

LINUX for S/390



ELF Application Binary Interface Supplement

LINUX for S/390



ELF Application Binary Interface Supplement

Note

Before using this information and the product it supports, read the information in "Notices" on page 59.

Edition 1.01 (July 2001)

This edition applies to version 2, release 2, modification 16 of the LINUX kernel and to all subsequent releases and modifications until otherwise indicated in new editions.

This edition replaces LINUX-1007-01.

Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.1; with no Invariant Sections, with no Front-Cover Texts, and with no Back-Cover Texts. A copy of the license is included in the section entitled "GNU Free Documentation License".

© **Copyright International Business Machines Corporation 2001, 2002. All rights reserved.**

US Government Users Restricted Rights – Use, duplication or disclosure restricted by GSA ADP Schedule Contract with IBM Corp.

Contents

Figures	v
--------------------------	----------

Tables	vii
-------------------------	------------

About this book	ix
----------------------------------	-----------

Who should read this book	ix
Prerequisite and related information	ix
How to send your comments	ix

Summary of changes.	xi
--------------------------------------	-----------

Chapter 1. Low-level system information 1

Machine interface.	2
Processor architecture	2
Data representation	3
Function calling sequence	9
Registers.	9
The stack frame	10
Parameter passing	12
Variable argument lists	14
Return values.	15
Operating system interface	15
Virtual address space	15
Page size	15
Virtual address assignments	16
Managing the process stack	16
Coding guidelines	16
Processor execution modes	17
Exception interface	18
Process initialization	18
Registers	19
Process stack	19
Coding examples	22
Code model overview	23
Function prolog and epilog	23
Profiling	25
Data objects	26
Function calls.	29
Branching	34
Dynamic stack space allocation.	35
DWARF definition	38

Chapter 2. Object files 39

ELF Header	39
Machine Information	39
Sections	39
Special Sections	39
Symbol Table.	40
Relocation	40

Chapter 3. Program loading and dynamic linking 45

Program Loading	45
Dynamic Linking	49
Dynamic Section.	49
Global Offset Table	49
Function Addresses.	50
Procedure Linkage Table	50

Appendix. GNU Free Documentation License 53

PREAMBLE	53
APPLICABILITY AND DEFINITIONS	53
VERBATIM COPYING.	54
COPYING IN QUANTITY	54
MODIFICATIONS	55
COMBINING DOCUMENTS	56
COLLECTIONS OF DOCUMENTS	57
AGGREGATION WITH INDEPENDENT WORKS	57
TRANSLATION	57
TERMINATION	58
FUTURE REVISIONS OF THIS LICENSE	58
How to use this License for your documents	58

Notices 59

Programming interface information	60
Trademarks	60

Bibliography 61

Index 63

Figures

1. Bit and byte numbering in halfwords	3	24. Code for profiling	26
2. Bit and byte numbering in words	3	25. Absolute addressing	27
3. Bit and byte numbering in doublewords	3	26. Small model position-independent addressing	28
4. Structure smaller than a word.	5	27. Large model position-independent addressing	29
5. No padding.	5	28. Absolute direct function call	30
6. Internal padding	5	29. Small model position-independent direct function call	31
7. Internal and tail padding	5	30. Large model position-independent direct function call	32
8. Union padding.	6	31. Absolute indirect function call	33
9. Bit numbering	7	32. Small model position-independent indirect function call	33
10. Left-to-right allocation	7	33. Large model position-independent indirect function call	34
11. Boundary alignment	7	34. Branch instruction	34
12. Storage unit sharing	8	35. Absolute switch code	35
13. Union allocation	8	36. Position-independent switch code, all models	35
14. Unnamed bit fields	8	37. Dynamic Stack Space Allocation	37
15. Standard stack frame	11	38. Relocation Fields.	40
16. Register save area	11	39. Executable File Example	45
17. Parameter list area	13	40. Process Image Segments	47
18. Parameter passing example	14	41. Procedure Linkage Table Example	51
19. Virtual address configuration	16	42. Special first entry in Procedure Linkage Table	52
20. Declaration for main	18		
21. Auxiliary vector structure.	19		
22. Initial Process Stack.	22		
23. Prolog and epilog example	25		

Tables

1. Scalar types	4	8. Auxiliary Vector Types Description.	39
2. Bit fields	6	9. Special Sections	39
3. Parameter passing example: Register allocation	14	10. Special Sections Description	39
4. Registers for return values	15	11. Relocation Types	42
5. Exceptions and Signals.	18	12. Relocation type descriptions	42
6. Auxiliary Vector Types, a_type	19	13. Program Header Segments	46
7. DWARF register number mapping	38	14. Shared Object Segment Example	48

About this book

The S/390[®] supplement to the Executable and Linkage Format Application Binary Interface (or ELF ABI), defines a system interface for compiled application programs. Its purpose is to establish a standard binary interface for application programs on LINUX[®] for S/390 systems.

Who should read this book

This book should be read by application programmers who wish to write programs that will install and run on any system compliant with the System V ABI, and by system programmers who wish to make their systems so compliant.

Prerequisite and related information

This book is a supplement to the generic "System V Application Binary Interface" and should be read in conjunction with it.

How to send your comments

Your feedback is important in helping to provide the most accurate and high-quality information. If you have any comments about this book or any other LINUX for S/390 documentation:

- Go to the LINUX for S/390 home page at:
<http://www.s390.ibm.com/linux/>
There you will find the feedback page where you can enter and submit your comments.
- Send your comments by e-mail to linux390@de.ibm.com. Be sure to include the name of the book, the part number of the book, the version of LINUX you are using, and, if applicable, the specific location of the text you are commenting on (for example, a page number or table number).
- There may be a comment form at the back of this book. Fill out a copy and return it by mail or by fax or give it to an IBM representative.

Summary of changes

Changes to this information for this edition include:

- Correction to addressing in Figure 40 on page 47.

Chapter 1. Low-level system information

Machine interface	2	Coding guidelines	16
Processor architecture	2	Processor execution modes	17
Data representation	3	Exception interface	18
Byte ordering	3	Process initialization	18
Fundamental types	4	Registers	19
Aggregates and unions	4	Process stack	19
Bit-fields.	6	Coding examples	22
Function calling sequence	9	Code model overview	23
Registers.	9	Function prolog and epilog	23
Register usage	10	Prolog	24
The stack frame	10	Epilog	24
Parameter passing	12	Prolog and epilog example	25
Variable argument lists	14	Profiling	25
Return values.	15	Data objects	26
Operating system interface	15	Function calls.	29
Virtual address space	15	Branching	34
Page size	15	Dynamic stack space allocation	35
Virtual address assignments	16	DWARF definition	38
Managing the process stack	16		

Machine interface

This section describes the processor-specific information for the S/390 processors.

Processor architecture

ESA/390 Principles of Operation (SA22-7201) defines the ESA/390 architecture.

Programs intended to execute directly on the processor use the ESA/390 instruction set, and the instruction encoding and semantics of the architecture.

An application program can assume that all instructions defined by the architecture that are neither privileged nor optional exist and work as documented.

To be ABI-conforming the processor must implement the instructions of the architecture, perform the specified operations, and produce the expected results. The ABI neither places performance constraints on systems nor specifies what instructions must be implemented in hardware. A software emulation of the architecture could conform to the ABI.

There are some instructions in the ESA/390 architecture which are described as 'optional'. LINUX for S/390 requires some of these to be available; in particular:

- additional floating point facilities,
- compare and move extended,
- immediate and relative instructions,
- string instructions.

The ABI guarantees that these instructions are present. In order to comply with the ABI the operating system must emulate these instructions on machines which do not support them in the hardware. Other instructions are not available in some current models; programs using these instructions do not conform to the S/390 ABI and executing them on machines without the extra capabilities will result in undefined behavior.

In the ESA/390 architecture a processor runs in big-endian mode. (See "Byte ordering" on page 3.)

Data representation

Byte ordering

The architecture defines an 8-bit byte, a 16-bit halfword, a 32-bit word and a 64-bit doubleword. Byte ordering defines how the bytes that make up halfwords, words and doublewords are ordered in memory. Most significant byte (MSB) ordering, or "Big-Endian" as it is sometimes called, means that the most significant byte of a structure is located in the lowest addressed byte position in a storage unit (byte 0).

Figure 1 to Figure 3 illustrate the conventions for bit and byte numbering within storage units of various widths. These conventions apply to both integer data and floating-point data, where the most significant byte of a floating-point value holds the sign and the exponent (or at least the start of the exponent). The figures show big-endian byte numbers in the upper left corners and bit numbers in the lower corners.

0	msb	1	lsb
0	7	8	15

Figure 1. Bit and byte numbering in halfwords

0	msb	1	2	3	lsb		
0	7	8	15	16	23	24	31

Figure 2. Bit and byte numbering in words

0	msb	1	2	3				
0		7	8	15	16	23	24	31
4		5	6	7	lsb			
32	39	40	47	48		55	56	63

Figure 3. Bit and byte numbering in doublewords

Fundamental types

Table 1 shows how ANSI C scalar types correspond to those of the S/390 processor. For all types a NULL pointer has the value zero (binary).

Table 1. Scalar types

Type	ANSI C	sizeof (bytes)	Alignment	type (S/390)
Character	signed char char unsigned char	1	1	byte
Short	signed short short unsigned short	2	2	halfword
Integer	signed int int unsigned int enum signed long long unsigned long	4	4	word
Long long	signed long long long long unsigned long long	8	8	doubleword
Pointer	any-type * any-type (*) ()	4	4	unsigned word
Floating point	float	4	4	single precision (IEEE)
	double	8	8	double precision (IEEE)
	long double ¹	16	16	extended precision (IEEE)

¹Compilers and systems may implement the long double data type in some other way, for performance reasons, using a compiler option. Examples of such formats could be two successive doubles or even a single double. Such usage does not conform to this ABI however, and runs the risk of passing a wrongly formatted floating-point number to another function as an argument. Programs using other formats should transform long double floating-point numbers to a conforming format before passing them.

Aggregates and unions

Aggregates (structures and arrays) and unions assume the alignment of their most strictly aligned component, that is, the component with the largest alignment. The size of any object, including aggregates and unions, is always a multiple of the alignment of the object. An array uses the same alignment as its elements. Structure and union objects may require padding to meet size and alignment constraints:

- An entire structure or union object is aligned on the same boundary as its most strictly aligned member.
- Each member is assigned to the lowest available offset with the appropriate alignment. This may require internal padding, depending on the previous member.
- If necessary, a structure's size is increased to make it a multiple of the structure's alignment. This may require tail padding if the last member does not end on the appropriate boundary.

In the following examples (Figure 4 to Figure 8), member byte offsets (for the big-endian implementation) appear in the upper left corners.

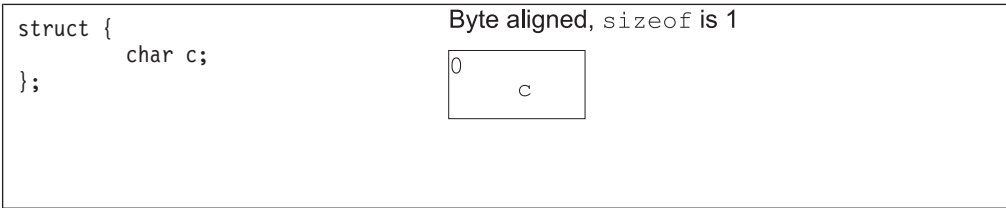


Figure 4. Structure smaller than a word

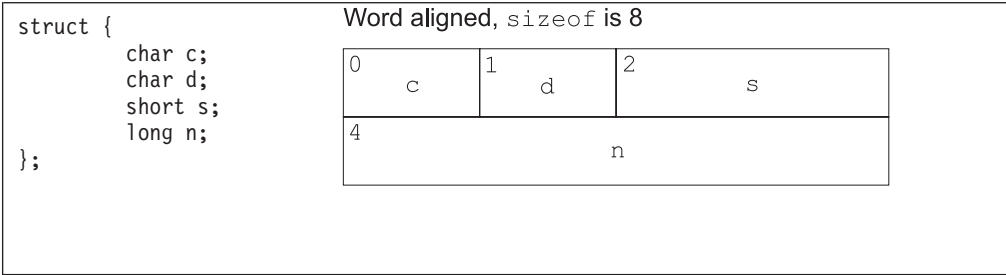


Figure 5. No padding

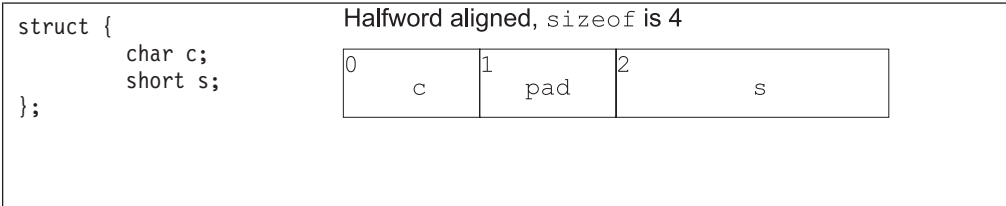


Figure 6. Internal padding

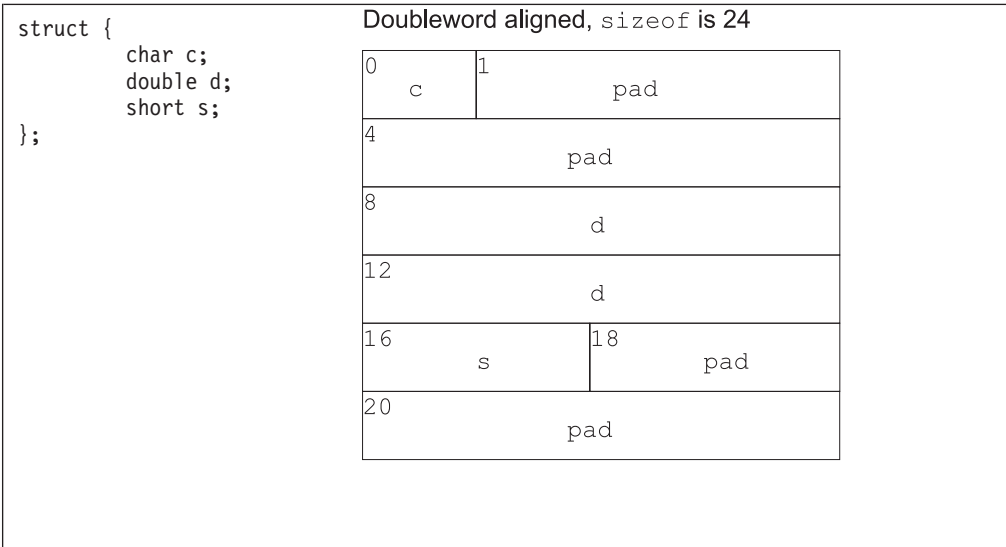


Figure 7. Internal and tail padding

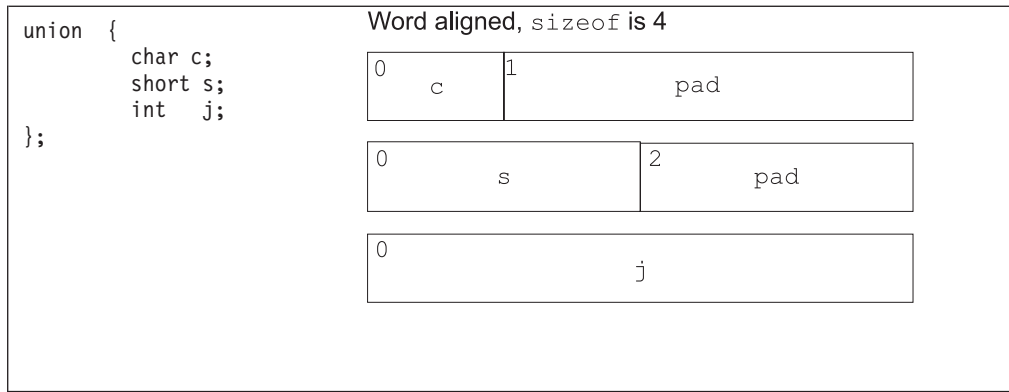


Figure 8. Union padding

Bit-fields

C struct and union definitions may have "bit-fields," defining integral objects with a specified number of bits (see Table 2).

