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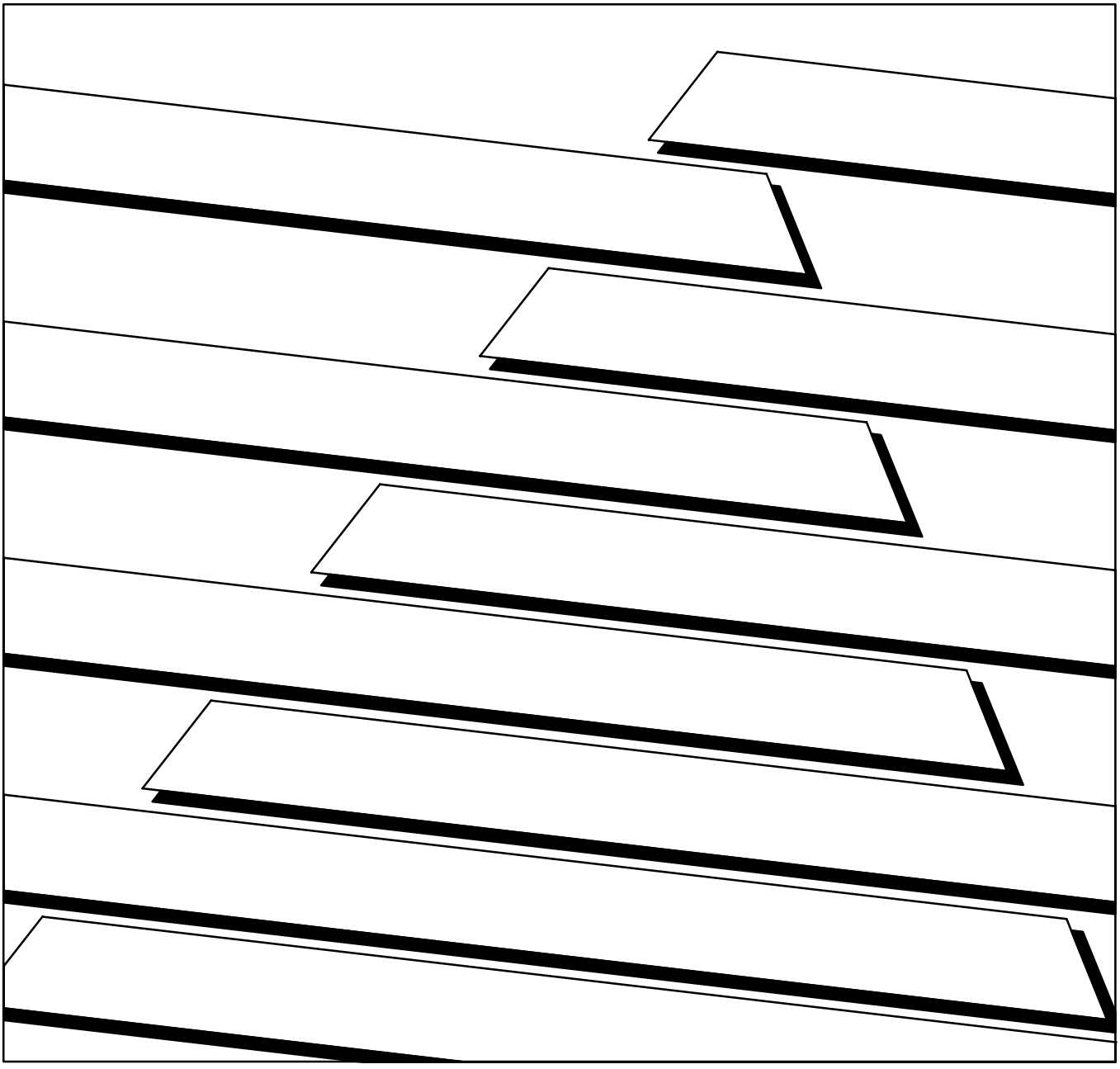
OS-9 Assembler/Linker

User Manual



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This manual reflectsedition 67 of r68, edition 95 of r68020, edition 64 of l68, and edition 47 of debug. These versions are to be used with Version 2.3 or greater of the OS-9 Operating System.

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Introduction

The Microware 68000 Macro Assembler is a full feature relocating macro assembler and linker for OS-9/68000® systems. It was designed for use with hand-written or compiler-generated programs.

This software is available as a resident assembler for use on OS-9/68000 systems, as a cross-compiler for OS-9 Level II-based 6809 computers, or as a cross-compiler for any of the following systems:

- a VAX computer running UNIX BSD4.2, UNIX 4.3, or VMS 4.6
- an Apollo computer running Domain 10.x
- a Sun Computer running SunOS 3.x
- a HP9000 computer running HP-UX 6.3
- a Delta Box computer running MV68

Some of the main features of the assembler/linker package are:

- support for OS-9's modular, multi-tasking environment
- built-in functions for calling OS-9 and generating system trap calls
- supports use of position-independent, re-entrant code
- allows programs to be written and assembled separately and then linked together which allows creation of standard subroutine libraries
- full macro capabilities
- can generate "stand alone" 68000/68020 code

This manual describes how to use the Macro Assembler package and also discusses very basic programming techniques for the OS-9 environment. It is not intended to be a comprehensive course on 68000 assembly language programming. If you are not familiar with these topics, you should consult the Motorola 68000 programming manuals and one of the many assembly language programming books available at bookstores and libraries.

Installation

The distribution disk or tape contains a number of files that should be copied to the working system disk according to the accompanying instructions. The original distribution media should then be stored in a safe place for backup purposes.

The executable files for r68 and l68 should be copied to the system's execution directory. OS9/68000 systems are generally supplied with these files already present in the CMDS directory.

The DEFS and LIB directories contain include files that resolve system definitions.

On OS-9/68000 systems, the DEFS and LIB directories should be located on the root directory of the system default working disk device. On OS-9/6809 systems (for 68000 cross-compilation), these directories should be called /dd/DEFS.68K and /dd/LIB.68K.

For UNIX systems, new directories should be created for the cross-software on the root device: /user and /user/bin. The macro assembler files should then be copied to /user/bin. `/user/bin` should be added to the shell program search list so that OS-9 cross file names do not conflict with other UNIX file names. The DEFS and LIB directories should be created within the /user directory (for example, /user/lib and /user/defs).

Concering This Manual

This manual covers both the 68000 and 68020 assembler and linker. The 68020 assembler can process all 68000 instructions and syntax. However there is a superset of 68020 instructions. Because of this discrepancy, all items specific to the 68020 assembler, linker, or debugger are shown in shaded boxes for easy reference. All other text references both the 68000 and 68020 programs. All references to OS-9/68000 or 68000 code includes 68020 unless specifically disclaimed.

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Chapter 1

Basic Information About Assembler

The Assembler

The assembler (r68) permits sections of assembly language source programs to be independently translated to **Relocatable Object Files** (ROF's). Global and local variables and program statement labels can be declared or referenced in each source program section. The assembler's macro facilities permit commonly used statement sequences to be defined, then used freely within the program with appropriate parameter substitution. `r68` also supports conditional assembly and inclusion of library source files.

`r68` is a two-pass assembler. During the first pass through the source program, the symbol table is created by scanning each line in order to identify symbolic name definitions. During the second pass, machine language instructions and data values are placed in the relocatable object file. The linker combines previously assembled relocatable object files in a separate pass.

The linker (l68) takes any number of program sections and/or library sections and combines them into a single executable OS-9 program. Global data and program references are automatically resolved during the linking process. The output of the linker is a binary executable file in the standard OS-9 memory module format. The linker also generates the appropriate **module header** for the program.

Important: For detailed information about memory modules refer to the OS-9 Technical Manual.

Rdump

`rdump` is a program you can use to examine the contents of library files. The syntax for rdump is:

```
rdump {<rof>} [<opts>]
```

`<rof>` must be a relocatable object file library. It usually has a suffix of .r or .l.

The rdump options are:

Option:	Description:
–a	Turns on all options: displays global symbols, local relocation information, and external references
–g	Displays the defined global symbols.
–l	Scans library for forward reference conflicts.
–o	Displays the local relocation information.
–r	Displays the external references.
–r	Displays the external references.

The Assembly Language Program Development Process

Writing and testing assembly language programs using r68 and l68 involves a basic edit, assemble, link, and test cycle. The assembler and linker can simplify this process if programs are written in sections that can be assembled separately, then linked together to form the entire program. If one program section must be changed for any reason, then only the revised section has to be reassembled.

The following is a summary of the steps involved in the assembly language development process:

1. Create a source program file using the text editor.

2. Run the assembler (r68) to translate the source file(s) to a relocatable object module(s).

3. If necessary, use the text editor to correct any errors reported by r68 in the offending source file and repeat step 2.

4. Combine all required relocatable modules using the linker (l68). If the linker reports errors, correct them and repeat step 2.

5. Run and test the program. The OS-9 system-state debugger or user debugger (debug) is frequently used to test programs.

6. If bugs are found in the program, use the text editor to correct the source file and then repeat the above steps.

Running r68

`r68` is a command program that you can run from the shell, from a shell procedure file, etc. The file and memory module names are r68. The r68 command line syntax is:

```
r68 <file_name> [<option(s)>]
```

Important: `r68020` is the name for the respective command program used with the 68020 assembler. The syntax for r68020 is the same as above.

The <file_name> can be followed by an option list. This allows you to control various factors such as object file or listing generation, listing format control, etc. An option list contains one or more options separated by spaces or commas. An option is turned on by its presence in the list preceded by a hyphen (–). Two hyphens (—) followed by an option turns off the function. If an option is not expressly given, the assembler will assume a default condition for it.

Important: Some command line options can be overridden by an opt statement within the source program.

By default, the output of r68 is directed to the standard output path (usually the terminal display). It may optionally be redirected to another pathlist, such as a printer, a disk file, or a pipe to another program. Output redirection is handled by the shell and not the assembler itself.

`r68` automatically handles memory allocation for its working data area. Most of the data area memory is needed for the symbol table. `r68` will request memory as needed up to the maximum available memory.

The following are typical r68 command lines. They are functionally identical, but the second command uses an alternative way of combining options:

```
r68 prog5  -l -s --c >/p

r68 prog5 -ls --c >/p
```

In this example, the source program is read from the file prog5. The options l and s are turned on, and c is turned off.

r68 Options

Up to 10 options are allowed on the command line. Each option is specified by a single letter preceded by a single hyphen (–) or two hyphens (—). Use a single hyphen (–) to turn on an option and two hyphens (—) to turn off an option.

Option:	Description:
–a[=]<sym>[=<val>]	Allows a symbol to be defined before the assembly begins. The symbol is defined as if it appeared as the label on a set directive. If a value is given, the label is set to that value. Otherwise, the default value of 1 is assumed. This option is most useful with the ifdef/ifndef directives.
.–c	Lists conditional assembly lines in an assembler listing. By default, this option is off.
–d <num>	Sets the number of lines per page for listing to <num>. Default is 66.*
–e	Suppresses printing of errors. (Default off)
–f	Uses a form feed for page eject, instead of line feeds. Uses form feed for top of form. (Default off)*
–g	Lists all generated code bytes. (Default off)*
–l	Writes a formatted assembler listing to standard output. If not used, only error messages are printed. (Default off)
–m=<num>	Specifies machine assembler to be used: 0 = 68000/68020 (Default).
–n	Omits line numbers from the assembler listing. This allows more room for comments.*
–o=<path>	Writes the relocatable output to the specified file (must be a mass storage file). (Default off)
–q	Suppresses warnings and nonfatal messages (quiet mode). (Default off)
–s	Prints the symbol table at the end of an assembly listing. (Default off)
–v	Displays assembler Version and Edition number on standard error path.
–x	Prints macro expansion in assembler listing. (Default off)*
* These options do not make sense unless the –l option is also used.	

Input File Format

`r68` reads the specified assembly source code file for its input. Each line in the file is a text string terminated by an end-of-line (return) character. The maximum length of an input line is 256 characters.

An input line is made up of one to four fields separated by spaces and/or tabs. The following fields may be used:

- a label field (optional)
- an operation field
- an operand field containing 0 or more operands depending on the operation
- a comment field (optional)

Important: There are also two special cases:

- An asterisk (*) in the first character position indicates a comment line. The entire line is printed in the listing, but is not otherwise processed.
- Blank lines are also included in the listing, but are likewise ignored.

Label Fields

The label field begins in the first character position of the line. Labels are required by some statements (equ and set). Labels are not allowed on others (for example, assembler directives such as spc, ttl, etc.).

The first character of the line must be a space or tab if the line does not contain a label. If the label is present, the assembler defines it as the address of the first byte of where the instruction's object code will be assigned. The exceptions to the rule are labels on set and equ statements. These are assigned the operand field value.

When a symbolic name in the label field of a source statement is followed by a colon (:), the name is known **globally** by all modules that are linked together. Because the label is known globally, a branch or jump can be done to a location in another module. For a global variable, the data offset can be referred to by other modules.

If no colon appears after the label, the label will be known only in the psect where it is defined. Care must be taken to access the labels in the appropriate context.

The label must be a legal symbolic name consisting of from 1 to 256 uppercase or lowercase characters, decimal digits, the dollar ($), period (.), or underline (_) characters. The first character may not be a dollar sign, period, or digit. Upper and lower case characters are distinct.

Labels (and names in general) must be unique. They cannot be defined more than once in a program (except when used with the set directive). Labels on set and equ statements are assigned the operand field value. These statements allow any value to be associated with a symbolic name.

The assembler determines the "type" of a label from the instruction associated with that label. If no instruction or directive is specified for a label in a vsect, the label type is initialized data; elsewhere the label type is that assigned to code. Whenever possible, however, labels should be placed on the same line as the instruction or directive with which they are associated.

The Operation Field

The operation field specifies the machine language instruction or assembler directive statement mnemonic name. It immediately follows the label field. It is separated from the prior field by one or more spaces. `r68` accepts instruction mnemonic names in either uppercase or lowercase characters.

Instructions cause two or more bytes of object code to be generated depending on the specific instruction and addressing mode. Some assembler directive statements (such as dz and dc) also cause object code to be generated.

Many 68000 instructions require a size attribute (for example, move.b d0,d1 or move.w d1,(sp)). If no size attribute is specified, a word (.w) is assumed. For example, move d0,d1 is a word move. Some instructions, however, have no choice of size attribute. In this case, no size attribute is allowed.

Operand Field

The operand field follows the instruction field. They must be separated by at least one space or tab. Some instructions do not use an operand field. Other instructions and assembler directives require one to specify an addressing mode, operand address, and/or parameters. Some require a source operand and a destination operand.

