

```
#define TRUE    1
#define FALSE   0
#define SIZE    200
void    main ( void )
{
    auto    int     i , prime , k ;  /* declaration of automatic variables */
    for ( i = 0 ; i <= SIZE ; i++ )
            mark [ i ] = TRUE ;
                :
}
```

A declaration is configured with storage class specifier, type specifier, initialize declarator, etc. The storage class specifier and type specifier specify the linkage, storage duration, and the type of an entity indicated by declarator. An initialize declarator list is a list of declarators each delimited with a comma. Each declarator may have additional type information or initializer or both.

If an identifier for an object is declared that it has no linkage, a type for the object must be perfect (the object with information related to the size) at the end of the declarator or initialize declarator (if it is with any initializer).

3.1 Storage Class Specifiers

A storage class specifier specifies the storage class of an object. It indicates the storage location of a value, which the object has, and the scope of the object. In a declaration, only 1 storage class specifier can be described.

The following 5 storage class specifiers are available :

Table 3-2 Storage Class Specifiers

Type of Specifier	Meaning
typedef	The typedef specifier declares a synonym for the specified type. See "3.6 typedef Declarations" for details of the typedef specifier.
extern	The extern specifier indicates (tells the compiler) that a variable immediately before this specifier is declared elsewhere in the program (i.e., an external variable).
static	The static specifier indicates that an object has static storage duration. For an object, which has static storage duration, an area is reserved before the program execution and a value to be stored is initialized only once. The object exits throughout the execution of the entire program and retains the value last stored in it.
auto	The auto specifier indicates that an object has automatic storage duration. For an object that has automatic storage duration, an area is reserved when the object enters a block to be declared. At entry into the declared block from its top, the object is initialized if so specified. If the object enters the block by jumping to a label within the block, the object will not be initialized. The area reserved for an object, which has automatic storage duration, will not be guaranteed after the execution of the declared block.
register	The register specifier indicates that an object is assigned to a register of the CPU. With the CC78K0S, it is allocated to the register or saddr area of the CPU. See "CHAPTER 11 EXTENDED FUNCTIONS" for details of register variables.

3.2 Type Specifiers

A type specifier specifies (or refers to) the type of an object. The following type specifiers are available :

- void
- char
- short
- int
- long
- float
- double
- long double
- signed
- unsigned
- Structure specifier and union specifier
- Enumeration specifiers
- typedef name

In the CC78K0S, the following type specifiers have been added.

- bit / boolean / __boolean

The followings explain the meaning of each type specifier and the limit values that can be expressed with the CC78K0S (the values enclosed in the parentheses). Since the CC78K0S supports only the single precision of IEEE Std 754-1985 for floating-point operations, double and long double data are regarded to have the same format as those of float data.

Type specifiers separated from each other with a slash have the same size.

Table 3-3 Type Specifiers

Type of Specifier	Meaning	Limit
void	Collection of null values	-
char	Size of the basic character set that can be stored	-
signed char	Signed integer	-128 to +127
unsigned char	Unsigned integer	0 to 255
short / signed short / short int /signed short int	Signed integer	-32768 to +32767
unsigned short / unsigned short int	Unsigned integer	0 to 65535
int / signed / signed int	Signed integer	-32768 to +32767
unsigned / unsigned int	Unsigned integer	0 to 65535
long / signed long / long int / signed long int	Signed integer	-2147483648 to +2147483647
unsigned long / unsigned long int	Unsigned integer	0 to 4294967295
float	Single precision floating point number	1.17549435E - 38F to 3.40282347E + 38F[Note]
double	Double precision floating point number	1.17549435E - 38F to 3.40282347E + 38F[Note]
long double	Extended precision floating point number	1.17549435E - 38F to 3.40282347E + 38F[Note]
structure/union specifier	Collection of member objects	-
enumeration specifier	Collection of int type constants	-
typedef	Synonym of specified type	-
bit / boolean / __boolean	Integers represented with a single bit	0 to 1

Note Range of absolute values

3.2.1 Structure specifier and union specifier

Both the structure specifier and union specifier indicate a collection of named members (objects). These member objects can have different types from one another.

(1) Structure specifier

The structure specifier declares a collection of two or more different types of variables as 1 object. Each type of object is called a member and can be given a name. For members, continuous areas are reserved in the order of their declarations.

However, because the 78K0S Series contains a restriction whereby word data is unable to be read from or written to odd addresses, the code size is prioritized by default, and align data is inserted to ensure members of 2 bytes or more are allocated to even addresses. Gaps may therefore occur between members due to the align data.

The -rc option can be specified to inhibit insertion of align data and enable structures to be packed. In this case, although the size of the data is reduced, members of 2 or more bytes allocated to odd addresses are read/written using 1-byte unit read/write code, which increases the code size.

The structure is declared as follows. The declaration will not yet allocate memory since it does not have a list of structure variables. For the definition of the structure variables, refer to "CHAPTER 7 STRUCTURES AND UNIONS".

```
struct  identifier { member declaration list } ;
```

< Example of structure declaration >

```
struct  tnode  {
        int     count ;
        struct  tnode   *left , *right ;
} ;
```

(2) Union specifier

The union specifier declares a collection of two or more different types of variables as 1 object. Each type of object is called a member and can be given a name. The members of a union overlay each other in area, namely, they share the same area.

The union declares as follows. The declaration will not yet allocate memory since it does not have a list of union variables. For the definition of the union variables, refer to "CHAPTER 7 STRUCTURES AND UNIONS".

```
union   identifier {member declaration list} ;
```

< Example of union declaration >

```
union   u_tag  {
        int     var1 ;
        long    var2 ;
} ;
```

Each member object can be any type other than the incomplete types or function types. The member can declare with the number of bits specified. The member with the number of bits specified is called a bit field. In the CC78K0S, extended functions related to bit field declaration have been added. For the details, refer to "11.5 (14) Bit field declaration".

(3) Bit field

A bit field is an integral type area consisting of a specified number of bits. For the bit field, int type, unsigned int type, and signed int type data can be specified.[Note 1] The MSB of an int field which has no qualifier or a signed int field will be judged as a sign bit.[Note 2]

If two or more bit fields exist, the second and subsequent bit fields are packed into the adjacent bit positions, provided there is an ample space within the same memory unit. By placing an unnamed bit field with a width of 0, the next bit field will not be packed into a space within the same memory unit. An unnamed bit field has no declarator and declares a colon and a width only.

Unary&operator (address) cannot be applied to the bit field object.

Notes 1. In the CC78K0S, char type, unsigned char type, and signed char type can also be specified. All of them are regarded as unsigned type since the CC78K0S does not support signed type bit field.

Notes 2. In the CC78K0S, the direction of bit field allocation can be changed by compiler option -rb (for the details, refer to "CHAPTER 11 EXTENDED FUNCTIONS").

< Example of bit field >

```
struct  data {
        unsigned int    a : 2 ;
        unsigned int    b : 3 ;
        unsigned int    c : 1 ;
} no1 ;
```

3.2.2 Enumeration specifiers

An enumeration type specifier indicates a list of objects to be put in sequence. Objects to be declared with the enum specifier will be declared as constants that have int types.

The enumeration specifier declares as shown below.

```
enum    identifier {enumerator list}
```

Objects are declared with an enumerator list. Values are defined for all objects in the list in the order of their declaration by assigning the value of 0 to the first object and the value of the previous object plus 1 to the 2nd and subsequent objects. A constant value may also be specified with "=".

In the following example, "hue" is assumed as the tag name of the enumeration, "col" as an object that has this (enum) type, and "cp" as a pointer to an object of this type. In this declaration, the values of the enumeration become "{0, 1, 20, 21}".

```
enum    hue  {
        chartreuse ,
        burgundy ,
        claret = 20 ,
        winedark
} ;

enum    hue     col , *cp ;
void    main ( void )  {
        col = claret ;
        cp = &col ;
        /* ... */  ( *cp != burgundy ) /* ... */
            :
}
```

3.2.3 Tags

A tag is a name given to a structure, union, or enumeration type. A tag has a declared data type and objects of the same type can be declared with a tag.

An identifier in the following declaration is a tag name.

```
structure/union dentifier  { member declaration list }
or
enum    identifier  { enumerator list }
```

A tag has the contents of the structure/union or enumeration defined by a member. In the next and subsequent declarations, the structure of a struct, union, or enum type becomes the same as that of the tag's list. In the subsequent declarations within the same scope, the list enclosed in braces must be omitted. The following type specifier is undefined with respect to its contents and thus the structure or union has an incomplete type.

```
structure/union identifier
```

A tag to specify the type of this type specifier can be used only when the object size is unnecessary. This is because of that by defining the contents of the tag within the same scope, the type specification becomes incomplete.

In the following example, the tag "tnode" specifies a structure that includes pointers to an integer and 2 objects of the same type.

```
struct  tnode {
        int     count ;
        struct  tnode   *left , *right ;
} ;
```

The next example declares "s" as an object of the type indicated by the tag (tnode) and "sp" as a pointer to the object of the type indicated by the tag. By this declaration, the expression "sp -> left" indicates a pointer to "struct tnode" on the left of the object pointed to by "sp" and the expression "s.right -> count" indicates "count" which is a member of "struct tnode" on the right of "s".

```
typedef struct  tnode   TNODE ;
struct  tnode {
        int     count ;
        struct  tnode   *left , *right ;
} ;

TNODE   s , *sp ;
void    main ( void )  {
        sp -> left = sp -> right ;
        s.right -> count = 2 ;
}
```

3.3 Type Qualifiers

2 type qualifiers are available : const and volatile. These type qualifiers affect Lvalues only.

Using an Lvalue that has non-const type qualifier cannot change an object that has been defined with const type qualifier. Using an Lvalue that has non-volatile type qualifier cannot reference an object that has been defined with volatile type qualifier.

An object that has volatile qualifier type can be changed by a method not recognizable by the compiler or may have other unnoticeable side effects. Therefore, an expression that references this object must be strictly evaluated according to the sequence rules that regulate abstractly how programs written in C should be executed. In addition, the values to be last stored in the object at every sequence point must be in agreement with those determined by the program except the changes due to the factors unrecognizable by the compiler as mentioned above.

If an array type is specified with type qualifiers, the qualifiers apply to the array members, not the array itself.

No type qualifier can be included in the specification of a function type. However, callt, __callt, callf, __callf, noauto, norec, __leaf, __interrupt, __interrupt_brk, __rtos_interrupt, __pascal, which are the type qualifiers unique to the CC78K0S mentioned in "2.2 Keywords", can be included as type qualifiers.

sreg, __sreg, __directmap, and __temp are also type qualifiers.

In the following example, "real_time_clock" can be changed by hardware, but such operations as assignment, increment, and decrement are not allowed in.

```
extern  const   volatile        int     real_time_clock ;
```

An example of modifying aggregate type data with type qualifiers is shown below.

```
const   struct  s  { int mem ; } cs = { 1 } ;
struct  s       ncs ;                           /* object ncs is changeable */
typedef int     A [ 2 ] [ 3 ] ;
const   A a = { { 4 , 5 , 6 } , { 7 , 8 , 9 } } ; /* array of const int array */
int     *pi ;
const   int     *pci ;

ncs = cs ;              /* correct */
cs = ncs ;
  /* violates restriction of Lvalue which has modifiable assignment operator */
pi = &ncs.mem ;         /* correct */
pi = &cs.mem ;  /* violates restriction of the type of assignment operator = */
pci = &cs.mem ;         /* correct */
pi = a [ 0 ] ;          /* incorrect : a [ 0 ] has " const int * " type */
```

3.4 Declarators

A declarator declares an identifier. Here, pointer declarators, array declarators, and function declarators are mainly discussed. By a declarator, the scope of an identifier and a function or object which has a storage duration and a type are determined.

The description of each declarator is shown below.

3.4.1 Pointer declarators

A pointer declarator indicates that an identifier to be declared is a pointer. A pointer points to (indicates) the location where a value is stored. Pointer declarations are performed as follows.

```
* type qualifier list   identifier
```

By this declaration, the identifier becomes a pointer to T1.

The following 2 declarations indicate a variable pointer to a constant value and an invariable pointer to a variable value, respectively.

```
const   int     *ptr_to_constant ;
int     *const  constant_ptr ;
```

The first declaration indicates that the value of the constant "const int" pointed by the pointer "ptr_to_constant" cannot be changed, but the pointer "ptr_to_constant" itself may be changed to point to another "const int". Likewise, the second declaration indicates that the value of the variable "int" pointed by the pointer "constant_ptr" may be changed, but the pointer "constant_ptr" itself must always point to the same position.

The declaration of the invariable pointer "constant_ptr" can be made distinct by including a definition for the pointer type to the int type data.

The following example declares "constant_ptr" as an object that has a const qualifier pointer type to int.

```
typedef int     *int_ptr ;
const   int_ptr constant_ptr ;
```

3.4.2 Array declarators

An array declarator declares to the compiler that an identifier to be declared is an object that has an array type. Array declaration is performed as shown below.

```
type    identifier      [ constant expression ]
```

By this declaration, the identifier becomes an array that has the declared type. The value of the constant expression becomes the number of elements in the array. The constant expression must be an integer constant expression which has a value greater than 0. In the declaration of an array, if a constant expression is not specified, the array becomes an incomplete type.

In the following example, a char type array "a[ ]" which consists of 11 elements and a char type pointer array "ap[ ]" which consists of 17 elements have been declared.

```
char    a [ 11 ] , *ap [ 17 ] ;
```

In the following 2 examples of declarations, "x" in the first declaration specifies a pointer to an int type data and "y" in the second declaration specifies an array to an int type data which has no size specification and is to be declared elsewhere in the program.

```
extern  int     *x ;
extern  int     y [ ] ;
```

3.4.3 Function declarators (including prototype declarations)

A function declarator declares the type of return value, argument, and the type of the argument value of a function to be referenced.

Function declaration is performed as follows.

```
type    identifier      (parameter list or identifier list)
```

By this declaration, the identifier becomes a function which has the parameter specified by the parameter type list and returns the value of the type declared before the identifier. Parameters of a function are specified by a parameter identifier lists. By these lists, an identifier, which indicates argument and its type, are specified. A macro defined in the header file "stdarg.h" converts the list described by the ellipsis (, ...) into parameters. For a function that has no parameter specification, the parameter list will become "void".

3.5 Type Names

A type name is the name of a data type that indicates the size of a function or object. Syntax-wise, it is a function or object declaration less identifiers.

Examples of type names are given below.

- int : Specifies an int type.
- int * : Specifies a pointer to an int type.
- int *[3] : Specifies an array which has 3 pointers to an int type.
- int (*) [3] : Specifies a pointer to an array which has 3 int types.
- int *( ) : Specifies a function which returns a pointer to an int type which has no parameter specification.
- int (*) (void) : Specifies a pointer to a function which returns an int type which no parameter specification.
- int (*const [ ]) (unsigned int, ...) : Specifies an indefinite number of arrays which have 1 parameter of unsigned int type and an invariable pointer to each function that returns an int type.

3.6 typedef Declarations

The typedef keyword defines that an identifier is a synonym to a specified type. The defined identifier becomes a typedef name.

The syntax of typedef names is shown below.

```
typedef type    identifier ;
```

In the following example, "distance" is an int type, the type of "metricp" is a pointer to a function that returns an int type that has no parameter specification, the type of "z" is a specified structure, and "zp" is a pointer to this structure.

```
typedef int     MILES , KLICKSP ( ) ;
typedef struct  { long re , im ; }      complex ;
 /* ... */
MILES   distance ;
extern  KLICKSP *metricp ;
complex z , *zp ;
```

In the following example, typedef name t is declared with signed int type, and typedef name plain is declared with int type, respectively, and the structure with 3 bit field members is declared. The bit field members are as follows.

- Bit field member with name t and the value 0 to 15
- Bit field member without a name and the const qualified value -16 to +15 (if accessed)
- Bit field member with name r and the value -16 to +15

```
typedef signed  int     t ;
typedef int     plain ;
struct  tag {
        unsigned        t : 4 ;
        const           t : 5 ;
        plain           r : 5 ;
} ;
```

In this example, these 2 bit field declarations differ in the point that the first bit field declaration has unsigned as the type specifier (therefore, t becomes the name of the structure member), and the second bit field declaration, on the other hand, has const as the type qualifier (qualifiers t which can be referred to as typedef name). After this declaration, if the following description is found within the effective range, the function f is declared as "function which has 1 parameter and returns signed int", and the parameter is declared as "pointer type for the function which has 1 parameter and returns signed int". The identifier t is declared as long type.

```
t       f ( t ( t ) ) ;
long    t ;
```

typedef names may be used to facilitate program reading. For example, the following 3 declarations for the function signal all specify the same type as the first declaration which does not use typedef.

```
typedef void    fv ( int ) ;
typedef void    ( *pfv ) ( int ) ;

void    ( *signal ( int , void ( * ) ( int ) ) ) ( int ) ;
fv      *signal ( int , fv * ) ;
pfv     signal ( int , pfv ) ;
```

3.7 Initialization

Initialization refers to setting a value in an object beforehand. An initializer carries out the initialization of an object.

Initialization is performed as follows.

```
object = { initializer list } ;
```

An initializer list must contain initializers for the number of objects to be initialized.

All expressions in initializers or an initializer list for objects that have static storage duration and objects that have an aggregate type or a union type must be specified with constant expressions.

Identifiers that declare block scope but have external or internal linkage cannot be initialized.

3.7.1 Initialization of objects which have a static storage duration

If no attempt is made to initialize an arithmetic type object that has static storage duration, the value of the object will be implicitly initialized to 0.

Likewise, a pointer type object which has a static storage duration will be initialized to a null pointer constant.

< Example >

```
unsigned int    gval1 ;         /* initialized by 0 */
static int      gval2 ;         /* initialized by 0 */
void    func ( void ) {
        static  char    aval ;  /* initialized by 0 */
}
```

3.7.2 Initialization of objects which have an automatic storage duration

The value of an object which has an automatic storage duration becomes indefinite and will not be guaranteed if it is not initialized.

< Example >

```
void    func ( void ) {
        char    aval ;  /* undefined at this point */
            :
        aval = 1 ;      /* initialized to 1 */
}
```

3.7.3 Initialization of character arrays

A char character array can be initialized with char string literal (char string enclosed with " "). Likewise, a character string in which a series of char string literal are contained initializes the individual members or elements of an array.

In the following example, the array objects s and t with "no type qualifier" are defined and the elements of each array will be initialized by char string literal.

```
char s [ ] = " abc " , t [ 3 ] = " abc " ;
```

The next example is the same as the above example of array initialization.

```
char    s [ ] = { ' a ' , ' b ' , ' c ' , ' \0 ' } ,
        t [ ] = { ' a ' , ' b ' , ' c ' } ;
```

The next example defines p as "pointer to char" type and the member is initialized by characteristic string literal so that length indicates "char array" type object.

```
char    *p = " abc " ;
```

3.7.4 Initialization of aggregate or union type objects

- Aggregate type

  An aggregate type object is initialized with a list of initializers described in ascending order of subscripts or members. The initializer list to be specified must be enclosed in braces.

  If the number of initializers in the list is less than the number of aggregate members, the members not covered by the initializers will be implicitly initialized just the same as an object which has a static storage duration.

  With an array with an unknown size, the number of its elements is governed by the number of initializers and the array will no longer become an incomplete type.

- Union type

  A union type object is initialized with an initializer for the first member of the union that is enclosed in braces.

In the following example, the array "x" with an unknown size will change to a 1-dimensional array that has 3 elements as a result of its initialization.

```
int     x [ ] = { 1 , 3 , 5 } ;
```

The next example shows a complete definition which has initializers enclosed in braces. "{1, 3, 5}" initializes "y [0] [0]", "y [0] [1]", and "y [0] [2]" in the 1st line of the array object "y [0]". Likewise, in the second line, the elements of the array objects "y [1]" and "y [2]" are initialized. The initial value of "y [3]" is 0 since it is not specified.

```
char    y [ 4 ] [ 3 ] = {
        { 1 , 3 , 5 } ,
        { 2 , 4 , 6 } ,
        { 3 , 5 , 7 } ,
} ;
```

The next example produces the same result as the above example.

```
char    z [ 4 ] [ 3 ] = {
        1 , 3 , 5 , 2 , 4 , 6 , 3 , 5 , 7
} ;
```

In the following example, the elements in the first row of "z" are initialized to the specified values and the rest of the elements are initialized to 0.

```
char    z [ 4 ] [ 3 ] = {
        { 1 } , { 2 } , { 3 } , { 4 }
} ;
```

In the next example, a 3-dimensional array is initialized.

q [0] [0] [0] are initialized to 1, q [1] [0] [0] to 2, and q [1] [0] [1] to 3. 4, 5 and 6 initialize q [2] [0] [0], q [2] [0] [1], and q [2] [1] [0], respectively. The rest of the elements are all initialized to 0.

```
short   q [ 4 ] [ 3 ] [ 2 ] = {
        { 1 } ,
        { 2 , 3 } ,
        { 4 , 5 , 6 }
} ;
```

The following example produces the same result as the above initialization of the 3-dimensional array.

```
short q [ 4 ] [ 3 ] [ 2 ] = {
        1 , 0 , 0 , 0 , 0 , 0 ,
        2 , 3 , 0 , 0 , 0 , 0 ,
        4 , 5 , 6
} ;
```

The following example shows a complete definition of the above initialization using braces.

```
short   q [ 4 ] [ 3 ] [ 2 ] = {
        {
                { 1 } ,
        } ,
        {
                { 2 , 3 } ,
        } ,
        {
                { 4 , 5 , 6 } ,
        }
} ;
```

CHAPTER 4 TYPE CONVERSIONS

In an expression, if 2 operands differ in data type, the compiler automatically performs a type conversion operation. This conversion is similar to a change obtained by the cast operator. This automatic type conversion is called an implicit type conversion. In this chapter, this implicit type conversion is explained.

Type conversion operations include usual arithmetic conversions, conversions involving truncation/round off, and conversions involving sign change. Table 4-1 gives a list of conversions between types.

Table 4-1 List of Conversions Between Types

Before Conversion		After Conversion										
		(signed) char	unsigned char	(signed) short int	unsigned short int	(signed) int	unsigned int	(signed) long int	unsigned long int	float	double	long double
(signed) char	+	\	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	-	\	NG	OK	NG	OK	NG	OK	NG	OK	OK	OK
unsigned char		Δ	\	OK	OK	OK	OK	OK	OK	OK	OK	OK
(signed) short int	+			\	OK	\	OK	OK	OK	OK	OK	OK
	-			\	NG	\	NG	OK	NG	OK	OK	OK
unsigned short int				Δ	\	Δ	\	OK	OK	OK	OK	OK
(signed) int	+			\	OK	\	OK	OK	OK	OK	OK	OK
	-			\	NG	\	NG	OK	NG	OK	OK	OK
unsigned int				Δ	\	Δ	\	OK	OK	OK	OK	OK
(signed) long int	+							\	OK	OK	OK	OK
	-							\	NG	OK	OK	OK
unsigned long int								Δ	\	OK	OK	OK
float										\	OK	OK
double											\	\
long double											\	\

Remarks 1. The signed keyword can be omitted. However, with a char type data, the data type is regarded as the signed char or unsigned char type depending on the compile-time condition (option).

Remarks 2. Conventions

OK : Type conversion will be performed properly.

\ : Type conversion will not be performed.

NG : A correct value will not be generated. (The data type will be regarded as an unsigned int type.)

Δ : The data type will not change bit-image-wise. However, if a positive number cannot represent it sufficiently, no correct value will be generated. (regarded as an unsigned integer)

Blank : An overflow in the result of the conversion will be truncated. The + or - sign of the data may be changed depending on the type after the conversion.

4.1 Arithmetic Operands

(1) Characters and integers (general integral promotion)

The data types of char, short int, and int bit fields (whether they are signed or unsigned) or of objects that have an enumeration type will be converted to int types if their values are within the range that can be represented with int types. If not within the range, they will be converted to unsigned int types. These implicit type conversions are referred to as "general integral general promotion". All other arithmetic types will not be changed by this general integral promotion.

General integral promotion will retain the value of the original data type including its sign.

char type data without type qualifier will normally be handled as signed char in the CC78K0S. It can be handled as an unsigned char with option.

(2) Signed integers and unsigned integers

When a value with an integer type is converted to another, the value will not be changed if the value can be expressed with the integer type after conversion.

When a signed integer is converted to an unsigned integer of the same or larger size, the value is not changed unless the value of the signed integer is negative. If the value of the signed integer is negative and the unsigned integer has a size larger than that of the signed integer, the signed integer is expanded to the signed integer with the same size as the unsigned integer, and then it is added with the value equal to the maximum number that can be expressed with the unsigned integer plus 1, and the signed integer before conversion is converted to the unsigned value.

When a value with an integer type is converted to an unsigned integer with a smaller size, the conversion result is a non-negative remainder which the value is divided with that value which 1 is added to the maximum number that can be expressed with an unsigned integer after conversion. When a value with an integer type is converted to a signed integer with smaller size or when an unsigned integer is converted to a signed integer with the same size, the overflown value is ignored if the value after conversion cannot be expressed. For the conversion pattern, refer to Table 4-1.

Conversion operations from signed integral type to unsigned integral type are as listed in Table 4-2 below.

Table 4-2 Conversions from Signed Integral Type to Unsigned Integral Type

		unsigned	
		Smaller in Value Range	Greater in Value Range
signed	+	/	OK
	-	/	+

OK : Type conversion will be performed properly.

+ : The data will be converted to a positive integer.

/ : The result of the conversion will be the remainder of the integer value, modulo the largest possible value of the type to be converted plus 1.

(3) Usual arithmetic type conversions

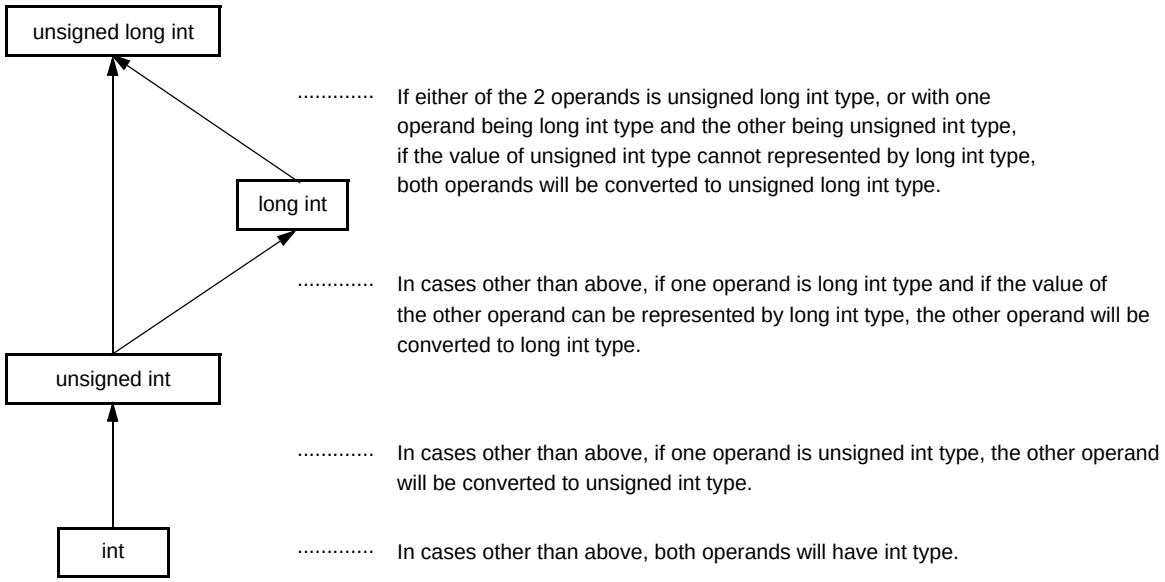
Types obtained as a result of operations on arithmetic type data will have a wide range of values.

The type conversion of the operation result is performed as follows.

- If either one of the operands has long double type, the other operand is converted to long double type.
- If either one of the operands has double type, the other operand is converted to double type.
- If either one of the operands has float type, the other operand is converted to float type.

In cases other than above, general integer expansion is performed for both operands according to the following rules. Figure 4-1 shows the rules.

Figure 4-1 Usual Arithmetic Type Conversions



In the CC78K0S, the conversion to int type can be intentionally disabled by compile condition (optimizing option) (For the details, refer to the CC78K0S C Compiler Operation User's Manual).

4.2 Other Operands

(1) Lvalues and function locators

An "Lvalue" refers to an expression that specifies an object (and has an incomplete type other than object type or void type).

Lvalues which do not have array types, incomplete types, or const qualifier types, and structures or unions which have no const qualifier type members are "modifiable Lvalues".

An Lvalue which has no array type will be converted to a value stored in the object to be specified, except when it is the operand of the sizeof operator, unary & operator, ++ operator, or -- operator or the left operand of an operator or an assignment operator. By being converted, it will no longer serve as an Lvalue.

The behaviors of Lvalues that have incomplete types but have no array types will not be guaranteed.

An Lvalue which has a "... array" type except character arrays will be converted to an expression which has a "pointer to ..." type. This expression is no longer an Lvalue.

A function locator is an expression that has a function type. With the exception of the operand of the sizeof operator or unary & operator, a function locator that has a "function type that returns ..." will be converted to an expression that has a "pointer type to a function that returns ...".

(2) void

The value (non-existent) of a void expression (i.e., an expression that has the void type) cannot be used in any way. Neither implicit nor explicit conversion to exclude void will be applied to this expression. If an expression of another type appears in the context which requires a void expression, the value of the expression or specifier is assumed to be non-existent.

(3) Pointers

A void pointer can be converted to a pointer to any incomplete type or object type. Conversely, a pointer to any incomplete type or object type can be converted to a void pointer. In either case, the result value must be equal to that of the original pointer.

An integer constant expression which has the value of 0 and has been cast to the void * type is referred to as a "null pointer constant". If the null pointer constant is substituted with, equal to, or compared with some pointer, the null pointer constant will be converted to that pointer.

CHAPTER 5 OPERATORS AND EXPRESSIONS

This chapter describes the operators and expressions to be used in the C language.

C has an abundance of operators for arithmetic, logical, and other operations. This rich set of operators also includes those for bit and address operations.

An expression is a string or combination of an operator and one or more operands. The operator defines the action to be performed on the operand(s) such as computation of a value, instructions on an object or function, generation of side effects, or a combination of these.

Examples of operators are given below.

```
#define TRUE    1
#define FALSE   0
#define SIZE    200

void  lprintf ( char * , int ) ;
void  putchar ( char c ) ;
char  mark [ SIZE + 1 ] ; ——————————————— +       /* Arithmetic operator */

void  main ( void )  {
      int     i , prime , k , count ;
      count = 0 ; ———————————————————————— =       /* Assignment operator */
      for ( i = 0 ; i <= SIZE ; i++ ) ———— ++      /* Postfix operator */
            mark [ i ] = TRUE ; ————————— <=      /* Relational operator */

      for ( i = 0 ; i <= SIZE ; i++ ) {
            if (mark [ i ] ) {
                prime = i + i + 3 ; ———— +       /* Arithmetic operator */
                lprintf ( " %d " , prime ) ;
                count++ ; ——————————————— ++      /* Postfix operator */
                if ( ( count%8 ) == 0 ) ——— ==      /* Relational operator */
                    putchar ( ' \n ' ) ;
                for ( k = i + prime ; k <= SIZE ; k += prime ) —— +=
                                                    /* Assignment operator */
                    mark [ k ] = FALSE ;
                }
        }

      lprintf ( " Total %d\n " , count ) ;
loop1 : ;
      goto    loop1 ;
}

lprintf ( char *s , int i ) {
      int     j ;
      char    *ss ;
      j = i ;
      ss = s ;
}

void  putchar ( char c )  {
      char    d ;
      d = c ;
}
```

Table 5-1 shows the evaluation precedence of operators used in C.

Table 5-1 Evaluation Precedence of Operators

Type of Expression	Operator	Linkage[Note]	Priority
Postfix	[ ] ( ) . -> ++ --	-->	Highest
Unary	++ -- & * + - ~ ! sizeof	<--	
Cast	(type)	<--	
Multiplicative	* / %	-->	
Additive	+ -	-->	
Bitwise shift	<< >>	-->	
Relational	< > <= >=	-->	
Equality	== !=	-->	
Bitwise AND	&	-->	
Bitwise XOR	^	-->	
Bitwise OR	|	-->	
Logical AND	&&	-->	
Logical OR	||	-->	
Conditional	? :	<--	
Assignment	= *= /= %= += -= <<= >>= &= ^= |=	<--	
Comma	,	-->	Lowest

Note Operations in the same line contain the same priority.

The arrow (<-- or -->) in the "LINKAGE" column denotes that when an expression contains two or more operators in the same precedence, the operations are carried out in the direction of the arrow "-->" (from left to right) or "<--" (from right to left).

5.1 Primary Expressions

Primary expressions include the following :

- Identifier declared as an object or function
  (identifier primary expression)
- Constant (constant primary expression)
- String literal (constant primary expression)
- Expression enclosed in parentheses
  (parenthesized expression)

An identifier which becomes a primary expression is an Lvalue if an object is declared or a function locator if a function is declared. The data type of a constant is determined according to the value specified for the constant as explained in "2.5 Constants". String literal(s) become an Lvalue that has a data type as explained in "2.6 String Literal".

5.2 Postfix Operators

A postfix operator is an operator that appears or is placed after an object or a function.

The types of postfix operators are given below.

- Subscript operators
- Function call operators
- Structure and union member (. ->)
- Postfix increment/decrement operators (++ --)

5.2.1 Subscript operators

SYNTAX

```
postfix-expression      [ subscripted expression ]
```

FUNCTION

- The [ ] subscript operator specifies or refers to a single member of an array object. The array or expression "E1 [E2]" is evaluated as if it were "(*(E1+(E2)))". In other words, the value of E1 is a pointer to the first member of the array and E2 (if it is an integer) indicates the E2th member of E1 (counting from 0). With a multidimensional array, subscript operators as many as the number of dimensions must be connected.
  In the following example, x becomes an int type array of 3*5. In other words, x is an array which has 3 members each consisting of 5 int type members.

```
int     x       [ 3 ] [ 5 ] ;
```

  A multidimensional array may be specified by connecting subscript operators. Assuming that E is an array of nth dimension (where n ≥ 2) consisting of i*j*...*k, the array can be specified with the n number of subscript operators. In this case, E becomes a pointer to an array of (n - 1)th dimension consisting of j*...*k.

NOTE

- A postfix expression must have a ".... pointer to object". The subscripted expression of an array must be specified with integral type data. The result of the expression will become "....." type.

5.2.2 Function call operators

SYNTAX

```
postfix-expression ( argument-expression list ) ;
```

FUNCTION

- The postfix "( )" operator calls a function. The function to be called is specified with a postfix expression and argument(s) to passed to the function are indicated in parentheses ( ).
- The description related to function includes the function prototype declaration, the function definition (the body of a function), and the function call. The function prototype declaration specifies the value a function returns, the type of argument, and the storage class.
- If the function prototype declaration is not referred to in a function call, each argument is extended with general integer. This is called "default actual argument extension". Performing a function prototype declaration avoids default actual argument extension and detects the mistakes of the type and number of argument and the type of return value.
- Calling a function which has neither storage class specification nor data type specification such as "identifier ( );" is interpreted as calling a function which has an external object and returns an int type which has no information on arguments. In other words, the following declaration will be made implicitly :

```
extern  int     identifier ( ) ;
```

[Example of function call]

```
int     func ( char , int ) ;           /* function prototype declaration */
char    a ;
int     b , ret ;
void    main ( void ) {
        ret = func ( a , b ) ;          /* function call */
}
int     func ( char c , int i )  {      /* function definition */
            :
        return  i ;
}
```

NOTE

- A function that returns an object other than array types can be called with this operator. The postfix expression must be of a pointer type to this function.
- In a function call including prototype, the type of argument must be of a type that can be assigned to the corresponding parameter(s). The number of arguments must also be in agreement.

5.2.3 Structure and union member (. ->)

(1) . (dot) operator

SYNTAX

```
postfix-expression . identifier
```

FUNCTION

- The "." (dot) operator (also called a member operator) specifies the individual members of a structure or union. The postfix expression is the name of the structure or union object to be specified, and the identifier is the name of the member.

(2) -> (arrow) operator

SYNTAX

```
postfix-expression -> identifier
```

FUNCTION

- The "->" (arrow) operator (also called an indirect membership operator) specifies the individual members of a structure or union. The postfix expression is the name of the pointer to the structure or union object to be specified, and the identifier is the name of the member.

< Examples of ".", "->" operators >

```
#include < stdlib.h >

union {
        struct  {
                int     type ;
        } n ;
        struct  {
                int     type ;
                int     intnode ;
        } ni ;
        struct  {
                int     type ;
                struct  {
                        long    longnode ;
                } *nl_p ;
        } nl ;
} u ;

void    func ( void )  {
        u.nl.type = 1 ;
        u.nl.nl_p -> longnode = -31415L ;
        /* ... */
        if ( u.n.type == 1 )
                u.nl.nl_p -> longnode = labs ( u.nl.nl_p -> longnode ) ;
}
```

5.2.4 Postfix increment/decrement operators (++ --)

(1) Postfix ++ (Increment) operator

SYNTAX

```
postfix-expression ++
```

FUNCTION

- The postfix ++ (Increment) operator increments the value of an object by 1. This increment operation is performed by taking the data type of the object into account.

(2) Postfix -- (Decrement) operator

SYNTAX

```
postfix expression --
```

FUNCTION

- The postfix -- (Decrement) operator decrements the value of an object by 1. This decrement operation is performed by taking the data type of the object into account.

NOTE

- The operand of the postfix increment or decrement operator must be a modifiable Lvalue (qualified or unqualified).

5.3 Unary Operators

A unary operator performs an operation on 1 object or parameter (i.e., operand). The following unary operators are available :

- Prefix increment/decrement operators (++ --)
- Address and indirection operators (& *)
- Unary arithmetic operators (+ - ~ !)
- sizeof operators

The followings explain each unary operators.

5.3.1 Prefix increment/decrement operators (++ --)

(1) Prefix ++(Increment) operator

SYNTAX

```
++ unary-expression
```

FUNCTION

- The prefix (Increment) operator increments the value of an object by 1. The expression "++E" of the prefix increment operator will produce the same result as the following expression.

```
E = E + 1
    or
E += 1
```

(2) Prefix -- (Decrement) operator

SYNTAX

```
-- unary-expression
```

FUNCTION

- The prefix -- (Decrement) operator decrements the value of an object by 1. The expression "--E" of the prefix decrement operator will produce the same result as the following expression :

```
E = E - 1
   or
E -= 1
```

5.3.2 Address and indirection operators (& *)

(1) Unary & operator

SYNTAX

```
& operand
```

FUNCTION

- The unary & (address) operator returns the pointer of a specified object (i.e., the address of the variable it precedes).

(2) Unary * operator

SYNTAX

```
 * operand
```

FUNCTION

- The unary * (indirection) operator returns the value indicated by a specified pointer (i.e., takes the value of the variable it precedes and uses that value as the address of the information in memory).

NOTE

- The operand of the unary & operator must be an Lvalue referring to an object not declared with the register storage class specifier. Neither a function locator nor a bit field can be used as the operand of this unary operator.
  The operand of the unary * operator must have a pointer type.

5.3.3 Unary arithmetic operators (+ - ~ !)

FUNCTIONS

- The + (unary plus) operator performs positive integral promotion on its operand.
- The - (unary minus) operator performs negative integral promotion on its operand.
- The ~ (tilde) operator is a bitwise one's complement operator which inverts all the bits in a byte of its operand.
- The ! NOT or logical negation operator returns "0" if its operand is "0" and "1" if it is not "0". In other words, the operator changes each "0" to "1" and "1" to "0".

SYNTAX

```
+ operand
- operand
~ operand
! operand
```

5.3.4 sizeof operators

SYNTAX

```
sizeof unary-expression
sizeof (type-name)
```

FUNCTION

- The sizeof operator returns the size of a specified object in bytes. The return value is governed by the data type of the object and the value of the object itself is not evaluated.
- The value to be returned by an unsigned char or signed char object (including its qualified type) on which a sizeof operation is performed is 1. With an array type object, the return value will be the total number of bytes in the array. With a structure or union type object, the result value will be the total number of bytes that the object would occupy including bytes necessary to pad out to the next appropriate alignment boundary.
- The type of the sizeof operation result is an integral type and its name is size_t. This name is defined in the < stddef.h > header. The sizeof operator is used mainly to allocate memory areas and transfer data to/from the I/O system.

EXAMPLE

- The following example finds the number of elements of an array by dividing the total number of bytes in the array by the size of a single element. Num becomes 5.

```
int     num ;
char    array [ ] = { 0 , 1 , 2 , 3 , 4 } ;

void    func ( void ) {
        num = sizeof array / sizeof array [ 0 ] ;
}
```

NOTE

- An expression that has a function type or incomplete type and an Lvalue which refers to a bit field object cannot be used as the operand of this operator.

5.4 Cast Operators

A cast is a special operator which forces one data type to be converted into another. The cast operator is mainly used when converting a pointer type.

- Cast Operators (type-name)

5.4.1 Cast Operators (type-name)

SYNTAX

```
(type-name)     expression
```

FUNCTION

- The cast operator converts the data type of another object (or the result of another expression) into the type specified in parentheses ( ).

EXAMPLE

```
void    func ( void )  {
        int     val ;
        float   f ;

        f = 3.14F ;
        val = ( int ) f ;               /* val becomes 3 by cast */
        val = * ( int * ) 0x10000 ;     /* cast constant */
}
```

5.5 Arithmetic Operators

- Multiplicative Operators (* / %)
- Additive Operators (+ -)

Arithmetic operators are divided into multiplying operators and adding operators. Multiplying operators find the product, quotient, and remainder of 2 operands. Adding operators find the sum and difference of 2 operands.

Table 5-2 Signs of Division/Remainder Division Operation Result

a / b		b	
		+	-
a	+	+	-
	-	-	+

a % b		b	
		+	-
a	+	+	+
	-	-	-

Remark a, b indicates each operand.

Division is performed with 2 integers whose sign, if any, is removed through the usual arithmetic conversion and the result will be truncated towards 0 if necessary. Likewise, a remainder or modulo division operation is performed with 2 integers whose sign, if any, is removed through the usual arithmetic conversion. Table 5-2 shows the results of calculations only on the signs of 2 operands in division and remainder division, respectively.

5.5.1 Multiplicative Operators (* / %)

(1) * operator

SYNTAX

```
E1 * E2
```

FUNCTION

- The binary * (multiplication) operator performs normal multiplication on 2 operands and returns the product.

(2) / operator

SYNTAX

```
E1 / E2
```

FUNCTION

- The / operator performs normal division on 2 operands and returns the quotient.

(3) % operator

SYNTAX

```
E1 % E2
```

FUNCTION

- The % operator performs a remainder (or modulo division) operation on 2 operands and returns the remainder in the result.

5.5.2 Additive Operators (+ -)

(1) + operator

SYNTAX

```
E1 + E2
```

FUNCTION

- The + operator performs addition on 2 operands and returns the sum of the 2 numbers.

(2) - operator

SYNTAX

```
E1 - E2
```

FUNCTION

- The - operator performs subtraction on 2 operands and returns the difference between the 2 numbers (the first operand minus the second operand).

5.6 Bitwise Shift Operators

A shift operator shifts its first (left) operand to the direction (left or right) indicated by the operator by the number of bits specified by its second operand. The types of shift operators are given below.

- Shift Operators (<< >>)

Table 5-3 Shift Operations

a << b		b[Note]
a	+	0
	-	0

a >> b		b[Note]
a	+	0
	-	-1

Note The table indicates when the right operand is greater than the number of bits in the left operand or when an overflow occurs in the result of the shift operation.
If the right operand is negative, the value is processed as an unsigned positive number.

Remark a, b indicates each operand.

The followings explain each shift operator. E1 and E2 indicate operands or expressions.

5.6.1 Shift Operators (<< >>)

(1) Left shift (<<) operators

FUNCTION

- The binary << (left shift) operator shifts the left operand to the left the number of bits specified by the right operand and fills zeros in vacated bits. If the left operand E1 has an unsigned type in "E1 << E2", the result will become a value obtained by multiplying "E1" by the "E2th" power of 2.

SYNTAX

```
E1 << E2
```

(2) Right shift (>>) operators

FUNCTION

- The binary >> (right shift) operator shifts the left operand to the right the number of bits specified by the right operand.
- If "E1" is unsigned, zeros are filled in vacated bits (Logical shift).
- If "E1" is signed, a copy of the sign bit is filled in vacated bits.
- If "E1" is unsigned or signed and have a non-negative value in "E1>>E2", the result will become a value obtained by dividing "E1" by the "E2th" power of 2.

SYNTAX

```
E1 >> E2
```

5.7 Relational Operators

There are 2 types of operators to indicate the relationship between 2 operands : "relational operator" and "equality operator".

The relational operator indicates the value relationship between 2 operands such as greater than and less than. The equality operators indicate that 2 operands are equal or not equal.

The relational operators and equality operators are shown below.

- Relational Operators (< > <= >=)
- Equality Operators (== !=)

The value relationship between 2 pointers compared by relational operators is determined by the relative location in the address space of the object indicated by the pointer.

In the CC78K0S, relational operators and equality operators generate "1" if the specified relationship is true and "0" if it is false. The results have int type.

5.7.1 Relational Operators (< > <= >=)

(1) < (less than) operator

SYNTAX

```
E1 < E2
```

FUNCTION

- The < (less than) operator returns "1" if the left operand is less than the right operand; otherwise, "0" is returned.

(2) > (greater than) operator

SYNTAX

```
E1 > E2
```

FUNCTION

- The > (greater than) operator returns "1" if the left operand is greater than the right operand; otherwise, "0" is returned.

(3) <= (less than or equal) operator

SYNTAX

```
E1 <= E2
```

FUNCTION

- The <= (less than or equal) operator returns "1" if the left operand is less than or equal to the right operand; otherwise, "0" is returned.

(4) >= (greater than or equal) operator

SYNTAX

```
E1 >= E2
```

FUNCTION

- The >= (greater than or equal) operator returns "1" if the left operand is greater than or equal to the right operand; otherwise, "0" is returned.

5.7.2 Equality Operators (== !=)

(1) == (equal) operator

FUNCTION

- The == (equal) operator returns "1" if its 2 operands are equal to each other; otherwise, "0" is returned.

SYNTAX

```
E1 == E2
```

(2) != (not equal) operator

FUNCTION

- The != (not equal) operator returns "1" if both operands are not equal to each other; otherwise, "0" is returned.

SYNTAX

```
E1 != E2
```

5.8 Bitwise Logical Operators

Bitwise logical operators perform a specified logical operation on the value of an object in bit units. The bitwise logical expressions include Bitwise AND (&), Bitwise Exclusive OR (^), and Bitwise Inclusive OR (|).

Each logical operation is indicated by the operators shown below.

- Bitwise AND Operators (&)
- Bitwise XOR Operators (^)
- Bitwise Inclusive OR Operators (|)

5.8.1 Bitwise AND Operators (&)

SYNTAX

```
E1 & E2
```

FUNCTION

- The binary "&" operator is a bitwise AND operator which returns an integral value that has "1" bits in positions where both operands have "1" bits and that has "0" bits everywhere else.
- The bitwise AND operator must be specified with an "& operator".

Table 5-4 Bitwise AND Operation

		Value of Each Bit in Left Operand	
		1	0
Value of each bit in right operand	1	1	0
	0	0	0

5.8.2 Bitwise XOR Operators (^)

SYNTAX

```
E1 ^ E2
```

FUNCTION

- The binary " ^ " (caret) operator is a bitwise exclusive OR operator which returns an integral value that has a "1" bit in each position where exactly one of the operands has a "1" bit and that has a "0" bit in each position where both operands have a "1" bit or both have a "0" bit.

Table 5-5 Bitwise XOR Operation

		Value of Each Bit in Left Operand	
		1	0
Value of each bit in right operand	1	0	1
	0	1	0

5.8.3 Bitwise Inclusive OR Operators (|)

SYNTAX

```
E1 | E2
```

FUNCTION

- The binary "|" operator is a bitwise inclusive OR operator which returns an integral value that has a "1" bit in each position where at least one of the operands has a "1" bit and that has a "0" bit in each position where both operands have a "0" bit.

Table 5-6 Bitwise OR Operation

		Value of Each Bit in Left Operand	
		1	0
Value of each bit in right operand	1	1	1
	0	1	0

5.9 Logical Operators

Logical operators perform logical OR and logical AND operations. A logical OR operation is specified with a logical OR operator, and a logical AND operation is specified with a logical AND operator. Each operator is shown below.

- Logical AND Operators (&&)
- Logical OR Operators (||)

Each operand of both the operators returns the value of int type "0" or "1".

5.9.1 Logical AND Operators (&&)

SYNTAX

```
E1 && E2
```

FUNCTION

- The && operator performs logical AND operation on 2 operands and returns a "1" if both operands have nonzero values. Otherwise, a "0" is returned. The type of the result is int.

Table 5-7 Logical AND Operation

		Value of Left Operand	
		Zero	Nonzero
Value of right operand	Zero	0	0
	Nonzero	0	1

NOTE

- This operator always evaluates its operands from left to right. If the value of the left operand is "0", the right operand is not evaluated.

5.9.2 Logical OR Operators (||)

SYNTAX

```
E1 || E2
```

FUNCTION

- The | | operator performs logical OR operation on 2 operands and returns a "0" if both operands are zero. Otherwise, a "1" is returned. The type of result is int.

Table 5-8 Logical OR Operation

		Value of Each Bit in Left Operand	
		Zero	Nonzero
Value of each bit in right operand	Zero	0	1
	Nonzero	1	1

NOTE

- This operator always evaluates its operands from left to right. If the value of the left operand is nonzero, the right operand is not evaluated.

5.10 Conditional Operators

Conditional operators judge the processing to be performed next by the value of the first operand. Conditional operators judge by "?" and ":". The types of conditional operators are given below.

- Conditional Operators (? :)

5.10.1 Conditional Operators (? :)

SYNTAX

```
1st-operand ? 2nd-operand : 3rd-operand
```

FUNCTION

- If the value of the first operand is nonzero, it evaluates the second operand before the colon. If the value of the first operand is zero, it evaluates the third operand after the colon. The result of the entire conditional expression will be the value of the second or third operand.

EXAMPLE

```
#define TRUE    1
#define FALSE   0
char    flag ;
int     ret ;
int     func ( ) {
        ret = flag ? TRUE : FALSE ;
        return  ret ;
}
```

NOTE

- If both the second and third operand types are arithmetic types, normal arithmetic type conversion is performed to make them common types. The type of result is the common type. If both the operand types are structure types or union types, the result becomes those types. If both the operand types are void types, the result is void type.

5.11 Assignment Operators

Assignment operators include a simple assignment expression that stores the right operand in the left operand and a compound assignment expression that stores the result of an operation on both operands in the left operand.

The assignment operators are shown below.

- Simple Assignment Operators (=)
- Compound Assignment Operators (*= /= %= += -= <<= >>= &= ^= |=)

5.11.1 Simple Assignment Operators (=)

SYNTAX

```
E1 = E2
```

FUNCTION

- The = (simple assignment) operator converts the right operand (expression) to the type of the left operand (Lvalue) before the value is stored.

  In the following example, the value of an int type to be returned from the function by the type conversion of the simple assignment expression will be converted to a char type and an overflow in the result will be truncated. And the comparison of the value with "-1" will be made after the value is converted back to the int type. If the variable "c" declared without qualifier is not interpreted as unsigned char, the result of the variable will not become negative and its comparison with "-1" will never result in equal. In such a case, the variable "c" must be declared with an int type to ensure complete portability.

```
int     f ( void ) ;

char    c ;
/* ... */   ( ( c = f ( ) ) == -1 )  /* ... */
```

5.11.2 Compound Assignment Operators (*= /= %= += -= <<= >>= &= ^= |=)

SYNTAX

```
E1 *= E2
E1 /= E2
E1 %= E2
E1 += E2
E1 -= E2
E1 <<= E2
E1 >>= E2
E1 &= E2
E1 ^= E2
E1 |= E2
```

FUNCTION

- The compound assignment operators perform a specified operation on both operands and stores the result in the left operand. The value to be stored in the left operand will be converted to the type of Lvalue (left operand).
- The compound assignment expression "E1 op = E2" (where op indicates a suitable binary operator) is equivalent to the simple assignment expression "E1 = E1 op (E2)", except that the Lvalue (E1) is only evaluated once. The following compound assignment expressions will produce the same result as the respective simple assignment expressions on the right.

```
a *= b ;        a = a * b ;
a /= b ;        a = a / b ;
a %= b ;        a = a % b ;
a += b ;        a = a + b ;
a -= b ;        a = a - b ;
a <<= b ;       a = a << b ;
a >>= b ;       a = a >> b ;
a &= b ;        a = a & b ;
a ^= b ;        a = a ^ b ;
a |= b ;        a = a | b ;
```

5.12 Comma Operator

The types of comma operators are given below.

- Comma Operator (,)

5.12.1 Comma Operator (,)

SYNTAX

```
E1 , E2
```

FUNCTION

- The comma operator evaluates the left operand as a void type (that is, ignores its value) and then evaluates the right operand. The type and value of the result of the comma expression are the type and value of the right operand.
- In contents where a comma has another meaning (as in a list of function arguments or in a list of variable initializations), comma expressions must be enclosed in parentheses. In other words, the comma operator described in this chapter will not appear in such a list.
- In the following example, the comma operator finds the value of the second argument of the function "f ( )". The value of the second argument becomes 5.

```
int     a , c , t ;
void    main ( void )  {
        f ( a , ( t = 3 , t + 2 ) , c ) ;
}
```

5.13 Constant Expressions

Constant expressions include general integral constant expressions, arithmetic constant expressions, address constant expressions, and initialization constant expressions. Most of these constant expressions can be calculated at translation time instead of execution time.

In a constant expression, the following operators cannot be used except when they appear inside sizeof expressions :

- Assignment operators
- Increment operators
- Decrement operators
- Function call operator
- Comma operator

(1) General integral constant expression

A general integral constant expression has a general integral type. The following operands may be used :

- Integer constants
- Enumerated value constants
- Character constants
- sizeof expressions
- Floating point constants

(2) Arithmetic constant expression

An arithmetic constant expression has an integral type. The following operands may be used :

- Integer constants
- Enumerated value constants
- Character constants
- sizeof expressions
- Floating point constants

(3) Address constant expression

An address constant expression is a pointer to an object that has a static storage duration or a pointer to a function locator. Such an expression must be created explicitly using the unary & operator or implicitly using an expression with an array type or function type. The following operands may be used. However, none of these operators can be used to access the value of an object.

- Array subscript operator "[ ]"
- "." (dot) operator
- "->" (arrow) operator
- "&" address operator
- "*" indirection operator
- Pointer casts

CHAPTER 6 CONTROL STRUCTURES OF C LANGUAGE

This chapter describes the program control structures of C language and the statements to be executed in C.

Generally speaking, no matter how a process is complicated, it can be expressed with 3 basic control structures. These 3 control structures are : Sequential, Conditional control (Selection), and Iteration. Branch is used to change the flow of a program by force.

(1) Sequential processing

Statements in a program are executed one by one from top to bottom in the order of their description in the program.

(2) Conditional control (selection) processing

According to the status of the program under execution, the next executable statement is selected and executed. The selection condition is specified in a control statement. The control statement determines which of the 2 alternative statement groups or multiway (three or more) alternative statement groups is to be executed.

(3) Looping (iteration) processing

The same processing is executed two or more times. The execution of an executable statement is repeated a specified number of times during the condition indicated by the control statement.

(4) Branch processing

C is caused to exit from the current program flow and control is transferred to a specified label. Program execution starts from the statement next to the specified label.

There are 6 types of statements used in C.

- Labeled Statements : Causes branch according to the value of switch statement and the destination of goto statement
- Compound Statements or Blocks : Collects two or more statements to be processed as 1 unit
- Expression Statements and Null Statements : A statement consisting of an expression and a semicolon
- Conditional Control Statements : Selects a statement out of several statements according to the value of the expression
- Looping Statements : Repeatedly performs a statement called the body of a loop until the control expression becomes equal to 0.
- Branch Statements : Causes unconditional branch to different destination

Description example of these statements is shown below.

[Description example]

```
#define SIZE    10
#define TRUE    1
#define FALSE   0

extern  void    putchar ( char ) ;
extern  void    lprintf ( char * , int ) ;

charmark [ SIZE + 1 ] ;
void    main ( void ) {
        int     i , prime , k , count ;

    count = 0 ;
    for ( i = 0 ; i <= SIZE ; i++ )          /* Looping statement */
        mark [ i ] = TRUE ;
    for ( i = 0 ; i <= SIZE ; i++ )  {       /* Looping statement */
        if ( mark [ i ] )  {                 /* if : Conditional statement */
            prime = i + i + 3 ;
            lprintf ( " %d " , prime ) ;
            if ( ( count%8 ) == 0 )          /* if : Conditional statement */
                putchar ( ' \n ' ) ;
            for ( k = i + prime ; k <= SIZE ; k += prime )
                mark [ k ] = FALSE ;
        }
    }
    lprintf ( " Total %d\n " , count ) ;

loop1: ;                                     /* loop1 : Labeled statement */
    goto    loop1 ;                          /* goto : Branch statement */
}
```

6.1 Labeled Statements

A labeled statement specifies the destination of switch or goto statement. The switch statement selects the statement specified by a control expression from among statements with two or more options. The labeled statement becomes the label of the statement to be executed by the switch statement. The goto statement causes unconditional branching to the applicable label from the normal flow of processing.

The types of labeled statements are given below.

- case label
- default label

6.1.1 case label

SYNTAX

```
case constant-expression : statement
```

FUNCTION

- case labels are used only in the body of a switch statement to enumerate values to be taken by the control expression of the switch statement.

EXAMPLE 1

```
int     f ( void ) , i ;
void    main ( void )  {
        /* ... */
        switch ( f ( ) ) {
                case 1 :
                        i = i + 4 ;
                        break ;
                case 2 :
                        i = i + 3 ;
                        break ;
                case 3 :
                        i = i + 2 ;
        }
        /* ... */
}
```

EXPLANATION

- In EXAMPLE 1, if the return value of f( ) is 1, the first case clause (statement) is selected and the expression "i=i+4" is executed. Likewise, if the return value of f( ) is 2 or 3, the second or third case statement is selected, respectively. Each break statement in the above example is to break out of the switch body.

  As in this example, case labels are used when two or more options are involved.

EXAMPLE 2

```
int    i ;
void   main ( void ) {
        /* ... */
        i = 2 ;
        switch ( i ) {
               case 1 :
                       i = i + 4 ;
               case 2 :
                       i = i + 3 ;
               case 3 :
                       i = i + 2 ;
        }
        /* ... */
}
```

EXPLANATION

- In example 2, the processing starts in the second case statement since i is 2. The third statement is also consecutively performed since the case statement does not include a break statement. Thus, if the constant expression and the control expression in the case statement match, the programs thereafter are performed sequentially. A break statement is used to exit the switch statement.

6.1.2 default label

SYNTAX

```
default : statement
```

FUNCTION

- A default label is a special case label used only in the body of a switch statement to specify a process to be executed by C if the value of the control expression does not match any of the case constants.

EXAMPLE

```
int     f ( void ) , i ;

switch ( f ( ) ) {
        case 1 :
                i = i + 4 ;
                break ;
        case 2 :
                i = i + 3 ;
                break ;
        case 3 :
                i = i + 2 ;
        default :
                i = 1 ;
}
```

EXPLANATION

- In the above example, if the return value of f( ) is 1, 2, or 3, the corresponding case clause (statement) is selected and the expression that follows the case label is executed. Each break statement in the above example is to break out of the switch body. If the return value of f( ) is other than 1 to 3, the expression that follows the default label is executed. In this case, the value of i becomes 1.

6.2 Compound Statements or Blocks

A compound statement or block is synonymous to each other and consists of two or more statements grouped together with enclosing braces and executed as 1 unit syntax-wise. In other words, by enclosing zero or more declarations followed by zero or more statements all in braces, these statements can be processed as a compound statement whenever a single statement is expected.

6.3 Expression Statements and Null Statements

An expression statement consists of a statement and a semicolon. A null statement consists of only a semicolon and is used for labels that require a statement and in looping that do not need any body.

The description examples of expression statements and null statements are given below.