Table 2. Bit fields

Bit-field type	Width n	Range
signed char	1 to 8	-2^{n-1} to $2^{n-1} - 1$
char		0 to $2^n - 1$
unsigned char		0 to $2^n - 1$
signed short	1 to 16	-2^{n-1} to $2^{n-1} - 1$
short		0 to $2^n - 1$
unsigned short		0 to $2^n - 1$
signed int	1 to 32	-2^{n-1} to $2^{n-1} - 1$
int		0 to $2^n - 1$
unsigned int		0 to $2^n - 1$
enum		0 to $2^n - 1$
signed long		-2^{n-1} to $2^{n-1} - 1$
long		0 to $2^n - 1$
unsigned long		0 to $2^n - 1$
signed long long	1 to 64	-2^{n-1} to $2^{n-1} - 1$
long long		0 to $2^n - 1$
unsigned long long		0 to $2^n - 1$

"Plain" bit-fields (that is, those neither signed nor unsigned) always have non-negative values. Although they may have type short, int or long (which can have negative values), bit-fields of these types have the same range as bit-fields of

the same size with the corresponding unsigned type. Bit-fields obey the same size and alignment rules as other structure and union members, with the following additions:

- Bit-fields are allocated from left to right (most to least significant).
- A bit-field must entirely reside in a storage unit appropriate for its declared type. Thus, a bit-field never crosses its unit boundary.
- Bit-fields must share a storage unit with other structure and union members (either bit-field or non-bit-field) if and only if there is sufficient space within the storage unit.
- Unnamed bit-fields’ types do not affect the alignment of a structure or union, although an individual bit-field’s member offsets obey the alignment constraints. An unnamed, zero-width bit-field shall prevent any further member, bit-field or other, from residing in the storage unit corresponding to the type of the zero-width bit-field.

The following examples (Figure 9 through Figure 14) show structure and union member byte offsets in the upper left corners. Bit numbers appear in the lower corners.

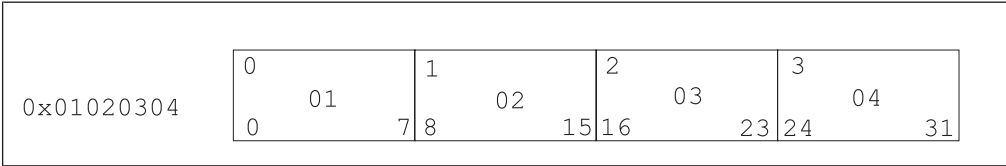


Figure 9. Bit numbering

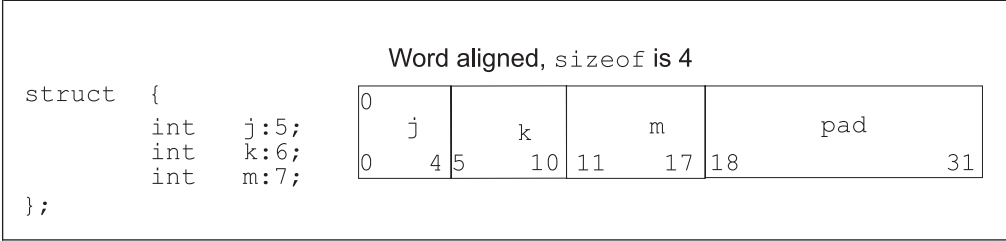


Figure 10. Left-to-right allocation

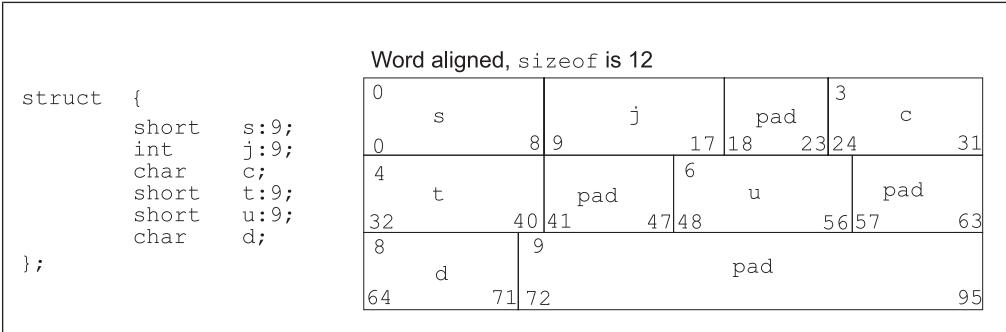


Figure 11. Boundary alignment

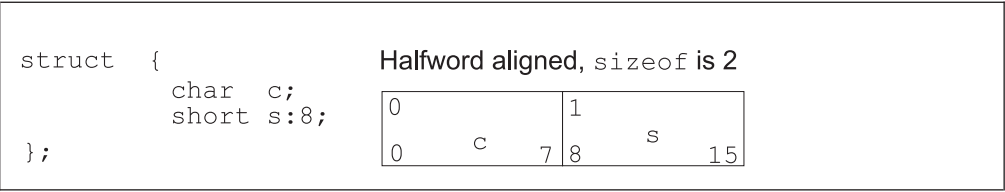


Figure 12. Storage unit sharing

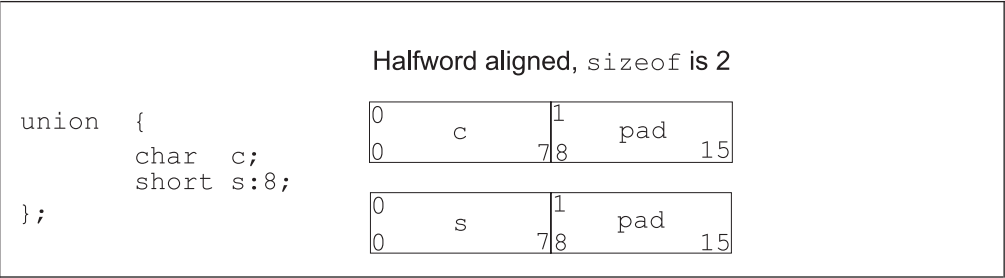


Figure 13. Union allocation

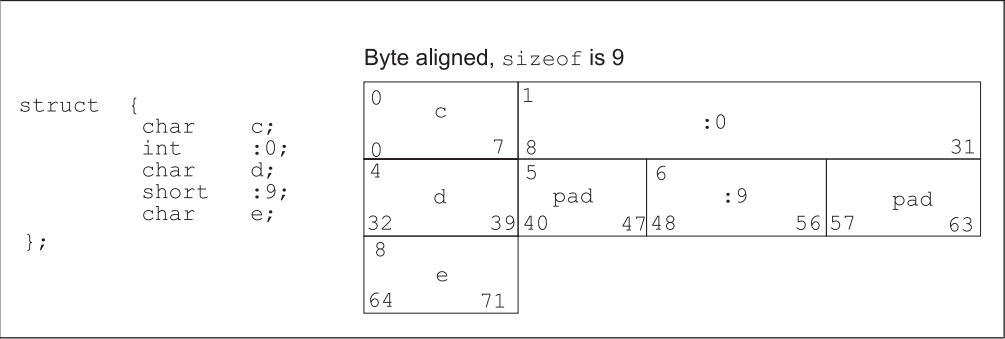


Figure 14. Unnamed bit fields

Function calling sequence

This section discusses the standard function calling sequence, including stack frame layout, register usage, and parameter passing.

Registers

The ABI makes the assumption that the processor has 16 general purpose registers and 16 IEEE floating point registers. S/390 processors have 16 general purpose registers; newer models have 16 IEEE floating point registers but older systems have only four non-IEEE floating point registers. On these older machines LINUX for S/390 emulates 16 IEEE registers within the kernel. The width of the general purpose registers is 32 bits, and the width of the floating point registers is 64 bits. The use of the registers is described in the table below.

Register name	Usage	Call effect
r0, r1	General purpose	Volatile ¹
r2, r3	Parameter passing and return values	Volatile
r4, r5	Parameter passing	Volatile
r6	Parameter passing	Saved ²
r7 - r11	Local variables	Saved
r12	Local variable, commonly used as GOT pointer	Saved
r13	Local variable, commonly used as Literal Pool pointer	Saved
r14	Return address	Volatile
r15	Stack pointer	Saved
f0, f2	Parameter passing and return values	Volatile
f4, f6	General purpose	Saved
f1, f3, f5, f7 - f15	General purpose	Volatile
Access register 0	Reserved for system use	Volatile
Access registers 1-15	General purpose	Volatile

¹Volatile: These registers are not preserved across function calls.

²Saved: These registers belong to the calling function. A called function shall save these registers' values before it changes them, restoring their values before it returns.

- Registers r6 through r13, r15, f4 and f6 are nonvolatile; that is, they "belong" to the calling function. A called function shall save these registers' values before it changes them, restoring their values before it returns.
- Registers r0, r1, r2, r3, r4, r5, r14, f0, f1, f2, f3, f5, f6 through f15 are volatile; that is, they are not preserved across function calls.
- Furthermore the values in registers r0 and r1 may be altered by the interface code in cross-module calls, so a function cannot depend on the values in these registers having the same values that were placed in them by the caller.

The following registers have assigned roles in the standard calling sequence:

r12	Global Offset Table pointer. If a position-independent module uses cross-linking the compiler <u>must</u> point r12 to the GOT as described in “Dynamic Linking” on page 49. If not this register may be used locally.
r13	Commonly used as the Literal Pool pointer. If the Literal Pool is not required this register may be used locally.
r14	This register will contain the address to which a called function will normally return. r14 is volatile across function calls.
r15	The stack pointer (stored in r15) will maintain an 8-byte alignment. It will always point to the lowest allocated valid stack frame, and will grow towards low addresses. The contents of the word addressed by this register may point to the previously allocated stack frame. If required it can be decremented by the called function – see “Dynamic stack space allocation” on page 35.

Signals can interrupt processes. Functions called during signal handling have no unusual restrictions on their use of registers. Moreover, if a signal handling function returns, the process will resume its original execution path with all registers restored to their original values. Thus programs and compilers may freely use all registers listed above, except those reserved for system use, without the danger of signal handlers inadvertently changing their values.

Register usage

With these calling conventions the following usage of the registers for inline assemblies is recommended:

- General registers r0 and r1 should be used internally whenever possible
- General registers r2 to r5 should be second choice
- General registers r12 to r15 should only be used for their standard function.

The stack frame

A function will be passed a frame on the runtime stack by the function which called it, and may allocate a new stack frame. A new stack frame is required if the called function will in turn call further functions (which must be passed the address of the new frame). This stack grows downwards from high addresses. Figure 15 on page 11 shows the stack frame organization. SP in the figure denotes the stack pointer (general purpose register r15) passed to the called function on entry. Maintenance of the back chain pointers is not a requirement of the ABI, but the storage area for these pointers must be allocated whether used or not.

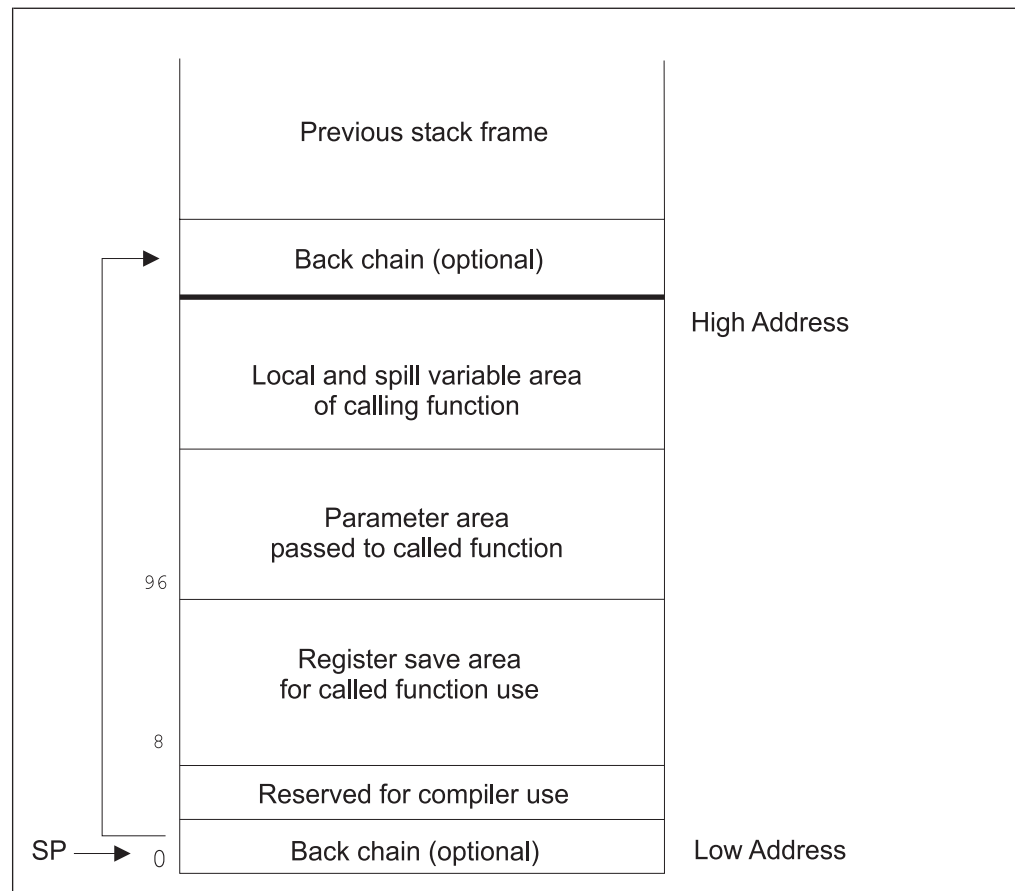


Figure 15. Standard stack frame

The format of the register save area created by the gcc compiler is:

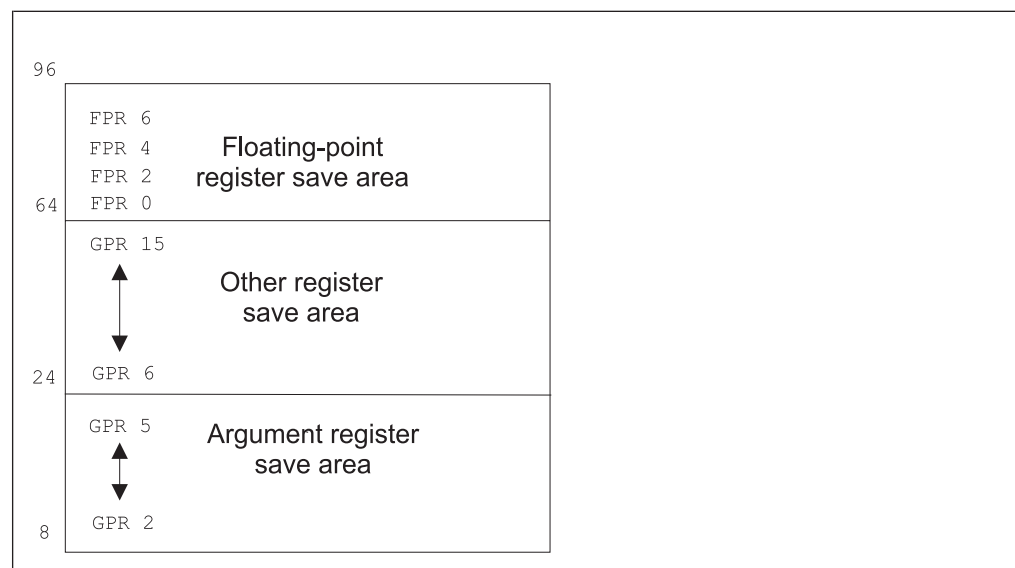


Figure 16. Register save area

The following requirements apply to the stack frame:

- The stack pointer shall maintain 8-byte alignment.

