

Stand-Alone Took Kit Assembler Source

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Notices

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Introduction

The Stand-Alone Tool Kit (SATK) provides tools and source code assisting the development of stand-alone programs for mainframe real, virtual or emulated hardware environments. Initially SATK used the GNU `binutils` project's assembler, `as`, and linker, `ld`. With the addition of A Small Mainframe Assembler (ASMA) to SATK, GNU `binutils` support is currently stabilized, and all future efforts will be developed using ASMA.

This document describes various facilities provided by SATK using ASMA and their conventions and standards. These facilities fall into two broad categories:

- hardware interaction by stand-alone software and
- assists for stand-alone software development itself.

An examples of hardware interaction might be establishing interrupt service routines, performing input/output operations or defining assigned storage usage. Examples of the second could be creating tables and searching them or establishing function calling conventions.

All of the the software described in this manual resides in the `srcasm` directory of SATK.

The manual is organized with summary sections at the beginning followed by detail section focused on individual areas.

General Source Conventions

Files that end in a suffix of `.asm` contain software that generates program content at the point at which they are copied into the assembly. Files that end in a suffix of `.mac` contain macro definitions that only generate program content at the point at which a macro is invoked but not at the point at which the source file is copied into the assembly. All file names in the `srcasm` and its sub-directories will use lower case. This ensures no conflict between hosting platforms that have a file system that is case insensitive versus those that are.

The ASMA `ASMPATH` environment variable must include at least the `srcasm` directory. Copied file names may contain a sub-directory or the sub-directory may be added to the

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ASMPATH environment variable as the user selects.

Term Definitions

SATK uses certain terms to define how a component is utilized in the context of other instruction sequences.

Inline refers to macro generated instructions intended for usage within the current sequence of instructions.

Routine refers to a separate program sequence entered using instructions such as BRANCH AND LINK or BRANCH AND SAVE. Calling conventions are specific to the routine.

Function refers to a routine accessed via a set of SATK standardized calling conventions.

Interrupt Service Routine (ISR) refers to a separate program sequence entered via a the acceptance by the CPU of an interrupt.

Program is any number of instructions executing in a bare-metal environment. This may be designed for a specific purpose or a more general purpose such as an operating system kernel. See the “SATK Use Cases” section for more information.

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Summary Reference

For convenience, this section includes summary information useful for the experienced user.

Disabled Wait States

Stand-alone programs frequently communicate termination conditions using disabled-wait state program status words. In such a PSW, interruptions are disabled and the PSW places the processor into a wait state. Because the processor is disabled for interrupts, externally initiated functions, for example an Initial Program Load or restart are required to cause further instruction execution. For this reason they are chosen to communicate the termination condition. The PSW instruction address defines the information containing aspect of the termination state. Inspection of the current PSW within the environment is required to ascertain the address. This section documents the disabled wait states used by SATK.

SATK reserves all addresses from X'0001' through X'FFFF' for its use. The following table documents these codes. By convention, an address of all zeros means successful termination of the stand-alone program. Stand-alone programs are encouraged to use disabled-wait state codes for abnormal terminations starting at X'10000' by allowing the DWAIT macro in `satk.mac` PGM parameter to default to '1'.

PSW Address	Component	Description
0000	DWAITEND	Successful termination
0008	TRAP64	Restart interrupt occurred without a restart ISR
0018	TRAP64	External interrupt occurred without an external ISR
0020	TRAP64	Supervisor-call interrupt occurred without a supervisor-call ISR
0028	TRAP64	Program interrupt occurred without a program ISR
0030	TRAP64	Machine-check interrupt occurred without a machine-check ISR
0038	TRAP64	Input/output interrupt occurred without an input/output ISR
0120	TRAP128	z/Architecture® restart interrupt occurred without a restart ISR
0130	TRAP128	z/Architecture external interrupt occurred without an external ISR
0140	TRAP128	z/Architecture supervisor-call interrupt occurred without a supervisor-call ISR
0150	TRAP128	z/Architecture program interrupt occurred without a program ISR
0160	TRAP128	z/Architecture machine-check interrupt occurred without a machine-check ISR
0170	TRAP128	z/Architecture input-output interrupt occurred without an input/output ISR
0400	HRCCMD	Hercules DIAGNOSE X'008' command failed
10BAD	DWAIT	Program abnormal termination due to an unspecified condition.

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SRCASM Files

This section describes in general terms the contents of supplied ASMA source files.

File	SATK FEAT	Description
function.mac	FUN	Stack-based callable functions
hercules.mac	HRC	Macros tailored for use with Hercules emulator.
satk.mac		Assists for basic machine architecture and operations.
selfrelo.mac	REL	Program embedded self relocation
table.mac	TBL	Generate and work with sequential fixed size entry tables

Components

This section summarizes the various SATK components. Individual files and components should be consulted for details.

Component	Related To	Type	Description
APROB	satk.mac	macro	Run-time detection of current architecture level.
ARCHLVL	satk.mac	macro	Detects assembly-time architecture level based upon the current XMODE PSW setting.
ASAIPL	satk.mac	macro	Introduce into a created assigned storage region an IPL PSW for program entry
ASALOAD	satk.mac	macro	Create an assigned storage region containing trap PSW's
ASAREA	satk.mac	macro	Defines assigned storage locations used by all architectures in the first storage page.
ASAZAREA	satk.mac	macro	Defines z/Architecture specific storage locations used in the second assigned storage page.
CALL	function.mac	macro	Call a function using an inline address
CALLR	function.mac	macro	Call a function based upon a register resident address
CCWFMT	struct.mac	macro	Defines format and field values of Channel Command Words
CCW0	IOFMT	dsect	Format-0 Channel Command Word definition
CCW1	IOFMT	dsect	Format-1 Channel Command Word definition
CPUWAIT	satk.mac	macro	Performs in-line synchronous wait for an I/O or external interruption.
CSW	IOFMT	dsect	Channel Status Word definition
DSECTS	satk.mac	macro	Unifies structure definition into a single macro for various structures
DWAIT	satk.mac	macro	Generates and optionally loads a formatted disabled wait PSW
DWAITEND	satk.mac	macro	Generates and optionally loads a normal termination disabled wait state PSW
ENADEV	satk.mac	macro	Enable a device preparing it for use.

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Component	Related To	Type	Description
ESA390	satk.mac	macro	Run-time change to ESA/390 architecture mode from z/Architecture.
FRAME	function.mac	macro	Define the function stack frame
HRCIPLP	hercules.mac	macro	Store Hercules IPL parameters in the first 4096 bytes of storage.
HRCCMD	hercules.mac	macro	Issue a Hercules command without a response.
IOFMT	satk.mac	macro	Defines various input/output related structures
IOCB	satk.mac	macro	Creates the control block for a specific I/O operation by RAWIO.
IOCBDS	satk.mac	macro	Defines the IOCB structure used by RAWIO.
IOINIT	satk.mac	macro	Prepare the I/O system for use.
IOTRFR	satk.mac	macro	Calculates the number of bytes actually transferred during an I/O operation.
IRB	IOFMT	dsect	Interrupt Response Block definition
LOCAL	function.mac	macro	Define the local usage of the stack frame by the following function.
ORB	satk.mac	macro	Assembles an Operation Request Block or a reserved bit mask
ORB	IOFMT	dsect	Operation Request Block definition
PSWB	PSWFMT	dsect	64-bit basic PSW format definition
PSWE	PSWFMT	dsect	64-bit extended mode single or bimodal addressing format PSW definition
PSWZ	PSWFMT	dsect	128-bit trimodal addressing format PSW definition
PSWFMT	satk.mac	macro	Defines PSW formats based upon current architecture level
RAWAIT	satk.mac	macro	Perform an inline wait for an unsolicited device interruption
RAWIO	satk.mac	macro	Perform an inline low-level I/O operation with a device.
RETURN	function.mac	macro	Return control to a function's caller.
SCHIB	IOFMT	dsect	Subchannel Information Block definition
SCSW	IOFMT	dsect	Subchannel Status Word definition
SIGCPU	satk.mac	macro	Generic run-time signaling of the running or other CPU.
SSMGR	satk.mac	macro	Static memory manager algorithm
SSMGRB	satk.mac	macro	Static memory manager algorithm control fields
TRAPS	satk.mac	macro	Generates or enables trap PSW for unsupported interrupt service routines.
ZARCH	satk.mac	macro	Run-time change to z/Architecture mode from ESA/390.
ZEROH	satk.mac	macro	Set to 0 high-order bits of a 32- or 64-bit register.
ZEROL	satk.mac	macro	Set to 0 low-order bits of a 32- or 64-bit register
ZEROLH	satk.mac	macro	Set to 0 high-order bits starting at bit 32 of a 64-bit register.
ZEROLL	satk.mac	macro	Set to 0 low-order bits ending at bit 32 of a 64-bit register.

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Architecture Levels

The symbolic variable `&ARCHLVL` defines the current architecture level in use by the program. `&ARCHLVL` is established by the `ARCHLVL` macro, in `satk.mac`, by examining the current `XMODE PSW` setting.

- 0 – architecture level not established or unknown,
- 1 – System/360 (S/360),
- 2 – System/370 (S/370) in basic-control mode
- 3 – System/370 in extended-control mode
- 4 – System/380 (S/380, a Hercules unique architecture)
- 5 – System/370 Extended Architecture (370-XA)
- 6 – Enterprise System Architecture/370 (ESA/370)
- 7 – Enterprise System Architecture/390 (ESA/390)
- 8 – Enterprise System Architecture/390 on a z/Architecture system, and
- 9 – z/Architecture

Key new capabilities offered by the various architecture levels. The columns with an 'H' indicate Hercules unique offerings. This list is not exhaustive but representative of those features of interest to SATK applications.

1	2	3	4	5	6	7	8	9	Capability
X	X	X	H						Parallel Channels
X	X	X	H	X	X	X	X	X	12-bit displacements - 4K
X	X	X	H	X	X	X	X	X	Format-0 CCW
	X	X	H	X	X	X	X	X	BRANCH AND SAVE
			H	X	X	X	X	X	31-bit addressing
				X	X	X	X	X	Channel Subsystem
				X	X	X	X	X	Format-1 CCW
	H	H	H			X	X	X	Relative instructions - +/-64K (BRC, J, etc.)
	H	H	H			X	X	X	Immediate instruction (CHI, AHI, etc.)
						X	X	X	12 additional floating point registers
						X	X	X	Floating-point control register
						X	X	X	Binary floating point
							X	X	Addressing mode instructions (SAMxx, TAM)
								X	Transport Mode (TCW)

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1	2	3	4	5	6	7	8	9	Capability
								X	64-bit addressing
								X	64-bit registers
								X	Relative long instructions +/- 2G (LARL, JLU, etc.)
								X	Extended immediate (CFI, etc.)
								X	20-bit displacements - 1M (LAY, AY, ALY, etc.)
								X	Decimal floating point

Operation Synonyms

Operation synonyms are defined by the `ARCHIND` macro in the file `satk.mac`. The native instruction mnemonic to which the synonym is assigned by architecture level is provided in the following table. '--' indicates no form of the instruction is supported by the architecture.

