ASM32 Reference Manual

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August 21, 2025

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The ASM32 Assembler

This document describes the use of the ASM32 Assembler for the VCPU-32. The ASM32 Assembly Language represents machine language instructions symbolically, and permits declaration of addresses symbolically as well. The Assembler's function is to translate an assembly language program, stored in a source file, into machine language.

As the concept for the VCPU-32 is heavily influenced by Hewlett Packards PA-RISC architecture, the following reference manual follows the structure of the PA RISC Assmebler manual.

For details about the VCPU-32 architecture please refer to

VCPU-32 System Architecture and instructions Set Reference

1.1 Assembler Features

The Assembler provides a number of features to make assembly language programming convenient. These features include:

- **Mnemonic Instructions:** Each machine instruction is represented by a mnemonic operation code, which is easier to remember than the binary machine language operation code. The operation code, together with operands, directs the Assembler to output a binary machine instruction to the object file.

- **Symbolic Addresses:** You can select a symbol to refer to the address of a location in virtual memory. The address is often referred to as the value of the symbol, which should not be confused with the value of the memory locations at that address.

- **Symbolic Constants:** A symbol can also be selected to stand for an integer constant.

- **Expressions:** Arithmetic expressions can be formed from symbolic constants, integer constants, and arithmetic operators. Expressions involving only symbolic and integer constants, defined in the current module, are called Symbolic Constants. They can be used wherever an integer constant can be used.

- **Storage Allocation:** In addition to encoding machine language instructions symbolically, storage may be initialized to constant values or simply reserved. Symbolic addresses and labels can be associated with these memory locations.

1.2 Program Structure

An assembly language program is a sequence of statements. Each statement contains up to four fields:

- Label
- Opcode or directive
- Operands
- Comments

The operands field cannot appear without an opcode field.
There are three classes of statements:

- **Instructions:** represent a single machine instruction in symbolic form.

- **Directives:** communicate information about the program to the Assembler or cause the Assembler to initialize or reserve one or more words of storage for data.

- **Comment** is starting with a ;. All text after the comment until end of line is ignored by the assembler.

The **labe**l field is used to associate a symbolic address with an instruction or data location, or to define a symbolic constant using the .EQU, .REG, .BYTE, .HALF, etc. directives. If a label appears on a line by itself, or with a comment only, the label is associated with the next address within the same subspace and location counter.

1.3 Symbols and Constants

Both addresses and constants can be represented symbolically. Labels represent a symbolic address except when the label is on an .EQU or .REG directive. If the label is on an .EQU or .REG directive, the label represents a symbolic constant.

The Label needs to end with a ":".

Symbols are composed of

- uppercase and lowercase letters (A-Z and a-z)
- underline
- decimal digits (0-9)

A symbol needs to begin with a letter.

The Assembler considers uppercase and lowercase letters in symbols not distinct. The mnemonics for operation codes, directives, and pseudo-operations can be written in either case.

The length of a symbol name is restricted to 32. The name of a symbol needs to be unique within a scope, This means it can not occur twice or more within an adressable range.

Integer constants can be written in decimal, octal, or hexadecimal notation, as in the C language.

1.4 Register and Register Mnemonics

The VCPU-32 features 3 types of registers:

- 16 general register R0 - R15
- 8 segment register S0 - S7
- 32 control register C0 - C31

  The PSW register is a maschine internal register which is not directly used in the ASM32 assembler.

Data is loaded from memory into general registers and stored into memory from general registers. Arithmetic and logical operations are performed on the contents of the general registers.

Some additional predefined register mnemonics are provided based on the standard procedure-calling convention.

1.4.1 General Register Mnemonics

Register	Mnemonic	Description
R9	ARG3	
R10	ARG2	
R11	ARG1	
R12	ARG0	
R13	DP	Global Data
R14	RL	Return Link
R15	SP	Stack Pointer

1.4.2 Segment Register Mnemonics

Register	Mnemonic	Description
S5	TS	Task Segment
S6	JS	Job Segment
S7	SS	System Segment

1.5 Expressions

Arithmetic expressions are often valuable in writing assembly code. The Assembler allows expressions involving integer constants and symbolic constants. These terms can be combined with the standard arithmetic operators.