- The stack pointer points to the first word of the lowest allocated stack frame. If the "back chain" is implemented this word will point to the previously allocated stack frame (towards higher addresses), except for the first stack frame, which shall have a back chain of zero (NULL). The stack shall grow downwards, in other words towards lower addresses.
- The called function may create a new stack frame by decrementing the stack pointer by the size of the new frame. This is required if this function calls further functions. The stack pointer must be restored prior to return.
- The parameter list area shall be allocated by the caller and shall be large enough to contain the arguments that the caller stores in it. Its contents are not preserved across calls.
- Other areas depend on the compiler and the code being compiled. The standard calling sequence does not define a maximum stack frame size.

The stack space for the register save area and back chain must be allocated by the caller. The size of these is 96 bytes.

Except for the stack frame header and any padding necessary to make the entire frame a multiple of 8 bytes in length, a function need not allocate space for the areas that it does not use. If a function does not call any other functions and does not require any of the other parts of the stack frame, it need not establish a stack frame. Any padding of the frame as a whole shall be within the local variable area; the parameter list area shall immediately follow the stack frame header, and the register save areas shall contain no padding.

Parameter passing

Arguments to called functions are passed in registers. Since all computations must be performed in registers, memory traffic can be eliminated if the caller can compute arguments into registers and pass them in the same registers to the called function, where the called function can then use these arguments for further computation in the same registers. The number of registers implemented in a processor architecture naturally limits the number of arguments that can be passed in this manner.

For LINUX for S/390, the following applies:

- General registers r2 to r6 are used for integer values.
- Floating point registers f0 and f2 are used for floating point values.

If there are more than five integral values or two floating point values, the rest of the arguments are passed on the stack 96 bytes above the initial stack pointer.

Beside these general rules the following rules apply:

- char, short and int are passed in general registers.
- long long are passed in two consecutive general registers if the next available register is smaller than 6. If the upper 32 bits would end in general register 6 then this register is skipped and the whole 64 bit value is passed on the stack.
- Structures with a size of 1, 2 or 4 bytes are passed as integral values.
- Structures with a size of 8 bytes are passed as an integral value in two registers.
- All other structures are passed by reference. If needed, the called function makes a copy of the value.
- Complex numbers are passed as structures.

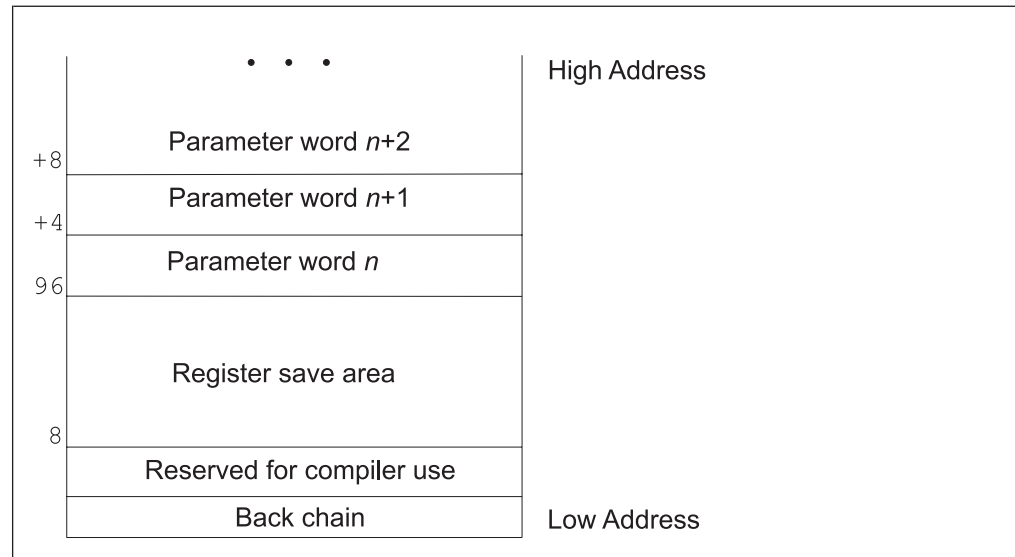


Figure 17. Parameter list area

The following algorithm specifies where argument data is passed for the C language. For this purpose, consider the arguments as ordered from left (first argument) to right, although the order of evaluation of the arguments is unspecified. In this algorithm `fr` contains the number of the next available floating-point register, `gr` contains the number of the next available general purpose register, and `starg` is the address of the next available stack argument word.

INITIALIZE

Set `fr=0`, `gr=2`, and `starg` to the address of parameter word 1.

SCAN If there are no more arguments, terminate. Otherwise, select one of the following depending on the type of the next argument:

DOUBLE_OR_FLOAT:

A `DOUBLE_OR_FLOAT` is one of the following:

- A single length floating point type,
- A double length floating point type.

If `fr>2`, that is, if there are no more available floating-point registers, go to **OTHER**. Otherwise, load the argument value into floating-point register `fr`, set `fr` to `fr+2`, and go to **SCAN**.

SIMPLE_ARG

A `SIMPLE_ARG` is one of the following:

- One of the simple integer types no more than 32 bits wide (`char`, `short`, `int`, `long`, `enum`).
- A pointer to an object of any type.
- A struct or a union of 1, 2 or 4 bytes.
- A struct or union of another size, or a long double, any of which shall be passed as a pointer to the object, or to a copy of the object where necessary to enforce call-by-value semantics. Only if the caller can ascertain that the object is "constant" can it pass a pointer to the object itself.

If `gr>6`, go to **OTHER**. Otherwise load the argument value into general register `gr`, set `gr` to `gr+1`, and go to **SCAN**. Values shorter than 32 bits are sign- or zero-extended (as appropriate) to 32 bits.

DOUBLE_ARG

A **DOUBLE_ARG** is one of type `long long`, or is a struct or a union of size 8 bytes.

If `gr>5` set `gr` to 7 and go to **OTHER**. Load the lower-addressed word of the `long long` into `gr` and the higher-addressed word into `gr+1`, set `gr` to `gr+2`, and go to **SCAN**.

OTHER

Arguments not otherwise handled above are passed in the parameter words of the caller's stack frame. **SIMPLE_ARGS**, as defined above, are considered to have 4-byte size, with simple integer types shorter than 32 bits sign- or zero-extended (as appropriate) to 32 bits. `float` arguments are considered to have 4-byte size; `long long` and `double` arguments are considered to have 8-byte size. Pad the stack by increasing `starg` to satisfy the alignment requirements of the argument, and copy the argument byte for byte to the new stack position. Update `starg` to point to the next byte after this copy, then go to **SCAN**.

The contents of registers and words which are skipped by the above algorithm for alignment purposes (padding) are undefined.

As an example, assume the declarations and the function call shown in Figure 18. The corresponding register allocation and storage would be as shown in Table 3.

```
int i, j, k, l;
long long ll;
double f, g, h;
int m;

x = func(i, j, g, k, l, ll, f, h, m);
```

Figure 18. Parameter passing example

Table 3. Parameter passing example: Register allocation

General purpose registers	Floating-point registers	Stack frame offset
r2: i	f0: g	96: ll
r3: j	f2: f	104: h
r4: k		112: m
r5: l		
r6: -		

In this example `r6` is unused as the `long long` variable `ll` will not fit into a single register.

Variable argument lists

Some otherwise portable C programs depend on the argument passing scheme, implicitly assuming that **1)** all arguments are passed on the stack, and **2)** arguments appear in increasing order on the stack. Programs that make these assumptions have never been portable, but they have worked on many

implementations. However, they do not work on the ESA/390 architecture because some arguments are passed in registers. Portable C programs use the header files `<stdarg.h>` or `<varargs.h>` to deal with variable argument lists on S/390 and other machines as well.

Return values

In general, arguments are returned in registers, as described in Table 4.

Table 4. Registers for return values

Type	Returned in register:
char, short, int and long	general register 2 (r2)
long long	general registers 2 and 3 (r2, r3)
double and float	floating point register 0 (f0)

Structures are returned on the stack, in the segment allocated by the caller. The pointer to the stack is passed as an invisible first argument in register 2.

Functions shall return float or double values in f0, with float values rounded to single precision. Functions shall return values of type int, long, enum, short and char, or a pointer to any type as unsigned or signed integers as appropriate, zero- or sign-extended to 32 bits if necessary, in r2. A structure or union whose size is 1, 2, 4 or 8 bytes shall be returned in r2 and r3 as if it were first stored in an 8-byte aligned memory area and then the lower addressed half were loaded into r2 and the higher into r3. Bits beyond the last member of the structure or union are not defined.

Values of type long long and unsigned long long shall be returned with the lower addressed half in r2 and the higher in r3.

Values of type long double and structures or unions that do not meet the requirements for being returned in registers are returned in a storage buffer allocated by the caller. The address of this buffer is passed as a hidden argument in r2 as if it were the first argument, causing gr in the argument passing algorithm above to be initialized to 3 instead of 2.

Operating system interface

Virtual address space

Processes execute in a 31-bit virtual address space. Memory management translates virtual addresses to physical addresses, hiding physical addressing and letting a process run anywhere in the system's real memory. Processes typically begin with three logical segments, commonly called "text", "data" and "stack". An object file may contain more segments (for example, for debugger use), and a process can also create additional segments for itself with system services.

Note: The term "virtual address" as used in this document refers to a 31-bit address generated by a program, as contrasted with the physical address to which it is mapped.

Page size

Memory is organized into pages, which are the system's smallest units of memory allocation. The hardware page size for the ESA/390 architecture is 4096 bytes.

Virtual address assignments

Processes have the full 31-bit address space available to them.

Figure 19 shows the virtual address configuration on the S/390 architecture. The segments with different properties are typically grouped in different areas of the address space. The loadable segments may begin at zero (0); the exact addresses depend on the executable file format (see Chapter 2, “Object files” on page 39 and Chapter 3, “Program loading and dynamic linking” on page 45). The process’ stack resides at the end of the virtual memory and grows downwards. Processes can control the amount of virtual memory allotted for stack space, as described below.

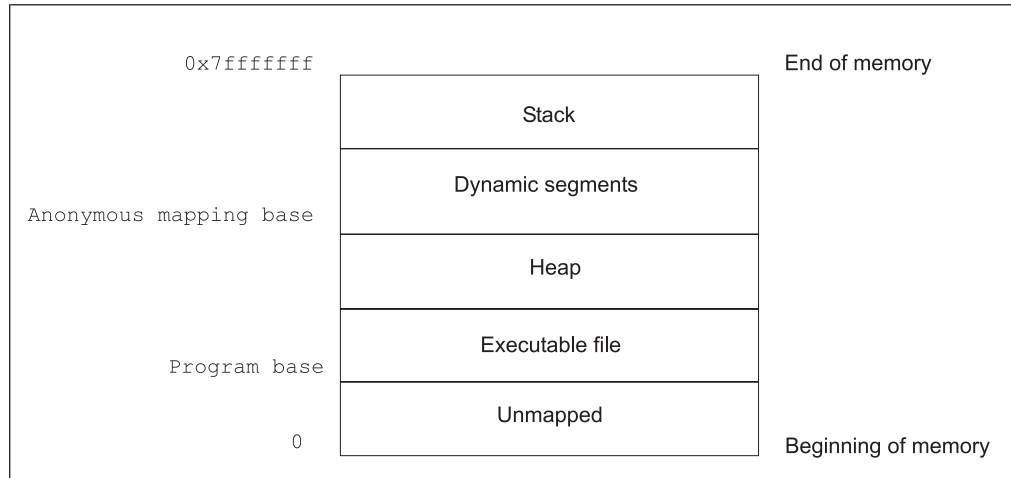


Figure 19. Virtual address configuration

Note: Although application programs may begin at virtual address 0, they conventionally begin above `0x1000` (4 Kbytes), leaving the initial 4 Kbytes with an invalid address mapping. Processes that reference this invalid memory (for example by de-referencing a null pointer) generate an translation exception as described in “Exception interface” on page 18.

Although applications may control their memory assignments, the typical arrangement follows the diagram above. When applications let the system choose addresses for dynamic segments (including shared object segments), the system will prefer addresses in the upper half of the address space (above 1 Gbyte).

Managing the process stack

The section “Process initialization” on page 18 describes the initial stack contents. Stack addresses can change from one system to the next – even from one process execution to the next on a single system. A program, therefore, should not depend on finding its stack at a particular virtual address.

A tunable configuration parameter controls the system maximum stack size. A process can also use `setrlimit` to set its own maximum stack size, up to the system limit. The stack segment is both readable and writable.

Coding guidelines

Operating system facilities, such as `mmap`, allow a process to establish address mappings in two ways. Firstly, the program can let the system choose an address. Secondly, the program can request the system to use an address the program

supplies. The second alternative can cause application portability problems because the requested address might not always be available. Differences in virtual address space can be particularly troublesome between different architectures, but the same problems can arise within a single architecture.

Processes' address spaces typically have three segments that can change size from one execution to the next: the stack (through `setrlimit`); the data segment (through `malloc`); and the dynamic segment area (through `mmap`). Changes in one area may affect the virtual addresses available for another. Consequently an address that is available in one process execution might not be available in the next. Thus a program that used `mmap` to request a mapping at a specific address could appear to work in some environments and fail in others. For this reason programs that want to establish a mapping in their address space should let the system choose the address.