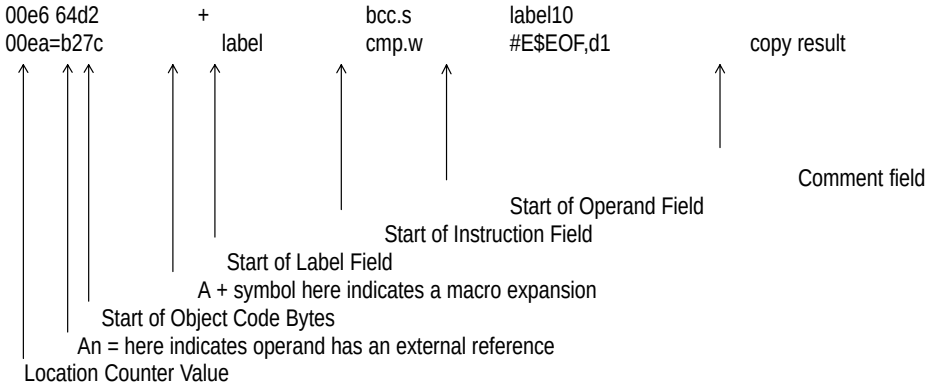
Important: See the specific instruction and assembler directive descriptions for the operand format, if any.

Comment Field

The last field of the source statement is the optional comment field. It can be used to include a descriptive comment in the source statement. This field is not processed other than being copied to the program listing.

Assembly Listing Format

If the –l option is given in the r68 command line, a formatted assembly listing is written to the standard output path. The output listing has the following format:



Evaluation of Expressions

Operands of many instructions and assembler directives can include numeric expressions in one or more places. The assembler can evaluate expressions of almost any complexity using a form similar to the algebraic notation used in programming languages such as BASIC and FORTRAN.

Expressions consist of operands and operators. Operands are symbolic names or constants. Operators specify an arithmetic or logical function. All assembler arithmetic uses long word (internally, 32 bit binary) signed or unsigned integers in the range of 0 to 4294967295 for unsigned numbers, or –2147483648 to +2147483647 for signed numbers.

In some cases, expressions must result in a value which must fit in one byte (for example, 8-bit displacement in branch instructions). Therefore, they must be in the range of 0 to 255 for unsigned values and –128 to 127 for signed values. If the result is outside of this range, an error message will be returned. Instructions that require a 16 bit value must result in a value within the range of 0 to 65535 (unsigned) or –32768 to +32767 (signed).

Expressions are evaluated from left-to-right using the algebraic order of operations (that is, multiplications and divisions are performed before additions and subtractions). Parentheses can be used to alter the natural order of evaluation.

Expression Operands

The following items may be used as operands within an expression:

Decimal Numbers
An optional minus sign followed by one to twelve digits. For example:

```
100          3164765      –32767
–999999      0            12
```

Hexadecimal Numbers
A dollar sign ($ or 0x) followed by one to eight hexadecimal characters (0-9, AF or a-f). For example:

```
$EC00        $1000        0xFFFF
$3           $0300        0xDEADFACE
```

Binary Numbers
A percent sign (%) followed by one to sixteen binary digits (0 or 1). For example:

```
%0101        %10101010    %1111000011110000
```

Floating Point Numbers

Specify floating point numbers in the following format (the exponent may be specified with either an upper or lower case e):

```
[-]digits[.digits[e[+/-][digits]
```

The range for floating point numbers is +/–2.2*10^–308 to +/–1.8*10^308. For example:

```
-1.           10.5          1e5
-1.36E-124    106352.671e4  123456789
```

Character Constants

A single character enclosed by single quotes (’). For example:

```
'X'          'c'          '5'
```

Symbolic Names

One to nine characters consisting of:

Character:	Description:
upper or lower case letters	(A-Z, a-z)
digits	(0-9)
Special characters:	
underscore	_
at sign	@
the dollar sign	$
period	.

The first character cannot be a digit, a dollar sign, or a period.

Symbolic names ending with a 68020 legal size specifier can cause ambiguities in the 68020 extended addressing modes. For example, to distinguish the label maxval.l from the symbol maxval with the size attribute of long, use (maxval).l.

Location Counter Symbols

The asterisk (*) and period (.) characters are two special symbols that represent the assembler’s internal location counters.

The asterisk character represents the value of the current location counter **before** the instruction assembled. The location counter in use depends on the vsect/psect block the assembler is currently processing. If the current block is within a psect but not in a vsect, “*” contains the value of the code location counter. If the current block is within a vsect, “*” contains the value of the non-remote initialized data counter or the remote initialized data counter as specified by the vsect [remote] parameter. For more information refer to the section on the VSECT directive.

The "*" is often used in expressions to calculate distances. For example:

```
0000 0000 lbl_1:    dc.b     0,0,0,0,0,0,0,0
     00000000
     0000
0008 fff8 lbl_2     dc.w     lbl_1-*  ;distance from here to lbl_1
000a 0004 lbl_3     dc.w     lbl_5-*  ;distance from here to lbl_5
000c fffe lbl_4     dc.w     *-lbl_5  ;distance from lbl_5 to here
000e 000e lbl_5     dc.w     *-lbl_1  ;distance from lbl_1 to here
```

The period character is used to represent the current value of the offset origin. The "offset org" is initialized by the ORG directive and is used by the DO and LO directives. For more information, refer to the individual descriptions of the DO, LO, and ORG directives.

Important: The expressions associated with the REPT, ds, dz, IF, SPC, COM, DO, and LO statements and the type, lang, attr rev, and stack size PSECT directives must evaluate to constant values. A relocatable result may change when linking or loading the module. Consequently, if a relocatable symbol is used in one of these expressions, it must be subtracted from another relocatable symbol so that the result is a constant.

Expression Operators

Operators used in expressions operate on one operand (negative and NOT) or on two operands (all others). The following table shows the available operators, listed in the order they are evaluated relative to each other; that is, logical OR operations are performed before multiplications. Operators listed on the same line have identical precedence and are processed from left to right when they occur in the same expression.

Assembler Operators By Order of Evaluation

Character:	Description:	Character:	Description:
–	negative	^	logical NOT
&	logical AND	! |	logical OR
*	multiplication	/	division
+	addition	–	subtraction
<<	shift left	>>	shift right

Logical operations are performed bitwise; that is, the logical function is performed bit-by-bit on each bit of the operands. Division and multiplication functions assume unsigned operands, but subtraction and addition functions work on signed (2's complement) or unsigned numbers. Division by zero or multiplication resulting in a product larger than 4294967295 have undefined results and are reported as errors.

Expressions Involving External Symbols

An **external symbol** is a symbol whose value is not known at the time the program section is assembled. The actual values of external references must be inserted later when the program is linked.

The linker can resolve a limited number of expressions involving external references. These expressions can consist only of simple addition and subtraction operations involving two operands at most. The following expression forms involving external references are supported. All other forms are illegal.

```
External + Absolute
External – Absolute
External – External
```

The linker performs subtraction by negating one operand and then adding it to the other operand. This method can cause problems on signed values of either word or byte length as the linker may report over/underflow errors. Therefore, care should be taken to minimize the complexity of expressions involving external names.

Symbolic Names

A symbolic name consists of up to 256 of the following characters:

Symbolic name:	Description:
alphanumerics	a-z, A-Z, 0-9
underscore	_
at sign	@
the dollar sign	$
period	.

The first character cannot be a digit, dollar sign, or a period. The following are examples of legal symbol names:

```
HERE          there         SPL030        PGM_A
Q1020.1       t$integer     L.123.X       a002@
```

Important: `r68` does not match lowercase letters to uppercase letters. The names val_A and VAL_A are considered different names.

Symbolic names ending with a 68020 legal size specifier can cause ambiguities in the 68020 extended addressing modes. For example, to distinguish the label maxval.l from the symbol maxval with the size attribute of long, use (maxval).l.

The following examples are illegal symbol names:

This symbol name:	is illegal because:
2move	starts with a digit
lbl#123	the pound sign (#) is not a legal name character.

Names are defined when first used as a label on an instruction or directive statement. They must be defined exactly one time in the program, with the exception of set labels. If a name is redefined (that is,used as a label more than once), an error message is printed on subsequent definition(s).

If a symbolic name is used in an expression and has not been defined, the name is assumed to be external to the psect. Information will be recorded about the reference so the linker can adjust the operand accordingly. However, external names cannot appear in operand expressions for assembler directives.

68000 Assembly Language Mnemonics

The assembler uses Motorola standard assembly language mnemonics and syntax. For more specific information about individual instructions, consult the following books:

M68000 16/32 Bit Microprocessor Programmer's Manual
Prentice-Hall, Fourth Edition

MC68020 32 Bit Microprocessor User's Manual
Prentice-Hall, Second Edition

MC68881 Floating-Point Coprocessor User's Manual
Prentice-Hall, First Edition

The following register names are reserved and cannot be redefined or used out of context:

Register name:	Definition:
An	Address register n
Dn	Data register n
pc or pcr	Program counter
sr	Status register
ccr	Condition codes
ssp	Supervisor stack pointer
usp	User stack pointer

Register name:	Definition:
sfc	Source function code
dfc	Destination function
cacr	Cache control register
vbr	Vector base register
caar	Cache address register
msp	Master stack pointer
isp	Interrupt stack pointer

The following definitions are used in addressing mode syntax:

Mode:	Definition:
Dn	Data Register Direct
An	Address Register Direct
Rn	Data or Address Register Direct
Xn.s	Index Register n (either address or data).s indicates the index register size. It is either .w (word) or .l (long, default)
(An)	Address Register Indirect
(An)+	Address Register Indirect with Postincrement
–(An)	Address Register Indirect with Predecrement
d(An)	Address Register Indirect with Offset
d(An,Xn.s)	Address Register Indirect with Index
(xxx).w	Absolute Short
(xxx).l	Absolute Long
d(pc)	Program Counter Indirect with Offset
d(pc,Xn.s)	Program Counter Indirect with Index
#xxx	Immediate Data

In the following definitions, (disp) is an expression. If disp is a symbol ending with .w or .l, the parentheses are required to distinguish the symbol name from the size extension. *S is an optional scale factor. If *S is used, it must be *1, *2, *4 or *8.

Expression:	Definition:
((disp).w,An)	Address Register Indirect with Offset
((disp).s,An,Xn.s*S)	Address Register Indirect with Index (Base Displacement)
([(disp).s,An],Xn.s*S,(disp).s)	Memory Indirect Post-indexed
([(disp).s,An,Xn.s*S],(disp).s)	Memory Indirect Pre-indexed

For the memory indirect addressing modes, all four parameters are optional. The assembler encodes the proper modes to indicate the suppression of the missing parameters. r68020 accepts the 68000 addressing modes d(An) and d(An,Xn.s). In this case, the 68020 brief format extension format is generated. If the operand begins with a left parenthesis ((), the 68020 full format extension format is always generated.

Example:	Extension length/modes:
clr.b var(a6)	Brief format
clr.b (var,a6)	Full format with 32-bit displacement
clr.b ((var).w,a6)	Full format with 16-bit displacement
clr.b (var,a6,d0.w*2)	Full format with sized index register
clr.b ([(var).w,a4])	Memory Indirect Post-indexed (no outer disp)
clr.b ([a4])	Memory Indirect (no inner or outer disp)
clr.b (d0)	Memory Indirect (no inner, outer disp or index)

The following table contains the condition codes used with the assembler instructions described in this chapter:

Mnemonic:	Condition:	Explanation:
cc	!C	Carry clear
cs	C	Carry set
eq	Z	Equal
ge	N.V+!N.!V	Greater than or equal
gt	N.V.Z+!N.!V.!Z	Greater than
hi	!C.!Z	Higher
hs	!C	Higher or the same
le	Z+N.!V+!N.V	Less than or equal
lo	C	Lower
ls	C+Z	Lower or the same
lt	N.!V+!N.V	Less than
mi	N	Minus
ne	!Z	Not equal
pl	!N	Plus
vc	!V	Overflow clear
vs	V	Overflow set

The following condition code bit symbols are used in the above table:

Symbol:	Description:
N	negative
V	overflow
Z	zero
C	carry

The following instruction mnemonic summary uses these conventions:

Convention:	Description:
<data>	Immediate data of appropriate size
.s	Indicates .w, .l, or .b The default is .w, if the size is not explicitly given.
<ea>	Any legal addressing mode for the instruction

Mnemonic:	Description:
abcd Dy,Dx	Add decimal with Extend Register
abcd –(Ay),–(Ax)	Add decimal with Extend Memory
add.s <ea>,Dn	Add binary register
add.s Dn,<ea>	Add binary memory
adda.s <ea>,An	Add address (.w or .l only)
addi.s #<data>,<ea>	Add immediate
addq.s #<data>,<ea>	Add quick
addx.s Dy,Dx	Add extended register
addx.s –(Ay),–(Ax)	Add extended memory
and.s <ea>,Dn	And logical register
and.s Dn,<ea>	And logical memory
andi.s #<data>,<ea>	And immediate
andi #<data>,ccr	And immediate to condition code
andi #<data>,sr	And immediate to status register

In the following 3 instructions, the shift direction (d) may be l (for left) or r (for right).

Mnemonic:	Description:
asd.s Dx,Dy	Arithmetic Shift register
asd.s #<data>,Dy	Arithmetic Shift immediate register
asd <ea>	Arithmetic Shift memory

In the following instructions, cc represents the branch condition code.

Mnemonic:	Description:
bcc <label>	Conditional branch word displacement
bcc.s <label>	Conditional branch byte displacement
bcc.b <label>	Conditional branch byte displacement
bcc.w <label>	Conditional branch word displacement
bcc.l <label>	Conditional branch long displacement
bchg.s Dn,<ea>	Test bit and change register (.b or .l)
bchg.s #<data>,<ea>	Test bit and change immediate (.b or .l)
bclr.s Dn,<ea>	Test bit and clear register (.b or .l)
bclr.s #<data>,<ea>	Test bit and clear immediate (.b or .l)
bfchg <ea>{offset:width}	Test Bit Field and Change
bfclr <ea>{offset:width}	Test Bit Field and Clear
bfexts <ea>{offset:width},Dn	Extract Bit Field Signed
bfextu <ea>{offset:width},Dn	Extract Bit Field Unsigned
bfffo <ea>{offset:width},Dn	Find First One in Bit Field
bfins Dn,<ea>{offset:width}	Insert Bit Field
bfset <ea>{offset:width}	Set Bit Field
bftst <ea>{offset:width}	Test Bit Field
bkpt #<data>	Breakpoint
bra <label>	Branch word displacement
bra.s <label>	Branch byte displacement
bra.b <label>	Branch byte displacement
bra.w <label>	Branch word displacement
bra.l <label>	Branch long displacement
bset.s Dn,<ea>	Test bit and set register (.b or .l)
bset.s #<data>,<ea>	Test bit and set immediate (.b or .l)
bsr <label>	Branch subroutine word displacement
bsr.s <label>	Branch subroutine byte displacement
bsr.b <label>	Branch subroutine byte displacement
bsr.w <label>	Branch subroutine word displacement
bsr.l <label>	Branch subroutine long displacement
btst.s Dn,<ea>	Test bit register (.b or .l)
btst.s #<data>,<ea>	Test bit immediate (.b or .l)
callm #<data>,<ea>	Call Module
cas Dc,Du,<ea>	Compare and Swap with Operand
cas2 Dc1:Dc2,Du1:Du2,(Rn1):(Rn2)	Compare and Swap with Operand
chk <ea>,Dn	Check register against bounds
chk.l <ea>	Check register against bounds
chk2.s <ea>,Rn	Check register against bounds (.b, .w, or .l)
clr.s <ea>	Clear operand
cmp.s <ea>,Dn	Compare data register
cmpa.s <ea>,An	Compare address register
cmpi.s #<data>,<ea>	Compare immediate
cmpm.s (Ay)+,(Ax)+	Compare memory
cmp2.s <ea>,Rn	Compare register against bounds (.b, .w or .l)

cc in the following instruction represents the branch condition code.