Operator	Operation
+	Integer addition
-	Integer subtraction
*	Integer multiplication
/	Integer division (result is truncated)
%	Modulo
L%	Left 22bit based on 32 bit value
R%	Right 10 bit based on 32 bit value

1.6 Parenthesized Subexpressions

The constant term of an expression may contain parenthesized subexpressions that alter the order of evaluation from the precedence normally associated with arithmetic operators.

For example

```
LDI R5, data5 + ( data7 - 4 ) * data0
```

1.7 Program structure

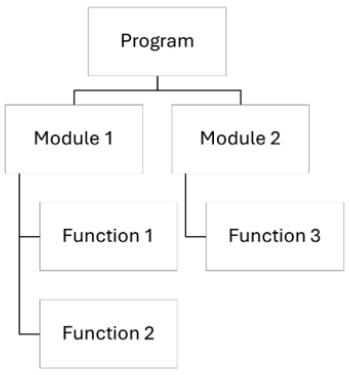
The structure of an assembler program for the ASM32 assembler has two flavours:

- **Bootstrap mode** The program consists of a GLOBAL area where all data and code sits within. There are no modules or functions allowed.
- **MODULE mode** The program consists of 1-n MODULES with functions. In this case no GLOBAL is allowed.

1.8 Scope

An assembler program has 3 Scope levels:

- Program Scope contains all information of a single source code file.
- Module Scope is the next level unit within a source file (Program Scope).
- Function Scope is the next level beyond the Module Scope.



The program scope is created automatically based on the source file. It is also called **Assembly Unit.** Per assembly run one source file is processed.

The directives .MODULE and .FUNCTION determine the scope level within a program.

The symbol table is organized according to the scope level. If a new symbol is defined it must be unique within the current scope. Reference to the symbol walks along the scope tree upwards. E.g. is a symbol is referenced on function scope, it is searched on function scope level. If it is not found it is searched on module scope level. If it is not found on module level, it is searched on program scope level.

1.9 Assembler Directives

Assembler directives allow to take special programming actions during the assembly process. The directives begin with a period (.) to distinguish them from machine instruction opcodes.

The format of a directive is:

Label: .DIRECTIVE [parameter]

.ALIGN	Aligns data address to the next address divisible by the number
.BUFFER	Reserves a buffer with size and initializes it to the given value
.BYTE	Reserves 8 bits (a byte) of storage and initializes it to the given value
.CODE	Defines the code address for the program loader or defines the following instructions as code.
.DATA	Defines the data address or defines the following directives as data.
.DOUBLE	Reserves 64 bits (a byte) of storage and initializes it to the given value
.END	Defines End of .PROGRAM, .GLOBAL, .MODULE, .FUNCTION
.EQU	Assigns an expression to an identifier
.EXPORT	Exports the name of a function
.FUNCTION	Start of Function scope
.FUNCTION MAIN	Defines the entry point of a program
.FUNCTION INIT	Defines the initialization routine entry point of a module
.GLOBAL	Defines the global area
.HALF	Reserves 16 bits (a byte) of storage and initializes it to the given value
.IMPORT	Imports all exported functions from a given module
.MODULE	Start of Module scope
.REG	Assigns a user defined name to a register
.STRING	Reserves a buffer initialized with a string
.WORD	Reserves 32 bits (a byte) of storage and initializes it to the given value

1.9.1 ALIGN

.ALIGN <parameter>

- **Label:** n.a.
- **Parameter:** any number 2, 3, 4, etc. or 1k = 1024
- **Function:** the data address is aligned to the next address which is divisible by the number without a remainder. If the number is not a 2^n, a warning is printed.

1.9.2 BUFFER

<name:> .BUFFER <parameter>

- **Label:** <name>:
- **Parameter:** size=<size in bytes,init=0xyy>
- **Function:** Reserves a buffer with size and initializes it to the given value. If no init value is given, the buffer is initialized to 0x00.

1.9.3 CODE

.CODE

- **Label:** n.a.
- **Parameter:** addr=0xyyyyyyyy
- **Function:** Defines the code 32-bit address for the program loader. This directive is only allowed in the GLOBAL Section.