Despite these warnings about requesting specific addresses the facility can be used properly. For example, a multiprocess application might map several files into the address space of each process and build relative pointers among the files' data. This could be done by having each process ask for a certain amount of memory at an address chosen by the system. After each process receives its own private address from the system it would map the desired files into memory at specific addresses within the original area. This collection of mappings could be at different addresses in each process but their relative positions would be fixed. Without the ability to ask for specific addresses, the application could not build shared data structures because the relative positions for files in each process would be unpredictable.

Processor execution modes

Two execution modes exist in the ESA/390 architecture: problem (user) state and supervisor state. Processes run in problem state (the less privileged). The operating system kernel runs in supervisor state. A program executes an supervisor call (`svc`) instruction to change execution modes.

Note that the ABI does not define the implementation of individual system calls. Instead programs shall use the system libraries. Programs with embedded system call or trap instructions do not conform to the ABI.

Exception interface

The ESA/390 exception mechanism allows the processor to change to supervisor state as a result of six different causes: system calls, I/O interrupts, external interrupts, machine checks, restart interruptions or program checks (unusual conditions arising in the execution of instructions).

When exceptions occur:

1. information (such as the address of the next instruction to be executed after control is returned to the original program) is saved,
2. program control passes from user to supervisor level, and
3. software continues execution at an address (the exception vector) predetermined for each exception.

Exceptions may be synchronous or asynchronous. Synchronous exceptions, being caused by instruction execution, can be explicitly generated by a process. The operating system handles an exception either by completing the faulting operation in a manner transparent to the application or by delivering a signal to the application. The correspondence between exceptions and signals is shown in Table 5.

Table 5. Exceptions and Signals

Exception Name	Signal	Examples
Illegal instruction	SIGILL	Illegal or privileged instruction, Invalid instruction form, Optional, unimplemented instruction
Storage access	SIGSEGV	Unmapped instruction or data location access, Storage protection violation
Alignment	SIGBUS	Invalid data item alignment, Invalid memory access
Breakpoint	SIGTRAP	Breakpoint program check
Floating exception	SIGFPE	Floating point overflow or underflow, Floating point divide by zero, Floating point conversion overflow, Other enabled floating point exceptions

The signals that an exception may give rise to are SIGILL, SIGSEGV, SIGBUS, SIGTRAP, and SIGFPE. If one of these signals is generated due to an exception when the signal is blocked, the behavior is undefined.

Process initialization

This section describes the machine state that exec creates for "infant" processes, including argument passing, register usage, and stack frame layout. Programming language systems use this initial program state to establish a standard environment for their application programs. For example, a C program begins executing at a function named main, conventionally declared in the way described in Figure 20:

```
extern int main (int argc, char *argv[ ], char *envp[ ] );
```

Figure 20. Declaration for main

Briefly, argc is a non-negative argument count; argv is an array of argument strings, with argv[argc] == 0, and envp is an array of environment strings, also terminated by a NULL pointer.

Although this section does not describe C program initialization, it gives the information necessary to implement the call to `main` or to the entry point for a program in any other language.

Registers

When a process is first entered (from an `exec` system call), the contents of registers other than those listed below are unspecified. Consequently, a program that requires registers to have specific values must set them explicitly during process initialization. It should not rely on the operating system to set all registers to 0. Following are the registers whose contents are specified:

r15	The initial stack pointer, aligned to a 8-byte boundary and pointing to a stack location that contains the argument count (see “Process stack” for further information about the initial stack layout)
fpc	The floating point control register contains 0, specifying “round to nearest” mode and the disabling of floating-point exceptions

Process stack

Every process has a stack, but the system defines no fixed stack address. Furthermore, a program’s stack address can change from one system to another – even from one process invocation to another. Thus the process initialization code must use the stack address in general purpose register r15. Data in the stack segment at addresses below the stack pointer contain undefined values.

Whereas the argument and environment vectors transmit information from one application program to another, the auxiliary vector conveys information from the operating system to the program. This vector is an array of structures, which are defined in Figure 21.

```
typedef struct {
    int a_type;
    union {
        long a_val;
        void *a_ptr;
        void (*a_fcn)();
    } a_un;
} auxv_t;
```

Figure 21. Auxiliary vector structure

The structures are interpreted according to the `a_type` member, as shown in Table 6.

Table 6. Auxiliary Vector Types, `a_type`

Name	Value	a_un
AT_NULL	0	ignored
AT_IGNORE	1	ignored
AT_EXECD	2	a_val
AT_PHDR	3	a_ptr
AT_PHEMT	4	a_val
AT_PHNUM	5	a_val
AT_PAGESZ	6	a_val

Table 6. Auxiliary Vector Types, *a_type* (continued)

AT_BASE	7	a_ptr
AT_FLAGS	8	a_val
AT_ENTRY	9	a_ptr
AT_NOTELF	10	a_val
AT_UID	11	a_val
AT_EUID	12	a_val
AT_GID	13	a_val
AT_EGID	14	a_val

a_type auxiliary vector types are described in '*Auxiliary Vector Types Description*' below.

Auxiliary Vector Types Description

AT_NULL

The auxiliary vector has no fixed length; so an entry of this type is used to denote the end of the vector. The corresponding value of *a_un* is undefined.

AT_IGNORE

This type indicates the entry has no meaning. The corresponding value of *a_un* is undefined.

AT_EXECD

exec may pass control to an interpreter program. When this happens, the system places either an entry of type AT_EXECD or one of type AT_PHDR in the auxiliary vector. The *a_val* field in the AT_EXECD entry contains a file descriptor for the application program's object file.

AT_PHDR

Under some conditions, the system creates the memory image of the application program before passing control to an interpreter program. When this happens, the *a_ptr* field of the AT_PHDR entry tells the interpreter where to find the program header table in the memory image. If the AT_PHDR entry is present, entries of types AT_PHEM, AT_PHNUM and AT_ENTRY must also be present. See the section Chapter 3, "Program loading and dynamic linking" on page 45 for more information about the program header table.

AT_PHEM

The *a_val* field of this entry holds the size, in bytes, of one entry in the program header table at which the AT_PHDR entry points.

AT_PHNUM

The *a_val* field of this entry holds the number of entries in the program header table at which the AT_PHDR entry points.

AT_PAGESZ

If present this entry's *a_val* field gives the system page size in bytes. The same information is also available through *sysconf*.

AT_BASE

The *a_ptr* member of this entry holds the base address at which the interpreter program was loaded into memory.

AT_FLAGS

If present, the `a_val` field of this entry holds 1-bit flags. Undefined bits are set to zero.

AT_ENTRY

The `a_ptr` field of this entry holds the entry point of the application program to which the interpreter program should transfer control.

AT_NOTELF

The `a_val` field of this entry is non-zero if the program is in another format than ELF, for example in the old COFF format.

AT_UID

The `a_ptr` field of this entry holds the real user id of the process.

AT_EUID

The `a_ptr` field of this entry holds the effective user id of the process.

AT_GID

The `a_ptr` field of this entry holds the real group id of the process.

AT_EGID

The `a_ptr` field of this entry holds the effective group id of the process.

Other auxiliary vector types are reserved. No flags are currently defined for `AT_FLAGS` on the S/390 architecture.

When a process receives control, its stack holds the arguments, environment, and auxiliary vector from `exec`. Argument strings, environment strings, and the auxiliary information appear in no specific order within the information block; the system makes no guarantees about their relative arrangement. The system may also leave an unspecified amount of memory between the null auxiliary vector entry and the beginning of the information block. A sample initial stack is shown in Figure 22 on page 22.

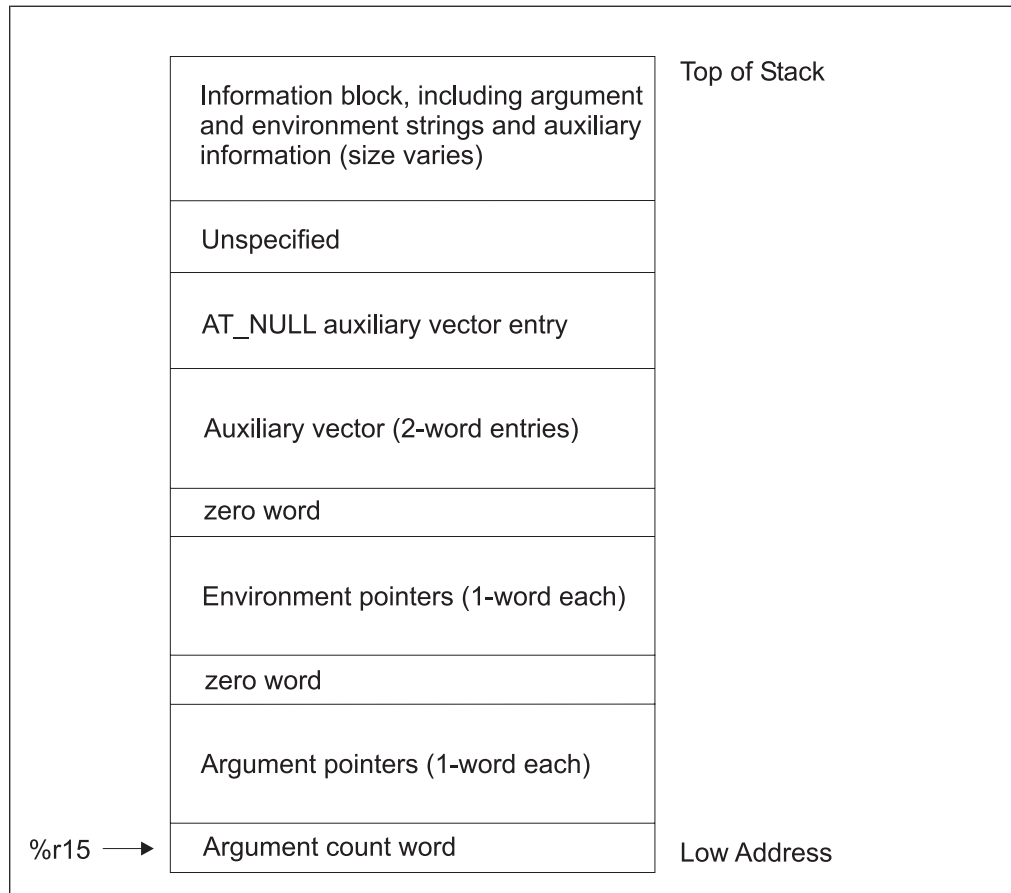


Figure 22. Initial Process Stack

Coding examples

This section describes example code sequences for fundamental operations such as calling functions, accessing static objects, and transferring control from one part of a program to another. Previous sections discussed how a program may use the machine or the operating system, and they specified what a program may and may not assume about the execution environment. Unlike previous material, the information in this section illustrates how operations may be done, not how they must be done.

As before, examples use the ANSI C language. Other programming languages may use the same conventions displayed below, but failure to do so does not prevent a program from conforming to the ABI. Two main object code models are available:

Absolute code

Instructions can hold absolute addresses under this model. To execute properly, the program must be loaded at a specific virtual address, making the program's absolute addresses coincide with the process' virtual addresses.

Position-independent code

Instructions under this model hold relative addresses, not absolute addresses. Consequently, the code is not tied to a specific load address, allowing it to execute properly at various positions in virtual memory.

The following sections describe the differences between these models. When different, code sequences for the models appear together for easier comparison.

Note: The examples below show code fragments with various simplifications. They are intended to explain addressing modes, not to show optimal code sequences or to reproduce compiler output.

Code model overview

When the system creates a process image, the executable file portion of the process has fixed addresses and the system chooses shared object library virtual addresses to avoid conflicts with other segments in the process. To maximize text sharing, shared objects conventionally use position-independent code, in which instructions contain no absolute addresses. Shared object text segments can be loaded at various virtual addresses without having to change the segment images. Thus multiple processes can share a single shared object text segment, even if the segment resides at a different virtual address in each process.

Position-independent code relies on two techniques:

- Control transfer instructions hold addresses relative to the Current Instruction Address (CIA), or use registers that hold the transfer address. A CIA-relative branch computes its destination address in terms of the CIA, not relative to any absolute address.
- When the program requires an absolute address, it computes the desired value. Instead of embedding absolute addresses in instructions (in the text segment), the compiler generates code to calculate an absolute address (in a register or in the stack or data segment) during execution.

Because the ESA/390 architecture provides CIA-relative branch instructions and also branch instructions using registers that hold the transfer address, compilers can satisfy the first condition easily.

A Global Offset Table (GOT), provides information for address calculation. Position-independent object files (executable and shared object files) have a table in their data segment that holds addresses. When the system creates the memory image for an object file, the table entries are relocated to reflect the absolute virtual address as assigned for an individual process. Because data segments are private for each process, the table entries can change – unlike text segments, which multiple processes share.

Two position-independent models give programs a choice between more efficient code with some size restrictions and less efficient code without those restrictions. Because of the processor architecture, a GOT with no more than 1024 entries (4096 bytes) is more efficient than a larger one. Programs that need more entries must use the larger, more general code. In the following sections, the term "small model position-independent code" is used to refer to code that assumes the smaller GOT, and "large model position-independent code" is used to refer to the general code.

Function prolog and epilog

This section describes the prolog and epilog code of functions. A function's prolog establishes a stack frame, if necessary, and may save any nonvolatile registers it uses. A function's epilog generally restores registers that were saved in the prolog code, restores the previous stack frame, and returns to the caller.

Prolog

The prolog of a function has to save the state of the calling function and set up the base register for the code of the function body. The following is in general done by the function prolog:

- Save all registers used within the function which the calling function assumes to be non-volatile.
- Set up the base register for the literal pool.
- Allocate stack space by decrementing the stack pointer.
- Set up the dynamic chain by storing the old stack pointer value at stack location zero if the "back chain" is implemented.
- Set up the GOT pointer if the compiler is generating position independent code. (A function that is position independent will probably want to load a pointer to the GOT into a nonvolatile register. This may be omitted if the function makes no external data references. If external data references are only made within conditional code, loading the GOT pointer may be deferred until it is known to be needed.)
- Set up the frame pointer if the function allocates stack space dynamically (with `alloca`).

The compiler tries to do as little as possible of the above; the ideal case is to do nothing at all (for a leaf function without symbolic references).

Epilog

The epilog of a function restores the registers saved in the prolog (which include the stack pointer) and branches to the return address.

Prolog and epilog example

```
.LC18:
.string "hello, world\n"
.align 4
.globl main
.type main,@function

main:
                                # Prolog
    STM    11,15,44(15)         # Save callers registers
    BRAS   13,.LTN0_0           # Set up literal pool and branch over
.LT0_0:
.LC21:
    .long   .LC18
.LC22:
    .long   printf
.LTN0_0:
    LR      1,15                # Load stack pointer in GPR 1
    AHI     15,-96              # Allocate stack space
    ST      1,0(15)             # Save backchain
                                # Prolog end

    L       2,.LC21-.LT0_0(13)
    L       1,.LC22-.LT0_0(13)
    BASR    14,1
    SLR     2,2

                                # Epilog
    L       4,152(15)           # Load return address
    LM      11,15,140(15)       # Restore registers
    BR      4                   # Branch back to caller
                                # Epilog end
```

Figure 23. Prolog and epilog example

Profiling

This section shows a way of providing profiling (entry counting) on S/390 systems. An ABI-conforming system is not required to provide profiling; however if it does this is one possible (not required) implementation.

