

# ASM32 Reference Manual

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# 1

## 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 **label** 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 labels and 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 or hexadecimal notation, as in the C language. In addition it is possible to structure hexadecimal constants by underscores.

Example: `0x0123_4567_89ab`.

## 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 machine 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:

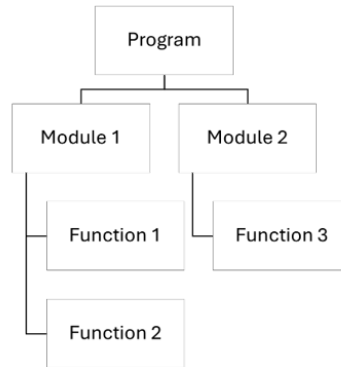
- **Standalone mode** The program consists of a GLOBAL area where all data and code sits within. There are no modules or functions allowed.
- **module mode** The program consists of 1-n MODULES with functions. In this case no GLOBAL is allowed.

## 1.8 Scope

In Standalone Mode there is only 1 scope level (program scope) allowed.

In Module Mode there are up to 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. if 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]**

The bold directives are implemented in Version 1 (A.00.1.xx).

<b>.ALIGN</b>	Aligns data address to the next address divisible by the number
<b>.BUFFER</b>	Reserves a buffer with size and initializes it to the given value
<b>.BYTE</b>	Reserves 8 bits (a byte) of storage and initializes it to the given value
<b>.CODE</b>	Defines the code address for the program loader or defines the following instructions as code.
<b>.DATA</b>	Defines the data address or defines the following directives as data.
<b>.DOUBLE</b>	Reserves 64 bits (a byte) of storage and initializes it to the given value
<b>.END</b>	Defines End of .PROGRAM, .GLOBAL, .MODULE, .FUNCTION
<b>.EQU</b>	Assigns an expression to an identifier
<b>.EXPORT</b>	Exports the name of a function
<b>.FUNCTION</b>	Start of Function scope
<b>.FUNCTION</b> MAIN	Defines the entry point of a program
<b>.FUNCTION</b> INIT	Defines the initialization routine entry point of a module
<b>.GLOBAL</b>	Defines the global area
<b>.HALF</b>	Reserves 16 bits (a byte) of storage and initializes it to the given value
<b>.IMPORT</b>	Imports all exported functions from a given module
<b>.MODULE</b>	Start of Module scope
<b>.REG</b>	Assigns a user defined name to a register
<b>.STRING</b>	Reserves a buffer initialized with a string
<b>.WORD</b>	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. For the alignment 0x00 is written to the output. 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. The buffer is aligned to word boundary. For the alignment 0x00 is written to the output.

### 1.9.3 BYTE

<name:> **.BYTE** <parameter>

- **Label:** <name>:
- **Parameter:** Number in decimal or 0xyy. Range from -128 to 127
- **Function:** Reserves 8 bits (a byte) of storage and initializes it to the given number. If no value is given, the byte is initialized to 0x00.

### 1.9.4 CODE

**.CODE**

- **Label:** Name of .text section - .text.name
- **Parameter:** addr=0xyyyyyyyy,align=0xzzzzzzzz,entry.
- **addr:** starts a new segment and a section and defines the code 32-bit address for the program loader.
- **align:** defines the alignment and is checked with the parameter addr.
- **entry:** defines this CODE section as entry.
- **Instructions:** All following instructions (until next .CODE) belong to this segment/section The Instructions are located on the address given by addr=.
- **Only in standalone mode:** This directive is only allowed in the GLOBAL Section.

### 1.9.5 DATA

#### **.DATA**

- **Label:** Name of .data section - .data.name
- **Parameter:** addr=0xyyyyyyyy,align=0xzzzzzzzz,base=Rxx
- **addr:** starts a new segment and a section and defines the code 32-bit address for the data area in the GLOBAL section.
- **align:** defines the alignment and is checked with the parameter addr.
- **base:** defines the base register to be used in offset calculation
- **Data:** All following data definitions (until next .DATA) belong to this segment/section and addresses begin with 0.
- **Only in standalone mode:** This directive is only allowed in the GLOBAL Section.

### 1.9.6 DOUBLE

#### **<name:> .DOUBLE <parameter>**

- **Label:** <name>:
- **Parameter:** Number in decimal or 0xyy. Range from -9,22337E+18 to 9,22337E+18
- **Function:** Reserves 64 bits (a double word) of storage and initializes it to the given number. If no value is given, the double word is initialized to 0x00. The double word is aligned to double word boundary. For the alignment 0x00 is written to the output.

### 1.9.7 END

#### **<.END <parameter>**

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

### 1.9.8 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.

### 1.9.9 EXPORT

**.EXPORT** <parameter>

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

### 1.9.10 FUNCTION

<name:> **.FUNCTION**

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

### 1.9.11 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).
- **Only in module mode**

### 1.9.12 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 executable program all INIT functions of all modules are executed before the MAIN function is called.
- **Only in module mode**

### 1.9.13 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.

### 1.9.14 HALF

#### **<name:> .HALF <parameter>**

- **Label:** <name>:
- **Parameter:** Number in decimal or 0xyy. Range from -32768 to 32767
- **Function:** Reserves 16 bits (a byte) of storage and initializes it to the given number. If no value is given, the half word is initialized to 0x00. The buffer is aligned to half word boundary. For the alignment 0x00 is written to the output.