1.9.4 DATA

.DATA

- **Label:** n.a.
- **Parameter:** addr=0xyyyyyyyy
- **Function:** Defines the code 32-bit address for the data area in the GLOBAL section. This directive is only allowed in the GLOBAL Section.

1.9.5 DOUBLE

<name:> .DOUBLE <parameter>

- **Label:** <name>:
- **Parameter:**init=0xyy>
- **Function:** Reserves 64 bits (a double word) of storage and initializes it to the given value. If no init value is given, the double word is initialized to 0x00.

1.9.6 END

<.END <parameter>

- **Label:** n.a.
- **Parameter:** .GLOBAL, .MODULE, .FUNCTION
- **Function:** Defines End of .GLOBAL, .MODULE, .FUNCTION and of Program.

1.9.7 EQU

<name> .EQU <parameter>

- **Label:** <name>:
- **Parameter:** name for value or expression
- **Function:** Assigns an expression to an identifier. Nested EQU are allowed. e.g. A1: .EQU 5, A2: .EQU A1.

1.9.8 EXPORT

.EXPORT <parameter>

- **Label:** n.a.
- **Parameter:** <name of FUNCTION>
- **Function:** Makes the FUNCTION accessible by other MODULES.

1.9.9 FUNCTION

<name:> .FUNCTION

- **Label:** <name>:
- **Parameter:** n.a.
- **Function:** Defines a function. This directive is only allowed in the MODULE Section. AFUNCTION con only be called if the FUNCTION is defined before in the same modue or if the FUNCTION is imported from another MODULE.

1.9.10 FUNCTION MAIN

<MAIN:> .FUNCTION

- **Label:** MAIN:
- **Parameter:** n.a.
- **Function:** Defines the main function of the program. One function with label MAIN is required on program level. Data address for data inside the function is maintained on stack (SP).

1.9.11 FUNCTION INIT

<INIT:> .FUNCTION

- **Label:** INIT:
- **Parameter:** n.a.
- **Function:** Defines the init function of the module. One INIT function is required per module. The INIT function should be defined as the last function of the MODULE. At loading time of the exectuable program all INIT functions of all modules are exectuted before the MAIN function is called.

1.9.12 GLOBAL

.GLOBAL

- **Label:** n.a.
- **Parameter:** n.a.
- **Function:** Defines the global area. In this area only the following directives are allowed: BUFFER, BYTE, DOUBLE, HALF, WORD, CODE, DATA. The global can not combined in the same source file with modules and functions.

1.9.13 HALF

<name:> .HALF <parameter>

- **Label:** <name>:
- **Parameter:**init=0xyy>
- **Function:** Reserves 16 bits (a byte) of storage and initializes it to the given value. If no init value is given, the half word is initialized to 0x00.

1.9.14 IMPORT

.IMPORT <parameter>

- **Label:** n.a.
- **Parameter:** <name of MODULE>
- **Function:** Makes all exported FUNCTIONS of the MODULE accessible. An imported FUNCTION can be called by <module name>.<function name>.

1.9.15 MODULE

<name:> .MODULE

- **Parameter:** n.a.
- **Function:** Defines a module. The instruction address is always set to 0x0000 (relative addressing). All instructions inside the module need to be in functions. Data address is in DP register.

1.9.16 REG

<name> .REG <parameter>

- **Label:** <name>:
- **Parameter:** register
- **Function:** Assigns a user defined name to a register. No nested REG are allowed.

1.9.17 STRING

<name:> .STRING <parameter>

- **Label:** <name>:
- **Parameter:** string data
- **Function:** string is terminated with 0x00

1.9.18 WORD

<name:> .WORD <parameter>

- **Label:** <name>:
- **Parameter:**init=0xyy>
- **Function:** Reserves 32 bits (a word) of storage and initializes it to the given value. If no init value is given, the word is initialized to 0x00.

1.10 ASM32 Output file structure

The output of the ASM32 assembler is based on the standard ELF format. It is adapted to the requirements of the ASM32.