Synonym	0	1	2-6	7, 8	9
\$AHI	--	--	--	AHI	AGHI
\$AL	AL	AL	AL	AL	ALG
\$ALR	ALR	ALR	ALR	ALR	ALGR
\$B	B	B	B	J	J
\$BAS	BAS	BAL	BAS	BAS	BAS
\$BASR	BASR	BALR	BASR	BASR	BASR
\$BC	BC	BC	BC	BRC	BRC
\$BCTR	BCTR	BCTR	BCTR	BCTR	BCTGR
\$BE	BE	BE	BE	JE	JE
\$BH	BH	BH	BH	JH	JH
\$BL	BL	BL	BL	JL	JL
\$BM	BM	BM	BM	JJM	JM
\$BNE	BNE	BNE	BNE	JNE	JNE
\$BNH	BNH	BNH	BNH	JNH	JNH
\$BNL	BNL	BNL	BNL	JNL	JNL
\$BNM	BNM	BNM	BNM	JNM	JNM
\$BNO	BNO	BNO	BNO	JNO	JNO
\$BNP	BNP	BNP	BNP	JNP	JNP

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Synonym	0	1	2-6	7, 8	9
\$BNZ	BNZ	BNZ	BNZ	JNZ	JNZ
\$BO	BO	BO	BO	JO	JO
\$BP	BP	BP	BP	JP	JP
\$BXLE	BXLE	BXLE	BXLE	JXLE	JXLEG
\$BZ	BZ	BZ	BZ	JZ	JZ
\$CH	CH	CH	CH	CH	CGH
\$CHI	--	--	--	CHI	CGHI
\$L	L	L	L	L	LG
\$LH	LHLPSW	LH	LH	LH	LGH
\$LPSW	LPSW	LPSW	LPSW	LPSW	LPSWE
\$LR	LR	LR	LR	LR	LGR
\$LTR	LTR	LTR	LTR	LTR	LTGR
\$NR	NR	NR	NR	NR	NGR
\$SL	SL	SL	SL	SL	SLG
\$SLR	SLR	SLR	SLR	SLR	SLGR
\$SR	SR	SR	SR	SR	SGR
\$ST	ST	ST	ST	ST	STG
\$STM	STM	STM	STM	STM	STMG
\$X	X	X	X	X	XG

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Assembler Source Structure

SATK is intended to make bare-metal programming easier, not harder. SATK provides a number of coded and tested source modules for building stand-alone programs with ASMA. These modules are in the `srcasm` directory. Any ASMA program using these source modules must include the `srcasm` directory in the `ASMPATH` environment variable directory search order list before executing the assembler.

Core capabilities are provided by the `satk.mac` source module. All users of ASMA source files will need to use the assembler `COPY` directive to include this file early in the program. Other capabilities must be manually included by use of a `COPY` directive for the needed file. This manual describes the capabilities offered by each file separately, discussing how the various components are for the file are used. Most separately included files have dependencies on the `satk.mac` source module, usually for architecture sensitive code generation or structure definitions. If files in `srcasm` are used, the `satk.mac` file must be included, unless otherwise indicated.

This manual is organized by file name with descriptions of each capability's design. The actual source file provides the ultimate definition of functions provided. Where the software or this document differ, this document is the basis for "working as designed". Errors of course can exist in the code or this documentation. Either requires correction.

Always refer to the actual source module for detailed macro parameter descriptions.

SATK Use Cases

The relationships between various components can be quite complex in a generalized system. The support by SATK of multiple hardware architectures complicates these considerations. SATK recognizes two use-cases:

1. a stand-alone application performing of one or more specific functions and
2. a control program providing resource management for one or more activities.

An application performs a single task. It supports use of the hardware in the way any application would, doing one piece of the task at a time. A control program is intended to manage the system resources for one or more application type tasks. The second use case has a much higher complexity. In both cases the tool kit only contributes to the end product. The support for each case may have elements in common with each other or entirely different ones. In some cases the same conceptual elements may be needed but implemented differently for the two environments.

An application typically does not require any complex interrupt handling. Although an ISR to provide information when a program interruption occurs might be desirable. It utilizes memory without consideration of other users, because of course there are none. All devices are dedicated to the use of the application. Examples of an application could be a boot loader

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or program installer onto IPL media. A “Hello World” program would be another.

A control program **does** require true interrupt handling, activity management and perhaps memory segregation, protecting different activities from each other. Devices may be shared or dedicated to specific activities. An example of a control program might be a simple kernel or program debugger. In the early stages of the control program it might need to operate like an application until it is ready to function as a resource controller for its activities. The SATK does not attempt to provide an interface to a control program for its activities. That is the role of the control program itself. Nor does SATK make any attempt at integrating the pieces it supplies into a unified application. That is the role of the actual program.

The following table looks at various capabilities needed by an application as opposed to a control program. The table assumes that a control program starts out as an application that initializes the control program itself. The table is of course not exhaustive and capability needs could be argued either way. The intent is to drive towards a source structure that matches the two use cases under consideration. Rows describe a capability. The capabilities are placed generally in a spectrum (subject to some debate) from simplest to most complex.

The meaning of the colors is explained below.

Appl.	CP Init.	CP	Type	Capability
yes	yes	yes	system	Tailor for architecture
yes	yes	yes	system	Assigned storage location definitions used
likely	maybe	no	I/O	Perform I/O without ISR
maybe	yes	no	storage	Assign memory usage
maybe	maybe	no	system	Detect run-time environment
maybe	maybe	no	CPU	Use timers without ISR
maybe	maybe	unlikely	storage	Perform self relocation
maybe	yes	maybe	CPU	Initialize ISR's
maybe	maybe	maybe	system	Platform specific support (Hercules, or others)
maybe	likely	likely	program	Manage tables
maybe	maybe	likely	program	Use function calls
maybe	maybe	likely	program	Format text output
maybe	maybe	yes	I/O	Understand specific device characteristics
maybe	maybe	yes	I/O	Discover and identify devices
maybe	maybe	yes	CPU	Utilize interrupt service routines (ISRs)
maybe	maybe	yes	CPU	Dispatch interrupts within ISRs
no	no	yes	program	Manage resources for activities

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Appl.	CP Init.	CP	Type	Capability
no	no	yes	program	One or more activities supported
no	no	yes	program	Activity services provided
no	no	yes	storage	Manage memory area allocation/release

From the table it is clear that the CP initialization does in fact model closely an application. There is also a clear demarcation in what an application or control program initialization component requires from that of an actual control program. The actual needs of a control program are specific to it. While the goals of SATK include a simple control program, it is out of scope for this manual focused on the contents and use of the `srcasm` directory. So nothing identified in **red** above can be found in that directory.

The components that may likely be required for an application are maintained in a single file, `satk.mac`. This file includes macros supporting everything in **blue** and **green**. It will normally be copied into the SATK application at its beginning. Use the `PRINT OFF` directive before and the `PRINT ON` directive to remove the file's contents from the listing. Use the `NOPRINT` operand of the `PRINT` directive to remove the `PRINT` directives themselves from the listing.

The capabilities in **yellow** and **orange** are areas of overlap. The capabilities in yellow are likely of use to an application and those in orange are possibly needed by a control program. Capabilities in yellow or orange are made available in separate files that must be explicitly included into the program by means of the `COPY` directive.

Most components fall into one of four roles:

- Definition – assembles one or more DSECTs describing control block structures,
- Creation – assembles one or more control structures matching its definition,
- Initialization/Termination – Run-time environment creation or destruction, or
- Process – run-time processes supported by the environment.

The following table will be used to summarize the role individual components have in providing the SATK capability.

Definition	Creation	Init/Term	Process
MACRO: DSECT...	MACRO : DSECT	Init: MACRO... Term: MACRO...	M: MACRO R: ROUTINE F: FUNCTION

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Local Modifications

The use of any of the source modules described in this manual is strictly optional. And if the code provided does not meet your needs you are free to modify it. It is recommended that modification be made outside of the SATK provided files in other directories, preserving the original source unchanged. Such directories must be included in the `ASMPATH` environment variable as is the `srcasm` directory to allow the files to be found by the `ASMA COPY` directive. To override SATK supplied source modules in their entirety, place the directory where the modified files exist, before the `srcasm` directory.

To override specific SATK supplied macros, place, the modified macros in a file residing in a directory other than `srcasm` with a name that does not match any of the files in `srcasm`. Place this directory after the `srcasm` directory in `ASMPATH`. The reason for this is that a macro defined with the same name as a previous macro overrides its previous definition. This new file could of course be placed in the `srcasm` directory itself, but doing so would mix local modifications with SATK, a practice which is discouraged.

To avoid any potential `ASMPATH` sequence issues, use a different directory with different file names and macro names unique to your modifications. This practice allows the directory containing local modifications to be placed anywhere in the `ASMPATH` search order.

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satk.mac

File `satk.mac` provides the following capabilities:

- Architecture Sensitivity – Supports code sensitive at assembly time (macros `ARCHLVL`, `ARCHIND`) or run-time (macro `APROB`) architecture level.
- Define Structures - assemble various hardware and SATK related structure definition `DSECTS` (macros `ASAREA`, `ASAZAREA`, `DSECTS`, `IOCBDS`, `IOFMT`, `PSWFMT`).
- Change Architecture Mode and signal processors (macros `ESA390`, `SIGCPU`, and `ZARCH`).
- Program Termination - normally (macro `DWAITEND`) or abnormally (macro `DWAIT`) terminate a program.
- Flying without a Net - Waiting and other considerations for programs without formal interrupt service routines (macros `ASALOAD`, `CPUWAIT`, `TRAP64`, `TRAP128`, `TRAPS`).
- Performing I/O – In-line initiation and completion of low-level device I/O in either channel or channel subsystem environments (macros `ENADEV`, `IOCB`, `IOINIT`, `ORB`, `RAWIO`).
- Static Memory Allocation – run-time allocation of unassigned memory locations (macro `SMMGR` and `SMMGRB`).

Architecture Sensitivity

SATK is intended to facilitate coding for any of the architectural systems in the mainframe family. The foundation for this is the use of the Machine Specification Language (MSL) files that define a CPU instruction set and the format of its critical system structures, the Program Status Word (PSW) and Channel Command Word (CCW). The MSL specified PSW, by default, becomes the initial `XMODE` directive `PSW` specification. See the *ASMA* manual for details concerning the `XMODE` directive and initial CPU targeting by the *ASMA* command line.