If a function is to be profiled it has to call the `_mcount` routine after the function prolog. This routine has a special linkage. It gets an address in register 1 and returns without having changed any register. The address is a pointer to a word-aligned one-word static data area, initialized to zero, in which the `_mcount` routine is to maintain a count of the number of times the function is called.

For example Figure 24 on page 26 shows how the code after the function prolog may look.

```

        STM    7,15,28(15)      # Save callers registers
        BRAS   13,.LTN0_0      # Jump to function prolog
.LTN0_0:
.LC3:    .long  _mcount         # Literal pool entry for _mcount
.LC4:    .long  .LP0            # Literal pool entry for profile counter
.LTN0_0:
        LR     1,15             # Stack pointer
        AHI    15,-96           # Allocate new
        ST     1,0(15)          # Save backchain
        LR     11,15            # Local stack pointer
        .data
        .align 4
.LP0:    .long  0               # Profile counter
        .text

        # Function profiler
        ST     14,4(15)         # Preserve r14
        L      14,.LC3-.LT0_0(13) # Load address of _mcount
        L      1,.LC4-.LT0_0(13) # Load address of profile counter
        BASR   14,14            # Branch to _mcount
        L      14,4(15)         # Restore r14

```

Figure 24. Code for profiling

Data objects

This section describes only objects with static storage duration. It excludes stack-resident objects because programs always compute their virtual addresses relative to the stack or frame pointers.

Because S/390 instructions cannot hold 31-bit addresses directly, a program has to build an address in a register and access memory through that register. In order to do so a function normally has a literal pool that holds the addresses of data objects used by the function. Register 13 is set up in the function prolog to point to the start of this literal pool.

Position-independent code cannot contain absolute addresses. In order to access a local symbol the literal pool contains the (signed) offset of the symbol relative to the start of the pool. Combining the offset loaded from the literal pool with the address in register 13 gives the absolute address of the local symbol. In the case of a global symbol the address of the symbol has to be loaded from the Global Offset Table. The offset in the GOT can either be contained in the instruction itself or in the literal pool. See Figure 25 on page 27 for an example.

Figure 25 through Figure 27 show sample assembly language equivalents to C language code for absolute and position-independent compilations. It is assumed that all shared objects are compiled as position-independent and only executable modules may have absolute addresses. The code in the figures contains many redundant operations as it is only intended to show how each C statement could have been compiled independently of its context. The function prolog is not shown, and it is assumed that it has loaded the address of the literal pool in register 13.

C	S/390 machine instructions (Assembler)
extern int src; extern int dst; extern int *ptr; dst = src;	<pre> # Literal pool .LT0: .LC1: .long dst .LC2: .long src # Code L 2,.LC1-.LT0(13) L 1,.LC2-.LT0(13) MVC 0(4,2),0(1) </pre>
ptr = &dst;	<pre> # Literal pool .LT0: .LC1: .long ptr .LC2: .long dst # Code L 1,.LC1-.LT0(13) MVC 0(4,1),.LC2-.LT0(13) </pre>
*ptr = src;	<pre> # Literal pool .LT0: .LC1: .long ptr .LC2: .long src # Code L 1,.LC1-.LT0(13) L 2,.LC2-.LT0(13) L 3,0(1) MVC 0(4,3),0(2) </pre>

Figure 25. Absolute addressing

C	S/390 machine instructions (Assembler)
extern int src; extern int dst; extern int *ptr; dst = src;	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC1-.LT0(13) LA 12,0(12,13) L 2,dst@GOT(12) L 1,src@GOT(12) MVC 0(4,2),0(1) </pre>
ptr = &dst;	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC1-.LT0(13) LA 12,0(12,13) L 1,ptr@GOT(12) L 2,dst@GOT(12) ST 2,0(1) </pre>
*ptr = src;	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC1-.LT0(13) LA 12,0(12,13) L 1,ptr@GOT(12) L 2,src@GOT(12) L 3,0(1) MVC 0(4,3),0(2) </pre>

Figure 26. Small model position-independent addressing

C	S/390 Assembler
extern int src; extern int dst; extern int *ptr; dst = src;	<pre> # Literal pool .LT0: .LC1: .long dst@GOT .LC2: .long src@GOT .LC3: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC3-.LT0(13) LA 12,0(12,13) L 2,.LC1-.LT0(13) L 1,.LC2-.LT0(13) L 2,0(2,12) L 1,0(1,12) MVC 0(4,2),0(1) </pre>
ptr = &dst;	<pre> # Literal pool .LT0: .LC1: .long ptr@GOT .LC2: .long dst@GOT .LC3: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC3-.LT0(13) LA 12,0(12,13) L 2,.LC1-.LT0(13) L 1,.LC2-.LT0(13) L 2,0(2,12) L 1,0(1,12) ST 1,0(2) </pre>
*ptr = src;	<pre> # Literal pool .LT0: .LC1: .long ptr@GOT .LC2: .long src@GOT .LC3: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC1-.LT0(13) LA 12,0(12,13) L 1,.LC1-.LT0(13) L 2,.LC2-.LT0(13) L 1,0(1,12) L 2,0(2,12) L 3,0(1) MVC 0(4,3),0(2) </pre>

Figure 27. Large model position-independent addressing

Function calls

Programs can use the ESA/390 BRAS instruction to make direct function calls. A BRAS instruction has a self-relative branch displacement that can reach 64 Kbytes in either direction. Hence the use of the BRAS instruction is limited to very rare cases. The usual method of calling a function is to load the address in a register and use the BASR instruction for the call. Register 14 is used as the first operand of BASR to hold the return address as shown in Figure 28 on page 30.

The called function may be in the same module (executable or shared object) as the caller, or it may be in a different module. In the former case, if the called function

is not in a shared object, the linkage editor resolves the symbol. In all other cases the linkage editor cannot directly resolve the symbol. Instead the linkage editor generates "glue" code and resolves the symbol to point to the glue code. The dynamic linker will provide the real address of the function in the Global Offset Table. The glue code loads this address and branches to the function itself. See "Procedure Linkage Table" on page 50 for more details.

C	S/390 machine instructions (Assembler)
extern void func(); extern void (*ptr)(); ptr = func;	<pre> # Literal pool .LT0: .LC1: .long ptr .LC2: .long func # Code L 1,.LC1-.LT0(13) MVC 0(4,1),.LC2-.LT0(13) </pre>
func();	<pre> # Literal pool .LT0: .LC1: .long func # Code L 1,.LC1-.LT0(13) BASR 14,1 </pre>
(*ptr) ();	<pre> # Literal pool .LT0: .LC1: .long ptr # Code L 1,.LC1-.LT0(13) L 1,0(1) BASR 14,1 </pre>

Figure 28. Absolute direct function call

C	S/390 machine instructions (Assembler)
extern void func(); extern void (*ptr)(); ptr = func;	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12, .LC1-.LT0(13) LA 12, 0(12,13) L 1, ptr@GOT(12) L 2, func@GOT(12) ST 2, 0(1) </pre>
func();	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_-.LT0 .LC2: .long func@PLT-.LT0 # Code L 12, .LC1-.LT0(13) LA 12, 0(12,13) L 1, .LC2-.LT0(13) BASR 14, 0(1,13) </pre>
(*ptr) ();	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12, .LC1-.LT0(13) LA 12, 0(12,13) L 1, ptr@GOT(12) L 2, 0(1) BASR 14, 2 </pre>

Figure 29. Small model position-independent direct function call

C	S/390 machine instructions (Assembler)
extern void func(); extern void (*ptr)(); ptr = func;	<pre> # Literal pool .LT0: .LC1: .long ptr@GOT .LC2: .long func@GOT .LC3: .long _GLOBAL_OFFSET_TABLE_- .LT0 # Code L 12,.LC3-.LT0(13) LA 12,0(12,13) L 2,.LC1-.LT0(13) L 1,.LC2-.LT0(13) L 2,0(2,12) L 1,0(1,12) ST 1,0(2) </pre>
func();	<pre> # Literal pool .LT0: .LC1: .long _GLOBAL_OFFSET_TABLE_- .LT0 .LC2: .long func@PLT-.LT0 # Code L 12,.LC1-.LT0(13) LA 12,0(12,13) L 1,.LC2-.LT0(13) BAS 14,0(1,13) </pre>
(*ptr) ();	<pre> # Literal pool .LT0: .LC1: .long ptr@GOT .LC2: .long _GLOBAL_OFFSET_TABLE_- .LT0 # Code L 12,.LC2-.LT0(13) LA 12,0(12,13) L 1,.LC1-.LT0(13) L 1,0(1,12) L 2,0(1) BASR 14,2 </pre>

Figure 30. Large model position-independent direct function call

[illegible]

Figure 31. Absolute indirect function call

[illegible]

Figure 32. Small model position-independent indirect function call

C	S/390 machine instructions (Assembler)
<pre>extern void func(); extern void (*ptr) (); ptr = func; (*ptr) ();</pre>	<pre> # Literal pool .LT0: .LC1: .long ptr@GOT .LC2: .long func@GOT .LC3: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC3-.LT0(13) LA 12,0(12,13) L 2,.LC1-.LT0(13) L 1,.LC2-.LT0(13) L 2,0(2,12) L 1,0(1,12) ST 1,0(2) # Literal pool .LT0: .LC1: .long ptr@GOT .LC2: .long _GLOBAL_OFFSET_TABLE_-.LT0 # Code L 12,.LC2-.LT0(13) LA 12,0(12,13) L 1,.LC1-.LT0(13) L 1,0(1,12) L 2,0(1) BASR 14,2</pre>

Figure 33. Large model position-independent indirect function call

Branching

Programs use branch instructions to control their execution flow. The ESA/390 architecture has a variety of branch instructions. The most commonly used of these performs a self-relative jump with a 128-Kbyte range (up to 64 Kbytes in either direction).

C	S/390 machine instructions (Assembler)
<pre>label: ... goto label;</pre>	<pre>.L01: ... BRC 15,.L01</pre>

Figure 34. Branch instruction

C language switch statements provide multi-way selection. When the case labels of a switch statement satisfy grouping constraints the compiler implements the selection with an address table. The following examples use several simplifying conventions to hide irrelevant details:

1. The selection expression resides in register 2.
2. The case label constants begin at zero.
3. The case labels, the default, and the address table use assembly names `.Lcasei`, `.Ldef` and `.Ltab` respectively.

C	S/390 machine instructions (Assembler)
switch(j) { case 0: ... case 1: ... case 3: ... default: ... }	<pre> # Literal pool .LT0: .LC1: .long .Ltab # Code LHI 1,3 CLR 2,1 BRC 2,.Ldef SLL 2,2 A 2,.LC1-.LT0(13) L 1,0(2) BR 1 .Ltab: .long .Lcase0 .long .Lcase1 .long .Ldef .long .Lcase3 </pre>

Figure 35. Absolute switch code

C	S/390 machine instructions (Assembler)
switch(j) { case 0: ... case 1: ... case 3: ... default: ... }	<pre> # Literal pool .LT0: .LC1: .long .Ltab-.LT0 # Code LHI 1,3 CLR 2,1 BRC 2,.Ldef SLL 2,2 L 1,.LC1-.LT0(13) LA 1,0(1,13) L 2,0(1,2) LA 2,0(2,13) BR 2 .Ltab: .long .Lcase0-.LT0 .long .Lcase1-.LT0 .long .Ldef-.LT0 .long .Lcase3-.LT0 </pre>

Figure 36. Position-independent switch code, all models

Dynamic stack space allocation

The GNU C compiler, and most recent compilers, support dynamic stack space allocation via `alloca`.

Figure 37 shows the stack frame before and after dynamic stack allocation. The local variables area is used for storage of function data, such as local variables, whose sizes are known to the compiler. This area is allocated at function entry and does not change in size or position during the function's activation.

The parameter list area holds "overflow" arguments passed in calls to other functions. (See the `OTHER` label in "Parameter passing" on page 12.) Its size is also known to the compiler and can be allocated along with the fixed frame area at function entry. However, the standard calling sequence requires that the parameter list area begin at a fixed offset (96) from the stack pointer, so this area must move when dynamic stack allocation occurs.

Data in the parameter list area are naturally addressed at constant offsets from the stack pointer. However, in the presence of dynamic stack allocation, the offsets from the stack pointer to the data in the local variables area are not constant. To provide addressability a frame pointer is established to locate the local variables area consistently throughout the function's activation.

Dynamic stack allocation is accomplished by "opening" the stack just above the parameter list area. The following steps show the process in detail:

1. After a new stack frame is acquired, and before the first dynamic space allocation, a new register, the frame pointer or FP, is set to the value of the stack pointer. The frame pointer is used for references to the function's local, non-static variables. The frame pointer does not change during the execution of a function, even though the stack pointer may change as a result of dynamic allocation.
2. The amount of dynamic space to be allocated is rounded up to a multiple of 8 bytes, so that 8-byte stack alignment is maintained.
3. The stack pointer is decreased by the rounded byte count, and the address of the previous stack frame (the back chain) may be stored at the word addressed by the new stack pointer. The back chain is not necessary to restore from this allocation at the end of the function since the frame pointer can be used to restore the stack pointer.

Figure 37 on page 37 is a snapshot of the stack layout after the prolog code has dynamically extended the stack frame.

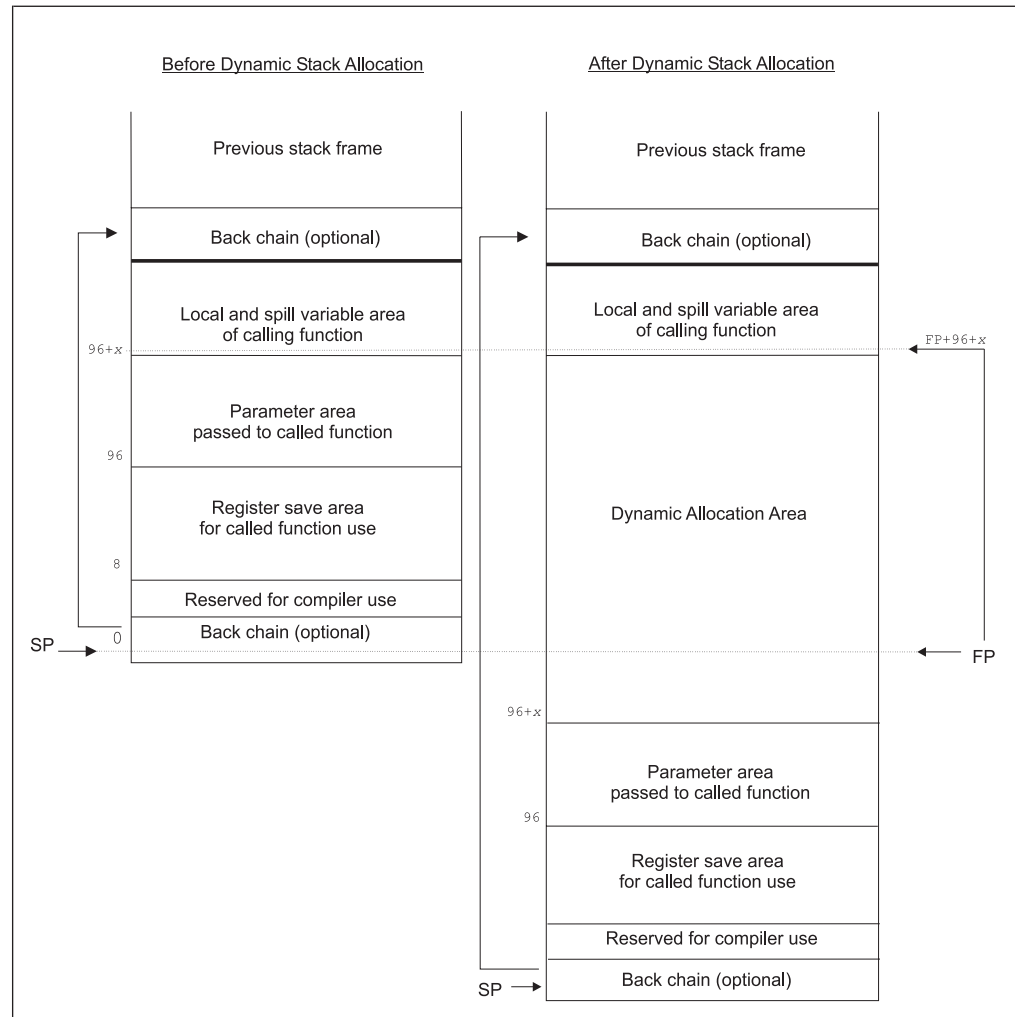


Figure 37. Dynamic Stack Space Allocation

The above process can be repeated as many times as desired within a single function activation. When it is time to return, the stack pointer is set to the value of the back chain, thereby removing all dynamically allocated stack space along with the rest of the stack frame. Naturally, a program must not reference the dynamically allocated stack area after it has been freed.