As in the following example, for a function to be called as an expression statement merely to obtain side effects, the value of its return value can be discarded by using a cast expression.

```
int     p ( int ) ;
void    main ( void )  {
        /* ... */
        ( void ) p ( 0 ) ;
}
```

A null statement can be used as the body of a looping statement as shown below.

```
char    *s ;
void    main ( void )  {
        /* ... */
        while ( *s++ != ' 0 ' ) ;
        /* ... */
}
```

In addition, it can be used to place a label before a brace "}" which closes a compound statement as shown below.

```
void    func ( void )  {
        /* ... */
        while ( loop1 )  {
                /* ... */
                while ( loop2 )  {
                        /* ... */
                        if ( want_out )
                                goto    end_loop1 ;
                        /* ... */
                }
end_loop1 : ;
        }
}
```

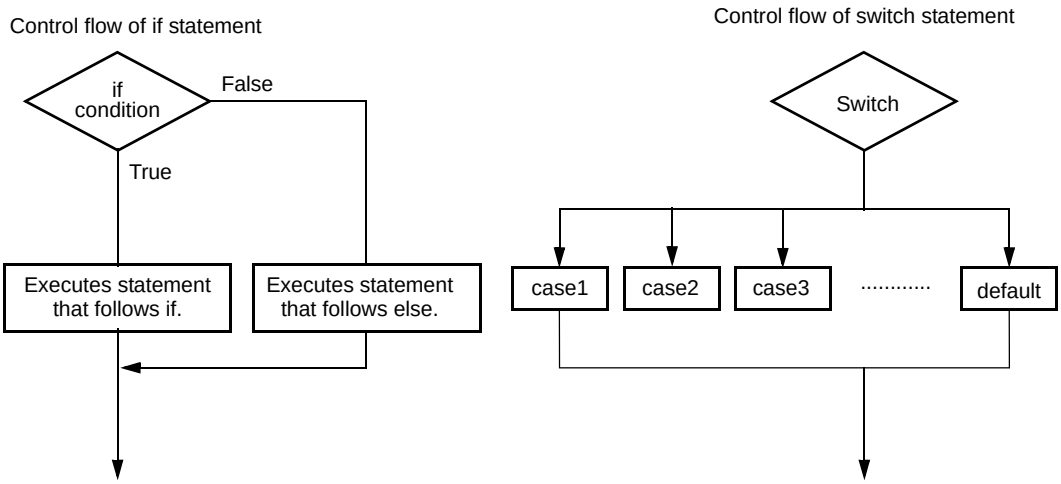
6.4 Conditional Control Statements

Conditional control (or selection) statements include if and switch statements. The if or switch statement allows the program to choose one of several groups of statements to execute, based on the value of the control expression enclosed in parentheses. The types of conditional control statements are given below.

- if and if ... else statements
- switch statement

The control flows of if and switch statements are illustrated in Figure 6-1 below.

Figure 6-1 Control Flows of Conditional Control Statements



6.4.1 if and if ... else statements

SYNTAX

```
if ( expression ) statement
if ( expression ) statement-1 else statement-2
```

FUNCTION

- An if statement executes the statement that follows the control expression enclosed in parentheses if the value of the control expression is nonzero.
- An if ... else statement executes the statement-1 that follows the control expression if the value of the control expression is nonzero or the statement-2 that follows else if the value of the control expression is zero.

EXAMPLE

```
unsigned char   uc ;
void    func ( void ) {
        if ( uc < 10 ) {
                /* 111 */
        } else {
                /* 222 */
        }
}
```

EXPLANATION

- In the above example, if the value of uc is less than 10 based on the control expression in the if statement, the block "{/*111*/}" is executed. If the value is greater than 10, the block "{/*222*/}" is executed.

NOTE

- When the processing after if statement/if...else statement is not enclosed with "{ }", only the processing of a line after the if statement/if...else statement is performed regarding it as the body.

6.4.2 switch statement

SYNTAX

```
switch (expression) statement
```

FUNCTION

- A switch statement has a multiway branching structure and passes control to one of a series of statements that have the case labels in the switch body depending on the value of the control expression enclosed in parentheses. If no case label that corresponds to the control expression exists, the statement that follows the default label is executed. If no default label exists, no statement is executed.

EXAMPLE

```
extern  void    func ( void ) ;
unsigned char   mode ;
void    main ( void ) {
        switch ( mode ) {
                case 2 :
                        mode = 8 ;
                        break ;
                case 4 :
                        mode = 2 ;
                        break ;
                case 8 :
                        func ( ) ;
        }
}
```

NOTE

- The same value cannot be set in each case label in the switch body. Only 1 default label can be used in the switch body.

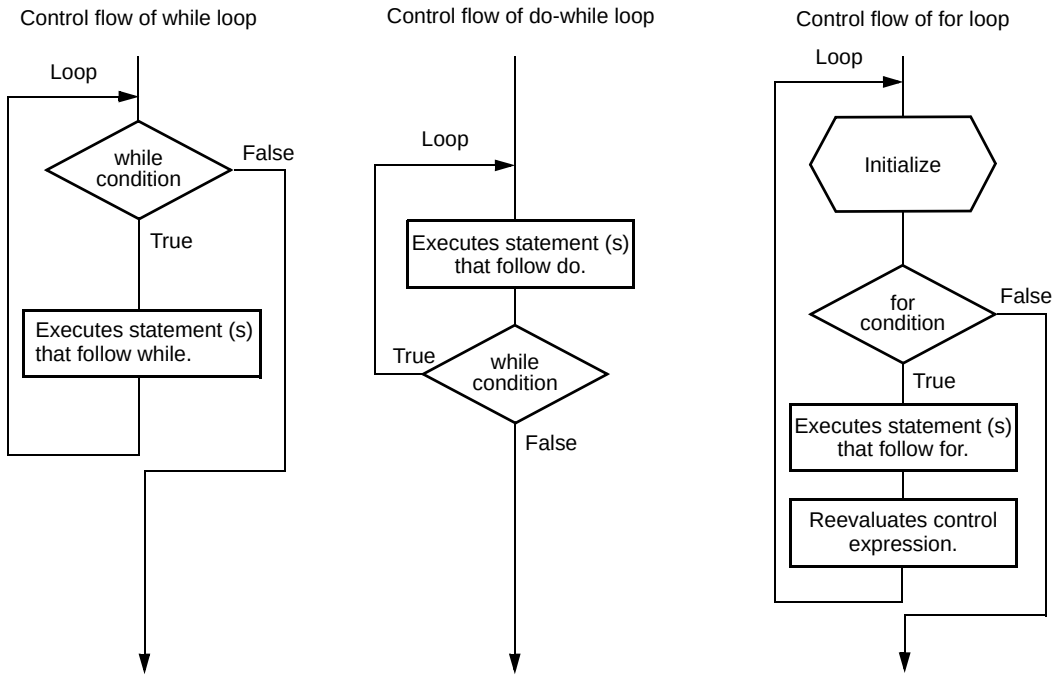
6.5 Looping Statements

A looping (or iteration) statement executes a group of statements in the loop body as long as the value of the control expression enclosed in parentheses is True (nonzero). C has the following 3 types of looping statements :

- while statement
- do statement
- for statement

The control flow of each type of looping statement is illustrated in Figure 6-2 below.

Figure 6-2 Control Flows of Looping Statements



6.5.1 while statement

SYNTAX

```
while ( expression ) statement
```

FUNCTION

- A while statement executes one or more statements (the body of the while loop) several times as long as the value of the control expression enclosed in parentheses is True (nonzero). The while statement evaluates the control expression before executing its loop body.

EXAMPLE

```
int     i , x ;
void    main ( void )  {
        i = 1 , x = 0 ;

        while ( i < 11 )  {
                x += i ;
                i++ ;
        }
}
```

EXPLANATION

- The above example finds the sum total of integers from 1 to 10 for x. The 2 statements enclosed in brace brackets are the body of this while loop. The control expression "i<11" returns 0 if the value of i becomes 11. For this reason, the loop body is executed repeatedly as long as the value of i is less than 11 (between 1 and 10).
- "while(1) {statement}" is used to endlessly perform a loop statement.

6.5.2 do statement

SYNTAX

```
do statements while ( expression ) ;
```

FUNCTION

- A do statement executes the body of the loop and then tests the control expression enclosed in parentheses to see if its value is True (nonzero). The do statement evaluates the control expression after the loop body has been executed.

EXAMPLE

```
int     i , x ;
void    main ( void ) {
        i = 1 , x = 0 ;

                do  {
                        x += i ;
                        i++ ;
                } while ( i < 11 ) ;
}
```

EXPLANATION

- The above example finds the sum total of integers from 1 to 10 for x. The 2 statements enclosed in brace brackets are the body of this do ... while loop. The control expression "i<11" returns 0 if the value of i becomes 11. For this reason, the loop body is executed repeatedly as long as the value of i is less than 11 (between 1 and 10). The body of the loop is always performed once or more since the control expression of a do statement is evaluated after execution.

6.5.3 for statement

SYNTAX

```
for ( 1st-expression ; 2nd-expression ; 3rd-expression ) statements
```

FUNCTION

- A for statement executes the body of the for loop a specified number of times as long as the value of the control expression is nonzero (True). Of the 3 expressions inside the parentheses separated by semicolons, the first expression is an initializing statement to initialize a variable to be used as a counter and execute only once in the beginning of the loop, the second is the control expression for testing the counter value, and the third is a step statement executed in the end of every loop and reevaluate the variable after the execution.

EXAMPLE

```
int     i , x = 0 ;

for ( i = 1 ; i < 11 ; ++i )
        x += i ;
```

EXPLANATION

- The above example finds the sum total of integers from 1 to 10 for x. "x+=i" is the body of this for loop. The control expression "i<11" returns 0 if the value of i becomes 11. For this reason, the loop body is executed repeatedly as long as the value of i is less than 11 (between 1 and 10).

NOTE

- When the processing after for statement is not enclosed with "{ }", only the processing of a line after the for statements is regarded as the body of the loop of the for statement.
- The first and the third expression of a for statement can be omitted. When the second expression is omitted, it is replaced with a constant other than 0. The description of "for (; ;) statement" is used to endlessly perform the body of the loop.

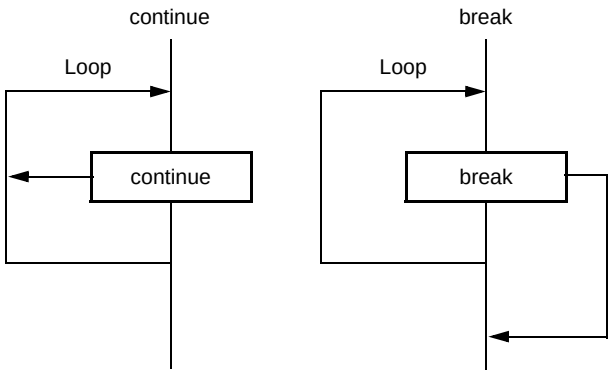
6.6 Branch Statements

A branch statement is used to exit from the current control flow and transfer control to elsewhere in the program. Branch statements include the following 4 statements :

- goto statement
- continue statement
- break statement
- return statement

The control flow of each type of branch statement is shown in Figure 6-3.

Figure 6-3 Control Flows of Branch Statements



6.6.1 goto statement

SYNTAX

```
goto identifier ;
```

FUNCTION

- A goto statement causes program execution to unconditionally jump to the label name specified in the goto statement within the current function.

EXAMPLE

```
do {
        /* ... */
        goto    point ;
        /* ... */
} while ( /* ... */ ) ;
        /* ... */
point : ;
```

EXPLANATION

- In the above example, when control is passed to the goto statement, C jumps out of the current do ... while loop processing without condition and transfers control to the statement next to "point".

NOTE

- The label name (branch destination) to be specified in a goto statement must have been specified within the current function that includes the goto statement. In other words, a goto can branch only within the current function - not from one function to another.

6.6.2 continue statement

FUNCTION

- A continue statement is used in the body of loops in a looping statement. continue ends one cycle of the loop by transferring control to the end of the loop body. When a continue statement is enclosed by more than 1 loop, it ends a cycle of the smallest enclosing loop.

SYNTAX

```
continue ;
```

EXAMPLE

```
while ( /* ... */ ) {
        /* ... */
        continue ;
        /* ... */
contin : ;
}
```

EXPLANATION

- In the above example, when the while loop processing by C reaches the continue statement, C unconditionally branches to the label "contin". The label "contin" indicates the branch destination and may be omitted. The same branching operation may be performed by using "goto contin ;" instead of continue.

NOTE

- A continue statement can only be used as the body of a loop or in the body of loops.

6.6.3 break statement

SYNTAX

```
break ;
```

FUNCTION

- A break statement may appear in the body of a loop and in the body of a switch statement and causes control to be transferred to the statement next to the loop or switch statement.

EXAMPLE

```
int     i ;
unsigned char   count , flag ;

void    main ( void ) {
        /* ... */
        for ( i = 0 ; i < 20 ; i++ )  {
                switch ( count )  {
                        case 10 :
                                flag = 1 ;
                                break ;         /* exit switch statement */
                        default :
                                func ( ) ;
                }
                if ( flag )
                        break ;                 /* exit for loop */
        }
}
```

EXPLANATION

- In the above example, break statements are used so that more than required evaluations are not performed in the body of the switch statement. If the corresponding case label is found in evaluating the switch statement, the break statement causes C to exit from the switch statement.

NOTE

- A break statement can only be used as the body of a looping or switch statement or in the loop or switch body.

6.6.4 return statement

SYNTAX

```
return expression ;
```

FUNCTION

- A return statement exits the function that includes the return and passes controls to the function that called the return, and it calls and returns the value of the return statement expression as the value of the function call expression.
- Two or more return statements may be used in a function.
- Using the closing brace bracket " } " at the end of a function produces the same result as when a return statement without expression is executed.

EXAMPLE

```
int     f ( int ) ;

void    main ( void )  {
        /* ... */
        int     i = 0 , y = 0 ;
        y = f ( i ) ;
        /* ... */
}

int     f ( int  i ) {
        int     x = 0 ;
        /* ... */
        return ( x ) ;
}
```

EXPLANATION

- In the above example, when control is passed to the return statement, the function f( ) returns a value to the function main. Because the value of the variable "x" is returned as the return value, the assignment operator causes the variable "y" to be substituted with the value of the variable "x".

NOTE

- With a void type function, an expression that indicates a return value cannot be used for a return statement.

CHAPTER 7 STRUCTURES AND UNIONS

A structure or union is a collection of member objects that have different types and grouped under 1 given name. The member objects of a structure are allocated successively to memory space, while the member objects of a union share the same memory.

7.1 Structures

As mentioned earlier, a structure is a collection of member objects successively allocated to memory space.

(1) Declaration of structure and structure variable

A structure declaration list and a structure variable are declared with the keyword "struct". Any name called a tag name can be given to the structure declaration list.
Subsequently, the structure variables of the same structure may be declared using this tag name.

[Declaration of structure]

```
struct  tag name { structure declaration list } variable name ;
```

In the following example, in the first struct declaration, int type array "code", char type arrays name, addr, and tel which have a tag name "data" are specified and no1 is declared as the structure variable. In the second struct declaration, the structure variables no2, no3, no4, and no5 that are of the same structure as no1 are declared.

[Example]

```
struct  data {
        int     code ;
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} no1 ;
struct  data    no2 , no3 , no4 , no5 ;
```

(2) Structure declaration list

A structure declaration list specifies the structure of a structure type to be declared. Individual elements in the structure declaration list are called members and an area is allocated for each of these members in the order of their declaration. In the following [Example of structure declaration list], an area is allocated in the order of variable a, array b, and 2-dimensional array c.

Neither an incomplete type (an array of unknown size) nor a function type can be specified as the type of each member. Therefore, the structure itself cannot be included in the structure declaration list.

Each member can have any object type other than the above 2 types. A bit field which specifies each member in bits can also be specified.

If a variable takes a binary value "0" or "1", the minimum required of bits is specified as 1 for a bit field. By this specification of the minimum required number of bits with the bit field, two or more members can be stored in an integer area.

[Example of structure declaration list]

```
int     a ;
char    b [ 7 ] ;
char    c [ 5 ] [ 10 ] ;
```

[Example of bit field declaration]

```
struct  bf_tag {
        unsigned int    a : 2 ;
        unsigned int    b : 3 ;     bit field
        unsigned int    c : 1 ;
} bit_field ;
```

(3) Arrays and pointers

Structure variables may also be declared as an array or referenced using a pointer.

[Structure arrays]

An array of structures is declared in the same ways as other objects.

```
struct  data  {
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} ;
struct  data    no [ 5 ] ;
```

[Structure pointers]

A pointer to a structure has the characteristics of the structure indicated by the pointer. In other words, if a structure pointer is incremented, adding the size of the structure to the pointer points to the next structure. In the following example, "dt_p" is a pointer to the value of "struct data" type. Here, if the pointer "dt_p" is incremented, the pointer becomes the same value as "&no [1]".

```
struct  data    no [ 5 ] ;
struct  data    *dt_p = no ;
```

(4) How to refer to structure members

A structure member may be referenced in 2 ways : one by using a structure variable and the other by using a pointer to a variable.

[Reference by using a structure variable]

The "." (dot) operator is used for referring to a structure member by using a structure variable.

```
struct  data  {
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} no [ 5 ] = { " NAME " , " ADDR " , " TEL " } , *data_ptr = no ;

void    main ( ) {
        char    c ;
        c = no [ 0 ] . name [ 1 ] ;
}
```

[Reference by using a pointer to a variable]

The "->" (arrow) operator is used for referring to a structure member by using a pointer to a variable.

```
struct  data  {
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} no [ 5 ] = { " NAME " , " ADDR " , " TEL " } , *data_ptr = no ;

void    main ( ) {
        char    c ;
        data_ptr -> tel [ 3 ] = ' E ' ;
}
```

7.2 Unions

As mentioned earlier, a union is a collection of members which share the same memory space (or overlap in memory).

(1) Declaration of union and union variable

A union declaration list and a union variable are declared with the keyword "union". Any name called a tag name can be given to the union declaration list. Subsequently, the union variables of the same union may be declared using this tag name.

[Declaration of union]

```
union tag name { union declaration list } variable name ;
```

In the following example, in the first union declaration, char type arrays "name", "addr", and "tel" which have a tag name "data" are specified and "no1" is declared as the union variable. In the second union declaration, the union variables "no2, no3, no4, and no5" which are of the same union as "no1" are declared.

```
union   data  {
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} no1 ;
union   data    no2 , no3 , no4 , no5 ;
```

(2) Union declaration list

A union declaration list specifies the structure of a union type to be declared. Each element on the union declaration list is called a member. Declared members are allocated to the same area. In the following [Example of union declaration list], an area is allocated to "c", which becomes the largest area of the members. The other members are not allocated new areas but use the same area.

Neither an incomplete type (an array of unknown size) nor a function type can be specified as the type of each member same as the union declaration list.

Each member can have any object type other than the above 2 types.

[Union declaration list]

```
int     a ;
char    b [ 7 ] ;
char    c [ 5 ] [ 10 ] ;
```

(3) Union arrays and pointers

Union variables may also be declared as an array or referenced using a pointer (in much the same way as structure arrays and pointers).

[Union arrays]

An array of unions is declared in the same ways as other objects.

```
union   data {
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} ;
union   data    no [ 5 ] ;
```

[Union pointers]

A pointer to a union has the characteristics of the union indicated by the pointer. In other words, if a union pointer is incremented, adding the size of the union to the pointer points to the next union.

In the following example, "dt_p" is a pointer to the value of "union data" type.

```
union   data    no [ 5 ] ;
union   data    *dt_p = no ;
```

(4) How to refer to union members

A union member (or union element) may be referenced in 2 ways : one by using a union variable and the other by using a pointer to a variable.

[Reference by using a union variable]

The "." (dot) operator is used for referring to a union member by using a union variable.

```
union   data {
        char    name [ 12 ] ;
        char    addr [ 50 ] ;
        char    tel [ 12 ] ;
} no [ 5 ] = { " NAME " , " ADDR " , " TEL " } ;

void    main ( void ) {
        no [ 0 ] .addr [ 10 ] = ' B ' ;
            :
}
```

[Reference by using a pointer to a variable]

The "->" (arrow) operator is used for referring to a union member by using a pointer to a variable.

```
union   data {
        char        name [ 12 ] ;
        char        addr [ 50 ] ;
        char        tel [ 12 ] ;
} *data_ptr ;

void        main ( void ) {
        data_ptr -> name [ 1 ] = ' N ' ;
            :
}
```

CHAPTER 8 EXTERNAL DEFINITIONS

In a program, lists of external declaration come after the preprocessing. These declaration are referred to as "external declaration" because they appear outside a function and have effective file ranges.

A declaration to give a name to external objects by identifiers or a declaration to secure storage for a function is called an external definition. If an identifier declared with external linkage is used in an expression (except the operand part of the sizeof operator), only 1 external definition for the identifier must exist somewhere in the entire program.

The syntax of external definitions is given below.

```
#define TRUE    1
#define FALSE   0
#define SIZE    200
void    printf ( char * , int ) ;
void    putchar ( char c ) ;

char    mark [ SIZE + 1 ] ;     /* External object declaration */

main ( )
{
        int     i , prime , k , count ;

        count = 0 ;

        for ( i = 0 ; i <= SIZE ; i++ )
                mark [ i ] = TRUE ;
        for ( i = 0 ; i <= SIZE ; i++ ) {
                if ( mark [ i ] ) {
                        prime = i + i + 3 ;
                        printf ( " %d " , prime ) ;
                        count++ ;
                        if ( ( count%8 ) == 0 ) putchar ( ' \n ' ) ;
                        for ( k = i + prime ; k <= SIZE ; k += prime )
                                mark [ k ] = FALSE ;
                }
        }
        printf ( " Total %d\n " , count ) ;

loop1 :
        goto    loop1 ;
}
```

8.1 Function Definition

A function definition is an external definition that begins with a declaration of the function. If the storage class specifier is omitted from the declaration, "extern" is assumed to have been defined. An external function definition means that the defined function may be referenced from other files. For example, in a program consisting of two or more files, if a function in another file is to be referenced, this function must be defined externally.

The storage class specifier of an external function is extern or static. If a function is declared as extern, the function can be referenced from another file. If declared as static, it cannot be referenced from another file.

In the following example, the storage class specifier is "extern" and the type specifier is "int". These two are default values and thus may be omitted from specification. The function declarator is "max(int a, int b)" and the body of the function is "{return a > b ? a : b ;)".

[Example of function definition]

```
extern  int     max ( int a , int b )
{
        return a > b ? a : b ;
}
```

Because this function definition specifies a parameter type in the function declaration, the type of argument is forcedly converted by the compiler. By using the form of an identifier list for the parameters, this type conversion can be described. An example of this identifier list is shown below.

```
extern  int     max ( a , b )
int     a , b ;
{
       return a > b ? a : b ;
}
```

As an argument to a function call, the address of the function may be passed. By using the function name in the expression, a pointer to the function can be generated.

```
int     f ( void ) ;
void    main ( )  {
    :
        g ( f ) ;
}
```

In the above example, the function g is passed to the function f by a pointer that points to the function f. The function g must be defined in either of the following 2 ways :

```
void    g ( int ( *funcp ) ( void ) )
{
        ( *funcp ) ( ) ;        /* or funcp ( ) ; */
}
```

or

```
void    g ( int func ( void ) )
{
        func ( ) ;              /* or ( *func ) ( ) ; */
}
```

8.2 External Object Definitions

An external object definition refers to the declaration of an identifier for an object that has file scope or initializer. If the declaration of an identifier for an object which has file scope has no initializer without storage class specification or has storage class static, the object definition is considered to be temporary, because it becomes a declaration which has file scope with initializer 0.

Examples of external object definitions are shown below.

[Example of external object definition]

- int i1 = 1 ; : Definition with external linkage
- static int i2 = 2 ; : Definition with internal linkage
- extern int i3 = 3 ; : Definition with external linkage
- int i4 ; : Temporary definition with external linkage
- static int i5 ; : Temporary definition with internal linkage
- int i1 ; : Valid temporary definition which refers to previous declaration
- int i2 ; : Violation of linkage rule
- int i3 ; : Valid temporary definition which refers to previous declaration
- int i4 ; : Valid temporary definition which refers to previous declaration
- int i5 ; : Violation of linkage rule
- extern int i1 ; : Reference to previous declaration which has external linkage
- extern int i2 ; : Reference to previous declaration which has internal linkage
- extern int i3 ; : Reference to previous declaration which has external linkage
- extern int i4 ; : Reference to previous declaration which has external linkage
- extern int i5 ; : Reference to previous declaration which has internal linkage

CHAPTER 9 PREPROCESSOR DIRECTIVES (COMPILER DIRECTIVES)

A preprocessor directive is a string of preprocessor tokens between the "#" preprocessor token and the line feed character.

Blank characters that can be used between preprocessor token strings are only spaces and horizontal tabs.

A preprocessor directive specifies the processing performed before compiling a source file. Preprocessor directives include such operations as processing or skipping a part of a source file depending on the condition, obtaining additional code from other source files, and replacing the original source code with other text as in macro expansion. The followings explain each preprocessor directive.

9.1 Conditional Compilation Directives

Conditional compilation skips part of a source file according to the value of a constant expression. If the value of the constant expression specified by a conditional compilation directive is 0, the statements that follow the directive are not compiled. The sizeof operator, cast operator, or an enumerated type constant cannot be used in the constant expression of any conditional compilation directive.

The types of Conditional compilation directives are given below.

- #if directive
- #elif directive
- #ifdef directive
- #ifndef directive
- #else directive
- #endif directive

In preprocessor directives, the following unary expressions called defined expressions may be used :

```
defined identifier
or
defined ( identifier )
```

The unary expressions return 1 if the identifier has been defined with the #define preprocessor directive and 0 if the identifier has never been defined or its definition has been canceled.

[Example]

- In this example, the unary expression returns 1 and compile between #if and #endif because SYM has been defined (for the explanation of #if through #endif, refer to the explanation in the following page and thereafter).

```
#define SYM     0

#if defined     SYM
    :
#endif
```

9.1.1 #if directive

SYNTAX

```
#if constant expression new-line " group "
```

FUNCTION

- The #if directive tells the translation phase of C to skip (discard) a section of source code if the value of the constant expression is 0.

EXAMPLE

```
#if FLAG == 0
    :
#endif
```

EXPLANATION

- In the above example, the constant expression "FLAG == 0" is evaluated to determine whether a set of statements (i.e., source code) between #if and #endif is to be used in the translation phase. If the value of "FLAG" is nonzero, the source code between #if and #endif will be discarded. If the value is zero, the source code between #if and #endif will be translated.

9.1.2 #elif directive

SYNTAX

```
#elif constant-expression new-line " group "
```

FUNCTION

- The #elif directive normally follows the #if directive. If the value of the constant expression of the #if directive is 0, the constant expression of the #elif directive is evaluated. If the constant expression of the #elif directive is 0, the translation phase of C will skip (discard) the statements (a section of source code) between #elif and #endif.

EXAMPLE

```
#if FLAG == 0
    :
#elif FLAG != 0
    :
#endif
```

EXPLANATION

- In the above example, the constant expression "FLAG= =0" or "FLAG!=0" is evaluated to determine whether a set of statements that follow #if and another set of statements that follow #elif is to be used in the translation phase. If the value of "FLAG" is zero, the source code between #if and #elif will be translated. If the value is nonzero, the source code between #elif and #endif will be translated.

9.1.3 #ifdef directive

SYNTAX

```
#ifdef  identifier      new-line        " group "
```

FUNCTION

- The #ifdef directive is equivalent to #if defined (identifier)
- If the identifier has been defined with the #define directive, the statements between #ifdef and #endif will be translated. If the identifier has never been defined or its definition has been canceled, the translation phase will skip the source code between #ifdef and #endif.

EXAMPLE

```
#define ON
#ifdef  ON
    :
#endif
```

EXPLANATION

- In the above example, the identifier "ON" has been defined with #define directive. Thus, the source code between #ifdef and #endif will be translated. If the identifier "ON" has never been defined, the source code between #ifdef and #endif will be discarded.

9.1.4 #ifndef directive

SYNTAX

```
#ifndef identifier      new-line        " group "
```

FUNCTION

- The #ifndef directive is equivalent to #if !defined (identifier). If the identifier has never been defined with the #define directive, the source code between #ifndef and #endif will not be translated.

EXAMPLE

```
#define ON
#ifndef ON
    :
#endif
```

EXPLANATION

- In the above example, the identifier "ON" has been defined with #define directive. Thus, the program between #ifndef and #endif will not be compiled. If the identifier "ON" has never been defined, the program between #ifndef and #endif will be compiled.

9.1.5 #else directive

SYNTAX

```
#else   new-line        " group "
```

FUNCTION

- The #else directive tells the translation phase of C to discard a section of source code that follows #else if the identifier of the preceding conditional translation directive is nonzero. The #if, #elif, #ifdef, or #ifndef directive may precede the #else directive.

EXAMPLE

```
#define ON
#ifdef  ON
    :
#else
    :
#endif
```

EXPLANATION

- In the above example, the identifier "ON" has been defined with #define directive. Thus, the source code between #ifndef and #endif will be translated. If the identifier "ON" has never been defined, the source code between #else and #endif will be translated.

9.1.6 #endif directive

SYNTAX

```
#endif  new-line
```

FUNCTION

- The #endif directive indicates the end of a #ifdef block.

EXAMPLE

```
#define ON
#ifdef  ON
    :
#endif
```

EXPLANATION

- In the above example, "#endif" indicates the end of the #ifdef block (effective range of #ifdef directive).

9.2 Source File Inclusion Directive

The preprocessor directive #include searches for a specified header file and replaces the #include by the entire contents of the specified file. The #include directive may take one of the following 3 forms for inclusion of other source files :

- #include < > directive
- #include " " directive
- #include preprocessing token string directive

A #include directive may appear in the source obtained by #include. In the CC78K0S, however, there are restrictions for #include directive nest. For the restrictions, refer to Table 1-1.

Remark Preprocessor token string : character string defined by #define directive

9.2.1 #include < > directive

SYNTAX

```
#include        < file-name >   new-line
```

FUNCTION

- If the directive form is #include < >, the C compiler searches the folder specified with -i compiler option, folder specified by the INC78K0S environment variable, and folder \NECTools32\inc78k0s registered in the registry for the header file specified in angle brackets and replaces the #include directive line with the entire contents of the specified file.

EXAMPLE

```
#include        < stdio.h >
```

EXPLANATION

- In the above example, the C compiler searches the folder specified by the INC78K0S environment variable and folder \NECTools32\inc78k0s registered in the registry for the file "stdio.h" and replaces the directive line "#include < stdio.h >" with the entire contents of the specified file "stdio.h".

  Remark The above folders differ depending on the installation method.

9.2.2 #include " " directive

SYNTAX

```
#include        " file-name "   new-line
```

FUNCTION

- If the directive form is #include " ", the current working folder is first searched for the header file specified in double quotes. If it is not found, the folder specified with -i compiler option, folder specified by the INC78K0S environment variable, and folder \NECTools32\inc78k0s registered in the registry is searched. Then, the compiler replaces the #include directive line with the entire contents of the specified file thus searched.

EXAMPLE

```
#include        " myprog.h "
```

EXPLANATION

- In the above example, the C compiler searches the current working folder, the folder specified by the INC78K0S environment variable, and folder \NECTools32\inc78k0s registered in the registry for the file "myprog.h" specified in double quotes and replaces the directive line #include "myprog.h" with the entire contents of the specified file "myprog.h".

  Remark The above folders differ depending on the installation method.

9.2.3 #include preprocessing token string directive

SYNTAX

```
#include        preprocessing token string      new-line
```

FUNCTION

- If the directive form is #include preprocessing token string, the header file to be searched is specified by macro replacement and the #include directive line is replaced by the entire contents of the specified file.

EXAMPLE

```
#define         INCFILE " myprog.h "
#include        INCFILE
```

EXPLANATION

- In the inclusion of other source files with the directive form : #include preprocessing token string, the specified "preprocessing token string" must be substituted with < file-name > or "file name" by macro replacement. If the token string is replaced by < file-name >, the C compiler searches the folder specified with -i compiler option, folder specified by the INC78K0S environment variable, and folder \NECTools32\inc78k0s registered in the registry for the specified file. If the token string is replaced by "file name", the current working folder is searched. If the specified file is not found, the folder specified with **-i** compiler option, folder specified by the INC78K0S environment variable, and folder \NECTools32\inc78k0s registered in the registry is searched.

  Remark The above folders differ depending on the installation method.

9.3 Macro Replacement Directives

The macro replacement directives #define and #undef are used to replace the character string specified by "identifier" with "substitution list" and to end the scope of the identifier given by the #define, respectively. The #define directive has 2 forms : Object format and Function format :

- Object format

  #define directive

- Function format

  #define ( ) directive

(1) Actual argument replacement

Actual argument replacement is executed after the arguments in the function-form macro call are identified. If the # or ## preprocessing token is not prefixed to a parameter in the replacement list or if the ## preprocessing token does not follow any such parameter, all macros in the list will be expanded before replacement with the corresponding macro arguments.

(2) # operator

The # preprocessing token replaces the corresponding macro argument with a char string processing token. In other words, if this preprocessing token is prefixed to a parameter in the replacement list, the corresponding macro argument will be translated into a character or character string.

(3) ## operator

The ## preprocessing token concatenates the 2 tokens on either side of the ## symbol into 1 token. This concatenation will take place before the next macro expansion and the ## preprocessing token will be deleted after the concatenation. The token generated from this concatenation will undergo macro expansion if it has a macro name.

[Example of ## operation]

The above macro replacement directive will be expanded as follows :

```
printf ( " x " " 1 " " = %d , x " " 2 " " = %s " , x1 , x2 ) ;
```

The concatenated char string will look like this.

```
printf ( " x1 = %d , x2 = %s " , x1 , x2 ) ;
```

```
#include        < stdio.h >
#define debug ( s , t ) printf ( " x " #s " = %d , x " #t " = %s " , x##s
, x##t ) ;

void    main ( )  {
        int     x1 , x2 ;
        debug ( 1 , 2 ) ;
}
```

(4) Re-scanning and further replacement

The preprocessing token string resulting from replacement of macro parameters in the list will be scanned again, together with all remaining preprocessing tokens in the source file. Macro names currently being (not including the remaining preprocessing tokens in the source file) replaced will not be replaced even if they are found during scanning of the replacement list.

(5) Scope of macro definition

A macro definition (#define directive) continues macro replacement until it encounters the corresponding #undef directive

9.3.1 #define directive

SYNTAX

```
#define identifier      replacement-list         new-line
```

FUNCTION

- The #define directive in its simplest form replaces the specified identifier (manifest) with a given replacement list (any character sequence that does not contain a new-line) whenever the same identifier appears in the source code after the definition by this directive.

EXAMPLE

```
#define PAI     3.1415
```

EXPLANATION

- In the above example, the identifier "PAI" will be replaced with "3.1415" whenever it appears in the source code after the definition by this directive.

9.3.2 #define ( ) directive

SYNTAX

```
#define identifier  ( " dentifier list " )  replacement-list    new-line
```

FUNCTION

- The function-form #define directive which has the form :

  #define name (name, ..., name) replacement list

  replaces the identifier specified in the function format with a given replacement list (any character sequence that does not contain a new-line). No white space is allowed between the first name and the opening parenthesis "(". This list of names (identifier list) may be empty. Because this form of the directive defines a macro, the macro call will be replaced with the parameters of the macro inside the parentheses.

EXAMPLE

```
#define F ( n )  ( n * n )
void    main ( ) {
        int     i ;
        i = F ( 2 ) ;
}
```

EXPLANATION

- In the above example, #define directive will replace "F(2)" with "(2*2)" and thus the value of i will become 4. For the safety' sake, be sure to enclose the replacement list in parentheses, because unlike a function definition, this function-form macro is merely to replace a sequence of characters.

9.3.3 #undef directive

SYNTAX

```
#undef  identifier      new-line
```

FUNCTION

- The #undef directive undefines the given identifier. In other words, this directive ends the scope of the identifier that has been set by the corresponding #define directive.

EXAMPLE

```
#define F ( n ) ( n * n )
    :
#undef  F
```

EXPLANATION

- In the above example, #undef directive will invalidate the identifier "F" previously specified by "#define F(n) (n*n)".

9.4 Line Control Directive

The preprocessor directive for line control "#line" replaces the line number to be used by the C compiler in translation with the number specified in this directive. If a string (character string) is given in addition to the number, the directive also replaces the source file name the C compiler has with the specified string.

(1) To change the line number

To change the line number, the specification is made as follows. 0 and numbers larger than 32767 cannot be specified.

```
#line   numeric-string  new-line
```

[Example]

```
#line   10
```

(2) To change the line number and the file name

To change the line number and file name, the specification is made as follows.

```
#line   numeric-string  " character string "    new-line
```

[Example]

```
#line   10      " file1.c "
```

(3) To change using preprocessor token string

In addition to the specifications above, the following specification can also be made. In this case, the specified preprocessor token string must be either one of the above 2 examples after all the replacement.

```
#line   preprocessing-token-string       new-line
```

[Example]

```
#define LINE_NUM        100
#line   LINE_NUM
```

9.5 #error Preprocess Directive

#error preprocess directive is a directive that outputs a message including the specified preprocessor tokens and incompletely terminates a compile. This preprocessor is used to terminate a compile.

This preprocessor is specified as follows.

```
#error  " preprocessing-token-string "  new-line
```

[Example]

- In this example, the macro name __K0S__, which indicates the device series that the CC78K0S has, is used. If the device is the 78K0S Series, the program between #if and #else is compiled. In the other cases, the program between #else and #endif is compiled, but the compile will be terminated with an error message "not for 78K0S" output by #error directive.

```
#if     __K0S__
    :
#else
#error  " not for 78K0S "
    :
#endif
```

9.6 #pragma Directives

#pragma directive is a directive to instruct the compiler to operate in the compiler definition method. In the CC78K0S, several #pragma directives to generate codes for the 78K0S Series (For the details of #pragma directives, refer to "CHAPTER 11 EXTENDED FUNCTIONS").

[Example]

- In this example, #pragma NOP directive enables the description to directly output a NOP instruction in the C source.

```
#pragma NOP
```

9.7 Null Directives

Source lines that contain only the # character and white space are called null directives. Null directives are simply discarded during preprocessing. In other words, these directives have no effect on the compiler. The syntax of null directives is given below.

```
# new-line
```

9.8 Compiler-Defined Macro Names

In the CC78K0S, the following macro names have been defined.

__LINE__	Line number of the current source line (decimal constant)
__FILE__	Source file name (string literal)
__DATE__	Date the source file was compiled (string literal in the form of "Mmm dd yyyy")
__TIME__	Time of day the source file was compiled (string literal in the form of "hh:mm:ss")
__STDC__	Decimal constant "1" that indicates the compliance with ANSI[Note] specification

Note ANSI is the acronym for American National Standards Institute

A #define or #undef preprocessor directive must not be applied to these macro name and defined identifiers. All the macro names of the compiler definition start with underscore followed by an uppercase character or the second underscore.

In addition to the above macro names, macro names indicating the series names of devices depending on the device subject to applied product development and macro names indicating device names are provided. To output the object code for the target device, these macro names must be specified by the option at compilation time or by the processor type in the C source.

- Macro name indicating the series names of devices

```
__K0S__
```

- Macro name indicating the device name

  "__" is added before the device type name and "_" is added after the device type name.

  Describe English characters in uppercase.

  < Example >

```
__9216_    __9216Y_
```

  Remark The device type names are the same as the ones specified by -c option. For the device type names, refer to the reference related to device files.

The CC78K0S has a macro name indicating the memory model.

Define as follows when the static model is specified

```
#define__STATIC_MODEL__   1
```

The device type for compile is specified by adding the followings to the command line

"-c device type name"

< Example >

```
cc78k0s  -c9216Y  prime.c
```

The device type does not need to be specified on compile by specifying it at the start of the C source program.

"#pragma PC (device type)"

< Example >

```
#pragma PC      ( 9216Y )
    :
```

However, the followings can be described before "#pragma PC (device type)"

- Comment statement
- Preprocessor directives that do not generate definition/reference of variables nor functions.

CHAPTER 10 LIBRARY FUNCTIONS

C has no instructions to transfer (input or output) data to and from external sources (peripheral devices and equipment). This is because of the C language designer's intent to hold the functions of C to a minimum. However, for actually developing a system, I/O operations are requisite. Thus, the CC78K0S is provided with library functions to perform I/O operations.

The CC78K0S is provided with library functions such as I/O, character/memory manipulation, program control, and mathematical functions. This chapter describes the library functions provided to the CC78K0S.

10.1 Interface Between Functions

To use a library function, the function must be called. Calling a library function is carried out by a call instruction. The arguments and return value of a function are passed by a stack and a register, respectively. However, the first argument is, if possible, also passed by the register. In addition, all of the arguments are passed by the register in the static model.

10.1.1 Arguments

Placing or removing arguments on or from the stack is performed by the caller (calling side). The callee (called side) only references the argument values. However, when the argument is passed by the register, the callee directly refers to the register and copies the value of the argument to another register, if necessary. Also, when specifying the function call interface automatic pascal function option -zr, removal of arguments from the stack is performed by the called side if the argument is passed on the stack.

Arguments are placed on the stack one by one in descending order from last to top if the argument is passed on the stack.

The minimum unit of data can be stacked is 16 bits. A data type larger than 16 bits is stacked in units of 16 bits one by one from its MSB. An 8-bit type data is extended to a 16-bit type data for stacking.

When in static model, all of arguments are passed by the register.

Maximum of 3 arguments and a total of 6 bytes can be passed. Passing the float, double, and structure arguments is not supported.

The following shows the list of the passing of the first argument. The second argument and thereafter is passed via a stack in the normal model.

The function interface (passing of argument and storing of return value) of the standard library is the same as that of normal function.

Table 10-1 List of Passing First Argument (Normal Model)

Type of First Argument	Passing Method
1-byte, 2-byte integers	AX
3-byte integer	AX, BC
4-byte integer	AX, BC
Floating-point number (float type)	AX, BC
Floating-point number (double type)	AX, BC
Others	Passed via a stack

Remark Of the types shown above, 1- to 4-byte integers include structures and unions.

Table 10-2 List of Passing Arguments (Static Model)

Type of Argument	1st Argument	2nd Argument	3rd Argument
1-byte integer	A	B	H
2-byte integer	AX	BC	HL

Remark If the arguments are a total of 4 bytes, some of the arguments are allocated to AX and BC, and the rest to HL or H.

1- to 4-byte integers do not include structures and unions.

10.1.2 Return values

The return value of a function is stored in units of 16 bits starting from its LSB in the direction from the register BC to the register DE. When returning a structure, the first address of the structure is stored in the register BC. When returning a pointer, the first address of the structure is stored in the register BC.

The following shows the list of the storing of the return value. The method of storing return values is the same as that of normal function.

(1) Normal model

Table 10-3 List of Storing Return Value (Normal Model)

Type of Return Value	Method of Storing
1 bit	CY
1-byte, 2-byte integers	BC
4-byte integer	BC (low-order), DE (high-order)
Floating-point number (float type)	BC (low-order), DE (high-order)
Floating-point number (double type)	BC (low-order), DE (high-order)
Structure	Copies the structure to return to the area specific to the function and stores the address to BC
Pointer	BC

(2) Static model

Table 10-4 List of Storing Return Value (Static Model)

Type of Return Value	Method of Storing
1 bit	CY
1-byte integer	A
2-byte integer	AX
4-byte integer	AX (low-order), BC (high-order)
Pointer	AX

10.1.3 Saving registers to be used by individual libraries

Library that uses HL (when in normal model) and DE(when in static model) saves the registers it uses to a stack.

Each library that uses a saddr area saves the saddr area it uses to a stack. A stack area is used as a work area for each library.

(1) No -zr option specified

The procedure of passing arguments and return value is shown below.

< Called function >

```
" long func ( int a , long b , char *c ) ; "
```

(a) Placing arguments on the stack (by the caller)

High-order 16 bits of arguments "c" and "b", low-order 16 bits of argument "b" are placed on the stack in the order named. a is passed by AX register.

(b) Calling func by call instruction (by the caller)

Return address is placed on the stack next to low-order 16 bits of argument "b" and control is transferred to the function func.

(c) Saving registers to be used within the function (by the callee)

If register HL is to be used, HL is placed on the stack.

(d) Placing the first argument passed by the register on the stack (by the callee)

(e) Processing func and storing the return value in registers (by the callee)

The low-order 16 bits of the return value "long" are stored in BC and the high-order 16 bits of the return value, in DE.

(f) Restoring the stored first argument (by the callee)

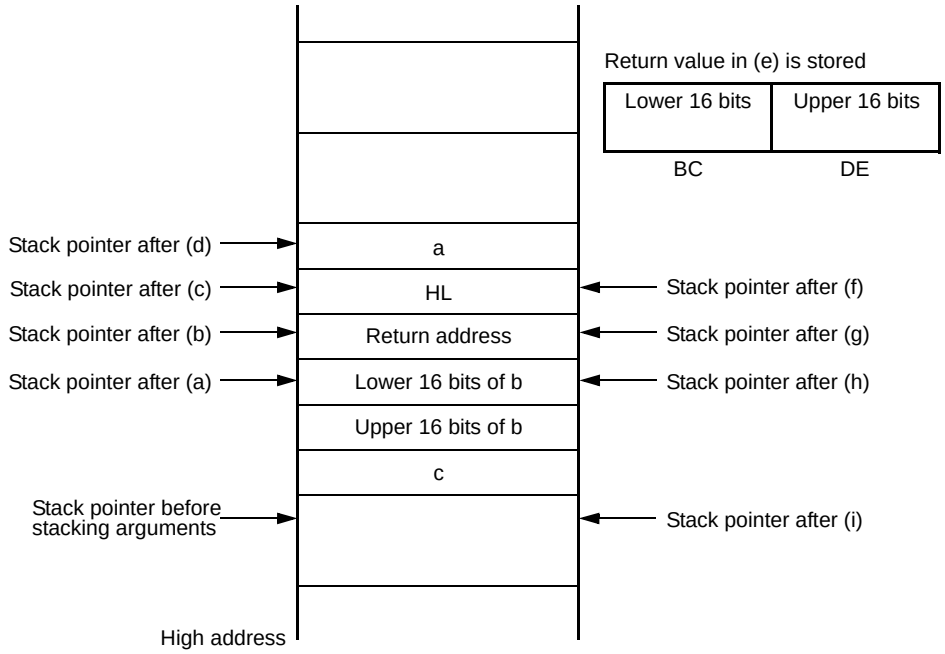
(g) Restoring the saved registers (by the callee)

(h) Returning control to the caller with ret instruction (by the callee)

(i) Removing arguments from the stack (by the caller)

The number of bytes (in units of 2 bytes) of the arguments is added to the stack pointer. In the example shown in Figure 10-1, 6 is added.

Figure 10-1 Stack Area When Function Is Called (No -zr Specified)



(2) If the -zr option is specified

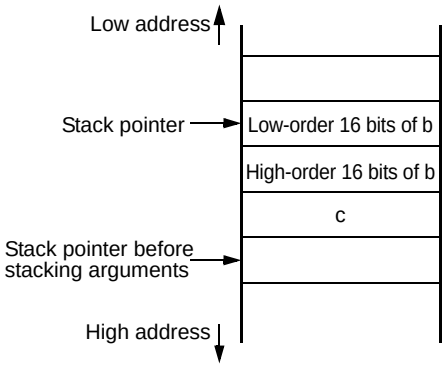
The following example shows the procedure of passing arguments and return values when the -zr option is specified.

< Called function >

```
" long func ( int a , long b , char *c ) ; "
```

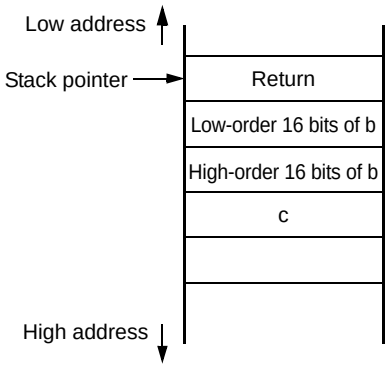
(a) Placing arguments on the stack (by the caller)

The high-order 16 bits of arguments "c" and "b" and the low-order 16 bits of argument "b" are placed on the stack in that order. a is passed by AX register.

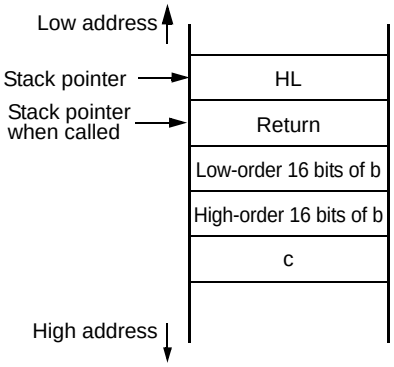


(b) Calling func by a call instruction (by the caller)

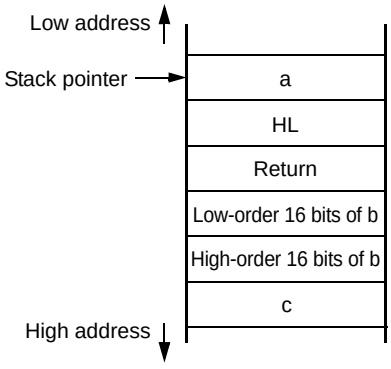
Control is transferred to the function func when the stack is in the state shown below.



(c) Saving the register used (by the callee)



(d) The first argument called by the register is placed on the stack

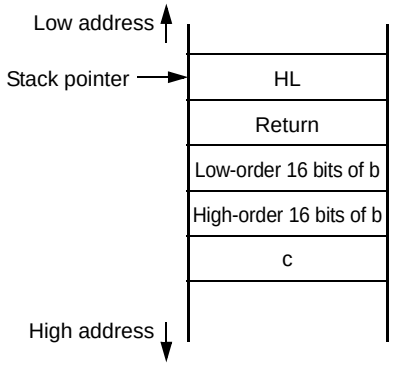


(e) Performing processing of the function func, and storing return values in the register (by the callee)

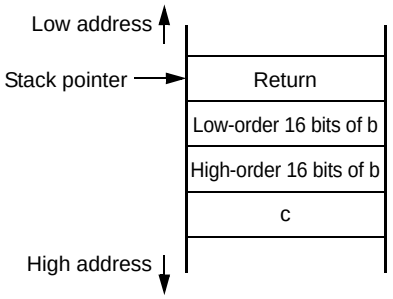
The low-order 16 bits of the return value are stored in BC and the high-order 16 bits are stored in DE.

BC	DE
Low-order 16 bits of return value	High-order 16 bits of return value

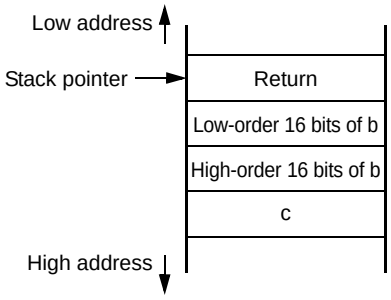
(f) Restoring the first placed argument (by the callee)



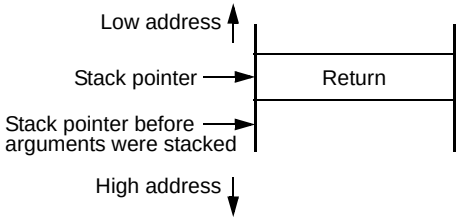
(g) Restoring the saved registers (by the callee)



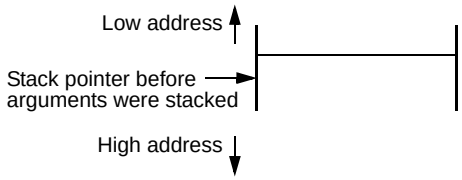
(h) Storing the return address in a register, moving the value of the stack pointer to the position where the argument is pushed to the stack, and removing the argument from the stack (on the called side).



(i) Restoring the return address stored in the register (by the callee)



(j) Returning control to the functions on the caller by the ret instruction (by the callee)



10.2 Headers

The CC78K0S has 13 headers (or header files). Each header defines or declares standard library functions, data type names, and macro names.

The headers of the CC78K0S are as shown below.

```
ctype.h          setjmp.h         stdarg.h (normal model only)    stdio.h
stdlib.h         string.h         error.h                         errno.h
limits.h         stddef.h         math.h (normal model only)      float.h
assert.h (normal model only)
```

Remark The functions to be supported differ depending on the memory models (normal model and static model). Also, functions that operate during normal operation differ depending on the -zi and -zl options. For functions that do not operate normally because of the existence of -zi and -zl options, a warning message "The prototype declaration is not performed" is output.

(1) ctype.h

This header is used to define character and string functions. In this standard header, the following library functions have been defined.

However, when the compiler option -za (the option that disables the functions not complying ANSI specifications and enables a part of the functions of ANSI specifications) is specified, _toupper and _tolower are not defined. Instead, tolow and toup are defined. When -za is not specified, tolow and toup are not defined. The function to be declared differs depending on the options and the specification models.

Table 10-5 Contents of ctype.h

Function	Existence of -zi, or -zl Specification							
	Normal Model				Static Model			
	None	ZI	ZL	ZI ZL	None	ZI	ZL	ZI ZL
isalnum	OK	OK	OK	OK	OK	NG	OK	NG
isalpha	OK	OK	OK	OK	OK	NG	OK	NG
iscntrl	OK	OK	OK	OK	OK	NG	OK	NG
isdigit	OK	OK	OK	OK	OK	NG	OK	NG
isgraph	OK	OK	OK	OK	OK	NG	OK	NG
islower	OK	OK	OK	OK	OK	NG	OK	NG
isprint	OK	OK	OK	OK	OK	NG	OK	NG
ispunct	OK	OK	OK	OK	OK	NG	OK	NG
isspace	OK	OK	OK	OK	OK	NG	OK	NG
isupper	OK	OK	OK	OK	OK	NG	OK	NG
isxdigit	OK	OK	OK	OK	OK	NG	OK	NG
tolower	OK	OK	OK	OK	OK	NG	OK	NG
toupper	OK	OK	OK	OK	OK	NG	OK	NG
isascii	OK	OK	OK	OK	OK	NG	OK	NG
toascii	OK	OK	OK	OK	OK	NG	OK	NG
_tolower	OK	OK	OK	OK	OK	NG	OK	NG
_toupper	OK	OK	OK	OK	OK	NG	OK	NG
tolow	OK	OK	OK	OK	OK	NG	OK	NG
toup	OK	OK	OK	OK	OK	NG	OK	NG

OK : Supported

NG : Not supported

(2) setjmp.h

This header is used to define program control functions. In this header, the following functions are defined. The function to be declared differs depending on the option and the specification models.

Table 10-6 Contents of setjmp.h

Function	Existence of -zi, or -zl Specification							
	Normal Model				Static Model			
	None	ZI	ZL	ZI ZL	None	ZI	ZL	ZI ZL
setjmp	OK	OK	OK	OK	OK	NG	OK	NG
longjmp	OK	OK	OK	OK	OK	NG	OK	NG

OK : Supported

NG : Not supported

In the header setjmp.h, the following object has been defined :

[Declaration of int array type jmp_buf]

- Normal model

```
typedef int     jmp_buf [ 11 ]
```

- Static model

```
typedef int     jmp_buf [ 3 ]
```

(3) stdarg.h (normal model only)

This header used to define special functions. In this header, the following 3 functions have been defined:

Table 10-7 Contents of stdarg.h

Function	Existence of -zi, or -zl Specification			
	Normal Model			
	None	ZI	ZL	ZI ZL
va_arg	OK	OK	OK	OK
va_start	Δ	Δ	Δ	Δ
va_starttop	Δ	Δ	Δ	Δ
va_end	OK	OK	OK	OK

OK : Supported

Δ : Operation is guaranteed, however there are limitations

In the header stdarg.h the following object has been declared :

[Declaration of pointer type "va_list" to char]

```
typedef char    *va_list ;
```

(4) stdio.h

This header is used to define I/O functions. In this header, next functions have been defined.

The function to be declared differs depending on the options and the specification models.

Table 10-8 Contents of stdio.h

Function	Existence of -zi, or -zl Specification							
	Normal Model				Static Model			
	None	ZI	ZL	ZI ZL	None	ZI	ZL	ZI ZL
sprintf	OK	-	OK	-	NG	NG	NG	NG
sscanf	OK	-	OK	-	NG	NG	NG	NG
printf	OK	-	OK	-	NG	NG	NG	NG
scanf	OK	-	OK	-	NG	NG	NG	NG
vprintf	OK	-	OK	-	NG	NG	NG	NG
vsprintf	OK	-	OK	-	NG	NG	NG	NG
getchar	OK	OK	OK	OK	OK	NG	OK	NG
gets	OK	OK	OK	OK	OK	OK	OK	OK
putchar	OK	OK	OK	OK	OK	NG	OK	NG
puts	OK	OK	OK	OK	OK	NG	OK	NG

OK : Supported

NG : Not supported

- : Operation is not guaranteed

The following macro names are declared.

```
#define EOF     ( -1 )
#define NULL    ( void * ) 0
```

(5) stdlib.h

This header is used to define character and string functions, memory functions, program control functions, mathematical functions, and special functions. In this standard header, the following library functions have been defined :

However, when the compiler option -za (the option that disables the functions not complying ANSI specifications and enables a part of the functions of ANSI specifications) is specified, brk, sbrk, itoa, ltoa, and ultoa are not defined. Instead, strbrk, strsbrk, stritoa, strltoa, and strultoa are defined. When -za is not specified, these functions are not defined.

Table 10-9 Contents of stdlib.h

Function	Existence of -zi, or -zl Specification							
	Normal Model				Static Model			
	None	ZI	ZL	ZI ZL	None	ZI	ZL	ZI ZL
atoi	OK	-	OK	-	OK	NG	OK	NG
atol	OK	OK	-	-	NG	NG	NG	NG
strtol	OK	OK	-	-	NG	NG	NG	NG
strtoul	OK	OK	-	-	NG	NG	NG	NG
calloc	OK	OK	OK	OK	OK	NG	OK	NG
free	OK	OK	OK	OK	OK	NG	OK	NG
malloc	OK	OK	OK	OK	OK	NG	OK	NG
realloc	OK	OK	OK	OK	OK	NG	OK	NG
abort	OK	OK	OK	OK	OK	OK	OK	OK
atexit	OK	OK	OK	OK	OK	NG	OK	NG
exit	OK	OK	OK	OK	OK	NG	OK	NG
abs	OK	OK	OK	OK	OK	NG	OK	NG
div	OK	NG	OK	NG	NG	NG	NG	NG
labs	OK	OK	-	-	NG	NG	NG	NG
ldiv	OK	OK	NG	NG	NG	NG	NG	NG
brk	OK	OK	OK	OK	OK	NG	OK	NG
sbrk	OK	OK	OK	OK	OK	NG	OK	NG
atof	OK	OK	OK	OK	NG	NG	NG	NG
strtod	OK	OK	OK	OK	NG	NG	NG	NG
itoa	OK	OK	OK	OK	OK	NG	OK	NG
ltoa	OK	OK	NG	NG	NG	NG	NG	NG
ultoa	OK	OK	NG	NG	NG	NG	NG	NG
rand	OK	-	OK	-	NG	NG	NG	NG
srand	OK	OK	OK	OK	NG	NG	NG	NG

Table 10-9 Contents of stdlib.h

Function	Existence of -zi, or -zl Specification							
	Normal Model				Static Model			
	None	ZI	ZL	ZI ZL	None	ZI	ZL	ZI ZL
bsearch	OK	OK	OK	OK	NG	NG	NG	NG
qsort	OK	OK	OK	OK	NG	NG	NG	NG
strbrk	OK	OK	OK	OK	OK	NG	OK	NG
strsbrk	OK	OK	OK	OK	OK	NG	OK	NG
stritoa	OK	OK	OK	OK	OK	NG	OK	NG
strltoa	OK	OK	NG	NG	NG	NG	NG	NG
strultoa	OK	OK	NG	NG	NG	NG	NG	NG

OK : Supported

NG : Not supported

- : Operation is not guaranteed

In the header stdlib.h the following objects have been defined :

[Declaration of structure type div_t which has int type members "quot" and "rem" (except static model)]

```
typedef struct {
        int     quot ;
        int     rem ;
} div_t ;
```

[Declaration of structure type ldiv_t which has long int type members "quot" and "rem" (except when -zI is specified in static model and normal model)]

```
typedef struct {
        long int        quot ;
        long int        rem ;
} ldiv_t ;
```

[Definition of macro name "RAND_MAX"]

```
#define RAND_MAX        32767
```

[Declaration of macro name]

```
#define EXIT_SUCCESS    0
#define EXIT_FAILURE    1
```

(6) string.h

This header is used to define character and string functions, memory functions, and special functions. In this header, the following functions have been defined. Function to be defined differs depending on the options and specification models.

Table 10-10 Contents of string.h

Function	Existence of -zi, or -zl Specification							
	Normal Model				Static Model			
	None	ZI	ZL	ZI ZL	None	ZI	ZL	ZI ZL
memcpy	OK	OK	OK	OK	OK	NG	OK	NG
memmove	OK	OK	OK	OK	OK	NG	OK	NG
strcpy	OK	OK	OK	OK	OK	OK	OK	OK
strncpy	OK	OK	OK	OK	OK	NG	OK	NG
strcat	OK	OK	OK	OK	OK	OK	OK	OK
strncat	OK	OK	OK	OK	OK	NG	OK	NG
memcmp	OK	-	OK	-	OK	NG	OK	NG
strcmp	OK	-	OK	-	OK	NG	OK	NG
strncmp	OK	-	OK	-	OK	NG	OK	NG
memchr	OK	OK	OK	OK	OK	NG	OK	NG
strchr	OK	OK	OK	OK	OK	NG	OK	NG
strcspn	OK	-	OK	-	OK	NG	OK	NG
strpbrk	OK	OK	OK	OK	OK	OK	OK	OK
strrchr	OK	OK	OK	OK	OK	NG	OK	NG
strspn	OK	-	OK	-	OK	NG	OK	NG
strstr	OK	OK	OK	OK	OK	OK	OK	OK
strtok	OK	OK	OK	OK	OK	OK	OK	OK
memset	OK	OK	OK	OK	OK	NG	OK	NG
strerror	OK	OK	OK	OK	OK	NG	OK	NG
strlen	OK	-	OK	-	OK	NG	OK	NG
strcoll	OK	-	OK	-	OK	NG	OK	NG
strxfrm	OK	-	OK	-	OK	NG	OK	NG

OK : Supported

NG : Not supported

- : Operation is not guaranteed

(7) error.h

error.h includes errno.h.