Architecture sensitivity is supported by three macros:

- `ARCHLVL` – establishing the current assembly time architecture level
- `ARCHIND` – establishing operation synonyms for use in generic statements and
- `APROB` – establishing the run time architecture level.

Definition	Creation	Init/Term	Process
--	<code>ARCHLVL</code> <code>ARCHIND</code>		M: <code>APROB</code>

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APROB

The `APROB` macro is one of the few macros not dependent upon architecture level. It is also not dependent upon the instruction set of the command-line selected CPU. At run-time it determines the architecture level, placing the value in a register. For a program wishing to validate its run-time architecture, it should be called very early in the program, if not the first macro used after control is passed to the program by the IPL process.

The `APROB` macro is designed to assemble and run in any standard mainframe compatible architecture system. Certain systems within the System/360 are not standard and `APROB` will not function on those systems. The result of the `APROB` macro may be compared to the preserved assembly time value supplied by the `ARCHLVL` macro to determine if the run time environment is supported by the program. See the section, "Architecture Levels" for the meaning of a the resulting value.

It is the responsibility of the program to decide how to handle an unexpected result.

ARCHIND

`ARCHIND` sets the operator synonyms for architecture "independent" code within SATK macros depending upon the current architecture level. By default the `ARCHLVL` macro will internally use the `ARCHIND` macro to establish a set of operation synonyms that are sensitive to the assembly time architecture. To suppress this automatic behavior use the `ARCHLVL` parameter `ARCHIND=NO`. `ARCHIND` macro can be used independently of the `ARCHLVL` macro.

The set of operation synonyms defined is based upon the `&ARCHLVL` symbolic variable. They allow an architecture independent operation to be coded allowing actual instruction generation to be tailored for an architecture. For example in some architectures the `BRANCH ON CONDITION (BC)` instruction is generated and for others the `BRANCH RELATIVE ON CONDITION (BRC)` instruction is used. The convention is that the "generic" instruction is preceded by a '\$'. So by coding `$BC` in the operation field, depending upon the detected architecture level, one or the other of these instructions will be generated by the single operation code. The creation of the synonyms does not effect the original instruction mnemonics and they are available for explicit use if desired. The System/370 level of instructions are used if the `&ARCHLVL` is zero. Unlike the `&ARCHLVL` symbolic variable, operation synonyms are available outside of macros.

ARCHLVL

The `ARCHLVL` macro is critical to nearly all SATK code. It controls how the macros generate code. It must be the first macro executed by an SATK using program. When setting the `XMODE PSW` setting in a program, use the `ARCHLVL` macro to set the `XMODE` setting rather than doing them separately. This ensures the level always matches the current setting.

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Assembly Time

At assembly time, recognition of the ASMA target architecture is provided by the `ARCHLVL` macro. The macro establishes the assembly time global arithmetic symbolic variable `&ARCHLVL`, universally used to drive architecture specific code generation. By default, the determination is based upon the current `XMODE PSW` setting as specified by the initially selected Machine Specification Language (MSL) CPU definition or later establish by explicit use of the `XMODE` directive itself in the program. As recommended above, when explicitly setting the `XMODE PSW` format, let `ARCHLVL` do it by using the `PSW` parameter. This ensures the `XMODE` setting, the architecture level and related operator synonyms are kept consistent, thereby avoiding surprises.

The current `XMODE PSW` setting is exposed to a macro by means of the `&SYSPSW` global symbolic variable. A macro dedicated to examining this setting, `ARCHLVL`, will set a global symbolic variable of the same name, `&ARCHLVL`, to an arithmetic value between 1 and 9, inclusive. See the section, "Architecture Levels" for the meaning of an assigned value. A value of zero indicates the `XMODE` setting has been disabled or is unrecognized. Only the `PSWS` format is not recognized by the `ARCHLVL` macro. Once the `&ARCHLVL` symbolic variable has been set, other macros utilize it to make code generation decisions.

ESA/390 Considerations

It is not possible to differentiate by `PSW` format between a native ESA/390 system or a z/Architecture system running in ESA/390 mode. By default, the `ARCHLVL` macro assumes a ESA/390 system is running on z/Architecture. To alter this assumption to being a native ESA/390 system, specify the `ARCHLVL` parameter `ZARCH=NO`.

Overriding the XMODE PSW Setting

To force a specific setting of the architecture level use the `ARCHLVL` parameter `SET=n`. 'n' in this case is a decimal integer between 1 and 9, inclusive. This parameter forces the `&ARCHLVL` symbolic variable to the specified value regardless of the current `XMODE PSW` setting. Operation synonyms, if not suppressed, will be created based upon the specified value.

The use of the `SET` parameter is independent from that of the `PSW` parameter. The program can both establish a new `XMODE PSW` setting and ignore it by use of the `SET` parameter. A good reason to do this is not apparent, but is possible.

Run Time

The assembly time architecture level can be preserved for run time by providing a label when the `ARCHLVL` macro is called. The symbol is used in an `EQU` directive setting the symbol's value to the value of the `&ARCHLVL` symbolic variable established by the `ARCHLVL` macro. In turn the symbol may be used in an address constant providing the assembly time architecture level to the program at run time.

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Defining Structures

Numerous structures are utilized by mainframe systems. Various macros support generation of these structures:

- `ASAREA` – Assigned storage area in addresses X'0' – X'1FF'.
- `ASAZAREA` – Assigned storage area specific to z/Architecture systems.
- `DSECTS` – Unifies structure generation in a single macro.
- `IOCBDS` – Defines the raw I/O control block
- `IOFMT` – Defines I/O related structures
- `PSWFMT` – Defines PSW format based upon the current architecture level

All macros ensure that a specific DSECT is created only once in the assembly. The `DSECTS` macro is recommended, but the individual macros may also be used.

Definition	Creation	Init/Term	Process
ASAREA ASAZAREA DSECTS See desc. IOFMT See desc. PSWFMT: PSWB PSWE PSWZ	ASAREA ASAZAREA	--	--

ASAREA

Defines the storage area in addresses X'0'-X'1FF' for all architecture uses. It is designed to actually generate content for the area in a CSECT or define a DSECT. In either case, a `USING` directive with register 0 is required. When created by the `DSECTS` macro, the `ASA` DSECT is created.

ASAZAREA

This macro is only needed to reference assigned storage areas starting at address X'11C0' on z/Architecture systems. It may generate actual content in a CSECT or define the area in a DSECT. The defined area only contains save areas. Unless a program expects to reference or use these areas, the `ASAZAREA` macro is not normally required even on z/Architecture systems. When created by the `DSECTS` macro, the `ASAZ` DSECT is created.

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DSECTS

The `DSECTS` macro is a wrapper for use of all of the other structure related macros. Its primary advantage is that it uses `PUSH` and `POP` directives in managing the `PRINT` directive settings. It uses a single parameter, `NAME`, that may use a sublist to specify the structure(s) being assembled. The “Level” column indicates whether the DSECT content is sensitive to the current architecture level (see “`ARCHLVL`” section). The following names are supported:

NAME	Level	Description
ASA	no	Defines assigned storage areas
ASAZ	no	Defines z/Architecture save areas
CCW	no	Defines both CCW formats
CCW0	no	Defines the Format-0 Channel Command Word
CCW1	no	Defines the Format-1 Channel Command Word
CHAN	no	Defines structures used by channel-based I/O: CCW0 and CSW
CS	no	Defines structures used by channel subsystem-based I/O: CCW0, CCW1, IRB, ORB, SCHIB and SCSW
CSW	no	Defines the Channel Status Word (CSW)
FRAME	yes	Defines the default function stack frame
IO	no	Defines all I/O related structures
IOCB	no	Defines the raw I/O control block
IRB	no	Defines the Interruption-Response Block
ORB	no	Defines the Operation-Request Block
PSW	yes	Defines the PSW structure(s) in use
SCHIB	no	Defines the Subchannel Information Block
SCSW	no	Defines the Subchannel Status Word
TABLE	no	Defines the SATK table definition structures (<code>DSECT TBL</code> and <code>TBLG</code>)

The `NAME=TABLE` parameter requires the `table.mac` file.

If the `NAME` parameter is omitted, based upon the current architecture level the DSECTs required for the current architecture level PSW, and related I/O structures are generated in addition to the `IOCB` DSECT.

IOCBDS

Defines the raw I/O control block. See the “Performing Input/Output Operations” section for

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information on its usage. The `DSECTS=IOCB` parameter also defines this structure.

IOFMT

Defines various hardware related I/O structures. Uses the same name for its `DSECT` parameter as does the `DSECTS` macro for the corresponding structure: `CCW`, `CCW0`, `CCW1`, `CSW`, `IRB`, `ORB`, `SCHIB`, `SCSW`. If `ALL` is used, all of the I/O related structures are defined.

PSWFMT

Based upon the architecture level one or more `DSECT`s is created defining the PSW format:

- Level 1 – `PSWB`
- Level 2-4 – `PSWB` and `PSWE`
- Levels 5-7 – `PSWE`
- Levels 8 and 9 – `PSWE` and `PSWZ`

Changing Architecture Mode and Processor Signaling

When preparing a program for z/Architecture mode, the system, will be in the ESA/390 mode following the Initial Program Load (IPL) function. The program itself must cause the system to enter z/Architecture mode. The change in architecture mode is a special case of processor signaling. Three macros are provided for this purpose:

- `ESA390` – enters ESA/390 mode from z/Architecture mode at run-time
- `SIGCPU` – generic signaling of the same or different processor.
- `ZARCH` – enters z/Architecture mode from ESA/390 mode at run-time.

All three macros have the same register requirements:

- an even/odd pair and
- a separate register for the address of the CPU being signaled.

All three macros allow detection of the success or failure of the operation. Each of the macros offer a `SUCCESS` and `FAIL` parameter. It is recommended either or both be used to ensure detection of the success or failure of the operation. If neither parameter is used, condition code 0 indicates success. Any other condition code setting indicates failure.

Definition	Creation	Init/Term	Process
--	--	--	M: ESA390

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Definition	Creation	Init/Term	Process
			M: SIGCPU M: ZARCH

Side-Effects of Architecture-Mode Changes

Changing from 32-bit registers to 64-bit registers can have interesting side effects. When encountered, a program interruption usually occurs,

The first recommendation made for managing the side effects when architecture mode is changed encourages use of disabled-wait PSW's for assigned storage area new PSW's. They can be loaded during the IPL function, particularly when using list-directed IPL by using the `ASALOAD` macro. Alternatively, the program can, after control is passed during the IPL function, introduce these PSW's into the assigned storage area by explicitly moving them from PSW's generated in the program by the `TRAPS` macro. Such trap PSW's do nothing for actually correcting the problem, but do control any adverse side effects, cleanly ceasing program execution at the point of failure.