Mnemonic:	Description:
dbcc dn,<label>	Test condition, decrement and branch
divs <ea>,Dn	Signed divide
divu <ea>,Dn	Unsigned divide
divs.w <ea>,Dn	Signed Divide – 32/16”16r:16q
divs.l <ea>,Dq	Signed Divide – 32/32”32q
divs.l <ea>,Dr:Dq	Signed Divide – 64/32”32r:32q
divsl.l <ea>,Dr:Dq	Signed Divide – 32/32”32r:32q
divu.w <ea>,Dn	Unsigned Divide – 32/16”16r:16q
divu.l <ea>,Dq	Unsigned Divide – 32/32”32q
divu.l <ea>,Dr:Dq	Unsigned Divide – 64/32”32r:32q
divul.l <ea>,Dr:Dq	Unsigned Divide – 32/32”32r:32q
eor.s Dn,<ea>	Exclusive OR
eori.s #<data>,<ea>	Exclusive OR immediate
eori #<date>,ccr	Exclusive OR condition code
eori #<data>,sr	Exclusive OR status register
exg Rx,Ry	Exchange registers
extb.l Dn	Extend byte to longword
ext.s Dn	Sign extend (.w or .l)
jmp <ea>	Jump
jsr <ea>	Jump to subroutine
lea <ea>,An	Load effective address
link An, #<displacement>	Link and allocate
link.l An, #<displacement>	Link and allocate (long displacement)

In the following three instructions, the shift direction (d) may be l (for left) or r (for right).

Mnemonic:	**Description:**	
lsd.s Dx,Dy	Logical shift data	
lsd.s #<data>,Dy	Logical shift immediate	
lsd <ea>	Logical shift memory	
move.s <ea>,<ea>	Move from source to destination	
move ccr,<ea>	Move from condition codes. This instruction is not available on the 68000. The OS-9 Kernel will emulate this instruction on the 68000 to allow user-state code to be easily transported from 68000 to 68010/68020.	
move <ea>,ccr	Move to condition codes	
move <ea>,sr	Move to status register	
move sr,<ea>	Move from status register. This is privileged on the 68010/68020. Avoid this instruction in programs that are to execute in user-state.	
move usp,An	Move from user stack pointer	
move An,usp	Move to user stack pointer	
movea.s <ea>,An	Move address (.w or .l)	
movem.s <ea>,<reg list>	Move multiple	
	Examples: d0	d0 only
	d0/d4/a5	d0,d4,a5
	d0–d7/a0–a5	d0 through d7,
		a0 through a5
movep.s dx,d(Ay)	Move peripheral data (.w or .l) from register to memory	
movep.s d(Ay),dx	Move peripheral data (.w or .l) from memory to register	
moveq.l #<data>,dn	Move quick	

For the next instructions, the following are valid registers for Rc: SFC, DFC, CACR, USP, VBR, CAAR, MSP, and ISP.

movec Rc,Rn	Move from control register
movec Rn,Rc	Move to control register

Mnemonic:	**Description:**
moves.s Rn,<ea>	Move to address space
moves.s <ea>,Rn	Move from address space
muls <ea>,Dn	Signed multiply
mulu <ea>,Dn	Unsigned multiply
muls.w <ea>,Dn	Signed Multiply 16 x 16”32
muls.l <ea>,Dl	Signed Multiply 32 x 32”32
muls.l <ea>,Dh:Dl	Signed Multiply 32 x 32”64
mulu.w <ea>,Dn	Unsigned Multiply 16 x 16”32
mulu.l <ea>,Dl	Unsigned Multiply 32 x 32”32
mulu.l <ea>,Dh:Dl	Unsigned Multiply 32 x 32”64
nbcd <ea>	Negate decimal with extend
neg.s <ea>	Negate
neg.s <ea>	Negate with extend
nop	No operation
not.s <ea>	Logical complement
or.s <ea>,Dn	Inclusive OR register
or.d Dn,<ea>	Inclusive OR memory
ori.s #data>,<ea>	Inclusive OR immediate
ori #<data>,ccr	Inclusive OR condition codes
ori #<data>,sr	Inclusive OR status register
pack –(Ax),–(Ay),#<adjust>	Pack BCD
pack Dx,Dy,#<adjust>	Pack BCD
pea <ea>	Push effective address
reset	Reset external devices

In the following 6 instructions, the shift direction (d) may be l (for left) or r (for right).

Mnemonic:	Description:
rod.s Dx,Dy	Rotate without extend register
rod.s #<data>,dy	Rotate without extend immediate
rod <ea>	Rotate without extend memory
roxd.s Dx,Dy	Rotate with extend register
roxd.s #<data>,dy	Rotate with extend immediate
roxd <ea>	Rotate with extend memory
rte	Return from exception
rtr	Return and restore condition codes
rts	Return from subroutine
rtd #<displacement>	Return and deallocate
rtm Rn	Return from module
sbcd Dy,Dx	Subtract decimal with extended register
sbcd –(Ay),–(Ax)	Subtract decimal with extended memory

cc in the following instruction represents the branch condition code.

Mnemonic:	Description:
scc <ea>	Set according to conditional registers
stop #<data>	Load and stop
sub.s <ea>,Dn	Subtract binary register
sub.s Dn,<ea>	Subtract binary memory
suba.s <ea>,An	Subtract address (.w or .l)
subi.s #<data>,<ea>	Subtract immediate
subq.s #<data>,<ea>	Subtract quick
subx.s Dy,Dx	Subtract with extend register
swap Dn	Swap register halves
tas <ea>	Test and set operand
trap #<vector>	Trap
trapv	Trap on overflow

In the following three instructions, cc uses standard condition codes.

Mnemonic:	Description:
trap cc	Trap on Condition
trap cc.w #<data>	Trap on Condition
trap cc.l #<data>	Trap on Condition
tst.s <ea>	Test operand
unlk An	Unlink
unpk –(Ax),–(Ay),#<adjust>	Unpack BCD
unpk Dx,Dy,#<adjust>	Unpack BCD

68881 Floating Point Coprocessor Mnemonics

The 68020 assembler (r68020) recognizes instructions and addressing modes referencing the 68881 floating point coprocessor. This section applies only to the 68020.

The following register names are reserved for referencing the 68881 and cannot be redefined or used out of context:

Register name:	Definition:
FPn	Floating point register (0-7)
FPcr	Floating point control register
FPsr	Floating point status register
FPiar	Floating point instruction address register

The assembler recognizes the following floating operand data format extensions:

Extension:	Description:
B	Byte Integer
W	Word Integer
L	Longword Integer
S	Single Precision Real
D	Double Precision Real
X	Extended Precision Real

The P (packed decimal real) data format is not supported.

Floating point constants can be given when a floating point instruction indicates immediate addressing. Floating point constants can be given in decimal format or left-justified hexadecimal format. The size of the immediate data value is determined from the data format extension given on the floating point instruction. Single precision values are stored internally as double precision and converted to single precision before storing into the instruction. Extended precision constants can be given only as hexadecimal values.

Floating Point Examples

Example:	Description:
fadd.l #10,fp0	Long integer value of 10 is converted to extended and added to fp0.
fadd.l #0x10,fp0	Same as above.
fadd.s #5,fp0	Single precision value of 5 is converted to extended and added to fp0.
fadd.s #0x40A0,fp0	Same as above.
fadd.d #1.3e4,fp0	Double precision value of 130000 is converted to extended precision and added to fp0.
fadd.d #0x40C964,fp0	Same as above.
fadd.x #0x3ff,fp0	Extended value of 3FF000000000000 is added to fp0.

Floating point expressions are not supported.

The 68881 instruction mnemonic summary uses the notation:

Notation:	Description:
<data>	Immediate data of appropriate size
<ea>	Any legal addressing mode for the instruction

In the 68881 instruction mnemonic summary, the following format describes the instructions:

Mnemonic:	Format:	Syntax:	Description:
<inst>	b,w,l,s,d or x	<syntax>	<description of instruction>
For example:			
fadd	b,w,l,s,d,x x	<ea>,FPn FPm,FPn	Add

The example above describes the fadd instruction. It shows that the fadd instruction may take the form fadd.b, fadd.w, fadd.l, etc. and use the syntax <ea>,FPn. fadd.x, however, may use the syntax FPm,FPn. For example:

```
fadd.x fp0,fp1
fadd.x #5,fp0
```

Dyadic Instructions

Dyadic floating point instructions require two source operands. The first source operand can be any effective address or a floating point register. The second source operand must be a floating point register. The results of the operation are stored in this same register. The general format of the dyadic instructions is as follows:

Mnemonic:	Format:	Syntax:
<dyadic inst>	b,w,l,s,d,x x	<ea>,FPn FPm,FPn

The following 68881 floating point instructions use the above dyadic syntax:

Mnemonic:	Description:
fadd	Add
fcmp	Compare
fdiv	Divide
fmod	Modulo remainder
fmul	Multiply
frem	IEEE remainder
fscale	Scale exponent
fsgldiv	Single precision divide
fsglmul	Single precision multiply
fsub	Subtract

Monadic Instructions

Monadic floating point instructions require only one source operand. These instructions can specify a source and destination operand. The source operand can be any effective address or a floating point register. The operation is performed on the source operand and the result is placed in the destination operand, which is always a floating point register. If the source operand is an effective address, any operand format can be given. If the source operand is a floating point register, only the x format is allowed. If no destination floating point register is given, the operation is performed on the given register and the resulting value is stored in the same register.

The general format of the monadic instructions is as follows:

Mnemonic:	Format:	Syntax:
<monadic inst>	b,w,l,s,d,x	<ea>,FPn
	x	FPm,FPn
	x	FPn

The following 68881 floating point instructions use the above monadic syntax:

Mnemonic:	**Description:**
fabs	Absolute value
facos	Arc cosine
fasin	Arc sine
fatan	Arc tangent
fatanh	Hyperbolic arc tangent
fcos	Cosine
fcosh	Hyperbolic cosine
fetox	e^x
fetoxm1	$e^{(x-1)}$
fgetexp	Get exponent
fgetman	Get mantissa
fint	Integer part
fintrz	Integer part; round to zero
flog10	Log_{10}
flog2	Log_2
flogn	Loge
flognp1	$Loge_{-1}$
fneg	Negate
fsin	Sine
fsinh	Hyperbolic sine
fsqrt	Square root
ftan	Tangent
ftanh	Hyperbolic tangent
ftentox	10^x
ftwotox	2^x

Data Movement Instructions

Mnemonic:	Format:	Syntax:	Description:
fmove	x	FPm,FPn	Floating move
	b,w,l,s,d,x	<ea>,FPn	
	b,w,l,s,d,x	FPm,<ea>	
	l	<ea>,FPcr	
	l	FPcr,<ea>	
fmovecr		#ccc,FPn	Move from constant ROM
fmovem	l,x	<flist>,<ea>	
	l,x	<ea>,<flist>	
	x	Dn,<ea>	
	x	<ea>,Dn	Move multiple floating registers. <flist> is a sequence of floating registers. Each register in the list is separated by a slash (/). Consecutive registers may be grouped using a hyphen (–) between the beginning and ending registers. If l format is given, only FPCR, FPSR or FPIAR are allowed. If x is given, only FP0–FP7 are allowed.

Program Control Instructions

Mnemonic:	Format:	Syntax:	Description:
fbcc		<label>	Branch on floating condition ***
fdbcc		Dn,<label>	Decrement and branch on floating condition ***
fnop			No operation
fscc		<ea>	Set on floating condition ***
ftst		<ea>	Test floating operand
*** This instruction uses floating point condition predicates for “cc”			

System Control Operations

Mnemonic:	Format:	Syntax:	Description:
frestore		<ea>	Restore internal state
fsave		<ea>	Save internal state
ftrapcc		#<data>	Trap on floating condition ***
*** This instruction uses floating point condition predicates for “cc”			

The fsincos instruction is a special dual monadic instruction. Consequently, two operands are given:

Mnemonic:	Format:	Syntax:	Description:
fsincos	b,w,l,s,d,x x	<ea>,FPc:FPs FPm,FPc:FPs	Simultaneous Sine and Cosine. FPc is the resulting cosine value, FPs is the resulting sine value.

Floating Point Condition Predicates used for CC

Mnemonic:	Description:
EQ	Equal
F	False
GE	Greater than or equal
GL	Greater or less than
GLE	Greater less or equal
GT	Greater than
LE	Less than or equal
LT	Less than
NE	Not equal
NGE	Not (greater than or equal)
NGL	Not (greater or less than)
NGLE	Not (greater less or equal)
NGT	Not (greater than)
NLE	Not (less than or equal)
NLT	Not (less than)
OGE	Ordered greater than or equal
OGL	Ordered greater or less than
OGT	Ordered greater than
OLE	Ordered less than or equal
OLT	Ordered less than
OR	Ordered
SEQ	Signaling equal
SF	Signaling false
SNE	Signaling not equal
ST	Signaling true
T	True
UEQ	Unordered or equal
UGE	Unordered or greater or equal
UGT	Unordered or greater than
ULE	Unordered or less or equal
ULT	Unordered or less than
UN	Unordered

Constant ROM Table

The following are offsets into the 68881 constant ROM that contain useful values:

Offset:	Constant:
$00	PI
$0B	$Log_{10}(2)$
$0C	e
$0D	$Log_2(e)$
$0E	$Log_{10}(e)$
$0F	0.0
$30	ln_2
$31	ln_{10}
$32	10^0
$33	10^1
$34	10^2
$35	10^4
$36	10^8
$37	10^{16}
$38	10^{32}
$39	10^{64}
$3A	10^{128}
$3B	10^{256}
$3C	10^{512}
$3D	10^{1024}
$3E	10^{2048}
$3F	10^{4096}

Chapter 2

Macros

Introduction to Macros

Identical or similar sequences of instructions may often be repeated in different places in a program. Writing a sequence of instructions repeatedly can be tedious if the sequence is long or must be used a number of times.

A **macro** is a definition of an instruction sequence that can be used numerous places within a program. The macro is given a name which is used similarly to any other instruction mnemonic. Whenever r68 encounters the name of a macro in the instruction field, it outputs all the instructions given in the macro definition. In effect, macros allow you to create new machine language instructions.

For example, suppose a program frequently must perform left shifts. You can define this two-instruction sequence as a macro. For example:

```
dasl   macro              do a shift left
       asl.l d1
       roxl.l d0
       endm
```

The macro and endm directives specify the beginning and the end of the macro definition, respectively. The label of the macro directive specifies the name of the macro. In this example, the name is dasl. When r68 encounters the dasl macro, it can output code for asl and roxl. Normally, only the macro name is listed, but you can use the –x option of r68 to cause all instructions of the **macro expansion** to be listed.