Even in the presence of signals, the above dynamic allocation scheme is "safe." If a signal interrupts allocation, one of three things can happen:

- The signal handler can return. The process then resumes the dynamic allocation from the point of interruption.
- The signal handler can execute a non-local goto or a jump. This resets the process to a new context in a previous stack frame, automatically discarding the dynamic allocation.
- The process can terminate.

Regardless of when the signal arrives during dynamic allocation, the result is a consistent (though possibly dead) process.

DWARF definition

This section defines the "Debug with Arbitrary Record Format" (DWARF) debugging format for the S/390 processor family. The S/390 ABI does not define a debug format. However, all systems that do implement DWARF shall use the following definitions.

DWARF is a specification developed for symbolic source-level debugging. The debugging information format does not favor the design of any compiler or debugger.

The DWARF definition requires some machine-specific definitions. The register number mapping is specified for the S/390 processors in Table 7.

Table 7. DWARF register number mapping

DWARF number	S/390 register
0-15	gpr0-gpr15
16	fpr0
17	fpr2
18	fpr4
19	fpr6
20	fpr1
21	fpr3
22	fpr5
23	fpr7
24	fpr8
25	fpr10
26	fpr12
27	fpr14
28	fpr9
29	fpr11
30	fpr13
31	fpr15
32-47	cr0-cr15
48-63	ar0-ar15
64	PSW mask
65	PSW address

Chapter 2. Object files

ELF Header	39	Symbol Table	40
Machine Information	39	Symbol Values	40
Sections	39	Relocation	40
Special Sections	39	Relocation Types	40

This section describes the Executable and Linking Format (ELF).

ELF Header

Machine Information

For file identification in `e_ident` the S/390 processor family requires the values shown in Table 8.

Table 8. Auxiliary Vector Types Description

Position	Value	Comments
<code>e_ident[EI_CLASS]</code>	ELFCLASS32	For all 32bit implementations
<code>e_ident[EI_DATA]</code>	ELFDATA32MSB	For all Big-Endian implementations

The ELF header's `e_flags` field holds bit flags associated with the file. Since the S/390 processor family defines no flags, this member contains zero.

Processor identification resides in the ELF header's `e_machine` field and must have the value 22, defined as the name `EM_S390`.

Sections

Special Sections

Various sections hold program and control information. The sections listed in Table 9 are used by the system and have the types and attributes shown.

Table 9. Special Sections

Name	Type	Attributes
<code>.got</code>	SHT_PROGBITS	SHF_ALLOC + SHF_WRITE
<code>.plt</code>	SHT_PROGBITS	SHF_ALLOC + SHF_WRITE + SHF_EXECINSTR

Special sections are described in Table 10.

Table 10. Special Sections Description

Name	Description
<code>.got</code>	This section holds the Global Offset Table, or GOT. See "Coding examples" on page 22 and "Global Offset Table" on page 49 for more information.
<code>.plt</code>	This section holds the Procedure Linkage Table, or PLT. See "Procedure Linkage Table" on page 50 for more information.

Symbol Table

Symbol Values

If an executable file contains a reference to a function defined in one of its associated shared objects, the symbol table section for the file will contain an entry for that symbol. The `st_shndx` field of that symbol table entry contains `SHN_UNDEF`. This informs the dynamic linker that the symbol definition for that function is not contained in the executable file itself. If that symbol has been allocated a Procedure Linkage Table entry in the executable file, and the `st_value` field for that symbol table entry is nonzero, the value is the virtual address of the first instruction of that PLT entry. Otherwise the `st_value` field contains zero. This PLT entry address is used by the dynamic linker in resolving references to the address of the function. See “Function Addresses” on page 50 for details.

Relocation

Relocation Types

Relocation entries describe how to alter the instruction and data relocation fields shown in Figure 38 (bit numbers appear in the lower box corners; byte numbers appear in the upper left box corners).

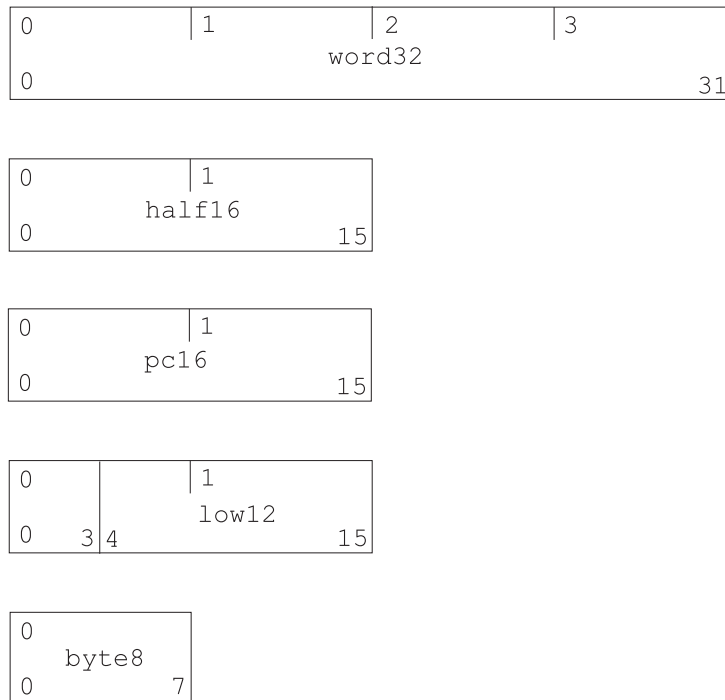


Figure 38. Relocation Fields

word32 This specifies a 32-bit field occupying 4 bytes, the alignment of which is 4 bytes unless otherwise specified.

half16 This specifies a 16-bit field occupying 2 bytes with 2-byte alignment (for example, the immediate field of an “Add Halfword Immediate” instruction).

pc16 This specifies a 16-bit field occupying 2 bytes with 2-byte alignment. The

signed value in this field is shifted to the left by 1 before it is used as a program counter relative displacement (for example, the immediate field of an "Branch Relative" instruction).

low12 This specifies a 12-bit field contained within a halfword with a 2-byte alignment. The 12 bit unsigned value is the displacement of a memory reference.

byte8 This specifies a 8-bit field with a 1-byte alignment.

Calculations in Table 11 on page 42 assume the actions are transforming a relocatable file into either an executable or a shared object file. Conceptually, the linkage editor merges one or more relocatable files to form the output. It first determines how to combine and locate the input files, next it updates the symbol values, and then it performs relocations.

Relocations applied to executable or shared object files are similar and accomplish the same result. The following notations are used in Table 11 on page 42:

- A** Represents the addend used to compute the value of the relocatable field.
- B** Represents the base address at which a shared object has been loaded into memory during execution. Generally, a shared object file is built with a 0 base virtual address, but the execution address will be different.
- G** Represents the section offset or address of the Global Offset Table. See "Coding examples" on page 22 and "Global Offset Table" on page 49 for more information.
- L** Represents the section offset or address of the Procedure Linkage Table entry for a symbol. A PLT entry redirects a function call to the proper destination. The linkage editor builds the initial PLT. See "Procedure Linkage Table" on page 50 for more information.
- O** Represents the offset into the GOT at which the address of the relocation entry's symbol will reside during execution. See "Coding examples" on page 22 and "Global Offset Table" on page 49 for more information.
- P** Represents the place (section offset or address) of the storage unit being relocated (computed using `r_offset`).
- R** Represents the offset of the symbol within the section in which the symbol is defined (its section-relative address).
- S** Represents the value of the symbol whose index resides in the relocation entry.

Relocation entries apply to bytes, halfwords or words. In either case, the `r_offset` value designates the offset or virtual address of the first byte of the affected storage unit. The relocation type specifies which bits to change and how to calculate their values. The S/390 family uses only the `Elf32_Rela` relocation entries with explicit addends. For the relocation entries, the `r_addend` field serves as the relocation addend. In all cases, the offset, addend, and the computed result use the byte order specified in the ELF header.

The following general rules apply to the interpretation of the relocation types in Table 11 on page 42:

- "+" and "-" denote 32-bit modulus addition and subtraction, respectively. ">>" denotes arithmetic right-shifting (shifting with sign copying) of the value of the left operand by the number of bits given by the right operand.

- For relocation type `half16`, the upper 16 bits of the value computed must be all ones or all zeroes. For relocation type `pc16`, the upper 15 bits of the value computed must be all ones or all zeroes and the lowest bit must be zero. For relocation type `low12`, the upper 20 bits of the value computed must all be zero and for relocation type `byte8`, the upper 24 bits of the value computed must all be zero.
- Reference in a calculation to the value `G` or `0` implicitly creates a GOT entry for the indicated symbol and a reference to `L` implicitly creates a PLT entry.

Table 11. Relocation Types

Name	Value	Field	Calculation
<code>R_390_NONE</code>	0	none	none
<code>R_390_8</code>	1	<code>byte8</code>	$S + A$
<code>R_390_12</code>	2	<code>low12</code>	$S + A$
<code>R_390_16</code>	3	<code>half16</code>	$S + A$
<code>R_390_32</code>	4	<code>word32</code>	$S + A$
<code>R_390_PC32</code>	5	<code>word32</code>	$S + A - P$
<code>R_390_GOT12</code>	6	<code>low12</code>	$0 + A$
<code>R_390_GOT32</code>	7	<code>word32</code>	$0 + A$
<code>R_390_PLT32</code>	8	<code>word32</code>	$L + A$
<code>R_390_COPY</code>	9	none	(see below)
<code>R_390_GLOB_DAT</code>	10	<code>word32</code>	$S + A$ (see below)
<code>R_390_JMP_SLOT</code>	11	none	(see below)
<code>R_390_RELATIVE</code>	12	<code>word32</code>	$B + A$ (see below)
<code>R_390_GOTOFF</code>	13	<code>word32</code>	$S + A - G$
<code>R_390_GOTPC</code>	14	<code>word32</code>	$G + A - P$
<code>R_390_GOT16</code>	15	<code>half16</code>	$0 + A$
<code>R_390_PC16</code>	16	<code>half16</code>	$S + A - P$
<code>R_390_PC16DBL</code>	17	<code>pc16</code>	$(S + A - P) \gg 1$
<code>R_390_PLT16DBL</code>	18	<code>pc16</code>	$(L + A - P) \gg 1$

Table 12. Relocation type descriptions

Name	Description
<code>R_390_COPY</code>	The linkage editor creates this relocation type for dynamic linking. Its offset member refers to a location in a writable segment. The symbol table index specifies a symbol that should exist both in the current object file and in a shared object. During execution, the dynamic linker copies data associated with the shared object's symbol to the location specified by the offset.
<code>R_390_GLOB_DAT</code>	This relocation type resembles <code>R_390_32</code> , except that it sets a Global Offset Table entry to the address of the specified symbol. This special relocation type allows one to determine the correspondence between symbols and GOT entries.

Table 12. Relocation type descriptions (continued)

R_390_JMP_SLOT	The linkage editor creates this relocation type for dynamic linking. Its offset member gives the location of a Procedure Linkage Table entry. The dynamic linker modifies the PLT entry to transfer control to the designated symbol's address (see "Procedure Linkage Table" on page 50).
R_390_RELATIVE	The linkage editor creates this relocation type for dynamic linking. Its offset member gives a location within a shared object that contains a value representing a relative address. The dynamic linker computes the corresponding virtual address by adding the virtual address at which the shared object was loaded to the relative address. Relocation entries for this type must specify 0 for the symbol table index.

Chapter 3. Program loading and dynamic linking

Program Loading	45	Global Offset Table	49
Dynamic Linking	49	Function Addresses.	50
Dynamic Section.	49	Procedure Linkage Table	50

This section describes how the Executable and Linking Format (ELF) is used in the construction and execution of programs.

Program Loading

As the system creates or augments a process image, it logically copies a file's segment to a virtual memory segment. When – and if – the system physically reads the file depends on the program's execution behavior, on the system load, and so on. A process does not require a physical page until it references the logical page during execution, and processes commonly leave many pages unreferenced. Therefore, if physical reads can be delayed they can frequently be dispensed with, improving system performance. To obtain this efficiency in practice, executable and shared object files must have segment images of which the offsets and virtual addresses are congruent modulo the page size.

Virtual addresses and file offsets for the S/390 processor family segments are congruent modulo 4 Kbytes. The value of the `p_align` field of each program header in a shared object file must be 0x1000 (4 Kbytes). Figure 39 is an example of an executable file assuming an executable program linked with a base address of 0x00400000 (4 Mbytes).