(8) errno.h

In this header, the following objects have been defined :

[Definitions of macro names "EDOM", "ERANGE", and "ENOMEM"]

```
#define EDOM    1
#define ERANGE  2
#define ENOMEM  3
```

[Declaration of volatile int type external variable errno]

```
extern volatile int errno ;
```

(9) limits.h

In this header, the following macro names have been defined :

```
#define CHAR_BIT        8
#define CHAR_MAX        +127
#define CHAR_MIN        -128
#define INT_MAX         +32767
#define INT_MIN         -32768
#define LONG_MAX        +2147483647
#define LONG_MIN        -2147483648

#define SCHAR_MAX       +127
#define SCHAR_MIN       -128
#define SHRT_MAX        +32767
#define SHRT_MIN        -32768
#define UCHAR_MAX       255U
#define UINT_MAX        65535U
#define ULONG_MAX       4294967295U
#define USHRT_MAX       65535U

#define SINT_MAX        +32767
#define SINT_MIN        -32768
#define SSHRT_MAX       +32767
#define SSHRT_MIN       -32768
```

However, when the -qu option, which regards unqualified char as unsigned char, is specified, CHAR_MAX and CHAR_MIN are declared by the macro __CHAR_UNSIGNED__ declared by the compiler as follows.

```
#define CHAR_MAX        ( 255U )
#define CHAR_MIN        ( 0 )
```

When the -zi option (int and short types are regarded as char type, unsigned int and unsigned short as unsigned char) is specified as a compiler option, INT_MAX, INT_MIN, SHRT_MAX, SHRT_MIN, SINT_MAX, SINT_MIN, SSHRT_MAX, SSHRT_MIN, UINT_MAX, and USHRT_MAX are declared as follows, via the macro __FROM_INT_TO_CHAR__ declared by the compiler.

```
#define INT_MAX         CHAR_MAX
#define INT_MIN         CHAR_MIN
#define SHRT_MAX        CHAR_MAX
#define SHRT_MIN        CHAR_MIN
#define SINT_MAXS       CHAR_MAX
#define SINT_MINS       CHAR_MIN
#define SSHRT_MAXS      CHAR_MAX
#define SSHRT_MINS      CHAR_MIN
#define UINT_MAX        UCHAR_MAX
#define USHRT_MAX       UCHAR_MIN
```

When the -zl option (long type is regarded as int type and unsigned long as unsigned int) is specified as a compiler option, LONG_MAX, LONG_MIN, and ULONG_MAX are declared as follows, via the macro __FROM_LONG_TO_INT__ declared by the compiler.

```
#define LONG_MAX        ( +32767 )
#define LONG_MIN        ( -32768 )
#define ULONG_MAX       ( 65535U )
```

(10) stddef.h

In this header, the following objects have been declared and defined :

[Declaration of int type "ptrdiff_t"]

```
typedef int     ptrdiff_t ;
```

[Declaration of unsigned int type "size_t"]

```
typedef unsigned int    size_t ;
```

[Definition of macro name "NULL"]

```
#define NULL    ( void * ) 0 ;
```

[Definition of macro name "offsetof"]

```
#define offsetof ( type , member )  ( ( size_t ) & ( ( ( type* ) 0 ) -> member ) )
```

Remark offsetof (type, member specifier)

offsetof is expanded to the general integer constant expression that has type size_t and the value is an offset value in byte units from the start of the structure (that is specified by the type) to the structure member (that is specified by the member specifier).

The member specifier must be the one that the result of evaluation of expression& (t. member specifier) becomes an address constant when static type t; is declared. When the specified member is a bit field, the operation will not be guaranteed.

(11) math.h (normal model only)

math.h defines the following functions.

Table 10-11 Contents of math.h

Function	Existence of -zi, or -zl Specification			
	Normal Model			
	None	ZI	ZL	ZI ZL
acos	OK	OK	OK	OK
asin	OK	OK	OK	OK
atan	OK	OK	OK	OK
atan2	OK	OK	OK	OK
cos	OK	OK	OK	OK
sin	OK	OK	OK	OK
tan	OK	OK	OK	OK
cosh	OK	OK	OK	OK
sinh	OK	OK	OK	OK
tanh	OK	OK	OK	OK
exp	OK	OK	OK	OK
frexp	OK	OK	OK	OK
ldexp	OK	OK	OK	OK
log	OK	OK	OK	OK
log10	OK	OK	OK	OK
modf	OK	OK	OK	OK
pow	OK	OK	OK	OK
sqrt	OK	OK	OK	OK
ceil	OK	OK	OK	OK
fabs	OK	OK	OK	OK

Table 10-11 Contents of math.h

Function	Existence of -zi, or -zl Specification			
	Normal Model			
	None	ZI	ZL	ZI ZL
floor	OK	OK	OK	OK
fmod	OK	OK	OK	OK
matherr	OK	NG	OK	NG
acosf	OK	OK	OK	OK
asinf	OK	OK	OK	OK
atanf	OK	OK	OK	OK
atan2f	OK	OK	OK	OK
cosf	OK	OK	OK	OK
sinf	OK	OK	OK	OK
tanf	OK	OK	OK	OK
coshf	OK	OK	OK	OK
sinhf	OK	OK	OK	OK
tanhf	OK	OK	OK	OK
expf	OK	OK	OK	OK
frexpf	OK	OK	OK	OK
ldexpf	OK	OK	OK	OK
logf	OK	OK	OK	OK
log10f	OK	OK	OK	OK
modff	OK	OK	OK	OK
powf	OK	OK	OK	OK
sqrtf	OK	OK	OK	OK
ceilf	OK	OK	OK	OK
fabsf	OK	OK	OK	OK
floorf	OK	OK	OK	OK
fmodf	OK	OK	OK	OK

OK : Supported

NG : Not supported

The following objects are defined.

[Definition of macro name "HUGE_VAL"]

```
#define HUGE_VAL  DBL_MAX
```

(12) float.h

float.h defines the following objects.

When the size of a double type is 32 bits, the macro to be defined are sorted by the macro __DOUBLE_IS_32BITS__ declared by the compiler.

```
#ifndef _FLOAT_H

#define FLT_ROUNDS              1
#define FLT_RADIX               2

#ifdef  __DOUBLE_IS_32BITS__
#define FLT_MANT_DIG            24
#define DBL_MANT_DIG            24
#define LDBL_MANT_DIG           24

#define FLT_DIG                 6
#define DBL_DIG                 6
#define LDBL_DIG                6

#define FLT_MIN_EXP             -125
#define DBL_MIN_EXP             -125
#define LDBL_MIN_EXP            -125

#define FLT_MIN_10_EXP          -37
#define DBL_MIN_10_EXP          -37
#define LDBL_MIN_10_EXP         -37
#define FLT_MAX_EXP             +128
#define DBL_MAX_EXP             +128
#define LDBL_MAX_EXP            +128

#define FLT_MAX_10_EXP          +38
#define DBL_MAX_10_EXP          +38
#define LDBL_MAX_10_EXP         +38

#define FLT_MAX                 3.40282347E+38F
#define DBL_MAX                 3.40282347E+38F
#define LDBL_MAX                3.40282347E+38F
#define FLT_EPSILON             1.19209290E-07F
#define DBL_EPSILON             1.19209290E-07F
#define LDBL_EPSILON            1.19209290E-07F

#define FLT_MIN                 1.17549435E-38F
#define DBL_MIN                 1.17549435E-38F
#define LDBL_MIN                1.17549435E-38F

#else   /* __DOUBLE_IS_32BITS__ */
#define FLT_MANT_DIG            24
#define DBL_MANT_DIG            53
#define LDBL_MANT_DIG           53
```

```
#define FLT_DIG                 6
#define DBL_DIG                 15
#define LDBL_DIG                15

#define FLT_MIN_EXP             -125
#define DBL_MIN_EXP             -1021
#define LDBL_MIN_EXP            -1021

#define FLT_MIN_10_EXP          -37
#define DBL_MIN_10_EXP          -307
#define LDBL_MIN_10_EXP         -307

#define FLT_MAX_EXP             +128
#define DBL_MAX_EXP             +1024
#define LDBL_MAX_EXP            +1024

#define FLT_MAX_10_EXP          +38
#define DBL_MAX_10_EXP          +308
#define LDBL_MAX_10_EXP         +308

#define FLT_MAX                 3.40282347E+38F
#define DBL_MAX                 1.7976931348623157E+308
#define LDBL_MAX                1.7976931348623157E+308

#define FLT_EPSILON             1.19209290E-07F
#define DBL_EPSILON             2.2204460492503131E-016
#define LDBL_EPSILON            2.2204460492503131E-016

#define FLT_MIN                 1.17549435E-38F
#define DBL_MIN                 2.225073858507201E-308
#define LDBL_MIN                2.225073858507201E-308
#endif  /* __DOUBLE_IS_32BITS__ */

#define _FLOAT_H
#endif  /* !_FLOAT_H */
```

(13) assert.h (normal model only)

Table 10-12 Contents of assert.h

Function	Existence of -zi, or -zl Specification			
	Normal Model			
	None	ZI	ZL	ZI ZL
__assertfail	OK	OK	OK	OK

OK : Supported

assert.h defines the following objects.

```
#ifdef  NDEBUG
#define assert ( p )    ( ( void ) 0 )
#else
extern  int     __assertfail ( char *__msg , char *__cond , char *__file ,
int__line ) ;
#define assert ( p )   ( ( p ) ? ( void ) 0 : ( void ) __assertfail
        " Assertion failed : %s , file %s , line %d\n " , #p , __FILE__ ,
__LINE__ ) )
#endif /* NDEBUG */
```

However, if the assert.h header file references another macro, NDEBUG, which is not defined by the assert.h header file, and if NDEBUG is defined as a macro when the assert.h is captured to the source file, the assert.h header file simply declares the assert macro as the one given below and does not define __assertfail.

```
#define assert ( p )    ( ( void ) 0 )
```

10.3 Re-entrantability (Normal Model Only)

Re-entrant is a state where a function called from a program can be consecutively called from another program.

The standard library of the CC78K0S does not use static area allowing re-entrantability. Therefore, data in the storage used by functions will not be destroyed by the call from another program.

However, the functions shown in (1) to (3) are not re-entrant.

(1) Functions that cannot be re-entranced

setjmp, longjmp, atexit, exit

(2) Functions that uses the area secured in the start-up routine

div, ldiv, brk, sbrk, rand, srand, strtok

(3) Functions that deals with floating point numbers

sprintf, sscanf, printf, scanf, vprintf, vsprintf[Note], atof, strtod, all the mathematical functions

Note Among sprintf, sscanf, printf, scanf, vprintf, and vsprintf, ones that do not support floating-point numbers are re-entrant.

10.4 Standard Library Functions

This section explains the standard library functions of the CC78K0S by classifying them by function as follows. All standard library functions are supported even when the -zf option is specified.

Table 10-13 List of Standard Library Functions

Type of Function	Function
Character & String Functions	is-
	toupper, tolower
	toascii
	_toupper/toup, _tolower/tolow
Program Control Functions	setjmp, longjmp
Special Functions	va_start (normal model only), va_starttop (normal model only), va_arg (normal model only), va_end (normal model only)
I/O Functions	sprintf (normal model only)
	sscanf (normal model only)
	printf (normal model only)
	scanf (normal model only)
	vprintf (normal model only)
	vsprintf (normal model only)
	getchar
	gets
	putchar
	puts
Utility Functions	atoi, atol
	strtol, strtoul
	calloc
	free
	malloc
	realloc
	abort
	atexit, exit
	abs, labs
	div (normal model only), ldiv (normal model only)
	brk, sbrk
	atof, strtod

Table 10-13 List of Standard Library Functions

Type of Function	Function
Utility Functions	itoa, ltoa (normal model only), ultoa (normal model only)
	rand, srand
	bsearch (normal model only)
	qsort (normal model only)
	strbrk
	strsbrk
	stritoa, strltoa (normal model only), strultoa (normal model only)
Character String / Memory Functions	memcpy, memmove
	strcpy, strncpy
	strcat, strncat
	memcmp
	strcmp, strncmp
	memchr
	strchr, strrchr
	strspn, strcspn
	strpbrk
	strstr
	strtok
	memset
	strerror
	strlen
	strcoll
	strxfrm
Mathematical Functions	acos (normal model only)
	asin (normal model only)
	atan (normal model only)
	atan2 (normal model only)
	cos (normal model only)
	sin (normal model only)
	tan (normal model only)
	cosh (normal model only)
	sinh (normal model only)

Table 10-13 List of Standard Library Functions

Type of Function	Function
Mathematical Functions	tanh (normal model only)
	exp (normal model only)
	frexp (normal model only)
	ldexp (normal model only)
	log (normal model only)
	log10 (normal model only)
	modf (normal model only)
	pow (normal model only)
	sqrt (normal model only)
	ceil (normal model only)
	fabs (normal model only)
	floor (normal model only)
	fmod (normal model only)
	matherr (normal model only)
	acosf (normal model only)
	asinf (normal model only)
	atanf (normal model only)
	atan2f (normal model only)
	cosf (normal model only)
	sinf (normal model only)
	tanf (normal model only)
	coshf (normal model only)
	sinhf (normal model only)
	tanhf (normal model only)
	expf (normal model only)
	frexpf (normal model only)
	ldexpf (normal model only)
	logf (normal model only)
	log10f (normal model only)
	modff (normal model only)
	powf (normal model only)
	sqrtf (normal model only)

Table 10-13 List of Standard Library Functions

Type of Function	Function
Mathematical Functions	ceilf (normal model only)
	fabsf (normal model only)
	floorf (normal model only)
	fmodf (normal model only)
Diagnostic Functions	__assertfail (normal model only)

10.4.1 Character & String Functions

(1) is-

FUNCTION

- is- judges the type of character.

HEADER

- ctype.h for all the character functions

FUNCTION PROTOTYPE

- int is- (int c) ;

Function	Arguments	Return Value
is-	c : Character to be judged	If character c is included in the character range : 1 If character c is not included in the character range : 0

EXPLANATION

Function	Character Range
isalpha	Alphabetic character A to Z or a to z
isupper	Uppercase letters A to Z
islower	Lowercase letters a to z
isdigit	Numeric characters 0 to 9
isalnum	Alphanumeric characters 0 to 9 and A to Z or a to z
isxdigit	Hexadecimal numbers 0 to 9 and A to F or a to f
isspace	White-space characters (space, tab, carriage return, new-line, vertical tab, and form-feed)
ispunct	Punctuation characters except white-space characters
isprint	Printable characters
isgraph	Printable nonblank characters
iscntrl	Control characters
isascii	ASCII code set

(2) toupper, tolower

FUNCTION

- The character functions toupper and tolower both convert one type of character to another.
- The toupper function returns the uppercase equivalent of c if c is a lowercase letter.
- The tolower function returns the lowercase equivalent of c if c is a uppercase letter.

HEADER

- ctype.h

FUNCTION PROTOTYPE

- int toupper (int c) ;
- int tolower (int c) ;

Function	Arguments	Return Value
toupper, tolower	c : Character to be converted	If c is a convertible character : Uppercase equivalent If not convertible : Character "c" is returned unchanged

EXPLANATION

toupper

- The toupper function checks to see if the argument is a lowercase letter and if so converts the letter to its uppercase equivalent.

tolower

- The tolower function checks to see if the argument is a uppercase letter and if so converts the letter to its lowercase equivalent.

(3) toascii

FUNCTION

- The character function toascii converts "c" to an ASCII code.

HEADER

- ctype.h

FUNCTION PROTOTYPE

- int toascii (int c) ;

Function	Arguments	Return Value
toascii	c : Character to be converted	Value obtained by converting the bits outside the ASCII code range of "c" to 0.

EXPLANATION

- The toascii function converts the bits (bits 7 to 15) of "c" outside the ASCII code range of "c" (bits 0 to 6) to "0" and returns the converted bit value.

(4) _toupper/toup, _tolower/tolow

FUNCTION

- The character function _toupper/toup subtracts "a" from "c" and adds "A" to the result.
- The character function _tolower/tolow subtracts "A" from "c" and adds "a" to the result.
  (_toupper is exactly the same as toup, and _tolower is exactly the same as the tolow)

  Remark a : Lowercase ;A : Uppercase

HEADER

- ctype.h

FUNCTION PROTOTYPE

- int _toupper/toup (int c) ;
- int _tolower/tolow (int c) ;

Function	Arguments	Return Value
_toupper/toup	c : Character to be converted	Value obtained by adding "A" to the result of subtraction "c" - "a"
_tolower/tolow		Value obtained by adding "a" to the result of subtraction "c" -"A"

Remark where a : Lowercase ;A : Uppercase

EXPLANATION

_toupper

- The _toupper function is similar to toupper except that it does not test to see if the argument is a lowercase letter.

_tolower

- The _tolower function is similar to tolower, except it does not test to see if the argument is an uppercase letter.

10.4.2 Program Control Functions

(1) setjmp, longjmp

FUNCTION

- The program control function setjmp saves the environment information (current state of the program) when a call to this function is made.
- The program control function longjmp restores the environment information saved by setjmp.

HEADER

- setjmp. h

FUNCTION PROTOTYPE

- int setjmp (jmp_buf env) ;
- void longjmp (jmp_buf env , int val) ;

Function	Arguments	Return Value
setjmp	env : Array to which environment information is to be saved	If called directly : 0 If returning from the corresponding longjmp : Value given by "val" or 1 if "val " is 0.
longjmp	env : Array to which environment information was saved by setjmp val : Return value to setjmp	longjmp will not return because program execution resumes at statement next to setjmp that saved environment to "env".

EXPLANATION

setjmp

- The setjmp, when called directly, saves saddr area, SP, and the return address of the function that are used as HL register or register variables to env and returns 0.

longjmp

- The longjmp restores the saved environment to env (saddr area and SP that are used as HL register or register variables). Program execution continues as if the corresponding setjmp returns val (however, if val is 0, 1 is returned).

10.4.3 Special Functions

(1) va_start (normal model only), va_starttop (normal model only), va_arg (normal model only), va_end (normal model only)

FUNCTION

- The va_start function (macro) is used to start a variable argument list.
- The va_starttop function (macro) is used to set processing of the variable number of arguments.
- The va_arg function (macro) obtains the value of an argument from a variable argument list.
- The va_end function (macro) indicates that the end of a variable argument list is reached.

HEADER

- stdarg.h

FUNCTION PROTOTYPE

- void va_start (va_list ap , parmN) ;
- void va_starttop (va_list ap , parmN) ;
- type va_arg (va_list ap , type) ;
- void va_end (va_list ap) ;

  {va_list is defined as typedef by stdarg.h.}

Function	Arguments	Return Value
va_start, va_starttop	ap : Variable to be initialized so as to be used in va_arg and va_end parmN : The argument before variable argument	None
va_arg	ap : Variable to process an argument list type : Type to point the relevant place of variable argument (type is a type of variable length; for example, int type if described as va_arg (va_list ap, int) or long type if described as va_arg (va_list ap, long))	Normal case : Value in the relevant place of variable argument If ap is a null pointer : 0
va_end	ap : Variable to process the variable number of arguments	None

EXPLANATION

va_start

- In the va_start macro, its argument ap must be a va_list type (char* type) object.
- A pointer to the next argument of parmN is stored in ap.
- parmN is the name of the last (right-most) parameter specified in the function's prototype.
- If parmN has the register storage class, proper operation of this function is not guaranteed.

va_starttop

- The first argument cannot be specified for the va_start function because the first argument is passed by a register.
- Use the macro as follows.

  (i) Use the va_starttop macro when specifying the first argument.

  (ii) Use the va_start macro when specifying the second and subsequent arguments.

va_arg

- In the va_arg macro, its argument ap must be the same as the va_list type object initialized with va_start (no guarantee for the other normal operation).
- va_arg returns value in the relevant place of variable arguments as a type of type.
  The relevant place is the first of variable arguments immediately after va_start and next proceeded in each va_arg.
- If the argument pointer ap is a null pointer, the va_arg returns 0 (of type type).

va_end

- The va_end macro sets a null pointer in the argument pointer ap to inform the macro processor that all the parameters in the variable argument list have been processed.

10.4.4 I/O Functions

(1) sprintf (normal model only)

FUNCTION

- The sprintf function writes data into a character string (array) according to the format.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int sprintf (char *s , const char *format , ...) ;

Function	Arguments	Return Value
sprintf	s : Pointer to the string into which the output is to be written format : Pointer to the string which indicates format commands ... : Zero or more arguments to be converted	Number of characters written in s (Terminating null character is not counted.)

EXPLANATION

- If there are fewer actual arguments than the formats, the proper operation is not guaranteed. In the case that the formats are run out despite the actual arguments still remain, the excess actual arguments are only evaluated and ignored.
- sprintf converts zero or more arguments that follow format according to the format command specified by format and writes (copies) them into the string s.
- Zero or more format commands may be used. Ordinary characters (other than format commands that begin with a % character) are output as is to the string s. Each format command takes zero or more arguments that follow format and outputs them to the string s.
- Each format command begins with a % character and is followed by these :

  (i) Zero or more flags (to be explained later) that modify the meaning of the format command

  (ii) Optional decimal integer which specify a minimum field width

  If the output width after the conversion is less than this minimum field width, this specifier pads the output with blanks of zeros on its left. (If the left-justifying flag "-" (minus) sign follows %, zeros are padded out to the right of the output.) The default padding is done with spaces. If the output is to be padded with 0s, place a 0 before the field width specifier. If the number or string is greater than the minimum field width, it will be printed in full even by overrunning the minimum.
- Optional precision (number of decimal places) specification (.integer)
  With d, i, o, u, x, and X type specifiers, the minimum number of digits is specified. With s type specifier, the maximum number of characters (maximum field width) is specified. The number of digits to be output following the decimal point is specified for e, E, and f conversions. The number of maximum effective digits is specified for g and G conversions. This precision specification must be made in the form of (.integers). If the integer part is omitted, 0 is assumed to have been specified. The amount of padding resulting from this precision specification takes precedence over the padding by the field width specification.
- Optional h, l and L modifiers
  The h modifier instructs the sprintf function to perform the d, i, o, u, x, or X type conversion that follows this modifier on short int or unsigned short int type. The h modifier instructs the sprintf function to perform the n type conversion that follows this modifier on a pointer to short int type.
  The l modifier instructs the sprintf function to perform the d, i, o, u, x, or X type conversion that follows this modifier on long int or unsigned long int type. The h modifier instructs the sprintf function to perform the n type conversion that follows this modifier on a pointer to long int type.
  For other type specifiers, the h, l or L modifier is ignored.
- Character that specifies the conversion (to be explained later)
  In the minimum field width or precision (number of decimal places) specification, * may be used in place of an integer string. In this case, the integer value will be given by the int argument (before the argument to be converted). Any negative field width resulting from this will be interpreted as a positive field that follows the - (minus) flag. All negative precision will be ignored.

The following flags are used to modify a format command :

Table 10-14 Flag of sprintf

Flag	Contents
-	The result of a conversion is left-justified within the field.
+	The result of a signed conversion always begins with a + or - sign.
space	If the result of a signed conversion has no sign, space is prefixed to the output. If the + (plus) flag and space flag are specified at the same time, the space flag will be ignored.
#	The result is converted in the "assignment form". In the o type conversion, precision is increased so that the first digit becomes 0. In the x or X type conversion, 0x or 0X is prefixed to a nonzero result. In the e, E, and f type conversions, a decimal point is forcibly inserted to all the output values (in the default without #, a decimal point is displayed only when there is a value to follow). In the g and G type conversions, a decimal point is forcibly inserted to all the output values, and truncation of 0 to follow will not be allowed (in the default without #, a decimal point is displayed only when there is a value to follow. The 0 to follow will be truncated). In all the other conversions, the # flag is ignored.

The format codes for output conversion specifications are as follows :

Table 10-15 Format Code of sprintf

Format code	Contents
d	Converts int argument to signed decimal format.
i	Converts int argument to signed decimal format.
o	Converts int argument to unsigned octal format.
u	Converts int argument to unsigned decimal format.
x	Converts int argument to unsigned hexadecimal format (with lowercase letters abcdef).
X	Converts int argument to unsigned hexadecimal format (with uppercase letters ABCDEF).

With d, i, o, u, x and X type specifiers, the minimum number of digits (minimum field width) of the result is specified. If the output is shorter than the minimum field width, it is padded with zeros. If no precision is specified, 1 is assumed to have been specified. Nothing will appear if 0 is converted with 0 precision.

Table 10-16 Precision Code of sprintf

Precision code	Contents
f	Converts double argument as a signed value with [-] dddd.dddd format. dddd is one or more decimal number(s). The number of digits before the decimal point is determined by the absolute value of the number, and the number of digits after the decimal point is determined by the required precision. When the precision is omitted, it is interpreted as 6.
e	Converts double argument as a signed value with [-] d.dddd e [sign] ddd format. d is 1 decimal number, and dddd is one or more decimal number(s). ddd is exactly a 3-digit decimal number, and the sign is + or -. When the precision is omitted, it is interpreted as 6.
E	The same format as that of e except E is added instead of e before the exponent.
g	Uses whichever shorter method of f or e format when converting double argument based on the specified precision. e format is used only when the exponent of the value is smaller than -4 or larger than the specified number by precision. The following 0 are truncated, and the decimal point is displayed only when one or more numbers follow.
G	The same format as that of g except E is added instead of e before the exponent.
c	Converts int argument to unsigned char and writes the result as a single character.
s	The associated argument is a pointer to a string of characters and the characters in the string are written up to the terminating null character (but not included in the output). If precision is specified, the characters exceeding the maximum field width will be truncated off the end. When the precision is not specified or larger than the array, the array must include a null character.
p	The associated argument is a pointer to void and the pointer value is displayed in hexadecimal 4 digits (with 0s prefixed to less than a 4-digit pointer value). The precision specification if any will be ignored.
n	The associated argument is an integer pointer into which the number of characters written thus far in the string "s" is placed. No conversion is performed.
%	Prints a % sign. The associated argument is not converted (but the flag and minimum field width specifications are effective).

- Operations for invalid conversion specifiers are not guaranteed.
- When the actual argument is a union or a structure, or the pointer to indicate them (except the character type array in % s conversion or the pointer in % p conversion), operations are not guaranteed.
- The conversion result will not be truncated even when there is no field width or the field width is small. In other words, when the number of characters of the conversion result are larger than the field width, the field is extended to the width that includes the conversion result.

- The formats of the special output character string in %f, %e, %E, %g, %G conversions are shown below.

  non-numeric -> "(NaN)"

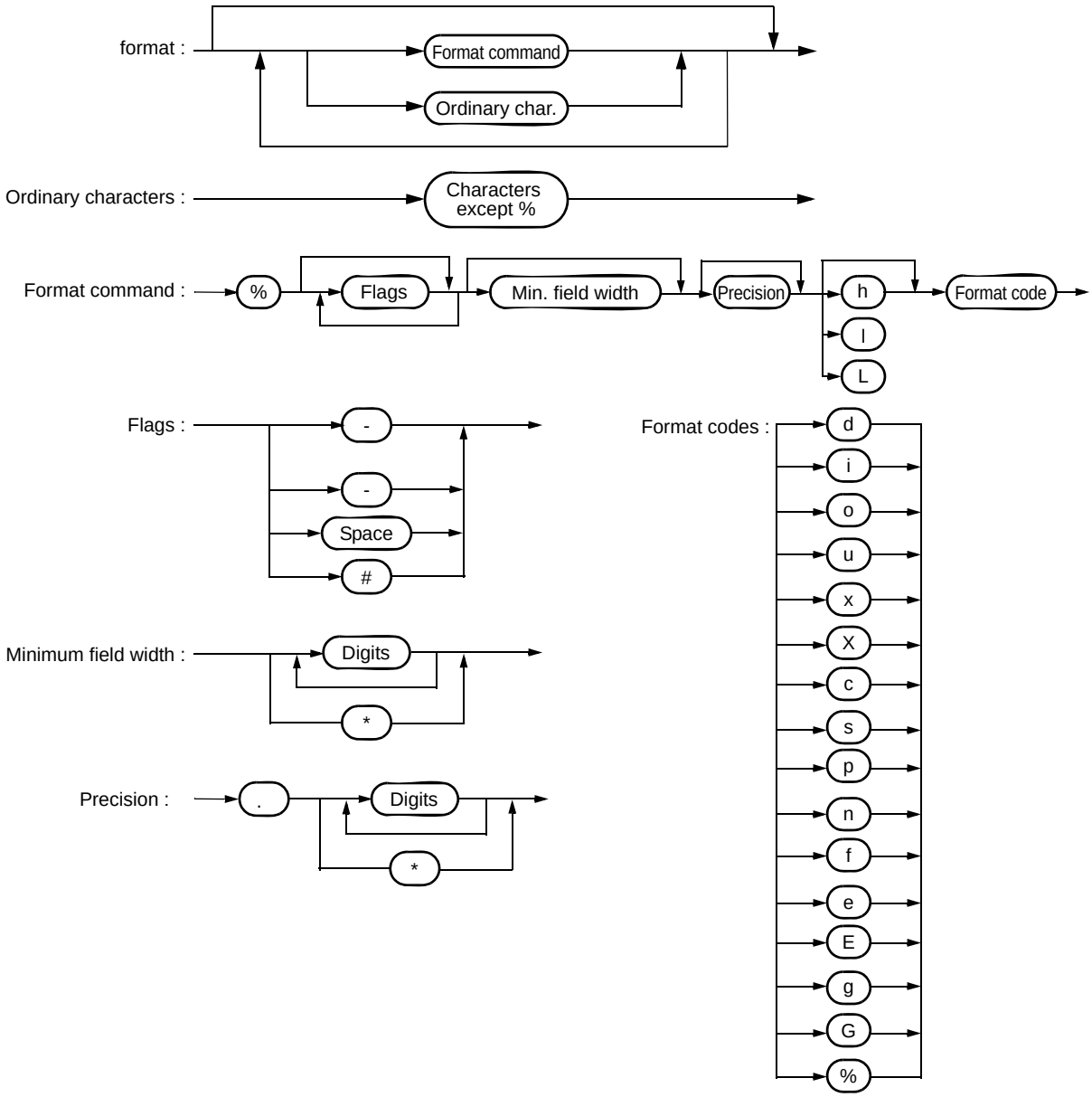
  +∞ -> "(+INF)"

  -∞ ->"(-INF)"

  sprintf writes a null character at the end of the string s. (This character is included in the return value count.)

  The syntax of format commands is illustrated in Figure 10-2.

Figure 10-2 Syntax of Format Commands



(2) sscanf (normal model only)

FUNCTION

- The sscanf function reads data from the input string (array) according to the format.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int sscanf (const char *s , const char *format , ...) ;

Function	Arguments	Return Value
sscanf	s : Pointer to the input string format : Pointer to the string which indicates the input format commands ... : Pointer to object in which converted values are to be stored, and zero or more arguments	If the string s is empty : -1 If the string s is not empty : Number of assigned input data items

EXPLANATION

- sscanf inputs data from the string pointed to by s. The string pointed to by format specifies the input string allowed for input. Zero or more arguments after format are used as pointers to an object. format specifies how data is to be converted from the input string.
- If there are insufficient arguments to match the format commands pointed to by format, proper operation by the compiler is not guaranteed.

  For excessive arguments, expression evaluation will be performed but no data will be input.
- The control string pointed to by format consists of zero or more format commands which are classified into the following 3 types :

  1 : White-space characters (one or more characters for which isspace becomes true)

  2 : Non-white-space characters (other than %)

  3 : Format specifiers

- Each format specifier begins with the % character and is followed by these :

  (i) Optional * character which suppresses assignment of data to the corresponding argument

  (ii) Optional decimal integer which specifies a maximum field width

  (iii) Optional h, l or L modifier which indicates the object size on the receiving side
  If h precedes the d, i, o, or x format specifier, the argument is a pointer to not int but short int.
  If l precedes any of these format specifiers, the argument is a pointer to long int.
  Likewise, if h precedes the u format specifier, the argument is a pointer to unsigned short int.
  If l precedes the u format specifier, the argument is a pointer to unsigned long int.
  If l precedes the conversion specifier e, E, f, g, G, the argument is a pointer to double (a pointer to float in default without l). If L precedes, it is ignored.

  Remark Conversion specifier : character to indicate the type of corresponding conversion (to be mentioned later)

sscanf executes the format commands in "format" in sequence and if any format command fails, the function will terminate.

(1) A white-space character in the control string causes sscanf to read any number (including zero) of white-space character up to the first non-white-space character (which will not be read). This white-space character command fails if it does not encounter any non-white-space character.

(2) A non-white-space character causes sscanf to read and discard a matching character. This command fails if the specified character is not found.

(3) The format commands define a collection of input streams for each type specifier (to be detailed later). The format commands are executed according to the following steps :

  - The input white-space characters (specified by isspace) are skipped over, except when the type specifier is [, c, or n.

  - The input data items are read from the string "s", except when the type specifier is n. The input data items are defined as the longest input stream of the first partial stream of the string indicated by the type specifier (but up to the maximum field width if so specified). The character next to the input data items is interpreted as not have been read. If the length of the input data items is 0, the format command execution fails.

  - The input data items (number of input characters with the type specifier n) are converted to the type specified by the type specifier except the type specifier %. If the input data items do not match with the specified type, the command execution fails. Unless assignment is suppressed by *, the result of the conversion is stored in the object pointed to by the first argument which follows "format" and has not yet received the result of the conversion.

The following type specifiers are available :

Table 10-17 Conversion Specifiers of sscanf

Conversion specifier	Contents
d	Converts a decimal integer (which may be signed). The corresponding argument must be a pointer to an integer.
I	Converts an integer (which may be signed). If a number is preceded by 0x or 0X, the number is interpreted as a hexadecimal integer. If a number is preceded by 0, the number is interpreted as an octal integer. Other numbers are regarded as decimal integers. The corresponding argument must be a pointer to an integer.
o	Converts an octal integer (which may be signed). The corresponding argument must be a pointer to an integer.
u	Converts an unsigned decimal integer. The corresponding argument must be a pointer to an unsigned integer.
x	Converts a hexadecimal integer (which may be signed).
e, E, f, g, G	Floating point value consists of optional sign (+ or -), one or more consecutive decimal number(s) including decimal point, optional exponent (e or E), and the following optional signed integer value. When overflow occurs as a result of conversion, or when underflow occurs with the conversion result $\pm\infty$, non-normalized number or ± 0 becomes the conversion result. The corresponding argument is a pointer to float.
s	Input a character string consisting of a non-blank character string. The corresponding argument is a pointer to an integer. 0x or 0X can be allocated at the first hexadecimal integer. The corresponding argument must be a pointer an array that has sufficient size to accommodate this character string and a null terminator. The null terminator will be automatically added.
[	Inputs a character string consisting of expected character groups (called a scanset). The corresponding argument must be a pointer to the first character of an array that has sufficient size to accommodate this character string and a null terminator. The null terminator will be automatically added. The format commands continue from this character up to the closing square bracket (1). The character string (called a scanlist) enclosed in the square brackets constitutes a scanset except when the character immediately after the opening square bracket is a circumflex ( ). When the character is a circumflex, all the characters other than a scanlist between the circumflex and the closing square bracket constitute a scanset. However, when a scanlist begins with [ ] or [^], this closing square bracket is contained in the scanlist and the next closing square list becomes the end of the scanlist. A hyphen (-) at other than the left or right end of a scanlist is interpreted as the punctuation mark for hyphenation if the character at the left of the range specifying hyphen (-) is not smaller than the right-hand character in ASCII code value.
c	Inputs a character string consisting of the number of characters specified by the field width. (If the field width specification is omitted, 1 is assumed.) The corresponding argument must be a pointer to the first character of an array that has sufficient size to accommodate this character string. The null terminator will not be added.
p	Reads an unsigned hexadecimal integer. The corresponding argument must be a pointer to void pointer.
n	Receives no input from the string s. The corresponding argument must be a pointer to an integer. The number of characters that are read thus far by this function from the string "s" is stored in the object that is pointed to by this pointer. The %n format command is not included in the return value assignment count.
%	Reads a % sign. Neither conversion nor assignment takes place.

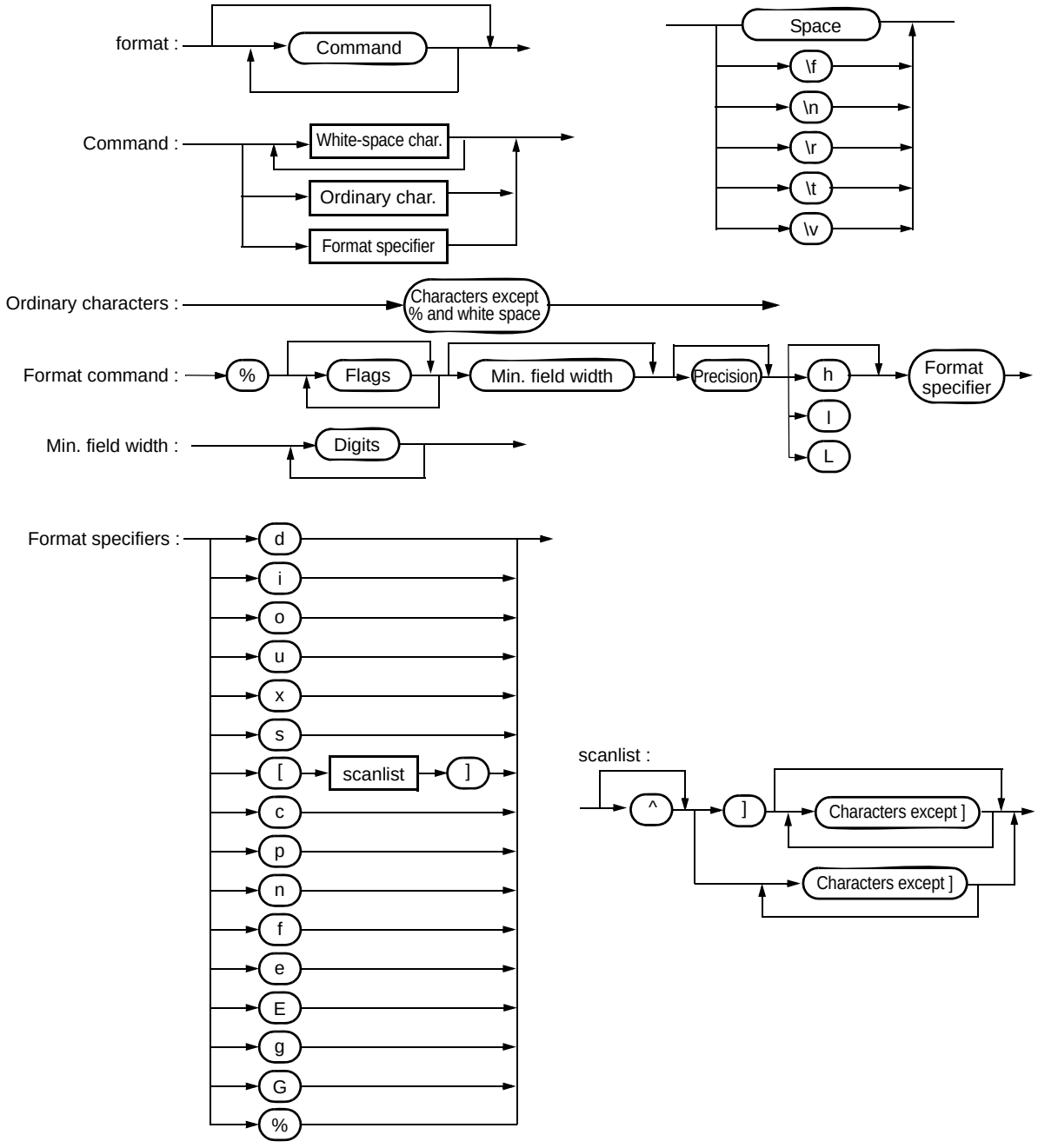
If a format specification is invalid, the format command execution fails.

If a null terminator appears in the input stream, sscanf will terminate.

If an overflow occurs in an integer conversion (with the d, i, o, u, x, or p format specifier), high-order bits will be truncated depending on the number of bits of the data type after the conversion.

The syntax of input format commands is illustrated below.

Figure 10-3 Syntax of Input Format Commands



(3) printf (normal model only)

FUNCTION

- printf outputs data to SFR according to the format.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int printf (const char *format , ...) ;

Function	Arguments	Return Value
printf	format : Pointer to the character string that indicates the output conversion specification ... : 0 or more arguments to be converted	Number of character output to s (the null character at the end is not counted)

EXPLANATION

- (0 or more) arguments following the format are converted and output using the putchar function, according to the output conversion specification specified in the format.
- The output conversion specification is 0 or more directives. Normal characters (other than the conversion specification starting with %) are output as is using the putchar function. The conversion specification is output using the putchar function by fetching and converting the following (0 or more) arguments.
- Each conversion specification is the same as that of the sprintf function.

(4) scanf (normal model only)

FUNCTION

- scanf reads data from SFR according to the format.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int scanf (const char *format , ...) ;

Function	Arguments	Return Value
scanf	format : Pointer to the character string to indicate input conversion specification ... : Pointer (0 or more) argument to the object to assign the converted value	When the character string s is not null : Number of input items assigned

EXPLANATION

- Performs input using getchar function. Specifies input string permitted by the character string format indicates. Uses the argument after the format as the pointer to an object. format specifies how the conversion is performed by the input string.
- When there are not enough arguments for the format, normal operation is not guaranteed. When the argument is excessive, the expression will be evaluated but not input.
- format consists of 0 or more directives. The directives are as follows.

  1 : One or more null character (character that makes isspace true)

  2 : Normal character (other than %)

  3 : Conversion indication

- If a conversion ends with a input character which conflicts with the input character, the conflicting input character is rounded down. The conversion indication is the same as that of the sscanf function.

(5) vprintf (normal model only)

FUNCTION

- vprintf outputs data to SFR according to the format.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int vprintf (const char *format, va_list p) ;

Function	Arguments	Return Value
vprintf	format : Pointer to the character string that indicates output conversion specification p : Pointer to the argument list	Number of output characters (the null character at the end is not counted)

EXPLANATION

- The argument that the pointer of the argument list indicates is converted and output using putchar function according to the output conversion specification specified by the format.
- Each conversion specification is the same as that of sprintf function.

(6) vsprintf (normal model only)

FUNCTION

- vsprintf writes data to character strings according to the format.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int vsprintf (char *s , const char *format, va_list p) ;

Function	Arguments	Return Value
vsprintf	s : Pointer to the character string that writes the output format : Pointer to the character string that indicates output conversion specification p : Pointer to the argument list	Number of characters output to s (the null character at the end is not counted)

EXPLANATION

- Writes out the argument that the pointer of argument list indicates to the character strings which s indicates according to the output conversion specification specified by format.
- The output specification is the same as that of sprintf function.

(7) getchar

FUNCTION

- getchar reads a character from SFR

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int getchar (void) ;

Function	Arguments	Return Value
getchar	None	A character read from SFR

EXPLANATION

- Returns the value read from SFR symbol P0 (port 0).
- Error check related to reading is not performed.
- To change SFR to read, it is necessary either that the source be changed to be re-registered to the library or that the user create a new getchar function.

(8) gets

FUNCTION

- gets reads a character string.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- char *gets (char *s) ;

Function	Arguments	Return Value
gets	s : Pointer to input character string	Normal : s If the end of the file is detected without reading a character : Null pointer

EXPLANATION

- Reads a character string using the getchar function and stores in the array that s indicates.
- When the end of the file is detected (getchar function returns -1) or when a line feed character is read, the reading of a character string ends. The line feed character read is abandoned, and a null character is written at the end of the character stored in the array in the end.
- When the return value is normal, it returns s.
- When the end of the file is detected and no character is read in the array, the contents of the array remains unchanged, and a null pointer is returned.

(9) putchar

FUNCTION

- putchar outputs a character to SFR.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int putchar (int c) ;

Function	Arguments	Return Value
putchar	c : Character to be output	Character to have been output

EXPLANATION

- Writes the character specified by c to the SFR symbol P0 (port 0) (converted to unsigned char type).
- Error check related to writing is not performed.
- To change SFR to write, it is necessary either that the source is changed and re-registered to the library or the user create a new putchar function.

(10) puts

FUNCTION

- puts outputs a character string.

HEADER

- stdio.h

FUNCTION PROTOTYPE

- int puts (const char *s) ;

Function	Arguments	Return Value
puts	s : Pointer to an output character string	Normal : 0 When putchar function returns -1 : -1

EXPLANATION

- Writes the character string indicated by s using putchar function, a line feed character is added at the end of the output.
- Writing of the null character at the end of the character string is not performed.
- When the return value is normal, 0 is returned, and when putchar function returns -1, -1 is returned.

10.4.5 Utility Functions

(1) atoi, atol

FUNCTION

- The string function atoi converts the contents of a decimal integer string to an int value.
- The string function atol converts the contents of a decimal integer string to a long int value.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- int atoi (const char *nptr) ;
- long int atol (const char *nptr) ;

Function	Arguments	Return Value
atoi	nptr : String to be converted	If converted properly : int value If positive overflow occurs : INT_MAX (32767) If negative overflow occurs : INT_MIN (-32768) If the string is invalid : 0
atol		If converted properly : long int value for positive overflow : LONG_MAX (2147483647) for negative overflow : LONG_MIN (-2147483648) If the string is invalid : 0

EXPLANATION

atoi

- The atoi function converts the first part of the string pointed to by pointer nptr to an int value.
- The atoi function skips over zero or more white-space characters (for which isspace becomes true) from the beginning of the string and converts the string from the character next to the skipped white-spaces to an integer (until other than digits or a null character appears in the string). If no digits to convert is found in the string, the function returns 0. If an overflow occurs, the function returns INT_MAX (32767) for positive overflow and INT_MIN (-32768) for negative overflow.

atol

- The atol function converts the first part of the string pointed to by pointer nptr to a long int value.
- The atol function skips over zero or more white-space characters (for which isspace becomes true) from the beginning of the string and converts the string from the character next to the skipped white-spaces to an integer (until other than digits or null character appears in the string). If no digits to convert is found in the string, the function returns 0. If an overflow occurs, the function returns LONG_MAX (2147483647) for positive overflow and LONG_MIN (-2147483648) for negative overflow.

(2) strtol, strtoul

FUNCTION

- The string function strtol converts a string to a long integer.
- The string function strtoul converts a string to an unsigned long integer.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- long int strtol (const char *nptr , char **endptr, int base) ;
- unsigned long int strtoul (const char *nptr, char **endptr, int base) ;

Function	Arguments	Return Value
strtol	nptr : String to be converted endptr : Address of char pointer base : Base for number represented in the string	If converted properly : long int value for positive overflow : LONG_MAX (2147483647) for negative overflow : LONG_MIN (-2147483648) If not converted : 0
strtoul		If converted properly : unsigned long If overflow occurs : ULONG_MAX (4294967295U) If not converted : 0

EXPLANATION

strtol

- The strtol function decomposes the string pointed by pointer nptr into the following 3 parts :

  (i) String of white-space characters that may be empty (to be specified by isspace)

  (ii) Integer representation by the base determined by the value of base

  (iii) String of one or more characters that cannot be recognized (including null terminators)

  The strtol function converts the part (ii) of the string into an integer and returns this integer value.

- A base of 0 indicates that the base should be determined from the leading digits of the string. A leading 0x or 0X indicates a hexadecimal number; a leading 0 indicates an octal number; otherwise, the number is interpreted as decimal. (In this case, the number may be signed).
- If the base is 2 to 36, the set of letters from a to z or A to Z which can be part of a number (and which may be signed) with any of these bases are taken to represent 10 to 35. A leading 0x or 0X is ignored if the base is 16.

- If endptr is not a null pointer, a pointer to the part (iii) of the string is stored in the object pointed to by endptr.
- If the correct value causes an overflow, the function returns LONG_MAX (2147483647) for the positive overflow or LONG_MIN (-2147483648) for the negative overflow depending on the sign and sets errno to ERANGE (ii).
- If the string (ii) is empty or the first non-white-space character of the string (ii) is not appropriate for an integer with the given base, the function performs no conversion and returns 0. In this case, the value of the string nptr is stored in the object pointed to by endptr (if it is not a null string). This holds true with the bases 0 and 2 to 36.

strtoul

- The strtoul function decomposes the string pointed by pointer nptr into the following 3 parts :

  (i) String of white-space characters that may be empty (to be specified by isspace)

  (ii) Integer representation by the base determined by the value of base

  (iii) String of one or more characters that cannot be recognized (including null terminators)

  The strtoul function converts the part (ii) of the string into a unsigned integer and returns this unsigned integer value.
- A base of 0 indicates that the base should be determined from the leading digits of the string. A leading 0x or 0X indicates a hexadecimal number; a leading 0 indicates an octal number; otherwise, the number is interpreted as decimal.
- If the base is 2 to 36, the set of letters from a to z or A to Z which can be part of a number (and which may be signed) with any of these bases are taken to represent 10 to 35. A leading 0x or 0X is ignored if the base is 16.
- If endptr is not a null pointer, a pointer to the part (iii) of the string is stored in the object pointed to by endptr.
- If the correct value causes an overflow, the function returns ULONG_MAX (4294967295U) and sets errno to ERANGE (ii).
- If the string (ii) is empty or the first non-white-space character of the string (ii) is not appropriate for an integer with the given base, the function performs no conversion and returns 0. In this case, the value of the string nptr is stored in the object pointed to by endptr (if it is not a null string). This holds true with the bases 0 and 2 to 36.

(3) calloc

FUNCTION

- The memory function calloc allocates an array area and then initializes the area to 0.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void *calloc (size_t nmemb , size_t size) ;

Function	Arguments	Return Value
calloc	nmemb : Number of members in the array size : Size of each member	If the requested size is allocated : Pointer to the beginning of the allocated area If the requested size is not allocated : Null pointer

EXPLANATION

- The calloc function allocates an area for an array consisting of n number of members (specified by nmemb), each of which has the number of bytes specified by size and initializes the area (array members) to zero.
- Returns the pointer to the beginning of the allocated area if the requested size is allocated.
- Returns the null pointer if the requested size is not allocated.
- The memory allocation will start from a break value and the address next to the allocated space will become a new break value. See "10.4.5 Utility Functions (11) brk, sbrk" for break value setting with the memory function brk.

(4) free

FUNCTION

- The memory function free releases the allocated block of memory.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void free (void *ptr) ;

Function	Arguments	Return Value
free	ptr : Pointer to the beginning of block to be released	None

EXPLANATION

- The free function releases the allocated space (before a break value) pointed to by ptr. (The malloc, calloc, or realloc called after the free will give you the space that was freed earlier.)
- If ptr does not point to the allocated space, the free will take no action. (Freeing the allocated space is performed by setting ptr as a new break value.)

(5) malloc

FUNCTION

- The memory function malloc allocates a block of memory.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void *malloc (size_t size) ;

Function	Arguments	Return Value
malloc	size : Size of memory block to be allocated	If the requested size is allocated : Pointer to the beginning of the allocated area If the requested size is not allocated : Null pointer

EXPLANATION

- The malloc function allocates a block of memory for the number of bytes specified by size and returns a pointer to the first byte of the allocated area.
- If memory cannot be allocated, the function returns a null pointer.
- This memory allocation will start from a break value and the address next to the allocated area will become a new break value. See "10.4.5 Utility Functions (11) brk, sbrk" for break value setting with the memory function brk.

(6) realloc

FUNCTION

- The memory function realloc reallocates a block of memory (namely, changes the size of the allocated memory).

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void *realloc (void *ptr , size_t size) ;

Function	Arguments	Return Value
realloc	ptr : Pointer to the beginning of block previously allocated size : New size to be given to this block	If the requested size is reallocated : Pointer to the beginning of the reallocated space If ptr is a null pointer : Pointer to the beginning of the allocated space If the requested size is not reallocated or "ptr" is not a null pointer : Null pointer

EXPLANATION

- The realloc function changes the size of the allocated space (before a break value) pointed to by ptr to that specified by size. If the value of size is greater than the size of the allocated space, the contents of the allocated space up to the original size will remain unchanged. The realloc function allocates only for the increased space. If the value of size is less than the size of the allocated space, the function will free the reduced space of the allocated space.
- If ptr is a null pointer, the realloc function will newly allocate a block of memory of the specified size (same as malloc).
- If ptr does not point to the block of memory previously allocated or if no memory can be allocated, the function executes nothing and returns a null pointer.
- Reallocation will be performed by setting the address of ptr plus the number of bytes specified by size as a new break value.

(7) abort

FUNCTION

- The program control function abort causes immediate, abnormal termination of a program.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void abort (void) ;

Function	Arguments	Return Value
abort	None	No return to its caller.

EXPLANATION

- The abort function loops and can never return to its caller.
- The user must create the abort processing routine.

(8) atexit, exit

FUNCTION

- atexit registers the function called at the normal termination.
- exit terminates a program.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- int atexit (void (*func) (void)) ;
- void exit (int status) ;

Function	Arguments	Return Value
atexit	func : Pointer to function to be registered	If function is registered as wrap-up function : 0 If function cannot be registered : 1
exit	status : Status value indicating termination	exit can never return.

EXPLANATION

atexit

- The atexit function registers the wrap-up function pointed to by func so that it is called without argument upon normal program termination by calling exit or returning from main.
- Up to 32 wrap-up functions may be established. If the warp-up function can be registered, atexit returns 0. If no more wrap-up function can be registered because 32 wrap-up functions have already been registered, the function returns 1.

exit

- The exit function causes immediate, normal termination of a program.
- This function calls the wrap-up functions in the reverse of the order in which they were registered with atexit.
- The exit function loops and can never return to its caller.
- The user must create the exit processing routine.

(9) abs, labs

FUNCTION

- The mathematical function abs returns the absolute value of its int type argument.
- The mathematical function labs returns the absolute value of its long type argument.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- int abs (int j) ;
- long int labs (long int j) ;

Function	Arguments	Return Value
abs	j : Any signed integer for which absolute value is to be obtained	If j falls within -32767 < j < 32767 : Absolute value of j If j is -32768 : -32768 (0x8000)
labs		If j falls within -2147483647 < j < 2147483647 : Absolute value of j If the value of j is -2147483648 : -2147483648 (0x80000000)

EXPLANATION

abs

- The abs returns the absolute value of its int type argument.
- If j is -32768, the function returns -32768.

labs

- The labs returns the absolute value of its long type argument.
- If the value of j is -2147483648, the function returns -2147483648.

(10) div (normal model only), ldiv (normal model only)

FUNCTION

- The mathematical function div performs the integer division of numerator divided by denominator.
- The mathematical function ldiv performs the long integer division of numerator divided by denominator.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- div_t div (int numer , int denom) ;
- ldiv_t ldiv (long int numer , long int denom) ;

Function	Arguments	Return Value
div	numer : Numerator of the division denom : Denominator of the division	Quotient to the quot element and the remainder to the rem element of div_t type member
ldiv		Quotient to the quot element and the remainder to the rem element of ldiv_t type member

EXPLANATION

div

- The div function performs the integer division of numerator divided by denominator.
- The absolute value of quotient is defined as the largest integer not greater than the absolute value of numer divided by the absolute value of denom. The remainder always has the same sign as the result of the division (plus if numer and denom have the same sign; otherwise minus).
- The remainder is the value of numer - denom*quotient.
- If denom is 0, the quotient becomes 0 and the remainder becomes numer.
- If numer is -32768 and denom is -1, the quotient becomes -32768 and the remainder becomes 0.

ldiv

- The ldiv function performs the long integer division of numerator divided by denominator.
- The absolute value of quotient is defined as the largest long int type integer not greater than the absolute value of numer divided by the absolute value of denom. The remainder always has the same sign as the result of the division (plus if numer and denom have the same sign; otherwise minus).
- The remainder is the value of numer - denom*quotient.
- If denom is 0, the quotient becomes 0 and the remainder becomes numer.
- If numer is -2147483648 and denom is -1, the quotient becomes -2147483648 and the remainder becomes 0.

(11) brk, sbrk

FUNCTION

- The memory function brk sets a break value.
- The memory function sbrk increments or decrements the set break value.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- int brk (char *endds) ;
- char *sbrk (int incr) ;

Function	Arguments	Return Value
brk	endds : Break value to be set block to be released	If break value is set properly : 0 If break value cannot be changed : -1
sbrk	incr : Value (bytes) by which set break value is to be incremented/decremented.	If incremented or decremented properly : Old break value If old break value cannot be incremented or decremented : -1

EXPLANATION

brk

- The brk function sets the value given by endds as a break value (the address next to the end address of an allocated block of memory).
- If endds is outside the permissible address range, the function sets no break value and sets errno to ENOMEM (3).

sbrk

- The sbrk function increments or decrements the set break value by the number of bytes specified by incr. (Increment or decrement is determined by the plus or minus sign of incr.)
- If the incremented or decremented break value is outside the permissible address range, the function does not change the original break value and sets errno to ENOMEM (3).

(12) atof, strtod

FUNCTION

- The string function atof converts the contents of a decimal integer string to a double value.
- The string function strtod converts the contents of a string to a double value.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- double atof (const char *nptr) ;
- double strtod (const char *nptr , char **endptr) ;

Function	Arguments	Return Value
atof	nptr : String to be converted	If converted properly : Converted value If positive overflow occurs : HUGE_VAL (with sign of overflowed value) If negative overflow occurs : 0 If the string is invalid : 0
strtod	nptr : String to be converted endptr : Pointer storing pointer pointing to unrecognizable block	If converted properly : Converted value If positive overflow occurs : HUGE_VAL (with sign of overflowed value) If negative overflow occurs : 0 If the string is invalid : 0

EXPLANATION

atof

- The atof function converts the string pointed to by pointer nptr to a double value.
- The atof function skips over zero or more white-space characters (for which isspace becomes true) from the beginning of the string and converts the string from the character next to the skipped white-spaces to a floating-point number (until other than digits or a null character appears in the string).
- A floating-point number is returned when converted properly.
- If an overflow occurs on conversion, HUGE_VAL with the sign of the overflowed value is returned and ERANGE is set to errno.
- If valid digits are deleted due to an underflow or an overflow, a non-normalized number and +0 are returned respectively, and ERANGE is set to errno.
- IF conversion cannot be performed, 0 is returned.

strtod

- The strtod function converts the string pointed to by pointer nptr to a double value.
- The strtod function skips over zero or more white-space characters (for which isspace becomes true) from the beginning of the string and converts the string from the character next to the skipped white-spaces to a floating-point number (until other than digits or null character appears in the string).
- A floating-point number is returned when converted properly.
- If an overflow occurs on conversion, HUGE_VAL with the sign of the overflowed value is returned and ERANGE is set to errno.
- If valid digits are deleted due to an underflow or an overflow, a non-normalized number and ±0 are returned respectively, and ERANGE is set to errno. In addition, endptr stores a pointer for next character string at that time.
- IF conversion cannot be performed, 0 is returned.

(13) itoa, ltoa (normal model only), ultoa (normal model only)

FUNCTION

- The string function itoa converts an int integer to its string equivalent.
- The string function ltoa converts a long int integer to its string equivalent.
- The string function ultoa converts an unsigned long integer to its string equivalent.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- char *itoa (int value , char *string , int radix) ;
- char *ltoa (long value , char *string , int radix) ;
- char *ultoa (unsigned long value , char *string , int radix) ;

Function	Arguments	Return Value
itoa, ltoa, ultoa	value : String to which integer is to be converted string : Pointer to the conversion result radix : Base of output string	If converted properly : Pointer to the converted string If not converted properly : Null pointer

EXPLANATION

itoa , ltoa , ultoa

- The itoa, ltoa, and ultoa functions all convert the integer value specified by value to its string equivalent which is terminated with a null character and store the result in the area pointed to by "string".
- The base of the output string is determined by radix, which must be in the range 2 through 36. Each function performs conversion based on the specified radix and returns a pointer to the converted string. If the specified radix is outside the range 2 through 36, the function performs no conversion and returns a null pointer.

(14) rand, srand

FUNCTION

- The mathematical function rand generates a sequence of pseudorandom numbers.
- The mathematical function srand sets a starting value (seed) for the sequence generated by rand.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- int rand (void) ;
- void srand (unsigned int seed) ;

Function	Arguments	Return Value
rand	None	Pseudorandom integer in the range of 0 to RAND_MAX
srand	seed : Starting value for pseudorandom number generator	None

EXPLANATION

rand

- Each time the rand function is called, it returns a pseudorandom integer in the range of 0 to RAND_MAX.

srand

- The srand function sets a starting value for a sequence of random numbers. seed is used to set a starting point for a progression of random numbers that is a return value when rand is called. If the same seed value is used, the sequence of pseudorandom numbers is the same when srand is called again.
- Calling rand before srand is used to set a seed is the same as calling rand after srand has been called with seed = 1. (The default seed is 1.)