The primary issue involves signed binary integers. Systems with 64-bit general registers do not have a separate set of 32-bit general registers. Rather, the low-order 32-bits of the 64-bit general register are used for the 32-bit register when in 32-bit mode. During 32-bit mode, the sign exists in bit 0 of the 32-bit register. However, after a change to z/Architecture the sign bit exists in bit 0 of the 64-bit register. Bit 0 of the 32-bit register is now bit 32 of the 64-bit register. The CPU reset that occurs during the IPL function will set all 64 bits of the 64 bit registers to 0, but the CPU will be in 32-bit mode. The effect of this is to cause the 64-bit register's contents to be interpreted as a positive integer rather than the negative integer intended during 32-bit register mode operation.

Only the program developer knows that the bits in a register are or are not to be interpreted as a signed integer. For any signed register value whose sign needs preservation after the architecture mode change, use the `LOAD (64<32)` register instruction:

```
LGFR    N,N
```

This instruction will propagate the 32-bit sign into bits 0-31 preserving the register's sign. When used for this purpose the first and second operands must identify the same register, unless changing the actual register that contains the value is intended.

Side-Effects of Address-Mode Changes

Similar effects can occur when changing addressing modes. In 24- and 31-bit addressing modes, the high order bits, the first eight and first, respectively, are ignored during address calculation. The most likely situation where this can be a problem involves a base register established from use of either the `BALR` or `BASR` instructions. These instructions, and some others, can set the high-order bits of the register. As long as the register contents are used in the same address mode as was in use when the value was set, no problems occur.

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When changing to a higher addressing mode, the previously ignored high-order bits become part of the address calculation resulting in the wrong addresses being used by an instruction relying upon the value established in the previous address mode. In addition to instructions causing an address mode change, the introduction of a PSW, either by the program using a `LOAD PSW` or `LOAD PSW EXTENDED` instruction or CPU during interruption recognition, can also change the address mode. The default address mode for SATK created PSW's is 24.

Again, only the program developer knows when a register contains an address and what bits should be ignored, if any. Before a change to a higher address mode, the program should ensure that the necessary high-order bits are set to 0.

Four macros are provided for the purpose of setting register bits to 0 depending upon the current architecture level and whether the register's high-order or low-order bits or only the lower half of the register are being set to zero in the case of 64-bit registers. The following table summarizes the usage and effected bits. Each macro has the same two required parameters:

- the register whose bits should be set to 0 and
- the number of bits including the starting bit.

Macro	Level	Register Bits	Starting Bit	ESA/390 or lower	Z/Architecture
ZEROH	0-8	0-31	High starting at 0	allowed	allowed
	9	0-63	High starting at 0	prohibited	allowed
ZEROL	0-8	0-31	Low starting at 31	allowed	allowed
	9	0-63	Low starting at 63	prohibited	allowed
ZEROLH	0-8	0-31	High starting at 0	allowed	allowed
	9	32-63	High starting at 32	allowed	allowed
ZEROLL	0-8	0-31	Low starting at 31	allowed	allowed
	9	32-63	Low starting at 63	allowed	allowed

On architecture levels other than 9, `ZEROLH` and `ZEROH` are equivalent and `ZEROLL` and `ZEROL` are equivalent and may be used interchangeably.

Definition	Creation	Init/Term	Process
--	--	--	M: ZEROH M: ZEROL M: ZEROLH M: ZEROLL

When executing, `ZEROH` and `ZEROL` use z/Architecture specific instructions, targeting the entire 64-bit register. If the program has not yet changed to z/Architecture, executing these

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instructions will cause a program interruption. In this case use `ZEROLH` or `ZEROLL` in the source program. This situation occurs if a program is assembled with an ASMA target of `-ts390x`, but the program has not yet actually changed to the z/Architecture mode when running. Matching the `XMODE PSW`, `ARCHLVL` and `ARCHIND` settings to the running architecture ensures correct instruction generation.

ESA390

Uses `SIGCPU` to change architecture mode to ESA/390. Rarely needed.

SIGCPU

Signal this or another CPU. Requires the address of the CPU being signaled in a half word supplied by the `CPUADDR` parameter. If omitted, `SIGCPU` assumes the CPU is signaling itself and allocates a half word into which it stores the current CPU's address. The signaling order must be a self defining term supplied by the `ORDER` parameter.

ZARCH

Uses `SIGCPU` to change architecture mode to z/Architecture.

ZEROH

Set the high-order bits of a 32-bit (architecture levels 0-8) or 64-bit (architecture level 9) register to 0.

ZEROL

Set the low-order bits of a 32-bit (architecture levels 0-8) or 64-bit (architecture level 9) register to 0.

ZEROLH

Set the high-order bits of a 32-bit (architecture levels 0-8) or the bits starting at 32 in a 64-bit (architecture level 9) register to 0.

ZEROLL

Set the low-order bits of a 32-bit (architecture levels 0-8) or the bits starting at 63 and ending with bit 32 in a 64-bit (architecture level 9) register to 0.

Terminating the Program

The only way to terminate a bare-metal mainframe program is to enter a “disabled-wait” state. A disabled wait state results when a PSW is introduced as the active PSW with the wait bit

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set, causing instruction execution to cease while waiting for an interruption, combined with disabling of interruptions by the same PSW. Because the masked interruptions are disabled, they will not be recognized if they occur and instruction execution will not continue. The combination of these flags in the PSW effectively halts the processor.

Two convenience macros are provided for the assembling of such PSW's:

- `DWAITEND` – for normal termination and
- `DWAIT` – for abnormal termination.

Both macros will generate a PSW properly formatted 64-bit PSW for creating a disabled wait state and will optionally introduce in-line the PSW as the active PSW by issuing the `LPSW` instruction regardless of the architecture. `LOAD PSW` functions properly for this purpose on all architectures. If the program loads a PSW created by `DWAIT` or `DWAITEND` it must also use a `LPSW` instruction. The program must not use `LPSWE` or `$LPSW`.

By convention, the instruction address of the disabled-wait state PSW will provide rudimentary information about the cause of the termination.

Definition	Creation	Init/Term	Process
--	--	M: <code>DWAIT</code> M: <code>DWAITEND</code>	--

DWAIT

This is the foundation for creating disabled wait state PSW's and optionally loading it. The macro uses the conventions for identifying SATK vs. program specific conditions described in the “Disabled Wait States” section previously. `PGM` and `CODE` parameters are hexadecimal digits, generating an address of `PPCCCC`, where 'P' is supplied by the `PGM` parameter and 'C' is supplied by the `CODE` parameter.

DWAITEND

This macro is equivalent to:

```
DWAIT PGM=0, CODE=000
```

Flying Without a Net

Formal ISR's, while necessary in some settings, can be overkill in others. ISR's are critical when multiple concurrent activities are in use. ISR's capture asynchronous events for later activity handling and recognize when an activity has a program issue. For a bare-metal program performing a single activity, the program itself can capture these events without the need of formal ISR's. This does not mean that interruptions do not happen, but they are

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handled directly by the program, that is, without formal ISR's.

There exists no mechanism to disable any class of interruptions from occurring when the right conditions exist for the interruption being accepted by the CPU. This is particularly true when things go awry. In some cases, the program needs to capture the event. That being said, each interruption class needs to have a valid new PSW established for it and in those cases where the program needs to recognize the event, the new PSW needs to support it. The following macros are used to facilitate the capturing of expected and unexpected interruptions

- **TRAPS** – Run-time enabling at assigned storage locations of disabled wait state new PSW's for unexpected interruptions.
- **TRAP64** – Creates disabled wait state PSW's inhibiting further action for unexpected interruptions for the class of architectures that utilize 64-bit PSW's (all pre-z/Architecture systems).
- **TRAP128** – Creates disabled wait state PSW's inhibiting further action for unexpected interruptions for the class of architectures that utilize 128-bit PSW's (currently only z/Architecture).
- **ASALOAD** – Establishes disabled wait state new PSWs before entering the program during the Initial Program Load function. Useful in IPL contexts not utilizing an IPL device. Device specific installation considerations required when preparing IPL media.
- **ASAIPL** – Establish an IPL PSW within the assigned storage area for program entry during the manually initiated Initial Program Load function.
- **CPUWAIT** – Wait for an expected event using a new PSW that passes control where and in which selected state required by the program.

Definition	Creation	Init/Term	Process
--	ASALOAD ASAIPL TRAP64 TRAP128	Init: TRAPS	M: CPUWAIT

TRAPS

Early in the execution of the program, valid PSW's for each interruption class can be established by using the **TRAPS** macro. **TRAPS** creates disabled-wait state PSW's and moves them to assigned storage locations allowing any interruption to be captured and ensuring an endless PSW loop does not result. Its actions are based upon the assembly current architecture level as reported by the **ARCHLVL** macro. Uses **TRAP64** and **TRAP128** to generate disabled wait PSW's as needed.

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Levels 1-9 TRAP64	Level 9 TRAP128	Location Description
X'0'-X'7'	X'1A0'-X'1AF'	Restart New PSW
X'58'-X'5F'	X'1B0'-X'1BF'	External New PSW
X'60'-X'67'	X'1C0'-X'1CF'	Supervisor-Call New PSW
X'68'-X'6F'	X'1D0'-X'1DF'	Program New PSW
X'70'-X'77'	X'1E0'-X'1EF'	Machine-Check New PSW
X'78'-X'7F'	X'1F0'-X'1FF'	Input/Output New PSW

The `ENABLE` parameter controls the actions of the `TRAPS` macro:

- `ENABLE=YES` causes the trap PSW's to be moved to their assigned storage locations from those generated by the `TRAPS` macro itself.
- `ENABLE=NO` causes the `TRAPS` macro to generate in-line the disabled wait PSW's intended for use by the `TRAPS ENABLE=ONLY` option.
- `ENABLE=ONLY` cause the PSW's created by the separate `TRAPS ENABLE=NO` option to be moved to their assigned storage locations.

TRAP64

Generates in-line 64-bit disabled wait state PSW's in the current architecture format or as specified by the `PSW` parameter. Each disabled-wait PSW has as its instruction address the assigned storage location of its corresponding Old PSW.

Because the Restart New PSW assigned storage location is not contiguous with the other New PSW's, it needs special options depending upon the context in which the PSW's are being generated.

- `RESTART=YES` causes the Restart New PSW to be included with the generated PSWs.
- `RESTART=ONLY` causes only the Restart New PSW to be generated, inhibiting the other New PSW's.
- `RESTART=NO` causes the other PSW's to be generated without the Restart New PSW.