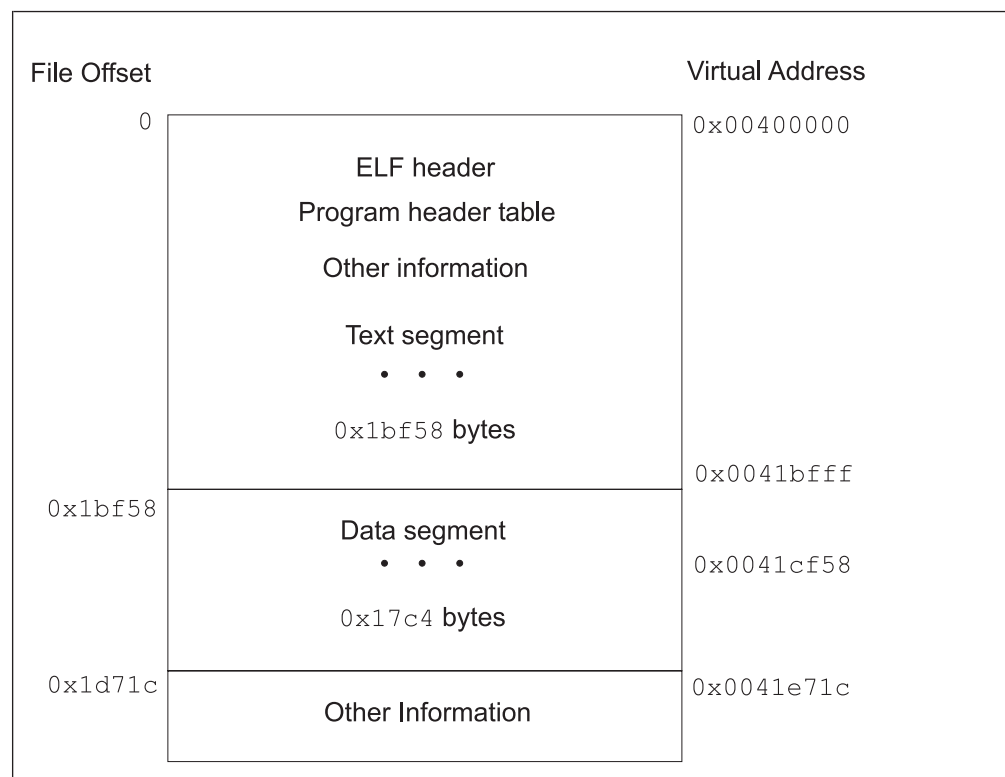


Figure 39. Executable File Example

Table 13. Program Header Segments

Member	Text	Data
p_type	PT_LOAD	PT_LOAD
p_offset	0x0	0x1bf58
p_vaddr	0x400000	0x41cf58
p_paddr	unspecified	unspecified
p_filesz	0x1bf58	0x17c4
p_memsz	0x1bf58	0x2578
p_flags	PF_R+PF_X	PF_R+PF_W
p_align	0x1000	0x1000

Although the file offsets and virtual addresses are congruent modulo 4 Kbytes for both text and data, up to four file pages can hold impure text or data (depending on page size and file system block size).

- The first text page contains the ELF header, the program header table, and other information.
- The last text page may hold a copy of the beginning of data.
- The first data page may have a copy of the end of text.
- The last data page may contain file information not relevant to the running process.

Logically, the system enforces memory permissions as if each segment were complete and separate; segment addresses are adjusted to ensure that each logical page in the address space has a single set of permissions. In the example in Table 13 the file region holding the end of text and the beginning of data is mapped twice; at one virtual address for text and at a different virtual address for data.

The end of the data segment requires special handling for uninitialized data, which the system defines to begin with zero values. Thus if the last data page of a file includes information beyond the logical memory page, the extraneous data must be set to zero by the loader, rather than to the unknown contents of the executable file. ‘Impurities’ in the other three segments are not logically part of the process image, and whether the system clears them is unspecified. The memory image for the program in Table 13 is presented in Figure 40.

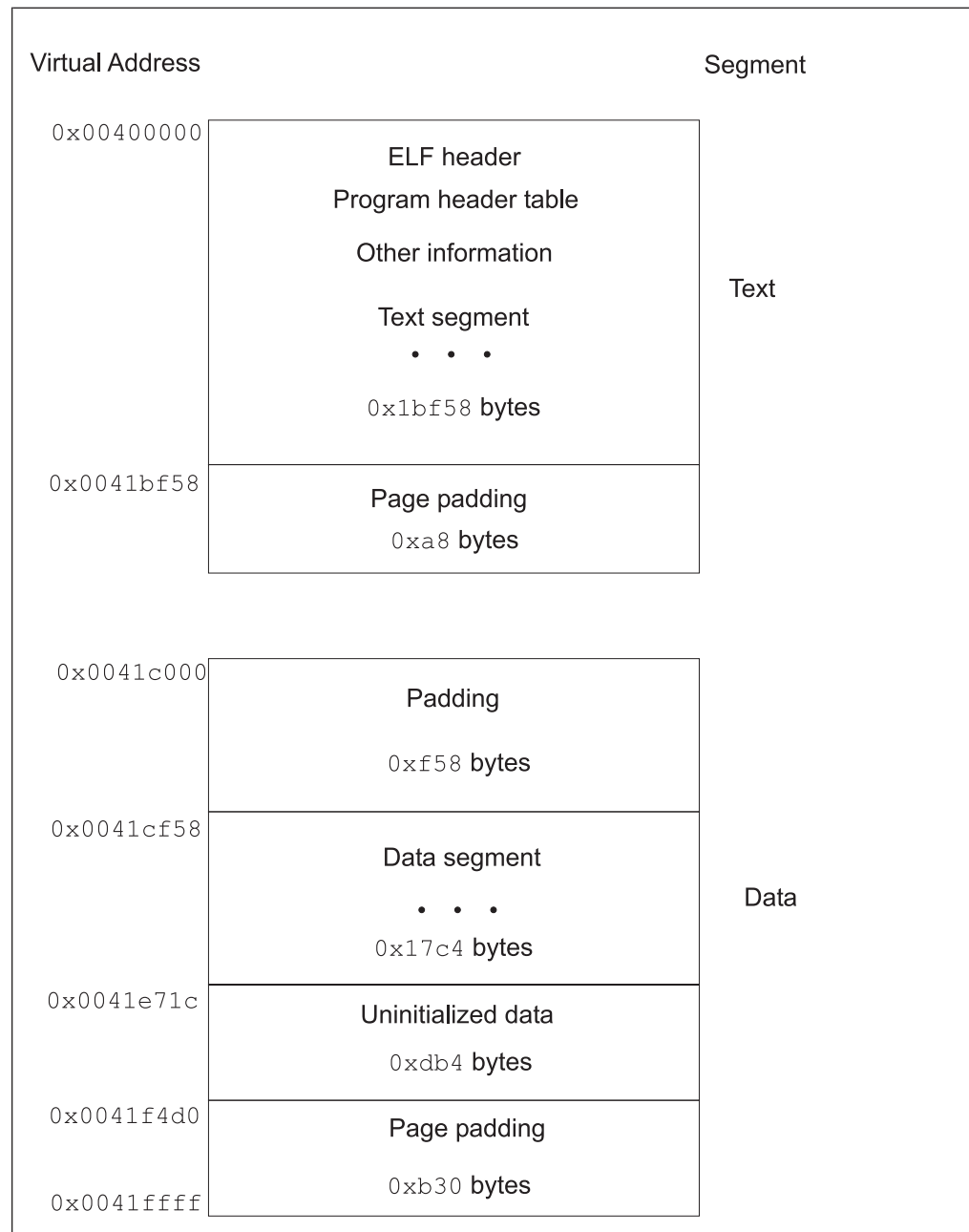


Figure 40. Process Image Segments

One aspect of segment loading differs between executable files and shared objects. Executable file segments may contain absolute code. For the process to execute correctly, the segments must reside at the virtual addresses assigned when building the executable file, with the system using the `p_vaddr` values unchanged as virtual addresses.

On the other hand, shared object segments typically contain position-independent code. This allows a segment's virtual address to change from one process to another, without invalidating execution behavior. Though the system chooses virtual addresses for individual processes, it maintains the "relative positions" of the segments. Because position-independent code uses relative addressing between segments, the difference between virtual addresses in memory must match the difference between virtual addresses in the file. Table 14 on page 48 shows possible

shared object virtual address assignments for several processes, illustrating constant relative positioning. The table also illustrates the base address computations.

Table 14. Shared Object Segment Example

Source	Text	Data	Base Address
File	0x00000200	0x0002a400	
Process 1	0x40000000	0x4002a400	0x40000000
Process 2	0x40010000	0x4003a400	0x40010000
Process 3	0x40020000	0x4004a400	0x40020000
Process 4	0x40030000	0x4005a400	0x40030000

Dynamic Linking

Dynamic Section

Dynamic section entries give information to the dynamic linker. Some of this information is processor-specific, including the interpretation of some entries in the dynamic structure.

DT_PLTGOT

The `d_ptr` field of this entry gives the address of the first byte in the Procedure Linkage Table (`.PLT` in “Procedure Linkage Table” on page 50).

DT_JMPREL

This entry is associated with a table of relocation entries for the PLT. For S/390 this entry is mandatory both for executable and shared object files. Moreover, the relocation table’s entries must have a one-to-one correspondence with the PLT. The table of `DT_JMPREL` relocation entries is wholly contained within the `DT_RELA` referenced table. See “Procedure Linkage Table” on page 50 for more information.

Global Offset Table

Position-independent code cannot, in general, contain absolute virtual addresses. Global Offset Tables hold absolute addresses in private data, thus making the addresses available without compromising the position-independence and sharability of a program’s text. A program references its GOT using position-independent addressing and extracts absolute values, thus redirecting position-independent references to absolute locations.

When the dynamic linker creates memory segments for a loadable object file, it processes the relocation entries, some of which will be of type `R_390_GLOB_DAT`, referring to the GOT. The dynamic linker determines the associated symbol values, calculates their absolute addresses, and sets the GOT entries to the proper values. Although the absolute addresses are unknown when the linkage editor builds an object file, the dynamic linker knows the addresses of all memory segments and can thus calculate the absolute addresses of the symbols contained therein.

A GOT entry provides direct access to the absolute address of a symbol without compromising position-independence and sharability. Because the executable file and shared objects have separate GOTs, a symbol may appear in several tables. The dynamic linker processes all the GOT relocations before giving control to any code in the process image, thus ensuring the absolute addresses are available during execution.

The dynamic linker may choose different memory segment addresses for the same shared object in different programs; it may even choose different library addresses for different executions of the same program. Nevertheless, memory segments do not change addresses once the process image is established. As long as a process exists, its memory segments reside at fixed virtual addresses.

The format and interpretation of the Global Offset Table is processor specific. For S/390 the symbol `_GLOBAL_OFFSET_TABLE_` may be used to access the table. The symbol refers to the start of the `.got` section. Two words in the GOT are reserved:

- The word at `_GLOBAL_OFFSET_TABLE_[0]` is set by the linkage editor to hold the address of the dynamic structure, referenced with the symbol `_DYNAMIC`. This allows a program, such as the dynamic linker, to find its own dynamic structure

without having yet processed its relocation entries. This is especially important for the dynamic linker, because it must initialize itself without relying on other programs to relocate its memory image.

- The word at `_GLOBAL_OFFSET_TABLE_[1]` is reserved for future use.

The Global Offset Table resides in the ELF `.got` section.

Function Addresses

References to a function address from an executable file and from the shared objects associated with the file must resolve to the same value. References from within shared objects will normally be resolved (by the dynamic linker) to the virtual address of the function itself. References from within the executable file to a function defined in a shared object will normally be resolved (by the linkage editor) to the address of the Procedure Linkage Table entry for that function within the executable file.

To allow comparisons of function addresses to work as expected, if an executable file references a function defined in a shared object, the linkage editor will place the address of the PLT entry for that function in its associated symbol table entry. See “Symbol Values” on page 40 for details. The dynamic linker treats such symbol table entries specially. If the dynamic linker is searching for a symbol and encounters a symbol table entry for that symbol in the executable file, it normally follows these rules:

- If the `st_shndx` field of the symbol table entry is not `SHN_UNDEF`, the dynamic linker has found a definition for the symbol and uses its `st_value` field as the symbol’s address.
- If the `st_shndx` field is `SHN_UNDEF` and the symbol is of type `STT_FUNC` and the `st_value` field is not zero, the dynamic linker recognizes this entry as special and uses the `st_value` field as the symbol’s address.
- Otherwise, the dynamic linker considers the symbol to be undefined within the executable file and continues processing.

Some relocations are associated with PLT entries. These entries are used for direct function calls rather than for references to function addresses. These relocations are not treated specially as described above because the dynamic linker must not redirect PLT entries to point to themselves.

Procedure Linkage Table

Much as the Global Offset Table redirects position-independent address calculations to absolute locations, the Procedure Linkage Table redirects position-independent function calls to absolute locations. The linkage editor cannot resolve execution transfers (such as function calls) from one executable or shared object to another, so instead it arranges for the program to transfer control to entries in the PLT. The dynamic linker determines the absolute addresses of the destinations and stores them in the GOT, from which they are loaded by the PLT entry. The dynamic linker can thus redirect the entries without compromising the position-independence and sharability of the program text. Executable files and shared object files have separate PLTs.

As mentioned above, a relocation table is associated with the PLT. The `DT_JMPREL` entry in the `_DYNAMIC` array gives the location of the first relocation entry. The relocation table entries match the PLT entries in a one-to-one correspondence (relocation table entry 1 applies to PLT entry 1 and so on). The relocation type for each entry shall be `R_390_JMP_SLOT`. The relocation offset shall specify the address

of the GOT entry containing the address of the function and the symbol table index shall reference the appropriate symbol.

To illustrate Procedure Linkage Tables, Figure 41 shows how the linkage editor might initialize the PLT when linking a shared executable or shared object.

*			# PLT for executables (not position independent)
PLT1	BASR	1,0	# Establish base
BASE1	L	1,AGOTENT-BASE1(1)	# Load address of the GOT entry
	L	1,0(0,1)	# Load function address from the GOT to r1
	BCR	15,1	# Jump to address
RET1	BASR	1,0	# Return from GOT first time (lazy binding)
BASE2	L	1,ASYMOFF-BASE2(1)	# Load offset in symbol table to r1
	BRC	15,-x	# Jump to start of PLT
	.word	0	# Filler
AGOTENT	.long	?	# Address of the GOT entry
ASYMOFF	.long	?	# Offset into the symbol table
*			# PLT for shared objects (position independent)
PLT1	BASR	1,0	# Establish base
BASE1	L	1,AGOTOFF-BASE1(1)	# Load offset into the GOT to r1
	L	1,(1,12)	# Load address from the GOT to r1
	BCR	15,1	# Jump to address
RET1	BASR	1,0	# Return from GOT first time (lazy binding)
BASE2	L	1,ASYMOFF-BASE2(1)	# Load offset in symbol table to r1
	BRC	15,-x	# Jump to start of PLT
	.word	0	# Filler
AGOTOFF	.long	?	# Offset in the GOT
ASYMOFF	.long	?	# Offset in the symbol table

Figure 41. Procedure Linkage Table Example

As described below the dynamic linker and the program cooperate to resolve symbolic references through the PLT. Again, the details described below are for explanation only. The precise execution-time behavior of the dynamic linker is not specified.

1. The caller of a function in a different shared object transfers control to the start of the PLT entry associated with the function.
2. The first part of the PLT entry loads the address from the GOT entry associated with the function to be called. The control is transferred to the code referenced by the address. If the function has already been called at least once, or lazy binding is not used, then the address found in the GOT is the address of the function.
3. If a function has never been called and lazy binding is used then the address in the GOT points to the second half of the PLT. The second half loads the offset in the symbol table associated with the called function. Control is then transferred to the special first entry of the PLT.
4. This first entry of the PLT entry (Figure 42 on page 52) calls the dynamic linker giving it the offset into the symbol table and the address of a structure that identifies the location of the caller.
5. The dynamic linker finds the real address of the symbol. It will store this address in the GOT entry of the function in the object code of the caller and it will then transfer control to the function.
6. Subsequent calls to the function from this object will find the resolved address in the first half of the PLT entry and will transfer control directly without invoking the dynamic linker.