(15) bsearch (normal model only)

FUNCTION

- The bsearch function performs a binary search.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void *bsearch (const void *key , const void *base , size_t nmemb , size_t size ,
  int (*compare) (const void *, const void *)) ;

Function	Arguments	Return Value
bsearch	key : Pointer to key for which search is made base : Pointer to sorted array which contains information to search nmemb : Number of array elements size : Size of an array compare : Pointer to function used to compare 2 keys	If the array contains the key : Pointer to the first member that matches "key" If the key is not contained in the array : Null pointer

EXPLANATION

- The bsearch function performs a binary search on the sorted array pointed to by base and returns a pointer to the first member that matches the key pointed to by key. The array pointed to by base must be an array which consists of nmemb number of members each of which has the size specified by size and must have been sorted in ascending order.
- The function pointed to by compare takes 2 arguments (key as the 1st argument and array element as the 2nd argument), compares the 2 arguments, and returns :

  Negative value if the 1st argument is less than the 2nd argument

  0 if both arguments are equal

  Positive integer if the 1st argument is greater than the 2nd argument
- When the -zr option is specified, the function passed to the argument of the bsearch function must be a pascal function.

(16) qsort (normal model only)

FUNCTION

- The qsort function sorts the members of a specified array using a quicksort algorithm.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- void qsort (void *base , size_t nmemb , size_t size , int (*compare) (const void * , const void *)) ;

Function	Arguments	Return Value
qsort	base : Pointer to array to be sorted nmemb : Number of members in the array size : Size of an array member compare : Pointer to function used to compare 2 keys	None

EXPLANATION

- The qsort function sorts the members of the array pointed to by base in ascending order. The array pointed to by base consists of nmemb number of members each of that has the size specified by size.
- The function pointed to by compare takes 2 arguments (array elements 1 and 2), compares the 2 arguments, and returns :
- The array element 1 as the 1st argument and array element 2 as the 2nd argument

  Negative value if the 1st argument is less than the 2nd argument
  0 if both arguments are equal
  Positive integer if the 1st argument is greater than the 2nd argument
- If the 2 array elements are equal, the element nearest to the top of the array will be sorted first.
- When the -zr option is specified, the function passed to the argument of the qsort function must be a pascal function.

(17) strbrk

FUNCTION

- strbrk sets a break value.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- int strbrk (char *endds) ;

Function	Arguments	Return Value
strbrk	endds : Break value to set	Normal : 0 When a break value cannot be changed : -1

EXPLANATION

- Sets the value given by endds to the break value (the address following the address at the end of the area to be allocated).
- When endds is out of the permissible range, the break value is not changed. ENOMEM(3) is set to errno and -1 is returned.

(18) strsbrk

FUNCTION

- strsbrk increases/decreases a break value.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- char *strsbrk(int incr);

Function	Arguments	Return Value
strsbrk	incr : Amount to increase/decrease a break value	Normal : Old break value When a break value cannot be increased/ decreased : -1

EXPLANATION

- incr byte increases/decreases a break value (depending on the sign of incr).
- When the break value is out of the permissible range after increasing/decreasing, a break value is not changed. ENOMEM(3) is set to errno, and -1 is returned.

(19) stritoa, strltoa (normal model only), strultoa (normal model only)

FUNCTION

- stritoa converts int to a character string.
- strltoa converts long to a character string.
- strultoa converts unsigned long to a character string.

HEADER

- stdlib.h

FUNCTION PROTOTYPE

- char *stritoa (int value , char *string , int radix) ;
- char *strltoa (long value , char *string , int radix) ;
- char *strultoa (unsigned long value , char *string , int radix) ;

Function	Arguments	Return Value
stritoa, strltoa, strultoa	value : Character string to convert string : Pointer to conversion result radix : Radix to specify	Normal : Pointer to the converted character string Others : Null pointer

EXPLANATION

stritoa, strltoa, strultoa

- Converts the specified numeric value value to the character string that ends with a null character, and the result will be stored to the area specified with string. The conversion is performed by the radix specified, and the pointer to the converted character string will be returned.
- radix must be the value range between 2 to 36. In other cases, the conversion is not performed and a null pointer is returned.

10.4.6 Character String / Memory Functions

(1) memcpy, memmove

FUNCTION

- The memory function memcpy copies a specified number of characters from a source area of memory to a destination area of memory.
- The memory function memmove is identical to memcpy, except that it allows overlap between the source and destination areas.

HEADER

- string.h

FUNCTION PROTOTYPE

- void *memcpy (void *s1, const void *s2 , size_t n) ;
- void *memmove (void *s1, const void *s2 , size_t n) ;

Function	Arguments	Return Value
memcpy, memmove	s1 : Pointer to object into which data is to be copied s2 : Pointer to object containing data to be copied n : Number of characters to be copied	Value of s1

EXPLANATION

memcpy

- The memcpy function copies n number of consecutive bytes from the object pointed to by s2 to the object pointed to by s1.
- If s2<s1<s2+n (s1 and s2 overlap), the memory copy operation by memcpy is not guaranteed (because copying starts in sequence from the beginning of the area).

memmove

- The memmove function also copies n number of consecutive bytes from the object pointed to by s2 to the object pointed to by s1.
- Even if s1 and s2 overlap, the function performs memory copying properly.

(2) strcpy, strncpy

FUNCTION

- The string function strcpy is used to copy the contents of one character string to another.
- The string function strncpy is used to copy up to a specified number of characters from one character string to another.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strcpy (char *s1 , const char *s2) ;
- char *strncpy (char *s1 , const char *s2 , size_t n) ;

Function	Arguments	Return Value
strcpy	s1: Pointer to copy destination array s2 : Pointer to copy source array	Value of s1
strncpy	s1: Pointer to copy destination array s2 : Pointer to copy source array n : Number of characters to be copied	Value of s1

EXPLANATION

strcpy

- The strcpy function copies the contents of the character string pointed to by s2 to the array pointed to by s1 (including the terminating character).
- If s2 < s1 < (s2 + Character length to be copied), the behavior of strcpy is not guaranteed (as copying starts in sequence from the beginning, not from the specified string).

strncpy

- The strncpy function copies up to the characters specified by n from the string pointed to by s2 to the array pointed to by s1.
- If s2 < s1 < (s2 + Character length to be copied or minimum value of s2 + n - 1), the behavior of strncpy is not guaranteed (as copying starts in sequence from the beginning, not from the specified string).
- If the string pointed by s2 is less than the characters specified by n, nulls will be appended to the end of s1 until n characters have been copied. If the string pointed to by s2 is longer than n characters, the resultant string that is pointed to by s1 will not be null terminated.

(3) strcat, strncat

FUNCTION

- The string function strcat concatenates one character string to another.
- The string function strncat concatenates up to a specified number of characters from one character string to another.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strcat (char *s1 , const char *s2) ;
- char *strncat (char *s1 , const char *s2 , size_t n) ;

Function	Arguments	Return Value
strcat	s1: Pointer to a string to which a copy of another string (s2) is to be concatenated s2 : Pointer to a string, copy of which is to be concatenated to another string (s1).	Value of s1
strncat	s1: Pointer to a string to which a copy of another string (s2) is to be concatenated s2 : Pointer to a string, copy of which is to be concatenated to another string (s1). n : Number of characters to be concatenated	Value of s1

EXPLANATION

strcat

- The strcat function concatenates a copy of the string pointed to by s2 (including the null terminator) to the string pointed to by s1. The null terminator originally ending s1 is overwritten by the first character of s2.
- When copying is performed between objects overlapping each other, the operation is not guaranteed.

strncat

- The strncat function concatenates not more than the characters specified by n of the string pointed to by s2 (excluding the null terminator) to the string pointed to by s1. The null terminator originally ending s1 is overwritten by the first character of s2.
- If the string pointed to by s2 has fewer characters than specified by n, the strncat function concatenates the string including the null terminator. If there are more characters than specified by n, the n character section is concatenated starting from the top.
- The null terminator must always be concatenated.
- When copying is performed between objects overlapping each other, the operation is not guaranteed.

(4) memcmp

FUNCTION

- The memory function memcmp compares 2 data objects, with respect to a given number of characters.

HEADER

- string.h

FUNCTION PROTOTYPE

- int memcmp (const void *s1 , const void *s2 , size_t n) ;

Function	Arguments	Return Value
memcmp	s1, s2 : Pointers to 2 data objects to be compared n : Number of characters to compare	If the n characters of both s1 and s2 are compared and found to be the same : 0 If the n characters of both s1 and s2 are compared and found to be different : Value differences that converted the initial differing characters into int (s1 letters - s2 letters)

EXPLANATION

- The memcmp function uses the n characters to compare the objects indicated by both s1 and s2.
- The memcmp function returns 0, when the n characters of both s1 and s2 are compared and found to be the same.
- The memcmp function returns the value differences (s1 letters - s2 letters) that converted the initial differing characters into int if, the n characters of both s1 and s2 are compared and found to be different.

(5) strcmp, strncmp

FUNCTION

- The string function strcmp compares 2 character strings.
- The string function strncmp compares not more than a specified number of characters from 2 character strings.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strcmp (char *s1 , const char *s2) ;
- char *strncmp (char *s1 , const char *s2 , size_t n) ;

Function	Arguments	Return Value
strcmp	s1: Pointer to one string to be compared s2 : Pointer to the other string to be compared	If s1 is equal to s2 : 0 If s1 is less than or greater than s2 : Value differences that converted the initial differing characters into int (s1 letters - s2 letters)
strncmp	s1: Pointer to one string to be compared s2 : Pointer to the other string to be compared n : Number of characters to compare	If the n characters of both s1 and s2 are compared and found to be the same : 0 If the n characters of both s1 and s2 are compared and found to be different : Value differences that converted the initial differing characters into int (s1 letters - s2 letters)

EXPLANATION

strcmp

- The strcmp function uses to compare the character strings indicated by both s1 and s2.
- If s1 is equal to s2, the function returns 0. If s1 is less than or greater than s2, the strcmp function returns the value differences (s1 letters - s2 letters) that converted the initial diffrering characters into int.

strncmp

- The strncmp function uses the n characters to compare the objects indicated by both s1 and s2.
- The strncmp function returns 0, when the n characters of both s1 and s2 are compared and found to be the same. The strncmp function returns the value differences (s1 letters - s2 letters) that converted the initial differing characters into int if, the n characters of both s1 and s2 are compared and found to be different.

(6) memchr

FUNCTION

- The memory function memchr converts a specified character to unsigned char, searches for it, and returns a pointer to the first occurrence of this character in an object of a given size.

HEADER

- string.h

FUNCTION PROTOTYPE

- void *memchr (const void *s , int c , size_t n) ;

Function	Arguments	Return Value
memchr	s : Pointer to objects in memory subject to search c : Character to be searched n : Number of bytes to be searched	If c is found : Pointer to the first occurrence of c If c is not found : Null pointer

EXPLANATION

- The memchr function first converts the character specified by c to unsigned char and then returns a pointer to the first occurrence of this character within the n number of bytes from the beginning of the object pointed to by s.
- If the character is not found, the function returns a null pointer.

(7) strchr, strrchr

FUNCTION

- The string function strchr returns a pointer to the first occurrence of a specified character in a string.
- The string function strrchr returns a pointer to the last occurrence of a specified character in a string.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strchr (const char *s , int c) ;
- char *strrchr (const char *s , int c) ;

Function	Arguments	Return Value
strchr, strrchr	s : Pointer to string to be searched c : Character specified for search	If c is found in s : Pointer indicating the first or last occurrence of c in string s If c is not found in s : Null pointer

EXPLANATION

strchr

- The strchr function searches the string pointed to by s for the character specified by c and returns a pointer to the first occurrence of c (converted to char type) in the string.
- The null terminator is regarded as part of the string.
- If the specified character is not found in the string, the function returns a null pointer.

strrchr

- The strrchr function searches the string pointed to by s for the character specified by c and returns a pointer to the last occurrence of c (converted to char type) in the string.
- The null terminator is regarded as part of the string.
- If no match is found, the function returns a null pointer.

(8) strspn, strcspn

FUNCTION

- The string function strspn returns the length of the initial substring of a string that is made up of only those characters contained in another string.
- The string function strcspn returns the length of the initial substring of a string that is made up of only those characters not contained in another string.

HEADER

- string.h

FUNCTION PROTOTYPE

- size_t strspn (const char *s1 , const char *s2) ;
- size_t strcspn (const char *s1 , const char *s2) ;

Function	Arguments	Return Value
strspn	s1 : Pointer to string to be searched s2 : Pointer to string whose characters are specified for match	Length of substring of the string s1 that is made up of only those characters contained in the string s2
strcspn		Length of substring of the string s1 that is made up of only those characters not contained in the s2

EXPLANATION

strspn

- The strspn function returns the length of the substring of the string pointed to by s1 that is made up of only those characters contained in the string pointed to by s2. In other words, this function returns the index of the first character in the string s1 that does not match any of the characters in the string s2.
- The null terminator of s2 is not regarded as part of s2.

strcspn

- The strcspn function returns the length of the substring of the string pointed to by s1 that is made up of only those characters not contained in the string pointed to by s2. In other words, this function returns the index of the first character in the string s1 that matches any of the characters in the string s2.
- The null terminator of s2 is not regarded as part of s2.

(9) strpbrk

FUNCTION

- The string function strpbrk returns a pointer to the first character in a string to be searched that matches any character in a specified string.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strpbrk (const char *s1 , const char *s2) ;

Function	Arguments	Return Value
strpbrk	s1 : Pointer to string to be searched s2 : Pointer to string whose characters are specified for match	If any match is found : Pointer to the first character in the string s1 that matches any character in the string s2 If no match is found : Null pointer

EXPLANATION

- The strpbrk function returns a pointer to the first character in the string pointed to by s1 that matches any character in the string pointed to by s2.
- If none of the characters in the string s2 is found in the string s1, the function returns a null pointer.

(10) strstr

FUNCTION

- The string function strstr returns a pointer to the first occurrence in the string to be searched of a specified string.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strstr (const char *s1 , const char *s2) ;

Function	Arguments	Return Value
strstr	s1 : Pointer to string to be searched s2 : Pointer to specified string	If s2 is found in s1 : Pointer to the first appearance in the string s1 of the string s2 If s2 is not found in s1 : Null pointer If s2 is a null string : Value of s1

EXPLANATION

- The strstr function returns a pointer to the first appearance in the string pointed to by s1 of the string pointed to by s2 (except the null terminator of s2).
- If the string s2 is not found in the string s1, the function returns a null pointer.
- If the string s2 is a null string, the function returns the value of s1.

(11) strtok

FUNCTION

- The string function strtok returns a pointer to a token taken from a string (by decomposing it into a string consisting of characters other than delimiters).

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strtok (char *s1 , const char *s2) ;

Function	Arguments	Return Value
strtok	s1 : Pointer to string from which tokens are to be obtained or null pointer s2 : Pointer to string containing delimiters of token	If it is found : Pointer to the first character of a token If there is no token to return : Null pointer

EXPLANATION

- A token is a string consisting of characters other than delimiters in the string to be specified.
- If s1 is a null pointer, the string pointed to by the saved pointer in the previous strtok call will be decomposed. However, if the saved pointer is a null pointer, the function returns a null pointer without doing anything.
- If s1 is not a null pointer, the string pointed to by s1 will be decomposed.
- The strtok function searches the string pointed to by s1 for any character not contained in the string pointed to by s2. If no character is found, the function changes the saved pointer to a null pointer and returns it. If any character is found, the character becomes the first character of a token.
- If the first character of a token is found, the function searches for any characters contained in the string s2 after the first character of the token. If none of the characters is found, the function changes the saved pointer to a null pointer. If any of the characters is found, the character is overwritten by a null character and a pointer to the next character becomes a pointer to be saved.
- The function returns a pointer to the first character of the token.

(12) memset

FUNCTION

- The memory function memset initializes a specified number of bytes in an object in memory with a specified character.

HEADER

- string.h

FUNCTION PROTOTYPE

- void *memset (void *s , int c , size_t n) ;

Function	Arguments	Return Value
memset	s : Pointer to object in memory to be initialized c : Character whose value is to be assigned to each byte n : Number of bytes to be initialized	Value of s

EXPLANATION

- The memset function first converts the character specified by c to unsigned char and then assigns the value of this character to the n number of bytes from the beginning of the object pointed to by s.

(13) strerror

FUNCTION

- The strerror function returns a pointer to the location which stores a string describing the error message associated with a given error number.

HEADER

- string.h

FUNCTION PROTOTYPE

- char *strerror (int errnum) ;

Function	Arguments	Return Value
strerror	errnum : Error number	If message associated with error number exists : Pointer to string describing error message If no message associated with error number exists : Null pointer

EXPLANATION

- The strerror function returns a pointer to one of the following strings associated with the value of errnum.

  0 : "Error 0"

  1 (EDOM) : "Argument too large"

  2 (ERANGE) : "Result too large"

  3 (ENOMEM) : "Not enough memory"

  Otherwise, the function returns a null pointer.

(14) strlen

FUNCTION

- The string function strlen returns the length of a character string.

HEADER

- string.h

FUNCTION PROTOTYPE

- size_t strlen (const char *s) ;

Function	Arguments	Return Value
strlen	s : Pointer to character string	Length of string s

EXPLANATION

- The strlen function returns the length of the null terminated string pointed to by s.

(15) strcoll

FUNCTION

- strcoll compares 2 character strings based on the information specific to the area.

HEADER

- string.h

FUNCTION PROTOTYPE

- int strcoll (const char *s1 , const char *s2) ;

Function	Arguments	Return Value
strcoll	s1 : Pointer to comparison character string s2 : Pointer to comparison character string	When character strings s1 and s2 are equal : 0 When character strings s1 and s2 are different : The difference between the values whose first different characters are converted to int (character of s1 - character of s2)

EXPLANATION

- The CC78K0S does not support operations specific to cultural sphere. The operations are the same as that of strcmp.

(16) strxfrm

FUNCTION

- strxfrm converts a character string based on the information specific to the area.

HEADER

- string.h

FUNCTION

- size_t strxfrm (char *s1 , const char *s2 , size_t n) ;

Function	Arguments	Return Value
strxfrm	s1 : Pointer to a compared character string s2 : Pointer to a compared character string n : Maximum number of characters to s1	Returns the length of the character string of the result of the conversion (does not include a character string to indicate the end). If the returned value is n or more, the contents of the array indicated by s1 is undefined.

EXPLANATION

- The CC78K0S does not support operations specific to cultural sphere. The operations are the same as those of the following functions.

```
strncpy (s1, s2, c) ;
return (strlen (s2)) ;
```

10.4.7 Mathematical Functions

(1) acos (normal model only)

FUNCTION

- acos finds acos.

HEADER

- math.h

FUNCTION PROTOTYPE

- double acos (double x) ;

Function	Arguments	Return Value
acos	x : Numeric value to perform operation	When -1 < x < 1 : acos of x When x < -1, 1 < x, x = NaN : NaN

EXPLANATION

- Calculates acos of x (range between 0 and π).
- When x is non-numeric, NaN is returned.
- In the case of the definition area error of x < -1, 1 < x, NaN is returned and EDOM is set.

(2) asin (normal model only)

FUNCTION

- asin finds asin.

HEADER

- math.h

FUNCTION PROTOTYPE

- double asin (double x) ;

Function	Arguments	Return Value
asin	x : Numeric value to perform operation	When -1 < x < 1 : asin of x When x < -1, 1 < x, x = NaN : NaN When x = -0 : -0 When underflow occurs : Non-normalized number

EXPLANATION

- Calculates asin (range between $-\pi/2$ and $+\pi/2$) of x.
- In the case of area error of x < -1, 1 < x, NaN is returned and EDOM is set to errno.
- When x is non-numeric, NaN is returned.
- When x is -0, -0 is returned.
- If underflow occurs as a result of conversion, a non-normalized number is returned.

(3) atan (normal model only)

FUNCTION

- atan finds atan.

HEADER

- math.h

FUNCTION PROTOTYPE

- double atan (double x) ;

Function	Arguments	Return Value
atan	x : Numeric value to perform operation	Normal : atan of x When x = NaN : NaN When x = -0 : -0

EXPLANATION

- Calculates atan (range between $-\pi/2$ and $+\pi/2$) of x.
- When x is non-numeric, NaN is returned.
- When x is -0, -0 is returned.
- If underflow occurs as a result of conversion, a non-normalized number is returned.

(4) atan2 (normal model only)

FUNCTION

- atan2 finds atan of y/x.

HEADER

- math.h

FUNCTION PROTOTYPE

- double atan2 (double y , double x) ;

Function	Arguments	Return Value
atan2	x : Numeric value to perform operation y : Numeric value to perform operation	Normal : atan of y/x When both x and y are 0 or y/x is the value that cannot be expressed, or either x or y is NaN and both x and y are +∞ : NaN When underflow occurs : Non-normalized number :

EXPLANATION

- atan (range between -π and +π) of y/x is calculated. When both x and y are 0 or y/x is the value that cannot be expressed, or when both x and y are infinite, NaN is returned and EDOM is set to errno.
- If either x or y is non-numeric, NaN is returned.
- If underflow occurs as a result of operation, non-normalized number is returned.

(5) cos (normal model only)

FUNCTION

- cos finds cos.

HEADER

- math.h

FUNCTION PROTOTYPE

- double cos (double x) ;

Function	Arguments	Return Value
cos	x : Numeric value to perform operation	Normal : cos of x When x = NaN, x = +∞ : NaN

EXPLANATION

- Calculates cos of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If the absolute value of x is extremely large, the result of an operation becomes an almost meaningless value.

(6) sin (normal model only)

FUNCTION

- sin finds sin.

HEADER

- math.h

FUNCTION PROTOTYPE

- double sin (double x) ;

Function	Arguments	Return Value
sin	x : Numeric value to perform operation	Normal : sin of x When x = NaN, x = +∞ : NaN When underflow occurs : Non-normalized number

EXPLANATION

- Calculates sin of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If underflow occurs as a result of operation, a non-normalized number is returned.
- If the absolute value of x is extremely large, the result of an operation becomes an almost meaningless value.

(7) tan (normal model only)

FUNCTION

- tan finds tan.

HEADER

- math.h

FUNCTION PROTOTYPE

- double tan (double x) ;

Function	Arguments	Return Value
tan	x : Numeric value to perform operation	Normal : tan of x When x = NaN, x = +∞ : NaN When underflow occurs : Non-normalized number

EXPLANATION

- Calculates tan of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If underflow occurs as a result of operation, a non-normalized number is returned.
- If the absolute value of x is extremely large, the result of an operation becomes an almost meaningless value.

(8) cosh (normal model only)

FUNCTION

- cosh finds cosh.

HEADER

- math.h

FUNCTION PROTOTYPE

- double cosh (double x) ;

Function	Arguments	Return Value
cosh	x : Numeric value to perform operation	Normal : cosh of x When overflow occurs, x = NaN, x = +∞ : HUGE_VAL (with positive sign) x = NaN : NaN

EXPLANATION

- Calculates cosh of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, a positive infinite value is returned.
- If overflow occurs as a result of operation, HUGE_VAL with a positive sign is returned, and ERANGE is set to errno.

(9) sinh (normal model only)

FUNCTION

- sinh finds sinh.

HEADER

- math.h

FUNCTION PROTOTYPE

- double sinh (double x) ;

Function	Arguments	Return Value
sinh	x : Numeric value to perform operation	Normal : sinh of x When x = NaN : NaN When x = +∞ : +∞ When overflow occurs : HUGE_VAL (with the sign of the overflown value) When underflow occurs : +0

EXPLANATION

- Calculates sinh of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- If overflow occurs as a result of operation, HUGE_VAL with the sign of the overflown value is returned, and ERANGE is set to errno.
- If underflow occurs as a result of operation, +0 is returned.

(10) tanh (normal model only)

FUNCTION

- tanh finds tanh.

HEADER

- math.h

FUNCTION PROTOTYPE

- double tanh (double x) ;

Function	Arguments	Return Value
tanh	x : Numeric value to perform operation	Normal : tanh of x When x = NaN : NaN When x = +∞ : +1 When underflow occurs : +0

EXPLANATION

- Calculates tanh of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +1 is returned.
- If underflow occurs as a result of operation, +0 is returned.

(11) exp (normal model only)

FUNCTION

- exp finds exponent function.

HEADER

- math.h

FUNCTION PROTOTYPE

- double exp (double x) ;

Function	Arguments	Return Value
exp	x : Numeric value to perform operation	Normal : Exponent function of x When x = NaN : NaN When x = +∞ : +∞ When overflow occurs : HUGE_VQAL (with positive sign) When underflow occurs : Non-normalized number When annihilation of valid digits occurs due to underflow : +0

EXPLANATION

- Calculates exponent function of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- If underflow occurs as a result of operation, non-normalized number is returned.
- If annihilation of valid digits due to underflow occurs as a result of operation, +0 is returned.
- If overflow occurs as a result of operation, HUGE_VAL with a positive sign is returned and ERANGE is set to errno.

(12) frexp (normal model only)

FUNCTION

- frexp finds mantissa and exponent part.

HEADER

- math.h

FUNCTION PROTOTYPE

- double frexp (double x , int *exp) ;

Function	Arguments	Return Value
frexp	x : Numeric value to perform operation exp : Pointer to store exponent part	Normal : Mantissa of x When x = NaN, x = +∞ : NaN When x = +0 : +0

EXPLANATION

- Divide a floating point number x to mantissa m and exponent n such as x = m * 2 ^ n and returns mantissa m.
- Exponent n is stored where the pointer exp indicates. The absolute value of m, however, is 0.5 or more and less than 1.0.
- If x is non-numeric, NaN is returned and the value of *exp is 0.
- If x is infinite, NaN is returned, and EDOM is set to errno with the value of *exp as 0.
- If x is +0, +0 is returned and the value of *exp is 0.

(13) ldexp (normal model only)

FUNCTION

- ldexp finds x * 2 ^ exp.

HEADER

- math.h

FUNCTION PROTOTYPE

- double ldexp (double x , int exp) ;

Function	Arguments	Return Value
ldexp	x : Numeric value to perform operation exp : Exponentiation	Normal : x * 2 ^ exp When x = NaN : NaN When x = +∞ : +∞ When x = +0 : +0 When overflow occurs : HUGE_VAL (with the sign of the overflown value) When underflow occurs : Non-normalized number When annihilation of valid digits occurs due to underflow : +0

EXPLANATION

- Calculates x * 2 ^ exp.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- If x is +0, +0 is returned.
- If overflow occurs as a result of operation, HUGE_VAL with the overflown value is returned and ERANGE is set to errno.
- If underflow occurs as a result of operation, non-normalized number is returned.
- If annihilation of valid digits due to underflow occurs as a result of operation, ±0 is returned.

(14) log (normal model only)

FUNCTION

- log finds natural logarithm.

HEADER

- math.h

FUNCTION PROTOTYPE

- double log (double x) ;

Function	Arguments	Return Value
log	x : Numeric value to perform operation	Normal : Natural logarithm of x When x < 0 : HUGE_VAL (with negative sign) When x is non-numeric : NaN When x is infinite : +∞

EXPLANATION

- Finds natural logarithm of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- In the case of area error of x < 0, HUGE_VAL with a negative sign is returned, EDOM is set to errno.
- If x = 0, HUGE_VAL with a negative sign is returned, and ERANGE is set to errno.

(15) log10 (normal model only)

FUNCTION

- log10 finds logarithm with 10 as the base.

HEADER

- math.h

FUNCTION PROTOTYPE

- double log10 (double x) ;

Function	Arguments	Return Value
log10	x : Numeric value to perform operation	Normal : Logarithm with 10 of x as the base When x < 0 : HUGE_VAL (with negative sign) When x is non-numeric : NaN When x is infinite : +∞

EXPLANATION

- Finds logarithm with 10 of x as the base.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- In the case of area error of x < 0, HUGE_VAL with a negative sign is returned, EDOM is set to errno.
- If x = 0, HUGE_VAL with a negative sign is returned, and ERANGE is set to errno.

(16) modf (normal model only)

FUNCTION

- modf finds fraction part and integer part.

HEADER

- math.h

FUNCTION PROTOTYPE

- double modf (double x , double *iptr) ;

Function	Arguments	Return Value
modf	x : Numeric value to perform operation iptr : Pointer to integer part	Normal : Fraction part of x When x is non-numeric or infinite : NaN When x is +0 : +0

EXPLANATION

- Divides a floating point number x to fraction part and integer part
- Returns fraction part with the same sign as that of x, and stores the integer part to the location indicated by the pointer iptr.
- If x is non-numeric, NaN is returned and stored to the location indicated by the pointer iptr.
- If x is infinite, NaN is returned and stored to the location indicated by the pointer iptr, and EDOM is set to errno.
- If x = +0, +0 is stored to the location indicated by the pointer iptr.

(17) pow (normal model only)

FUNCTION

- pow finds yth power of x.

HEADER

- math.h

FUNCTION PROTOTYPE

- double pow (double x , double y) ;

Function	Arguments	Return Value
pow	x : Numeric value to perform operation y : Multiplier	Normal : x ^ y Either when x = NaN or y = NaN, x = +∞ and y = 0 x < 0 and y ≠ integer, x < 0 and y = +∞, x = 0 and y < 0 : NaN When underflow occurs : Non-normalized number When overflow occurs : HUGE_VAL (with the sign of overflown value) When annihilation of valid digits occurs due to underflow : +0

EXPLANATION

- Calculates x ^ y.
- If overflow occurs as a result of operation, HUGE_VAL with the sign of overflown value is returned, and ERANGE is set to errno.
- When x = NaN or y = NaN, NaN is returned.
- Either when x = +∞ and y = 0, x < 0 and y ≠ integer, x < 0 and y = +∞ or x = 0 and y < 0, NaN is returned and EDOM is set to errno.
- If underflow occurs, a non-normalized number is returned.
- If annihilation of valid digits occurs due to underflow, ±0 is returned.

(18) sqrt (normal model only)

FUNCTION

- sqrt finds square root.

HEADER

- math.h

FUNCTION PROTOTYPE

- double sqrt (double x) ;

Function	Arguments	Return Value
sqrt	x : Numeric value to perform operation	When x > 0 : Square root of x When x = +0 : +0 When x < 0 : NaN

EXPLANATION

- Calculates the square root of x.
- In the case of area error of x < 0, 0 is returned and EDOM is set to errno.
- If x is non-numeric, NaN is returned.
- If x is +0, +0 is returned.

(19) ceil (normal model only)

FUNCTION

- ceil finds the minimum integer no less than x.

HEADER

- math.h

FUNCTION PROTOTYPE

- double ceil (double x) ;

Function	Arguments	Return Value
ceil	x : Numeric value to perform operation	Normal : The minimum integer no less than x When x is non-numeric or x = +∞ : NaN When x = -0 : +0 When the minimum integer no less than x cannot be expressed : x

EXPLANATION

- Finds the minimum integer no less than x.
- If x is non-numeric, NaN is returned.
- If x is -0, +0 is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If the minimum integer no less than x cannot be expressed, x is returned.

(20) fabs (normal model only)

FUNCTION

- fabs returns the absolute value of the floating point number x .

HEADER

- math.h

FUNCTION PROTOTYPE

- double fabs (double x) ;

Function	Arguments	Return Value
fabs	x : Numeric value to find the absolute value	Normal : Absolute value of x When x is non-numeric : NaN When x = -0 : +0

EXPLANATION

- Finds the absolute value of x.
- If x is non-numeric, NaN is returned.
- If x is -0, +0 is returned.

(21) floor (normal model only)

FUNCTION

- floor finds the maximum integer no more than x.

HEADER

- math.h

FUNCTION PROTOTYPE

- double floor (double x) ;

Function	Arguments	Return Value
floor	x : Numeric value to perform operation	Normal : The maximum integer no more than x When x is non-numeric or x = +∞ : NaN When x = -0 : +0 When the maximum integer no more than x cannot be expressed : x

EXPLANATION

- Finds the maximum integer no more than x.
- If x is non-numeric, NaN is returned.
- If x is -0, +0 is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If the maximum integer no more than x cannot be expressed, x is returned.

(22) fmod (normal model only)

FUNCTION

- fmod finds the remainder of x/y.

HEADER

- math.h

FUNCTION PROTOTYPE

- double fmod (double x , double y) ;

Function	Arguments	Return Value
fmod	x : Numeric value to perform operation y : Numeric value to perform operation	Normal : Remainder of x/y When x is non-numeric or y is non-numeric, when y is +0, when x is +∞ : NaN When x ≠ ∞ and y = +∞ : x

EXPLANATION

- Calculates the remainder of x/y expressed with x - i*y. i is an integer.
- If y ≠ 0, the return value has the same sign as that of x and the absolute value is less than that of y.
- If y is + 0 or x = +∞, NaN is returned and EDOM is set to errno.
- If x is non-numeric or y is non-numeric, NaN is returned.
- If y is infinite, x is returned unless x is infinite.

(23) matherr (normal model only)

FUNCTION

- matherr performs exception processing of the library that deals with floating point numbers.

HEADER

- math.h

FUNCTION PROTOTYPE

- void matherr (struct exception *x) ;

Function	Arguments	Return Value

matherr	`struct exception {`
	`  int  type;`
	`  char  *name;`
	`}`
	
	type :
	Numeric value to indicate arithmetic exception
	name :
	Function name
		None

EXPLANATION

- When an exception is generated, matherr is automatically called in the standard library and run-time library that deal with floating-point numbers.
- When called from the standard library, EDOM and ERANGE are set to errno.

  The following shows the relationship between the arithmetic exception type and errno.

Type	Arithmetic Exception	Value Set to errno
1	Underflow	ERANGE
2	Annihilation	ERANGE
3	Overflow	ERANGE
4	Zero division	EDOM
5	Inoperable	EDOM

Original error processing can be performed by changing or creating matherr.

(24) acosf (normal model only)

FUNCTION

- acosf finds acos.

HEADER

- math.h

FUNCTION PROTOTYPE

- float acosf (float x) ;

Function	Arguments	Return Value
acosf	x : Numeric value to perform operation	When -1 < x < 1 : acos of x When x < -1, 1 < x, x = : NaN

EXPLANATION

- Calculates acos (range between 0 and π) of x.
- If x is non-numeric, NaN is returned.
- In the case of definition area error of x < -1, 1 < x, NaN is returned and EDOM is set to errno.

(25) asinf (normal model only)

FUNCTION

- asinf finds asin.

HEADER

- math.h

FUNCTION PROTOTYPE

- float asinf (float x) ;

Function	Arguments	Return Value
asinf	x : Numeric value to perform operation	When -1 < x < 1 : asin of x When x < -1, 1 < x, x = NaN : NaN x = -0 : -0 When underflow occurs : Non-normalized number

EXPLANATION

- Calculates asin (range between $-\pi/2$ and $+\pi/2$) of x.
- If x is non-numeric, NaN is returned.
- In the case of definition area error of x < -1, 1 < x, NaN is returned and EDOM is set to errno.
- If x = -0, -0 is returned.
- If underflow occurs as a result of operation, a non-normalized number is returned.

(26) atanf (normal model only)

FUNCTION

- atanf finds atan.

HEADER

- math.h

FUNCTION PROTOTYPE

- float atanf (float x) ;

Function	Arguments	Return Value
atanf	x : Numeric value to perform operation	Normal : atan of x When x = NaN : NaN When x = -0 : -0

EXPLANATION

- Calculates atan (range between $-\pi/2$ and $+\pi/2$) of x.
- If x is non-numeric, NaN is returned.
- If x = -0, -0 is returned.
- If underflow occurs as a result of operation, a non-normalized number is returned.

(27) atan2f (normal model only)

FUNCTION

- atan2f finds atan of y/x.

HEADER

- math.h

FUNCTION PROTOTYPE

- float atan21 (float y , float x) ;

Function	Arguments	Return Value
atan21	x : Numeric value to perform operation y : Numeric value to perform operation	Normal : atan of y/x When both x and y are 0 or a value whose y/x cannot be expressed, or either x or y is NaN, both x and y are +∞ : NaN When underflow occurs : Non-normalized number

EXPLANATION

- Calculates atan (range between -π and +π) of y/x. When both x and y are 0 or the value whose y/x cannot be expressed, or when both x and y are infinite, NaN is returned and EDOM is set to errno.
- When either x or y is non-numeric, NaN is returned.
- If underflow occurs as a result of operation, a non-normalized number is returned.

(28) cosf (normal model only)

FUNCTION

- cosf finds cos.

HEADER

- math.h

FUNCTION PROTOTYPE

- float cosf (float x) ;

Function	Arguments	Return Value
cosf	x : Numeric value to perform operation	Normal : cos of x When x = NaN, x = +∞ : NaN

EXPLANATION

- Calculates cos of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If the absolute value of x is extremely large, the result of an operation becomes an almost meaningless value.

(29) sinf (normal model only)

FUNCTION

- sinf finds sin.

HEADER

- math.h

FUNCTION PROTOTYPE

- float sinf (float x) ;

Function	Arguments	Return Value
sinf	x : Numeric value to perform operation	Normal : sin of x When x = NaN, x = +∞ : NaN When underflow occurs : Non-normalized number

EXPLANATION

- Calculates sin of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If underflow occurs as a result of operation, a non-normalized number is returned.
- If the absolute value of x is extremely large, the result of an operation becomes an almost meaningless value.

(30) tanf (normal model only)

FUNCTION

- tanf finds tan.

HEADER

- math.h

FUNCTION PROTOTYPE

- float tanf (float x) ;

Function	Arguments	Return Value
tanf	x : Numeric value to perform operation	Normal : tan of x When x = NaN, x = +∞ : NaN When underflow occurs : Non-normalized number

EXPLANATION

- Calculates tan of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If underflow occurs as a result of operation, a non-normalized number is returned.
- If the absolute value of x is extremely large, the result of an operation becomes an almost meaningless value.

(31) coshf (normal model only)

FUNCTION

- coshf finds cosh.

HEADER

- math.h

FUNCTION PROTOTYPE

- float coshf (float x) ;

Function	Arguments	Return Value
coshf	x : Numeric value to perform operation	Normal : cosh of x When overflow occurs, x = +∞ : HUGE_VAL (with a positive sign) x = NaN : NaN

EXPLANATION

- Calculates cosh of x.
- If x is non-numeric, NaN is returned.
- If x is infinite, positive infinite value is returned.
- If overflow occurs as a result of operation, HUGE_VAL with a positive sign is returned and ERANGE is set to errno.

(32) sinhf (normal model only)

FUNCTION

- sinhf finds sinh.

HEADER

- math.h

FUNCTION PROTOTYPE

- float sinhf (float x) ;

Function	Arguments	Return Value
sinhf	x : Numeric value to perform operation	Normal : sinh of x When overflow occurs : HUGE_VAL (with a sign of the overflown value) x = NaN : NaN When x = +∞ : +∞ When underflow occurs : +0

EXPLANATION

- Calculates sinh of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- If overflow occurs as a result of operation, HUGE_VAL with the sign of overflown value is returned and ERANGE is set to errno.
- If underflow occurs as a result of operation, ±0 is returned.

(33) tanhf (normal model only)

FUNCTION

- tanhf finds tanh.

HEADER

- math.h

FUNCTION PROTOTYPE

- float tanhf (float x) ;

Function	Arguments	Return Value
tanhf	x : Numeric value to perform operation	Normal : tanh of x x = NaN : NaN When x = +∞ : +1 When underflow occurs : +0

EXPLANATION

- Calculates tanh of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +1 is returned.
- If underflow occurs as a result of operation, ±0 is returned.

(34) expf (normal model only)

FUNCTION

- expf finds exponent function.

HEADER

- math.h

FUNCTION PROTOTYPE

- float expf (float x) ;

Function	Arguments	Return Value
expf	x : Numeric value to perform operation	Normal : Exponent function of x When overflow occurs : HUGE_VAL (with positive sign) x = NaN : NaN When x = +∞ : +∞ When underflow occurs : Non-normalized number When annihilation of effective digits occurs due to underflow : +0

EXPLANATION

- Calculates exponent function of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- If overflow occurs as a result of operation, HUGE_VAL with a positive sign is returned and ERANGE is set to errno.
- If underflow occurs as a result of operation, non-normalized number is returned.
- If annihilation of effective digits occurs due to underflow as a result of operation, +0 is returned.

(35) frexpf (normal model only)

FUNCTION

- frexpf finds mantissa and exponent part.

HEADER

- math.h

FUNCTION PROTOTYPE

- float frexpf (float x , int *exp) ;

Function	Arguments	Return Value
frexpf	x : Numeric value to perform operation exp : Pointer to store exponent part	Normal : Mantissa of x When x = NaN, x = +∞ : NaN When x = +0 : +0

EXPLANATION

- Divides a floating-point number x to mantissa m and exponent n such as x = m * 2 ^ n and returns mantissa m.
- Exponent n is stored in where the pointer exp indicates. The absolute value of m, however, is 0.5 or more and less than 1.0.
- If x is non-numeric, NaN is returned and the value of *exp is 0.
- If x is +∞, NaN is returned, and EDOM is set to errno with the value of *exp as 0.
- If x is +0, +0 is returned and the value of *exp is 0.

(36) ldexpf (normal model only)

FUNCTION

- ldexpf finds x * 2 ^ exp.

HEADER

- math.h

FUNCTION PROTOTYPE

- float ldexpf (float x , int exp) ;

Function	Arguments	Return Value
ldexpf	x : Numeric value to perform operation exp : Exponentiation	Normal : x * 2 ^ exp When x = NaN : NaN When x = +∞ : +∞ When x = +0 : +0 When overflow occurs : HUGE_VAL (with the sign of overflown value) When underflow occurs : Non-normalized numberV When annihilation of valid digits occurs due to underflow : +0

EXPLANATION

- Calculates x * 2 ^ exp.
- If x is non-numeric, NaN is returned. If x is +∞, +∞ is returned. If x is +0, +0 is returned.
- If overflow occurs as a result of operation, HUGE_VAL with the sign of overflown value is returned and ERANGE is set to errno.
- If underflow occurs as a result of operation, non-normalized number is returned .
- If annihilation of valid digits due to underflow occurs as a result of operation, ±0 is returned.

(37) logf (normal model only)

FUNCTION

- logf finds natural logarithm.

HEADER

- math.h

FUNCTION PROTOTYPE

- float logf (float x) ;

Function	Arguments	Return Value
logf	x : Numeric value to perform operation	Normal : Natural logarithm of x When x is non-numeric : NaN When x is infinite : +∞ When x < 0 : HUGE_VAL (with negative sign)

EXPLANATION

- Finds natural logarithm of x.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- In the case of area error of x < 0, HUGE_VAL with a negative sign is returned, and EDOM is set to errno.
- If x = 0, HUGE_VAL with a negative sign is returned, and ERANGE is set to errno.

(38) log10f (normal model only)

FUNCTION

- log10f finds logarithm with 10 as the base.

HEADER

- math.h

FUNCTION PROTOTYPE

- float log10f (float x) ;

Function	Arguments	Return Value
log10f	x : Numeric value to perform operation	Normal : Logarithm with 10 of x as the base When x is non-numeric : NaN When x = +∞ : +∞ When x < 0 : HUGE_VAL (with negative sign)

EXPLANATION

- Finds logarithm with 10 of x as the base.
- If x is non-numeric, NaN is returned.
- If x is +∞, +∞ is returned.
- In the case of area error of x < 0, HUGE_VAL with a negative sign is returned, and EDOM is set to errno.
- If x = 0, HUGE_VAL with a negative sign is returned, and ERANGE is set to errno.

(39) modff (normal model only)

FUNCTION

- modff finds fraction part and integer part.

HEADER

- math.h

FUNCTION PROTOTYPE

- float modff (float x , float *iptr) ;

Function	Arguments	Return Value
modff	x : Numeric value to perform operation iptr : Pointer for integer part	Normal : Fraction part of x When x is non-numeric or infinite : NaN When x = +0 : +0

EXPLANATION

- Divides a floating point number x to fraction part and integer part.
- Returns fraction part with the same sign as that of x, and stores integer part to location indicated by the pointer iptr.
- If x is non-numeric, NaN is returned and stored location indicated by the pointer iptr.
- If x is infinite, NaN is returned and stored location indicated by the pointer iptr, and EDOM is set to errno.
- If x = +0, +0 is returned and stored location indicated by the pointer iptr.

(40) powf (normal model only)

FUNCTION

- powf finds yth power of x.

HEADER

- math.h

FUNCTION PROTOTYPE

- float powf (float x , float y) ;

Function	Arguments	Return Value
powf	x : Numeric value to perform operation y : Multiplier	Normal : x ^ y Either when x = NaN or y = NaN x = +∞ and y = 0 x < 0 and y ≠ integer, x < 0 and y = +∞ x = 0 and y < 0 : NaN When underflow occurs : Non-normalized number When overflow occurs : HUGE_VAL (with the sign of overflown value) When annihilation of valid digits occurs due to underflow : +0

EXPLANATION

- Calculates x ^ y.
- If overflow occurs as a result of operation, HUGE_VAL with the sign of overflown value is returned, and ERANGE is set to errno.
- When x = NaN or y = NaN, NaN is returned.
- Either when x = +∞ and y = 0, x < 0 and y ≠ integer, x < 0 and y = +∞, or x = 0 and y < 0, NaN is returned and EDOM is set to errno.
- If underflow occurs, a non-normalized number is returned.
- If annihilation of valid digits occurs due to underflow, ±0 is returned.

(41) sqrtf (normal model only)

FUNCTION

- sqrtf finds square root.

HEADER

- math.h

FUNCTION PROTOTYPE

- float sqrtf (float x) ;

Function	Arguments	Return Value
sqrtf	x : Numeric value to perform operation	When x > 0 : Square root of x When x = +0 : +0 When x < 0 : NaN

EXPLANATION

- Calculates the square root of x.
- In the case of area error of x < 0, 0 is returned and EDOM is set to errno.
- If x is non-numeric, NaN is returned.
- If x is +0, +0 is returned.

(42) ceilf (normal model only)

FUNCTION

- ceilf finds the minimum integer no less than x.

HEADER

- math.h

FUNCTION PROTOTYPE

- float ceilf (float x) ;

Function	Arguments	Return Value
ceilf	x : Numeric value to perform operation	Normal : The minimum integer no less than x When x is non-numeric or x = +∞ : NaN When x = -0 : +0 When the minimum integer no less than x cannot be expressed : x

EXPLANATION

- Finds the minimum integer no less than x.
- If x is non-numeric, NaN is returned.
- If x is -0, +0 is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If the minimum integer no less than x cannot be expressed, x is returned.

(43) fabsf (normal model only)

FUNCTION

- fabsf returns the absolute value of the floating point number x.

HEADER

- math.h

FUNCTION PROTOTYPE

- float fabsf (float x) ;

Function	Arguments	Return Value
fabsf	x : Numeric value to find the absolute value	Normal : Absolute value of x When x is non-numeric : NaN When x = -0 : +0

EXPLANATION

- Finds the absolute value of x.
- If x is non-numeric, NaN is returned.
- If x is -0, +0 is returned.

(44) floorf (normal model only)

FUNCTION

- floorf finds the maximum integer no more than x.

HEADER

- math.h

FUNCTION PROTOTYPE

- float floorf (float x) ;

Function	Arguments	Return Value
floorf	x : Numeric value to perform operation	Normal : The maximum integer no more than x When x is non-numeric or infinite : NaN When x = -0 : +0 When the maximum integer no more than x cannot be expressed : x

EXPLANATION

- Finds the maximum integer no more than x.
- If x is non-numeric, NaN is returned.
- If x is -0, +0 is returned.
- If x is infinite, NaN is returned and EDOM is set to errno.
- If the maximum integer no more than x cannot be expressed, x is returned.

(45) fmodf (normal model only)

FUNCTION

- fmodf finds the remainder of x/y.

HEADER

- math.h

FUNCTION PROTOTYPE

- float fmodf (float x , float y) ;

Function	Arguments	Return Value
fmodf	x : Numeric value to perform operation y : Numeric value to perform operation	Normal : Remainder of x/y When x is non-numeric or y is non-numeric, When y is +0, when x is +∞ : NaN When x ≠ ∞ and y = +∞ : x

EXPLANATION

- Calculates the remainder of x/y expressed with x - i*y. i is an integer.
- If y ≠ 0, the return value has the same sign as that of x and the absolute value is less than y.
- If y is +0 or x = +∞, NaN is returned and EDOM is set to errno.
- If x is non-numeric or y is non-numeric, NaN is returned.
- If y is infinite, x is returned unless x is infinite.

10.4.8 Diagnostic Functions

(1) __assertfail (normal model only)

FUNCTION

- __assertfail supports assert macro.

HEADER

- assert.h

FUNCTION PROTOTYPE

- int __assertfail (char*__msg , char*__cond , char*__file , int__line) ;

Function	Arguments	Return Value
__assertfail	__msg : Pointer to character string to indicate output conversion specification to be passed to printf function __cond : Actual argument of assert macro __file : Source file name __line : Source line number	Undefined

EXPLANATION

- A __assertfail function receives information from assert macro (refer to 10.2 (13) assert.h (normal model only)), calls printf function, outputs information, and calls abort function.
- An assert macro adds diagnostic function to a program. When an assert macro is executed, if p is false (equal to 0), an assert macro passes information related to the specific call that has brought the false value (actual argument text, source file name, and source line number are included in the information. The other two are the values of macro __FILE__ and __LINE__, respectively) to __assertfail function.

10.5 Batch Files for Update of Startup Routine and Library Functions

The CC78K0S is provided with batch files for updating a part of the standard library functions and the startup routine. The batch files in the bat folder are shown in Table 10-18 below.

Remark The files d9026.78k in the bat folder are used during batch file activation for updating library, not for development. When developing a system, it is necessary to have a device file (sold separately).

Table 10-18 Batch Files for Updating Library Functions

Batch File	Application
mkstup.bat	Updates the startup routine (cstart*.asm). When changing the startup routine, perform assembly using this batch file.
reprom.bat	Updates the firmware ROM termination routine (rom.asm). When changing rom.asm, update the library using this batch file.
repgetc.bat	Updates the getchar function. The default assumption sets P0 of the SFR to input port. When it is necessary to change this setting, change the defined value of EQU of PORT in getchar.asm and update the library using this batch file.
repputc.bat	Updates the putchar function. The default assumption sets P0 of the SFR to output port. When it is necessary to change this setting, change the defined value of EQU of PORT in putchar.asm and update the library using this batch file.
repputcs.bat	Updates the putchar function to SM78K0S-supporting. When it is necessary to check the output of the putchar function using the SM78K0S, update the library using this batch file.
repselo.bat	Saves/restores the reserved area of the compiler (_@KREGxx) as part of the save/restore processing of the setjmp/longjmp functions (the default assumption is to not save/restore). Update the library using this batch file when the -qr option is specified.
repselon.bat	Does not save/restore the reserved area of the compiler (_@KREGxx) as part of the save/restore processing of the setjmp/longjmp functions (the default assumption is to not save/restore). Update the library using this batch file when the -qr option is not specified.
repcmul.bat	Updates runtime libraries @@csmul and @@cumul that are included in the multiplication library. By default, operations are enabled with a device in which the SFR for the multiplier (MUL0) is allocated to address FF10H. When using a device in which the SFR for the multiplier (MUL0) is allocated to other than address FF10H, specify the device, then update the libraries using this batch file.
repimul.bat	Adds or deletes runtime libraries @@ismul and @@iumul to the multiplication library. @@ismul and @@iumul, which support the multiplier, are not included by default. When using @@ismul and @@iumul, add them to the multiplication library using this batch file. Also use this batch file when deleting the added @@ismul and @@iumul.
replmul.bat	Adds or deletes runtime libraries @@lsmul and @@lumul to the multiplication library. @@lsmul and @@lumul, which support the multiplier, are not included by default. When using @@lsmul and @@lumul, add them to the multiplication library using this batch file. Also use this batch file when deleting the added @@lsmul and @@lumul.

10.5.1 Using batch files

Use the batch files in the subfolder bat. Because these files are the batch files used to activate the assembler and librarian, an environment in which the RA78K0S assembler package Ver.1.50 or later operates is necessary. Before using the batch files, set the folder that contains the RA78K0S execution format file using the environment variable PATH.

Create a subfolder (lib) of the same level as bat for the batch files and put the post-assembly files in this subfolder. When a C startup routine or library is installed in a subfolder lib that is the same level as bat, these files are overwritten.

To use the batch files, move the current folder to the subfolder bat and execute each batch file. At this time, the following parameters are necessary.

Product type = chiptype (classification of target chip)

9216 ... u PD789216, etc.

The following is an illustration of how to use each batch file.

The batch file for :

(1) Startup routine

mkstup chiptype

< Example >

```
mkstup 9216
```

(2) Firmware ROM routine update

reprom chiptype

< Example >

```
reprom 9216
```

(3) getchar function update

repgetc chiptype

< Example >

```
repgetc 9216
```

(4) putchar function update

repputc chiptype

< Example >

```
repputc 9216
```

(5) putchar function (SM78K0S-supporting) update

repputcs chiptype

< Example >

```
repputcs 9216
```

(6) setjmp/longjmp function update (with restore/save processing)

repselo chiptype

< Example >

```
repselo 9216
```

(7) setjmp/longjmp function update (without restore/save processing)

repselon chiptype

< Example >

```
repselon 9216
```

(8) Runtime libraries that support multiplier (@@csmul, @@cumul) update

repcmul.bat chiptype

< Example >

```
repcmul.bat 9832
```

(9) Runtime libraries that support multiplier (@@ismul, @@iumul) add/delete

repimul.bat chiptype add/del

< Example >

```
repimul.bat 9832 add
```

(10) Runtime libraries that support multiplier (@@lsmul, @@lumul) add/delete

replmul.bat chiptype add/del

< Example >

```
replmul.bat 9832 add
```

CHAPTER 11 EXTENDED FUNCTIONS

This chapter describes the extended functions unique to the CC78K0S and not specified in the ANSI (American National Standards Institute) Standard for C.

The extended functions of the CC78K0S are used to generate codes for effective utilization of the target devices in the 78K0S Series. Not all of these extended functions are always effective. Therefore, it is recommended to use only the effective ones according to the user's purpose. For the effective use of the extended functions, refer to "CHAPTER 13 EFFECTIVE UTILIZATION OF COMPILER" along with this chapter.

C source programs created by using the extended functions of the CC78K0S utilize microcontroller-dependent functions. As regards portability to other microcontrollers, they are compatible at the C language level. For this reason, C source programs developed by using these extended functions are portable to other microcontrollers with easy-to-make modifications.

Remark In the explanation of this chapter, "RTOS" stands for the 78K0 Series real-time OS.

11.1 Macro Names

The CC78K0S has 2 types of macro names : those indicating the series names for target devices and those indicating device names (processor types). These macro names are specified according to the option at compile time to output object code for a specific target device or according to the processor type in the C source. In the example below, __K0S__ and __9216_ are specified.

For details of these macro names, see "9.8 Compiler-Defined Macro Names".

< Example >

```
Compile option
        > CC78K0S -c9216 prime.c ...

Specification of device type :
        #pragma pc ( 9216 )
```

11.2 Keywords

The CC78K0S is added with the following tokens as keywords to realize the extended function. These tokens cannot be used as labels nor variable names as well as ANSI-C keywords. All the keywords must be described in lowercase letters. A keyword containing any uppercase letter is not interpreted as such by the C compiler.

The following shows the list of keywords added to the CC78K0S. Of these keywords, ones not starting with "__" can be disabled by specifying the option (-za) that enables only ANSI-C language specifications (for the ANSI-C keywords, refer to "2.2 Keywords").

Table 11-1 List of Added Keywords

Keyword		Use
__callt	callt	callt/__callt functions
__callf	callf	callf/__callf functions
__sreg	sreg	sreg/__sreg variables
	noauto	noauto functions
__leaf	norec	norec/__leaf functions
__boolean	boolean	boolean type/__boolean type variables
	bit	bit type variables
__interrupt		Hardware interrupt
__interrupt_brk		Software interrupt
__asm		ASM statements
__rtos_interrupt		Handler to allocate for RTOS
__pascal		Pascal function
__directmap		Absolute address allocation specification
__temp		Temporary variable

Note A warning is output for the descriptions callf, __callf, __interrupt_brk, and __rtos_interrupt and they are ignored.

(1) Functions

The keywords callt, __callt, noauto, norec, __leaf, __interrupt, and __pascal are attribute qualifiers. These keywords must be described before any function declaration. The format of each attribute qualifier is shown below.

attribute qualifier ordinary declarator function name (parameter type list/identifier list)

< Example >

```
__callt int func ( int ) ;
```

Attribute qualifier specifications are limited to those listed below. (The noauto and norec/__leaf qualifiers cannot be specified at the same time.) callt and __callt, callf and __callf, norec and __leaf are regarded as the same specifications. However, the qualifier added with "__" are enabled even when the -za option is specified.

- callt
- noauto
- norec
- callt noauto
- callt norec
- noauto callt
- norec callt
- __interrupt
- __pascal
- __pascal noauto
- __pascal callt
- noauto __pascal
- callt __pascal
- callt noauto __pascal

(2) Variables

- The same regulations apply to the sreg or __sreg specification as to the register in C language (refer to "11.5 (3) How to use the saddr area (sreg / __sreg)" for details).
- The same regulations apply to the bit, boolean or __boolean specification as to the char or int type specifier in C language.
  However, these types can be specified only to the variables defined outside a function (external variables).
- The same regulations apply to the __directmap specification as to the type qualifier in C language (refer to 11.5 (31) Absolute address allocation specification (__directmap) for details).
- The same regulations apply to the __temp specification as to the type qualifier in C language (refer to 11.5 (33) Temporary variables (__temp) for details).

11.3 Memory

The memory model is determined by the memory space of the target device.

(1) Memory model

Since memory space is a maximum of 64 KB, the model is 64 KB with code division and data division combined.

(2) Register bank

There is no register bank.

(3) Memory space

The CC78K0S uses memory space as shown below.

(a) Normal model (default)

Figure 11-1 Utilization of Memory Space (Normal Model)

Address		Use	Size (bytes)
00	40 - 7FH	CALLT table	64
FE	20 - D7H	sreg variables, boolean type variables	184
FE	D8 - E7H	Register variables[Note 1]	16
FE	E8 - EFH	Arguments of norec functions[Note 2]	8
FE	F0 - F7H	Automatic variables of norec functions[Note 3]	8
FE	F8 - FFH	Arguments of runtime library[Note 4]	8
FF	00 - FFH	sfr variables	256

(b) Static model (at -sm16 specification)

Figure 11-2 Utilization of Memory Space (Static Model)

Address		Use	Size (bytes)
00	40 - 7FH	CALLT table	64
FE	20 - EFH	sreg variables, boolean type variables	208
FE	F0 - FFH	Shared area[Note 5]	16
FE	Consecutive areas between 20 and FFH	For arguments, automatic variables, and work[Note 6]	8
FF	00 - FFH	sfr variables	256

Notes 1. Area not used for register variables is used for sreg variables and boolean type variables.

Notes 2. If not completely used for register variables, area not used for norec function arguments is used for sreg variables and boolean type variables.

Notes 3. If not completely used for register variables and norec function arguments, area not used for norec function automatic variables is used for sreg variables and boolean type variables.

Notes 4. If not completely used for register variables and norec function arguments/automatic variables, area not used for runtime library arguments is used for sreg variables and boolean type variables.

Notes 5. The area used by the compiler differs depending on the parameters of the -sm option. The area not used as a shared area can be used as sreg and boolean type variables.

Notes 6. Valid only when the static model expansion specification option (-zm) is specified.

Remark If the register variable optimization option (-qr) is not specified, the area in Notes 1 to 3 is always used for sreg variables and boolean type variables.

11.4 #pragma Directive

The #pragma directive is one of the preprocessing directives supported by ANSI. The #pragma directive, depending on the character string to follow #pragma, instructs the compiler to translate in the method determined by the compiler. If the compiler does not support the #pragma directive, the #pragma directive is ignored and compilation is continued. In the case that keywords are added depending on the directive, an error is output if the C source includes the keywords. In order to avoid this, either the keywords in the C source should be deleted or sorted by #ifdef directive.

The CC78K0S supports the following #pragma directives to realize the extended functions.

The keywords specified after #pragma can be described either in uppercase or lowercase letters.

For the extended functions using #pragma directives, refer to "11.5 How to Use Extended Functions".

Table 11-2 List of #pragma Directives

#pragma Directive	Applications
#pragma sfr	Describes SFR name in C -> "11.5 (4) How to use the sfr area (sfr)"
#pragma asm	Inserts ASM statement in C source -> "11.5 (8) ASM statements (#asm #endasm / __asm)"
#pragma vect #pragma interrupt	Describes interrupt processing in C -> "11.5 (9) Interrupt functions (#pragma vect / #pragma interrupt)"
#pragma di #pragma ei	Describes DI/EI instructions in C -> "11.5 (11) Interrupt functions (#pragma DI, #pragma EI)"
#pragma halt #pragma stop #pragma nop	Describes CPU control instructions in C -> "11.5 (12) CPU control instruction (#pragma HALT / STOP / NOP)"
#pragma access	Uses absolute address access functions -> "11.5 (13) Absolute address access function (#pragma access)"
#pragma section	Changes compiler output section name and specify section location -> "11.5 (15) Changing compiler output section name (#pragma section ...)"
#pragma name	Changes module name -> "11.5 (17) Module name changing function (#pragma name)"
#pragma rot	Uses rotate function -> "11.5 (18) Rotate function (#pragma rot)"
#pragma mul	Uses multiplication function -> 11.5 (19) Multiplication function (#pragma mul)
#pragma div	Uses division function -> 11.5 (20) Division function (#pragma div)
#pragma bcd	Uses BCD operation function -> 11.5 (21) BCD operation function (#pragma bcd)
#pragma opc	Uses data insertion function -> 11.5 (22) Data insertion function (#pragma opc)
#pragma realregister	Uses register direct reference function -> 11.5 (29) Register direct reference function (#pragma realregister)
#pragma inline	Expands the standard library functions memcpy and memset inline -> 11.5 (30) Memory manipulation function (#pragma inline)

11.5 How to Use Extended Functions

The types of extended functions are given below.