TRAP128

Generates in-line 128-bit disabled wait state PSW's in z/Architecture format. Each disabled-wait PSW has as its instruction address the assigned storage location of its corresponding z/Architecture Old PSW.

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ASALOAD

The `ASALOAD` macro initiates a new region with a starting address of 0, causing its contents to be placed at absolute 0. It allows, during the IPL function, initialization of the new PSW assigned storage locations trapping interruptions for which the program is not prepared to support. The value of doing this during the IPL function is that early program errors, including an incorrect IPL PSW can be caught.

The region created by the `ASALOAD` macro is always 512 bytes in length.

Unless the entire physical image is loaded into storage, the placement of the region within the image does change the initialization of the assigned storage area. If the entire image is being loaded into storage, the image must be loaded at absolute address 0 and the region created by the `ASALOAD` macro must be the first region of the image.

Refer to the *ASMA* manual for details on the relationships of regions, control sections and the image.

ASAIPL

The `ASAIPL` macro is intended to inject into the `ASALOAD` created region a valid PSW at absolute address 0. This PSW is suitable for the use with either the IPL or restart functions.

`ASAIPL` must be preceded in the assembly by an `ASALOAD` macro creating the region and control section containing the assigned storage location content.

The PSW placed at the start of the `ASALOAD` created region overwrites the restart trap PSW created by the `ASALOAD` macro itself at absolute address 0. If the program wishes to trap any subsequent attempts to restart the program with a restart interruption, subsequent to control being passed to the program, it must overwrite the IPL or restart new PSW with a trap PSW. The `TRAP64` macro can create the PSW by use of the `RESTART=ONLY` parameter. The program can then move this PSW to absolute addresses 0-7, inclusive.

CPUWAIT

On occasion a program without the complexity of interrupt service routines may need to wait for specific events expected by the program. These events are:

- expired timers, and
- input/output operations.

If the program does not have any interrupt service routines, how can this be accomplished? At the level of the interruption an interrupt service routine is nothing more than a place to which control is passed to handle the interrupt. Because such events can occur asynchronously from the running program, interrupt service routines typically require saving upon entry and a restoration of the program's state. By causing the interruption to pass control to a place where the program's state is known, only the passing of control is required.

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If a program expects to wait, the place at which its state is known is at the point in the program where it expects to perform the wait. In other words, inline, is the best place to perform the wait. The `CPUWAIT` macro performs an inline wait. It does this by:

1. establishing a new PSW for the interrupt class upon which it is waiting that passes control following the instructions, and optionally saving the previous new PSW;
2. loading an enabled wait PSW for the anticipated event; and
3. receiving program control following the event
4. passing control as specified by the class' related parameter, optionally restoring the previous new PSW before doing so.

The need to save program state is eliminated because the program ceases instruction execution. The formal interrupt service routine is eliminated because the instructions following the `CPUWAIT` macro process the event.

Two events are supported by the `CPUWAIT` macro:

- External interruptions and/or
- Input/Output interruptions.

Both are supported by the same `CPUWAIT` macro depending upon its parameters. This allows for example, with the appropriate preparation by the program to wait for an input/output event or a timeout if the input/output event doesn't occur.

In either case the program continues execution following the `CPUWAIT` macro. The `CPUWAIT` macro passes control as specified by its parameters. It also allows the program to differentiate between the interruption classes by setting the condition code:

- 1 – an external interruption occurred, or
- 2 – an input/output interruption occurred.

The parameters and their relationships are summarized below.

External	Input/Output	Description
EXT	IO	<p>Describes whether and how control is passed for the interruption</p> <ul style="list-style-type: none">• YES – control is passed to the statements following the <code>CPUWAIT</code> macro• NEW – uses the <code>EPSW</code> or <code>IPSW</code> as a template for the required state upon returning to the program and explicitly uses the PSW for passing control by issuing a <code>LOAD PSW</code> or <code>LOAD PSW EXTENDED</code> instruction.• label – branches to the label if the interruption occurred

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External	Input/Output	Description
		If omitted the interruption class is not enabled and any interruptions remain pending.
EPSW	IPSW	Provides a PSW template for the interruption class new PSW. The template PSW except for its: <ul style="list-style-type: none"> • interruption masks, and • condition code. Required if <code>EXT=NEW</code> or <code>IO=NEW</code> specified.
ESA	ISA	<code>YES</code> causes the interruption class' new PSW to be saved and restored before and after waiting, respectively. <code>NO</code> does not preserve the previous new PSW. Defaults to <code>YES</code> .
AM		If <code>EXT</code> or <code>IO</code> specifies either <code>YES</code> or <code>label</code> , this address mode is used. Defaults to 24-bit addressing. If <code>EXT</code> or <code>IO</code> specifies <code>NEW</code> , the template PSW's address mode is used.
RELO		Specify <code>YES</code> to cause relocation if <code>EXT=YES</code> or <code>label</code> , or <code>IO=YES</code> or <code>label</code> . Ignored for <code>EXT=NEW</code> or <code>IO=NEW</code> . Defaults to <code>NO</code> . Relocation of the template PSW instruction address when either <code>EXT=NEW</code> or <code>IO=NEW</code> is the responsibility of the program before it is used by the <code>CPUWAIT</code> macro.
REG		A register required for use by the <code>CPUWAIT</code> macro. Defaults to 1.
Not applicable	CHAN	Allows the waiting PSW's channel masks to be specified for System/360 or System/370 BC-mode environments. Defaults to 254 (all channels enabled).

The program should examine any interruption information supplied in assigned storage locations related to the interruption class. Presumably the CPU is placed into a wait state for the purpose of waiting for an event to occur. Generally, because the interruption classes supported by the `CPUWAIT` macro may occur for multiple reasons, only by examination of the interruption information is it possible to determine if the expected event occurred.

Performing Input/Output Operations

Mainframe systems from their inception are designed to perform input/output operations in an interruption driven environment. Interruptions result from initiated input/output operations and other input/output related notifications occur through interruptions. While it is technically

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possible to perform input/output operations without utilizing interruptions, it is not possible to be informed of input/output related notifications without interruptions. The use of the input/output system without interruptions has never been encouraged. SATK therefore only supports the input/output system utilizing interruptions.

Interruptions resulting from initiated input/output operations are referred to as “solicited” interruptions. Event notification interruptions outside of input/output operations are referred to as “unsolicited” interruptions.

Mainframes have utilized two different architectures for the input/output system. Both are based upon the concepts of channel programs executed by the channel with the aid of the devices themselves. From the view of the CPU, Initiating and termination of the channel programs differs between the two architectures. The form and structure of input/output notifications also differ. Providing a simple, consistent interface to the two different I/O architectures without losing flexibility is the primary goal of the supplied macros.

The first architecture, used individual channels controlled by the program for input/output operations. By the third generation of mainframes, this system was replaced by a channel subsystem that managed all of the physical channels and performed input/output operations on behalf of the program. As the technology advanced, the information necessary for the channel subsystem to perform its tasks increased. New storage based structures were introduced for this purpose.

The macros have no knowledge of the operations, channel commands or details of successful or failed activities. The program (and developer) must supply such knowledge. Under either architecture, the macros will **initiate** an operation and **detect** its success or failure as defined by the program under either architecture. In very simple settings, the input/output operations can be transferred between the two input/output architectures without program changes. See the `hello.asm` sample program for an example of this usage. Because facilities differ between the two architectures, this transportability is not generally likely for complex operations.

The input/output operations typically involve three aspects of the input/output architecture:

- preparing the CPU for input/output operations,
- making individual devices ready for use and then
- using the device for operations.

Seven macros work together for these functions:

- `IOINIT` – prepares the CPU for input/output operations, typically used once by the program;
- `IOCB` – the assembled structure used to define an input/output device used by the program, used once for each device;
- `IOCBDS` – creates a DSECT named `IOCB`, defining the `IOCB` structure fields, used once by the program;

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- `ENADEV` – makes devices defined by an `IOCB` macro ready for use by the CPU;
- `RAWIO` – performs an inline input/output operation with an `IOCB` defined device; and
- `IOTRFR` – calculate the number of bytes actually transferred following a successful I/O operation.
- `RAWAIT` – performs an inline wait for an unsolicited interruption from the `IOCB` defined device.

All, except `IOINIT` utilize a common structure in performing these function.

The generated `IOCB` structure links the program, the input/output system and actions with the device. Because the `ENADEV`, `RAWAIT`, and `RAWIO` macros are strictly driven through the `IOCB` a single use of the these two macros can be used for all devices and all input/output operations by simply addressing a different `IOCB` before executing the inline instructions. This is intended to allow these three macro to be placed in a subroutine and reused by the program.

Definition	Creation	Init/Term	Process
<code>IOCBDS</code>	<code>IOCB</code>	Init: <code>IOINIT</code> Init: <code>ENADEV</code>	M: <code>IOTRFR</code> M: <code>RAWIO</code> M: <code>RAWAIT</code>

All of the macros, with the exception of `IOCBDS`, are dependent upon the current architecture level implied by the current `XMODE` `PSW` setting. The architecture level is used to determine which I/O architecture scheme is in use. Channel command words can utilize either of two formats. Only the `IOTRFR` macro is sensitive to the CCW format specified by the `XMODE` `CCW` setting.

IOCB Structure

The `IOCB` structure links all of the macros (with the exception of the `IOINIT` macro) to the program and each other. The `IOCB` is the mechanism by which a SATK program and the input/output related macros communicate with each other and attached devices. The `IOCB` also normalizes the differences between the two input/output architectures. The `IOCBDS` macro identifies certain fields within the structure as read-only. The program should not alter these fields. They are critical to the operation of the macros.

The two input/output architectures both depend upon assigned storage areas and the use of channel-command words for communication with a device performing an input/output operations. Each uses a similar, although not identical, structure for communicating the results of an operation. Locating this information differs, but its location is made transparent to the SATK program through use of the `IOCB` structure.

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The channel subsystem specific structures are not inherently part of the IOCB structure, although the IOCB macro can as a convenience create the Operation-Request Block (ORB) and reserve space for the transient needs of the program for access Subchannel-Information Block (SCHIB) and Interrupt-Response Block (IRB) access. Even when the IOCB provides these structures, they are external to the IOCB structure. The addresses for each are used by the I/O macros as if the structures were created separate from the IOCB. Whether a field is read-only or not, the information within the IOCB structure is shared between the I/O macros and the program.

The IOCB structure is assembled by the `IOCB` macro and defined by the `IOCBDS` macro. All fields may be examined by the program, but only specific fields should be modified by the program. These fields are identified by an 'X' in the IOCB dummy section created by `IOCBDS`. Intentionally the IOCB structure may be completely specified during assembly or completely created during program execution or some combination. Regardless of the creation, each device using the I/O macros described in this section requires an IOCB structure.