*			# PLT0 for static object (not position-independent)
PLT0	ST	1,28(15)	# R1 has offset into symbol table
	BASR	1,0	# Establish base
BASE1	L	1,AGOT-BASE1(1)	# Get address of GOT
	MVC	24(4,15),4(1)	# Move loader info to stack
	L	1,8(1)	# Get address of loader
	BR	1	# Jump to loader
	.word	0	# Filler
AGOT	.long	got	# Address of GOT
			# PLT0 for shared object (position-independent)
PLT0	ST	1,28(15)	# R1 has offset into symbol table
	L	1,4(12)	# Get loader info (object struct address)
	ST	1,24(15)	# Store address
	L	1,8(12)	# Entry address of loader in R1
	BR	1	# Jump to loader

Figure 42. Special first entry in Procedure Linkage Table

The `LD_BIND_NOW` environment variable can change dynamic linking behavior. If its value is not null the dynamic linker resolves the function call binding at load time, before transferring control to the program. In other words the dynamic linker processes relocation entries of type `R_390_JMP_SLOT` during process initialization. If `LD_BIND_NOW` is null the dynamic linker evaluates PLT entries lazily, delaying symbol resolution and relocation until the first execution of a table entry.

Note: Lazy binding generally improves overall application performance because unused symbols do not incur the overhead of dynamic linking. Nevertheless, two situations make lazy binding undesirable for some applications:

1. The initial reference to a shared object function takes longer than subsequent calls because the dynamic linker intercepts the call to resolve the symbol, and some applications cannot tolerate this unpredictability.
2. If an error occurs and the dynamic linker cannot resolve the symbol, the dynamic linker will terminate the program. Under lazy binding, this might occur at arbitrary times. Once again, some applications cannot tolerate this unpredictability. By turning off lazy binding, the dynamic linker forces the failure to occur during process initialization, before the application receives control.

Appendix. GNU Free Documentation License

PREAMBLE	53	COLLECTIONS OF DOCUMENTS	57
APPLICABILITY AND DEFINITIONS	53	AGGREGATION WITH INDEPENDENT WORKS	57
VERBATIM COPYING.	54	TRANSLATION	57
COPYING IN QUANTITY	54	TERMINATION	58
MODIFICATIONS	55	FUTURE REVISIONS OF THIS LICENSE	58
COMBINING DOCUMENTS	56	How to use this License for your documents	58

A current copy of the license can be found at:

http://www.linuxbase.org/spec/refspecs/LSB_1.2.0/gLSB/gfdl.html

Version 1.1, March 2000

Copyright (C) 2000 Free Software Foundation, Inc. 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

PREAMBLE

The purpose of this License is to make a manual, textbook, or other written document "free" in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or noncommercially. Secondly, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others. This License is a kind of "copyleft", which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software. We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. The "Document", below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as "you".

A "Modified Version" of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A "Secondary Section" is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document's overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (For example, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical

connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The "Invariant Sections" are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License.

The "Cover Texts" are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License.

A "Transparent" copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, whose contents can be viewed and edited directly and straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup has been designed to thwart or discourage subsequent modification by readers is not Transparent. A copy that is not "Transparent" is called "Opaque".

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML designed for human modification. Opaque formats include PostScript, PDF, proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML produced by some word processors for output purposes only.

The "Title Page" means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, "Title Page" means the text near the most prominent appearance of the work's title, preceding the beginning of the body of the text.

VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

COPYING IN QUANTITY

If you publish printed copies of the Document numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also

clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a publicly-accessible computer-network location containing a complete Transparent copy of the Document, free of added material, which the general network-using public has access to download anonymously at no charge using public-standard network protocols. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

- Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.
- List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has less than five).
- State on the Title page the name of the publisher of the Modified Version, as the publisher.
- Preserve all the copyright notices of the Document.
- Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.
- Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.
- Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.
- Include an unaltered copy of this License.

- Preserve the section entitled "History", and its title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.
- Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.
- In any section entitled "Acknowledgements" or "Dedications", preserve the section's title, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.
- Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.
- Delete any section entitled "Endorsements". Such a section may not be included in the Modified Version.
- Do not retitle any existing section as "Endorsements" or to conflict in title with any Invariant Section.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version's license notice. These titles must be distinct from any other section titles.

You may add a section entitled "Endorsements", provided it contains nothing but endorsements of your Modified Version by various parties--for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections entitled "History" in the various original documents, forming one section entitled "History"; likewise combine any sections entitled "Acknowledgements", and any sections entitled "Dedications". You must delete all sections entitled "Endorsements."

COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, does not as a whole count as a Modified Version of the Document, provided no compilation copyright is claimed for the compilation. Such a compilation is called an "aggregate", and this License does not apply to the other self-contained works thus compiled with the Document, on account of their being thus compiled, if they are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one quarter of the entire aggregate, the Document's Cover Texts may be placed on covers that surround only the Document within the aggregate. Otherwise they must appear on covers around the whole aggregate.

TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License provided that you also include the original English version of this License. In case of a disagreement between the translation and the original English version of this License, the original English version will prevail.

TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided for under this License. Any other attempt to copy, modify, sublicense or distribute the Document is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.

FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See <http://www.gnu.org/copyleft/>.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License "or any later version" applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation.

How to use this License for your documents

To use this License in a document you have written, include a copy of the License in the document and put the following copyright and license notices just after the title page:

Copyright (c) YEAR YOUR NAME. Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.1 or any later version published by the Free Software Foundation; with the Invariant Sections being LIST THEIR TITLES, with the Front-Cover Texts being LIST, and with the Back-Cover Texts being LIST.
A copy of the license is included in the section entitled
"GNU Free Documentation License".

If you have no Invariant Sections, write "with no Invariant Sections" instead of saying which ones are invariant. If you have no Front-Cover Texts, write "no Front-Cover Texts" instead of "Front-Cover Texts being LIST"; likewise for Back-Cover Texts.

If your document contains nontrivial examples of program code, we recommend releasing these examples in parallel under your choice of free software license, such as the GNU General Public License, to permit their use in free software.

Notices

This information was developed for products and services offered in the U.S.A. IBM may not offer the products, services, or features discussed in this document in other countries. Consult your local IBM representative for information about the products and services currently available in your area. Any reference to an IBM product, program, or service is not intended to state or imply that only that IBM product, program, or service may be used. Any functionally equivalent product, program, or service that does not infringe any IBM intellectual property right may be used instead. However, it is the user's responsibility to evaluate and verify the operation of any non-IBM product, program, or service.

IBM may have patents or pending patent applications covering subject matter described in this document. The furnishing of this document does not give you any license to these patents. You can send license inquiries, in writing, to:

IBM Director of Licensing
IBM Corporation
North Castle Drive
Armonk, NY 10504-1785
U.S.A.

For license inquiries regarding double-byte (DBCS) information, contact the IBM Intellectual Property Department in your country or send inquiries, in writing, to:

IBM World Trade Asia Corporation
Licensing
2-31 Roppongi 3-chome, Minato-ku
Tokyo 106-0032, Japan

The following paragraph does not apply to the United Kingdom or any other country where such provisions are inconsistent with local law:

INTERNATIONAL BUSINESS MACHINES CORPORATION PROVIDES THIS PUBLICATION "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF NON-INFRINGEMENT, MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. Some states do not allow disclaimer of express or implied warranties in certain transactions, therefore, this statement may not apply to you.

This information could include technical inaccuracies or typographical errors. Changes are periodically made to the information herein; these changes will be incorporated in new editions of the publication. IBM may make improvements and/or changes in the product(s) and/or the program(s) described in this publication at any time without notice.

Any references in this information to non-IBM Web sites are provided for convenience only and do not in any manner serve as an endorsement of those Web sites. The materials at those Web sites are not part of the materials for this IBM product and use of those Web sites is at your own risk.

IBM may use or distribute any of the information you supply in any way it believes appropriate without incurring any obligation to you.

Information concerning non-IBM products was obtained from the suppliers of those products, their published announcements or other publicly available sources. IBM has not tested those products and cannot confirm the accuracy of performance, compatibility or any other claims related to non-IBM products. Questions on the capabilities of non-IBM products should be addressed to the suppliers of those products.

COPYRIGHT LICENSE:

This information contains sample application programs in source language, which illustrate programming techniques on various operating platforms. You may copy, modify, and distribute these sample programs in any form without payment to IBM, for the purposes of developing, using, marketing or distributing application programs conforming to the application programming interface for the operating platform for which the sample programs are written. These examples have not been thoroughly tested under all conditions. IBM, therefore, cannot guarantee or imply reliability, serviceability, or function of these programs. You may copy, modify, and distribute these sample programs in any form without payment to IBM for the purposes of developing, using, marketing, or distributing application programs conforming to IBM's application programming interfaces.

Programming interface information

This book contains information and examples which are not intended to be used as a programming interface of LINUX for S/390.

Trademarks

The following terms are trademarks of International Business Machines Corporation in the United States, other countries, or both:

IBM	ESA/390
S/390	System/390
zSeries	z/Architecture

LINUX is a registered trademark of Linus Torvalds and others.

Other company, product, and service names may be trademarks or service marks of others.

Bibliography

Related publications:

- *ESA/390 Principles of Operation: SA22-7201*
- *System V Application Binary Interface*

Index

A

- absolute code 22
- address
 - application 16
 - function 50
 - indirect 26
 - mapping 16
 - virtual 15, 16, 45, 49
- address space 15
- aggregates 4
- application address 16
- arguments 13, 14
 - to main 18
- arrays 4
- auxiliary vector 19
 - base address 20
 - effective group id 21
 - effective user id 21
 - end 20
 - entries 20
 - entry point 21
 - entry size 20
 - file descriptor 20
 - flags 21
 - ignore 20
 - not ELF 21
 - page size 20
 - program header table 20
 - real group id 21
 - real user id 21
 - types 19, 39

B

- base address, auxiliary vector 20
- big-endian 2, 3
- binding, lazy 51
- bit-fields 6
- branch instructions 34
- byte ordering
 - doubleword 3
 - halfword 3
 - word 3

C

- calling convention, registers 10
- calling sequence, function 9
- char type 4, 6
- code
 - absolute 22
 - examples 22
 - guidelines 16
 - model 23
 - position-independent 22
- current instruction address 23

D

- data objects 26
- Debug with Arbitrary Record Format (DWARF) 38
- doubleword byte ordering 3
- dynamic linking 40, 43, 49, 50
- dynamic section 49
- dynamic segments 16
- dynamic stack space allocation 35

E

- ELF header 39, 46
- entry counting 25
- enum type 4, 6
- epilog, function 23, 24
- exceptions 18

F

- file descriptor, auxiliary vector 20
- file identification 39
- flags, auxiliary vector 21
- floating point control register 19
- floating point type 4
- frame pointer 35
- function
 - address 50
 - allocating dynamic stack 35
 - call 29
 - calling sequence 9
 - epilog 23, 24
 - main 18
 - prolog 23, 24
 - return values 15

G

- Global Offset Table (GOT) 10, 23, 26, 30, 39, 41, 42, 49, 50

H

- halfword byte ordering 3
- header
 - ELF 39, 46
 - program 46

I

- initial process stack 22
- initialization of process 18
- int type 4, 6

L

- lazy binding 51
- link register 23

- linkage editor 50
- linkage table, procedure 50
- linking, dynamic 49, 50
- literal pool 10, 26
- long long type 4, 6
- long type 4, 6

M

- main
 - arguments 18
 - function 18

N

- notices 59

O

- object file 39, 49

P

- page size 15
- parameter
 - list 35
 - passing 12
- pointer
 - frame 35
 - stack 10, 19, 23, 35
- pointer type 4
- position-independent code 22, 49
- Principles of Operation 2
- problem state 17
- Procedure Linkage Table (PLT) 40, 41, 43, 49, 50
- process image 45
- process image segments 47
- process initialization 18
- process stack 16, 19
- processor execution mode 17
- processor identification 39
- profile 25
- program base 16
- program header 46
- program header table, auxiliary vector 20
- program loading 45
- prolog, function 23, 24

R

- register
 - calling convention 10
 - DWARF mapping 38
 - floating point 9
 - floating point control 19
 - general 9
 - link 23

register (*continued*)
 parameter passing 12
 usage 10, 19
relocation
 entries 40
 types 42
return address 10
return values 15

S

section
 dynamic 49
 special 39
shared object segment 48
short type 4, 6
signal handling 10
signed char type 4, 6
signed int type 4, 6
signed long long type 4, 6
signed long type 4, 6
signed short type 4, 6
space allocation 35
special sections 39
stack 24
 dynamic space allocation 35
 frame 10, 23, 25, 35
 initial process 22
 pointer 10, 19, 23, 35
 process 16, 19
 runtime 10
structures 4
 as return values 15
supervisor state 17
switch 34
symbol
 table 40
 values 40

T

trademarks 60
type
 char 4, 6
 enum 4, 6
 floating point 4
 int 4, 6
 long 4, 6
 long long 4, 6
 pointer 4
 short 4, 6
 signed char 4, 6
 signed int 4, 6
 signed long 4, 6
 signed long long 4, 6
 signed short 4, 6
 unsigned char 4, 6
 unsigned int 4, 6
 unsigned long 4, 6
 unsigned long long 4, 6
 unsigned short 4, 6

U

unions 4
unsigned char type 4, 6

unsigned int type 4, 6
unsigned long long type 4, 6
unsigned long type 4, 6
unsigned short type 4, 6
user state 17

V

virtual address 15, 16, 45, 49

W

word byte ordering 3

Readers' Comments — We'd Like to Hear from You

LINUX for S/390
ELF Application Binary Interface
Supplement

Publication No. LINUX-1007-02

Overall, how satisfied are you with the information in this book?

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Overall satisfaction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

How satisfied are you that the information in this book is:

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Accurate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Complete	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Easy to find	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Easy to understand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Well organized	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Applicable to your tasks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please tell us how we can improve this book:

Thank you for your responses. May we contact you? ☐ Yes ☐ No

When you send comments to IBM, you grant IBM a nonexclusive right to use or distribute your comments in any way it believes appropriate without incurring any obligation to you.

Name

Address

Company or Organization

Phone No.



Cut or Fold
Along Line

Fold and Tape

Please do not staple

Fold and Tape



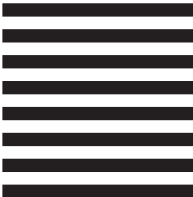
NO POSTAGE
NECESSARY
IF MAILED IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST-CLASS MAIL PERMIT NO. 40 ARMONK, NEW YORK

POSTAGE WILL BE PAID BY ADDRESSEE

IBM CORPORATION
Attn: LINUX for S/390
6300 Diagonal Highway
Boulder, CO, USA 80301-9151



Fold and Tape

Please do not staple

Fold and Tape

Cut or Fold
Along Line



Printed in U.S.A.

LINUX-1007-02