(1) callt functions (callt / __callt)

(2) Register variables (register)

(3) How to use the saddr area (sreg / __sreg)

(4) How to use the sfr area (sfr)

(5) noauto functions (noauto)

(6) norec functions (norec)

(7) bit type variables, boolean type variables (bit / boolean / __boolean)

(8) ASM statements (#asm #endasm / __asm)

(9) Interrupt functions (#pragma vect / #pragma interrupt)

(10) Interrupt function qualifier (__interrupt)

(11) Interrupt functions (#pragma DI, #pragma EI)

(12) CPU control instruction (#pragma HALT / STOP / NOP)

(13) Absolute address access function (#pragma access)

(14) Bit field declaration

(15) Changing compiler output section name (#pragma section ...)

(16) Binary constant (Binary constant 0bxxx)

(17) Module name changing function (#pragma name)

(18) Rotate function (#pragma rot)

(19) Multiplication function (#pragma mul)

(20) Division function (#pragma div)

(21) BCD operation function (#pragma bcd)

(22) Data insertion function (#pragma opc)

(23) Static model

(24) Type modification (-zi)

(25) Pascal function (__pascal)

(26) Automatic pascal functionization of function call interface (-zr)

(27) Method of int expansion limitation of argument/return value (-zb)

(28) Array offset calculation simplification method (-qw2 / -qw4)

(29) Register direct reference function (#pragma realregister)

(30) Memory manipulation function (#pragma inline)

(31) Absolute address allocation specification (__directmap)

(32) Static model expansion specification (-zm)

(33) Temporary variables (__temp)

(34) Library supporting prologue/epilogue (-zd)

This section describes each of these extended functions in the following format :

FUNCTION :	Outlines a function that can be implemented with the extended function.
EFFECT :	Explains the effect brought about by the extended function.
USAGE :	Explains how to use the extended function.
EXAMPLE :	Indicates an application example of the extended function.
RESTRICTIONS :	Explains restrictions if any on the use of the extended function.
EXPLANATION :	Explains the above application example.
COMPATIBILITY :	Explains the compatibility of a C source program developed by another C compiler when it is to be compiled with the CC78K0S.

(1) callt functions (callt / __callt)

FUNCTION

- The callt instruction stores the address of a function to be called in an area [40H to 7FH] called the callt table, so that the function can be called with a shorter code than the one used to call the function directly.
- To call a function declared by the callt (or __callt) (called the callt function), a name with ? prefixed to the function name is used. To call the function, the callt instruction is used.
- The function to be called is not different from the ordinary function.

EFFECT

- The object code can be shortened.

USAGE

- Add the callt/__callt attribute to the function to be called as follows (described at the beginning) :

```
callt   extern  type-name       function-name
__callt extern  type-name       function-name
```

EXAMPLE

```
__callt void func1 ( void ) ;

__callt void func1 ( void ) {
                :
        /* function body */
                :
}
```

RESTRICTIONS

- The address of each function declared with callt/__callt will be allocated to the callt table at the time of linking object modules. For this reason, when using the callt table in an assembler source module, the routine to be created must be made "relocatable" using symbols.
- A check on the number of callt functions is made at linking time.
- When the -za option is specified, __callt is enabled and callt is disabled.
- The area of the callt table is 40H to 7FH.
- When the callt table is used exceeding the number of callt attribute functions permitted, a compile error will occur.
- The callt table is used by specifying the -ql option. For that reason, the number of callt attributes permitted per 1 load module and the total in the linking modules is as shown in Table 11-3.
- When the option for using the library that supports prologue/epilogue (-zd option) is specified, the -ql4 option cannot be used. Also, because 2 callt entries are used by the library that supports prologue/epilogue in the case of a normal model and up to 10 in the case of a static model, the maximum number of callt entries is reduced two in the case of a normal model and no more than 10 in the case of a static model.

Table 11-3 The Number of callt Attribute Functions That Can Be Used When the -ql Option Is Specified

- When -qq option is not specified simultaneously

Option	-ql1	-ql2	-ql3	-ql4
Normal model	30	27	13	0
Static model	30	29	15	2

- When -qq option is specified simultaneously

Option	-ql1	-ql2	-ql3	-ql4
Normal model	30	27	18	11
Static model	30	29	20	13

- Cases where the -ql option is not used and the defaults are as shown below.

Table 11-4 Restrictions on callt Function Usage

callt Function	Restriction Value
Number per load module	30 max.
Total number in linked module	30 max.

EXAMPLE

```
(C source)
============ ca1.c ============          ============ ca2.c ============
__callt extern  int     tsub ( ) ;

void    main ( )                        __callt int     tsub ( )
{                                       {
        int     ret_val ;                       int     val ;
        ret_val = tsub ( ) ;                    return  val ;
}                                       }
```

```
(Output object of compiler)
ca1 module
        EXTRN   ?tsub                   ; Declaration
        callt   [ ?tsub ]               ; Call

ca2 module
        PUBLIC  _tsub                   ; Declaration
        PUBLIC  ?tsub                   ;
@@CALT  CSEG    CALLT0                  ; Allocation to segment
?tsub : DW      _tsub
@@CODE  CSEG
_tsub :                                 ; Function definition
                :
                                        ; Function body
                :
```

EXPLANATION

- The callt attribute is given to the function tsub( ) so that it can be stored in the callt table.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if the keyword callt/__callt is not used.
- To change functions to callt functions, observe the procedure described in the USAGE above.

< From the CC78K0S to another C compiler >

- #define must be used. For details, see "11.6 Modifications of C Source".

(2) Register variables (register)

FUNCTION

- Allocates the declared variables (including arguments of function) to the register (HL) and saddr area (_@KREG00 to _@KREG15). Saves and restores registers or saddr area during the preprocessing/ postprocessing of the module that declared a register.
- In the case of the static model, the allocation is performed based on the number of times referenced. Therefore, it is undefined to which register or saddr area the register variable is allocated.
- For the details of the allocation of register variables, refer to "11.7 Function Call Interface".
- Register variables are allocated to different areas depending on the compile condition as shown below (for each option, refer to the CC78K0S C Compiler Operation User's Manual).

  (i) In the case of the normal model, the register variables are allocated in the declared sequence to register HL or the saddr area [FED0H to FEDFH]. If there is no stack frame, register variables are allocated to register HL. Only when the -qr option is specified, register variables are allocated to the saddr area.

  (ii) In the case of the static model, the register variables are allocated to register DE or _@KREGxx secured by -sm specification according to the number of times referenced. Only when the -zm2 option is specified, register variables are allocated to the _@KREGxx. For details of the -zm2 option, refer to "(32) Static model expansion specification (-zm)".

EFFECT

- Instructions to the variables allocated to the register or saddr area are generally shorter in code length than those to memory. This helps shorten object and also improves program execution speed.

USAGE

- Declare a variable with the register storage class specifier as follows :

```
register        type-name       variable-name
```

EXAMPLE

```
void    main ( void ) {
        register        unsigned char  c ;
                :
}
```

RESTRICTIONS

- If register variables are not used so frequently, object code may increase (depending on the size and contents of the source).
- Register variable declarations may be used for char/int/short/long/float/double/long double and pointer data types.

(Normal model)

- char uses half the area of other types. long/float/double/long double use twice the area. Between chars there are byte boundaries but in other cases, there are word boundaries.
- In the case of int/short and pointer, a maximum of 8 variables per function is usable. From the 9th variable, the register variables are assigned to the normal memory.
- In the case of a function without a stack frame, a maximum of 8 variables per function is usable for int/short and pointer. From the 9th variable, the register variables are assigned to the normal memory.

(Static model)

- char uses half the area of other types.
- In the case of int/short and pointer, a maximum of 1 variable per function is usable.
- From the 2nd variable, the register variables are assigned to the normal memory.
- The register variables are invalid for long/float/double/long double.

Table 11-5 Restrictions on Register Variables Usage

Data Type	Usable Number (per Function)	
	Normal Model	Static Model
int/short	8 variables max.	1 variable max.
Pointer	8 variables max. (9 variables max. if function without stack frame)	1 variable max.

EXAMPLE

< C source >

```
void    func ( ) ;
void    main ( )
{
        register        int     i , j ;
        i = 0 ;
        j = 1 ;
        i += j ;
        func ( ) ;
}
```

- When the -sm option is not specified (Example of register variable allocation to register HL and the saddr area)

  The following labels are declared by the startup routine (Refer to "APPENDIX A LIST OF LABELS FOR saddr AREA").

  < Output object of compiler >

```
        EXTRN   _@KREG00        ; References the saddr area to be used
_main :
        push    hl              ; Saves the contents of the register at
                                ; the beginning of the function
        movw    ax , _@KREG14   ; Saves the contents of the saddr at
                                ; the beginning of the function
        push    ax              ;

        movw    hl , #00H       ; The following codes are output in
                                ; the middle of the function
        movw    ax, hl          ;
        incw    ax              ;
        movw    _@KREG14 , ax   ;
        xch     a , x           ;
        add     a , l           ;
        xch     a , x           ;
        addc    a , l           ;
        movw    hl, ax          ;
        call    !_func          ;

        pop     ax              ; Restores contents of the saddr at
                                ; the end of the function
        movw    _@KREG00 , ax   ;
        pop     hl              ; Restores contents of the register at
                                ; the end of the function
        ret
```

- When the -sm option is specified (Example of register variable allocation to register DE)

```
_main :
        push    de              ; Saves the contents of the register at
                                ; the beginning of the function

        movw    de , #00H       ;
        movw    de , ax         ;
        incw    ax              ;
        movw    !?L0003 + 1 , a ;
        xch     a , x           ;
        mov     !?L0003 , a     ;
        add     a , e           ;
        xch     a , x           ;
        addc    a , d           ;
        mov     de , ax         ;
        call    !_func          ;
        pop     de              ; Restores the contents of the register
                                ; at the end of the function
        ret
```

EXPLANATION

- To use register variables, you only need to declare them with the register storage class specifier.
- Label _@KREG00, etc. includes the modules declared with PUBLIC in the library attached to the CC78K0S.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if the other C compiler supports register declarations.
- To change to register variables, add the register declarations for the variables to the program.

< From the CC78K0S to another C compiler >

- The C source program need not be modified if the other compiler supports register declarations.
- How many variable registers can be used and to which area they will be allocated depend on the implementations of the other C compiler.

(3) How to use the saddr area (sreg / __sreg)

(a) Usage with sreg declaration

FUNCTION

- The external variables and in-function static variables (called sreg variable) declared with keyword sreg or __sreg are automatically allocated to saddr area [FE20H to FED7H] (normal model) and [FE20H to FEEFH] (static model) with relocatability. When those variables exceed the area shown above, a compile error occurs.
- The sreg variables are treated in the same manner as the ordinary variables in the C source.
- Each bit of sreg variables of char, short, int, and long type becomes boolean type variable automatically.
- sreg variables declared without an initial value take 0 as the initial value.
- Of the sreg variables declared in the assembler source, the saddr area [FE20H to FEFFH] can be referred to. The area [FEB8H to FEFFH] (normal model) and [FED0H to FEFFH] (static model) are used by compiler so that care must be taken (refer to Figure 11-1).

EFFECT

- Instructions to the saddr area are generally shorter in code length than those to memory. This helps shorten object code and also improves program execution speed.

USAGE

- Declare variables with the keywords sreg and __sreg inside a module and a function which defines the variables. Only the variable with a static storage class specifier can become a sreg variable inside a function.

```
sreg   type-name variable-name / sreg   static  type-name  variable-name
__sreg type-name variable-name / __sreg static  type-name  variable-name
```

- Declare the following variables inside a module which refers to sreg external variables. They can be described inside a function as well.

```
extern  sreg    type-name   variable-name / extern  __sreg  type-name
variable-name
```

RESTRICTIONS

- If const type is specified, or if sreg/__sreg is specified for a function, a warning message is output, and the sreg declaration is ignored.
- char type uses a half the space of other types and long/float/double/long double types use a space twice as wide as other types.
- Between char types there are byte boundaries, but in other cases, there are word boundaries.
- When -za is specified, only __sreg is enabled and sreg is disabled.
- In the case of int/short and pointer, a maximum of 92 variables per load module is usable (when saddr area [FE20H to FED7H] is used). Note that the number of usable variables decreases when bit, boolean type variables, register variables, or norec and noauto functions are used (normal model).
- In the case of int/short and pointer, a maximum of 104 variables per load module is usable (when saddr area [FE20H to FEEFH] is used). Note that the number of usable variables decreases when bit, boolean type variables, and shared areas are used (static model).

The following shows the maximum number of sreg variables that can be used per 1 load module.

Table 11-6 Restrictions on sreg Variables Usage

Data Type	Usable Number of sreg Variables (per load module)	
	When saddr Area [FE20H to FED7H] is Used	When saddr Area [FE20H to FEEFH] is Used
int/short, pointer	92 variables max.Note	104 variables max.Note

Note When bit and boolean type variables are used, the usable number is decreased.

EXAMPLE

< C source >

```
extern  sreg    int     hsmm0 ;
extern  sreg    int     hsmm1 ;
extern  sreg    int     *hsptr ;

void    main ( ) {
        hsmm0 -= hsmm1 ;
}
```

The following example shows a definition code for sreg variable that the user creates. If extern declaration is not made in the C source, the CC78K0S outputs the following codes. In this case, the ORG quasi-directive will not be output.

< Assembler source >

```
                PUBLIC  _hsmm0  ; Declaration
                PUBLIC  _hsmm1  ;
                PUBLIC  _hsptr  ;

@@DATS          DSEG    SADDRP  ; Allocation to segment
                ORG     0FE20H  ;
_hsmm0 :        DS      ( 2 )   ;
_hsmm1 :        DS      ( 2 )   ;
_hsptr :        DS      ( 2 )   ;
```

The following codes are output in the function.

< Output object of compiler >

```
movw    ax , _hsmm0
xch     a , x
sub     a , _hsmm1
xch     a , x
subc    a , _hsmm1 + 1
movw    _hsmm0 , ax
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modifications are not needed if the other compiler does not use the keyword sreg/__sreg.
  To change to sreg variable, modifications are made according to the method shown above.

< From the CC78K0S to another C compiler >

- Modifications are made by #define. For the details, refer to "11.6 Modifications of C Source". Thereby, sreg variables are handled as ordinary variables.

(b) Usage with saddr automatic allocation option of external variables/external static variables (-rd)

FUNCTION

- External variables/external static variables (except const type) are automatically allocated to the saddr area regardless of whether sreg declaration is made or not.
- Depending on the value of n and the specification of m, the external static variables and external static variables to allocate can be specified as follows.

Table 11-7 Variables Allocated to saddr Area by -rd Option

Value of n	Variables Allocated to saddr Area
1	Variables of char and unsigned char types
2	Variables for when n = 1, plus variables of short, unsigned short, int, unsigned int, enum, and pointer type
4	Variables for when n = 2, plus variables of long, unsigned long, float, double, and long double type
m	Structures, unions, and arrays
When omitted	All variables

- Variables declared with the keyword sreg are allocated to the saddr area, regardless of the above specification.
- The above rule also applies to variables referenced by extern declaration, and processing is performed as if these variables were allocated to the saddr area.
- The variables allocated to the saddr area by this option are treated in the same manner as the sreg variable. The functions and restrictions of these variables are as described in (a).

METHOD OF SPECIFICATION

- Specify the -rd [n] [m] (n : 1, 2, or 4) option.

RESTRICTIONS

- In -rd [n] [m] option, modules specifying different n, m value cannot be linked each other.

(c) Usage with saddr automatic allocation option of internal static variables (-rs)

FUNCTION

- Automatically allocates internal static variables (except const type) to saddr area regardless of with/ without sreg declaration.
- Depending on the value of n and the specification of m, the internal static variables to allocate can be specified as follows.

Table 11-8 Variables Allocated to saddr Area by -rs Option

Value of n	Variables Allocated to saddr Area
1	Variables of char and unsigned char types
2	Variables for when n = 1, plus variables of short, unsigned short, int, unsigned int, enum, and pointer type
4	Variables if n is 2 and variables of long, unsigned long, float, double, and long double type
m	Structures, unions, and arrays
When omitted	All variables (including structures, unions, and arrays in this case only)

- Variables declared with the keyword sreg are allocated to the saddr area regardless of the above specification.
- The variables allocated to the saddr area by this option are handled in the same manner as the sreg variable. The functions and restrictions for these variables are as described in (a).

METHOD OF SPECIFICATION

- Specify the -rs [n] [m] (n : 1, 2, or 4) option.

  Remark In -rs [n] [m] option, modules specifying different n, m value can also be linked each other.

(d) Usage with saddr automatic allocation option for arguments/automatic variables (-rk)

FUNCTION

- Arguments and automatic variables (except const type) are automatically allocated to the saddr area regardless of whether or not a sreg declaration exists.
- The arguments and automatic variables to be allocated are specified using the values of n and the specification of m.

Table 11-9 Variables Allocated to saddr Area by -rk Option

Value of n	Variables Allocated to saddr Area
1	Variables of char and unsigned char types
2	Variables for when n = 1, plus variables of short, unsigned short, int, unsigned int, enum, and pointer type
4	Variables for when n = 2, plus variables of long, unsigned long, float, double, and long double type
m	Structures, unions, and arrays
When omitted	All variables

- Variables declared with sreg are allocated to the saddr area regardless of the above specifications.
- Variables allocated to the saddr area by this option are handled in the same way as sreg variables.

USAGE

- Specify the -rk [n] [m] option (where n is 1, 2, or 4).

  Remark In -rk [n] [m] option, modules specifying different n, m value can also be linked each other.

RESTRICTIONS

- Only the static model is supported. When the -sm option is not specified, a warning message is output and the automatic allocation is ignored.
- Arguments/variables that have been declared register variable are not allocated to the saddr area.
- When the -qv option is specified simultaneously, allocation to register DE has priority.

EXAMPLE

< C source >

```
sub ( int hsmarg )
{
        int     hsmauto ;
        hsmauto = hsmarg ;
}
```

< Output object of compiler >

```
@@DATS          DSEG    SADDRP
?L0003 :        DS      ( 2 )
?L0004 :        DS      ( 2 )
@@CODE          CSEG
_sub :
                movw    ?L0003 , ax
                movw    ?L0004 , ax     ; hsmauto
                ret
```

(4) How to use the sfr area (sfr)

FUNCTION

- The sfr area refers to a group of special function registers such as mode registers and control registers for the various peripherals of the 78K0S Series microcontrollers.
- By declaring use of sfr names, manipulations on the sfr area can be described at the C source level.
- sfr variables are external variables without initial value (undefined).
- A write check will be performed on read-only sfr variables.
- A read check will be performed on write-only sfr variables.
- Assignment of an illegal data to an sfr variable will result in a compile error.
- The sfr names that can be used are those allocated to an area consisting of addresses FF00H to FFFFH.

EFFECT

- Manipulations to the sfr area can be described in the C source level.
- Instructions to the sfr area are shorter in code length than those to memory. This helps shorten object code and also improves program execution speed.

USAGE

- Declare the use of an sfr name in the C source with the #pragma preprocessor directive, as follows (The keyword sfr can be described in uppercase or lowercase letters.) :

```
#pragma sfr
```

- The #pragma sfr directive must be described at the beginning of the C source line. If #pragma PC (processor type) is specified, however, describe #pragma sfr after that.
  The following statement and directives may precede the #pragma sfr directive :
  (i) Comment statement
  (ii) Preprocessor directives which do not define nor refer to a variable or function
- In the C source program, describe an sfr name that the device has as is (without change). In this case, the sfr need not be declared.

RESTRICTIONS

- All sfr names must be described in uppercase letters. Lowercase letters are treated as ordinary variables.

EXAMPLE

< C source >

```
#ifdef  __K0S__
        #pragma sfr
#endif

void    main ( )
{
        P0 -= RXB00 ;
        /* RXB00 = 10 ;  ==> error */
}
```

Codes that relate to declarations are not output and the following codes are output in the middle of the function.

< Output object of compiler >

```
mov     a , P0
sub     a , RXB00
mov     P0 , a
```

COMPATIBILITY

< From another C compiler to the CC78K0S>

- Those portions of the C source program not dependent on the device or compiler need not be modified.

< From the CC78K0S to another C compiler >

- Delete the "#pragma sfr" statement or sort by "#ifdef" and add the declaration of the variable that was formerly a sfr variable. The following shows an example.

```
#ifdef  __K0S__
        #pragma sfr
#else
/* Declaration of variables */
unsigned char   P0 ;
#endif

void    main ( void ) {
        P0 = 0 ;
}
```

- In case of a device which has the sfr or its alternative functions, a dedicated library must be created to access that area.

(5) noauto functions (noauto)

FUNCTION

- noauto function sets restrictions for automatic variables not to output the codes of preprocessing/ postprocessing (generation of stack frame).
- All the arguments are allocated to registers or saddr area (FEDCH to FEDFH) for register variables. If there is an argument that cannot be allocated to registers, a compile error occurs.
- Automatic variables can be used only if all the automatic variables are allocated to the registers or saddr area for register variable-use left over after argument allocation.
- The noauto function allocates arguments to the saddr area for register variable-use, but only if the -qr option has been specified during the compilation.
- The noauto function stores arguments other than arguments allocated to the register in the saddr area for register variable-use, and stores the arguments' description in ascending sequence (Refer to "APPENDIX A LIST OF LABELS FOR saddr AREA").
- The code for calling the noauto function output is the same code as the code for calling a normal function.
- When the -sm option is specified, a warning message is only output to the line in which noauto is described first, and all the noauto functions are handled as normal functions.

EFFECT

- The object code can be shortened and execution speed can be improved.

USAGE

- Declare a function with the noauto attribute in the function declaration, as follows:

```
noauto  type-name       function-name
```

RESTRICTIONS

- When the -za option is specified, noauto function is disabled.
- The arguments of noauto function have restrictions for their types and numbers. The following shows the types of arguments that can be used inside a noauto function. Arguments other than long/signed long/ unsigned long, float/double/long double are allocated to register HL.
  - Pointer
  - char / signed char / unsigned char
  - int / signed int / unsigned int
  - short / signed short / unsigned short
  - long / signed long / unsigned long
  - float / double / long double
- The number of arguments that can be used is a maximum of 6 bytes in total size.
- These restrictions are checked at the time of compile.
- If arguments are declared with a register, the register declaration is ignored.

EXAMPLE

(C source)

- When the -qr option is specified

< C source >

```
noauto  short   nfunc ( short a , short b , short c ) ;
short   l , m ;
void    main ( )
{
        static short    ii , jj , kk ;
        l = nfunc ( ii , jj , kk ) ;
}
noauto  short   nfunc ( short a , short b , short c )
{
        m = a + b + c ;
        return ( m ) ;
}
```

< Output object of compiler >

```
@@CODE  CSEG
_main :
; line  5 :     static short ii , jj , kk   ;
; line  6 :     l = nfunc ( ii , jj , kk )  ;
        movw    ax , !?L0005    ; kk
        xch     a , x
        mov     a!?L0005 + 1    ; kk
        push    ax
        mov     a , !?L0004     ; jj
        xch     a , x
        mov     a , !?L0004 + 1 ; jj
        push    ax
        mov     a , !?L0003     ; ii
        xch     a , x
        mov     a , !?L0003 + 1 ; ii
        call    !_nfunc         ; Calls function nfunc(a , b , c)
        pop     ax
        pop     ax
        movw    ax , bc
        mov     !_l + 1 , a ; Assigns return value to external variable l
        xch     a , x
        mov     !_l , a
; line  7 :     }
        ret
; line  8 :     noauto short nfunc ( short a , short b , short c )
; line  9 :     {
_nfunc :
        push    hl              ; Saves HL
        xch     a , x           ;
        xch     a , _@KREG12    ; Sets argument a to _@KREG12
        xch     a , x           ;
        xch     a , _@KREG13    ;
        push    ax              ; Saves _@KREG14
        movw    ax , _@KREG14   ;
        push    ax              ;
        movw    ax , sp         ;
        movw    hl , ax         ;
        mov     a , [ hl + 10 ] ;
        xch     a , x           ;
        mov     _@KREG14 , ax   ; Sets argument c to _@KREG14
        mov     a , [ hl + 8 ]  ;
        xch     a , x           ;
        mov     a , [ hl + 9 ]  ;
        movw    hl , ax         ; Sets argument b to HL
; line  10 :    m = a + b + c   ;
        movw    ax , hl         ;
        xch     a , x           ;
        add     a , _@KREG12    ;
        xch     a , x           ;
        addc    a , _@KREG13    ;
        xch     a , x           ;
        add     a , _@KREG14    ;

        xch     a , x           ;
        addc    a , _@KREG15    ; Adds b(HL) and c(_@KREG14)to a(_@KREG12)
        mov     !_m + l , a ; Assigns operation result to external variable m
        xch     a , x
        mov     !_m , a
; line  11 :    return ( m )    ;
        xch     a , x
        movw    bc , ax     ; Returns the contents of external variable m
```

```
; line  12 :    }
        pop     ax              ;
        movw    _@KREG14 , ax   ; Restores _@KREG14
        pop     ax              ;
        movw    _@KREG12 , ax   ; Restores _@KREG12
        pop     hl              ; Restores HL
        ret
```

EXPLANATION

- In the above example, the noauto attribute is added at the header part of the C source.

  noauto is declared and stack frame formation is not performed.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if the keyword noauto is not used.
- To change variables to noauto variables, modify the program according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- #define must be used. For details, see "11.6 Modifications of C Source".

(6) norec functions (norec)

FUNCTION

- A function that does not call another function by itself can be changed to a norec function.
- With norec functions, code for preprocessing and post-processing (stack frame formation) is not output.
- The arguments of norec function are allocated to registers and saddr area (FEE8H to FEEFH) for arguments of norec function.
- If arguments cannot be allocated to registers and saddr area, a compile error occurs.
- Arguments are stored either in the register or the saddr area (FEE8H to FEEFH) and the norec function is called.
- Automatic variables are allocated to the saddr area (FEF0H to FEF7H) and so are the register variables.
- The saddr area is not used for allocation when the -qr option is specified during compilation.
- If arguments other than long/float/double/long double types are used, the first argument is stored in register AX, the second in register DE, the third and successive arguments are stored in the saddr area. Note that the arguments stored in registers AX and DE are 1 argument each regardless of the type of argument.
- The argument stored in register AX is copied to register DE if DE does not have the argument stored at the beginning of the norec function. If there is an argument stored in register DE already, the argument stored in AX is copied to _@RTARG6 and 7.
- If automatic variables other than long/float/double/long double types are used, the arguments that are left after allocation are stored in the declared order; DE, _@RTARG6 and 7, and _@NRARG0, 1...
  If automatic variables long/float/double/long double types are used, the arguments that are left after allocation are stored in the declared order; _@NRARG0, 1...
  The rest of the arguments are stored in the saddr area in the declared order (Refer to "APPENDIX A LIST OF LABELS FOR saddr AREA").

EFFECT

- The object code can be shortened and program execution speed can be improved.

USAGE

- Declare a function with the norec attribute in the function declaration, as follows :

```
norec   type-namez      function-name
```

- __leaf can also be described instead of norec.

RESTRICTIONS

- No other function can be called from a norec function.
- There are restrictions on the type and number of arguments and automatic variables that can be used in a norec function.
- When -za is specified, norec is disabled and only __leaf is enabled.
- When the -sm option is specified, a warning message is only output to the line in which norec is described first, and all the norec functions are handled as normal functions.
- The restrictions for arguments and automatic variables are checked at the time of compile, and an error occurs.
- If arguments and automatic variables are declared with a register, the register declaration is ignored.
- The following shows the types of arguments and automatic variables that can be used in norec functions. norec functions are allocated to the saddr area consecutively if between char/signed char/unsigned char, however if connected to other types, allocation is performed in 2-byte alignment.
    - Pointer
    - char / signed char / unsigned char
    - int / signed int / unsigned int
    - short / signed short / unsigned short
    - long / signed long / unsigned long
    - float / double / long double

(When the -qr option is not specified)

- The number of arguments that can be used in a norec function is 2 variables, if other than long/float/double/long double types. Arguments cannot be used for long/float/double/long double types.
- Automatic variables can use the area that is the combined total of the number of bytes remaining unused by arguments. If types other than long/float/double/long double are used, automatic variables can use up to 4 bytes. Arguments can not be used for long/float/double/long double types.

(When the -qr option is specified)

- The number of arguments is 6 variables, if types other than long/float/double/long double are used, and 2 variables if long/float/double/long double types are used.
- Automatic variables can use the area that is the combined total of the number of bytes remaining unused by arguments and the number of saddr area bytes. If types other than long/float/double/long double are used, automatic variables can use up to 20 bytes and if long/float/double/long double types are used, automatic variables can use up to 16 bytes.
- These restrictions are checked at the time of compilation and an error will occur if not satisfied.

EXAMPLE

< C source >

```
norec   int     rout ( int  a , int  b , int  c ) ;

int     i ,  j ;
void    main ( ) {
        int     k , l , m ;
        i = l + rout ( k , l , m ) + ++k ;
}

norec   int     rout ( int a , int b , int c )
{
        int     x , y ;
        return ( x + ( a << 2 ) ) ;
}
```

- When the -qr option is specified

< Output object of compiler >

```
        EXTRN   _@NRARG0            ; References saddr area to be used
        EXTRN   _@NRARG1            ;
        EXTRN   _@NRARG6            ;
             :
        _@NRARG0    <- m            ; Stores argument to saddr area
             :
        de          <- 1            ; Stores argument to DE
              :
        ax          <- k            ; Stores argument to AX
        call    !_rout              ; n Calls norec function

_rout :
        movw    _@RTARG6 , ax
                                    ; Receives argument from saddr area
        mov     c , #02H
        xch     a , x
        add     a , a
        xch     a , x
        rolc    a , 1
        dbnz    c , $$ - 5
        xch     a , x
        add     a , _@NRARG1        ; Use automatic variables of saddr area
        xch     a , x               ;
        addc    a , _@NRARG1 + 1    ; Use automatic variables of saddr area
        movw    bc , ax             ;
        ret
```

EXPLANATION

- In the above example, the norec attribute is added in the definition of the rout function as well to indicate that the function is norec.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if the keyword norec is not used.
- To change variables to norec variables, modify the program according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- #define must be used. For details, see "11.6 Modifications of C Source".

(7) bit type variables, boolean type variables (bit / boolean / __boolean)

FUNCTION

- A bit or boolean type variable is handled as 1-bit data and allocated to saddr area.
- This variable can be handled the same as an external variable that has no initial value (or has an unknown value).
- To this variable, the C compiler outputs the following bit manipulation instructions :

```
SET1 , CLR1 , NOT1 , BT , BF instruction
```

EFFECT

- Programming at the assembler source level can be performed in C, and the saddr and sfr area can be accessed in bit units.

USAGE

- Declare a bit or boolean type inside a module in which the bit or boolean type variable is to be used, as follows :
- __boolean can also be described instead of bit.

```
bit             variable-name
boolean         variable-name
__boolean       variable-name
```

- Declare a bit or boolean type inside a module in which the bit or boolean type variable is to be used, as follows :

```
extern  bit             variable-name
extern  boolean         variable-name
extern  __boolean       variable-name
```

- char, int, short, and long type sreg variables (except the elements of arrays and members of structures) and 8-bit sfr variables can be automatically used as bit type variables.

```
variable-name.n (where n = 0 to 31)
```

RESTRICTIONS

- An operation on 2 bit or boolean type variables is performed by using the CY (Carry) flag.
  For this reason, the contents of the carry flag between statements are not guaranteed.
- Arrays cannot be defined or referenced.
- A bit or boolean type variable cannot be used as a member of a structure or union.
- This type of variable cannot be used as the argument type of a function.
- A bit type variable cannot be used as a type of automatic variable (other than static model).
- With bit type variables only, up to 1472 variables can be used per load module (when saddr area [FE20H to FED7H] is used) (normal model).
- With bit type variables only, up to 1664 variables can be used per load module (when saddr area [FE20H to FEEEH] is used) (static model).
- The variable cannot be declared with an initial value.
- If the variable is described along with const declaration, the const declaration is ignored.
- Only operations using 0 and 1 can be performed by the operators and constants shown in Table 11-10.
- *, & (pointer reference, address reference), and sizeof operations cannot be performed.
- When the -za option is specified, only __boolean is enabled.

Table 11-10 Operators Using Only Constants 0 or 1 (with Bit Type Variable)

Classification	Operator
Assignment	=
Bitwise AND	&, &=
Bitwise OR	|, |=
Bitwise XOR	^, ^=
Logical AND	&&
Logical OR	||
Equal	==
Not Equal	!=

Remark In the case that sreg variables are used or if -rd, -rs, and -rk (saddr automatic allocation option) options are specified, the number of usable bit type variables is decreased.

EXAMPLE

< C source >

```
#define ON      1
#define OFF     0

extern  bit     data1 ;
extern  bit     data2 ;

void    main ( )
{
        data1 = ON ;
        data2 = OFF ;
        while ( data1 )  {
                data1 = data2 ;
                testb ( ) ;
        }

        if ( data1 && data2 ) {
                chgb ( ) ;
        }
}
```

This example is for cases when the user has generated a definition code for a bit type variable. If an extern declaration has not been attached, the compiler outputs the following code. The ORG quasi-directive is not output in this case.

< Assembler source >

```
PUBLIC  _data1          ; Declaration
PUBLIC  _data2

@@BITS  BSEG            ; Allocation to segment
        ORG    0FE20H
_data1  DBIT
_data2  DBIT
```

The following codes are output in a function

< Output object of compiler >

```
set1    _data1                  Initialized
clr1    _data2                  Initialized
bf_     _data1 , $?L0001        Judgment
bf      _data1 , $?L0005        Logical AND expression
bf      _data2 , $?L0005        Logical AND expression
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if the keyword bit, boolean, or __boolean is not used.
- To change variables to bit or boolean type variables, modify the program according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- #define must be used. For details, see "11.6 Modifications of C Source" (As a result of this, the bit or boolean type variables are handled as ordinary variables.).

(8) ASM statements (#asm #endasm / __asm)

FUNCTION

(a) #asm - #endasm

- The assembler source program described by the user can be embedded in an assembler source file to be output by the CC78K0S by using the preprocessor directives #asm and #endasm.
- #asm and #endasm lines will not be output.

(b) __asm

- An assembly instruction is output by describing an assembly code to a character string literal and is inserted in an assembler source.

EFFECT

- To manipulate the global variables of the C source in the assembler source
- To implement functions that cannot be described in the C source
- To hand-optimize the assembler source output by the C compiler and embed it in the C source (to obtain efficient object)

USAGE

(a) #asm - #endasm

- Indicate the start of the assembler source with the #asm directive and the end of the assembler source with the #endasm directive. Describe the assembler source between #asm and #endasm.

```
#asm
    :           /* assembler source */
#endasm
```

(b) __asm

- Use of __asm is declared by the #pragma asm specification made at the beginning of the module in which the ASM statement is to be described (the uppercase letters and lowercase letters are distinguished for the keywords following #pragma).
- The following items can be described before #pragma asm :

  (i) Comment

  (ii) Other #pragma directive

  (iii) Preprocessing directive not creating variable definition/reference or function definition/reference

- The ASM statement is described in the following format in the C source :

```
__asm ( string literal ) ;
```

- The description method of character string literal conforms to ANSI, and a line can be continued by using an escape character string (\n : line feed, \t : tab) or \, or character strings can be linked.

RESTRICTIONS

- Nesting of #asm directives is not allowed.
- If ASM statements are used, no object module file will be created. Instead, an assembler source file will be created.
- Only lowercase letters can be described for __asm. If __asm is described with uppercase and lowercase characters mixed, it is regarded as a user function.
- When the -za option is specified, only __asm is enabled.
- #asm - #endasm and __asm block can only be described inside a function of the C source. Therefore, the assembler source is output to CSEG of segment name @@CODE.

EXAMPLE

(a) #asm - #endasm

< C source >

```
void    main ( ) {
        #asm
                callt [ init ]
        #endasm
}
```

The assembler source written by the user is output to the assembler source file.

< Output object of compiler >

```
@@CODE  CSEG
_main :
        callt [ init ]
        ret
        END
```

EXPLANATION

- In the above example, statements between #asm and #endasm will be output as an assembler source program to the assembler source file.

(b) __asm

< C source >

```
#pragma asm

int     a , b ;

void    main ( ) {
        __asm ( " \tmovw ax , !_a \t ; ax <- a " ) ;
        __asm ( " \tmovw !_b , ax \t ; b <- ax " ) ;
}
```

< Assembler source >

```
@@CODE  CSEG
_main :
        movw    ax , !_a        ; ax <- a
        movw    !_b , ax        ; b <- ax
        ret
        END
```

COMPATIBILITY

- With the C compiler which supports #asm, modify the program according to the format specified by the C compiler.
- If the target device is different, modify the assembler source part of the program.

(9) Interrupt functions (#pragma vect / #pragma interrupt)

FUNCTION

- The address of a described function name is registered to an interrupt vector table corresponding to a specified interrupt request name.
- An interrupt function outputs a code to save or restore the following data (except that used in the ASM statement) to or from the stack at the beginning and end of the function :

  (1) Registers

  (2) saddr area for register variables

  (3) saddr area for arguments/auto variables of norec function (regardless of whether the arguments or variables are used)

  (4) saddr area for run time library (normal model only)

  Note, however, that depending on the specification or status of the interrupt function, saving/restoring is performed differently, as follows :

- If no change is specified, codes that saves/restores register contents, and that saves/restores the contents of the saddr area are not output regardless of whether to use the codes or not.
- If no change is not specified and if a function is called in the interrupt function, however, the entire register area is saved or restored, regardless of whether use of registers is specified or not.

(In the case of the normal model)

- If the -qr option is not specified at compile time, the saddr area for register variable and the saddr area for the arguments/auto variable of the norec function is not used; therefore, the saving/restoring code is not output.

  If the size of the saving code is smaller than that of the restoring code, the restoring code is output.

- Table 11-11 summarizes the above and shows the saving/restoring area.

Table 11-11 Saving/Restoring Area When Interrupt Function Is Used

Save/Restore Area	NO BANK	Function Called		Function Not Called	
		Without -qr	With -qr	Without -qr	With -qr
Register used	NG	NG	NG	OK	OK
All registers	NG	OK	OK	NG	NG
saddr area for runtime library used	NG	NG	NG	OK	OK
saddr area for all runtime libraries	NG	OK	OK	NG	NG
saddr area for register variable used	NG	NG	OK	NG	OK
All saddr area for arguments/auto variables of norec function	NG	NG	OK	NG	NG

OK : Saved

NG : Not saved

(Static model)

- Since the saddr area for register variables, the saddr area for automatic variables or norec function arguments, and the saddr area for the runtime library are not used when the -sm option is specified during compilation, only the save and restore code for registers is output; not the code for saddr area.

  However, when leafwork 1 to 16 has been specified, the code for saving and restoring the byte number to the stack is output from the higher-level address of shared area at the beginning and end of the interrupt function (Refer to "(23) Static model" when the -zm option is not specified, and "(32) Static model expansion specification (-zm)" when the -zm option is specified).

  Remark If there is an ASM statement in an interrupt function, and if the area reserved for registers of the compiler is used in that ASM statement, the area must be saved by the user.

EFFECT

- Interrupt functions can be described at the C source level.

USAGE

- Specify an interrupt request name, a function name, stack switching, registers, and whether the saddr area is saved/restored, with the #pragma directive. Describe the #pragma directive at the beginning of the C source. The #pragma directive is described at the start of the C source (for the interrupt request names, refer to the user's manual of the target device used).
- To describe #pragma PC (processor type), describe this #pragma directive after that. The following items can be described before this #pragma directive :

  (i) Comment statements

  (ii) Preprocessor directive which does neither define nor refer to a variable or a function

```
#pragma Δ vect (or interrupt) Δ interrupt request name Δ function name Δ
    [Stack change specification] Δ [Stack use specification
                                    No change specification
                                    Shared area save/restore specification
                                    Save/restore target]
```

Interrupt request name :	Described in uppercase letters. Refer to the user's manual of the target device used (example : NMI, INTP0, etc.).	
Function name :	Name of the function that describes interrupt processing	
Stack change specification :	SP = array name [+ offset location] (example : SP = buff + 10)	
	Define the array by unsigned char (example : unsigned char buff [10];).	
Stack use specification :	STACK (default)	
No change specification :	NOBANK	
Shared area save/restore specification :	leafwork 1 to 16	
Save/restore target :	SAVE_R	Save/restore target limited to registers
	SAVE_RN	Save/restore target limited to registers and _@NRATxx (when -sm, -zm option specified)
Δ :	Space	

RESTRICTIONS

- Register bank specification is not supported.
- An interrupt request name must be described in uppercase letters.
- A duplication check on interrupt request names will be made within only 1 module.
- If the same or another interrupt occurs due to the contents of the priority specification flag register and interrupt mask flag register while a vectored interrupt is processed, the contents of the registers may be changed if no change is specified, resulting in an error. The compiler, however, cannot check this error.
- As the interrupt function, callt / noauto / norec / __callt / __leaf /__pascal cannot be specified.
- An interrupt function is specified with void type (example : void func (void);) because it cannot have an argument nor return value.
- Even if an ASM statement exists in the interrupt function, codes saving all the registers and variable areas are not output. If an area reserved for the compiler is used in the ASM statement in the interrupt function, therefore, or if a function is called in the ASM statement, the user must save the registers and variable areas.
- If leafwork 1 to 16 is specified when the -sm option is not specified, a warning is output and the save/restore specification of the shared area is ignored.
- When stack change is specified, the stack pointer is changed to the location where offset is added to the array name symbol. The area of the array name is not secured by the #pragma directive. It needs to be defined separately as global unsigned char type array.
- The code that changes the stack pointer is generated at the start of a function, and the code that sets the stack pointer back is generated at the end of a function.
- When keywords sreg/__sreg are added to the array for stack change, it is regarded that two or more variables with the different attributes and the same name are defined, and a compile error occurs. It is possible to allocate an array in saddr area by the -rd option, but code and speed efficiency will not be improved because the array is used as a stack. It is recommended to use the saddr area for purposes other than a stack.
- The stack change cannot be specified simultaneously with the no change. If specified so, an error occurs.
- The stack change must be described before the stack use/register bank specification. If the stack change is described after the stack use/register bank specification, an error occurs.
- If a function specifying no change, register bank, or stack change as the saving destination in #pragma vect/ #pragma interrupt specification is not defined in the same module, a warning message is output and the stack change is ignored. In this case, the default stack is used.

EXAMPLE

- When a shared area save/restore is specified (static model only)

< C source >

```
#pragma interrupt INTP0 inter leafwork4
void    func ( ) ;
void    inter ( )
{
        func ( ) ;
}
```

< Output object of compiler >

```
        EXTRN   _@KREG12
        EXTRN   _@KREG14

@@CODE          CSEG
_inter :
        push    ax              ; Saves register
        push    bc              ;      "
        push    hl              ;      "
        movw    ax , _@KREG12   ; Saves shared area
        push    ax              ;      "
        movw    ax , _@KREG14   ;      "
        push    ax              ;      "
        call    !_func
        pop     ax              ;  Restores shared area
        movw    _@KREG14 , ax   ;      "
        pop     ax              ;      "
        movw    _@KREG12 , ax   ;      "
        pop     hl              ; Restores register
        pop     bc              ;      "
        pop     ax              ;      "
        reti

@@VECT06        CSEG    AT      0006H
_@vect06 :
        DW      _inter
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if interrupt functions are not used at all.
- To change an ordinary function to an interrupt function, modify the program according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- An interrupt function can be used as an ordinary function by deleting its specification with the #pragma vect, #pragma interrupt directive.
- When an ordinary function is to be used as an interrupt function, change the program according to the specifications of each compiler.

(10) Interrupt function qualifier (__interrupt)

FUNCTION

- A function declared with the __interrupt qualifier is regarded as a hardware interrupt function, and execution is returned by the return RETI instruction for non-maskable/maskable interrupt function.
- A function declared with this qualifier is regarded as (non-maskable/maskable/software) interrupt function, and saves or restores the registers and variable areas (1) and (4) below, which are used as the work area of the compiler, to or from the stack.
  If a function call is described in this function, however, all the variable areas are saved to the stack.

  (1) Registers

  (2) saddr area for register variables

  (3) saddr area for arguments/auto variables of norec function (Regardless of usage)

  (4) saddr area for run time library

  Remark If the -qr option is not specified (default) at compile time, save/restore codes are not output because areas (2) and (3) are not used. If the -sm option is specified at compilation, save/restore codes are not output because areas (2), (3) and (4) are not used.

EFFECT

- By declaring a function with this qualifier, the setting of a vector table and interrupt function definition can be described in separate files.

USAGE

- Describe either __interrupt or __interrupt_brk as the qualifier of an interrupt function.

  < For non-maskable/maskable interrupt function >

```
__interrupt     void    func ( ) { processing }
```

RESTRICTIONS

- __interrupt_brk is not supported because there is no software interrupt. A warning message is output where __interrupt_brk first appeared, the keyword is ignored, and __interrupt_brk is handled as a normal function.
- The interrupt function cannot specify callt / noauto / norec / __callt / __leaf / __pascal.

CAUTIONS

- The vector address is not set by merely declaring this qualifier. The vector address must be separately set by using the #pragma vect/interrupt directive or assembler description.
- The saddr area and registers are saved to the stack.
- Even if the vector address is set or the saving destination is changed by #pragma vect (or interrupt) ..., the change in the saving destination is ignored if there is no function definition in the same file, and the default stack is assumed.
- To define an interrupt function in the same file as the #pragma vect (or interrupt) ... specification, the function name specified by #pragma vect (or interrupt) ... is judged as the interrupt function, even if this qualifier is not described (for details of #pragma vect/interrupt, refer to USAGE of "(9) Interrupt functions (#pragma vect / #pragma interrupt)").

EXAMPLE

- Declare or define interrupt functions in the following format. The code to set the vector address is generated by #pragma interrupt.

```
#pragma interrupt   INTP0   inter

__interrupt     void    inter ( ) ;             /* prototype declaration */
__interrupt     void    inter ( ) { processing } ;      /* function body */
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified unless interrupt functions are supported.
- Modify the interrupt functions, if necessary, according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- #define must be used to allow the interrupt qualifiers to be handled as ordinary functions.
- To use the interrupt qualifiers as interrupt functions, modify the program according to the specifications of each compiler.

(11) Interrupt functions (#pragma DI, #pragma EI)

FUNCTIONS

- Codes DI and EI are output to the object and an object file is created.
- If the #pragma directive is missing, DI( ) and EI( ) are regarded as ordinary functions.
- If "DI( );" is described at the beginning in a function (except the declaration of an automatic variable, comment, and preprocessor directive), the DI code is output before the preprocessing of the function (immediately after the label of the function name).
- To output the code of DI after the preprocessing of the function, open a new block before describing "DI( );" (delimit this block with "{").
- If "EI( );" is described at the end of a function (except comments and preprocessor directive), the EI code is output after the post-processing of the function (immediately before the code RET).
- To output the EI code before the post-processing of a function, close a new block after describing "EI( );" (delimit this block with "}").

EFFECT

- A function disabling interrupts can be created.

USAGE

- Describe the #pragma DI and #pragma EI directives at the beginning of the C source. However, the following statement and directives may precede the #pragma DI and #pragma EI directives :

  (i) Comment statement

  (ii) Other #pragma directives

  (iii) Preprocessor directive which does neither define nor refer to a variable or function

- Describe DI( ); or EI( ); in the source in the same manner as function call.
- DI and EI can be described in either uppercase or lowercase letters after #pragma.

RESTRICTIONS

- When using these interrupt functions, DI and EI cannot be used as function names.
- DI and EI must be described in uppercase letters. If described in lowercase letters, they will be handled as ordinary functions.

EXAMPLE

```
#ifdef  __K0S__
        #pragma DI
        #pragma EI
#endif
```

< C source 1 >

```
#pragma DI
#pragma EI
void    main ( )
{
        DI ( ) ;
        ; function body
        EI ( ) ;
}
```

< Output object of compiler >

```
_main :
        di
        ; preprocessing
        ; function body
        ; postprocessing
        ei
        ret
```

- To output DI and EI after and before preprocessing/post-processing

< C source 2 >

```
#pragma DI
#pragma EI
void    main ( )
{
        {
                DI ( ) ;
                ; function body
                EI ( ) ;
        }
}
```

< Output object of compiler >

```
_main :
        ; preprocessing
        di
        ; function body
        ei
        ; post-processing
        ret
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if interrupt functions are not used at all.
- To change an ordinary function to an interrupt function, modify the program according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- Delete the #pragma DI and #pragma EI directives or invalidate these directives by separating them with #ifdef and DI and EI can be used as ordinary function names (example : #ifdef__K0S__ ... #endif).
- When an ordinary function is to be used as an interrupt function, modify the program according to the specifications of each compiler.

(12) CPU control instruction (#pragma HALT / STOP / NOP)

FUNCTION

- The following codes are output to the object to create an object file :

  (1) Instruction for HALT operation (HALT)

  (2) Instruction for STOP operation (STOP)

  (3) NOP instruction

EFFECT

- The standby function of a microcontroller can be used with a C program.
- The clock can be advanced without the CPU operating.

USAGE

- Describe the #pragma HALT, #pragma STOP, and #pragma NOP instructions at the beginning of the C source.
- The following items can be described before the #pragma directive :

  (i) Comment statement

  (ii) Other #pragma directive

  (iii) Preprocessor directive which does neither define nor refer to a variable or function

- The keywords following #pragma can be described in either uppercase or lowercase letters.
- Describe as follows in uppercase letters in the C source in the same format as function call :

  (1) HALT ( ) ;

  (2) STOP ( ) ;

  (3) NOP ( ) ;

RESTRICTIONS

- When this feature is used, HALT, STOP, and NOP cannot be used as function names.
- Describe HALT, STOP, and NOP in uppercase letters. If they are described in lowercase letters, they are handled as ordinary functions.

EXAMPLE

< C source >

```
#pragma HALT
#pragma STOP
#pragma NOP
void    main ( )
{
        HALT ( ) ;
        STOP ( ) ;
        NOP ( ) ;
}
```

< Output object of compiler >

```
@@CODE  CSEG
_main :
        halt
        stop
        nop
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The C source program need not be modified if the CPU control instructions are not used.
- Modify the program according to the procedure described in USAGE above when the CPU control instructions are used.

< From the CC78K0S to another C compiler >

- If "#pragma HALT", "#pragma STOP", and "#pragma NOP" statements are delimited by means of deletion or with #ifdef, HALT, STOP, and NOP can be used as function names.
- To use these instructions as the CPU control instructions, modify the program according to the specifications of each compiler.

(13) Absolute address access function (#pragma access)

FUNCTION

- A code to access the ordinary RAM space is output to the object through direct in-line expansion, not by function call, and an object file can be created.
- If the #pragma directive is not described, a function accessing an absolute address is regarded as an ordinary function.

EFFECT

- A specific address in the ordinary memory space can be easily accessed through C description.

USAGE

- Describe the #pragma access directive at the beginning of the C source.
- Describe the directive in the source in the same format as function call.
- The following items can be described before #pragma access :

  (i) Comment statement

  (ii) Other #pragma directives

  (iii) Preprocessor directive which does neither define nor refer to a variable or function

- The keywords following #pragma can be described in either uppercase or lowercase letters.
  The following 4 function names are available for absolute address accessing :

```
peekb , peekw , pokeb , pokew
```

[List of functions for absolute address accessing]

(a) unsigned char peekb (addr) ;
unsigned int addr ;

Returns 1-byte contents of address addr.

(b) unsigned int peekw (addr) ;
unsigned int addr ;

Returns 2-byte contents of address addr.

(c) void pokeb (addr, data) ;
unsigned int addr ;
unsigned char data ;

Writes 1-byte contents of data to the position indicated by address addr.

(d) void pokew (addr, data) ;
unsigned int addr ;
unsigned int data ;

Writes 2-byte contents of data to the position indicated by address addr.

RESTRICTIONS

- A function name for absolute address accessing must not be used.
- Describe functions for absolute address accessing in lowercase letters. Functions described in uppercase letters are handled as ordinary functions.

EXAMPLE

< C source >

```
#pragma access

char    a ;
int     b ;

void    main ( )
{
        a = peekb ( 0x1234 ) ;
        a = peekb ( 0xfe23 ) ;
        b = peekw ( 0x1256 ) ;
        b = peekw ( 0xfe68 ) ;

        pokeb ( 0x1234 , 5 ) ;
        pokeb ( 0xfe23 , 5 ) ;
        pokew ( 0x1256 , 7 ) ;
        pokew ( 0xfe68 , 7 ) ;
}
```

< Output assembler source >

```
  :       :
mov     a , !01234H
mov     !_a , a
mov     a , 0FE23H
mov     !_a , a
mov     a , !01256H
xch     a , x
mov     a , !01257H
movw    de , #_b
callt   [ @@deist ]
movw    ax , 0FE68H
callt   [ @@deist ]

mov     a , #05H
mov     !01234H , a
mov     0FE23H , #05H
movw    ax , #07H
mov     !01257H , a
xch     a , x
mov     !01256H , a
movw    ax , #07H
movw    0FE68H , ax
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The source program need not be modified if a function for absolute address accessing is not used.
- Modify the program according to the procedure described in USAGE above if a function for absolute address accessing is used.

< From the CC78K0S to another C compiler >

- Delimit the "#pragma access" statement by means of deletion or with #ifdef. As a function name, the function name of absolute address accessing can be used.
- To use a function for absolute address accessing, the program must be modified according to the specifications of each compiler (#asm, #endasm, asm, etc.).

(14) Bit field declaration

(a) Extension of type specifier

FUNCTION

- The bit field of unsigned char type is not allocated straddling over a byte boundary.
- The bit field of unsigned int type is not allocated straddling over a word boundary, but can be allocated straddling over a byte boundary.
- The bit fields of the same type are allocated in the same byte units (or word units). If the types are different, the bit fields are allocated in different byte units (or word units).

EFFECT

- The memory can be saved, the object code can be shortened, and the execution speed can be improved.

USAGE

- As a bit field type specifier, unsigned char type can be specified in addition to unsigned int type. Declare as follows.

```
struct  tag-name {
        unsigned char   Field name :  bit width ;
        unsigned char   Field name :  bit width ;
           :
        unsigned int    Field name :  bit width ;
} ;
```

EXAMPLE

```
struct  tagname {
        unsigned char   A : 1 ;
        unsigned char   B : 1 ;
           :
        unsigned int    C : 2 ;
        unsigned int    D : 1 ;
           :
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The source program need not be modified.
- Change the type specifier to use unsigned char as the type specifier.

< From the CC78K0S to another C compiler >

- The source program need not be modified if unsigned char is not used as a type specifier.
- Change unsigned char, if it is used as a type specifier, into unsigned int.

(b) Allocation direction of bit field

FUNCTION

- The direction in which a bit field is to be allocated is changed and the bit field is allocated from the MSB side when the -rb option is specified.
- If the -rb option is not specified, the bit field is allocated from the LSB side.

USAGE

- Specify the -rb option at compile time to allocate the bit field from the MSB side.
- Do not specify the option to allocate the bit field from the LSB side.

EXAMPLE 1

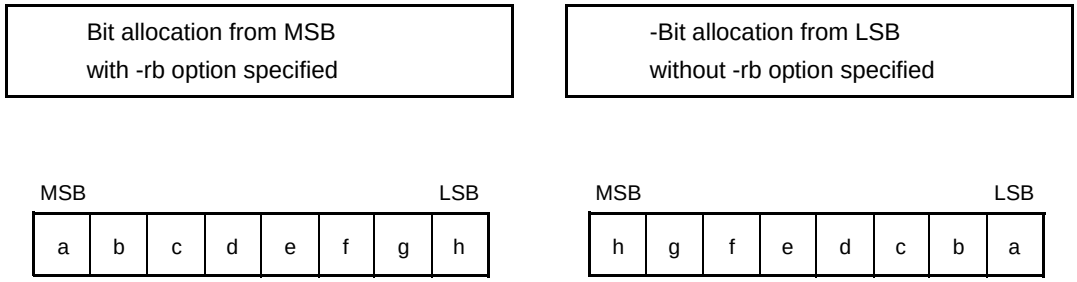
< Bit field declaration >

```
struct  t {
        unsigned char   a : 1 ;
        unsigned char   b : 1 ;
        unsigned char   c : 1 ;
        unsigned char   d : 1 ;
        unsigned char   e : 1 ;
        unsigned char   f : 1 ;
        unsigned char   g : 1 ;
        unsigned char   h : 1 ;
} ;
```

EXPLANATION

- Because a through h are 8 bits or less, they are allocated in 1-byte units.

Figure 11-3 Bit Allocation by Bit Field Declaration (Example 1)



EXAMPLE 2

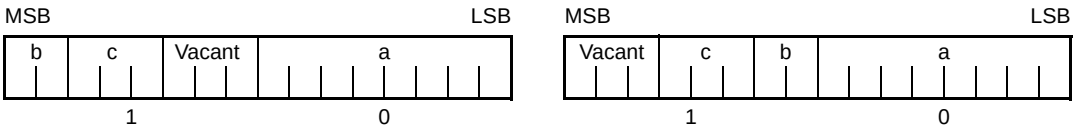
< Bit field declaration >

```
struct  t {
        char            a ;
        unsigned char   b : 2 ;
        unsigned char   c : 3 ;
        unsigned char   d : 4 ;
        int             e ;
        unsigned char   f : 5 ;
        unsigned char   g : 6 ;
        unsigned char   h : 2 ;
        unsigned int    i : 2 ;
} ;
```

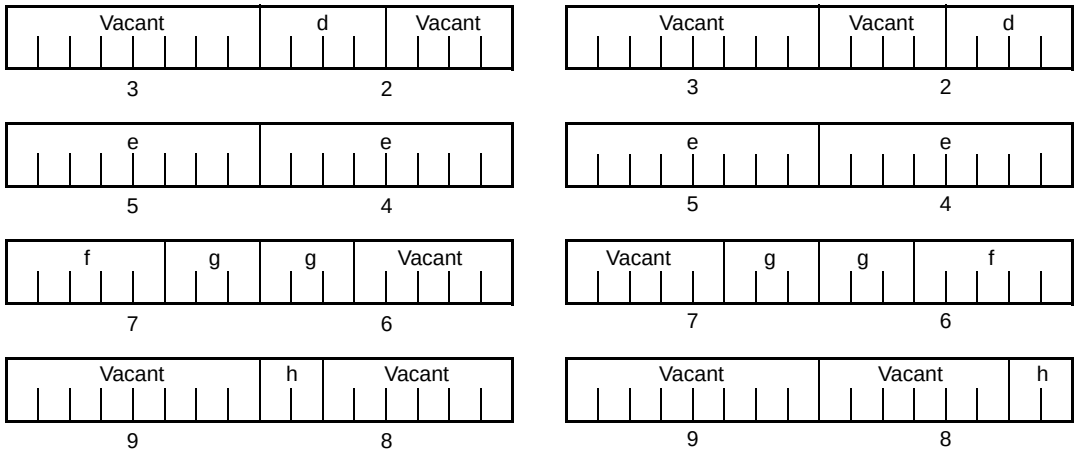
EXPLANATION

Figure 11-4 Bit Allocation by Bit Field Declaration (Example 2)

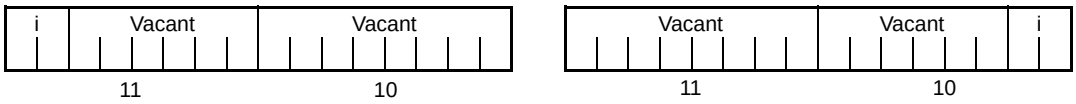
Bit field allocated from the MSB side when the -rb option is specified	Bit field allocated from the LSB side when the -rb option is not specified



Member a of char type is allocated to the first byte unit. Members b and c are allocated to subsequent byte units, starting from the second byte unit. If a byte unit does not have enough space to hold the type char member, that member will be allocated to the following byte unit. In this case, if there is only space for 3 bits in the second byte unit, and member d has 4 bits, it will be allocated to the third byte unit.