Macros should not be confused with subroutines, although they are similar. A macro repetitively duplicates an **in line** code sequence every time it is used and allows some alteration of the instruction operands. Subroutines appear exactly once and never change. Subroutines are called using special instructions (bsr, jsr, and rts).

In those cases where macros and subroutines can be used interchangeably, macros usually produce longer but slightly faster programs. Short macros (6 bytes or less) are usually faster and shorter than subroutines because of the overhead of the needed bsr and rts instructions.

Macros can be an important and useful programming tool that can significantly extend r68's capabilities. In addition to creating instruction sequences, you can also use them to create complex constant tables and data structures.

ATTENTION: When you use macros, you should carefully document them. Macros can impair the readability of a program if they are used indiscriminately and unnecessarily. This can make it extremely difficult to understand the program logic.

Macro Structure

A macro definition consists of three sections:

```
<name> macro  * the macro statement assigns a name to the macro *
 .
 .
body          * the macro body contains the macro statements *
 .
 .
endm          * the endm statement indicates the end of the macro *
```

The macro name must be defined by the label given in the macro statement. The name can be any legal assembler label. You can redefine the 68000 instructions themselves by defining macros having identical names. This gives r68 the capability to be used as a cross-assembler for non-68000 processors by definition and/or redefinition of the instruction set of the target CPU.

ATTENTION: Redefinition of assembler directives such as ds can have unpredictable consequences.

The body of the macro can contain any number of legal r68 instructions or directive statements including references to previously defined macros.

The last statement of a macro definition must be endm.

The text of macro definitions are stored on a temporary file created and maintained by r68. This file has a 1K buffer to minimize disk accesses. Therefore, programs that use more than 1K of macro storage space should be arranged so that short, frequently used macros are defined first so they are kept in the memory buffer instead of disk space.

The body of a macro definition may contain a call to another macro. The definition of a new macro within another, however, is not permitted. Macro calls may be nested up to eight levels. For example, the following macro consists of two iterations of the mac1 macro:

```
times2       macro
mac1
mac1
endm
```

Macro Arguments

Arguments permit variations in the expansion of a macro. For example, you can use arguments to specify operands, register names, constants, or variables in each occurrence of a macro.

A macro can have up to nine formal arguments in the operand fields. Each argument consists of a backslash character and the sequence number of the formal argument (\1, \2 ... \9). When the macro is expanded, each formal argument is replaced by the corresponding text string **actual argument** given in the macro call. You can use arguments in any part of the operand field not in the instruction or label fields. Formal arguments can be used in any order and any number of times.

For example, the macro below performs the typical instruction sequence to an I$WritLn:

```
writ         macro
moveq  #\1,d0             Get path
moveq  #\2,d1             Number of chars to write
lea    \3(a6),a0          Get address of buffer
os9 I$WritLn
endm
```

This macro uses three arguments:

- \1 for the path number
- \2 for the number of characters to write
- \3 for the address of the buffer.

When writ is referenced, each argument is replaced by the corresponding string given in the macro call, for example:

```
writ 1,2,Buf
```

The macro call above is expanded to the code sequence:

```
moveq #1,d0
moveq #2.d1
lea   Buf(a6),a0
os9 I$Writln
```

If an argument string includes special characters such as backslashes or commas, the string must be enclosed in double quotes.

An argument may be declared null by omitting all or some arguments in the macro call. This makes the corresponding argument an empty string so no substitution occurs when it is referenced.

There are two special argument operators that are useful in constructing more complex macros. They are:

Operator:	Description:
\Ln	Returns the length of the actual argument n, in bytes.
\#	Returns the number of actual arguments passed in the given macro call.

These special operators are most commonly used with r68's conditional assembly facilities to test the validity of arguments used in a macro call, or to change the way a macro works according to the actual arguments used. When macros are performing error checking, they can report errors using the fail directive.

For example, you could expand the writ macro on the previous page for error checking:

```
writ     macro
ifne \#-3                          Must have exactly three arguments
fail writ: must have three arguments
endc
ifgt \L3-29                        File name can be 1 - 29 chars
fail writ: File name too long
endc
moveq  #\1,d0                                        Get path
path moveq  #\2,d1                    Number of chars to write
lea    \3(a6),a0                        Get address of buffer
os9 I$WritLn
endm
```

Macro Automatic Internal Labels

Sometimes it is necessary to use labels within a macro. If a macro containing a label is to be used more than once, a method of generating unique label names is required to avoid multiple definition errors. A backslash followed by an at sign (\@) appearing in a label in a macro expansion is replaced with a macro expansion serial number.

The macro expansion serial number is incremented each time the macro is expanded and is unique to that particular macro expansion.

Here is an example of a macro that uses unique labels:

```
test        macro
            tst.b  stat(a6)
            beq.s  t\@a
            addq.l #1,count(a6)
t\@a
            endm
```

The macro expands as follows:

```
            tst.b  stat(a6)
            beq.s  t00001a
            addq.l #1,count(a6)
t00001a
```

The second expansion is:

```
            tst.b  stat(a6)
            beq.s  t00002a
            addq.l #1,count(a6)
t00002a
```

Important: `\@` simply expands to a number. Proper syntax must be observed when constructing labels.

Chapter 3

Relocatable Program Sections

Relocatable Program Sections

A primary purpose of r68 is to permit programs to be composed of different segments that can be assembled separately.

Important: To clarify the following discussion, **segments** are synonymous with **source files**.

OS-9 processes use at least two separate areas of memory: the program object code in memory module format and a data area used for the program's variables and the stack. The linker (l68) combines all of the segments into a single OS-9 memory module and a coordinated data storage area. By using global symbolic names, code in each segment can reference variables declared in other segments or may transfer program control to labels in other segments.

When the assembler source program for each segment is written, it must be divided into distinct sections for variable storage definitions (vsects) and for program instructions (psects). The output of the assembler is a distinct relocatable object file (ROF) containing the object code output plus information about the variable storage declarations for the linker to use.

The linker reads the ROFs, assigns space in the data storage area, and combines all the object code into a single executable memory module. As it does so, it must alter the operands of instructions to refer to the final variable assignments and must also adjust program control transfer instructions that refer to labels in other segments.

For example, if three segments called A, B, and C are processed by the linker, the resulting memory allocation is shown in the simplified memory map below.

Figure 3.1
Executable Memory Module

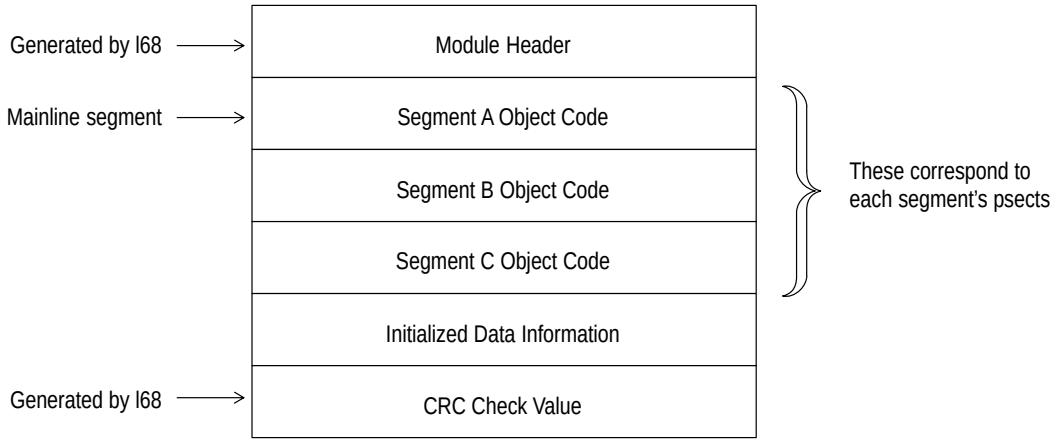
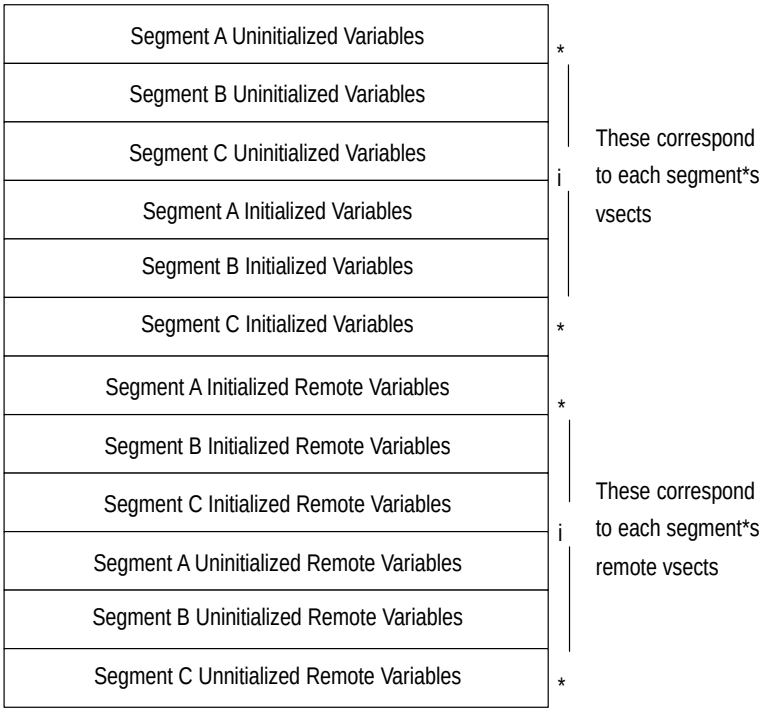


Figure 3.2
Process Data Area



Program Section Declarations: Psect and Vsect

Most program statements are included in sections called **psects** and **vsects** (program and variable sections, respectively).

A psect contains the program instructions and variable declarations. Each source file may have only one psect. Global symbols (labels with a colon (:) suffix) in this section are accessible from all other program segments. Similarly, statements in this section can reference global symbols properly defined in other program segments. Statements in this section may also appear in linkage maps and symbolic debugger symbol lists. The psect is terminated by a matching ends or endsect statement.

Global and local variable storage are declared inside one or more vsects within the psect. Vsects are usually nested within a psect, but vsects cannot be nested within themselves.

A variable declaration section begins with a vsect statement and ends with an ends or endsect statement. There are two types of variable declarations: initialized and uninitialized. These correspond to the assembly language storage allocation mnemonics dc and ds, respectively. `l68` combines all initialized variable declarations from all program segments into a single initialized data memory area. Similarly, all the uninitialized data declarations are combined into a single uninitialized data memory area.

There is a third type of vsect declaration regarding **remote** data. This vsect accumulates large amounts (greater than 32K) of data declarations. The linker places remote vsect declarations after the end of the initialized and uninitialized data allocation. The size of the remote data area is limited only by the amount of physical memory on the system.

Important: Instructions accessing the remote data area must use long (32-bit) indexed addressing modes.

Certain types of statements can appear outside (usually before) the psect. These are generally set and equ (and possibly the lo and do statements). These declare symbolic constants and symbolic offsets. Labels on these statements are local to the assembly of the source file and are not usable during assembly of other program segments. Additionally, these statements cannot reference any global symbols.

For example, the oskdefs file is intended to be included outside the psect of each source program. Although technically a vsect can similarly appear outside the psect, the usefulness of such a vsect is limited to defining the expected type of an external symbol as a data area symbol because no actual storage would be assigned to it by the linker.

Diagram of Typical Program Layout

```
nam example
ttl sections and declarations

labconstequ 1                                   Local constant definitions
space   equ $20
mode    set 1
        use /h0/defs/oskdefs                    Include local definitions file

        psect nam,typ,rev,ed,stack,gblcode      Start of psect

        vsect                                   Start of nested vsect
gblunin:ds.l 1                                  Global uninitialized data
gblinit:dc.b “string”,0                         Global initialized data
locunin ds.l 1                                  Local uninitialized data
locinit dc.b “hello”,0                          Local initialized data
        ends                                    End of vsect

gblcode:                                        Global code label
        move.l gblunin(a6),d0                   Global uninitialized data reference
        lea gblinit(a6),a0                      Global initialized data reference
        bsr.s intcode                           Internal code reference
        bsr extcode                             External code reference
        move.l d0,extdat(a6)                    External data reference
        rts

        vsect                                   Start of nested vsect
indat   ds.l 1                                  Local uninitialized data
        ends                                    End of vsect

intcode rts                                     Local code label

        ends                                    End of psect
```

Location Counters

r68 maintains a set of address counters that keep track of relative memory addresses of object code, initialized data, uninitialized data, and remote data. It is important to remember that location counter values are relative and not the actual physical memory addresses. Actual memory locations are not known until the program has been linked and loaded into memory.

The psect statement resets the instruction and data location counters, and assembles subsequent instructions into the ROF object code file. As object code is generated, the instruction location counter is advanced accordingly. An asterisk (*) symbol can be used in expressions to refer to the current relative value of this counter.

The vsect statement causes r68 to use the variable (data) location counters and places information about subsequently declared variables into the appropriate ROF data description area. As variables are declared, the initialized data location counter and the uninitialized data location counter are advanced accordingly. An asterisk (*) represents the value of the initialized data location. The uninitialized data counter is not directly accessible.

You cannot preset any of the counters to a specific value; there is no ORG statement for the data or instruction counters.

The Mainline Segment

Each complete program must have one segment which is called the **mainline segment**. It gives the linker the information necessary to create the OS-9 module header (the module name, the initial entry point, etc.).

A small program having only one segment will have only a mainline segment. Programs created by linking two or more segments together will have a mainline segment followed by the other segments.

Whether or not a segment can be used as a mainline segment is determined by the typelang value appearing on the psect directive. This is discussed in detail in the next section.

The Psect Directive

Syntax

```
psect <name>,<typelang>,<attrev>,<edition>,<stacksize>,<entrypt>,<trapent>
```

Legal Psect Statements

Any 68000 instruction mnemonic
dc
dz
align
vsect
endsect
os9
tcall
ends

ATTENTION: `ds` cannot be used within a psect.

The psect is the program code section. There can only be one psect per source file. The psect directive initializes all assembler location counters and marks the start of the program segment. All instruction statements and vsect data reservations must be declared within the psect .. endsect block.

The psect may have a parameter list containing a name followed by five or six expressions if the psect is to be a **mainline** segment, or it can have no parameter list at all. If a parameter list is provided, the parameter list will be stored in the ROF for later use by the linker to generate the memory module header. If no parameter list is provided, the psect name defaults to program and all other parameters have default values of zero.

The elements of the psect parameter list are as follows:

Parmeter:	Definition:
name	Up to 20 bytes for a name the linker uses to identify the psect. Any printable character may be used except a space or comma; however, the name must begin with a non-numeric character. The name does not need to be unique from other psect names, but it is easier to identify psects that the linker has problems with if the names are different.
typelang	A word expression used as the executable module type/language word. If the psect is not a mainline segment, the type/language word must be zero.
attrev	A word expression used as the executable module attribute/revision word.
edition	A word expression used as the executable module edition word.
stacksize	A long word expression that estimates the amount of stack storage required by pthis psect. The linker totals the value in all psects to appear in the executable module and adds the value to any stack storage requirement for the entire program.
entrypt	A long word expression used as the program entry point offset for psect goes here. If the psect is not a mainline segment, this is 0.
trapent	A long word expression indicating the Uninitialized Trap entry point offset. This is used for handling user-mode trap instruction processing. Only give this parameter if the program includes code to handle uninitialized traps. Otherwise, omit this parameter; do **not** use zero. This parameter is used only in mainline psects.