We use the **ELFIO library** from Serge Lamikhov-Center. The library can be found here:

```
https://github.com/serge1/ELFIO
```

ELFIO is a lightweight, header-only C++ library for reading and generating ELF (Executable and Linkable Format) binary files. It is completely standalone, requiring no external dependencies, and integrates seamlessly into any C++ project. Built to ISO C++ standards, ELFIO ensures compatibility across a wide range of architectures and compilers.

These are the specific adaptions (so far) for writing by ASM32:

ELF header

create	ELFCLASS32, ELFDATA2MSB
set_type	ET_EXEC
set_maschine	EM_res121 (will assign maschine type later)
set_entry	CODE_ADDR

text section header

sections.add	".text"
set_name	GLOBAL or module name
set_type	SHT_PROGBITS
set_flags	SHF_ALLOC | SHF_EXECINSTR

text segment header

set_type	PT_LOAD
set_virtual_address	CODE_ADDR
set_physical_address	CODE_ADDR
set_flags	PF_X | PF_R (Execute | Read)
set_align	PAGE_SIZE

data section header

sections.add	".data"
set_name	GLOBAL or module name
set_type	SHT_PROGBITS
set_flags	SHF_ALLOC | SHF_WRITE

data segment header

set_type	PT_LOAD
set_virtual_address	DATA_ADDR
set_physical_address	DATA_ADDR
set_flags	PF_W | PF_R (Write | Read)
set_align	PAGE_SIZE

1.11 Example Program Standalone Mode

```
; ======================================
; Example program ASM32 Bootstrap Mode
; ======================================
;  Global area
; ======================================
                    .GLOBAL
                    .CODE addr=0x1000_0000
                    .DATA addr=0x2000_0000

W1:                 .WORD   init=0x05
S1:                 .STRING "Hello world"
REG1:               .REG    R1
PARAM:              .EQU    2

                    .CODE
                    ADCH    R1,R2(R3)
                    ADC.L   R1,-47
                    ADC.O   R1,R2,W1

                    .DATA
W2:                 .WORD

                    .CODE
                    ADC.L   R2,-47

                    .END
```

```
ELF Header

create                ELFCLASS32, ELFDATA2LSB
set_type              ET_EXEC
set_maschine          EM_res121
set_entry             0x1000_0000

text section

sections.add          ".text"
set_name              "GLOBAL"
set_type              SHT_PROGBITS
set_flags             SHF_ALLOC | SHF_EXECINSTR
set_addr_align        (0x10)

text segment

set_type              PT_LOAD
set_virtual_address   0x1000_0000
set_physical_address  0x1000_0000
set_flags             PF_X | PF_R (Execute | Read)
set_align             4096

data section

sections.add          ".data"
set_name              "GLOBAL"
set_type              SHT_PROGBITS
```

```
set_flags             SHF_ALLOC | SHF_WRITE
set_addr_align        (0x04)

data segment

set_type              PT_LOAD
set_virtual_address   0x2000_0000
set_physical_address  0x2000_0000
set_flags             PF_W | PF_R (Write | Read)
set_align             4096
```

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Assembler Processing

The assembler processes the sourcecode within the following steps:

- Main program
- Lexer
- Parser
- Codegen

2.0.1 Main Program

The main program establishes the overall environment, opens the source file, reads the sourcline and passes into the lexer. In parallel it builds a tree structure SRCNode global program sourceline as a base for printing sourclines, binary instructions and errormessages

The main programm contains a couple of DEBUG Switches, which provide additonal listings. Currently they are implemented as global variables which can be set to TRUE or FALSE.

- **DBG_TOKEN** Prints the list of tokens generated by the lexer.
- **DBG_PARSER** Prints details of the parsing process.
- **DBG_GENBIN** Prints details of codegen process.
- **DBG_SYMTAB** Prints the symbol table.
- **DBG_AST** Prints the abstract syntax tree.
- **DBG_SOURCE** Prints a list of address, maschine code, sourceline number and source text and corresponding errors:
- **DBG_DIS** Prints input lines for the VCPU32 disassembler.

2.0.2 Lexer

The Lexer reads the source line and extracts the tokens and provides the tokenList. This is a linked list with all tokens, sourcline number and column. During processing the lexer converts **hexadecimal values to decimal** values and masks L% and R% values accordingly.