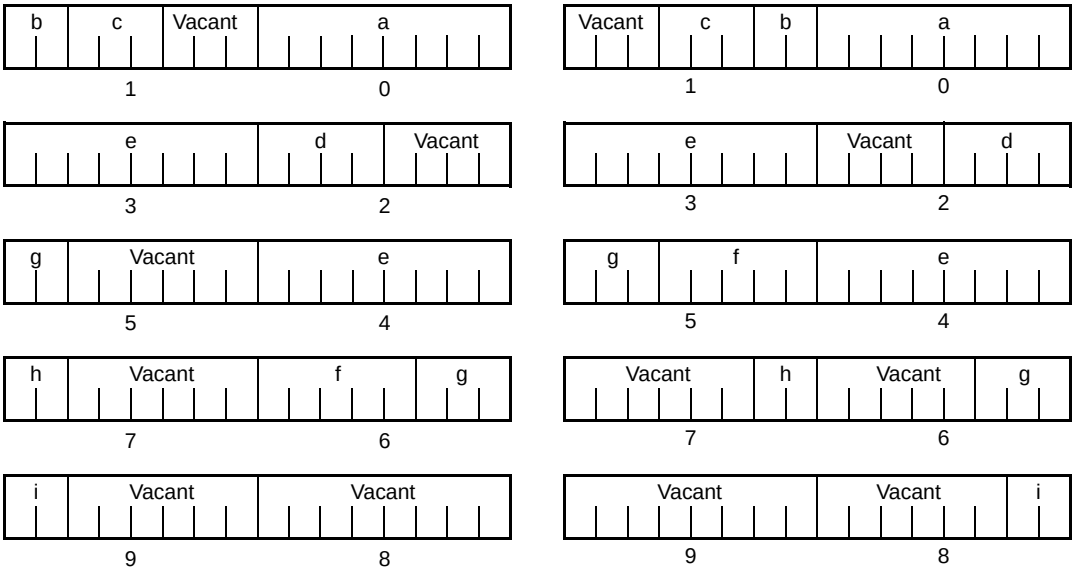
Since member g is a bit field of type unsigned int, it can be allocated across byte boundaries. Since h is a bit field of type unsigned char, it is not allocated in the same byte unit as the g bit field of type unsigned int, but is allocated in the next byte unit.



Since i is a bit field of type unsigned int, it is allocated in the next word unit.

When the -rc option is specified (to pack the structure members), the above bit field becomes as follows.

Figure 11-5 Bit Allocation by Bit Field Declaration (Example 2) (with -rc Option Specified)



Remark The numbers below the allocation diagrams indicate the byte offset values from the beginning of the structure.

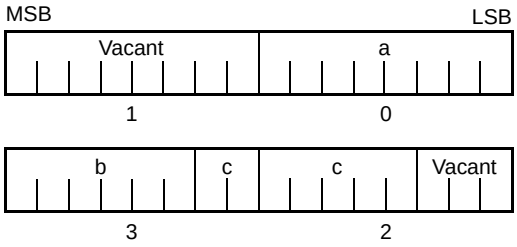
EXAMPLE 3

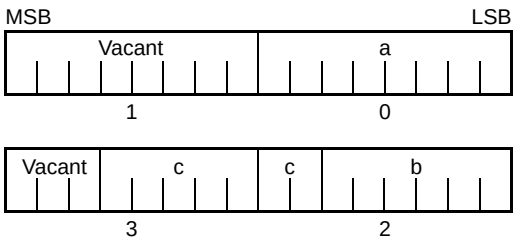
< Bit field declaration >

```
struct  t {
        char            a ;
        unsigned int    b : 6 ;
        unsigned int    c : 7 ;
        unsigned int    d : 4 ;
        unsigned char   e : 3 ;
        unsigned int    f : 10 ;
        unsigned int    g : 2 ;
        unsigned int    h : 5 ;
        unsigned int    i : 6 ;
} ;
```

Figure 11-6 Bit Allocation by Bit Field Declaration (Example 3)

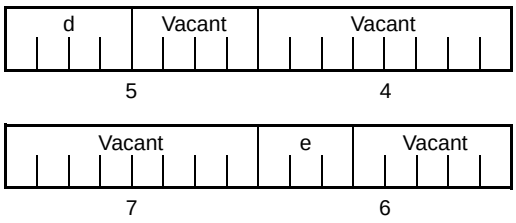
Bit field allocated from the MSB side when the -rb option is specified	Bit field allocated from the LSB side when the -rb option is not specified

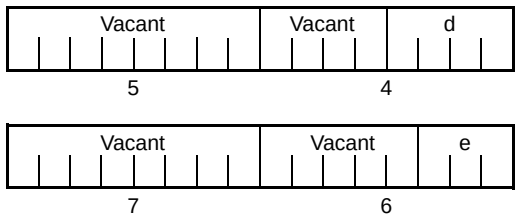




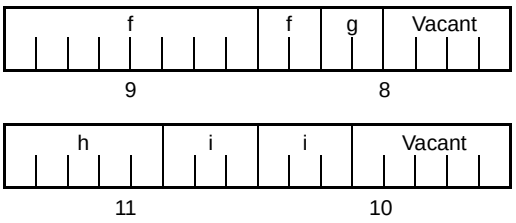
Since b and c are bit fields of type unsigned int, they are allocated from the next word unit.

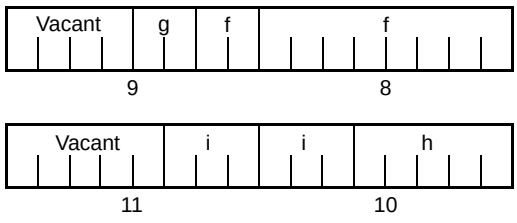
Since d is also a bit field of type unsigned int, it is allocated from the next word unit.





Since e is a bit field of type unsigned char, it is allocated to the next byte unit.

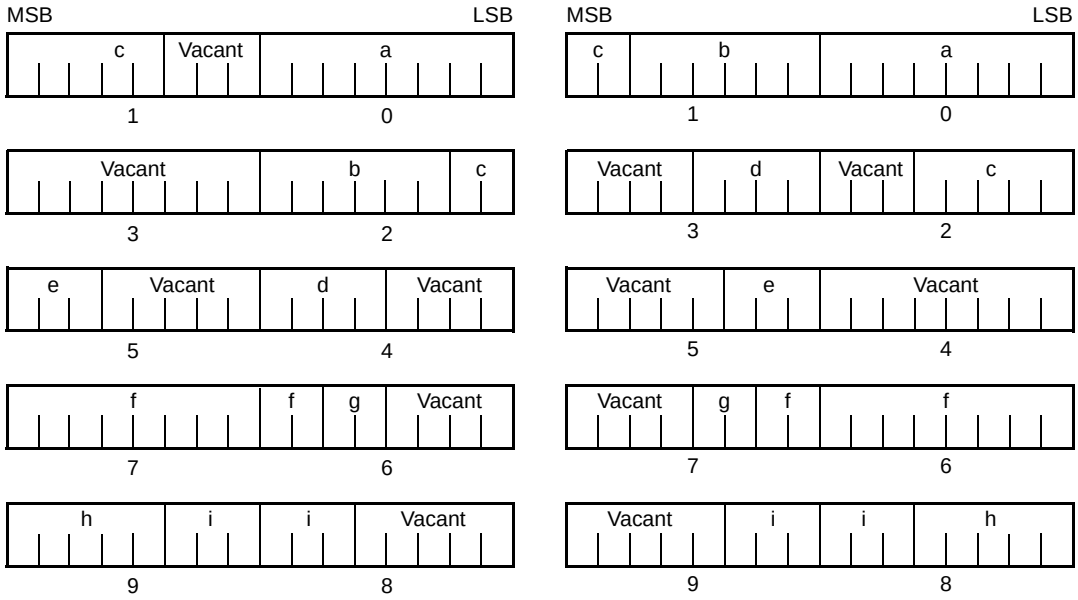




f and g, and h and i are each allocated to separate word units.

When the -rc option is specified (to pack the structure members), the above bit field becomes as follows.

Figure 11-7 Bit Allocation by Bit Field Declaration (Example 3) (with -rc Option Specified)



Remark The numbers below the allocation diagrams indicate the byte offset values from the beginning of the structure.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The source program need not be modified.

< From the CC78K0S to another C compiler >

- The source program must be modified if the -rb option is used and coding is performed taking the bit field allocation sequence into consideration.

(15) Changing compiler output section name (#pragma section ...)

FUNCTION

- A compiler output section name is changed and a start address is specified. If the start address is omitted, the default allocation is assumed. For the compiler output section name and default location, refer to "APPENDIX B LIST OF SEGMENT NAMES". In addition, the location of sections can be specified by omitting the start address and using the link directive file at the time of link. For the link directives, refer to the RA78K0S Assembler Package Operation User's Manual.
- To change section names @@CALT with an AT start address specified, the callt functions must be described before or after the other functions in the source file.
- If data are described after the #pragma instruction is described, those data are located in the data change section. Another change instruction is possible, and if data are described after the rechange instruction, those data are located in the rechange section. If data defined before a change are redefined after the change, they are located in the rechanged section. Furthermore, this is valid in the same way for static variables (within the function).

EFFECT

- Changing the compiler output section repeatedly in 1 file enables to locate each section independently, so that data can be located in data units to be located independently.

USAGE

- Specify the name of the section which is to be changed, a new section name, and the start address of the section, by using the #pragma directive as indicated below.
- Describe this #pragma directive at the beginning of the C source.
- Describe this #pragma directive after #pragma PC (processor type).
- The following items can be described before this #pragma directive :

  (i) Comment statement

  (ii) Preprocessor directive which does neither define nor refer to a variable or a function

  However, all sections in BSEG and DSEG, and the @@CNST section in CSEG can be described anywhere in the C source, and rechange instructions can be performed repeatedly. To return to the original section name, describe the compiler output section name in the changed section.
  Declare as follows at the beginning of the file :

```
#pragma  section  compiler output section name  new section name  [ AT start
address ]
```

- Of the keywords to be described after #pragma, be sure to describe the compiler output section name in uppercase letters. section, AT can be described in either uppercase or lowercase letters, or in combination of those.

- The format in which the new section name is to be described conforms to the assembler specifications (up to 8 letters can be used for a segment name).
- Only the hexadecimal numbers of the C language and the hexadecimal numbers of the assembler can be described as the start address.

[Hexadecimal numbers of C language]

```
0xn / 0xn ... n
0Xn / 0Xn ... n
( n = 0 , 1 , 2 , 3 , 4 , 5 , 6 , 7 , 8 , 9 , A , B , C , D , E , F )
```

[Hexadecimal numbers of assembler]

```
nH / n ... nH
nh / n ... nh
( n = 0 , 1 , 2 , 3 , 4 , 5 , 6 , 7 , 8 , 9 , A , B , C , D , E , F )
```

- The hexadecimal number must start with a numeral.

  Example : To express a numeric value with a value of 255 in hexadecimal number, specify zero before F. It is therefore 0FFH.

- For sections other than the @@CNST section in CSEG, that is, sections which locate functions, this #pragma instruction cannot be described in other than the beginning of the C source (after the C text is described). If described, it causes an error.
- If this #pragma instruction is executed after the C text is described, an assembler source file is created without an object module file being created.
- If this #pragma instruction is after the C text is described, a file which contains this #pragma instruction and which does not have the C text (including external reference declarations for variables and functions) cannot be included. This results in an error (refer to "CODING Error EXAMPLE 1").
- #include statement cannot be described in a file which executes this #pragma instruction following the C text description. If described, it causes an error (refer to "CODING Error EXAMPLE 2").
- If #include statement follows the C text, this #pragma instruction cannot be described after this description. If described, it causes an error (refer to "CODING Error EXAMPLE 3").

EXAMPLE 1

Section name @@CODE is changed to CC1 and address 2400H is specified as the start address.

< C source >

```
#pragma section @@CODE  CC1     AT      2400H

void    main ( )
{
        ; Function body
}
```

< Output object >

```
CC1     CSEG    AT      2400H
_main :
        ; Preprocessing
        ; Function body
        ; Post-processing
        ret
```

EXAMPLE 2

The following is a code example in which the main C code is followed by a #pragma directive. The contents are allocated in the section following "//".

```
#pragma section @@DATA      ??DATA
        int         a1 ;                    // ??DATA
        sreg        int     b1 ;            // @@DATS
        int         c1 = 1 ;                // @@INIT and @@R_INIT
        const int   d1 = 1 ;                // @@CNST
#pragma section @@DATS      ??DATS
        int         a2 ;                    // ??DATA
        sreg int    b2 ;                    // ??DATS
        int         c2 = 1 ;                // @@INIT and @@R_INIT
        const int   d2 = 1 ;                // @@CNST
#pragma section @@DATA      ??DATA2
        // ??DATA is automatically closed and ??DATA2 becomes valid
        int         a3 ;                    // ??DATA2
        sreg int    b3 ;                    // ??DATS
        int         c3 = 3 ;                // @@INIT and @@R_INIT
        const int   d3 = 3 ;                // @@CNST
#pragma section @@DATA      @@DATA
        // ??DATA2 is closed and processing returns to the default @@DATA
#pragma section @@INIT      ??INIT
#pragma section @@R_INIT    ??R_INIT
        // ROMization is invalidated unless both names (@@INIT and @@R_INIT)
        // are changed. This is the user's responsibility.
        int         a4 ;                    // @@DATA
        sreg int    b4 ;                    // ??DATS
        int         c4 = 1 ;                // ??INIT and ??R_INIT
        const int   d4 = 1 ;                // @@CNST
#pragma section @@INIT      @@INIT
#pragma section @@R_INIT    @@R_INIT
        // ??INIT and ??R_INIT are closed and processing returns to
        // the default setting
#pragma section @@BITS      ??BITS
        __boolean e4 ;                      // ??BITS
#pragma section @@CNST      ??CNST
        char    *const p = " Hello " ;      // p and "Hello" are both  ??CNSTT
```

EXAMPLE 3

```
#pragma section @@INIT      ??INIT1
#pragma section @@R_INIT    ??R_INIT1
#pragma section @@DATA      ??DATA1
        char        c1 ;
        int         i2 ;
#pragma section @@INIT      ??INIT2
#pragma section @@R_INIT    ??R_INIT2
#pragma section @@DATA      ??DATA2
        char        c1 ;
        int         i2 = 1 ;
#pragma section @@DATA      ??DATA3
#pragma section @@INIT      ??INIT3
#pragma section @@R_INIT    ??R_INIT3
extern  char        c1 ;                    // ??DATA3
        int         i2 ;                    // ??INIT3 and ??R_INIT3
#pragma section @@DATA      ??DATA4
#pragma section @@INIT      ??INIT4
#pragma section @@R_INIT    ??R_INIT4
```

Restrictions when this #pragma directive has been specified after the main C code are explained in the following coding error examples.

CODING ERROR EXAMPLE 1

```
a1.h
        #pragma section @@DATA  ??DATA1         // File containing only the
                                                // #pragma section.

a2.h
        extern  int     func1( void ) ;
        #pragma section @@DATA  ??DATA2         // File containing the main
                                                // C code followed by the
                                                // #pragma directive.

a3.h
        #pragma section @@DATA  ??DATA3         // File containing only the
                                                // #pragma section.

a4.h
        #pragma section @@DATA  ??DATA3
        extern  int     func2 ( void ) ;        // File that includes the
                                                // main C code.

a.c
        #include " a1.h "
        #include " a2.h "
        #include " a3.h "       // <- Results in an error.
                                 // Because the a2.h file contains the main
                                 // C code followed by this #pragma directive,
                                 // file a3.h, which includes only this
                                 // #pragma directive, cannot be included.
        #include " a4.h "
```

CODING ERROR EXAMPLE 2

```
b1.h
        const int       i ;

b2.h
        const int       j ;
        #include " b1.h "       // This does not result in an error since
                                 // it is not file (b.c) in which the main C
                                 // code is followed by this #pragma directive.

b.c
        const int       k ;
        #pragma section @@DATA  ??DATA1
        #include " b2.h "       // <- Results in an error
                                 // Since an #include statement cannot be coded
                                 // afterward in file (b.c) in which the main C
                                 // code is followed by this #pragma directive.
```

CODING ERROR EXAMPLE 3

```
c1.h
        extern int      j ;
        #pragma section @@DATA  ??DATA1 // This does not result in an error
                                        // since the #pragma directive is
                                        // included and processed before the
                                        // processing of c3.h.

c2.h
        extern int      k ;
        #pragma section @@DATA  ??DATA2 // <- Results in an error.
                                        // This #include statement is
                                        // specified after the main C code in
                                        // c3.h, and the #pragma directive
                                        // cannot be specified afterward.

c3.h
        #include " c1.h "
        extern int      i ;
        #include " c2.h "
        #pragma section @@DATA  ??DATA3 // <- Results in an error.
                                        // This #include statement is
                                        // specified after the main C code,
                                        // and the #pragma directive cannot
                                        // be specified afterward.

c.c
        #include " c3.h "
        #pragma section @@DATA  ??DATA4 // <- Results in an error.
                                        // This #include statement is
                                        // specified after the main C code in
                                        // c3.h, and the #pragma directive
                                        // cannot be specified afterward.
        int     i ;
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The source program need not be modified if the section name change function is not supported.
- To change the section name, modify the source program according to the procedure described in USAGE above.

< From the CC78K0S to another C compiler >

- Delete or delimit #pragma section ... with #ifdef.
- To change the section name, modify the program according to the specifications of each compiler.

RESTRICTIONS

- A section name that indicates a segment for vector table (e.g., @@VECT02, etc.) must not be changed.
- If two or more sections with the same name as the one specifying the AT start address exist in another file, a link error occurs.
- Section names (@@BANK1, etc.) that indicate segments for bank function use cannot be changed.
- When changing compiler output section names @@DATS, @@BITS, and @@INIS, limit the range of the specified address within 0FE20H to 0FED7H.

CAUTION

- A section is equivalent to a segment of the assembler.
- The compiler does not check whether the new section name is in duplicate with another symbol. Therefore, the user must check to see whether the section name is not in duplicate by assembling the output assemble list.
- If a section name (*) related to ROMization is changed by using #pragma section, the start-up routine must be changed by the user on his/her own responsibility.

  (*) ROMization-related section name

```
@@R_INIT , @@R_INIS , @@INIT , @@INIS
```

  The start-up routine to be used when a section related to ROMization is changed, and an example of changing the end module are described later.

[Examples of Changing Start-up Routine in Connection with Changing Section Name Related to ROMization]

Here are examples of changing the start-up routine (cstart.asm or cstartn.asm) and end module (rom.asm) in connection with changing a section name related to ROMization.

< C source >

```
#pragma section @@R_INIT        RTT1
#pragma section @@INIT          TT1
```

If a section name that stores an external variable with an initial value has been changed by describing #pragma section indicated above, the user must add to the start-up routine the initial processing of the external variable to be stored to the new section.

To the start-up routine, therefore, add the declaration of the first label of the new section and the portion that copies the initial value, and add the portion that declares the end label to the end module, as described below.

RTT1_S and RTT1_E are the names of the first and end labels of section RTT1, and TT1_S and TT1_E are the names of the first and end labels of section TT1.

(a) Changing start-up routine cstartx.asm

(i) Add the declaration of the label indicating the end of the section with the changed name

```
    :
EXTRN   _main , _exi t , _@STBEG
EXTRN   _?R_INIT , _?R_INIS , _?DATA , _?DATS

EXTRN   RTT1_E , TT1_E  <- Adds EXTRN declaration of RTT1_E and TT1_E
    :
```

(ii) Add a section to copy the initial values from the RTT1 section with the changed name to the TT1 section.

```
    :
LDATS1 :
        MOVW    AX , HL
        CMPW    AX , #_?DATS
        BZ      $LDATS2
        MOV     A , #0
        MOV     [ HL ] , A
        INCW    HL
        BR      $LDATS1
LDATS2 :                          ┐
        MOVW    DE , #TT1_S       │
        MOVW    HL , #RTT1_S      │
LTT1 :                            │
        MOVW    AX , HL           │
        CMPW    AX , #RTT1_E      │  Adds section to copy the initial values
        BZ      $LTT2             │  from the RTT1 section to the TT1 section
        MOV     A , [ HL ]        │
        MOV     [ DE ] , A        │
        INCW    HL                │
        INCW    DE                │
        BR      $LTT1             ┘
LTT2 :
;
        CALL    !_main ; main ( ) ;
        MOVW    AX , #0
        CALL    !_exit ; exit ( 0 ) ;
        BR      $$
;
```

(iii) Set the label of the start of the section with the changed name.

```
  :
@@R_INIT        SEG
_@R_INIT :
@@R_INIS        CSEG    UNITP
_@R_INIS :
@@INIT          DSEG
_@INIT :
@@DATA          DSEG
_@DATA :
@@INIS          DSEG    SADDRP
_@INIS :
@@DATS          DSEG    SADDRP
_@DATS :

RTT1            CSEG    ; Indicates the start of the RTT1 section
RTT1_S :                ; Adds the label setting
TT1             DSEG    ; Indicates the start of the TT1 section
TT1_S :                 ; Adds the label setting

@@CALT          CSEG    CALLT0
@@CNST          CSEG
@@BITS          BSEG
;
        END
```

(b) Changing end module rom.asm

(i) Add the declaration of the label indicating the end of the section with the changed name

```
NAME            @rom
;
PUBLIC          _?R_INIT , _?R_INIS
PUBLIC          _?INIT , _?DATA , _?INIS , _?DATS

PUBLIC          RTT1_E , TT1_E          <- Adds RTT1_E and TT1_E

;
@@R_INIT        CSEG
_?R_INIT :
@@R_INIS        CSEG    UNITP
_?R_INIS :
@@INIT          DSEG
_?INIT :
@@DATA          DSEG
_?DATA :
@@INIS          DSEG    SADDRP
_?INIS :
@@DATS          DSEG    SADDRP
_?DATS
  :
```

(ii) Setting the label indicating the end

```
    :
RTT1            CSEG    ; Adds the label setting indicating the end of
                        ; the RTT1 section.
RTT1_E :                ; Adds the label setting

TT1     DSEG            ; Adds the label setting indicating the end of
                        ; the TT1 section.
TT1_E :                 ; Adds the label setting

;
        END
```

(16) Binary constant (Binary constant 0bxxx)

FUNCTION

- Describes binary constants to the location where integer constants can be described.

EFFECT

- Constants can be described in bit strings without being replaced with octal or hexadecimal number.

  Readability is also improved.

USAGE

- Describe binary constants in the C source. The following shows the description method of binary constants.

```
0b      binary number
0B      binary number
```

  Remark Binary number : either "0" or "1"

- A binary constant has 0b or 0B at the start and is followed by the list of numbers 0 or 1.
- The value of a binary constant is calculated with 2 as the base.
- The type of a binary constant is the first one that can express the value in the following list.

  (i) Subscripted binary number : int,
  unsigned int,
  long int
  unsigned long int

  (ii) Subscripted u or U : unsigned int,
  unsigned long int

  (iii) Subscripted l or L : long int
  unsigned long int

  (iv) Subscripted u or U and subscripted l or L with

  : unsigned long int

EXAMPLE

< C source >

```
        unsigned        i ;
        i = 0b11100101 ;
Output object of compiler is the same as the following case.
        unsigned        i ;
        i = 0xE5 ;
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modifications are not needed.

< From the CC78K0S to another C compiler >

- Modifications are needed to meet the specification of the compiler if the compiler supports binary constants.
- Modifications into other integer formats such as octal, decimal, and hexadecimal are needed if the compiler does not support binary constants.

(17) Module name changing function (#pragma name)

FUNCTION

- Outputs the first 8 letters of the specified module name to the symbol information table in a object module file.
- Outputs the first 8 letters of the specified module name to the assemble list file as symbol information (MOD_NAM) when -g2 is specified and as NAME pseudo instruction when -ng is specified.
- If a module name with nine or more letters are specified, a warning message is output.
- If unauthorized letters are described, an error occurs and the processing is aborted.
- If more than one of this #pragma directive exists, a warning message is output, and whichever described later is enabled.

EFFECT

- The module name of an object can be changed to any name.

USAGE

- The following shows the description method.

```
#pragma name    module name
```

A module name must consist of the characters that the OS authorizes as a file name except "(" ")". Upper/lowercase is distinguished.

EXAMPLE

```
#pragma name    module1
    :
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modifications are not needed if the compiler does not support the module name changing function.
- To change a module name, modification is made according to USAGE above.

< From the CC78K0S to another C compiler >

- #pragma name ... is deleted or sorted by #ifdef.
- To change a module name, modification is needed depending on the specification of each compiler.

(18) Rotate function (#pragma rot)

FUNCTION

- Outputs the code that rotates the value of an expression to the object with direct inline expansion instead of function call and generates an object file.
- If there is not a #pragma directive, the rotate function is regarded as an ordinary function.

EFFECT

- Rotate function is realized by the C source or ASM description without describing the processing to perform rotate.

USAGE

- Describe in the source in the same format as the function call. There are the following 4 function names.

```
rorb , rolb , rorw , rolw
```

[List of functions for rotate]

(a) unsigned char rorb (x , y) ;
unsigned char x ;
unsigned char y ;

Rotates x to right for y times.

(b) unsigned char rolb (x , y) ;
unsigned char x ;
unsigned char y ;

Rotates x to left for y times.

(c) unsigned int rorw (x , y) ;
unsigned int x ;
unsigned char y ;

Rotates x to right for y times.

(d) unsigned int rolw (x , y) ;
unsigned int x ;
unsigned char y ;

Rotates x to left for y times.

Remark The above mentioned function declaration is not affected by the -zi option.

- Declare the use of the function for rotate by the #pragma rot directive of the module.
  However, the followings can be described before #pragma rot.
  (i) Comments
  (ii) Other #pragma directives
  (iii) Preprocessing directives which do not generate definition/reference of variables and definition/ reference of functions
- Keywords following #pragma can be described in either uppercase or lowercase letters.

EXAMPLE

< C source >

```
#pragma rot
unsigned char   a = 0x11 ;
unsigned char   b = 2 ;
unsigned char   c ;
void    main ( ) {
        c = rorb ( a , b ) ;
}
```

< Output assembler source >

```
mov     a , !_b
mov     c , a
mov     a , !_a
ror     a , 1
dbnz    c , $$-1
mov     !_c , a
```

RESTRICTIONS

- The function names for rotate cannot be used as the function names.
- The function names for rotate must be described in lowercase letters. If the functions for rotate are described in uppercase letters, they are handled as ordinary functions.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modification is not needed if the compiler does not use the functions for rotate.
- To change to functions for rotate, modifications are made according to USAGE above.

< From the CC78K0S to another C compiler >

- #pragma rot statement is deleted or sorted by #ifdef.
- To use as a function for rotate, modification is needed depending on the specification of each compiler (#asm, #endasm or asm( ) ; , etc.).

(19) Multiplication function (#pragma mul)

FUNCTION

- Outputs the code that multiplies the value of an expression to the object with direct inline expansion instead of function call and generates an object file.
- If there is not a #pragma directive, the multiplication function is regarded as an ordinary function.

EFFECT

- Codes that are compatible with the CC78K0 and utilize the data size of the multiplication instruction I/O are generated. Therefore, codes with smaller size than the description of ordinary multiplication expressions can be generated.

USAGE

- Describe in the same format as that of function call in the source.

```
mulu
```

[List of multiplication function]

unsigned int mulu (x , y) ;
unsigned char x ;
unsigned char y ;

Performs unsigned multiplication of x and y.

- Declare the use of functions for multiplication by #pragma mul directive of the module.
  However, the followings can be described before #pragma mul.

  (i) Comments

  (ii) Other #pragma directives

  (iii) Preprocessing directives that do not generate definition/reference of variables and definition/reference of functions

- Keywords following #pragma can be described in either uppercase or lowercase letters.

RESTRICTIONS

- Multiplication functions are not expanded in line, but are called by the library.

EXAMPLE

< C source >

```
#pragma mul
unsigned char   a = 0x11 ;
unsigned char   b = 2 ;
unsigned int    i ;
void    main ( )
{
        i = mulu ( a , b ) ;
}
```

< Output object of compiler >

```
mov     a , !_b
mov     x , a
mov     a , !_a
callt   [ @@mulu ]
movw    de , #_i
callt   [ @@deist ]
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modifications are not needed if the compiler does not use the functions for multiplication.
- To change to functions for multiplication, modification is made according to USAGE above.

< From the CC78K0S to another C compiler >

- #pragma mul statement is deleted or sorted by #ifdef. Function names for multiplication can be used as the function names.
- To use as functions for multiplication, modification is needed depending on the specification of each compiler (#asm, #endasm or asm( ) ; , etc.).

(20) Division function (#pragma div)

FUNCTION

- Outputs the code which divides the value of an expression from object with direct inline expansion instead of function call and generates an object code file.
- If there is not a #pragma directive, the function for division is regarded as an ordinary function.

EFFECT

- Codes that are compatible with the CC78K0 and utilize the data size of the division instruction I/O are generated. Therefore, codes with faster execution speed and smaller size than the description of ordinary division expressions can be generated.

USAGE

- Describe in the same format as that of function call in the source. There are the following 2 functions for division.

```
divuw , moduw
```

[List of division function]

(a) unsigned int divuw (x , y) ;
unsigned int x ;
unsigned char y ;

Performs unsigned division of x and y and returns the quotient.

(b) unsigned char moduw (x , y) ;
unsigned int x ;
unsigned char y ;

Performs unsigned division of x and y and returns the remainder.

Remark The above mentioned function declaration is not affected by the -zi option.

- Declare the use of the function for divisions by the #pragma div directive of the module.
  However, the followings can be described before #pragma div.
  (i) Comments
  (ii) Other #pragma directives
  (iii) Preprocessing directives which do not generate definition/reference of variables and definition/ reference of functions
- Keywords following #pragma can be described in either uppercase or lowercase letters.

RESTRICTIONS

- The division functions are not expanded in line, but are called by the library.

EXAMPLE

< C source >

```
#pragma div
unsigned int    a = 0x1234 ;
unsigned char   b = 0x12 ;
unsigned char   c ;
unsigned int    i ;
void    main ( ) {
        i = divuw ( a , b ) ;
        c = moduw ( a , b ) ;
}
```

< Output object of compiler >

```
mov     a , !_b
mov     c , a
movw    de , #_a
callt   [ @@deilo ]
callt   [ @@divuw ]
movw    de , #_i
callt   [ @@deist ]
mov     a , !_b
mov     c , a
movw    de , #_a
callt   [ @@deilo ]
callt   [ @@divuw ]
mov     a , c
mov     !_c , a
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modification is not needed if the compiler does not use the functions for division.
- To change to functions for division, modifications are made according to USAGE above.

< From the CC78K0S to another C compiler >

- #pragma div statement is deleted or sorted by #ifdef. The function names for division can be used as the function name.
- To use as a function for division, modification is needed depending on the specification of each compiler (#asm, #endasm or asm( ) ; , etc.).

(21) BCD operation function (#pragma bcd)

FUNCTION

- Outputs the code that performs a BCD operation on the expression value in an object by direct inline expansion rather than by function call, and generates an object file.
- If there are no #pragma directives, the function for BCD operation is regarded as an ordinary function.

EFFECT

- Even if the process of the BCD operation is not described, the BCD operation function can be realized by the C source or ASM statements.

USAGE

- The same format as that of a function call is coded in the source. There are 13 types of function name for BCD operation, as listed below. Refer to [List of functions for BCD operation], later in this chapter for more information.

```
adbcdb , sbbcdb , adbcdbe , sbbcdbe , adbcdw , sbbcdw , adbcdwe ,
sbbcdwe , bcdtob , btobcde , bcdtow , wtobcd , btobcd
```

- Use of functions for division is declared by the module's #pragma bcd directive. The following items, however, can be coded before #pragma bcd.

  (i) Comments

  (ii) Other #pragma directives

  (iii) Preprocessing directives that do not generate definitions/references of variables or function definitions/ references

- Either uppercase or lowercase letters can be used for keywords described after #pragma.

RESTRICTIONS

- BCD operation function names cannot be used as function names.
- The BCD operation function is coded in lowercase letters. If uppercase letters are used, these functions are regarded as an ordinary functions.
- The adbcdwe and sbbcdwe are not supported in the static model.

EXAMPLE

< C source >

```
#pragma bcd
unsigned char   a = 0x12 ;
unsigned char   b = 0x34 ;
unsigned char   c ;
void    main ( )
{
        c = adbcdb ( a , b ) ;
        c = sbbcdb ( b , a ) ;
}
```

< Output assembler source >

```
mov     a , !_a
add     a , !_b
adjba
mov     !_c , a
mov     a , !_b
sub     a , !_a
adjbs
mov     !_c , a
```

[List of functions for BCD operation]

(a) unsigned char adbcdb (x , y) ;

unsigned char x ;

unsigned char y ;

Decimal addition is carried out by the BCD adjustment instruction.

(b) unsigned char sbbcdb (x , y) ;

unsigned char x ;

unsigned char y ;

Decimal subtraction is carried out by the BCD adjustment instruction.

(c) unsigned int adbcdbe (x , y) ;

unsigned char x ;

unsigned char y ;

Decimal addition is carried out by the BCD adjustment instruction (with result expansion).

(d) unsigned int sbbcdbe (x , y) ;

unsigned char x ;

unsigned char y ;

Decimal subtraction is carried out by the BCD adjustment instruction (with result expansion). If a borrow occurs, the high-order digits are set to 0x99.

(e) unsigned int adbcdw (x , y) ;

unsigned int x ;

unsigned int y ;

Decimal addition is carried out by the BCD adjustment instruction.

(f) unsigned int sbbcdw (x , y) ;

unsigned int x ;

unsigned int y ;

Decimal subtraction is carried out by the BCD adjustment instruction.

(g) unsigned long adbcdwe (x , y) ;

unsigned int x ;

unsigned int y ;

Decimal addition is carried out by the BCD adjustment instruction (with result expansion).

(h) unsigned long sbbcdwe (x , y) ;
unsigned int x ;
unsigned int y ;

Decimal subtraction is carried out by the BCD adjustment instruction (with result expansion). If a borrow is occurred, the higher digits are set to 0x9999.

(i) unsigned char bcdtob (x) .
unsigned char x ;

Values in decimal number are converted to binary number values.

(j) unsigned int btobcde (x) ;
unsigned char x ;

Values in binary number are converted to decimal number values.

(k) unsigned int bcdtow (x) ;
unsigned int x ;

Values in decimal number are converted to binary number values.

(l) unsigned int wtobcd (x) ;
unsigned int x ;

Values in decimal number are converted to binary number values. However, if the value of x exceeds 10000, 0xffff is returned.

(m) unsigned char btobcd (x) ;
unsigned char x ;

Values in decimal number are converted to those in binary number. However, the overflow is discarded.

Remark The above-mentioned function declarations are not influenced by the -zi and -zl options.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Corrections are not needed if functions for the BCD operations are not used.
- To change another function to the function for BCD operation, use the description above.

< From the CC78K0S to another C compiler >

- The #pragma bcd statements are either deleted or separated by #ifdef. A BCD operation function name can be used as a function name.
- If using "pragma bcd" as a BCD operation function, the changes to the program source must conform to the C compiler’s specifications (#asm, #endasm or asm( ); etc.).

(22) Data insertion function (#pragma opc)

FUNCTION

- Inserts constant data into the current address.
- When there is not a #pragma directive, the function for data insertion is regarded as an ordinary function.

EFFECT

- Specific data and instruction can be embedded in the code area without using the ASM statement.
  When ASM is used, an object cannot be obtained without the intermediary of assembler. On the other hand, if the data insertion function is used, an object can be obtained without the intermediary of assembler.

USAGE

- Describe using uppercase letters in the source in the same format as that of function call.
- The function name for data insertion is __OPC.

  [List of data insertion functions]

  void __OPC (unsigned char x , ...) ;

  Insert the value of the constant described in the argument to the current address.

  Arguments can describe only constants.
- Declare the use of functions for data insertion by the #pragma opc directive.
  However, the followings can be described before #pragma opc.

  (i) Comments

  (ii) Other #pragma directives

  (iii) Preprocessing directives which do not generate definition/reference of variables and definition/ reference of functions
- Keywords following #pragma can be described in either uppercase or lowercase letters.

RESTRICTIONS

- The function names for data insertion cannot be used as the function names (when #opc is specified).
- __OPC must be described in uppercase letters. If they are described in lowercase letters, they are handled as ordinary functions.

EXAMPLE

< C source >

```
#pragma opc
void    main ( ) {
        __OPC ( 0xBF ) ;
        __OPC ( 0xA1 , 0x12 ) ;
        __OPC ( 0x10 , 0x34 , 0x12 ) ;
}
```

< Output object of compiler >

```
_main :
; line  4 : __OPC ( 0xBF ) ;
        DB      0BFH
; line  5 : __OPC ( 0xA1 , 0x12 ) ;
        DB      0A1H
        DB      012H
; line  6 : __OPC ( 0x10 , 0x34 , 0x12 ) ;
        DB      010H
        DB      034H
        DB      012H
; line  7 : }
        ret
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modification is not needed if the compiler does not use the functions for data insertion.
- To change to functions for data insertion, use the USAGE above.

< From the CC78K0S to another C compiler >

- The #pragma opc statement is deleted or delimited by #ifdef. Function names for data insertion can be used as function names.
- To use as a function for data insertion, changes to the program source must conform to the specification of the C compiler (#asm, #endasm or asm( ) ; , etc.).

(23) Static model

FUNCTION

- All arguments are passed through registers (Refer to "11.7.5 Static model function call interface").
- Function arguments that are passed through registers are allocated in the function-specific static area.
- Automatic variables are allocated to the function-specific static area.
- In the case of the leaf function[Note], arguments and automatic variables are allocated to the saddr area below 0FEFFH, in the order of description starting from the high-order addresses. Since the saddr area is commonly used by the leaf functions of all modules, this area is referred to as the shared area. The maximum size of the shared area is defined by the parameter when the -sm option is specified.

```
-sm [ nn ] : nn = 0-16
```

nn bytes are assigned as shared area and the rest are allocated to the function-specific static area. If nn = 00 is specified or this specification is omitted, the shared area is not used.

Note For the functions that do not call functions, it is not necessary to describe norec/__leaf since the compiler executes automatic determination.

- It is possible to add the sreg/__sreg keywords to function arguments and automatic variables. Function arguments and automatic variables that have the sreg/__sreg keywords added are allocated to the saddr area. As a result, bit manipulation becomes possible.
- By specifying the -rk option, function arguments and automatic variables (except for the static variables in functions) are allocated to saddr and bit manipulation becomes possible (Refer to "(3) How to use the saddr area (sreg / __sreg)").
- The compiler executes the following macro definition automatically.

```
#define __STATIC_MODEL__        1
```

EFFECT

- Normally, instructions that access the static area are shorter and faster than those that access static frames. Accordingly, it is possible to shorten object codes and increase execution speed.
- The save/restore processing of arguments and variables that use the saddr area (register variables in interrupt functions, norec function argument/automatic variables, run time library augments) is not performed, as a result, it is possible to increase the speed of interrupt processing.
- Memory space can be saved since the data area is commonly used by several leaf functions.

USAGE

- Specify the -sm option during compilation.

  The object in this case is called the static model, while the object without specification of the -sm option is called normal model.

EXAMPLE

- An example of the -sm4 specification is as follows.

  < C source >

```
void    sub ( char , char , char ) ;
void    main ( )
{
        char    i = 1 ;
        char    j , k ;
        j = 2 ;
        k = i + j ;
        sub ( i ,  j , k ) ;
}
void    sub ( char p1 , char p2 , char p3 )
{
        char    a1 , a2 ;
        a1 = 1<<p1 ;
        a2 = p2 + p3 ;
}
```

< Output object of compiler >

```
@@DATA          DSEG
?L0003 :        DS      ( 1 )           ; Automatic variable i of function main
?L0004 :        DS      ( 1 )           ; Automatic variable j of function main
?L0005 :        DS      ( 1 )           ; Automatic variable k of function main
?L0008 :        DS      ( 1 )           ; Automatic variable a2 of function sub

; line  1 :     void sub ( char , char , char ) ;
; line  2 :     void main ( )
; line  3 :     {

@@CODE          CSEG
_main :
; line  4 :     char    i = 1 ;
                mov     a , #01H        ; 1
                mov     !?L0003 , a     ; i     ; Automatic variable i
; line  5 :     char    j , k ;
; line  6 :     j = 2 ;
                inc     a
                mov     !?L0004 , a     ; j     ; Automatic variable j
; line  7 :     k = i + j ;
                add     a , !?L0003     ; i     ; Add i and j
                mov     !?L0005 , a     ; k     ; Substitute for k
; line  8 :     sub ( i , j , k ) ;
                movw    hl , ax                 ; Passes k through register H
                mov     a , !?L0004     ; j
                movw    bc , ax                 ; Passes j through register B
                movw    a , !?L0003     ; i     ; Passes i through register A
                call    !_sub
; line  9 :     }
                ret
; line  10 :    void sub ( char p1 , char p2 , char p3 )
; line  11 :    {
_sub :
                mov     _@KREG15 , a            ; Allocates the 1st argument to
                                                ; the shared area
                movw    ax , bc
                mov     _@KREG14 , a            ; Allocates the 2nd argument to
                                                ; the shared area
                movw    ax , hl
                mov     _@KREG13 , a            ; Allocates the 1st argument to
                                                ; the shared area
; line  12 :    char       a1 , a2 ;
; line  13 :    a1 = p1 ;
                mov     a , _@KREG15    ; p1    ; 1st argument p1
                mov     _@KREG12 , a    ; a1    ; Automatic variable a1 is in
                                                ; the shared area
; line  14 :    a2 = p2 + p3 ;
                mov     a , _@KREG14    ; p2    ; 2nd argument p2
                add     a ,_@KREG13     ; p3    ; Adds 3rd argument p3
                mov     !?L0008 , a     ; a2    ; Automatic variable a2 is in
                                                ; the specific function area
; line   15 :   }
                ret
```

RESTRICTIONS

- Module of a static model cannot be link with a modules of a normal model. However, modules of a static model can be linked each other even if the maximum size of the shared area is different.
- Floating-point numbers are not supported. If the float and double keywords are described, a fatal error occurs.
- Arguments are limited to a maximum of 3 arguments and 6 bytes in total.
- It is impossible to use variable length arguments since arguments are not passed through stacks. Using variable length arguments causes an error.
- Arguments and return values of structures/unions cannot be used. The description of these arguments and values causes an error.
- The noauto/norec/__leaf functions cannot be used. A warning message is output and the descriptions are ignored (Refer to "(5) noauto functions (noauto)", "(6) norec functions (norec)").
- Recursive functions cannot be used. As function arguments and the automatic variable area are statically secured, recursive functions cannot be used. An error is generated for recursive functions that can be detected by the compiler.
- A prototype declaration cannot be omitted. An error is generated if neither the no function's real definition nor a prototype declaration exist, in spite of there being a function call.
- Due to the restrictions of arguments and inability to use recursive functions, some standard libraries cannot be used.
- If the -zl option has not been specified, a warning is output and processing is carried out as if the -zl option was specified. long types are therefore always regarded as int types (see "(24) Type modification (-zi)").

COMPATIBILITY

< From another C compiler to the CC78K0S >

- When creating objects of normal model, source modification is not needed unless the -sm option is specified.
- To create a static model object, modifications are made according to the method above.

< From the CC78K0S to another C compiler >

- Source modification is not needed if re-compiling is performed by another compiler.

CAUTION

- Since arguments/automatic variables are secured statically, the contents of arguments/automatic variables in recursive functions may be destroyed. An error occurs when the function calls itself directly. However, no error occurs when the function calls itself after an other function is called since the compiler cannot detect this processing.
- During an interruption, the contents of arguments/automatic variables may be destroyed if the function being processed is called by interrupt servicing (interrupt functions and functions that are called by interrupt functions).
- During an interruption, save/return of the shared area is not executed even when the functions being processed are using the shared area.

(24) Type modification (-zi)

(a) Change from int/short type to char type

FUNCTION

- int and short types are regarded as char type. In other words, int and short descriptions become equal to a char description.
- Details of the type modification are given as follows (Some -qu options are affected).

Table 11-12 Details of Type Modification (Change from int and short Type to char Type)

Type Described in C Source	Option	Type after Modification
short, short int, int	With -qu	unsigned char
short, short int, int	Without -qu	signed char
unsigned short, unsigned short int, unsigned, unsigned int	-	unsigned char
signed short, signed short int, signed, signed int	-	signed char

- Outputs warning message to the line where the int or short keywords first appeared in C source.
- The -qc option becomes effective regardless of whether it is specified. A warning message is output when there is no -qc option specification, and the -qc option becomes effective.
- If the -za option is specified at the same time (such as the -zai option), a warning message is output (only when -w2 is specified).
- The following statement can be described by a type specifier and omitted, so are regarded as char type.

  (i) Arguments and returned values of functions

  (ii) Type specifier omitted variables/function declaration
- The compiler executes the following macro definition automatically.

```
#define __FROM_INT_TO_CHAR__    1
```

- Some standard libraries cannot be used.

USAGE

- The -zi option is specified.

RESTRICTIONS

- -zi specified and -zi unspecified modules cannot be linked together.

(b) Change from long type to int type

FUNCTION

- long type is regarded as int type. In other words, a long description becomes equal to an int description.
- Details of the type modification are given as follows.

Table 11-13 Details of Type Modification (Change from long Type to int Type)

Type Described in C Source	Type after Modification
unsigned long, unsigned long int	unsigned int
long, long int, signed long, signed long int	signed int

- Outputs warning message to the line where the long keyword first appeared in C source.
- If the -za option is specified at the same time (-zal), a warning message is output (only when -w2 is specified).
- The compiler executes the following macro definition automatically.

```
#define __FROM_LONG_TO_INT__    1
```

- Some standard libraries cannot be used.

USAGE

- The -zl option is specified.

RESTRICTIONS

- -zl specified and -zl unspecified modules cannot be linked together.

(25) Pascal function (__pascal)

FUNCTION

- Generates the code that the correction of the stack used for the place of arguments during the function call is performed on the called function side, not on the side calling the function.

EFFECT

- Object code can be shortened if a lot of function call appears.

USAGE

- When a function is declared, a __pascal attribute is added to the beginning.

RESTRICTIONS

- The pascal function does not support variable length arguments. If a variable length argument is defined, a warning is output and the __pascal keyword is disregarded.
- In pascal function, the keywords norec / __interrupt cannot be specified. If they are specified, in the case of the norec keyword, the __pascal keyword is disregarded and in the case of the __interrupt / __interrupt_brk / __rtos_interrupt keywords, an error is output.
- If a prototype declaration is incomplete, it won't operate normally, so a warning message is output when a pascal function's physical definition or prototype declaration is missing.
- Pascal functions are not supported when the static model specification option (-sm) is specified. If -sm is specified when using the pascal function, a warning message is output to the place where the __pascal keyword first appeared, and the __pascal keyword in the input file is ignored.

EXPLANATION

- The -zr option enables the change of all functions to the pascal function. However, if the pascal function is used for the functions that have few calls, the object code may increase.

EXAMPLE

< C source >

```
__pascal        int     func ( int a , int b , int c ) ;
void    main ( )
{
        int     ret_val ;

        ret_val = func ( 5 , 10 , 15 ) ;
}
__pascal        int     func ( int a , int b , int c )
{
        return ( a + b + c ) ;
}
```

< Output object of compiler >

```
_main :
        push    hl
        movw    ax , #02H
        callt   [ _@cprep ]
        movw    ax , #0FH       ; 15
        push    ax
        mov     x , #0AH        ; 10
        push    ax
        mov     x , #05H        ; 5
        call    !_func
        movw    ax , bc         ; The stack is not modified here.
        mov     [ hl + 1 ] , a  ; ret_val
        xch     a , x
        mov     [ hl ] , a      ; ret_val
        pop     ax
        pop     hl
        ret

_func :
        push    hl
        push    ax
        movw    ax , sp
        movw    hl , ax
        mov     a , [hl]        ; a
        mov     a , [ hl + 6 ]  ; b
        xch     a , x
        mov     a , [ hl + 1 ]  ; a
        addc    a , [ hl + 7 ]  ; b
        xch     a , x
        add     a , [ hl + 8 ]  ; c
        xch     a , x
        addc    a , [ hl + 9 ]  ; c
        movw    bc , ax
        pop     ax
        pop     hl
        pop     de              ; Obtains the return address
        pop     ax              ;
        pop     ax              ; The 4-byte stack that was consumed by
                                ; the caller is modified.
        push    de              ; Return address is reloaded
```

COMPATIBILITY

< From other C compiler to the CC78K0S >

- If the reserved word, __pascal is not used, modification is not required.
- To change to the Pascal function, change according to the above method.

< From the CC78K0S to another C compiler >

- Compatibility is maintained by using #define.
- By this conversion, the Pascal function is regarded as an ordinary function.

(26) Automatic pascal functionization of function call interface (-zr)

FUNCTION

- With the exception of norec / __interrupt variable length argument functions, __pascal attributes are added to all functions.

USAGE

- The -zr option is specified during compilation.

RESTRICTIONS

- Modules in which the -zr option is specified and modules in which the -zr option is not specified cannot be linked. If a link is executed, it results in a link error.
- It is impossible to specify the static model specification option (-sm) and the -zr option at the same time. If specified, a warning message is output and the -zr option is ignored.
- Since the mathematical function standard library does not support the pascal function, the -zr option cannot be used when the mathematical function standard library is used.

  Remark For pascal function call interface, refer to "11.7.6 Pascal function call interface".

(27) Method of int expansion limitation of argument/return value (-zb)

FUNCTION

- When the type definition of the function return value is char/unsigned char, the int expansion code of the return value is not generated.
- When the prototype of the function argument is defined and the argument definition of the prototype is char/unsigned char, the int expansion code of the argument is not generated.

EFFECT

- The object code is reduced and the execution speed improved since the int expansion codes are not generated.

USAGE

- The -zb option is specified during compilation.

EXAMPLE

< C source >

```
unsigned char   func1 ( unsigned char x , unsigned char y ) ;
unsigned char   c , d , e ;
void    main ( )
{
        c = func1 ( d , e ) ;
        c = func2 ( d , e ) ;
}
unsigned char   func1 ( unsigned char x , unsigned char y )
{
        return  x + y ;
}
```

- When -zb is specified

< Output object of compiler >

```
_main :
; line  5 :     c = func1 ( d , e ) ;
        mov     a , !_e
        xch     a , x           ; Do not execute int expansion
        push    ax
        mov     a , !_d
        xch     a , x           ; Do not execute int expansion
        call    !_func1
        pop     ax
        mov     a , c
        mov     !_c , a
; line  6 :     c = func2 ( d , e ) ;
        mov     a , !_e
        xch     a , x
        xch     a , a           ; Execute int expansion since there is
                                ; no prototype declaration

        push    ax
        mov     a , !_d
        xch     a , x
        xor     a , a           ; Execute int expansion since there is
                                ; no prototype declaration

        call    !_func2
        pop     ax
        mov     a , c
        mov     !_c , a
;line   7:      }
        ret
; line  8 :
; line  9 :     unsigned char   func1 ( unsigned char x , unsigned char y )
_func1 :
        push    hl
        push    ax
        movw    ax , sp
        movw    hl , ax
; line  10 :    return x + y ;
        mov     a , [ hl ]      ; x
        add     a , [ hl + 6 ]  ; y
        mov     c , a
; line  11 :    }
        pop     ax
        pop     hl
        ret
        END
```

RESTRICTIONS

- If the files are different between the definition of the function body and the prototype declaration to this function, the program may operate incorrectly.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- If the prototype declarations for all definitions of function bodies are not correctly performed, perform correct prototype declaration. Alternatively, do not specify the -zb option.

< From the CC78K0S to another C compiler >

- No modification is needed.

(28) Array offset calculation simplification method (-qw2 / -qw4)

FUNCTION

- When calculating the offset of char/unsigned char/unsigned int/short/unsigned short types and the index is an unsigned char-type variable, a code to calculate only low-order bytes is generated based on the presumption that there is no carry-over.
- When the -qw2 option is specified, a code to calculate only low-order bytes for the offset is generated only when referencing the sequence of the saddr area configuration with an unsigned char variable.
- When the -qw4 option is specified, a code to calculate only lower bytes for the offset is generated with a size-based priority only when referencing the sequence of the saddr area configuration with an unsigned char variable.

EFFECT

- Realizes object code reduction and execution speed improvement since the offset calculation code is simplified.

USAGE

- Specifies the -qw2 and -qw4 options during compilation.

EXAMPLE

< C source >

```
unsigned char           c ;
unsigned char           ary [ 10 ] ;
sreg unsigned char      sary [ 10 ] ;
void    main ( )
{
        unsigned char   a ;

        a = ary [ c ] ;
        a = sary [ c ] ;
}
```

- When -qw2 is specified

< Output object of compiler >

```
_main :
        push    hl
        push    ax
        movw    ax , sp
        movw    hl , ax
; line  6 :     unsigned char   a ;
; line  7 :     a = ary [ c ] ;
        mov     a , !_c
        xch     a , x
        xor     a , a
        addw    ax , #_ary
        movw    de , ax
        mov     a , [ de ]
        mov     [ hl + 1 ] , a          ; a
; line  8 :     a = sary [ c ] ;
        mov     a , !_c
        add     a , #low ( _sary )
        mov     e , a                   ; Calculate only low-order bytes
        mov     d , #0FEH               ; 254
        mov     a , [ de ]
        mov     [ hl + 1 ] , a          ; a
; line  9 : }
        pop     ax
        pop     hl
        ret
        END
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- No modification is needed.

< From the CC78K0S to another C compiler >

- No modification is needed.

(29) Register direct reference function (#pragma realregister)

FUNCTION

- Output the code that accesses the object register with direct in-line expansion instead of function call, and generates an object file.
- When there is no #pragma directive, the register direct reference function is regarded as an ordinary function.

EFFECT

- Due to the C description, register access can be performed easily.

USAGE

- This function is described in the same format as a function call (Refer to [Register direct reference function list] later in this chapter).

  There are 21 types of register direct reference function names.

```
__geta , __seta , __getax , __setax , __getcy , __setcy , __set1cy ,
__clr1cy , __not1cy , __inca , __deca , __rora , __rorca , __rola ,
__rolca , __shla , __shra , __ashra , __nega , __coma , __absa
```

- By using the #pragma realregister directive in a module, use of register direct reference function is declared.

  The followings can be described before the #pragma realregister directive.

  (i) Comments

  (ii) Other #pragma directives

  (iii) Preprocess directives that do not generate variable definitions/references nor function definitions/ references

EXAMPLE

< C source >

```
#pragma realregister
unsigned char   c = 0x88 , d , e ;
void    main ( )
{
        __seta ( c ) ;          /* Sets the variable of C in A register */
        __shla ( ) ;            /* Logically shifts 1 bit to left */
        d = __geta ( ) ;        /* Sets the value of A register in variable d */
        if ( __getcy ( ) ) {    /* Refers CY (checks overflow) */
                e = 1 ;         /* Sets e to 1 when CY = = 1 */
        }
}
```

< Output object of compiler >

```
_main :
; line  5 :   __seta ( c ) ;      /* Sets the variable of C in A register */
        mov   a , !_c
; line  6 :   __shla ( ) ;        /* Logically shift 1 bit to left */
        add   a , a
; line  7 :   d = __geta ( ) ;    /* Sets value of A register in variable d */
        mov   !_d , a
; line  8 :   if ( __getcy ( ) ) {    /* Refers CY (checks overflow) */
        bnc   $?L0003
; line  9 :   e = 1 ;             /* Sets e to 1 when CY = = 1 */
        mov   a , #01H ;1
        mov   !_e , a
?L0003 :
; line  10 :  }
; line  11 :  }
        ret
```

[Register direct reference function list]

(1) unsigned char __geta (void) ;

Obtains the value of the A register.

(2) void __seta (unsigned char x) ;

Sets x in the A register.

(3) unsigned int __getax (void) ;

Obtains the value of the AX register.

(4) void __setax (unsigned int x) ;

Sets x in the AX register.

(5) bit __getcy (void) ;

Obtains the value of the CY flag.

(6) void __setcy (unsigned char x) ;

Sets the lower 1 bit of x in the CY flag.

(7) void __set1cy (void) ;

Generates the set1 CY instruction.

(8) void __clr1cy (void) ;

Generates the clr1 CY instruction.

(9) void __not1cy (void) ;

Generates the not1 CY instruction.

(10) void __inca (void) ;

Generates the inc a instruction.

(11) void __deca (void) ;

Generates the dec a instruction.

(12) void __rora (void) ;

Generates 1 ror a, instruction.

(13) void __rorca (void) ;

Generates 1 rorc a, instruction.

(14) void __rola (void) ;

Generates 1 rol a, instruction.

(15) void __rolca (void) ;

Generates 1 rolc a, instruction.

(16) void __shla (void) ;

Generates the code that performs logical-shift of the A register 1 bit to the left.

(17) void __shra (void) ;

Generates the code that performs a logical-shift of the A register 1 bit to the right.

(18) void __ashra (void) ;

Generates the code that performs an arithmetic-shift of the A register 1 bit to the right.

(19) void __nega (void) ;

Generates the code that obtains 2's complement in the A register.

(20) void __coma (void) ;

Generates the code that obtains 1's complement in the A register.

(21) void __absa (void) ;

Generates the code that obtains the absolute value of the A register.

RESTRICTIONS

- The function name for that register direct reference cannot be not used as function name. The register direct reference function is described in lowercase letters. A function described in uppercase letters are regarded as an ordinary function.
- The values of the A and AX registers, and the CY flag that are set by the __seta, __setax, and __setcy functions are not retained in the next code generation.
- The timing that is referenced by a and AX registers, and the CY flag with the __geta, __getax, and __getcy function are corresponds to the evaluation sequence of the expression.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- If the register direct reference function is not used, modification is not necessary.
- To change to the register direct referencing function, use the method above.

< From the CC78K0S to another C compiler >

- The "#pragma realregister" directive should be deleted or delimited using #ifdef. Register direct reference function names can be used as function names.
- When using "pragma realregister" as a register direct reference function, the change to the source program must conform to the specification of the C compiler (#asm, #endasm, or asm( );, etc.).

CAUTION

- There is no guarantee that CY, A, AX will be saved as intended before the register direct reference function is executed. Accordingly, it is recommended to use this function before values change by describing it in the first term of the expansion.

(30) Memory manipulation function (#pragma inline)

FUNCTION

- An object file is generated by the output of the standard library memory manipulation functions memcpy and memset with direct inline expansion instead of function call.
- When there is no #pragma directive, the code that calls the standard library functions is generated.

EFFECT

- Compared with when a standard library function is called, the execution speed is improved.
- Object code is reduced if a constant is specified for the specified character number.

USAGE

- The function is described in the source in the same format as a function call.
- The following items can be described before #pragma inline.

  (i) Comments

  (ii) Other #pragma directives

  (iii) Preprocess directives that do not generate variable definitions/references or function definitions/ references

EXAMPLE

< C source >

```
#pragma inline
char    ary1 [ 100 ] , ary2 [ 100 ] ;
void    main ( )
{
        memset ( ary1 , ' A ' , 50 ) ;
        memcpy ( ary1 , ary2 , 50 ) ;
}
```

- When -sm is not specified

< Output object of compiler >

```
_main :
        push    hl
; line  5 :     memset ( ary1 , ' A ' , 50 ) ;
        movw    de , #_ary1
        mov     a , #041H       ; 65
        mov     c , #032H       ; 50
        mov     [ de ] , a
        incw    de
        dbnz    c , $$-2
; line  6 :     memcpy ( ary1 , ary2 , 50 ) ;
        movw    de , #_ary1
        movw    hl , #_ary2
        mov     c , #032H       ; 50
        mov     a , [ hl ]
        mov     [ de ] , a
        incw    de
        incw    hl
        dbnz    c , $$-4
; line  7 :     }
        pop     hl
        ret
```

- When -sm is specified

```
_main :
        push    de
; line  5 :     memset ( ary1 , ' A ' , 50 ) ;
        movw    hl , #_ary1
        mov     a , #041H       ; 65
        mov     c , #032H       ; 50
        mov     [ hl ] , a
        incw    hl
        dbnz    c , $$-2
; line  6 :     memcpy ( ary1 , ary2 , 50 ) ;
        movw    hl , #_ary1
        movw    de , #_ary2
        mov     c , #032H       ; 50
        mov     a , [ de ]
        mov     [ hl ] , a
        incw    de
        incw    hl
        dbnz    c , $$-4
; line  7 :     }
        pop     de
        ret
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modification is not needed if the memory manipulation function is not used.
- When changing the memory manipulation function, use the method above.

< From the CC78K0S to another C compiler >

- The #pragma inline directive should be deleted or delimited using #ifdef.

(31) Absolute address allocation specification (__directmap)

FUNCTION

- The initial value of an external variable declared by __directmap and a static variable in a function is regarded as the allocation address specification, and variables are allocated to the specified addresses.
- The __directmap variable in the C source is treated as an ordinary variable.
- Because the initial value is regarded as the allocation address specification, the initial value cannot be defined and remains an undefined value.
- The specifiable address specification range, secured area range linked by the module for securing the area for the specified addresses, and variable duplication check range are shown below.

Address Specification Range	Secured Area Range	Duplication Check Range
0x80 - 0xffff	0xfd00 - 0xfeff	0xf000 - 0xfeff

- If the address specification is outside the address specification range, an error is output.
- If the allocation address of a variable declared by __directmap is duplicated and is within the duplication check range, a W0762 warning message is output and the name of the duplicated variable is displayed.
- If the address specification range is inside the saddr area, the __sreg declaration is made automatically and the saddr instruction is generated.
- If char/unsigned char/short/unsigned short/int/unsigned int/long/unsigned long type variables declared by __directmap are bit referenced, sreg/__sreg must be specified along with __directmap. If they are not, an error occurs.