The Vsect Directive

Syntax

```
vsect [remote]
```

Legal Internal Statements

ds
dc
dz
endsect
align

The vsect is the variable storage section containing either initialized, uninitialized variable, or remotely-addressable variable storage definitions. Thevsect directive causes r68 to change the location counter from the code location counter to the data location counters. The data location counter employed depends on the statement used and the presence of the word remote after the vsect directive.

There are four data location counters. One for each of the following types of data: initialized, uninitialized, remote initialized, and remote uninitialized.

The initialized and uninitialized data are intended to be accessed by the 68000 register indirect with offset addressing mode: n(An). Because the range of this addressing mode is limited to 64K, the total size of these data areas is also limited to 64K.

The remote data areas are intended to be addressed with the 68000 indexed register indirect with offset addressing mode: n(An,Xn.l) or the 68020 32-bit offset addressing modes. These data areas are limited only by the available contiguous system memory.

When ds is used, the uninitialized data location counter is used. When a remote vsect is in effect, the ds applies to the remote data location counter.

The dc and dz directives are used to set initial data values. The assembler uses the initialized data location counter for these directives. The constants appear in the data area of the program when executed. These values can then be modified, if desired.

The dc and dz directives can also appear outside of a vsect (in the body of the psect). In this case, the constants are assembled into the code area of the program. Do not change constants defined in this manner. To do so would cause the program to be self-modifying and non-re-entrant.

Important: The data location counters maintain their values from each vsect block to the next. Because the linker handles the actual data allocation, there is no facility to adjust the data location counters.

Relocatable Object File Format

The object code output by the assembler must be processed by the linker before the code is executable. The assembler writes the object code in a special relocatable object file format (ROF) to allow the linker to link together separately assembled modules into a single executable module. The ROF contains information such as the global data definitions, code entry points, external references, actual object code, and initialized data.

It is unlikely that a programmer would have to deal with the internals of an ROF. The information given here is for informational purposes. You can use the rdump program to extract this data from existing relocatable files.

There are eight sections to a relocatable object file:

- the Header section
- the External Definitions section
- the Object Code
- the Initialized Data
- the Remote Initialized Data
- the Debug Information
- the External Reference section
- the Local Reference section

The Header Section

ROF Sync Bytes (4 Bytes)
Sync bytes used by l68 to recognize an ROF.

Type/Language (2 Bytes)
The type/language word from the psect. The linker uses this to determine the desired OS-9 module format. If this word is zero, the routine is assumed to be a subroutine type module. Only the mainline segment can have this word be non-zero.

Attribute/revision (2 Bytes)
Attribute/revision word to place in the OS-9 module. It is only meaningful on a mainline segment.

Assembly Valid (2 Bytes)
Word used to prevent the linker from linking erroneous modules. It will be non-zero if assembly errors have occurred.

Series (2 Bytes)
Tells the linker which assembler version was used. This prevents problems that could occur in mixing different versions of the linker and assembler.

Date/Time Assembled (6 Bytes)
Indicates the date and time of assembly.

Edition Number (2 Bytes)
OS-9 edition number to be placed in the output module for mainline segments. For non-mainline segments, this word is informational only.

Size of Static Storage (4 Bytes)
Tells the linker how much static data storage to reserve for the module.

This value is determined from the total size of the ds directives in the vsects.

Size of Initialized Data (4 Bytes)
Tells the linker how much initialized data is contained in the module. The size is determined by the total size of all the dc directives in the vsects.

Size of the Object Code (4 Bytes)
This is determined from the size of assembled code.

Size of Stack Required (4 Bytes)
Tells the linker how much stack space the module requires. The value is obtained directly from the psect directive.

Offset to Entry Point (4 Bytes)
Offset to the entry point in the object code. The offset is relative to the beginning of the module. The value is obtained directly from the psect directive.

Offset to Uninitialized Trap Entry Point (4 Bytes)
Offset to the entry point in the object code which is called when a tcall is made without installing the appropriate trap handler. The offset is relative to the beginning of the module and is obtained directly from the psect directive.

Size of Remote Static Storage (4 Bytes)
Tells the linker how much remote static data storage to reserve for the module. This value is determined from the total size of the remote ds directives in the remote vsects.

Size of Remote Initialized Data (4 Bytes)
Tells the linker how much remote initialized data is contained in the module. The size is determined by the total size of all the dc directives in the remote vsects.

Size of the Debug (4 Bytes)
This is determined from the size of assembled debugger code.

Name of Module (Variable Length)
Null terminated ASCII string taken directly from the psect directive. The linker uses the name to identify the psect in case of an unresolved reference or other error.

External Definition Section

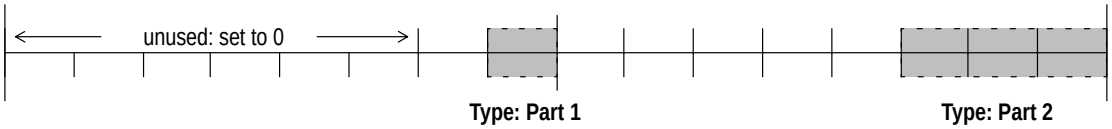
External Definition Count (2 Bytes)
The count indicates the number of external definitions that will follow.

The external definitions are placed in the linker's symbol table and can be referenced by any other module

External Definitions (Variable)
Each external definition has the following format:

```
Name (1–n bytes)
Type Definition (2 bytes)
Symbol value (4 bytes)
```

The type is determined by bit 0 of the first byte and bit 0-2 of the second byte:



The value of bit 0 of the first byte determines the interpretation of bit 0-2 of the second byte:

Type: Part 1

0: not common
1: common

Type: Part 2

bit 0	bit 1	bit 2
0: data	0: not remote	0: uninitialized 1: initialized
	1: remote	0: uninitialized 1: initialized
1: code or equ	0: code 1: equ	set to 0
unused: set to 0	0: not remote 1: remote	unused: set to 0

The Object Code Section

Object Code for the Module (Variable Length)
The size of this section is found in the Size of Object Code bytes defined in the header section.

The Initialized Data Section

Initialized Data (Variable Length)
The size of this section is found in the Size of Initialized Data defined in the header section.

Important: You may omit the object code section and/or the initialized data section. If both are missing and the static data count is zero, the module can only contain absolute (equ) symbols. In this case, the linker extracts only those symbols that resolve an external reference. The OS-9 sys.l library module is an example. It contains nothing but equ'ed symbol definitions.

The Initialized Remote Data Section

Initialized Remote Data (Variable Length)
The size of this section is found in the Size of Remote Static storage bytes in the header section.

The Debug Information Section

Debug Information (Variable Length)
The size of this section is found in the Size of debug bytes in the header section.

External Reference Section

External References Count (2 Bytes)
The count indicates the number of references to external symbols that follow.

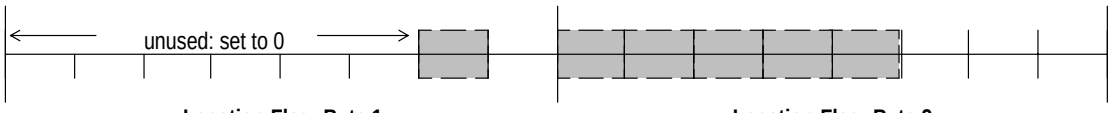
External References (Variable)
Each external reference has the following format:

Name (1–n bytes)
Reference Count (2 bytes)
References (reference count x 6 bytes): Location Flag (2 bytes)
Reference Offset (4 bytes)

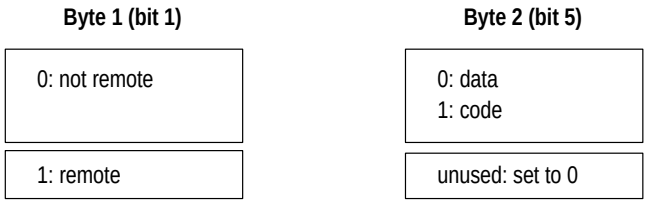
The Reference Count indicates the number of References to follow.

Each Reference has both a Location Flag and Reference Offset.

The location is determined by bit 1 of the first byte and bit 3-7 of the second byte of the Location Flag:



The value of Bit 1 in the first byte determines the interpretation of bit 5 in the second byte:



The other location bits of the second byte are interpreted as follows:

Bits 3-4: Size of Reference to External Symbol
01 = 1 byte
10 = 2 bytes
11 = 4 bytes

Bit 6: Relative Reference Flag
If set, this tells the linker that the reference is relative to the location of the reference.

Bit 7: Negative Reference Flag
If set, this tells the linker to add the negative of the symbols location when resolved.

The Reference Offset is the offset into the code or initialized data section where the Reference appears.

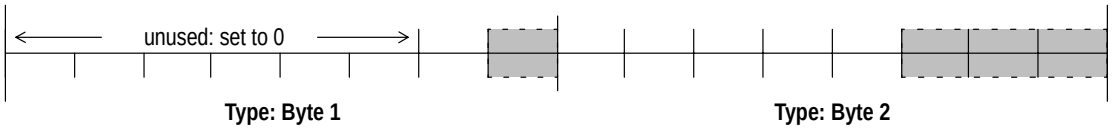
Local Reference Section

Local References Count (2 Bytes)
The count indicates the number of local references that follow.

Local References (Variable)
These are references in the code or initialized data areas that reference code or data in the psect. Each local reference has the following format:

Type/Location flag (2 bytes)
Local Offset (4 bytes)

The type definition is determined by bit 0 of the first byte and bit 0-2 of the second byte:



The value of bit 0 of the first byte determines the interpretation of bit 0-2 of the second byte:

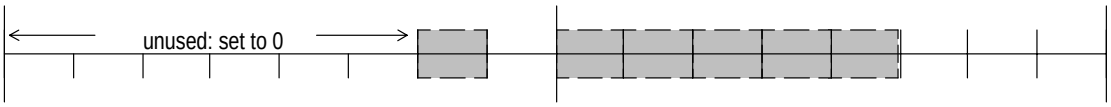
Type: Byte 1

bit 0
0: not common
1: common

Type: Byte 2

bit 0	bit 1	bit 2
0: data	0: not remote	0: uninitialized 1: initialized
	1: remote	0: uninitialized 1: initialized
1: code or equ	unused: set to 0	not used
unused: set to 0	0: not remote 1: remote	unused: set to 0

The location is determined by bit 1 of the first byte and bit 3-7 of the second byte:



The value of bit 1 of the first byte determines the interpretation of bit 5 of the second byte:

Location: Byte 1	Location: Byte 2 (bit5)
0: not remote	0: data 1: code
1: remote	unused: set to 0

The other location bits of the second byte are interpreted as follows:

Bits 3-4: Size of Local Reference
01 = 1 byte
10 = 2 bytes
11 = 4 bytes

Bit 6: Relative Reference
If set, this tells the linker that the reference is relative to the location of the reference.

Bit 7: Negative Reference
If set, this tells the linker to add the negative of the symbols location when resolved.

Chapter 4

Assembler Directive Statements

What Are Directive Statements

Assembler directive statements give the assembler information that affects the assembly process, but usually do not cause code to be generated. Read the descriptions carefully. Some directives require labels, labels are optional on others, and a few directives cannot have labels.

end

End Program

Syntax

```
end
```

Function

end indicates the end of a program. Its use is optional. If not present in the source file, end is assumed upon an end-of-file condition. end statements may not have labels.

equ
set

Assign Value to Symbolic Name

Syntax

```
<label> equ <expression>
<label> set <expression>
```

Function

`equ` and `set` assign a value to a symbolic name (the label) and thus require labels. The value assigned to the symbol is the value of the operand, which may be an expression, a name, or a constant. You can use them in any program section.

Two differences exist between the equ and set statements:

- Symbols defined by equ can be defined only once in the program.
- Symbols defined by set can be redefined again by subsequent set statements.

The equ statement label name cannot have been defined previously. The operand cannot include a name that has not yet been defined (as yet undefined names whose definitions also use undefined names). Good programming practice dictates that all equates are at the beginning of the program.

`equ` is normally used to define program symbolic constants, especially those used in conjunction with instructions. set is usually used for symbols used to control the assembler operations, especially conditional assembly and listing control.

ATTENTION: `set` cannot reference external names. `equ` cannot reference another equ that references an external name. For example:

```
joe equ moe
moe equ external
```

Examples

```
FIVE        equ         5
  OFFSET    equ         address-base
  TRUE      equ         $FF
  FALSE     equ         0
  SUBSET    set         TRUE
            ifne        SUBSET
            use         subset.defs
            else
            use         full.defs
            endc
  SUBSET    set         FALSE
```

fail

Return Error Message

Syntax

```
fail <textstring>
```

Function

`fail` forces an assembler error to be reported. `<textstring>` is displayed as the error message which is processed in the same manner as r68-generated error messages. Because the entire line following the fail keyword is assumed to be the error message, this statement cannot have a comment field.

`fail` is most commonly used with conditional assembly directives that you set up to test for various illegal conditions, especially within macro definitions.

Example

```
ifeq      maxval
fail      maxval cannot be zero
endc
```

if...else...endc

Conditional Assembly

Syntax

```
ifxx      <expression>
          <statements>
[else]
          <statements>
endc
```

Function

The ifxx statements provide conditional assembly capabilities. This is the ability to selectively assemble specific parts of a program depending on a variable or computed value. A single source file could, therefore, selectively generate multiple versions of a program.

Conditional compilation uses statements similar to the branching statements found in high level languages such as Pascal and BASIC.

ifxx uses a symbolic name or an expression as an operand. A comparison is made with the result. If the result of the comparison is true, statements following the if statement are processed. Otherwise, the following statements are not processed until an endc (or else) statement is encountered.

For example, the following ifeq statement compares the value of its operand to zero:

```
ifeq switch
  .                                  Assembled only if switch = 0
  .
endc
```

The else statement allows the if statement to explicitly select one of two program sections to assemble depending on the truth of the if statement. Statements following the else statement are processed only if the result of the comparison is false. For example:

```
ifeq switch
  .                                  Assembled only if switch = 0
  .
else
  .                          Assembled only if switch does not = 0
  .
endc
```

The endc statement marks the end of a conditionally assembled program section.

Multiple if statements may be used, and may be nested within other if statements. They cannot have labels.

There are several kinds of if statements, each performing a different comparison:

Statement:	Description:
ifeq	True if operand equals zero.
ifne	True if operand does not equal zero.
iflt	True if operand is less than zero.
ifle	True if operand is less than or equal to zero.
ifgt	True if operand is greater than zero.
ifge	True if operand is greater than or equal to zero.
ifdef	True only if the specified symbol is defined.
ifndef	True only if the specified symbol is not defined.