The IOCB is utilized for multiple purposes related to the input/output system. Some fields are expected to be modified by the program as needed. These

- Provide the logical identification of the corresponding device or subchannel as known by the program, field `IOCBDEV`;
- Identify the input/output operations to be performed, fields `IOCBCAW` or `IOCBORB`;
- Specify conditions related to the device or subchannel operation representing errors, of special significance or completely ignored, fields `IOCBUM`, `IOCBCM`, and `IOCBWAIT`; and
- Locate structures required by the channel subsystem used by the `ENADEV`, `RAWIO` or `RAWAIT` macros, fields `IOCBIRB` and `IOCBSIB`.

Other fields, are expected to only be examined by the program, but not modified. These fields:

- Provide the corresponding I/O system designation for the device or subchannel when interacting with it, initialized by `ENADEV`, field `IOCBID`;
- Normalize I/O architecture specific interruption information into the IOCB structure for examination by the `IOTRFR`, `RAWIO` or `RAWAIT` macros, fields `IOCBSCCW`, `IOCBSCNT`, `IOCBUS`, and, `IOCBCS`; and
- Internally used by `RAWIO` or `RAWAIT`, fields `IOCBZERO`, `IOCBUT`, `IOCBCT`, `IOCBSC`.

The following table summarizes the relationships between the various macros, the IOCB fields and the program. The column heading 'CH' indicates the field is used by channel-based input/output system. The column heading 'CS' indicates that the field is used by the channel subsystem.

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IOCB Field	Program	CH	CS	IOCB Parm.	ENADEV	RAWIO	IOTRFR	RAWAIT
IOCBDID	RO	X	X		initializes	input		input
IOCBDEV	RW	X	X	DEV	input			
IOCBUM	RW	X	X	UERR		input		
IOCBCM	RW	X	X	CERR		input		
IOCBUS	RO	X	X			updates		updates
IOBCS	RO	X	X			updates		updates
IOCBUT	RO	X	X			updates		updates
IOCBCT	RO	X	X			updates		
IOCBSC	RO		X					updates
IOCBWAIT	RW	X	X	WAIT				input
IOCBSCCW	RO	X	X			updates	input	
IOCBSCNT	RO	X	X			updates	input	
IOBCAW	RW	X	***	CCW, KEY *		input		
IOCBORB	RW	***	X	ORB		input		
IOCBIRB	RW		X	IRB		input **		input **
IOCBSIB	RW		X	SCHIB	input **			

* IOCB macro parameters **CCW**, **KEY** and **FLAG** are used to initialize the generated ORB when an explicit **ORB** parameter is omitted.

** The field is not altered by the macro. However, the area to which it points is updated by the macro.

*** The **IOBCAW** and **IOCBORB** fields overlap or correspond. Both fields serve to identify to the I/O system the location of the channel program constituting the initiated input/output operations depending upon the system in use. The **IOBCAW** directly locates the channel program. The **IOCBORB** field indirectly locates the channel program by providing the location of the ORB that contains the explicit location.

Using the Input/Output Macros

This section describes the steps required in a program to use the basic input/output macros. The following two sections give details related to the use of the macros in a specific input/output architecture.

The **RAWIO** and **RAWAIT** macros depend upon detecting a solicited or unsolicited interruption, respectively, from the targeted device. Interruptions from any other device are ignored and

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lost. See the input/output architecture considerations concerning the `IOINIT` macro for details on managing interruptions.

Step 1 – Define the Input/Output Structures to the Assembly

Assemble the input/output related dummy sections:

- `DSECT` macro omitting the `NAME` parameter, selecting architecture sensitive dummy sections,
- `DSECT NAME=(CH, IOCB)`, for a channel I/O system,
- `DSECT NAME=(CS, IOCB)`, for a I/O channel subsystem, or
- `DSECT NAME=IOCB`, equivalent to using the `IOCBDS` macro itself.

Step 2 – Assemble Device Definitions

Use the `IOCB` macro to define the devices the program plans to use. `IOCB` definitions are static. The macros described here do not perform device discovery involving the use of the `SENSE ID` channel command. There is nothing stopping the program from using a dynamically altered `IOCB` for that purpose.

Device definitions may be placed anywhere in the assembly. Each macro that uses the `IOCB` structure expects to address the contents via a `USING` directive for the `IOCB` dummy section.

If the channel program consists of the same input/output operations it may be assembled with the device definition.

Step 3 – Prepare the CPU for Input/Output Operations

Use the `IOINIT` macro to prepare the CPU to accept interruptions from various sources. The `IOINIT` macros loads the appropriate control register for this purpose. By default, all input/output channels or subchannels are enabled for interruption recognition by the CPU.

Step 4 – Enable Each Device for Input/Output Operations

For each device, use the `ENADEV` macro to prepare the device for use. By incorporating the `ENADEV` macro in a subroutine, a single use of the macro may be used for each device by simply loading the register used to address the `IOCB` dummy section with each `IOCB`'s address.

Step 5 – Perform an Input/Output Operation

The `RAWIO` macro initiates the execution of a channel program by a device or subchannel using the `IOCB` structure associated with the device. It performs the operations and accumulated solicited interruption information for analysis of its success or failure. Special handling of a physical end-of-file condition (`EOF` parameter) or need to access device sense

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data (`SENSE` parameter) are provided. If either are used the unit exception or unit check conditions, respectively, must not be set in the IOCB `IOCBUM` field or `IOCB` macro `UERR` parameter.

Depending upon the needs of the program the IOCB fields may be updated for the specific operation. Different operations with a device or subchannel may require different handling of the status indicators. Some may be errors in some settings but not others. Program alteration of the `IOCBUM` or `IOCBCM` fields may be required. Correspondingly, a different sequence of input/output operations may require changes to the IOCB or channel subsystem structures to utilize a different channel program by alteration of the `IOCBCAW` or the address of the first channel command word in the channel subsystem Operation-Request Block.

For input/output operations where the number of bytes transferred is unpredictable, the `IOTRFR` macro calculates the number of bytes actually transferred based upon the accumulated status information in the IOCB. The macro assumes a successful completion of the input/output operation. This usually requires suppression of incorrect length indication. Non-default `IOCBUM`, `CCW` and `ORB` flags may be required to properly utilize the indication.

Step 6 – Detect Device Attention or Other Event

Some devices utilize the attention unit status to indicate that input is available. This is usually the case for devices used by an operator, for example a console or graphic display unit. Use the `RAWAIT` macro to perform this function. The macro waits for an unsolicited interruption from the device with any of the status indications set by the `IOCB` macro `WAIT` parameter or contained in the `IOCBWAIT` IOCB field at the time the `RAWAIT` macro is executed by the program.

By default, the `IOCB WAIT` parameter sets the attention status.

Channel Input/Output Considerations

No special considerations exist for use of the `IOCBDS`, `ENADEV`, or `IOTRFR` macros.

IOCB

The `IOCB` macro positional macro parameter `DEV` specifies a device's channel and unit address.

The address assigned to channel attached device when using the Hercules emulator is the address provided in the device's configuration statement.

IOINIT

Control register 2 is loaded by the `IOINIT` macro on System/370 or System/380 systems.

The CPU reset that is part of the IPL function will set all bits in control register 2 to ones. If all channels are to be enabled for interruptions, then `IOINIT` is superfluous following an IPL.

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System/360 systems do not support control registers and on these systems, `IOINIT` generates no instructions.

Managing I/O Interrupts on System/370 in EC mode or System/380

To ensure interruptions are not lost though, a channel must not be enabled for interruptions if the program is not prepared to lose the interruption. At the level of an interruption, the CPU is unable to differentiate between solicited or unsolicited interruptions. If the CPU is enabled for input/output interruptions by the PSW, and an interruption occurs from a device that is on a channel that is enabled for interruptions, the CPU will accept it. If the channel is not enabled for interruptions, the interruption will remain pending until such time as it is enabled.

By separating a device or set of devices onto its own channel, the program can control which devices have the potential for lose. Devices used exclusively with `RAWIO`, can generally be safely used without concern. Unsolicited interruptions though can occur at any time in relationship to other operations. Hence devices which may require use of the `RAWAIT` macro should be separated. In this setting `IOINIT` can manage which channels can present an interrupt and which can not. Before issuing the `RAWAIT` macro, `IOINIT` can enable the channel on which the device resides and disable the others. Before issuing the `RAWIO` macro, `IOINIT` can be used to disable interruptions from these devices and enable them for the other devices used for normal operations. In the case of a solicited operation following the detection of an unsolicited event, no change in enabled channels is required.

More advanced management of interruptions requires formal interrupt service routines.

Managing I/O Interrupts on System/370 in BC Mode

The same considerations apply to System/370 in BC mode. However, the use of channel masks in control register 2 only apply to channels 6 or above. For channels 0 through 5 inclusive the techniques described in the following section apply.

Managing I/O Interrupts on System/360

The same considerations apply to System/360 as on System/370. However, the “knob” that controls channel interrupts is within the PSW itself. The PSW enabling input/output interruptions is embedded within the `CPUWAIT` macro used by the `RAWIO` or `RAWAIT` macro. Run-time modification of the mask within this waiting PSW is not readily available. In this case separate `RAWIO` or `RAWAIT` macros should be used with the appropriate enabling channel mask set by the `CHAN` parameter available on the two macros.

RAWIO

Input/output operations are initiated at the device by means of a `START IO` instruction. The CPU then waits for solicited interruptions until the accumulated status provided by the CSW indicates the channel end and device end status.

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Any interruption that occurs for the target device is considered a solicited interruption by the `RAWIO` macro. No mechanism exists to differentiate between solicited and unsolicited interruptions for channel attached devices. Only the state of the program knows which is expected.

RAWAIT

Any interruption that occurs for the target device is considered an unsolicited interruption by the `RAWAIT` macro. No mechanism exists to differentiate between solicited and unsolicited interruptions for channel attached devices. Only the state of the program knows which is expected.

Multiple status conditions are possible for unsolicited interruptions besides the attention unit status.

Channel Subsystem Considerations

No special considerations exist for use of the `IOCBDS` or `IOTRFR` macros. While simple scenarios may not require an understanding of the roles of the channel subsystem specific structures, generally programmer familiarity will be required.

IOCB

The `IOCB` macro positional macro parameter `DEV` specifies a subchannel's device number. The device number is analogous to a channel attached device's channel and unit addresses. The subchannel device number when using the Hercules emulator is the address provided in the device's configuration statement.

The areas identified by the `SCHIB` or `IRB` parameters must be large enough to contain the structure that may be stored. For the `SCHIB`, this is 13 full words, 52 bytes, full word aligned. For the `IRB` this must be 24 full words, 96 bytes, full word aligned. It is possible for all `IOCB`'s to share the same 96-byte area for their respective `SCHIB` or `IRB` because at any given point in time the area will be used either for only a single `SCHIB` (by the `ENADEV` macro) or `IRB` (either the `RAWIO` or `RAWAIT` macro) related to one subchannel.