EFFECT

- One or more variables can be allocated to the same arbitrary address.

USAGE

- Declare __directmap in the module in which the variable to be allocated in an absolute address is to be defined.

```
__directmap   Type name   Variable name                  = Allocation address specification;
__directmap   static      Type name      Variable name   = Allocation address specification;
__directmap   __sreg      Type name      Variable name   = Allocation address specification;
__directmap   __sreg      static         Type name       Variable name= Allocation address
specification;
```

- If __directmap is declared for a structure/union/array, specify the address in braces {}.
- __directmap does not have to be declared in a module in which a __directmap external variable is referenced, so only declare extern.

```
extern Type name Variable name;
extern __sreg Type name Variable name;
```

- To generate the saddr instruction in a module in which a __directmap external variable allocated inside the saddr area is referenced, __sreg must be used together to make extern__sreg Type name Variable name;.

EXAMPLE

< C source >

```
__directmap     char            c = 0xfe00 ;
__directmap     __sreg char     d = 0xfe20 ;
__directmap     __sreg char     e = 0xfe21 ;
__directmap     struct  x {
        char    a ;
        char    b ;
} xx = { 0xfe30 } ;
void    main ( )
{
        c = 1 ;
        d = 0x12 ;
        e.5 = 1 ;
        xx.a = 5 ;
        xx.b = 10 ;
}
```

< Output object >

```
        PUBLIC  _c
        PUBLIC  _d
        PUBLIC  _e
        PUBLIC  _xx
        PUBLIC  _main
_c      EQU     0FE00H      ; Addresses for variables declared by __directmap
_d      EQU     0FE20H      ; are defined by EQU
_e      EQU     0FE21H      ;
_xx     EQU     0FE30H      ;
        EXTRN   __mmfe00    ; EXTRN output for linking secured area modules
        EXTRN   __mmfe20    ;
        EXTRN   __mmfe21    ;
        EXTRN   __mmfe30    ;
        EXTRN   __mmfe31    ;
@@CODE  CSEG
_main :
; line  10 :    c = 1 ;
        mov     a , #01H        ;1
        mov     !_c , a
; line  11 :    d = 0x12 ;
        mov     _d , #012H      ; saddr instruction output because address
                                ; specified in saddr area
; line  12 :     e.5 = 1 ;
        set1     _e.5           ; Bit manipulation possible because __sreg
                                ; also used
; line  13 :     xx.a = 5 ;
        mov     _xx , #05H      ; saddr instruction output because address
                                ; specified in saddr area
; line  14 :    xx.b = 10 ;
        mov     _xx + 1 , #0AH  ; saddr instruction output because address
                                ; specified in saddr area
; line  15 :    }
        ret
```

RESTRICTIONS

- __directmap cannot be specified for function arguments, return values, or automatic variables. If it is specified in these cases, an error occurs.
- If short/unsigned short/int/unsigned int/long/unsigned long type variables are allocated to odd addresses, the correct code will be generated in the file declared by __directmap, but illegal code if these variables are referenced by an extern declaration from an external file.
- If an address outside the secured area range is specified, the variable area will not be secured, making it necessary to either describe a directive file or create a separate module for securing the area.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- No modification is necessary if the keyword __directmap is not used.
- To change to the __directmap variable, modify according to the description method above.

< From the CC78K0S to another C compiler >

- Compatibility can be attained using #define (refer to "11.6 Modifications of C Source" for details).
- When the __directmap is being used as the absolute address allocation specification, modify according to the specifications of each compiler.

(32) Static model expansion specification (-zm)

FUNCTION

- The 8-byte saddr area of _@NRAT00 to _@NRAT07 is secured as area reserved by the compiler for arguments and work.
- Temporary variables can be used by declaring __temp for arguments and automatic variables (refer to "(33) Temporary variables (__temp)" for details).
- The number of argument declarations that can be described ranges from 3 to 6 for int-sized variables and 3 to 9 for char-sized variables. The 4th and subsequent arguments are set by the calling side to the area of _@NRAT00 to _@NRAT05 and copied by the called side to a separate area. However, if __temp has been declared for a leaf function or an argument, the called side will not copy the argument, and the _@NRATxx area where the argument was set will be used as is.
- Structures and unions that are 2 bytes or smaller can be described for arguments.
- Structures and unions can be described for function return values. If the structures and unions are 2 bytes or smaller, the value will be returned. If 3 bytes or larger the return value will be stored in a static area secured for storing return values and returned to the top address of that area.
- The 8-byte area of _@NRAT00 to _@NRAT07 is also used as the leaf function shared area. In shared-area allocation, the 8-byte area of _@NRAT00 to _@NRAT07 is allocated to first, and then the _@KREGxx area secured by specifying the -sm option.
- Arrays, unions, and structures can also be allocated to _@NRATxx and _@KREGxx, provided their size fits into the _@KREGxx area secured by specifying _@NRATxx and -sm.
- Interrupt functions that are targeted for saving are shown in Table 11-14 below.

Table 11-14 Interrupt Functions Targeted for Saving

Restore/Save Area	NO BANK	With Function Call		Without Function Call	
		-zm1	-zm2	-zm1	-zm2
Registers used	NG	NG	NG	OK	OK
All registers	NG	OK	OK	NG	NG
Entire _@NRATxx area	NG	OK	OK	NG	NG
Entire _@KREGxx area	NG	OK	NG	NG	NG
@KREGxx area used	NG	NG	OK	NG	OK

OK : Saved

NG : Not saved

Note, however, that when #pragma interrupt is specified, the interrupt functions that are targeted for saving can be limited by specifying as follows.

SAVE_R (save/restore targets limited to registers)

SAVE_RN (save/restore targets limited to registers and _@NRATxx).

- The only difference between the -zm1 and -zm2 options is in the treatment of the _@KREGxx area secured by specifying -sm.
  When the -zm1 option is specified, the _@KREGxx area is only used for leaf function shared area.
  When the -zm2 option is specified, the _@KREGxx area is saved/restored and arguments and automatic variables are allocated there (compatibility with the -qr option in the normal model).
- If the -zm option is specified when the -sm option has not been specified, a W0055 warning message is output and the -zm option specification is disregarded.

EFFECT

- Restrictions on existing static models can be relaxed, improving descriptiveness.

USAGE

- Specify the -zm option along with the -sm option when compiling.

EXAMPLE 1

< C source >

```
char    funcl ( char a , char b , char c , char d , char e ) ;
char    func2 ( char a , char b , char c , char d ) ;
void    main ( )
{
        char    a = 1 , b = 2 , c = 3 , d = 4 , e = 5 , r ;
        r = func1 ( a , b , c , d , e ) ;
}
char    func1 ( char a , char b , char c , char d , char e )
{
        char    r ;

        r = func2 ( a , b , c , d ) ;
        return  e + r ;
}
char    func2 ( char a , char b , char c , char d )
{
        return  a + b + c + d ;
}
```

- When -sm8, -zm1, and -qc are specified

< Output object >

```
_main :
; line  5 :     char    a = 1 , b = 2 , c = 3 , d = 4 , e = 5 , r ;
        mov     a , #01H        ; 1
        mov     !L0003 , a      ; a
        inc     a
        mov     !L0004 , a      ; b
        inc     a
        mov     !L0005 , a      ; c
        inc     a
        mov     !L0006 , a      ; d
        inc     a
        mov     !L0007 , a      ; e
; line  6 :
; line  7 :     r = func1 ( a , b , c , d , e ) ;
        mov     _@NRAT01 , a    ; 5th argument set in saddr area for
                                ; passing arguments
        mov     a , !L0006      ; d
        mov     _@NRAT00 , a    ; 4th argument set in saddr area for
                                ; passing arguments
        mov     a , !L0005      ; c
        movw    hl , ax
        mov     a , !L0004      ; b
        movw    bc , ax
        mov     a , !L0003      ; a
        call    !_func1
        mov     !L0008 , a      ; r
; line  8 :     }
        ret
; line  9 :    char    func1 ( char a , char b , char c , char d , char e )
; line  10 :    {
_func1 :
        mov     !L0011, a
        movw    ax , bc
        mov     !L0012 , a
        movw    ax , hl
        mov     !L0013 , a
        mov     a , _@NRAT00    ; Copied to static area
        mov     !L0014 , a      ;
        mov     a , _@NRAT01    ; Copied to static area
        mov     !L0015 , a
; line  11 :    char    r ;
; line  12 :
; line  13 :    r = func2 ( a , b , c , d )
        mov     a , !L0014      ; d
        mov     _@NRAT00,a      ; 4th argument set in saddr area for
                                ; passing arguments
        mov     a , !L0013      ; c
        movw    hl , ax
        mov     a , !L0012      ; b
        movw    bc , ax
        mov     a , !L0011      ; a
        call    !_func2
        mov     !L0016 , a      ; r
; line  14 :    return  e + r ;
        add     a , !L0015      ; e
L0010 :
; line  15 :    }
        ret
```

```
; line  16 :    char    func2 ( char a , char b , char c , char d )
; line  17 :    {
_func2 :
        mov     _@NRAT01 , a
        movw    ax , bc
        mov     _@NRAT02 , a
        movw    ax , hl
        mov     _@NRAT03 , a
; line  18 :    return  a + b + c + d ;
        mov     a , _@NRAT01    ; a
        add     a , _@NRAT02    ; b
        add     a , _@NRAT03    ; c
        add     a , _@NRAT00    ; d _@NRAT00 used as is for leaf function
L0018 :
; line  19 :    }
        ret
```

- When -sm8, -zm2, and -qc are specified

< Output object >

```
@@CODE  CSEG
_main :
        movw    ax , _@KREG10   ;
        push    ax              ; Area of _@KREG10 to _@KREG15 saved
        movw    ax , _@KREG12   ;
        push    ax              ;
        movw    ax , _@KREG14   ;
        push    ax              ;
; line  5 :     char    a = 1 , b = 2 , c = 3 , d = 4 , e = 5 , r ;
        mov     _@KREG15 , #01H ; a , 1 Variables allocated to _@KREG11
                                ;       to _@KREG15
        mov     _@KREG14 , #02H ; b , 2
        mov     _@KREG13 , #03H ; c , 3
        mov     _@KREG12 , #04H ; d , 4
        mov     _@KREG11 , #05H ; e , 5
; line  6 :
; line  7 :     r = func1 ( a , b , c,  d , e ) ;
        mov     a , _@KREG11    ; e
        mov     _@NRAT01 , a    ; 5th argument set in saddr area for
                                ; passing arguments
        mov     a , _@KREG12    ; d
        mov     _@NRAT00 , a    ; 4th argument set in saddr area for
                                ; passing arguments
        mov     a , _@KREG13    ; c
        movw    hl , ax
        mov     a , _@KREG14    ; b
        movw    bc , ax
        mov     a , _@KREG15    ; a
        call    !_func1
        mov     _@KREG10 , a    ; r
; line  8 :     }
        pop     ax              ;
        movw    _@KREG14,ax     ; Area of _@KREG10 to _@KREG15 restored
        pop     ax              ;
        movw    _@KREG12,ax     ;
        pop     ax              ;
        mov     w_@KREG10 , ax  ;
        ret
```

```
; line  9 :     char func1 ( char a , char b , char c , char d , char e )
; line  10:     {
_func1 :
        mov     _@NRAT06 , a    ; Register a saved
        movw    ax , _@KREG10   ;
        push    ax              ; Area of _@KREG10 to _@KREG15 saved
        movw    ax , _@KREG12   ;
        push    ax              ;
        movw    ax , _@KREG14   ;
        push    ax              ;
        mov     a , _@NART06    ; Register a restored
        mov     _@KREG15 , a
        movw    ax , bc
        mov     _@KREG14 , a
        movw    ax , hl
        mov     _@KREG13 , a
        mov     a , _@NART00    ; Copied to _@KREG12
        mov     _@KREG12 , a
        mov     a , _@NART01    ; Copied to _@KREG11
        mov     _@KREG11 , a
; line  11 :    char r ;
; line  12 :
; line  13 :    r = func2 ( a , b , c , d )
        mov     a ,  _@KREG12   ; d
        mov     _@NRAT00 , a    ; 4th argument set in saddr area for
                                ; passing arguments
        mov     a , _@KREG13    ; c
        movw    hl , ax
        mov     a , _@KREG14    ; b
        movw    bc , ax
        mov     a , _@KREG15    ; a
        call    !_func2
        mov     _@KREG10 , a    ; r
; line  14 :    return e + r ;
        add     a , _@KREG11    ; e
L0004 :
; line  15 :    }
        movw    hl , ax         ; Register a saved
        pop     ax              ;
        movw    _@KREG14 , ax   ; Area of _@KREG10 to _@KREG15 restored
        pop     ax              ;
        movw    _@KREG12 , ax   ;
        pop     ax              ;
        movw    _@KREG10 , ax   ;
        movw    ax , hl         ; Register a restored
        ret
; line  16 :    char func2 ( char a , char b , char c , char d )
; line  17 :    {
_func2 :
        mov     _@NRAT01 , a
        movw    ax , bc
        mov     _@NRAT02 , a
        movw    ax , hl
        mov     _@NRAT03 , a
; line  18 :    return a + b + c + d ;
        mov     a , _@NRAT01    ; a
        add     a , _@NRAT02    ; b
        add     a , _@NRAT03    ; c
        add     a , _@NRAT00    ; d _@NRAT00 used as is for leaf function
L0006 :
; line  19 :    }
        ret
```

EXAMPLE 2

< C source >

```
__sreg  struct  x {
        unsigned char   a ;
        unsigned char   b : 1 ;
        unsigned char   c : 1 ;
} xx , yy ;
__sreg  struct  y {
        int     a ;
        int     b ;
} ss , tt ;
struct  x       func1 ( struct x ) ;
struct  y       func2 ( ) ;
void main ( )
{
        yy = func1 ( xx ) ;
        tt = func2 ( ) ;
}
struct  x       func1 ( struct x aa )
{
        aa.a = 0x12 ;
        aa.b = 0 ;
        aa.c = 1 ;
        return aa ;
}
struct  y       func2 ( )
{
        return  tt ;
}
```

- When -sm and -zm are specified

< Output object >

```
@@CODE CSEG
_main :
; line  14 :    yy = func1 ( xx ) ;
        movw    ax , _xx
        call    !_func1
        movw    _yy , ax
; line  15 :    tt = func2 ( ) ;
        call    !_func2
        movw    hl , ax
        push    de
        movw    de , #_tt
        mov     c , #04H                ; 4
        mov     a , [ hl ]
        mov     [ de ] , a
        incw    hl
        incw    de
        dbnz    c , $$-4
        pop     de
; line  16 :    }
        ret
; line  17 :    struct   x       func1 ( struct x aa )
; line  18 :    {
_func1 :
        movw    _@NRAT00 , ax
; line  19 :    aa.a = 0x12 ;
        mov     _@NRAT00 , #012H        ; aa ,18
; line  20 :    aa.b = 0 ;
        clr1    _@NRAT01.0
; line  21 :    aa.c = 1 ;
        set1    _@NRAT01.1
; line  22 :    return  aa ;
        movw    ax , _@NRAT00           ; aa Value returned because 2
                                        ; bytes or smaller
;line   23 :    }
        ret
; line  24 :    struct  y       func2 ( )
; line  25 :    {
; line  26 :    return  tt ;
        movw    hl , #_tt               ; Return value copied to secured
                                        ; static area
        push    de                      ; because 3 bytes or larger
        movw    de , #L0007
        mov     c , #04H                ; 4
        mov     a , [ hl ]
        mov     [ de ] , a
        incw    hl
        incw    de
        dbnz    c , $$-4
        pop     de
        movw    ax , #L0007         ; Returned top address of static area
; line  27 :    }
        ret
```

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The source program need not be modified.

< From the CC78K0S to another C compiler >

- The source program need not be modified.

(33) Temporary variables (__temp)

FUNCTION

- Arguments and automatic variables are allocated to the area of _@NRAT00 to _@NRAT07, regardless of whether they correspond to a leaf function. If arguments and automatic variables are not allocated to the area of _@NRAT00 to _@NRAT07 they will be treated in the same way as when __temp is not declared.
- The values of arguments and automatic variables declared by __temp are discarded upon a function call.
- __temp cannot be declared for external and static variables.
- If __sreg is declared as well, char/unsigned char/short/unsigned short/int/unsigned int variables can be bit manipulated.
- If __temp is declared when the -sm and -zm options have not been specified, a W0339 warning message is output and the __temp declaration in the file is disregarded.

EFFECT

- Because arguments and automatic variables declared by __temp share the area of _@NRAT00 to _@NRAT07, an argument and automatic variable area can be reserved.
- If the sections containing arguments and those containing automatic variables are clearly identified and the __temp declaration is applied to variables that do not require a guaranteed value match before and after a function call, memory can be reserved.

USAGE

- Specify the -sm and -zm options during compilation and declare __temp for arguments and automatic variables.

EXAMPLE

< C source >

```
void    func1 ( __temp char a , char b , char c , __sreg __temp char d ) ;
void    func2 ( char a ) ;
void    main ( )
{
        func1 ( 1 , 2 , 3 , 4 ) ;
}
void    func1 ( __temp char a , char b , char c , __sreg __temp char d )
{
        __temp  char    r ;

        d.1 = 0 ;
        r = a + b + c + d ;
        func2 ( r ) ;
}
void    func2 ( char r )
{
        int     a = 1 , b = 2 ;
        r++ ;
}
```

- When -sm, -zm, and -qc are specified

< Output object >

```
@@CODE CSEG
_main :
; line  5 :     func1 ( 1 , 2 , 3 , 4 ) ;
        mov     a , #04H                ; 4
        mov     _@NRAT00 , a
        mov     h , #03H                ; 3
        mov     b , #02H                ; 2
        mov     a , #01H                ; 1
        call     !_func1
; line  6 :     }
        ret
; line  7 :     void func1 ( __temp char a , char b , char c , __sreg __temp
char d )
; line  8 :     {
_func1 :
        mov     _@NRAT01 , a            ; Allocated to _@NRAT01
        mov     a , b
        mov     !L0005 , a
        mov     a , h
        mov     !L0006 , a
                                        ; Argument allocated to _@NRAT00 is
                                        ; unchanged
; line  9 :     __temp  char    r ;
; line  10 :
; line  11 :    d.1 = 0 ;
        clr1    _@NRAT00.1              ; Bit manipulation possible
; line  12 : r = a + b + c + d ;
        mov     a , _@NRAT01            ; a
        add     a , !L0005              ; b
        add     a , !L0006              ; c
        add     a , _@NRAT00            ; d
        mov     _@NRAT02 , a            ; r _@NRAT02 used
; line  13 :    func2 ( r ) ;
        call    !_func2
; line  14 :    }
                                        ; Values of _@NRAT00 to _@NRAT02
                                        ; changed after return
        ret
; line  15 :    void     func2 ( char r )
; line  16 :    {
_func2 :
        mov     _@NRAT00 , a
; line  17 :    int     a = 1 , b = 2 ;
        movw    _@NRAT02 , #01H         ; a , 1
        movw    _@NRAT04 , #02H         ; b , 2
; line  18 :    r++ ;
        inc     _@NRAT00
; line  19 :    }
        ret
```

< Output object >

```
@@CODE  CSEG
_main :
; line  5 :     func1 ( 1 , 2 , 3 , 4 ) ;
        mov     a , #04H                ; 4
        mov     _@NRAT00 , a
        mov     h , #03H                ; 3
        mov     b , #02H                ; 2
        mov     a , #01H                ; 1
        call    !_func1
; line  6 :     }
        ret
; line  7 :     void    func1 ( __temp char a , char b , char c , __sreg
__temp char d )
; line  8 :     {
_func1 :
        mov     _@NRAT01 , a            ; Allocated to _@NRAT01
        movw    ax , bc
        mov     !L0005 , a
        movw    ax , hl
        mov     !L0006 , a
                                        ; Argument allocated to _@NRAT00 is
                                        ; unchanged
; line  9 :     __temp  char    r ;
; line  10 :
; line  11 :    d.1 = 0 ;
        clr1    _@NRAT00.1              ; Bit manipulation possible
; line  12 :    r = a + b + c + d ;
        mov     a , _@NRAT01            ; a
        add     a , !L0005              ; b
        add     a , !L0006              ; c
        add     a , _@NRAT00            ; d
        mov     _@NRAT02 , a            ; r _@NRAT02 used
; line  13 :    func2 ( r ) ;
        call    !_func2
; line  14 :    }
                                        ; Values of _@NRAT00 to _@NRAT02
                                        ; changed after return
        ret
; line  15 :    void    func2 ( char r )
; line  16 :    {
_func2 :
        mov     _@NRAT00 , a
; line  17 :    int     a = 1 , b = 2 ;
        movw    ax , #01H               ; 1
        movw    _@NRAT02 , ax           ; a
        incw    ax
        movw    _@NRAT04 , ax           ; b
; line  18 :    r++ ;
        inc     _@NRAT00
; line  19 :    }
        ret
```

RESTRICTIONS

- If there are 3 arguments or fewer when a function is called, arguments and automatic variables declared by __temp can be described for the arguments at function call. If there are 4 or more arguments, because the values of the arguments could be discarded during argument evaluation, values described cannot be guaranteed.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- Modification is not necessary if the reserved word __temp is not used.
- To change to a temporary variable, modify according to the description method above.

< From the CC78K0S to another C compiler >

- Compatibility can be attained using #define (refer to "11.6 Modifications of C Source" for details). This modification means that the __temp variable is treated as an ordinary variable.

(34) Library supporting prologue/epilogue (-zd)

FUNCTION

- A specified pattern of the prologue/epilogue code can be replaced with a library call.
- Number of callt entries that users can use is reduced two in the case of a normal model and up to 10 in the case of a static model.
- The library replacement patterns in the case of a normal model are as follows.
  HL,_@KREGxx save/copy, stack frame secure -> callt [@@cprep2]
  HL,_@KREGxx restore, stack frame release -> callt [@@cdisp2]
- In the case of a static model, arguments are allocated to _@NRATxx and _@KREGxx so that the first 3 arguments accord with the patterns described below. When char and int are mixed, the allocation interval is adjusted so that it accords with the patterns of multiple int type arguments.
- The library replacement pattern in the case of a static model is as follows.

< For char 2 arguments >

```
mov     _@NRAT00 , a            ->  callt [ @@nrcp2 ]
movw     ax , bc
mov     _@NRAT01 , a

mov     _@KREG15 , a            ->  callt [ @@krcp2 ]
movw     ax , bc
mov     _@KREG14 , a
```

< For char 3 arguments >

```
mov     _@NRAT05 , a            ->  callt [ @@nrcp3 ]
movw    ax , bc
mov     _@NRAT06 , a
movw    ax , hl
mov     _@NRAT07 , a

mov     _@KREG15 , a            ->  callt [ @@krcp3 ]
movw    ax , bc
mov     _@KREG14 , a
movw    ax , hl
mov     _@KREG13 , a

mov     _@NRAT06 , a            ->  call !@@nkrc3
movw    ax , bc
mov     _@NRAT07 , a
movw    ax , hl
mov     _@KREG15 , a
```

< For int 2 arguments >

```
movw    _@NRAT00 , ax           ->  callt [ @@nrip2 ]
movw    ax , bc
movw    _@NRAT02 , ax

movw    _@KREG14 , ax           ->  callt [ @@krip2 ]
movw    ax , bc
movw    _@KREG12 , ax
```

< For int 3 arguments >

```
movw    _@NRAT02 , ax           ->  callt [ @@nrip3 ]
movw    ax , bc
movw    _@NRAT04 , ax
movw    ax , hl
movw    _@NRAT06 , ax

movw    _@KREG14 , ax           ->  callt [ @@krip3 ]
movw    ax , bc
movw    _@KREG12 , ax
movw    ax , hl
movw    _@KREG10 , ax

movw    _@NRAT04 , ax           ->  call !@@nkri31
movw    ax , bc
movw    _@NRAT06 , ax
movw    ax , hl
movw    _@KREG14 , ax

movw    _@NRAT06 , ax           ->  call !@@nkri32
movw    ax , bc
movw    _@KREG14 , ax
movw    ax , hl
movw    _@KREG12 , ax
```

< For save/restore >

```
_@NRAT00 to _@NRAT07 save       ->  callt [ @@nrsave ]

_@NRAT00 to _@NRAT07 restore    ->  callt [ @@nrload ]

_@KREG14 to 15 save             ->  call !@@krs02

_@KREG12 to 15 save             ->  call !@@krs04
                                ->  call !@@krs04i
_@KREG10 to 15 save             ->  call !@@krs06
                                ->  call !@@krs06i

_@KREG08 to 15 save             ->  call !@@krs08
                                ->  call !@@krs08i
_@KREG06 to 15 save             ->  call !@@krs10
                                ->  call !@@krs10i

_@KREG04 to 15 save             ->  call !@@krs12
                                ->  call !@@krs12i

_@KREG02 to 15 save             ->  call !@@krs14
                                ->  call !@@krs14i

_@KREG00 to 15 save             ->  call !@@krs16
                                ->  call !@@krs16i

_@KREG14 to 15 restore          ->  call !@@krl02

_@KREG12 to 15 restore          ->  call !@@krl04
                                ->  call !@@krl04i

_@KREG10 to 15 restore          ->  call !@@krl06
                                ->  call !@@krl06i

_@KREG08 to 15 restore          ->  call !@@krl08
                                ->  call !@@krl08i

_@KREG06 to 15 restore          ->  call !@@krl10
                                ->  call !@@krl10i

_@KREG04 to 15 restore          ->  call !@@krl12
                                ->  call !@@krl12i

_@KREG02 to 15 restore          ->  call !@@krl14
                                ->  call !@@krl14i

_@KREG00 to 15 restore          ->  call !@@krl16
                                ->  call !@@krl16i
```

EFFECT

- By replacing prolog and epilog code with a library, object code can be shortened.

USAGE

- Specify the -zd option during compilation.

EXAMPLE 1

< C source >

```
int     func1 ( int a , int b , int c ) ;
int     func2 ( int a , int b , int c ) ;
void    main ( )
{
        int     r ;

        r = func1 ( 1 , 2 , 3 ) ;
}
int     func1 ( int a , int b , int c )
{
        return  func2 ( a + 1 , b + 1 , c + 1 ) ;
}
int     func2 ( int a , int b , int c )
{
        return  a + b + c ;
}
```

- When -sm8, -zm2d, and -qc are specified

```
@@CODE  CSEG
_main :
        movw    ax , _@KREG14
        push    ax
; line  5 :     int     r ;
; line  6 :
; line  7 :     r = func1 ( 1 , 2 , 3 ) ;
        movw    hl , #03H               ; 3
        movw    bc , #02H               ; 2
        movw    ax , #01H               ; 1
        call    !_func1
        movw    _@KREG14 , ax           ; r
; line  8 :     }
        pop     ax
        movw    _@KREG14 , ax
        ret
; line  9 :     int     func1 ( int a , int b , int c )
; line  10 :    {
_func1 :
        call    !@@krs06
        callt   [ @@krip3 ]
; line  11 :    return  func2 ( a + 1 , b + 1 , c + 1 ) ;
        movw    ax , _@KREG10           ; c
        incw    ax
        movw    hl , ax
        movw    ax , _@KREG12           ; b
        incw    ax
        movw    bc , ax
        movw    ax , _@KREG14           ; a
        incw    ax
        call    !_func2
L0004 :
; line  12 :    }
        call    !@@krl06
        ret
; line  13 :    int     func2 ( int a , int b , int c )
; line  14 :    {
_func2 :
        callt   [ @@nrip3 ]
; line  15 :    return  a + b + c ;
        movw    ax , _@NRAT02           ; a
        xch     a , x
        add     a , _@NRAT04            ; b
        xch     a , x
        addc    a , _@NRAT05            ; b
        xch     a , x
        add     a , _@NRAT06            ; c
        xch     a , x
        addc    a , _@NRAT07            ; c
L0006 :
; line  16 :    }
        ret
```

EXAMPLE 2

< C source >

```
int     func ( register int a , register int b ) ;
void    main ( )
{
        register int    a = 1 , b = 2 , c = 3 , r ;
        r = func ( a , b ) ;
}
int     func ( register int a , register int b )
{
        register int    r ;

        r = a + b ;
        return  r ;
}
```

- When -qr and -zd are specified

< Output object >

```
@@CODE  CSEG
_main :
        movw    de , #03100H
        callt   [ @@cprep2 ]
; line  4 :     register int    a = 1 , b = 2 , c = 3 , r ;
        movw    hl , #01H               ; 1
        movw    ax , hl
        incw    ax
        movw    _@KREG14 , ax           ; b
        incw    ax
        movw    _@KREG12 , ax           ; c
; line  5 :
; line  6 :     r = func ( a , b ) ;
        movw    ax , _@KREG14           ; b
        push    ax
        movw    ax , hl
        call    !_func
        pop     ax
        movw    ax , bc
        movw    _@KREG10 , ax           ; r
; line  7 :     }
        movw    ax , #03100H
        callt   [ @@cdisp2 ]
        ret
; line  8 :     int     func ( register int a , register int b )
; line  9 :     {
_func :
        movw    de , #0E840H
        callt   [ @@cprep2 ]
; line  10 :    register int    r ;
; line  11 :
; line  12 :    r = a + b ;
        movw    ax , hl
        xch     a , x
        add     a , _@KREG12            ; a
        xch     a , x
        addc    a , _@KREG13            ; a
        movw    _@KREG14 , ax           ; r
L0004 :
; line  14 :    }
        movw    ax , #0E840H
        callt   [ @@cdisp2 ]
        ret
```

RESTRICTIONS

- The optimization specification option -ql4 cannot be specified at the same time as the -zd option. If it is specified, a W0052 warning message is output and the -ql4 option is replaced with the -ql3 option and processed.

CAUTION

- The argument copy pattern in the case of a static model will be pattern-matched only when register has not been specified for any of the first 3 arguments or __temp has been specified for all of the first 3 arguments. Therefore, because pattern matching will not be performed if the -qv option is specified or if register/__temp are partially specified for the first 3 arguments, it will no longer be possible to replace the -zd option specification.

COMPATIBILITY

< From another C compiler to the CC78K0S >

- The source program need not be modified.
- To replace the prologue/epilogue code with a library, modify the source program according to the description method above.

< From the CC78K0S to another C compiler >

- The source program need not be modified.

11.6 Modifications of C Source

By using the extended functions of the CC78K0S, efficient object generation can be realized. However, these extended functions are intended to cope with the 78K0S Series. So, to use them for other devices, the C source may need to be modified. Here, how to make the C source portable from another C compiler to the CC78K0S and vice versa is explained.

< From another C compiler to the CC78K0S >

- #pragma[Note]

  If the other C compiler supports the #pragma preprocessor directive, the C source must be modified. The method and extent of modifications to the C source depend on the specifications of the other C compiler.

- Extended specifications

  If the other C compiler has extended specifications such as addition of keywords, the C source must be modified. The method and extent of modifications to the C source depend on the specifications of the other C compiler.

  Note #pragma is one of the preprocessing directives supported by ANSI. The character string following the #pragma is identified as a directive to the compiler. If the compiler does not support this directive, the #pragma directive is ignored and the compile will be continued until it properly ends.

< From the CC78K0S to another C compiler >

- Because the CC78K0S has added keywords as the extended functions, the C source must be made portable to the other C compiler by deleting such keywords or invalidating them with #ifdef.

EXAMPLE

(1) To invalidate a keyword (Same applies to callf, sreg, noauto, and norec, etc.)

```
#ifndef __K0S__
#define callt           /* makes callt as ordinary function */
#endif
```

(2) To change from one type to another

```
#ifndef __K0S__
#define bit     char    /* changes bit type to char type variable */
#endif
```

11.7 Function Call Interface

The following will be explained about the interface between functions at function call.

(1) Return value (common in all the functions)

(2) Ordinary function call interface

  (a) Passing arguments

  (b) Location and order of storing arguments

  (c) Location and order of storing automatic variables

(3) noauto function call interface (normal model only)

  (a) Passing arguments

  (b) Location and order of storing arguments

  (c) Location and order of storing automatic variables

(4) norec function call interface (normal model)

  (a) Passing arguments

  (b) Location and order of storing arguments

  (c) Location and order of storing automatic variables

(5) Static model function call interface

  (a) Passing arguments

  (b) Location and order of storing arguments

  (c) Location and order of storing automatic variables

(6) Pascal function call interface

11.7.1 Return value

The function called stores the return value in the registers and carry flags as shown in Table 11-15.

Table 11-15 Location of Storing Return Value

Type	Location of Storing	
	Normal Model	Static Model
1-byte integer	BC	A
2-byte integer		AX
4-byte integer	BC (Lower), DE (Upper)	Not supported
Pointer	BC	AX
Structure, union	BC (if copied to the area specific to the function, the start address of the structure or union)	Not supported
1 bit	CY (carry flag)	CY (carry flag)
Floating-point number (float type)	BC (Lower), DE (Upper)	Not supported
Floating-point number (double type)	BC (Lower), DE (Upper)	Not supported

11.7.2 Ordinary function call interface

When all the arguments are allocated to registers and there is not an automatic variable, the ordinary function call interface is the same as noauto function call interface.

(1) Passing arguments

- There are 2 types of arguments; arguments that are allocated to a register and normal arguments.
- An argument that is allocated to a register is an argument that has undergone register declaration and is allocated to a register or _@KREGxx as long as an allocatable register and _@KREGxx exist. However, arguments are allocated to _@KREGxx only when -qr is specified. Arguments that are allocated to a register or _@KREGxx are referred to as register arguments hereafter.
- Refer to "APPENDIX A LIST OF LABELS FOR saddr AREA" for _@KREGxx.
- The remaining arguments are allocated to a stack.
- On the function call side, both the arguments declared with registers and the ordinary arguments are passed in the same manner. The second argument and later are passed via a stack, and the first argument is passed via a register or stack.
- On the function definition side, arguments passed via register or stack are saved in the place where arguments are allocated.
- Register arguments are copied in a register or _@KREGxx. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those on the function definition side (receiving side).
- Normal arguments are loaded on a stack. When an argument is passed via a stack, the area where the arguments are passed to becomes the area to which they are allocated.
- Saving and restoring registers to which arguments are allocated is performed on the function definition side.

- The location where the first argument is passed is shown in Table 11-16.

Table 11-16 Details of Type Modification (Change from int and short Type to char Type)

Type	Location of Storing
1-byte data[Note] 2-byte data[Note]	AX
3-byte data[Note]	AX, BC
4-byte data[Note]	AX, BC
Floating-point number (float type)	AX, BC
Floating-point number (double type)	AX, BC
Others	Passed via stack

Note 1- to 4-byte data include structure, union, and pointer.

(2) Location and order of storing arguments

- There are 2 types of arguments : arguments allocated to registers and ordinary arguments. Arguments allocated to registers are arguments declared with registers and arguments when -qv is specified.
- The arguments not allocated to registers are allocated to stacks. The arguments allocated to stacks are placed on the stack sequentially from the last argument.
- Saving and restoring registers to which arguments are allocated is performed on the function definition side.
- On the function definition side, the arguments that are passed via a register or stack are stored in the area to which arguments are allocated.
- The register arguments are copied to a register or _@KREGxx. Copying to _@KREGxx is performed only when -qr is specified. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those on the function definition side (receiving side).
- On the function caller, both register arguments and normal arguments are passed using the same method.
  The second or later arguments are passed via a stack. The first argument is passed via a register and stack.
  Refer to Table 11-16 for the place where the first argument is passed.

(Registers to be used)

HL

Arguments are not allocated to HL when there is a stack frame.

(saddr area to be used)

_@KREG12 to 15

(Allocation sequence)

- Registers

char type :	The sequence is L-H.
int, short, and enum type :	HL

- saddr area

char type :	The sequence is _@KREG12, _@KREG13, _@KREG14, and _@KREG15.
int, short, and enum type :	The sequence is _@KREG12 to 13 and _@KREG14 to 15.
long, float, double type :	The sequence is _@KREG12 to 13 (low-order)-_@KREG14 to 15 (high-order).

(3) Location and order of storing automatic variables

- There are 2 types of automatic variables : automatic variables to be allocated to registers and ordinary automatic variables. The automatic variables to be allocated to registers are ones which are declared with registers and automatic variables with -qv is specified. They are allocated to register _@KREGxx as long as there are allocable registers and _@KREGxx. However, automatic variables are allocated to _@KREGxx only when -qr is specified.
  The automatic variables allocated to registers and _@KREGxx are called register variables hereafter.
- For _@KREGxx, refer to "APPENDIX A LIST OF LABELS FOR saddr AREA".
- The register variables are allocated after register arguments are allocated. Therefore, the register variables are allocated to register when there are excess registers after the allocation of register arguments.
- The automatic variables not allocated to a register are allocated to a stack.
- The save and restoration to registers and _@KREGxx to allocate automatic variables are performed on the function definition side.

(a) Automatic variable allocation sequence

The allocation sequence of automatic variables to _@KREGxx is as follows.

(Registers to be used)

HL

Arguments are not allocated to HL when there is a stack frame.

(saddr area to be used)

_@KREG00 to 15

(Allocation sequence)

- Registers
  char type : The sequence is L and H.
  int, short, and enum type:HL
- saddr area
  char type : The sequence is _@KREG00, _@KREG01 ..., and _@KREG11.
  int, short, and enum type : The sequence is _@KREG00 to 01, _@KREG02 to 03 ... and _@KREG10 to 15.
  long, float, double type : The sequence is _@KREG00 to 03, _@KREG04 to 07, and _@KREG12 to 15.
- The automatic variables that are allocated to a stack are loaded on the stack in the sequence of declaration.

[Example]

< C source 1 >

```
void    func0 ( register int , int ) ;
void    main ( )
{
func0 ( 0x1234 , 0x5678 ) ;
}
void    func0 ( register int p1 , int p2 )
{
        register int    r ;
        int             a ;
        r = p2 ;
        a = p1 ;
}
```

< Output code >

```
_main :
; line  4 :     func0 ( 0x1234 , 0x5678 ) ;
        movw    ax , #05678H    ; 22136
        push    ax                      ; Argument passed via a stack
        movw    ax , #01234H    ; 4660  ; The first argument that is passed
                                        ; via a register
        call    !_func0                 ; Function call
        pop     ax                      ; Argument passed via a stack
; line  5 :     }
        ret
; line  6 :     void     func0 ( register int p1 , int p2 )
; line  7 :     {
_func0 :
        push    hl
        xch     a , x
        xch     a , _@KREG12
        xch     a , x
        xch     a , _@KREG13            ; Allocate register argument p1 to
                                        ; _@KREG12
        push    ax                      ; Saves the saddr area for register
                                        ; argument
        movw    ax , _@KREG00
        push    ax                      ; Saves the saddr area for a register
                                        ; variable
        push    ax                      ; Reserves area for the automatic
                                        ; variable a
        movw    ax , sp
        movw    hl , ax
; line  8 :     register int    r ;
; line  9 :     int             a ;
; line  10 :    r = p2 ;
        mov     a , [ hl + 10 ] ; p2    ; Argument p2 passed via a stack
        xch     a , x
        mov     a , [ hl + 11 ] ; p2
        movw    _@KREG00 , ax   ; r     ; Assigns to register variable
                                        ; _@KREG00
; line  11 :    a = p1 ;
        movw    ax , _@KREG12   ; p1    ; Register argument _@KREG12
        mov     [ hl + 1 ] , a  ; a
        xch     a , x
        mov     [ hl ] , a      ; a     ; Assigns to automatic variable a
; line  12 :    }
        pop     ax                      ; Releases area of the automatic
                                        ; variable a
        pop     ax
        movw    _@KREG00 , ax           ; Restores the saddr area for a
                                        ; register variables
        pop     ax
        movew    _@KREG12 , ax          ; Restores the saddr area for a
                                        ; register argument
        pop     hl
        ret
```

< C source 2 >

```
void    func1 ( int , register int ) ;
void    main ( )
{
        func1 ( 0x1234 , 0x5678 ) ;
}
void    func1 ( int p1 , register int p2 )
{
        register int    r ;
        int             a ;
        r = p2 ;
        a = p1 ;
}
```

< Output code >

```
_main :
; line  4 :     func1 ( 0x1234 , 0x5678 ) ;
        movw    ax , #05678H    ; 22136
        push    ax                      ; Argument passed via a stack
        movw    ax , #01234H    ; 4660  ; The first argument that is passed
                                        ; via a register
        call    !_func1                 ; Function call
        pop     ax                      ; Argument passed via a stack
; line  5 :     }
        ret
; line  6 :     void     func1 ( int p1 , register int p2 )
; line  7 :     {
_func1 :
        push    hl
        push    ax                      ; Loads the first argument p1 on the
                                        ; stack
        movw    ax , _@KREG00
        push    ax                      ; Saves the saddr area for register
                                        ; variables
        movw    ax , _@KREG12
        push    ax                      ; Saves the saddr area for register
                                        ; arguments
        push    ax                      ; Reserves area for the automatic
                                        ; variable a
        movw    ax , sp
        movw    hl , ax
        mov     a , [ hl + 12 ]         ; Argument p2 passed via a stack and
                                        ; received via the saddr area
        xch     a , x
        mov     a , [ hl + 13 ]
        movw    _@KREG12 , ax           ; Allocates the register argument to
                                        ; _@KREG12.
; line  8 :     register int    r ;
; line  9 :     int a ;
; line  10 :    r = p2 ;
        movw    ax , _@KREG12   ; p2
        movw    _@KREG00 , ax   ; r     ; Register variable _@KREG00
; line  11 :    a = p1;
        mov     a , [ hl + 6 ]  ; p1    ; Argument p1 (low-order) passed via
                                        ; a stack and received by a register
        mov     [ hl ] , a      ; a     ; Automatic variable a (low-order)
        xch     a , x
        mov     a , [ hl + 7 ]  ; p1    ; Argument p1 (high-order) passed via
                                        ; a stack and received by a register
        mov     [ hl + 1 ] , a  ; a     ; Automatic variable a (high-order)
; line  12 :    }
        pop     ax                      ; Releases area for the automatic
                                        ; variable a
        pop     ax
        movw    _@KREG12 , ax           ; Restores the saddr area for register
                                        ; arguments
        pop     ax
        movw    _@KREG00 , ax           ; Restores the saddr area for register
                                        ; variables
        pop     ax
        pop     hl
        ret
```

11.7.3 noauto function call interface (normal model only)

(1) Passing arguments

- On the function caller, arguments are passed in the same way as in an ordinary function. Refer to "11.7.2 Ordinary function call interface".
- On the function definition side, arguments passed via a register or stack are copied to a register as well as _@KREG12 to 15. Copying to _@KREG12 to 15 is performed only when -qr is specified. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those on the function definition side (receiving side).
- Saving and restoring registers to which arguments are allocated is performed on the function definition side.

(2) Location and order of storing arguments

- On the function definition side, all arguments are allocated to registers and _@KREG12 to 15. However, arguments are allocated to _@KREG12 to 15 only when -qr is specified.
- If there are arguments that are not allocated to registers or _@KREG12 to 15 an error will result.
- On the function caller, arguments are passed in the same way as in an ordinary function (Refer to "11.7.2 Ordinary function call interface").
- On the function definition side, the arguments passed via a register or stack are copied to a register as well as _@KREG12 to 15. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those on the function definition side (receiving side).
- Saving and restoring registers to which arguments are allocated is performed on the function definition side.

(Allocation sequence)

- The allocation sequence is the same as in a ordinary function (Refer to "11.7.2 Ordinary function call interface").

(3) Location and order of storing automatic variables

- Automatic variables are allocated to registers and _@KREG12 to 15. However, automatic variables are allocated to _@KREG12 to 15 only when -qr is specified. For _@KREG12 to 15, refer to "APPENDIX A LIST OF LABELS FOR saddr AREA".
- Automatic variables are allocated to registers when there are excess registers after the allocation of arguments. When -qr is specified, automatic variables are allocated also to _@KREG12 to 15.
- If an automatic variable cannot be allocated to registers and _@KREG12 to 15, an error occurs.
- The save and restoration of the register and _@KREG12 to 15 to which automatic variables are allocated are performed on the function definition side.

(Allocation sequence)

- The order of allocating automatic variables to registers is the same as the order of allocating arguments.
- The automatic variables allocated to _@KREG12 to 15 are allocated in the order of declaration.

[Example]

< C source >

```
noauto  void    func2 ( int , int ) ;
void    main ( )
{
        func2 ( 0x1234 , 0x5678 ) ;
}
noauto  void    func2 ( int p1 , int p2 )
{
    :
}
```

< Output code >

```
_main :
; line  4 :     func2 ( 0x1234 , 0x5678 ) ;
        movw    ax , #05678H    ; 22136
        push    ax                      ; Argument passed via a stack
        movw    ax , #01234H    ; 4660  ; The first argument that is passed
                                        ; via a register
        call    !_func2                 ; Function call
        pop     ax                      ; Argument passed via a stack
; line  5 :     }
        ret
; line  6 :     noauto  void    func2 ( int p1 , int p2 )
; line  7 :     {
_func2 :
        push    hl                      ; Saves a register for the argument
        xch     a , x
        xch     a , _@KREG12            ; Allocate the argument p1 to _@KREG12
                                        ; (lower)
        xch     a , x
        xch     a , _@KREG13            ; Allocate the argument p1 to _@KREG13
                                        ; (higher)
        push    ax                      ; Saves the saddr area for arguments
        movw    ax , sp
        movw    hl , ax
        mov     a , [ hl + 6 ]          ; Argument p2 (low-order) passed via a
                                        ; stack and received via a register
        xch     a , x
        mov     a , [ hl + 7 ]          ; Argument p2 (high-order) passed via
                                        ; a stack and received via a register
        movw    hl , ax                 ; Allocate arguments to HL
            :
        pop     ax
        movw    _@KREG12 , ax           ; Restore the saddr area for argument
        pop     hl                      ; Restores the register for argument
        ret
```

11.7.4 norec function call interface (normal model)

(1) Passing arguments

All arguments are allocated to _@NRARGx and _@RTARG6 and 7. On the function caller, arguments are passed via register _@NRARGx.

On the function definition side, arguments passed via registers are copied to registers, or to _@RTARG6 and 7 (Refer to "APPENDIX A LIST OF LABELS FOR saddr AREA").

(2) Location and order of storing arguments

- On the function definition side, all arguments are allocated to registers, _@NRARGx, _@RTARG6 and 7. Arguments are allocated to _@NRARGx only when -qr is specified.
- Arguments are allocated to _@RTARG6 and 7 only when there are arguments in DE (Refer to "APPENDIX A LIST OF LABELS FOR saddr AREA").
- If there are arguments that are not allocated to registers, _@NRARGx, _@RTARG6 and 7, an error will result.
- On the function caller, arguments are passed via registers and _@NRARGx.
- On the function definition side, arguments that are passed via registers are copied to registers or _@RTARG6 and 7. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those in the function definition side (receiving side). If the arguments are passed via registers, the area where the arguments are passed becomes the area to which they are allocated.
- If arguments can no longer be passed via a register, they can be allocated to _@NRARGx and passed via there. In this case, passing is carried out with registers and _@NRARGx intermingled.

(Argument allocation sequence)

- Arguments allocated to _@NRARGx are allocated in the sequence of declaration.
- Arguments allocated to registers are allocated to registers, _@RTARG6 and 7 according to the following rules.

(Registers to be used)

- When 1 argument is used in char, int, short, enum, or pointer type : AX pass, DE receive
- When two or more arguments are used in char, int, short, enum, or pointer type : AX and DE pass _@RTARG6, 7 and DE receive

(Allocation sequence)

- char, int, short, enum, and pointer type : In the sequence of DE, _@RTARG6 and 7

(3) Location and order of storing automatic variables

- The automatic variables are allocated to registers and _@NRARGx as long as there are allocable registers and _@NRARGx. If there is no allocable register, they are allocated to _@NRATxx. However, automatic variables are allocated to _@NRARGx and _@NRATxx only when -qr is specified. For _@NRATxx, refer to "APPENDIX A LIST OF LABELS FOR saddr AREA".
  If there is an automatic variable that cannot be allocated to a register, _@NRARGx and _@NRATxx, an error occurs.
- The save and restoration of registers to which automatic variables are allocated are performed on the function definition side.

(Allocation sequence)

- The order of allocating automatic variables to registers, _@RTARG6 to 7 is the same as the order of allocating arguments.
- The automatic variables allocated to _@NRARGx, _@NRATxx are allocated in the order of declaration.

[Example]

- In the normal model

< C source >

```
norec   void    func3 ( char , int , char , int ) ;
void    main ( )
{
        func3 ( 0x12 , 0x34 , 0x56 , 0x78 ) ;
}
norec   void    func3 ( char p1 , int p2 , char p3 , int p4 )
{
        int     a ;
        a = p2 ;
}
```

- When -qr is specified

< Output code >

```
_main :
; line  4 :     func3 ( 0x12 , 0x34 , 0x56 , 0x78 ) ;
        movw    _@NRARG1 , #078H ; 120 ; Argument is passed via _@NRARG1
        mov     _@NRARG0 , #056H ; 86  ; Argument is passed via _@NRARG0
        movw    de , #034H       ; 52  ; Argument is passed via register DE
        mov     a , #012H        ; 18  ; Argument is passed via register A
        call    !_func3                ; Function call
        ret
; line  6 :    norec   void    func3 ( char p1 , int p2 , char p3 , int p4 )
; line  7 :     {
_func3 :
        mov     _@RTARG6 , a     ; Allocates the argument p1 to _@RTARG6
; line  8 :     int     a ;
; line  9 :     a = p2 ;
        movw    ax , de          ; Argument p2
        movw    _@NRARG2 , ax    ; a   ; Automatic variable a
        ret
```

11.7.5 Static model function call interface

(1) Passing arguments

- On the function caller, both the register arguments and the normal arguments are passed in the same way.
  There can be a maximum of 3 arguments, up to 6 bytes, and all arguments are passed via registers.
- On the function definition side, the arguments passed via a register are stored in the area to which they are allocated. Register arguments are copied to registers. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those on the function definition side (receiving side).
- Ordinary functions are allocated to the function-specific area.

(2) Location and order of storing arguments

(a) Argument storage location

- There are 2 types of arguments : arguments to be allocated to registers and normal arguments.
- The arguments allocated to registers are arguments that have undergone a register declaration.
- On the function definition side, the arguments that are passed via a register or stack are stored in the area to which arguments are allocated.
  Register arguments are copied to a register. Even when the arguments are passed via registers, register copying is necessary since the registers on the function caller (passing side) are different to those on the function definition side (receiving side). Normal arguments are allocated to the function-specific area.
- Saving and restoring registers to which arguments/automatic variables are allocated is performed on the function definition side.
- The remaining arguments are allocated to the function-specific area.
- On the function caller, both register arguments and normal arguments are passed in the same way.
  There can be a maximum of 3 arguments, up to 6 bytes, and all arguments are passed via a register. Refer to Table 11-17 for the area to which arguments are passed.

Table 11-17 Areas to Which Arguments Are Passed in the Static Model

Data Size	The First Argument	The Second Argument	The Third Argument
1-byte data[Note]	A	B	H
2-byte data[Note]	AX	BC	HL
4-byte data[Note]	Allocates to AX and BC and the remainder allocated to H or HL.		

Note Neither structures nor unions are included in 1- to 4- byte data.

(b) Argument allocation sequence

- Arguments allocated to the function-specific area are allocated sequentially from the last argument.
- Register arguments are allocated to register DE according to the following rules.

(Registers to be used)

DE

(Allocation sequence)

char type :	sequence of D, E
int, short, enum type :	DE

(3) Location and order of storing automatic variables

(a) Storage location of automatic variables

- There are 2 types of automatic variables : automatic variables to be allocated to registers and normal automatic variables.
- Automatic variables allocated to registers are register-declared automatic variables and automatic variables specified at -qv specification.
- Register variables are allocated after register arguments are allocated. For this reason, the allocation of register variables to registers is performed only when registers are superfluous after register argument allocation.
- The remaining automatic variables are allocated to the function-specific area.
- Saving and restoring registers to which arguments are allocated is performed on the function definition side.

(b) Automatic variable allocation sequence

- Automatic variables are allocated to register DE according to the following rules.

(Registers to be used)

DE

(Allocation sequence)

char type :	sequence of E, D
int, short, enum type :	DE

- The automatic variables that are allocated to the function-specific area are allocated in the sequence of declaration.

[EXAMPLE 1]

< C source >

```
void    func4 ( register int , char ) ;
void    func ( void ) ;
void    main ( )
{
        func4 ( 0x1234 , 0x56 ) ;
}
void    func4 ( register int p1 , char p2 )
{
        register char   r ;
        int             a ;
        r = p2 ;
        a = p1 ; func ( ) ;
}
```

< Output code >

```
@@DATA  DSEG
L0005   : DS    ( 1 )                   ; Argument p2
L0006   : DS    ( 1 )                   ; Automatic variable r
L0007   : DS    ( 2 )                   ; Automatic variable a

; line  1 :     void    func4 ( register int , char ) ; void func ( void ) ;
; line  2 :     void    main ( )
; line  3 :     {

@@CODE  CSEG
_main :
; line  4 :     func4 ( 0x1234 , 0x56 ) ;
        mov     b , #056H     ; 86    ; Pass the second argument via register B
        movw    ax , #01234H  ; 4660  ; Pass the first argument via register AX
        call    !_func4               ; Function call
; line  5 :     }
        ret
; line  6 :     void    func4 ( register int p1 , char p2 )
; line  7 :     {
_func4 :
        push    de                    ; Saves register for register argument
        movw    de , ax               ; Allocate a register argument p1 to DE
        movw    a , b

        mov     !L0005 , a            ; Copy argument p2 to L0005
; line  8 :     register char r ;
; line  9 :     int           a ;
; line  10 :    r = p2 ;
        mov     !L0006 , a    ; r     ; Automatic variable r
; line  11 :    a = p1 ; func ( ) ;
        movw    ax , de               ; Register argument p1
        movw    !L0007 , ax   ; a     ; Automatic variable a
        callt   [ @@hlist ]
; line  12 :    }
        pop     de                ; Returns the register for register argument
        ret
```

[EXAMPLE 2]

< C source >

```
void    func5 ( int , register char ) ;
void    func ( void ) ;
void    main ( )
{
        func5 (0x1234 , 0x56 ) ;
}
void    func5 ( int p1, register char p2 )
{
        register char   r ;
        int             a ;
        r = p2 ;
        a = p1 ; func ( ) ;
}
```

- When -nq is specified

< Output code >

```
@@DATA  DSEG
L0005   : DS  ( 2 )
L0006   : DS  ( 2 )

; line  1 :   void  func5 ( int , register char ) ; void func ( void ) ;
; line  2 :   void  main ( )
; line  3 :   {

@@CODE  CSEG
_main :
; line  4 :   func5 ( 0x1234 , 0x56 ) ;
        mov   b , #056H     ; 86    ; Pass the second argument via register B
        movw  ax , #01234H  ; 4660  ; Pass the first argument via register AX
        call  !_func5               ; Function call
; line  5 :   }
        ret
; line  6 :   void    func5 ( int p1 , register char p2 )
; line  7 :   {
_func5 :
        push  de                    ; Saves a register for register variables
                                    ; and register arguments.
        movw  !L0005 , ax           ; Copy argument p1 to L0005
        callt [ @@hlist]
        movw  ax , bc
        mov   de , ax               ; Allocates a register argument p2 to d.
; line  8 :   register char r ;
; line  9 :   int           a ;
; line  10 :  r = p2 ;
        movw  ax , de               ; Register argument p2
        mov   e , a                 ; Register variable r
; line  11 :  a = p1 ; func ( ) ;
        movw  hl , #L0005   ; p1    ; Argument p1
        callt [ @@hlilo ]
        movw  hl , #L0006   ; a     ; Automatic variable a
        callt [ @@hlist ]
        call  !_func
; line  12 :  }
        pop   de                ; Restores the register for register arguments
        ret
```

11.7.6 Pascal function call interface

The difference between this function interface and other function interfaces is that the correction of stacks used for loading of arguments when a function is called is done by the function side that was called, rather than the function caller. All other points are the same as the function attributes specified at the same time.

[Area to which arguments are allocated]

[Sequence in which arguments are allocated]

[Area to which automatic variables are allocated]

[Sequence in which automatic variables are allocated]

- If the noauto attribute is specified at the same time, the features are the same as when a noauto function is called (Refer to "11.7.3 noauto function call interface (normal model only)").
- If the noauto attribute is not specified at the same time, the features are the same when an ordinary function is called (Refer to "11.7.2 Ordinary function call interface").

[EXAMPLE 1]

< C source >

```
__pascal        void    func0 ( register int , int ) ;
void    main ( )
{
        func0 ( 0x1234 , 0x5678 ) ;
}
__pascal        void    func0 ( register int p1 , int p2 )
{
        register int    r ;
        int     a ;
        r = p2 ;
        a = p1 ;
}
```

- When -qr option is specified

< Output code >

```
_main :
; line  4 :   func0 ( 0x1234 , 0x5678 ) ;
        movw  ax , #05678H    ; 22136
        push  ax                      /* Stack is passed via the argument */
        movw  ax , #01234H    ; 4660  /* The first argument that is passed */
                                      /* via a register */
        call  !_func0                 /* Function call */
                                      /* Stack is not corrected here */
; line  5 :   }
        ret
; line  6 :   __pascal        void    func0 ( register int p1 , int p2 )
; line  7 :   {
_func0 :
        push  hl
        xch   a , x
        xch   a , _@KREG12
        xch   a , x
        xch   a , _@KREG13    /* Allocate a register argument p1 to _@KREG12 */
        push  ax              /* Saves the saddr area for register arguments */
        movw  ax, _@KREG14
        push  ax              /* Saves the saddr area for register variable */
        push  ax              /* Reserves the area automatic variable a */
        movw  ax , sp
        movw  hl , ax
; line  8 :   register int    r ;
; line  9 :   int             a ;
; line  10 :  r = p2 ;
        mov   a , [ hl+10 ]   ; p2  /* Stack transfer argument p2 */
        xch   a , x
        mov   a , [ hl+11 ]   ; p2
        movw  _@KREG14 , ax   ; r   /* Assign to register variable _@KREG14 */
; line  11 :  a = p1 ;
        movw  ax , _@KREG12   ; p1  /* Register argument _@KREG12 */
        mov   [ hl+1 ] , a    ; a
        xch   a , x
        mov   [ hl ] , a      ; a   /* Assign to automatic variable a */
; line  12 :  }
        pop   ax            /* Releases the automatic variable a area */
        pop   ax
        movw  _@KREG14 , ax /* Restore the saddr area for register argument */
        pop   ax
        movw  _@KREG12 , ax /* Restore the saddr area for register argument */
        pop   hl
        pop   de            /* Obtains the return address */
        pop   ax            /* The stack consumed by arguments passed via */
                            /* a stack is corrected */
        push  de            /* Reloads the return address */
        ret
```

[EXAMPLE 2]

< C source >

```
__pascal        noauto  void    func2 ( int , int ) ;
void    main ( )
{
        func2 ( 0x1234 , 0x5678 ) ;
}
__pascal        noauto  void    func2 ( int p1 , int p2 )
{
    :
}
```

- When -qr option is specified

< Output code >

```
_main :
; line  4 :   func2 ( 0x1234 , 0x5678 ) ;
        movw  ax , #05678H  ; 22136
        push  ax                    /* Argument passed via a stack */
        movw  ax , #01234H  ; 4660   /* The first argument that is */
                                    /* passed via a register */
        call  !_func2               /* Function call */
                                    /* The stack is not corrected here */
; line  5 :   }
        ret
; line  6 :   __pascal     noauto  void    func2 ( int p1 , int p2 )
; line  7 :   {
_func2 :
        push  hl              /* Saves the register for arguments */
        xch   a , x
        xch   a , _@KREG12    /* Allocate argument p1 to _@KREG12 */
                              /* (low-order) */
        xch   a , x
        xch   a , _@KREG13    /* Allocate argument p1 to _@KREG13 */
                              /* (high-order) */
        push  ax              /* Saves the saddr area for arguments */
        movw  ax , sp
        movw  hl , ax
        mov   a , [ hl + 6 ]  /* Argument p2 (low-order) passed via a */
                              /* stack and received by a register */
        xch   a , x
        mov   a , [ hl + 7 ]  /* Argument p2 (high-order) passed via a */
                              /* stack and received by register */
        movw  hl , ax         /* Allocates arguments to HL */
             :
        pop   ax
        movw  _@KREG12 , ax   /* Restore the saddr area for arguments */
        pop   hl              /* Restores the register for arguments */
        pop   de              /* Obtains the return address */
        pop   ax              /* The stack consumed by arguments passed */
                              /* via a stack is corrected*/
        push  de              /* Reloads the return address */
        ret
```

CHAPTER 12 REFERENCING THE ASSEMBLER

This chapter describes how to link a program written in assembly language.

If a function called from a C source program is written in another language, both object modules are linked by the linker. This chapter describes the procedure for calling a program written in another language from a program written in the C language and the procedure for calling a program written in the C language from a program written in another language.

How to interface with another language by using the RA78K0S Assembler Package and the CC78K0S is described in this order :

(1) Calling Assembly Language Routines from C Language

(2) Calling C Language Routines from Assembly Language

(3) Referencing variables defined in the C language

(4) Referencing variables defined in the assembly language from the C language

(5) Cautions

12.1 Accessing Arguments / Automatic Variables

The procedure to access arguments and automatic variables of the CC78K0S is described in the following.