The if statements that test for less than or greater than zero can test the relative value of two symbols if the symbols are subtracted in the operand expression. For example, the following statement is true if min is greater than max (the statement literally means if max-min < 0):

```
iflt    max-min
```

The ifdef and ifndef directives are different from the other conditional assembly instructions in that their operand field is a single label rather than an expression. For ifdef, if the specified symbol has been defined, the instructions within the conditional are assembled. For ifndef, if the symbol has not been defined, the conditional is assembled. A symbol is considered to be defined if it appears in the label field before the reference during the first pass.

ATTENTION: Conditionals based on undefined (but to be defined) values cause phasing errors. When writing condition assembly, ensure that the conditional evaluates to the same value during the first and second pass or phasing errors are likely to result.

The ifdef and ifndef directives are useful for assembling sections of code based on the presence of a symbol. `ifdef` and `ifndef` are most useful when symbols are defined on the command line. This allows makefiles to pass symbols affecting the assembly without actually changing any definitions in a file.

nam
ttl

Rename Program
Rename Listing Title

Syntax

```
nam string
ttl string
```

Function

`nam` specifies the program name that is printed in a program listing. `ttl` specifies the title line that is printed in a program listing. These statements cannot have label or comment fields.

The program name is printed on the left side of the second line of each listing page, followed by a dash, then by the title line. The name and title may be changed as often as desired.

Examples

```
nam Datac
ttl Data Acquisition System
```

Generates:

```
Datac – Data Acquisition System
```

opt

Set Assembler Options

Syntax

```
opt <option>
```

Function

`opt` allows any of several assembler control options to be set or reset. Options are denoted by a single character. A preceding hyphen (–) turns the specified option off. One exception is the d option which must be followed by a number. This statement must not have label or comment fields.

Options

Option:	Description:
[–]c	Prints a listing of conditional assembly lines in an assembler listing. (Default off)
d <num>	Sets the number of lines per page to <num> for a listing. (Default 66)
[–]e	Prints errors. (Default on)
[–]f	Uses form feed for page eject instead of line feeds. Form feed for top of form. (Default off)
[–]g	Lists all code bytes generated. (Default off)
[–]n	Omits line numbers from the assembler listing. This allows more room for comments.
[–]l	Writes a formatted assembler listing to standard output. If not used, only error messages are printed. (Default off)
m=<num>	Specifies the microprocessor that the assembler is to be used with: 0 = 68000/68020. (Default)
o=<path>	Writes the relocatable output to the specified (mass storage) file.
[–]q	Quiet mode. Suppresses warnings and nonfatal messages.
[–]s	Prints the entire symbol table at the end of the assembly listing. (Default off)
[–]x	Prints macro expansion in assembler listing. (Default off)

pag
spc

Begin New Page in Listing
Put Blank Line(s) in Listing

Syntax

```
pag[e]
spc <expression>
```

Function

`pag` and `spc` improve the readability of program listings. They are not printed. They cannot have labels.

`pag` causes the assembler to begin a new page of the listing.

`spc` puts blank lines in the listing. The value of the operand determines the number of blank lines to generate, which can be an expression, constant, or name. If no operand is used, a single blank line is generated.

rept ..endr

Repeat Assembly Sequence

Syntax

```
rept <expr>
     <statements>
endr
```

Function

`rept` repeats the assembly of a sequence of instructions a specified number of times. The result of the operand expression is used as the repeat count. The expression cannot include external or undefined symbols. `rept` loops cannot be nested.

Example

```
*  20 cycle delay
   REPT 10
   nop
   ENDR
```

use

Use External File

Syntax

```
use  pathlist
use “pathlist”
use <pathlist>
```

Function

`use` statements cause the assembler to temporarily stop reading the current input file. It then requests OS-9 to open the specified pathlist, from which input lines are read until an end-of-file occurs. At that point, the latest file is closed and the assembler resumes reading the previous file from the statement following the use statement.

use statements can be nested (for example, a file being read due to a use statement can also perform use statements) up to the number of simultaneously open files the operating system allows (usually 29, not including the standard I/O paths).

Full or relative pathlists may be specified. If a relative pathlist is specified, it is relative to the current working data directory.

If the pathlist is enclosed in quotation marks, the assembler searches for the file in the directory where the source file is located.

If the pathlist is enclosed in angle brackets (< >), the assembler searches for the file in /dd/defs on OS-9 systems, or the appropriate directories for cross-assemblers.

Chapter 5

Pseudo-Instructions

What Are Psuedo-Instructions

Pseudo-instructions are special assembler statements that generate object code but do not correspond to actual 68000 machine instructions. Their primary purpose is to create special sequences of code and/or constant data to be included in the program. Labels are optional on pseudo-instructions.

align

Align to Even Byte Boundary

Syntax

```
align
```

Function

`align` aligns the next generated code or next assigned data offset on an even byte boundary in memory. If the current value of the instruction counter is non-even, a zero byte is inserted in the object code. The CPU program counter must always be word aligned for instructions.

If the align directive is specified in a vsect, both the initialized and uninitialized location counters are aligned.

This statement is generally used after odd length constant tables, character strings, or character data are imbedded in the object code.

See Also

The dc and ds descriptions.

com

Reserve Memory for Common Block

Syntax

```
<label>: com.s <size>
```

The size extension .s can be .b for bytes
.w for words (default)
.l for longwords

Function

`com` reserves an area of memory in the appropriate vsect for use as an overlaid common block. The com <label> can appear in any number of psects. The size of the data area actually assigned by the linker is the maximum of the sizes given on all the com statements for that label.

To facilitate initialization of common blocks, the label is allowed to appear on initialized data directives. In this case, the data definition is used instead of the size given on the com statement.

The com statement can be used in a remote vsect to allocate a common block in the remote memory area.

Examples

The following allocates a non-remote data common block of 100 bytes. Both references to block1(a6) in each file refer to the same address.

File t1.a

```
            vsect
block1:      com    100
             ends
             clr.b  block1(a6)
```

File t2.a

```
            vsect
block1:      com    100
             ends
             clr.b  block1(a6)
```

The following example demonstrates how initialization of a common block is done. The first block2 com directive reserves 12 bytes of memory. The block2 definition in s2.a defines initialized data for the common area. The initializing data definitions supersedes the sizes given on any com directive. Therefore, for best results, the sizes of the com directives and the amount of initializing data should agree.

File s1.a

```
            vsect
block2:     com    12
            ends
            move.l block2+8(a6),d0
```

File s2.a

```
           vsect
block2:     dc.l1,2,3
            ends
```

dc

Define Constant

Syntax

```
<label> dc.s <expression> {, <expression>}
```

The size extension .s can be
.b for bytes
.w for words (default)
.l for longwords

Function

dc generates sequences of one or more constants (initialized data) of various sizes within the program. The argument(s) is a list of one or more expressions or character strings. If more than one expression or string is used, they are separated by commas.

A dc used in a vsect creates an initialized data variable (read/write) in the process' data area. The initialization value is stored in a special section of the object code and is copied to the appropriate locations in the data area by the F$FORK system call.

A dc used outside a vsect is used to create **read-only** constants in the program area. The program should not change these constants.

Character string constants can be any sequence of printable ASCII characters enclosed in double quotes. For dc.w and dc.l, a string constant is padded with zeroes on the right end if it does not fill the final word or long word. Therefore, dc.b is the most natural format for strings. It is good practice to use an align directive after dc.b directives to make sure the instruction counter is left on an even word boundary.

Examples

```
dc.b 1,20,“A”

dc.b index/2+1,0,0,1

dc.w 1,10,100,1000,10000

dc.w $F900,$FA00,$FB00,$FC00

dc.b “most programmers are strange people”

dc.b “0123456789”
```

ds

Define Storage

Syntax

```
<label> ds.s <expr>
```

Function

`ds` is used within vsects to declare storage for uninitialized variables in the data area. `.s` is a size specifier. It may be .b (byte), .w (word), or .l (long). <expr> specifies the size of the variable in bytes, words or longwords (depending on the size given for the ds extension). This value is added to the appropriate uninitialized data location counter in order to update it.

When ds is used to declare variables, a label is usually specified which is assigned the relative address of the variable. In OS-9, the address is not absolute, so indexed addressing modes are used to access variables. The actual relative address is not actually assigned until the linker processes the ROF.

The remote data area must be accessed using the indexed register indirect with offset addressing mode: n(An,Xn.l).

Important: `ds.w` and `ds.l` align to an even byte boundary if the respective location counter is non-even.

dz

Reserve Zero Bytes

Syntax

```
<label> dz.s <expression>
```

The size extension .s can be
.b for bytes
.w for words (default)
.l for longwords

Function

`dz` is used to fill memory with a sequence of bytes, each having a value of zero. The 16 bit expression is used as the number of zero values to be placed in the appropriate code or initialized data section.

Under OS-9, it is unnecessary and undesirable to reserve zero bytes in the initialized data area (vsect). The data area is automatically zeroed by the fork system call, so a dz in the vsect only wastes space in the object code area.

A dz used within a psect is used to create a read-only zero constant that should not be changed by the program. A dz used within a vsect is considered as **initialized data** that can be altered by the program.

Examples

`dz.b 24`	Reserve 24 zero value bytes
`dz.w 1`	Reserve 1 zero value word

do
lo
org

Assign Offset Counter Value to Label
Decrement Offset Counter, Then Assign Value to Label
Set Offset Counter Origin

Syntax

```
<label> do.s <expression>
<label> lo.s <expression>
          org <expression>
```

The size extension .s can be .b for bytes
.w for words (default)
.l for longwords

Function

`do` and `lo` are used to assign an increasing or decreasing set of values to a set of symbolic names, respectively. It has nothing to do with memory allocation.

Many times it is desirable to define a group of names with sequentially related values. Some examples are error codes, character sets and stacked variables. `do` and `lo` provide a convenient means of doing this.

Each time a do is encountered, its label is given the current value of the offset counter. The offset counter is then incremented by the result of the expression multiplied by 1 for a byte, 2 for a word, or 4 for a long. When an lo statement is encountered, the offset counter is decremented by the appropriate size and the result is assigned to its label. This is useful in conjunction with the 68000 link instruction.

`org` sets or changes the origin (starting value) of the offset counter.

Example

```
org $500

joe do.l 1   is the same as      joe equ 500
moe do.l 1                       moe equ 504

org 'A'
A            do.b 1                Gives label A the value of its ASCII code
B            do.b 1                Gives label B the value of its ASCII code
C            do.b 1                Gives label C the value of its ASCII code
D            do.b 1                Gives label D the value of its ASCII code
E            do.b 1                Gives label E the value of its ASCII code
```

os9

Call OS9 System Call

Syntax

```
os9 <expression>
```

Function

`os9` is a convenient way to generate OS-9 system calls. Its operand is a word value to be used as the request code. The output is equivalent to the instruction sequence:

```
trap #0
dc.w <expression>
```

System symbolic names are available in the sys.l system library file. These names are commonly used with the os9 statement to improve the readability, portability, and maintainability of assembly language software.

Examples

`os9 I$Read`	Calls OS-9 READ service request.
`os9 F$Exit`	Calls OS-9 EXIT service request.

tcall

Generate User Trap Call

Syntax

```
tcall <vector>,<function>
```

Function

`tcall` is a built-in macro to generate user trap calls. User traps are used to access the OS-9 standard library modules (cio and math) or user-written trap handlers. `tcall` has two arguments, a vector number (zero through 15) and a function code. The output is equivalent to the instruction sequence:

```
trap #<vector>
dc.w <function>
```

For example, the following tcall is used to access the double-precision floating point comparison in the math module:

```
tcall T$Math,T$DCmp
```

Important: `tcall #0` is the equivalent to the os9 statement.

Chapter 6

The Linker

Understanding the Linker

The linker (l68) transforms the r68 assembler output into a single OS-9 format memory module. A memory module must minimally consist of a module header, a module body, and a cyclic redundancy check (CRC).

Many modules require more than this basic information. Program and Trap Handler Modules, for example, require a data memory requirement and stack memory requirement. File manager, device driver, and device descriptor modules all require special information unique to each. The contents of the assembly language relocatable output files (ROFs) provide the linker with the information required to create each type of memory module. The linker allows references to occur between modules in order for one module to reference a symbol in another module. This involves adjusting the operands of many machine-language instructions.

The Root Psect

A program usually consists of many small code segments which, when processed by the linker, form the final executable memory module. Each code segment is called a **psect**. The psect is the module unit with which the linker operates. The psect provides the following information to the linker:

- the identifying information about the psect
- the size of the code, data, initialized data, and remote memory area
- the symbols defined by the individual psect
- the symbols referenced by the psect
- relocation information
- the actual code and initialized data

The **root psect** is the psect from which all other references are resolved. The file containing the root psect must be named first on the l68 command line. The root psect is distinguished from other psects by the appearance of a non-zero type/language field in the psect directive of the source file. All other psects processed in the linkage must have a zero type/language field.

The psect directive in the root psect provides the linker with the name of the psect and prototype module header information. The type/language, attribute/revision, edition number, stack requirement, module entry point offset, and uninitialized trap handler entry offset appear in the psect directive. They are used to set up the corresponding entries in the module header. Many of these values can be altered by using linker command line options.

The Subroutine Psect

A zero type/language field in the psect directive indicates a subroutine psect. These psects are usually subroutines that provide supporting code for the root psect. Linker library files are simply separately assembled psects, merged together into a single file. Except for the psect name and stack size reservation fields, all fields in the psect directive are zero.

The Linker Execution

When a program is being assembled, the assembler does not know the addresses of names which are external references to other program sections. For example, the bsr instruction to a label in another program section cannot have its offset computed because the address of the destination label is not known until all sections are combined by the linker. Therefore, when an external reference is encountered, the assembler sets up information in the ROF which identifies the instructions that reference external names. Because the assembler is not aware of what the actual offset within the module will be, each section is assembled as though it starts at offset 0.

The linker uses the ROFs produced by the assembler as input. The linker reads all the ROFs and then assigns each ROF a relative starting offset for its data storage space and a relative starting offset for its object code space.

Important: Because OS-9 requires programs to be position-independent code with separate position-independent data areas, these addresses remain relative. OS-9 assigns these physical memory areas when a program is loaded and executed.

The linker processes the input files in three phases.

During the first phase, the linker reads all the input files in the order they appear on the command line. Each psect is checked for validity. The global symbol definitions are entered into the defined symbol table. If a symbol of the same name already exists in the defined symbol table, an error message is generated.

Each global symbol is then checked against the undefined symbol table. If the global symbol defines an external reference, the symbol is removed from the undefined symbol table. Finally, the reference list is examined to identify references to undefined symbols that are not yet in the undefined symbol table. Any such symbols are then added to the undefined symbol table.

After examining the input files, the linker reads the library files. They are processed using the same procedures as used for input files, with minor exceptions. A psect appearing in a library file is retained for the final module only if the psect defines an as yet undefined symbol. After each psect in a library file is processed, the undefined symbol table is examined to see if any symbols are still undefined. If so, library file processing continues. If not, the next psect in the library file or the next library file is processed.