2.0.3 Parser

The Parser reads the tokenList and generates the symbol table (SymNode) and the abstract syntax tree (ASTNode). The parser consists of mutliple subprocessing routines for label (ParseLabel), directives (ParseDirectives) and instructions (Parseinstruction).

All tokens are translated to uppercase to ensure a common naming inside symboltable etc.

2.0.4 ParseLabel

This is a simple routine which just moves a valid label token into a field named label. It will be processes with the ParseInstruction or ParseDirective routine.

If the label is called MAIN or INIT and the directive is .FUNCTION, it is checekd whether MAIN is unique across the source and if every module consists of a INIT function.

2.0.5 ParseDirective

The tokens identified as directives (starting with a .) are checked against a table dirCodeTab. If the directive is valid the appropriate processing takes place.

For each directive an entry in the symbol table is created. **MODULE** and **FUNCTON** directives and their corresponding end functions build scope levels withinn the symbol table tree.

SymbolTable

- scope type
- scope level -> program=1, module=2, function=3
- scope name
- label
- function -> directive (without .)
- value
- variable type
- linenr
- code address

- data address
- pointer to children nodes
- number of children nodes

Scope types:

- SCOPE_PROGRAM
- SCOPE_MODULE
- SCOPE_FUNCTION
- SCOPE_DIRECT

Variable Type

- Value
- Memory global
- Memory local
- Label

MODULE and FUNCTION processing

If a MODULE directive is detected, scopetype is set to SCOPE_MODULE, dataAdr is set to zero. If .ENDMODULE is detected, scope level is set back to SCOPE_PROGRAM. Analog processing for FUNCTION.

EQU and REG processing

For both directives it is checked if a directive with the same name (label) is already defined on the same scope level. If not, then the Symbol is inserted in the symboltable.

REG directives can not be nested, e.g. H1 .REG R7 and H2 .REG H1 is not allowed.

EQU directives can be nested, e.g. H1 .EQU 556 and H2 .EQU H1. In this case H1 must be defined prior to H2.

BYTE, HALF, WORD, DOUBLE, BUFFER, STRING processing

Depending of the scope level (module or function) the variable type is set to Memory global (module level) or Memory local (function level). It is checked if a directive with the same name (label) is already existing on the same scope level. If not, then the Symbol is inserted in the symboltable. BYTE, HALF, WORD and DOUBLE are aligned automatically by the assembler, e.g. WORD to word address.

BUFFER and STRING are aligned to WORD address.

If no init= parameter is provided, BYTE, HALF, WORD, DOUBLE and BUFFER are initialized to 0x00.

The values of the above variables is written to the output file with their corresponding address.

EXPORT and IMPORT processing

2.0.6 ParseInstruction

The tokens identified as instructions are checked against a table opCodeTab. If the opcoode is valid the further processing takes place in base of the type of the opcode. An entry in the opCodeTab assigns every opcode to an OpType. This Optype determines smae parsing procedure for a goup of opcodes which have the same mnemonic structure.

For every group a dedicated parsing routine is in place. In these routines every token is analyzed. if the token is an expected token an entry into the abstract systax tree (AST) is created.

AST

- node type
- value in character of the entry
- numeric value of the entry if available
- linenr of the source line
- column number of the token
- scopelevel (program, module, function)
- name of the scope
- adress of the corresponging node of the symbol table for easier search function in the symbol table.
- operand type to define the type of the value (register, memorylocation, label, value)
- address of code
- binary word of the instruction derived from opCodeTab.
- pointer to children nodes
- number of children nodes

2.0.7 ParseExpression

Expressions are recursively parsed. **ParseExpression** calls **ParseTerm** and calculates plus, minus, or, xor operations.

ParseTerm calls **ParseFactor** and calculates multiply, division, modulo, and operations.

ParseFactor processes the numbers, substitutes the EQU or global/local offsets.

2.0.8 Codegen

The codegen routine reads the **AST** sequentially, calculates code address and populates the binary word of the instruction.

The procedure GenBinOption checks the options by groups of instructions with the same options.

For instructions using a memory location the memory type can be:

- Memory global (in module) offset is calculated as the data offset within the module and register R13.
- Memory local (in function) tbd