12.1.1 Normal model

- On the function call side, register arguments are passed in the same way as regular arguments.
  The first argument uses the following registers and stacks, and subsequent arguments are passed via stacks.

Table 12-1 Passing Arguments (Function Call Side)

Type	Passing Location (First Argument)	Passing Location (Second and Later Arguments)
1-byte, 2-byte data	AX	Stack passing
3-byte, 4-byte data	AX, BC	Stack passing
Floating-point number	AX, BC	Stack passing
Others	Stack passing	Stack passing

  Remark 1- to 4-byte data includes structures and unions.

- On the function definition side, arguments passed via a register or stack are stored to the argument allocation location.
  Register arguments are copied to a register or saddr area (_@KREGxx). Even when passing is done via a register, the registers on the function call side (passing side) and the function definition side (receiving side) differ, and therefore register copying is performed.
  Normal arguments passed via a register are pushed to a stack on the function definition side. If passing is done via a stack, the passing location simply becomes the argument allocation location.
  Saving and restoring of registers that allocate arguments is performed on the function definition side.

- The arguments of functions and the values of automatic variables declared inside functions are stored in the following registers, saddr areas, or stack frames using an option. The base pointer used when storing in a stack frame uses the HL register.
  If the function argument is register declared or specified by the -qv option and specified by the -qr option, it is allocated to the saddr area.

Table 12-2 Storing of Arguments/Automatic Variables (Inside Called Function)

Option	Argument/auto Variable	Storage Location	Priority Level
-qv (register allocation option)	Declared argument or automatic variable	HL register (only when base pointer is not required)	char type : L, H, in this order int, short, enum type : HL
-qr (saddr allocation option)	register declared argument or automatic variable	HL register (only when base pointer is not required) Argument : _@KREG12 to 15 [0FEE4H to 0FEE7H] Automatic variable : _@KREG00 to 11 [0FED8H to 0FEE3H]	Only the number of bytes of the variable or argument is allocated, in order of appearance. Allocated to register as char type : L, H, in this order int, short, enum type : HL
-qrv	Declared argument or automatic variable	HL register (only when base pointer is not required) Argument : _@KREG12 to 15 [0FEE4H to 0FEE7H] Automatic variable : _@KREG00 to 11 [0FED8H to 0FEE3H]	Only the number of bytes of the variable or argument is allocated, in order of appearance. Allocated to register as char type : L, H, in this order int, short, enum type : HL
Default	Declared argument, automatic variable	Stack frame	Order of appearance

The following example shows the function call.

- C source : Normal model at the -qrv specification

```
void    func0 ( register int , int ) ;
void    main ( ) {
        func0 ( 0x1234 , 0x5678 ) ;
}
void    func0 ( register int p1 , int p2 ) {
        register int    r ;
        int     a ;
        r = p2 ;
        a = p1 ;
}
```

< Output assembler source >

```
    EXTRN   _@KREG12
    EXTRN   _@KREG13
    EXTRN   _@KREG10
    EXTRN   _@KREG14
    PUBLIC  _func0
    PUBLIC  _main

@@CODE      CSEG
_main :
    movw    ax , #05678H    ; 22136
    push    ax                      ; Argument passed on stack
    movw    ax , #01234H    ; 4660  ; 1st argument passed on register
    call    !_func0                 ; Function call
    pop     ax                      ; Argument passed on stack
    ret
_func0 :
    push    hl                      ; Save the register for arguments
    xch     a , x
    xch     a , _@KREG12
    xch     a , x
    xch     a , _@KREG13    ; Allocate register argument p1 to _@KREG12
    push    ax              ; Save the saddr area for register arguments
    movw    ax , _@KREG10
    push    ax              ; Save the saddr area for register variables
    movw    ax , _@KREG14
    push    ax              ; Save the saddr area for automatic variables
    movw    ax , sp
    movw    hl , ax
    mov     a , [ hl + 10 ]         ; Argument p2 passed on stack
    xch     a , x
    mov     a , [ hl + 11 ]
    movw    hl , ax                 ; Assigned to HL
    movw    ax , hl                 ; Argument p2
    movw    _@KREG10 , ax   ; r     ; Assigned to register variables r
    movw    ax, _@KREG12    ; p1    ; Register argument p1
    movw    _@KREG14 , ax   ; a     ; Assigned to automatic variable a
    pop     ax
    movw    _@KREG14 , ax   ; Restore the saddr area for register variables
    pop     ax
    movw    _@KREG10 , ax   ; Restore the saddr area for automatic variables
    pop     ax
    movw    _@KREG12 , ax   ; Restore the saddr area for register arguments
    pop     hl              ; Restore the register for arguments
    ret
    END
```

12.1.2 Static model

- On the function call side, register arguments are passed in the same way as regular arguments.
- Up to 3 arguments, or a total of 6 bytes, can be passed, all via a register.

Table 12-3 Passing Arguments (Function Call Side)

Type	Passing Location (First Argument)	Passing Location (Second Argument)	Passing Location (Third Argument)
1-byte data	A	B	H
2-byte data	AX	BC	HL
4-byte data	Allocated to AX and BC, remainder allocated to H or HL		

Remark 1- to 4-byte data does not include structures and unions.

- On the function definition side, arguments passed via a register are stored to the argument allocation location.
  Arguments (register arguments) declared with register are allocated to registers whenever possible, and regular arguments are allocated to areas reserved for specific functions.
- All register arguments are passed via registers, but the registers on the function call side (passing side) and the function definition side (receiving side) differ, and therefore register copying is performed.
- Saving and restoring of registers allocated an argument/automatic variable is performed on the function definition side.
- Function arguments and the values of automatic variables declared inside functions are stored to the function-specific areas listed below using an option. Function-specific areas are static areas in RAM reserved for each function.

Table 12-4 Storing of Arguments/Automatic Variables (Inside Called Function)

Option	Argument/auto Variable	Storage Location	Priority Level
-qv (register allocation option)	Declared argument or automatic variable	DE register	Arguments : char type : D, E, in this order int, short, enum type : DE Automatic variables : char type : E, D, in this order int, short, enum type : DE
Default	Declared argument, automatic variable	Function-specific area	Arguments are allocated starting from the 1st argument, automatic variables are allocated by order of appearance
Default	Argument, register variable declared with register	DE register	Only the number of bytes of the variable or argument is allocated, according to the number of times referenced. Other than the number of bytes of the variable or argument is allocated to the area peculiar to the function.

The following example shows the function call.

< C source : Static Model at -sm and -qv specifications >

```
void    sub ( ) ;
void    func ( register int , char ) ;
void    main ( ) {
        func ( 0x1234 , 0x56 ) ;
}
void    func ( register int  p1 , char  p2 ) {
        register char   r ;
        int     a ;
        r = p2 ;
        a = p1 ;
        sub ( ) ;
}
```

< Output assembler source >

```
    PUBLIC  _func
    PUBLIC  _main
        :
@@DATA      DSEG
?L0005 :    DS      ( 1 )           ; Argument p2
?L0006 :    DS      ( 1 )           ; Register variable r
?L0007 :    DS      ( 2 )           ; Automatic variable a
        :
@@CODE  CSEG
_main :
    mov     b , #056H       ; 86    ; Pass the 2nd argument by register B
    movw    ax , #01234H    ; 4660  ; Pass the 1st argument by register AX
    call    !_func                  ; Function call
    ret
_func :
    push    de                      ; Save registers for register arguments
    movw    de , ax                 ; Allocate register arguments p1 to DE
    movw ax,bc
    mov     !?L0005 , a             ; Copy argument p2 to ?L0005
    mov     !?L0006 , a     ; r     ; Assigned to register variable r
    movw    ax , de                 ; Register argument p1
    mov     !?L0007 + 1 , a ; a
    xch     a , x
    mov     !?L0007 , a     ; a     ; Assigned to automatic variable a
    call    !_sub
    pop     de              ; Restores the register for register arguments
    ret
    END
```

12.2 Storing Return Values

Return values during function calls are stored to registers and carry flags.

The storage locations of return values are shown in the table below.

Table 12-5 Storage Location of Return Values

Type	Normal Model	Static Model
1-byte integer	BC	A
2-byte integer		AX
4-byte integer	BC (low-order), DE (high-order)	Not supported
Pointer	BC	AX
Structure, union	BC (start address of structure or union copied to function-specific area)	Not supported
1 bit	CY (carry flag)	CY (carry flag)
Floating-point number	BC (low-order), DE (high-order)	Not supported

12.3 Calling Assembly Language Routines from C Language

This section shows examples when the normal model (default) is used. If the -qv option, -qr option, and -qrv option are specified, arguments are stored as indicated in Table 12-2. However, the HL register is allocated only when no base pointer is required (when base pointer is not used).

Calling an assembly language routine from the C language is described as follows.

- C language function calling procedure
- Saving data from the assembly language routine and returning

12.3.1 C language function calling procedure

This is a C language program example that calls an assembly language routine.

```
extern  int     FUNC ( int , long ) ;   /* Function prototype */

void    main ( )
{
        int     i , j ;
        long    l ;

        i = 1 ;
        l = 0x54321 ;
        j = FUNC ( i , l ) ;            /* Function call */
}
```

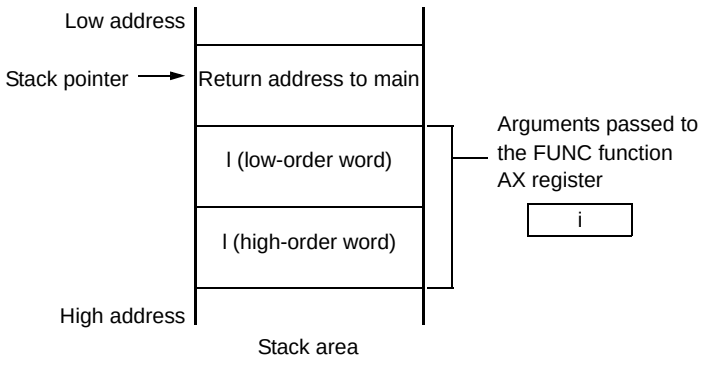
In this program example, the interface and control flow with the program that is executing are as follows.

(i) Placing the first argument passed from the main function to the FUNC function in the register, and the second and subsequent arguments on the stack.

(ii) Passing control to the FUNC function by using the CALL instruction.

The next figure shows the stack immediately after control moves to the FUNC function in the above program example.

Figure 12-1 Stack Area After a Call



12.3.2 Saving data from the assembly language routine and returning

The following processing are performed in the FUNC function called from the main function.

(1) Save the base pointer, work register.

(2) Copy the stack pointer (SP) to the base pointer (HL).

(3) Perform the processing in the FUNC function.

(4) Set the return value.

(5) Restore the saved register.

(6) Return to the main function.

Next, an example of an assembly language program is explained.

```
$PROCESSOR ( 9026 )

        PUBLIC  _FUNC
        PUBLIC  _DT1
        PUBLIC  _DT2

@@DATA  DSEG
_DT1 :  DS      ( 2 )
_DT2 :  DS      ( 4 )

@@CODE  CSEG
_FUNC :
        PUSH    HL                      ; save base pointer     (1)
        PUSH    AX
        MOVW    AX , SP                 ; copy stack pointer    (2)
        MOVW    HL , AX
        MOV     A , [ HL ]              ; arg1
        MOVW    !_DT1 , A               ; move 1st argument ( i )
        XCH     A , X
        MOV     A , [ HL + 1 ]          ; arg1
        MOV     !_DT1 + 1 , A
        MOV     A , [ HL + 8 ]          ; arg2
        XCH     A , X
        MOV     A , [ HL + 9 ]          ; arg2
        MOVW    BC , AX
        MOV     A , [ HL + 6 ]          ; arg2
        XCH     A , X
        MOV     A , [ HL + 7 ]          ; arg2
        MOVW    DE , #_DT2
        XCH     A , X
        MOV     [ DE ],A                ; move 2nd argument ( l )
        XCH     A , X
        INCW    DE
        MOV     [ DE ] , A
        XCHW    AX , BC
        INCW    DE
        XCH     A , X
        MOV     [ DE ] , A
        XCH     A , X
        INCW    DE
        MOV     [ DE ] , A
        XCHW    AX , BC
        MOVW    BC , #0AH               ; set return value      (4)
        POP     AX
        POP     HL                      ; restore base pointer  (5)
        RET                                                     (6)
        END
```

(1) Saving base pointer, work register

A label with "_" prefixed to the function name described in the C source is described. Base pointers and work registers are saved with the same name as function names described inside the C source.

After the label is described, the HL register (base pointer) is saved.

In the case of programs generated by the C compiler, other functions are called without saving the register for register variables. Therefore, if changing the values of these registers for functions that are called, be sure to save the values beforehand. However, if register variables are not used on the call side, saving the work register is not required.

(2) Copying to base pointer (HL) of stack pointer (SP)

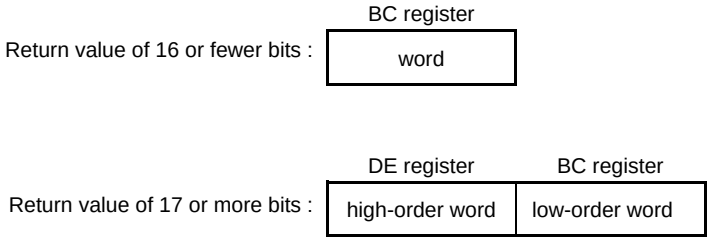
The stack pointer (SP) changes due to "PUSH, POP" inside functions. Therefore, the stack pointer is copied to register "HL" and used as the base pointer of arguments.

(3) Basic processing of FUNC function

After processings (1) and (2) are performed, the basic processing of called functions is performed.

(4) Setting the return value

If there is a return value, it is set in the "BC" and "DE" registers. If there is no return value, setting is unnecessary.

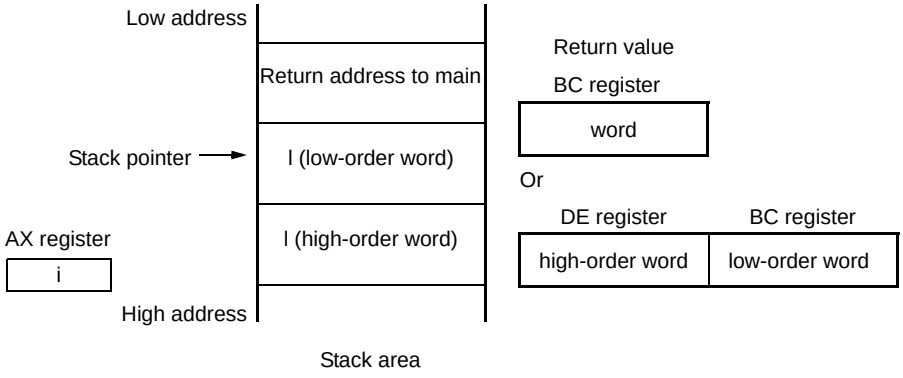


(5) Restoring the registers

Restore the saved base pointer and work register.

(6) Returning to the main function

Figure 12-2 Stack Area After Returning



12.4 Calling C Language Routines from Assembly Language

12.4.1 Calling the C language function from an assembly language program

The procedure for calling a function written in the C language from an assembly language routine is :

(1) Place the arguments on the stack.

(2) Save the C work registers (AX, BC, and DE).

(3) Call the C language function.

(4) Increment the value of the stack pointer (SP) by the number of bytes of arguments.

(5) Reference the return value of the C language function (in BC or DE and BC).

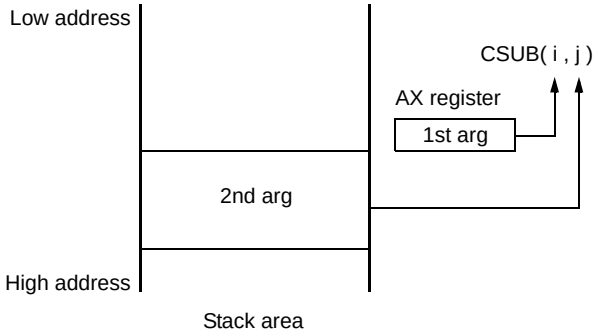
This is an example of an assembly language program.

```
$PROCESSOR ( 9216 )

        NAME    FUNC2
        EXTRN   _CSUB
        PUBLIC  _FUNC2

@@CODE  CSEG
_FUNC2 :
        movw    ax , #20H       ; set 2nd argument ( j )
        push    ax              ;
        movw    ax , #21H       ; set 1st argument ( i )
        call    !_CSUB          ; call " CSUB ( i , j ) "
        pop     ax              ;
        ret
        END
```

(1) Stacking arguments

Any arguments are placed on the stack. Figure 12-3 shows argument passing.

Figure 12-3 Placing Arguments on Stack



(2) Saving the work registers (AX, BC, and DE)

The 3 register pairs of AX, BC, and DE are used in the C language. Their values are not restored when returning. Therefore, if the values in registers are needed, they are saved on the calling side.

Save or restore the registers before or after an argument pass code. The HL register is always saved on the side of the C language when it is used in the C language.

(3) Calling a C language function

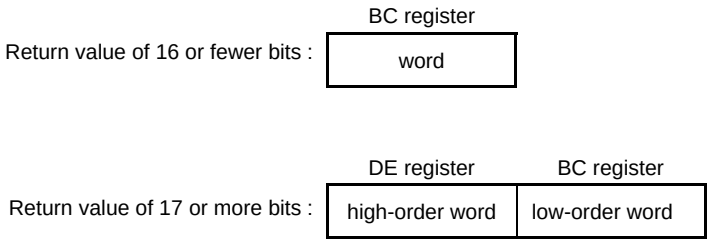
A CALL instruction calls a C language function. If the C language function is a "callt" function, the callt instruction performs the call, and if a "callf" function, the callf instruction performs it.

(4) Restoring the stack pointer (SP)

The stack pointer is restored by the number of bytes that hold the arguments.

(5) Referencing the return value (BC and DE)

The return value from the C language is returned as follows.

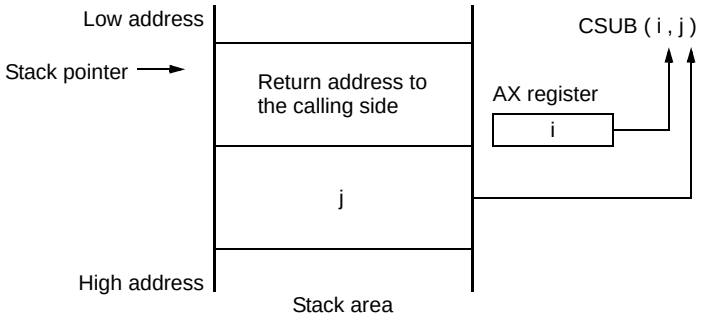


(6) Referencing arguments in a C language function

To correctly pass the "i" and "j" arguments to the C language program shown below, they are placed on the stack as shown in Figure 12-4.

```
void    CSUB ( i , j )
int     i , j ;
{
        i += j ;
}
```

Figure 12-4 Passing Arguments to C Language



12.5 Referencing Variables Defined in Other Languages

12.5.1 Referencing variables defined in the C language

If external variables defined in a C language program are referenced in an assembly language routine, the extern declaration is used. Underscores "_" are added to the beginning of the variables defined in the assembly language routine.

< C language program example >

```
extern  void    subf ( ) ;

char    c = 0 ;
int     i = 0 ;
void    main ( )
{
        subf ( ) ;
}
```

The following occurs in the RA78K0S assembler.

```
$PROCESSOR ( 9216 )

        PUBLIC  _subf
        EXTRN   _c
        EXTRN   _i

@@CODE  CSEG
_subf :
        MOV     a , #04H
        MOV     !_c , a
        MOVW    ax , #07H       ; 7
        MOVW    de , #_i
        INCW    DE
        MOV     [ DE ] , A
        DECW    DE
        XCH     A , X
        MOV     [ DE ] , A
        RET
        END
```

12.5.2 Referencing variables defined in the assembly language from the C language

Variables defined in assembly language are referenced from the C language in this way.

< C language program example >

```
extern  char    c ;
extern  int     i ;

void    subf ( )
{
        c = ' A ' ;
        i = 4 ;
}
```

The following occurs in the RA78K0S assembler.

```
        NAME    ASMSUB

        PUBLIC  _c
        PUBLIC  _i

ABC     DSEG
_c :    DB      0
_i :    DW      0

        END
```

12.6 Cautions

(1) "_" (underscore)

The CC78K0S adds an underscore "_" (ASCII code "5FH") to external definitions and reference names of the object modules to be output. In the next C program example, "j = FUNC(i, l);" is taken as "a reference to the external name _FUNC".

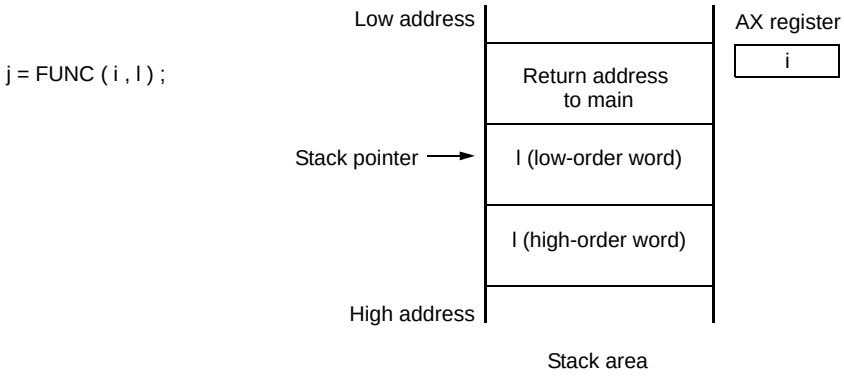
```
extern  int     FUNC ( int , long ) ;   /* Function prototype */

void    main ( )
{
        int     i , j ;
        long    l ;

        i = 1 ;
        l = 0x54321 ;
        j = FUNC ( i , l ) ;            /* Function call */
}
```

The routine name is written as "_FUNC" in RA78K0S.

(2) Argument positions on the stack

The arguments placed on the stack are placed from the postfix argument to the prefix argument in the direction from the High address to the Low address.

Figure 12-5 Stack Positions of Arguments



CHAPTER 13 EFFECTIVE UTILIZATION OF COMPILER

This chapter introduces how to effectively use the CC78K0S.

13.1 Efficient Coding

When developing 78K0S Series microcomputer-applied products, efficient object generation may be realized with the CC78K0S by utilizing the saddr area, callt table, or callf area of the device.

- Use external variables
  - if (saddr area is usable)
    - sreg/__sreg variables are used/ compiler option (-rd) is used
- Use 1-bit data
  - if (saddr is usable)
    - bit/boolean/ __boolean type variables are used
- Function definition
  - if (function to be called several times)
    - if (callt area is usable)
      - Use as __callt/callt function (effective for reducing code size)
    - if (not used recursively)
      - Use as __leaf/norec function
  - if (automatic variables are not used)
    - Use as noauto function
  - if (automatic variables are used &&saddr area is usable)

(1) Using external variable

When defining an external variable, specify the external variable to be defined as a sreg/__sreg variable if the saddr area can be used. Instructions to sreg/__sreg variables are shorter in code length than instructions to memory. This helps shorten object code and improve program execution speed. (The same can be also performed by specifying the -rd option, instead of using the sreg variable.)

```
Definition of sreg/__sreg variable :    extern sreg int variable-name ;
                                        extern __sreg int variable-name ;
```

Remark Refer to "11.5 (3) How to use the saddr area (sreg / __sreg)".

(2) 1-bit data

A data object which only uses 1-bit data should be declared as a bit type variable (or boolean/__boolean type variable). A bit manipulation instruction will be generated for an operation on bit/boolean/__boolean type variable. Because saddr area is used as well as sreg variable, the codes can be shortened and the execution speed can be improved.

```
Declaration of bit/boolean type variable :      bit variable-name ;
                                                boolean variable-name ;
                                                __boolean variable-name ;
```

Remark Refer to "11.5 (7) bit type variables, boolean type variables (bit / boolean / __boolean)".

(3) Function definitions

For a function to be called over and over again, object code should be shortened or a structure which allows call at high speeds should be provided. If the callt table can be used for functions to be called frequently, such functions should be defined as callt functions. The callt functions can be called faster than ordinary function calls with shorter codes because the callt functions are called using the callt/callf area of the device.

```
Definition of callt function :  callt   int     tsub ( )  {
            :
}
```

Remark Refer to "11.5 (1) callt functions (callt / __callt)", and "11.5 (6) norec functions (norec)".

In addition to the use of the saddr area, the objects that do not need the modification of the C source by compiling with the optimization option can be generated. For the effect of each -q suboption, refer to the CC78K0S C Compiler Operation User's Manual.

(4) Optimization option

The optimization options that emphasize the object code size the most is as follows.

< Object code is emphasized the most >

```
-qx3
```

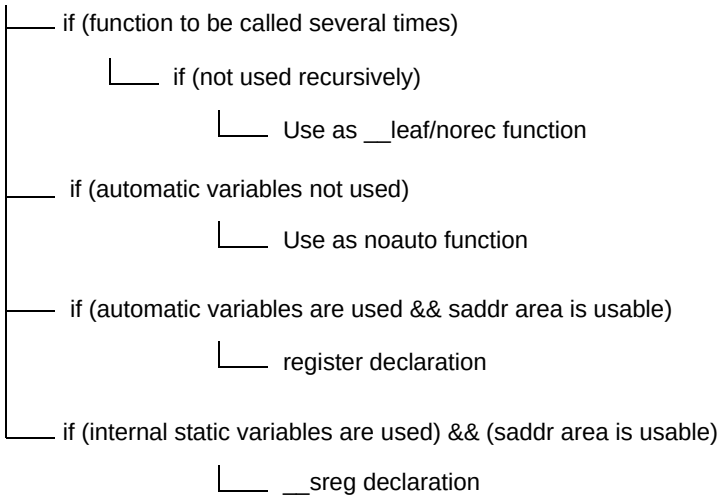
The further shortening of the code size and the improvement of the execution speed is possible by adding __sreg to variables. However, this is restricted to the cases when the saddr area can be used. When the areas are run out and cannot be used, a compile error occurs.

If execution speed is also highly emphasized, specify the -qx2 default.

In addition, the object efficiency can be improved by adding the extended functions supported by the CC78K0S to the C source.

(5) Using extended description

- Function definition



- Functions not used recursively

Of the functions to be called over and over again, the ones which are not used recursively should be defined as __leaf/norec functions. norec functions become functions that do not have preprocessing/ postprocessing (stack frame). Therefore, the object code can be shortened and the execution speed can be improved compared to the ordinary functions.

Remark For the definition of norec function (norec int rout ( )...), refer to "11.5 (6) norec functions (norec)" and "11.7.4 norec function call interface (normal model)".

- Functions which do not use automatic variables

Functions that do not use automatic variables should be defined as noauto functions. These functions will not output code for stack frame formation and their arguments will be passed to registers as much as possible. These functions help shorten object code and improve program execution speed.

Remark Refer to "11.5 (5) noauto functions (noauto)", "11.7.3 noauto function call interface (normal model only)" about noauto function definition (noauto int sub1 (int i) ...).

- Functions which use automatic variables

  If the saddr area can be used for a function that does not use automatic variables, declare the function with the register storage class specifier. By this register declaration, the object declared as register will be allocated to a register. A program using registers operates faster than that using memory and object code can be shortened as well.

  Remark Refer to "11.5 (2) Register variables (register)" about definition of register variable (register int i; ...).

- Functions which use internal static variables

  If the saddr area can be used for a function that uses internal static variables, declare the function with __sreg or specify the -rs option. In the same way as with sreg variables, the object code can be shortened and the execution speed can be improved.

  Remark Refer to "11.5 (3) How to use the saddr area (sreg / __sreg)".

In addition, the code efficiency and the execution speed can be improved in the following method.

- Use of SFR name (or SFR bit name).

  #pragma sfr

- Use of __sreg declaration for bit fields which consist only of 1-bit members (unsigned char type can be used for members).

```
__sreg  struct  bf {
        unsigned char   a : 1 ;
        unsigned char   b : 1 ;
        unsigned char   c : 1 ;
        unsigned char   d : 1 ;
        unsigned char   e : 1 ;
        unsigned char   f : 1 ;
} bf_1 ;
```

- Use of multiplication and division embedded function.

  #pragma mul

  #pragma div

- Description of only the modules whose speed needs to be improved in the assembly language.

APPENDIX A LIST OF LABELS FOR saddr AREA

In the CC78K0S, the saddr area is referenced by the following label names. Therefore, the label names in the C source program and in assembler source program that have the same names as the following cannot be used.

A.1 Normal Model

(a) Register variables

Table A-1 Register Variables (Normal Model)

Label Name	Address
_@KREG00	0FED8H
_@KREG01	0FED9H
_@KREG02	0FEDAH
_@KREG03	0FEDBH
_@KREG04	0FEDCH
_@KREG05	0FEDDH
_@KREG06	0FEDEH
_@KREG07	0FEDFH
_@KREG08	0FEE0H
_@KREG09	0FEE1H
_@KREG10	0FEE2H
_@KREG11	0FEE3H
_@KREG12	0FEE4H[Note]
_@KREG13	0FEE5H[Note]
_@KREG14	0FEE6H[Note]
_@KREG15	0FEE7H[Note]

Note When the arguments of the function are declared by register or the -qv option is specified and the -qr option is specified, arguments are allocated to the saddr area.

(b) Arguments of norec function

Table A-2 Arguments of norec Function (Normal Model)

Label Name	Address
_@NRARG0	0FEE8H
_@NRARG1	0FEEAH
_@NRARG2	0FEECH
_@NRARG3	0FEEEH

(c) Automatic variables of norec function

Table A-3 Automatic Variables of norec Function

Label Name	Address
_@NRAT00	0FEF0H
_@NRAT01	0FEF1H
_@NRAT02	0FEF2H
_@NRAT03	0FEF3H
_@NRAT04	0FEF4H
_@NRAT05	0FEF5H
_@NRAT06	0FEF6H
_@NRAT07	0FEF7H

(d) Arguments of runtime library

Table A-4 Arguments of Runtime Library

Label Name	Address
_@RTARG0	0FEF8H
_@RTARG1	0FEF9H
_@RTARG2	0FEFAH
_@RTARG3	0FEFBH
_@RTARG4	0FEFCH
_@RTARG5	0FEFDH
_@RTARG6	0FEFEH
_@RTARG7	0FEFFH

A.2 Static Model

(a) Shared area

Table A-5 Shared Area (Static Model)

Label Name	Address
_@KREG00	0FEF0H
_@KREG01	0FEF1H
_@KREG02	0FEF2H
_@KREG03	0FEF3H
_@KREG04	0FEF4H
_@KREG05	0FEF5H
_@KREG06	0FEF6H
_@KREG07	0FEF7H
_@KREG08	0FEF8H
_@KREG09	0FEF9H
_@KREG10	0FEFAH
_@KREG11	0FEFBH
_@KREG12	0FEFCH
_@KREG13	0FEFDH
_@KREG14	0FEFEH
_@KREG15	0FEFFH

(b) For arguments, automatic variables, and work

Table A-6 For Arguments, Automatic Variables, and Work

Label Name	Address
_@NRAT00	0FExxH[Note]
_@NRAT01	_@NRAT00 + 1
_@NRAT02	_@NRAT00 + 2
_@NRAT03	_@NRAT00 + 3
_@NRAT04	_@NRAT00 + 4
_@NRAT05	_@NRAT00 + 5
_@NRAT06	_@NRAT00 + 6
_@NRAT07	_@NRAT00 + 7

Note Arbitrary address in the saddr area

APPENDIX B LIST OF SEGMENT NAMES

This chapter explains all the segments that the compiler outputs and their locations.

(1) and (2) show the option and re-allocation attributes used in the table.

This section describes all the segments and allocations that are output by compiler.

(1) CSEG re-allocation attribute

CALLT0 :	Allocates the specified segment so that the start address is a multiple of two within the range of 40H to 7FH.
AT absolute expression :	Allocates the specified segment to an absolute address (within the range of 0000H to FEFFH).
FIXED :	Allocates the specified segment within the range of 0800H to 0FFFH.
UNITP :	Allocates the specified segment so that the start address is a multiple of two within any position (within the range of 80H to 0FA7EH).

(2) DSEG re-allocation attribute

SADDRP :	Allocates the specified segment so that the start address is a multiple of two within the range of FE20H to FEFFH in the saddr area.
UNITP :	Allocates the specified segment so that the start address is a multiple of two within any position (default is within the RAM area).

B.1 List of Segment Names

B.1.1 Program area and data area

Table B-1 List of Segment Name (Program Area and Data Area)

Section Name	Segment Type	Re-allocation Attribute	Description
@@CODE	CSEG		Segment for code portion
@@LCODE	CSEG		Segment for library code
@@CNST	CSEG		Segment for const variable
@@R_INIT	CSEG		Segment for initialization data (with initial value)
@@R_INIS	CSEG	UNITP	Segment for initialization data (sreg variable with initial value)
@@CALT	CSEG	CALLT0	Segment for callt function table
@@VECTnn	CSEG	AT 00nnH	Segment for vector table[Note]
@@INIT	DSEG		Segment for data area (with initial value)
@@DATA	DSEG		Segment for data area (without initial value)
@@INIS	DSEG	SADDRP	Segment for data area (sreg variable with initial value)
@@DATS	DSEG	SADDRP	Segment for data area (sreg variable without initial value)
@@BITS	BSEG		Segment for boolean-type and bit-type variables

Note The value of nn changes depending on the interrupt types.

B.2 Location of Segment

Table B-2 Location of Segment

Segment Type	Destination of Allocation (Default)
CSEG	ROM
BSEG	saddr area of RAM
DSEG	RAM

B.3 Example of C Source

```
#pragma INTERRUPT       INTP0   inter   /* Interrupt vector */

void    inter ( void ) ;        /* Interrupt function prototype declaration */
const   int     i_cnst = 1 ;        /* const variable */
callt   void    f_clt ( void ) ;    /* callt function prototype declaration */
boolean b_bit ;                     /* boolean-type variable */
long    l_init = 2 ;                /* External variable with initial value */
int     i_data ;                /* External variable without initial value */
sreg    int     sr_inis = 3 ;       /* sreg variable with initial value */
sreg    int     sr_dats ;           /* sreg variable without initial value */

void    main ( )                    /* Function definition */
{
        int     i ;
        i = 100 ;
}

void    inter ( )                   /* Interrupt function definition */
{
        unsigned char   uc = 0 ;
        uc++ ;
        if ( b_bit )
        b_bit = 0 ;
}

callt   void    f_clt ( )           /* callf function definition */
{
}
```

B.4 Example of Output Assembler Module

Quasi-directives and instruction sets in an assembler source vary depending on the device.

Refer to the RA78K0S Assembler Package Operation User's Manual for details.

```
; 78K/0S Series C Compiler V1.60 Assembler Source
;                            Date : xx xxx xxxx Time : xx : xx : xx

; Command   : -c9026 sampk0s.c -sa -ng
; In-file   : sampk0s.c
; Asm-file  : sampk0s.asm
; Para-file :

$PROCESSOR ( 9026 )
$NODEBUG
$NODEBUGA
$KANJICODE    SJIS
$TOL_INF      03FH , 0130H , 00H , 00H

              EXTRN   _@cprep
              PUBLIC  _inter
              PUBLIC  _i_cnst
              PUBLIC  ?f_clt
              PUBLIC  _i_cnst
              PUBLIC  _b_bit
              PUBLIC   _l_init
              PUBLIC  _i_data
              PUBLIC  _sr_inis
              PUBLIC  _sr_dats
              PUBLIC  _main
              PUBLIC  _f_clt
              PUBLIC  _@vect06

@@BITS        BSEG                        ; Segment for boolean-type variable
_b_bit        BIT

@@CNST        CSEG                        ; Segment for const variable
_i_cnst :     DW      01H                 ; 1

@@R_INIT      CSEG                        ; Segment for initialization data
                                        ; (External variable with initial value)
              DW      00002H , 00000H     ; 2

@@INIT        DSEG                        ; Segment for data area
                                       ; (External variable with initial value)
_l_init :     DS      ( 4 )
@@DATA        DSEG    UNITP               ; Segment for data area
                                      ; (External variable without initial value)
_i_data :     DS      ( 2 )

@@R_INIS      CSEG                        ; Segment for initialization data
                                          ; (sreg variable with initial value)
              DW      03H                 ; 3

@@INIS        DSEG    SADDRP              ; Segment for data area
                                          ; (sreg variable with initial value)
_sr_inis :    DS      ( 2 )
```

```
@@DATS        DSEG    SADDRP              ; Segment for data area
                                        ; (sreg variable without initial value)
_sr_dats :    DS      ( 2 )

@@CALT        CSEG    CALLT0              ; Segment for callt function
?f_clt :      DW      _f_clt

; line  1 :   #pragma INTERRUPT   INTP0   inter   /* Interrupt vector */
; line  2 :
; line  3 :   void    inter ( void ) ;            /* Interrupt function */
                                                  /* prototype declaration */
; line  4 :   const   int     i_cnst = 1 ;        /* const variable */
; line  5 :   callt   void    f_clt ( void ) ;    /* callt function prototype */
                                                  /* declaration */
; line  6 :   boolean b_bit ;                     /* boolean-type variable */
; line  7 :   long    l_init = 2 ;                /* External variable with */
                                                  /* initial value */
; line  8 :   int     i_data ;                    /* External variable */
                                                  /* without initial value */
; line  9 :   sreg    int     sr_inis = 3 ;       /* sreg variable with */
                                                  /* initial value */
; line  10 :  sreg    int     sr_dats ;           /* sreg variable without */
                                                  /* initial value */
; line  11 :
; line  12 :  void    main ( )                    /* Function definition */
; line  13 :  {

@@CODE  CSEG                                      ; Segment for code portion
_main :
        push  hl                                  ; [ INF ] 1 , 4
        movw  ax , #02H                           ; [ INF ] 3 , 6
        callt [ _@cprep ]                         ; [ INF ] 1 , 8
; line  14 :  int     i ;
; line  15 :  i = 100 ;
        movw  ax , #064H      ; 100               ; [ INF ] 3 , 6
        mov   [ hl + 1 ] , a  ; i                 ; [ INF ] 2 , 6
        xch   a , x                               ; [ INF ] 1 , 4
        mov   [ hl ] , a      ; i                 ; [ INF ] 1 , 6
; line  16 :  }
        pop   ax                                  ; [ INF ] 1 , 6
        pop   hl                                  ; [ INF ] 1 , 6
        ret                                       ; [ INF ] 1 , 6
; line  17 :
; line  18 :  void    inter ( )           /* Interrupt function definition */
; line  19 :  {
_inter :
        push  ax                                  ; [ INF ] 1 , 4
        push  de                                  ; [ INF ] 1 , 4
        push  hl                                  ; [ INF ] 1 , 4
        movw  ax , #02H                           ; [ INF ] 3 , 6
        callt [ _@cprep ]                         ; [ INF ] 1 , 8
; line  20 :  unsigned char   uc = 0 ;
        xor   a , a                               ; [ INF ] 2 , 4
        mov   [ hl + 1 ] , a  ; uc                ; [ INF ] 2 , 6
; line  21 :  uc++ ;
        inc   a                                   ; [ INF ] 2 , 4
        xch   a , [ hl + 1 ]  ; uc                ; [ INF ] 2 , 8
; line  22 :  if ( b_bit )
        bf    _b_bit , $L0005                     ; [ INF ] 4 , 10
; line  23 :  b_bit = 0 ;
        clr1  _b_bit                              ; [ INF ] 3 , 6
```

```
L0005 :
; line  24 :  }
        pop   ax                                    ; [ INF ] 1 , 6
        pop   hl                                    ; [ INF ] 1 , 6
        pop   de                                    ; [ INF ] 1 , 6
        pop   ax                                    ; [ INF ] 1 , 6
        reti                                        ; [ INF ] 1 , 8
; line  26 :
; line  27 :  callt   void f_clt ( )          /* callt function definition */
; line  28 :  {
_f_clt:
; line  29 :  }
        ret                                         ; [ INF ] 1 , 6

@@VECT06      CSEG    AT      0006H                 ; Interrupt vector
_@vect06 :
        DW    _inter
        END

; *** Code Information ***
;
; $FILE C:\NECTools32\work\sampk0s.c
;
; $FUNC main ( 13 )
;       void = ( void )
;       CODE SIZE = 15 bytes , CLOCK_SIZE = 58 clocks , STACK_SIZE = 6 bytes
;
; $FUNC inter ( 19 )
;       void =  ( void )
;       CODE SIZE = 27 bytes , CLOCK_SIZE = 96 clocks , STACK_SIZE = 10 bytes
;
; $FUNC f_clt ( 27 )
;       void = ( void )
;       CODE SIZE = 1 bytes , CLOCK_SIZE = 6 clocks , STACK_SIZE = 0 bytes
;
; Target chip : uPD789026
; Device file : Vx.xx
```

APPENDIX C LIST OF RUNTIME LIBRARIES

Table C-1 shows the runtime library list.

These operational instructions are called in the format where @@, etc. are attached at the beginning of the function name.

However, cstart, cprep, and cdisp are called in the format with _@ attached to the top.

No library supports are available for operations not in Table C-1. The compiler executes in-line development.

long addition and subtraction, and/or/xor and shift may be developed in-line.

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Increment	lsinc	OK	-	Increments signed long
	luinc	OK	-	Increments unsigned long
	finc	OK	-	Increments float
Decrement	lsdec	OK	-	Decrements signed long
	ludec	OK	-	Decrements unsigned long
	fdec	OK	-	Decrements float
Sign reverse	lsrev	OK	-	Reverses the sign of signed long
	lurev	OK	-	Reverses the sign of unsigned long
	frev	OK	-	Reverses the sign of float
1's complement	lscom	OK	-	Obtains 1's complement of signed long
	lucom	OK	-	Obtains 1's complement of unsigned long
Logical NOT	lsnot	OK	-	Negates signed long
	lunot	OK	-	Negates unsigned long
	fnot	OK	-	Negates float
Multiply	csmul	OK	OK	Performs multiplication between signed char data
	cumul	OK	OK	Performs multiplication between unsigned char data
	ismul	OK	OK	Performs multiplication between signed int data
	iumul	OK	OK	Performs multiplication between unsigned int data
	lsmul	OK	-	Performs multiplication between signed long data
	lumul	OK	-	Performs multiplication between unsigned long data
	fmul	OK	-	Performs multiplication between float data

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Divide	csdiv	OK	OK	Performs division between signed char data
	cudiv	OK	OK	Performs division between unsigned char data
	isdiv	OK	OK	Performs division between signed int data
	iudiv	OK	OK	Performs division between unsigned int data
	lsdiv	OK	-	Performs division between signed long data
	ludiv	OK	-	Performs division between unsigned long data
	fdiv	OK	-	Performs division between float data
Remainder	csrem	OK	OK	Obtains remainder after division between signed char data
	curem	OK	OK	Obtains remainder after division between unsigned char data
	isrem	OK	OK	Obtains remainder after division between signed int data
	iurem	OK	OK	Obtains remainder after division between unsigned int data
	lsrem	OK	-	Obtains remainder after division between signed long data
	lurem	OK	-	Obtains remainder after division between unsigned long data
Add	lsadd	OK	-	Performs addition between signed long data
	luadd	OK	-	Performs addition between unsigned long data
	fadd	OK	-	Performs addition between float data
Subtract	lssub	OK	-	Performs subtraction between signed long data
	lusub	OK	-	Performs subtraction between unsigned long data
	fsub	OK	-	Performs subtraction between float data
Shift left	islsh	OK	OK	Shifts singed int data to the left
	iulsh	OK	OK	Shifts unsigned int data to the left
	lslsh	OK	-	Shifts singed long data to the left
	lulsh	OK	-	Shifts unsigned long data to the left
Shift right	isrsh	OK	OK	Shifts signed int data to the right
	iursh	OK	OK	Shifts unsigned int data to the right
	lsrsh	OK	-	Shifts signed long data to the right
	lursh	OK	-	Shifts unsigned long data to the right

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Compare	cscmp	OK	OK	Compares signed char data
	iscmp	OK	OK	Compares signed int data
	lscmp	OK	-	Compares signed long data
	lucmp	OK	-	Compares unsigned long data
	fcmp	OK	-	Compares float data
Bit AND	lsband	OK	-	Performs an AND operation between signed long data
	luband	OK	-	Performs an AND operation between unsigned long data
Bit OR	lsbor	OK	-	Performs an OR operation between signed long data
	lubor	OK	-	Performs an OR operation between unsigned long data
Bit XOR	lsbxor	OK	-	Performs an XOR operation between signed long data
	lubxor	OK	-	Performs an XOR operation between unsigned long data
Logical AND	fand	OK	-	Performs a logical AND operation between 2 float data
Logical OR	for	OK	-	Performs a logical OR operation between 2 float data
Conversion from floating-point number	ftols	OK	-	Converts from float to signed long
	ftolu	OK	-	Converts from float to unsigned long
Conversion to floating-point number	lstof	OK	-	Converts from signed long to float
	lutof	OK	-	Converts from unsigned long to float
Conversion from bit	btol	OK	-	Converts from bit to long

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	

Startup routine	cstart	OK	OK	Startup module
				- After an area (2 * 32 bytes) where a function that will be registered is reserved with the atexit function, sets the beginning label name to _@FNCTBL.
				- Reserve a break area (32 bytes), sets the beginning label name to _@MEMTOP, and then sets the next label name of the area to _@MEMBTM.
				- Define the segment in the reset vector table as follows, and set the beginning address of the startup module.
				`@@VECT00 CSEG AT 0000H`
				`DW _@cstart`
				- Set 0 to the variable _errno to which the error number is input.
				- Set the variable _@FNCENT, to which the number of functions registered by the atexit function is input, to 0.
				- Set the address of _@MEMTOP to the variable _@BRKADR as the initial break value.
				- Set 1 as the initial value for the variable _@SEED, which is the source of pseudo random numbers for the rand function.
				- Perform copy processing of initialized data and execute 0 clear of external data without an initial value.
				- Call the main function (user program)
				- Call the exit function by parameter 0.

Pre- and post-processing of function	cprep	OK	-	Pre-processing of function
	cdisp	OK	-	Post-processing of function
	cprep2	OK	-	Pre-processing of function (including the saddr area for register variables)
	cdisp2	OK	-	Post-processing of function (including the saddr area for register variables)

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Pre- and post-processing of function	nrcp2	-	OK	For copying arguments
	nrcp3	-	OK	
	krcp2	-	OK	
	krcp3	-	OK	
	nkrc3	-	OK	
	nrip2	-	OK	
	nrip3	-	OK	
	krip2	-	OK	
	krip3	-	OK	
	nkri31	-	OK	
	nkri32	-	OK	
	nrsave	-	OK	For saving _@NRATxx
	nrload	-	OK	For restoring _@NRATxx
	krs02	-	OK	For saving _@KREGxx
	krs04	-	OK	
	krs04i	-	OK	
	krs06	-	OK	
	krs06i	-	OK	
	krs08	-	OK	
	krs08i	-	OK	
	krs10	-	OK	
	krs10i	-	OK	
	krs12	-	OK	
	krs12i	-	OK	
	krs14	-	OK	
	krs14i	-	OK	
	krs16	-	OK	
	krs16i	-	OK	

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Pre- and post-processing of function	krl02	-	OK	For restoring _@KREGxx
	krl04	-	OK	
	krl04i	-	OK	
	krl06	-	OK	
	krl06i	-	OK	
	krl08	-	OK	
	krl08i	-	OK	
	krl10	-	OK	
	krl10i	-	OK	
	krl12	-	OK	
	krl12i	-	OK	
	krl14	-	OK	
	krl14i	-	OK	
	krl16	-	OK	
	krl16i	-	OK	
	hdwinit	OK	OK	Performs initialization processing of peripheral devices (sfr) immediately after CPU reset.
BCD-type conversion	bcdtob	OK	OK	Converts 1-byte bcd to 1-byte binary
	btobcd	OK	OK	Converts 1-byte binary to 2-byte bcd
	bcdtow	OK	OK	Converts 2-byte bcd to 2-byte binary
	wtobcd	OK	OK	Converts 2-byte binary to 2-byte bcd
	bbcd	OK	OK	Converts 1-byte binary to 1-byte bcd

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Auxiliary	mulu	OK	OK	mulu instruction-compatible
	divuw	OK	OK	divuw instruction-compatible
	clra0	OK	OK	For replacing the fixed-type instruction pattern
	clra1	OK	OK	
	clrax0	OK	OK	
	clrax1	OK	OK	
	clrbc0	OK	OK	
	clrbc1	OK	OK	
	cmpa0	OK	OK	
	cmpa1	OK	OK	
	cmpc0	OK	OK	
	cmpax0	OK	OK	
	cmpax1	OK	OK	
	movca	OK	OK	
	movac	OK	OK	
	ctoi	OK	OK	
	uctoi	OK	OK	
	adjba	OK	OK	
	adjbs	OK	OK	
	addrde	OK	OK	
	addrhl	OK	OK	
	shl4	OK	OK	
	shr4	OK	OK	
	tabled	OK	OK	
	tableh	OK	OK	
	apdecd	OK	OK	
	apdech	OK	OK	
	apincd	OK	OK	
	apinch	OK	OK	
	deilo	OK	OK	
	deist	OK	OK	
	deiinc	OK	OK	
	deidec	OK	OK	

Table C-1 Runtime Libraries

Classification	Function Name	Supported Model		Function
		Normal Model	Static Model	
Auxiliary	hlilo	OK	OK	For replacing the fixed-type instruction pattern
	hlist	OK	OK	
	hliinc	OK	OK	
	hlidec	OK	OK	
	dellab	OK	-	
	dell03	OK	-	
	della4	OK	-	
	delsab	OK	-	
	dels03	OK	-	
	hlllab	OK	-	
	hlll03	OK	-	
	hllla4	OK	-	
	hllsab	OK	-	
	hlls03	OK	-	
	hliadd	OK	OK	
	hlisub	OK	OK	
	hlicmp	OK	OK	
	hliand	OK	OK	
	hlior	OK	OK	
	hlixor	OK	OK	
	imule	OK	OK	
	isdive	OK	OK	
	iudive	OK	OK	
	isreme	OK	OK	
	iureme	OK	OK	
	iadde	OK	OK	
	isube	OK	OK	
	iande	OK	OK	
	iore	OK	OK	
	ixore	OK	OK	

APPENDIX D LIST OF LIBRARY STACK CONSUMPTION

Table D-1 shows the number of stacks consumed from the standard libraries.

Table D-1 List of Standard Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
ctype.h	isalnum	0	0
	isalpha	0	0
	iscntrl	0	0
	isdigit	0	0
	isgraph	0	0
	islower	0	0
	isprint	0	0
	ispunct	0	0
	isspace	0	0
	isupper	0	0
	isxdigit	0	0
	tolower	0	0
	toupper	0	0
	isascii	0	0
	toascii	0	0
	_tolower	0	0
	_toupper	0	0
	tolow	0	0
	toup	0	0
setjmp.h	setjmp	4	4
	longjmp	2	2
stdarg.h	va_arg	0	-
	va_start	0	-
	va_end	0	-

Table D-1 List of Standard Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
stdio.h	sprintf	52 (72)[Note 1]	-
	sscanf	290 (304)[Note 1]	-
	printf	54 (72)[Note 1]	-
	scanf	294 (304)[Note 1]	-
	vprintf	52 (72)[Note 1]	-
	vsprintf	52 (72)[Note 1]	-
	getchar	0	0
	gets	6	6
	putchar	0	0
	puts	4	4

Table D-1 List of Standard Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
stdlib.h	atoi	4	4
	atol	10	-
	strtol	20	-
	strtoul	20	-
	calloc	14	14
	free	8	8
	malloc	6	6
	realloc	12	12
	abort	0	0
	atexit	0	0
	exit	$2 + n^{\text{Note 2}}$	$2 + n^{\text{Note 2}}$
	abs	0	0
	div	6	-
	labs	2	-
	ldiv	16	-
	brk	0	0
	sbrk	4	4
	atof	33	-
	strtod	33	-
	itoa	10	10
	ltoa	16	-
	ultoa	16	-
	rand	14	-
	srand	0	-
	bsearch	$32 + n^{\text{Note 4}}$	-
	qsort	$16 + n^{\text{Note 5}}$	-
	strbrk	0	0
	strsbrk	4	4
	stritoa	10	10
	strltoa	16	-
	strultoa	16	-

Table D-1 List of Standard Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
string.h	memcpy	4	6
	memmove	4	8
	strcpy	2	4
	strncpy	4	6
	strcat	2	4
	strncat	4	6
	memcmp	2	4
	strcmp	2	2
	strncmp	2	4
	memchr	2	2
	strchr	2	0
	strcspn	6	6
	strpbrk	4	4
	strrchr	4	4
	strspn	6	6
	strstr	4	4
	strtok	4	4
	memset	4	4
	strerror	0	0
	strlen	0	0
	strcoll	2	2
	strxfrm	4	4

Table D-1 List of Standard Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
math.h	acos	24	-
	asin	24	-
	atan	20	-
	atan2	21	-
	cos	24 (34)[Note 6]	-
	sin	24 (34)[Note 6]	-
	tan	26 (34)[Note 6]	-
	cosh	24	-
	sinh	25	-
	tanh	30	-
	exp	22	-
	frexp	2 (10)[Note 6]	-
	ldexp	2 (10)[Note 6]	-
	log	24 (34)[Note 6]	-
	log10	24 (34)[Note 6]	-
	modf	2 (10)[Note 6]	-
	pow	25 (35)[Note 6]	-
	sqrt	18	-
	ceil	2	-
	fabs	0	-
	floor	2	-
	fmod	2 (10)[Note 6]	-
	matherr	0	-
	acosf	24	-
	asinf	24	-
	atanf	20	-
	atan2f	21	-
	cosf	24 (34)[Note 6]	-
	sinf	24 (34)[Note 6]	-
	tanf	26 (34)[Note 6]	-
	coshf	24	-
	sinhf	25	-

Table D-1 List of Standard Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
math.h	tanhf	30	-
	expf	22	-
	frexpf	2 (10)Note 6	-
	ldexpf	2 (10)Note 6	-
	logf	24 (34)Note 6	-
	log10f	24 (34)Note 6	-
	modff	2 (10)Note 6	-
	powf	25 (35)Note 6	-
	sqrtf	18	-
	ceilf	2	-
	fabsf	0	-
	floorf	2	-
	fmodf	2 (10)Note 6	-
assert.h	__assertfail	66 (84)Note 7	-

Notes 1. Values in parentheses are for when the version that supports floating-point numbers is used.

Notes 2. n is the total stack consumption among external functions registered by the atexit function.

Notes 3. Values in the parentheses are for when a multiplier is used.

Notes 4. n is the stack consumption of external functions called from bsearch.

Notes 5. n is (20 + stack consumption of external functions called from qsort) x (1 + number of times recursive calls occurred).

Notes 6. Values in parentheses are for when an operation exception occurs.

Notes 7. Values in parentheses are for when the printf version that supports floating-point numbers is used.

Table D-2 shows the number of stacks consumed from the runtime libraries.

Table D-2 List of Runtime Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
Increment	lsinc	0	-
	luinc	0	-
	finc	12 (22)Note 1	-
Decrement	lsdec	0	-
	ludec	0	-
	fdec	12 (22)Note 1	-
Sign reverse	lsrev	0	-
	lurev	0	-
	frev	0	-
1’s complement	lscom	0	-
	lucom	0	-
Logical NOT	lsnot	0	-
	lunot	0	-
	fnot	0	-
Multiply	csmul	4 (1)Note 2	4 (1)Note 2
	cumul	4 (1)Note 2	4 (1)Note 2
	ismul	6 (5)Note 2	6 (5)Note 2
	iumul	6 (5)Note 2	6 (5)Note 2
	lsmul	6 (7)Note 2	-
	lumul	6 (7)Note 2	-
	fmul	8 (18)Note 1	-
Divide	csdiv	8	8
	cudiv	4	4
	isdiv	8	12
	iudiv	4	6
	lsdiv	10	-
	ludiv	6	-
	fdiv	8 (18)Note 1	-

Table D-2 List of Runtime Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
Remainder	csrem	8	8
	curem	4	4
	isrem	8	12
	iurem	4	6
	lsrem	10	-
	lurem	6	-
Add	lsadd	0	-
	luadd	0	-
	fadd	8 (18)Note 1	-
Subtract	lssub	0	-
	lusub	0	-
	fsub	8 (18)Note 1	-
Shift left	islsh	0	0
	iulsh	0	0
	lslsh	2	-
	lulsh	2	-
Shift right	isrsh	0	0
	iursh	0	0
	lsrsh	2	-
	lursh	2	-
Compare	cscmp	0	2
	iscmp	0	2
	lscmp	2	-
	lucmp	2	-
	fcmp	4 (14)Note 1	-
Bit AND	lsband	0	-
	luband	0	-
Bit OR	lsbor	0	-
	lubor	0	-
Bit XOR	lsbxor	0	-
	lubxor	0	-
Logical AND	fand	0	-
Logical OR	for	0	-

Table D-2 List of Runtime Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
Conversion from floating-point number	ftols	4	-
	ftolu	4	-
Conversion to floating-point number	lstof	12 (22)[Note 1]	-
	lutof	12 (22)[Note 1]	-
Conversion from bit	btol	0	-
Startup routine	cstart	2	2
Pre- and post-processing of function	cprep	2 + n[Note 3]	-
	cdisp	0	-
	cprep2	Size of automatic variable + register variable	-
	cdisp2	0	-
	nrcp2	-	0
	nrcp3	-	0
	krcp2	-	0
	krcp3	-	0
	nkrc3	-	0
	nrip2	-	0
	nrip3	-	0
	krip2	-	0
	krip3	-	0
	nkri31	-	0
	nkri32	-	0
	nrsave	-	8
	nrload	-	0
	krs02	-	2
	krs04	-	4
	krs04i	-	4
	krs06	-	6
	krs06i	-	6
	krs08	-	8
	krs08i	-	8
	krs10	-	10
	krs10i	-	10
	krs12	-	12

Table D-2 List of Runtime Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
Pre- and post-processing of function	krs12i	-	12
	krs14	-	14
	krs14i	-	14
	krs16	-	16
	krs16i	-	16
	krl02	-	0
	krl04	-	0
	krl04i	-	0
	krl06	-	0
	krl06i	-	0
	krl08	-	0
	krl08i	-	0
	krl10	-	0
	krl10i	-	0
	krl12	-	0
	krl12i	-	0
	krl14	-	0
	krl14i	-	0
	krl16	-	0
	krl16i	-	0
	hdwinit	0	0
BCD-type conversion	4	4	4
	8	8	8
	4	4	4
	10	10	10
	8	8	8

Table D-2 List of Runtime Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
Auxiliary	mulu	4	4
	divuw	6	6
	clra0	0	0
	clra1	0	0
	clrax0	0	0
	clrax1	0	0
	clrbc0	0	0
	clrbc1	0	0
	cmpa0	0	0
	cmpa1	0	0
	cmpc0	0	0
	cmpax0	0	0
	cmpax1	0	0
	movca	0	0
	movac	0	0
	ctoi	0	0
	uctoi	0	0
	adjba	2	2
	adjbs	1	1
	addrde	0	0
	addrhl	0	0
	shl4	0	0
	shr4	0	0
	tabled	0	0
	tableh	0	0
	apdecd	0	0
	apdech	0	0
	apincd	0	0
	apinch	0	0
	deilo	0	0
	deist	0	0
	deiinc	0	0
	deidec	0	0
	hlilo	0	0

Table D-2 List of Runtime Library Stack Consumption

Classification	Function Name	Normal Model	Static Model
Auxiliary	hlist	0	0
	hliinc	0	0
	hlidec	0	0
	dellab	2	-
	dell03	0	-
	della4	0	-
	delsab	0	-
	dels03	2	-
	hlllab	0	-
	hlll03	0	-
	hllla4	0	-
	hllsab	0	-
	hlls03	0	-
	hliadd	0	0
	hlisub	0	0
	hlicmp	0	0
	hliand	0	0
	hlior	0	0
	hlixor	0	0
	imule	10	10
	isdive	12	16
	iudive	8	10
	isreme	12	16
	iureme	8	10
	iadde	0	0
	isube	2	2
	iande	0	0
	iore	0	0
	ixore	0	0

Notes 1. Values in parentheses are for when an operation exception occurs (when the matherr function included with the compiler is used).

Notes 2. Values in the parentheses are for when a multiplier is used.

Notes 3. n is the size of the automatic variable to be secured.

APPENDIX E LIST OF MAXIMUM INTERRUPT DISABLED TIME FOR LIBRARIES

Time during which an interrupt is disabled is provided for libraries for which a multiplier is used in order that the contents of the operation are not destroyed during an interrupt.

Table E-1 shows the maximum interrupt disabled time for libraries for which a multiplier is used.

No periods during which an interrupt is disabled are provided for libraries for which a multiplier is not used.

Table E-1 Maximum Interrupt Disabled Time (Number of Clocks) for Libraries

Classification	Function Name	Model supported	
		Normal Model	Static Model
Multiplication	csmul	52	52
	cumul	52	52
	ismul	60	60
	iumul	60	60
	lsmul	80	-
	lumul	80	-

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