A symbol psect is handled as a special case by the linker. It contains no code or data, only symbols defining constants. When a symbol psect is processed, only the symbols defining as yet undefined symbols are placed in the defined symbol table. Symbol psects are used in the sys.l system library file to define system constants and offset values. This procedure minimizes the amount of symbol table memory required for linking modules against the system library.

During the second phase, the linker determines the size of the code, data, initialized data, and remote memory areas.

The offsets of all code symbols are assigned based on each psect's position in the final module. If the –a option is used, a symbol reference list is examined to determine if any code falls outside of the 16-bit offset addressing mode limit. If any portion of the psect is farther than 32K from the destination, an entry is reserved in the jumptable.

The offsets of all data symbols are assigned. The uninitialized data memory is assigned first, followed by the initialized data memory including the linker-generated jumptable. Finally the remote memory area is assigned. The total size of the uninitialized and initialized data areas cannot exceed 64K. The size of the remote memory area is limited only by the amount of contiguous free memory in the system.

The linker creates the output module during the third phase. The module header for the appropriate module type is created and written to the output file. Each input psect is re-read from the appropriate input or library file. The code and initialized data segments are read into an internal buffer.

The reference list in the psect is read to determine the locations of all operands referencing external symbols. These operands are then adjusted to reflect the destination's position in the output module.

If the –a option is used and the reference cannot reach the destination with the 16-bit offset addressing mode, the reference is changed to reference a jump table entry.

The code and initialized data segments are then written to the output file. As each segment is written out, the OS-9 module CRC is calculated. The CRC is then written into the output module when all psects have been processed.

Linker Library Files

Library files are created by concatenating one or more ROFs into a single file. To change a single psect in a library file, the entire library must be re-created from the ROFs, substituting the new psect for the old.

The linker performs only one pass over the input files to locate symbol definitions. Because of this, the order in which the psects appear in the library file is very important. The psects must be ordered so that the references are generally forward references. Consider the following example:

```
psect main_c
       defines:    main
       references: sub_1

psect sub1_c
       defines:    sub_1, sub1a
       references: sub2

psect sub2_c
       defines:    sub2
       references: printf
```

The psect sub1_c must appear in the library before any psect containing a symbol that sub1_c references. If the sub2_c psect were to appear before the sub1_c psect, the symbol definition for sub2 would not be found. Remember, a psect appearing in a library file is retained for the final module only if the psect defines an as yet undefined symbol.

To examine this library relationship, use the –l option of rdump.

Linker Defined and Linker Recognized Symbols

The linker defines some symbols at link time that cannot be determined until the final code and data offsets are determined. The linker-defined symbols are:

Symbol:	Index register:	References:
_jmptbl	a6	Offset to jumptable
end	a6	Last data offset assigned
bname	pcr	Offset from the beginning of the module to module name
btext	pcr	Offset from pc to beginning of the module

The linker recognizes certain global labels as overrides to selected fields in the module header. The linker places the value of these symbols into the appropriate field of the module header:

Symbol:	Definition:
_sysedit	Edition number to place at M$Edit
_sysperm	Permission value to place at M$Accs
_sysattr	Attribute/revision value to place at M$Attr

These symbols are typically set with the equ directive as:

```
_sysedit: equ 21                          ;edition number
_sysperm: equ PRead_|Read                 ;module access permissions
_sysattr: equ(ReEnt|Ghost)<<8|revision    ;module attributes
```

The Linker Command Line

The linker command line has the following syntax:

```
l68 [options] <mainline> [<rof2> {<rofN>} ] [options]
```

`<mainline>` is the pathlist of the mainline segment from which external references are resolved and a module header is generated. A mainline module is indicated by non-zero type/lang value in the psect directive.

Names of additional ROFs (rof2 through rofN) used in the linkage process follow the mainline ROF pathlist. No other ROF can contain a mainline psect. The mainline and all subroutine files appear in the final linked object module whether actually referenced or not. There is no limit to the number of ROFs that may be used. Only 32 library files, however, may be specified. All l68 input files must be in relocatable object format (ROF).

Psects that contain no data or code are handled by l68 in a special way. This type of psect contains only symbols that define constants (for example, equ). Only the symbols that define external references are placed in the linker's symbol table. If used, this type of psect is the last psect given and handles remaining unresolved references. An example of this is the sys.l file (system definition library).

Linker Command Line Options

The following options can appear on the command line (options are case significant):

Option:	Description:
–a	Converts out-of-range bsrs and PC-relative leas to jump table references. bsrs that address labels over 32K distant are automatically converted to jsrs using a jump table (in the initialized data area) that contains the desired destination address. leas are changed to move instructions that move the destination from a jump instruction in the jump table. The linker automatically builds the required jump tables and includes them in the output file. This allows large programs to overcome the +/– 32K offset limit of bsr instructions without violating the OS-9 requirement for position independent code.
–e=<n>	Sets the module edition number. <n> is used for the edition number in the final output module. 1 is used if this option is not given.
–g	Outputs symbol modules for use by the user and/or source debugger. If the ".r" files were created with the "–g" option, two symbol files are created; one file name with .stb appended the other with .dbg appended. If not compiled with the "–g" option, only the .stb file is created. If a directory named STB is present in the current execution directory, the symbol files are placed there. Otherwise, they are placed in the current execution directory.
–j	Prints jump table calculation map. See the description in the –a option.
–l=<path>	Uses <path> as a library file. A library file consists of one or more merged assembly ROF files. Each psect in the file is checked to see if it resolves any unresolved references. If so, the module is included in the final output module, otherwise it is skipped. No mainline psects are allowed in a library file. This option can be repeated up to 32 times in one command line to specify multiple library files. Library files are searched in the order given on the command line. The standard definition files are sys.l for assembly language or clib.l for the C compiler.
–M=<mem>[k]	Adds <mem> K to the stack memory allocation.
–m	Prints the linkage map indicating the base addresses of the psects in the final object module.
–n=<name>	Uses <name> as the module name.
–o=<path>	Writes linker object (memory module) output to the specified file, relative to the execution directory. The last element in <path> is used as the module name unless overridden by the –n option.

Option:	Description:
–O=<path>	Writes linker object (memory module) output to the specified file, relative to the data directory. The last element in <path> is used as the module name unless overridden by the –n option.
–p=<n>	Sets the permission word in the module header to <n>. <n> must be hexadecimal.
–r	Outputs a raw binary file for a non-OS-9 target system. The output will not be in memory module format.
–r=<n>	Outputs a raw binary file for non-OS-9 target systems with an object code base address at absolute address <n>. <n> must be a hexadecimal address. The base address is used to make absolute addressing references operate correctly.
–s	Prints a list of relative addresses assigned to symbols in the final object module. The symbols are listed in numeric order. This option is usually used with the –m option.
–S	Sets the *sticky* bit in the module header, causing the module to remain in the module directory, even if the link count becomes zero.
–w	When used with –s, it displays symbols in alphabetic instead of numeric order.
–z	Reads module names from standard input.
–z=<file>	Reads module names from <file>.

Linking Code for Non-OS-9 Systems

The linker can generate raw code to run in non-OS-9 environments. The output is a pure binary file which is not in OS-9 memory module format.

The linker –r option is used to create raw output files. The hexadecimal address to place the modules in ROM is specified using the –r option. The address is used to make absolute references come out correctly.

Because it is assumed that the code will not be executed via the OS-9 fork system call (which performs data area initialization), no initialized data may be used (for example, dc in a vsect).

Your initialization code must set up the stack pointer (a7) to point to a stack RAM area, and the a6 register must point to the beginning of a global/static RAM area (vsect) which should be initialized to zeros.

Chapter 7

OS-9 Programming Techniques

Rules for Programming Techniques

One of OS-9's main features is its powerful memory management capabilities using software or software/hardware methods. This results in much more efficient and flexible use of system memory than in other operating systems.

In order for these techniques to work properly, you must follow certain rules when writing assembly language programs. Programmers who use only high-level languages such as C, BASIC, Pascal, etc., need not be as concerned with these rules because the compilers automatically carry them out.

The key to being able to effectively use these methods is to have a good knowledge of the environment OS-9 provides for programs and also the instructions and addressing modes of the specific processor.

RULE 1: All executable code must be in memory module format.
The OS-9 memory module is the basis of both memory management and the advanced modular programming techniques the operating system supports. The assembler and linker automatically generate the module header and CRC check values. For detailed information concerning memory modules, see the *OS-9 Technical Manual*.

RULE 2: Program and data areas must be separate.
All object code for a program is located in a memory module which is **read-only**. Programs should never modify themselves. Therefore, a separate memory area is used for variables. Every process has a unique data area. Every process does not necessarily have a unique program memory module. This allows two or more tasks to share the same copy of a program if they are running the same program. This technique is an automatic function of OS-9 that results in efficient use of available memory.

RULE 3: All object code must be position-independent.
OS-9 must be able to dynamically map a memory module to any block of physical addresses to allow a process to access more than one module at the same time. It also allows memory management on systems that do not have memory management hardware with address relocation functions.

Writing position-independent code involves using only PC-relative addressing in branches and in accessing constant tables. Absolute memory addresses should never be used in a program.

RULE 4: All data storage must be position-independent.
OS-9 assigns the address of the program's data area at the time the process is started by the F$Fork system call. Use of a position-independent data area lets OS-9 run on systems with limited or nonexistent memory management hardware. As with the object code module, absolute addressing of variables is not permitted. Instead, OS-9 programs use the convention that register A6 is a pointer (base address register) to the program's data area, and all addressing of variables use the 68000 indexed addressing modes. The initialized and uninitialized data area are accessed by the Register Indirect with Offset addressing mode: n(An). The remote data area is accessed by the Indexed Register Indirect with Offset addressing mode: n(An,Xn).

Program and Data Memory References

OS-9 does not limit the memory size of a program's code or data. However, due to the characteristics of the 68000 architecture, certain restrictions exist. These depend on the addressing modes used. Because of the software techniques OS-9 uses to provide a multi-user and multi-tasking environment, user state programs cannot use either the absolute short or absolute long addressing modes for addressing code and data memory.

All references to the program code must use a **PC-relative** addressing mode:

n(pcr)	Relative with Offset
n(pcr,Xn)	Relative with Index and Offset or any relative branch instructions

All references to the program data must use a **register indirect** addressing mode:

(An)	Register Indirect
(An)+	Postincrement Register Indirect
–(An)	Predecrement Register Indirect.
n(An)	Register Indirect with Offset
n(An,Xn)	Indexed Register Indirect with Offset

The offsets of these addressing modes are 16-bit signed offsets. This limits the usefulness of the offset to +/–32K. Many non-trivial programs rapidly exceed this 32K limit. Because it is undesirable to require assembly language programmers and compilers to generate worst-case code all the time, the OS-9 assembler and linker provide facilities to access distant program and data addresses.

Data Area References

OS-9 places the address of the data memory for a process in the A6 register. The labels appearing in the program's vsects represent offsets. When applied against the A6 register, these labels yield the address of the desired data. Because the offset is limited by the hardware addressing mode to a 16-bit signed value, the offset can address only 32K. To fully use the 64K range that an unsigned offset would provide, the linker automatically starts assigning the data storage offsets from $8000. When OS-9 assigns data memory for a process, the A6 register is automatically adjusted to point 32K past the actual base of the data memory. This method allows a full 64K of addressability from the Register Indirect with Offset addressing mode.

The 32K data memory base adjustment is done only for user state program and trap handler modules. No adjustment is made for system state modules such as device drivers or file managers.

The total size of the initialized and uninitialized data memory cannot exceed 64K. To do so would cause the memory beyond 64K from the base pointer to be unaddressable with the Register Indirect with Offset addressing mode.

The following is an example of referencing the initialized and uninitialized data areas:

```
        vsect
varname ds.l 1   ;an integer variable
counter dc.l 500 ;an integer variable initialized to 500
        ends
        .
        .
        move.l varname(a6),d0 ;access the uninitialized data memory
        cmp.l  d0,counter(a6) ;access the initialized data memory
```

The only way to offset beyond the 64K data memory limit is to use the Indexed Register Indirect with Offset addressing mode. The offset for this addressing mode is only 8-bits signed, which renders it useless for this purpose. The index register, however, can be loaded with a 32-bit constant representing the offset to the data. This method yields a 4.2 gigabyte unsigned offset.

There are two basic ways of accessing remote variables. Thie first method involves moving the 32-bit offset into a register and then using that register as an index from the data memory pointer (a6):

```
        vsect remote
bigone: ds.l 100000       ;declare a very large array
        ends
        .
        .
        move.l #bigone,d0 ;get offset into bigone
        add.l  d4,d0      ;add subscript
        move.l 0(a6,d0.l),d2           ;get the array value
```

The second method involves copying the data pointer to a temporary address register and then adding the 32-bit offset to the temporary register. It can then be used in simple Register Indirect addressing mode to access the remote variable. For example, the address of bigone can be determined by:

```
move.l a6,a0             ;get the base address of the data
adda.l #bigone,a0        ;add in the offset to bigone
move.l (a0),d2           ;get the array value
```

Code Area References

Many of OS-9's capabilities are due to the use of memory modules. All OS-9 object code must be in memory module format. Use of memory modules is simple because l68 automatically generates them.

Another important requirement for OS-9 object code is position-independence. Use of **position-independent code** (PIC) is essential. It allows OS-9 to dynamically add or remove modules from a process' memory space. PIC allows OS-9 to load a program at any address where free memory is available. Absolute addressing should never be used.

Fortunately, the 68000 instruction set is generally well suited for writing PIC. PIC programming techniques require that only program counter relative (PCR) addressing modes be used to access the program object code area. The bsr, Bcc, and DBcc instructions do this inherently. Notice that the 68000 addressing scheme does not allow an operand addressed as PCR to be modified. This enforces the OS-9 design philosophy that no program should modify itself.

When addressing constants, constant tables or addresses of routines within the program object code, the PCR addressing modes (d(PC) and d(PC,Xi)) can only be used on instructions that do not alter their objects. Directly stated, PCR addressing modes can never appear as a destination address or as an address of data to modify. The 68000 addressing modes themselves discourage self-modifying programs.

The lea and pea instructions can be used with PCR addressing modes to obtain actual addresses within the program area at run time. For example, to obtain the address of a constant table the following instruction can be used:

```
lea table(PC),a2
```

The offset in the PCR addressing mode is limited to a 16-bit signed value. This limitation restricts the use of this addressing mode to destinations within 32K of the reference. Because many non-trivial programs easily exceed this limit, the linker provides a facility to overcome this limitation.

The –a option of the l68 linker causes the linker to direct certain PCR references to a jump table in the data area. For each bsr instruction that does not reach its destination address, the linker will replace the bsr instruction with a jsr instruction. The destination of this instruction references a jump table.

The linker creates the jump table as initialized data, the size of which is added to the total initialized data allocation for the program. Each jump table entry is an absolute long jmp instruction whose destination is initially an offset from the beginning of the program module to the reference.

The relocation information placed in the module by the linker is then used by the kernel to adjust the offsets in the jump table to reflect the absolute address of the actual reference. Only long (16-bit offset) bsr instructions are affected. All other branch style instructions (Bcc, DBcc, etc.) are still limited to the 32K restriction.