IONIT

Control register 6 is loaded by the `IOINIT` macro on systems having a channel subsystem with a mask enabling all subchannel subclasses for interruptions. Control register 6 is set to all zeros by the CPU reset that occurs during the IPL function. Without a setting of mask bits in control register 6, no subchannel interruptions will be recognized by the CPU. `IOINIT` is required when a channel subsystem is in use.

Managing Subchannel Interruptions

The potential for interruption loss exists with channel subsystem interruptions in the same

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way with channel attached devices. Because the channel subsystem takes over responsibility for management of the channels, interruptions are managed through the concept of an interruption subclass. When the I/O reset associated with the IPL function occurs, all subchannels are placed in interruption subclass 0. Interruption subclasses are limited to eight, subclasses 0 through 7 inclusive. By adjusting the enabled interruption subclass in control register 6, the program can control which devices are enabled at any given time. By disabling an interruption subclass, all subchannel assigned to the subclass remain interruption pending until the CPU is enabled for input/output interruptions and the interruption subclass is enabled by its mask bit being set to one in control register 6. As with channel attached devices, the interruption mask can be manipulated by the `IOINIT` macro.

See the `ENADEV` considerations for setting a subchannel's interruption subclass.

ENADEV

The operation of `ENADEV` on channel subsystem is more complex than for channel attached devices. Each subchannel in the channel subsystem is examined by using the `STORE SUBCHANNEL` instruction until the device number, IOCB `IOCBDEV` field, is found or until all subchannels have been examined. Once the subchannel with the device number is located, the `IOCBDID` IOCB field is initialized with the subchannel's subsystem identification number. The subchannel itself is enabled with the channel subsystem using a `MODIFY SUBCHANNEL` instruction.

By default the subchannel will utilize an interruption subclass of zero. The interruption subclass can be modified when the subchannel is enabled by supplying a value in the register identified by the `ENADEV CLS` keyword parameter. If the `CLS` parameter is omitted, the interruption subclass remains unchanged. See the section "Managing Subchannel Interruptions" why this may be useful.

By specifying the `CSNS=YES` parameter, the subchannels enabled by the macro will be enabled for concurrent sense. Separate macros must be use to enable a mixture of some subchannels enabled for concurrent sense and some that are not.

The strategy used by the `ENADEV` macro in locating the subchannel associated with a device number is not encouraged for many devices. Rather than searching the subchannels for each desired device number, it is more efficient to scan the subchannels once and repetitively scan a memory resident table containing the device numbers sought by the program until each is found or the subchannels are exhausted. For a small number of devices this strategy is simpler if less efficient.

RAWIO

Input/output operations are initiated at the subchannel by means of a `START SUBCHANNEL` instruction. The CPU then waits for solicited interruptions from the subchannel until primary status is presented by the SCSW stored with the IRB by the `TEST SUBCHANNEL` instruction. Interruptions occurring subsequent to the `START SUBCHANNEL` instruction are assumed to be

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solicited by the `RAWIO` macro.

Depending upon the nature of the input/output operations a program supplied Operation-Request Block, ORB, may be required. The ORB macro may be used to assemble the structure.

If the program elects to use different channel programs with the subchannel with which an IOCB is associated, the ORB must be updated by the program before the `RAWIO` macro is used regardless of whether it is supplied by the program or supplied by the `RAWIO` macro.

Use of concurrent sense is possible with the `RAWIO` macro provided the subchannel has been enabled for it through use of the `ENADEV CSNS=YES` parameter. The location to which control is passed for unit check device status must be prepared to examine the IRB, located by the IOCB `IOCBIRB` field, for concurrent sense. The assumption is that the sense information is available in the stored IRB. The SCSW bit 14 and the ERW bit 7 must both be one for concurrent sense information to be present in the IRB ECW. Detailed formats for areas other than the SCSW must be supplied by the programmer.

RAWAIT

The `RAWAIT` macro waits for an interruption from the target subchannel. Any interruption from the target subchannel for which the SCSW device active status is present is treated as an error.

Only the attention unit status condition is reflected to the program via an unsolicited interruption. Other status conditions present with channel attached devices are handled directly by the channel subsystem.

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Functions

The use of a program stack and associated function calls proves to be a very useful programming technique. SATK has adapted, with a few adjustments, the Executable and Linking Format (ELF) function calling conventions for s390 CPU's. Macros for the use of such conventions in assembler programs are provided in the file `function.mac` found in the `srcasm` directory. This section describes these conventions, how they have been adapted and implemented by SATK.

The ELF file format is the standard used by the UNIX family of operating systems for representing unlinked object modules and linked executable programs. Each processor/system supporting this file format also provides an Application Binary Interface (ABI) Supplement defining how the file format is adapted to the specific processor. The ABI also defines how program languages implemented for the specific system will compile structures, manage a function call stack and perform function calls. The ABI is closely tied to the C programming language, but its use is not restricted to C. Both of the ELF standard and the ABI supplement are of significant interest to compiler and operating system developers that utilize the two references.

Because SATK does not directly support the ELF standard object file format, the macros provided for use with ASMA are not actually ABI compliant. Use of similar macros in the files `ABI-lcls.S`, `ABI-s390.S`, `ABI-s390x.S` and `ABI.S` found in the `src` directory with the GNU assembler are ABI compliant. The GNU assembler, `as`, does actually support the ELF file format.

The SATK implementation of functions relies heavily on these references:

- *S/390 ELF Application Binary Interface Supplement*,
http://refspecs.linuxfoundation.org/ELF/zSeries/lzsabi0_s390/book1.html
- *zSeries ELF Application Binary Interface Supplement*,
http://refspecs.linuxfoundation.org/ELF/zSeries/lzsabi0_zSeries.html

Why Functions?

Any branching instruction interrupts the default sequential instruction execution of a CPU. This is true for subroutine branching instructions. When using such instructions, the only state the subroutine must preserve is the location to which control must be returned when the subroutine has completed. This seems simple. And it is. However, for the assembly language programmer what becomes more complex is ensuring critical caller state, particularly in registers, is not lost while execution is occurring within the subroutine. If multiple subroutines are involved, or a subroutine needs to call another, the complexity starts to become unmanageable for the assembler programmer.

The natural recourse for this challenge is to establish a set of conventions observed by all subroutines and a reusable strategy for the preservation of program state during the call to a subroutine. The program state, regardless of the number of subroutine calls, is preserved in

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the program stack. Each subroutine gets a portion of the stack, a stack frame, for preserving its own state. The subroutines play by a set of rules that preserve the state.

Program state requiring preservation is variable data (as opposed to constant data) that must not be altered while a subroutine is executing on behalf of the program. Such variable data can reside in two places. One is memory used by the calling portion of the program. The second is resident within CPU registers at the point the subroutine is actually called. For the variable data in CPU registers to be preserved, there is only one place where the data can be preserved, namely memory. The stack frame supports the preservation of both. The first form of variable data can reside in the stack frame itself while the program is running as local data. The second form, CPU registers, must be transferred to storage, also in the stack frame, to preserve it, and returned to the registers from the stack frame thereby preserving it. Once the subroutine's caller's state has been preserved, the subroutine is free to use CPU registers and store its own local data in its own stack frame. Somewhere in this process, must a new stack frame become available for use of the called subroutine. For such interactions to occur, the program and all subroutines must support the same set of conventions, particularly with regard to CPU registers that participate in the process of state preservation and how each stack frame is structured.

The set of conventions for the purpose of simplifying the use of subroutines are collectively described here as “functions.” Functions solve much of the programming challenge in the use of subroutines for the assembly language programmer (and compiler developers too). It should be obvious that it is very desirable for these conventions' implementation be as efficient as possible. The conventions will be used in numerous programs and any inefficiencies will be magnified through this usage. The point at which a function call is made, the entering of the called function (prolog) and the point of return (epilog) by the called function become the critical points where the conventions are managed. It is within these key points that the stack is managed. The CPU instructions, the registers and roles within the CPU will drive the conventions.

The Stack

The program stack, as described in the previous section, is at the core of function usage. The stack resides in memory. Before any functions can be called the location of the stack must be known. The bare-metal program must establish the program stack. The program stack grows downward in memory, starting at some address with stack frames added at lower memory locations. As frames are removed, the stack address returns to addresses higher in memory.

The `STACK` and `STKINIT` macros provide support for stack initialization. The `STACK` macro defines an assembler label that represents the program's bottom of the stack location. The `STKINIT` macro performs run-time initialization of the stack. The stack must be initialized before any run-time function calls can be made. Unpredictable results will occur otherwise.

`STKINIT` accepts a run-time value in a register, a symbol of an address constant that defines the bottom of the stack or a symbol created by the `STACK` macro.

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The “bottom of the stack” address establishes the bottom stack frame. It must already have space reserved in storage for preservation of the portion of the program initializing the stack. This allows the code that initializes the stack to then proceed to call functions dependent upon the stack. The initializing code, while being able to utilize functions, is itself not a function. The program stack frame format defines the size of this first stack frame.

The Stack Frame

As defined by the ELF ABI supplements, the stack frame consists of three areas, only one of which is required:

1. A back pointer to the previous stack frame and accompanying language processor reserved field, both of which are either present or absent,
2. Required register save area and
3. Optional function local fields.

The first two areas are global to the program. All functions will expect the same structure. The third area is local to a specific function and varies.

Function local fields are specific to a given function's use of the stack. For each function that uses local stack fields, the function definition must be preceded by a `LOCAL` macro and one or more `DS` directives defining its local fields.

For many modern systems, the back pointer is not required for the support of functions. By default SATK does not include the back pointer or language processor reserved field in the stack frame structure, although it can be forced. Why one would want to do this when it is not needed and compatibility is not an issue is unclear. But these two fields can be forced.

The structure of the register save area is required and must be the same for all functions in the ASMA assembled bare metal program. The `FRAME` macro defines this format by creating a `DSECT` for the stack frame. Due to the difference in register sizes, the register save areas and other fields will differ in size between 64-bit and 32-bit register CPU's.

Register Usage

The ELF ABI supplements describe register usage. Register content is described as “saved” or as being “volatile”. These terms are expressed from the point at which a function is called, and whether the content of a register can be expected to be the same before and after the call. Saved registers have their contents preserved across a function call. Volatile registers do not.

The supplements referenced above are oriented to a certain level of architecture that provides certain capabilities. The SATK attempts to provide support for all levels of the architecture, some of which may not offer those capabilities.

Assuming a register is used to point to a function's own stack frame, that register would need to be preserved across function calls.