The following is an example of a modified bsr instruction. Consider the jump table fragment:

```
jmptbl+0   jmp printf
jmptbl+6   jmp fprintf
jmptbl+12  jmp sprintf
```

An out of range bsr:

```
bsr fprintf
```

is replaced by:

```
jsr _jmptbl+6(a6)
```

The –a option also causes lea (and pea) instructions involving a PCR reference to be directed through the jump table. OS-9 programs commonly use the lea instruction to determine the address of a table, or in the case of a C program, a function. Often, this instruction cannot address its destination because of the range limit. In this case, each lea instruction that does not reach its destination address is replaced by a move which references the destination address appearing in the jump table.

For example, an out of range lea:

```
lea fprintf(pcr),a0
```

would be replaced by:

```
move.l _jmptbl+8(a6),a0
```

An out of range pea:

```
pea fprintf(pcr),a0
```

would be replaced by:

```
move.l _jmptbl+8(a6),-(sp)
```

Only one jump table entry is created for each unique unreachable destination, regardless of the number of times a destination could not be reached. This allows resolution of the reference without changing the size of the code. Both the original code and the substitute code are four bytes long.

Appendix A

Example Program

The following example is the assembly language program UpDn: a program that converts the case of input to either upper or lower. This program is provided to give an example of the form and structure of an assembly language program.

```
                          nam          UpDn
                          ttl          OS-9/68000  Example Assembly Prog
                          ********************************
* This program converts characters from upper case to lower case
* (default) or from lower case to upper case (with -u option)

                          use          defsfile

 00000001 Edition         equ          1
 00000101 Typ_Lang        equ          (Prgrm<<8)+Objct
 00008000 Attr_Rev        equ          (ReEnt<<8)+0
                          psect        updn,Typ_Lang,Attr_Rev,Edition,1024,UpDn

 00000000 StdIn           equ          0              standard input path
 00000001 StdOut          equ          1              standard output path
 00000002 StdErr          equ          2              standard error path

                          vsect
 00000000 Char            ds.b         1              one character I/O buffer
0000   41 LowBound        dc.b         'A'            low bound to convert
0001   5a HiBound         dc.b         'Z'            upper bound to convert
 00000002                 ends

0000=5379 HelpStr         dc.b         "Syntax: updn [-u]",C$LF
0012=4675                 dc.b         "Function: converts upper to lower ",C$LF
0043=4f70                 dc.b         "Options:",C$LF
004c=2020                 dc.b         " -u : converts lower to upper",C$LF,C$CR
 00000071 HelpLen         equ          *-HelpStr

*  Entry Point and Initialization
0078 600e                 bra.s        PrsOpt10       parse options

007a 101d PrsOpt          move.b       (a5)+,d0       get parameter byte
007c b03c                 cmp.b        #'-',d0        parameter leadin?
0080 671e                 beq.s        PrsOpt20       branch if so
0082=b03c                 cmp.b        #C$CR,d0       carriage return?
0086 6606                 bne.s        PrtHelp        abort if not
```

```
0088 51cd PrsOpt10        dbra        d5,PrsOpt      until no more option bytes
008c 602a                 bra.s       UpDn10

008e 7002 PrtHelp         moveq       #StdErr,d0     standard error path
0090 41fa                 lea         HelpStr(pc),a0 help message string
0094 223c                 move.l      #HelpLen,d1    length of string
009a=4e40                 os9         I$WritLn       output help message
009e 604c                 bra.s       UpDn90         exit

00a0 5345 PrsOpt20        subq.w      #1,d5          decr option cnt
00a2 65ea                 bcs.s       PrtHelp        abort if end of parameters
00a4 101d                 move.b      (a5)+,d0       get option character
00a6 0a00                 eori.b      #'u',d0        is it a "-u" option?
00aa 0200                 andi.b      #^('a'-'A'),d0 (ignore case difference)
00ae 66de                 bne.s       PrtHelp        abort if not
00b0 3d7c                 move.w      #'az',LowBound(a6) reset convert bounds
00b6 60d0                 bra.s       PrsOpt10       check for other options

00b8 7000 UpDn10          moveq       #StdIn,d0      from standard input
00ba 7201                 moveq       #1,d1          read one character
00bc 41ee                 lea         Char(a6),a0    into "Char"
00c0=4e40                 os9         I$Read
00c4 6520                 bcs.s       UpDn80         abort if error
00c6 102e                 move.b      Char(a6),d0    get character
00ca b02e                 cmp.b       LowBound(a6),d0 in range?
00ce 650c                 blo.s       UpDn20         branch if not
00d0 b02e                 cmp.b       HiBound(a6),d0 in range?
00d4 6206                 bhi.s       UpDn20         branch if not
00d6 0a2e                 eori.b      #'a'-'A',Char(a6) convert characters case
00dc 7001 UpDn20          moveq       #StdOut,d0     to standard output
00de 7201                 moveq       #1,d1          write the character
00e0=4e40                 os9         I$WritLn
00e4 64d2                 bcc.s       UpDn10         repeat if no error

00e6=b27c UpDn80          cmp.w       #E$EOF,d1      end of file error?
00ea 6602                 bne.s       UpDn99         abort if not
00ec 7200 UpDn90          moveq       #0,d1          return without error
00ee=4e40 UpDn99          os9         F$Exit         exit

 000000f2                 ends
```

Appendix **B**

Assembler and Linker Error Messages

Assembler Error Messages

When r68 detects an error, it prints an error message in the listing just before the source line containing the error. It is possible for a statement to have two or more errors, in which case each error is reported on a different line preceding the erroneous source line.

If the assembler listing is inhibited by the absence of the `-l` option, error messages and printing of erroneous lines still occurs. At the end of the assembly, the total number of errors and warnings are given as part of the assembly summary statistics. The error messages, erroneous source lines, and the assembly summary are all written to the assembler task's error/status path which may be redirected by the shell. For example:

```
r68 sourcefile  o=sourcefile.o > src.error
```

Note that calling the assembler with the listing and object code generation both disabled by the absence of the `-l -o` options can be used to perform a quick assembly just to check for errors. This allows many errors to be found and corrected before printing of a lengthy listing. For example:

```
r68 sourcefile
```

Sometimes the assembler will stop processing of an erroneous line so additional errors following on the same line may not be detected, so corrections should be made carefully.

Error messages consist of brief phrases which describe the kind of error the assembler detected. Each error message is explained in detail in the following table.

Error Message:	Description:
Bad label	The statement's label has an illegal character or does not begin with a letter.
Bad Mnemonic	A mnemonic was found in mnemonic field that was not recognized or was not allowed in the current program section.
Bad number	The numeric constant definition contains a character that is not allowed in the current radix.
Bad operand	An operand expression is missing or incorrectly formed.
Bad operator	An arithmetic expression is incorrectly formed.
Bad option	An option is unrecognized or incorrectly specified.
Bracket missing	The opening or closing bracket is missing.
Can't open file	A problem was encountered opening an input file.

Error Message:	Description:
Can't open macro work file	A problem was encountered opening a macro work file.
Comma expected	A comma was expected but not found.
Conditional nesting error	A mismatched if/else/endc conditional assembly directive was found.
Constant definition	A constant definition is incorrectly formed.
ENDM without MACRO	An endm was found, with no matching macro.
ENDR without REPT	An endr was found, with no matching rept.
Fail <message>	A fail directive was encountered.
File close error	A problem was encountered closing an input file.
Illegal addressing mode	The addressing mode cannot be used in the instruction.
Illegal external reference	External names cannot be used with assembler directives. If an operand expression contains an external name, the only operation allowed in the expression is binary plus and minus.
Illegal index register	The register cannot be used as an index register.
Illegal suffix	An illegal suffix was found in an instruction.
Label missing	This statement is missing the required label.
Macro arg too long	The Macro argument is too long. No more than 60 characters total can be passed to a macro.
Macro file error	A problem was encountered accessing the macro work file.
Macro nesting too deep	The macro calls are nested too deeply. Macro calls may only be nested up to 8 levels deep.
Nested MACRO definitions	A macro cannot be defined inside a macro definition.
Nested REPT	Repeat blocks cannot be nested.
New symbol in pass two	See symbol lost.
No input files	An input file must be specified.
No param for arg	A macro expansion is attempting to access an argument that was not passed by the macro call.
Phasing error	A label has a different value during pass two than it did during pass one.
Redefined name	The name appears more than once in the label field other than on a set directive.
Symbol lost?	Assembler symbol lookup error. The error could be caused by symbol table overflow or bad memory.
Too many args	Too many arguments were passed to the macro. No more than 9 arguments may be passed to a macro.
Too many object files	Only one –o= command line option is allowed.
Undefined org"*"	(program counter org) cannot be accessed within a vsect.
Unmatched quotes	A beginning or ending quotation mark was expected but not found.

Linker Error Messages

The following is a comprehensive list of the error, warning, and informational messages issued by the OS-9/68000 linker (l68). In this section, the following syntax conventions are used:

- '<file>' Represents the actual file name in questions.
- '<n>' Represents the actual number in question.
- '<char>' Represents the actual character in question.

The following table lists Linker error messages and a description of each message.

Error Message:	Description:
'<file>' contains a 6809 module	A module from the 6809 assembler was encountered.
'<file>' contains assembly errors	A module was encountered that had assembly errors. Fix the errors and re–link.
'<file>' contains no root psect	The first file given on the command line must contain a root psect. A root psect is the psect from which all references are resolved. A root psect is specified by non–zero type and language fields in the module's psect directive.
'<file>' created by assembler too new for this linker	The r68 and l68 programs are not compatible editions. Be sure the correct programs are installed in the execution directory.
'<file>' is not a relocatable module	The relocatable module header in '<file>' was either not present or incorrectly formed. All relocatable object headers start with the bytes: $DE $AD $FA $CE. Use the dump utility on the input file to verify this. The most likely cause of this error is the wrong file was given on the command line.
'<file>' rof<4 and code>32k. Must be re–assembled.	This message is caused when the linker processes an old version of assembler output that contains more than 32k of code. Re–assembly of the source file will fix the problem.
bad syscrc size	This is an internal linker error. Contact Microware if this error can be reproduced at will.
can't create output file	The output file for the module (given by the –o= option) cannot be created. Possible causes are no access permissions or no disk space.
can't create symbol file	The symbol file for the module cannot be created. Possible causes are no access permissions or no disk space.
can't open '<file>'	One of the input files given could not be opened. Possible causes are no access permissions, non–existent file or no free memory.
can't open '<file>' name file	The –z=<file> could not be opened. Possible causes are no access permissions, non–existent file or no free memory.
can't reopen input file '<file>'	This is an internal linker error. Contact Microware if this error can be reproduced at will.

Error Message:	Description:

duplicate symbol names	The linker has determined that the same symbol name appears in more than one psect in the allocation of the final module. Consider the following program fragment:
	`main()`
	`{`
	`  strcat();`
	`}`
	`strlen()`
	`{`
	`  return;`
	`}`
	When compiled and linked, linkage will fail and return the messages:
	`Symbol 'strlen' defined by psect 'strings_c' in file '/dd/lib/clib.l' has already appeared in psect 'prog_c' in file 'ctmp.001543.r`
	`Symbol 'strcat' from psect 'strings_c' in file '/dd/lib/clibn.l caused name clashes.`
	Since both prog_c and strings_c define the symbol strlen, the linker cannot resolve the reference to strcat without causing the definition of strlen to be ambiguous. The first message indicates that strlen was defined in both prog_c and string_c. The second message identifies the symbol that the linker was attempting to resolve when it found the name clash.

error reading input file '<file>'	The linker could not read the input file. Either a physical error occurred or the input file was incorrectly formatted. All input files must be output from the assembler.
error writing file '<file>'	The linker could not write the output file. Possible causes are disk errors or media full.
initialized data (or jumptable) allowed only on program or trap handler modules	Initialized data is supported only for program modules (entered by F$Fork) or trap handler modules (entered by F$TLink). Modules such as system modules, device drivers and file managers cannot have initialized data. Initialized data is generated by the C Compiler when C initializers appear for static or global data. Initialized data is generated by the assembler when a data initialization directive (dc, dz, etc.) appears in a vsect.
jmp total > guess (<n>/<n>)	This is an internal linker error. Contact Microware if this error can be reproduced at will.
no data storage allocation (vsect) allowed on non–object modules	Only modules of type object code can contain data storage allocation. Other module types (usually language runtime interpreters) define data storage allocations in a different manner.
no initialized static data allowed on raw output	Initialized data cannot be allocated to a program designed to run without OS–9. Uninitialized data is allowed. The linker prints the size of the uninitialized data requirement for raw modules.
no root psect found	The first module given on the command line must contain a root psect. A root psect is a module in which the psect directive indicates a non–zero type and language word. A zero type and language word means a subroutine module. The root psect is the psect from which all references are resolved.
non–remote data allocation value exceeds 64k	See the discussion in the manual on data area references for a description of the linker memory limits.
odd count for crc	This is an internal linker error. Contact Microware if this error can be reproduced at will.

Error Message:	Description:

operand size error	This message occurs when an operand value exceeds the legal range for the size of the operand. It is displayed with additional text such as:
	`l68: error – operand size error`
	`The value of symbol 'funny' ($193) is too large for a byte operand.`
	`The offending operand is at offset $13c1 in the code area of psect 'main'in file 'pt.r'.`
	In this case, the value for the symbol funny is (in hex) $193. This value is too large to fit in a byte–size operand. The next line indicates where in the psect the operand appears. In this case the operand appears at offset (in hex) $13c1 in the code area. The location counter field on the assembly listing is the offset value. Finally, the offending psect name and the file in which the psect appears is displayed.

out of memory	The linker cannot obtain enough memory to do the linkage. Memory usage requirements depend on many factors: number of input files, number of psects, number of global symbols and undefined references. The largest use of memory is during the second pass when each psect's references must be adjusted for the final program module. To do this step, the linker must be able to get as much memory as the largest psect used. A psect that is 128k long requires a 128k buffer to link.
reference location error (<n>)	This is an internal linker error. This is caused by information from the assembler that the linker does not expect. If this happens, be sure the assembler and linker are properly installed on the system from the original distribution medium. Contact Microware if this error can be reproduced at will.
root psect found in both <file1> and <file2>	Only one root psect is allowed for a program. A root psect is defined as a psect in which the Type/Language field is non–zero. The root psect is the initial psect from which all external references are resolved.
symbol 'name' not found during pass 2	This is an internal linker error. Contact Microware if this error can be reproduced at will.
too many data references <n>	This is an internal linker error. Contact Microware if this error can be reproduced at will.
unknown option –<char>	An option given is not an option recognized by the linker.
unknown reference type <n>	This is an internal linker error. Contact Microware if this error can be reproduced at will.

unresolved references	The symbols previously listed by the linker are not defined by a psect given on the command lines or in libraries. This is commonly caused by improperly ordered library files. See Chapter 6 and the discussion of Linker Library Files for details on library searching. Additional error messages such as the following normally appear previous to this message:
	`Symbol 'funny' unresolved.`
	`Referenced [<n> times] by psect 'main' in file 'pt.r'`

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