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On mainframe systems, establishing the return location for a subroutine call (which is in essence what a function is) requires a register. Whatever may be in it before the call to a function, it will obviously be different as a result of the call. So that register is volatile.

The ABI has its roots in the C programming language. This influences some aspects of the use of registers. For example, a C function can return one and only one value as a result of the function call. Some number of registers, platform dependent, are allowed to contain parameters of the call. For mainframe systems this is 4, one of which being the register that contains the value returned by the function. These registers are described as volatile. The return value register is obvious. Whatever was in the register before the call will be replaced by what the called function returns. The reason the other parameter registers are described as volatile is less obvious. Realizing that a called function can itself call a function using these same parameter registers for its call makes it clear why they are likely to be volatile.

Mainframe systems utilize different registers for floating point values than those for binary integer data. Floating point function parameters and return values are defined in terms of the floating point registers with similar consideration for preservation or volatility.

If any registers are altered as a result of the function call process, those must also be considered volatile.

Ultimately it is the responsibility of the **called** function to preserve those registers designated as not being volatile. It is the responsibility of the **calling** function to preserve across function calls those values of volatile registers, usually saving the value within its portion of the stack frame, before a function call.

SATK Function Register Conventions

The following table describes the register conventions of SATK functions. Volatile registers are highlighted in yellow. General registers are prefixed with the letter 'R'. Floating point registers are prefixed with the letter 'F'. Access registers are prefixed with the letter 'A'. Control registers are prefixed with the letter 'C'. 'FPC' designates the Floating-Point-Control register.

The 'Levels' column indicates in which architecture levels the convention applies.

Registers	Levels	Register Usage Description	Volatile
R0	all	Available for local function usage	yes
R1	all	Available for local function usage	yes
R2-R5	all	On function entry, optional binary integer parameter	yes
	all	On function exit, optional binary integer returned value	
R6	all	On function entry, optional binary integer parameter	no
		After entry, available for local function usage	
R7-R12	all	Available for local function usage	no

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Registers	Levels	Register Usage Description	Volatile
R13	all	Function base register	no
R14	all	Function return address	yes
R15	all	On function entry, caller's stack frame pointer	no
	all	After function entry, function stack frame pointer	
F0, F2	all	On function entry, optional floating point parameter	yes
		On function exit, optional floating point returned value	
F4, F6	all	Local function floating point values	no
F1, F3, F5, F7-F15	7-9	Local function floating point values	no
FPC	7-9	Available for local function usage	yes
A0-A15	6-9	Available for local function usage	yes
C0-C15	2-9	Global system control values	yes

Alterations in these conventions are possible. However, the use of the SATK supplied macros requires that R13-R15 are not modified. Use of registers R13-R15 is enforced by use of the macros contained in `function.mac`. The one register whose content must not be altered before a function is called is R15. The value of the stack pointer upon entry to a function must be the same when a function is called. It is recommended that use of R15 be avoided when using SATK functions.

The following sections provided additional details with regard to specific registers and how their SATK usage may differ from those identified in the ELF ABI references.

R2-R5

The ELF ABI supplements restrict a function to a single return value in R2. The SATK extends the use of registers for return values to any of the additional parameter passing registers.

R12

The ELF ABI supplements use R12 for the address of the global offset table, aka the GOT. The GOT is specific to the ELF file format. Accessing global addresses is straight forward in assembly. Simply defining an address constant for the location suffices. SATK generalizes the use of R12.

If the bare-metal program has a structure that forms the basis of its global context, usage of R12 for its address would be consistent with the ELF ABI usage of R12.

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R13

The ELF ABI supplements define the use of R13 as “Local variable, commonly used as Literal Pool pointer”. The architectures targeted by the ELF ABI all have the ability to use the PSW instruction address for relative addressing. This eliminates the need of a base register required for the function for branching purposes. Some architectures supported by SATK do not have this option. Branching within the function requires a base register for that purpose. For this reason, the SATK establishes a base register for the entire function.

R15

While the rules can be more flexible within the SATK, the one register that should be avoided by the program is R15 when a program stack is in use. It is managed by the SATK function macros. If a function must use R15, it must restore its value following before using the `CALL` macro.

A0, A1

The ELF ABI supplements restrict the use of A0 and both A0 and A1, depending upon the supplement, to system usage. The actual usage is in support of thread local storage. The address of the thread local storage is supplied in register A0 or both A0 and A1. SATK does not support the concept of thread local storage, so makes these volatile registers generally available.

Stack Frame Definition

The format of the stack frame must be defined before any functions may be called. The `FRAME` macro creates a `DSECT`, `STKF` in a 32-bit register architecture or `STKG` in a 64-bit register architecture. The `FRAME` macro may be called once in either of these contexts. Once called and having defined the stack frame format, it can not be changed for the entire program.

The assignment of volatile and non-volatile registers allows use of a single `STORE MULTIPLE` (`STM` or `STMG`) and `LOAD MULTIPLE` (`LM` or `LMG`) instruction when preserving and restoring, respectively, general register content. This is not the case for floating point registers. Each floating point register requires its own individual `STORE` (`STD`) and `LOAD` (`LD`) instruction.

Technically, only caller state that must be preserved requires storing of the register content into the stack frame. Most bare-metal programs do not require use of floating point registers. Usually the back pointer and compiler reserved fields are not needed. These considerations are allow allow optional sizes for the stack frame itself and the number of instructions required to preserve a function caller's state.

Four parameters of the `FRAME` macro allow the **global** setting of the state that may preserved by functions defined in the program. If space within the stack frame is not defined then the corresponding state may not be saved by any function.

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- `BACKPTR` controls whether space for a back pointer and compiler reserved field are reserved in the stack frame.
- `FP` controls whether space for floating point registers, specifically the four universally available floating point registers is reserved in the stack frame
- `AFP` reserves additional space for the additional 12 floating point registers available on some architectures.
- `PACK` removes reserved space from the stack frame for volatile parameter registers.

General Registers

Generally all parameter registers and registers required to preserve the calling function's state are saved in the stack. While the ELF ABI supplements provide space for the calling function's general and floating point registers, SATK by default only provides space for the general registers. Space for the volatile general registers is removed from the stack by specifying `PACK=YES`. Note that `PACK=YES` influences the space reserved for floating point parameter registers as well if space is reserved for them.

If `PACK=YES` space is reserved for ten general registers, R6-R15. If `PACK=NO`, space is reserved for registers fourteen registers, R2-R15. The registers saved in the stack frame matches the save area. Regardless of the value of the `PACK` parameter, only registers R6-R15 are restored.

Floating Point Registers

The need to manage floating point registers being an exceptional case for bare-metal programs. To provide space in the stack frame allowing saving of the universally available four floating point registers, specify on the `FP=YES`. For architectures that support the additional twelve floating point registers, space is provided by including the parameter `AFP=YES`. Both the `FP` and `AFP` parameters default to `NO`. `FP=YES` is required for `AFP=YES` to reserve space.

To disable the saving of floating point parameter registers, specify the parameter `PACK=YES`. This parameter removes space in the frame stack definition for parameter registers.

The following table summarizes the floating point registers for which space is reserved. `PACK=NO`, `FP=NO` and `AFP=NO` are the default parameter settings.

PACK	FP	AFP	Registers	Reserves Space
NO	NO	NO	0	
NO	NO	YES	0	
NO	YES	NO	4	F0, F2, F4, F6
NO	YES	YES	16	F0-F15

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PACK	FP	AFP	Registers	Reserves Space
YES	NO	NO	0	
YES	NO	YES	0	
YES	YES	NO	2	F4, F6
YES	YES	YES	14	F1, F3, F4-F15

Whether any floating point registers are actually saved or restored in the reserved space is controlled by the corresponding `FUNCTION` macro parameters `FP` and `AFP`. The `FRAME` macro only reserves space allowing the `FUNCTION` to use the space reserved when its parameters direct it to do so.

Back Pointer and Compiler Reserved Field

To provide space for the back pointer and the compiler reserved field, use the `BACKPTR=YES` parameter setting. If space is allocated for the back pointer, it will automatically be saved into the stack frame during a function call. By default, `BACKPTR=NO` and space is not reserved for either the back pointer or the compiler reserved field.

Local Function Usage of the Stack Frame

Usage by a function of the stack frame is supported by reserving additional space in the stack frame for the function's fields. The `LOCAL` and `FUNCTION` macros cooperate to achieve this result. The `LOCAL` macro, coded before a function definition and followed by `DS` assembler directives, defines and reserves space for the following function's usage of the stack frame. The `DS` assembler directives define the individual fields used by the function. The last `DS` assembler directive must be followed by the `FUNCTION` macro to both complete the stack frame definition for the function and define the function's prolog logic.

The `LOCAL` macro remembers the current control section and then makes the stack frame `DSECT` active, positioning the location counter following the space reserved by the `FRAME` macro. The `FUNCTION` macro ensures the stack remains on double words and returns to the control section remembered by the `LOCAL` macro. The stack frame size resulting from the additional space is used by the `FUNCTION` macro to establish the new stack frame pointer for the defined function.

Function Definition

A SATK function is defined using two macros, the `FUNCTION` and `RETURN` macros, and optionally local stack frame usage as described in the previous section. The `FUNCTION` macro defines the entry point of the function and the prolog code.

The function prolog code:

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- establishes the register conventions expected by the defined function,
- provides a base register of R13 for the function,
- saves the caller's state in the caller's stack frame,
- creates a new stack frame for use of the function, pointed to by R15, and
- saves the back pointer if the `BACKPTR=YES` was supplied on the `FRAME` macro.

The `RETURN` macro completes the function definition by supplying the function epilog code. It must follow a `FUNCTION` macro. Only one `RETURN` macro may be used in a function definition, namely the one that terminates the function. Returning to a function's caller must use the `RETURN` macro. Multiple points from which a function may need to return must branch to the single `RETURN` macro to do so. Each `FUNCTION` macro must be paired with a corresponding `RETURN` macro.

The function epilog code:

- restores the caller's state and
- returns to the caller.

It is the responsibility of the function to return in R2-R5 any returned values before returning to the caller.

Local frame usage by the function is defined previous to the `FUNCTION` macro that defines the function. The `LOCAL` macro must not be used between a `FUNCTION` and `RETURN` macro.

The `FUNCTION` macro has only two parameters, the `FP` and `AFP` parameters. They define whether the function prolog and epilog code should save and restore the universal four floating point registers and the twelve additional registers if available. Save areas must have been reserved in the stack frame structure by the `FRAME` macro for these registers to actually be saved and restored. Specify `FP=YES` and optionally `AFP=YES` with the `FUNCTION` macro for the respective floating point registers to be saved by the `FUNCTION` prolog code, and restored by the `RETURN` epilog code.