### 1.9.15 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>.
- **Only in module mode**

### 1.9.16 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.
- **Only in module mode**



### 1.9.17 REG

<name> .REG <parameter>

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

### 1.9.18 STRING

<name:> .STRING <parameter>

- **Label:** <name>:
- **Parameter:** string data
- **Function:** string is terminated with 0x00. Length of string may not exceed line. The string is aligned to word boundary. For the alignment 0x00 is written to the output.

### 1.9.19 WORD

<name:> .WORD <parameter>

- **Label:** <name>:
- **Parameter:** Number in decimal or 0xyy. Range from -2147483648 to 2147483647
- **Function:** Reserves 32 bits (a word) of storage and initializes it to the given number. If no 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.

## 1.11 Example Program Standalone Mode

```

1 ; =====
2 ; Example program ASM32 Bootstrap Mode
3 ; =====
4 ; Global area
5 ; =====
6
7 .GLOBAL
8 CODE1: .CODE addr=0x0000_0020,align=0x0000_0010,entry
9 ADCH R1,R2(R3)
10
11 DATA1: .DATA addr=0x0000_0030,align=0x0000_0010
12
13 BUFF: .BUFFER size=5,init=0x99
14
15 StartReg: .REG R1
16 Foo_Bar: .EQU 47
17
18 S_1: .STRING "HALLO"
19 Word_01: .WORD 0x0123_4567
20
21 DATA2: .DATA addr=0x0003_0000,align=0x0001_0000
22
23 B1: .BYTE 0x01
24 .ALIGN 16
25 H1: .HALF 0x0123
26 D1: .DOUBLE 0x0123_4567_89ab_cdef
27 AB_C1:
28 ADCH R1,R2(R3)
29 ADD R1,Foo_Bar
30 ADC.O StartReg,R2
31 X: ADD R1,R2
32
33 ADC.L R2,-47
34 B AB_C1
35 B X
36
37 CODE2: .CODE addr=0x0001_0000,align=0x0001_0000,
38
39 ADCH R3,R4(R5)
40 ADD R1,R2
41 ADC.L R2,-47
42 ADD R1,R2
43 .END

```

E: Segment CODE1 overlaps with segment DATA1

```

+-----+
|                                     |
|                                     | ELF FILE                               |
|                                     |
+-----+
ELF Header

Class:      ELF32
Encoding:    Big endian
ELFVersion: Current
OS/ABI:      Linux
ABI Version: 0
Type:        Executable file
Machine:     Advanced Micro Devices X86-64 processor
Version:     Current
Entry:       0x20
Flags:       0x0

Section Headers:
[ Nr ] Type              Addr            Size             ES    Flg Lk   Inf  Al   Name
[  0 ] NULL              0x00000000    0x00000000    0x00   0x00 0x000 0x00
[  1 ] STRTAB             0x00000000    0x00000041    0x00   0x00 0x000 0x01  .shstrtab
[  2 ] PROGBITS           0x00000030    0x00000014    0x00  WA  0x00 0x000 0x04  .data.DATA1
[  3 ] PROGBITS           0x00030000    0x00000011    0x00  WA  0x00 0x000 0x04  .data.DATA2
[  4 ] PROGBITS           0x00000020    0x00000020    0x00  AX  0x00 0x000 0x10  .text.CODE1
[  5 ] PROGBITS           0x00010000    0x00000010    0x00  AX  0x00 0x000 0x10  .text.CODE2
[  6 ] NOTE               0x00000000    0x00000038    0x00   0x00 0x000 0x01  .note

Key to Flags: W (write), A (alloc), X (execute),
               M (merge), S (strings), I (info),
               L (link order), O (extra OS processing required),
               G (group), T (TLS), C (compressed), E (exclude)

Program Headers:
[ Nr ] Type              VirtAddr      PhysAddr      FileSize      Mem.Size      Flags      Align
[  0 ] LOAD              0x00000030    0x00000030    0x00000014    0x00000014    RW         0x00000010
[  1 ] LOAD              0x00030000    0x00030000    0x00000011    0x00000011    RW         0x00010000
[  2 ] LOAD              0x00000020    0x00000020    0x00000020    0x00000020    R E        0x00000010
[  3 ] LOAD              0x00010000    0x00010000    0x00000010    0x00000010    R E        0x00010000

[0] .data.DATA1
[1] .data.DATA2
[2] .text.CODE1
[3] .text.CODE2

Note section (.note)
  No Name      Data size  Description
  [ 0 ] Created by ASM32 0x00000000 0x00000001
  [ 1 ] A.00.1.18      0x00000000 0x00000001

Section Data:
.shstrtab
[0x00000000] 0x00 0x2e 0x73 0x68 0x73 0x74 0x72 0x74 0x61 0x62 0x00 0x2e 0x64 0x61 0x74 0x61
[0x00000010] 0x2e 0x44 0x41 0x54 0x41 0x31 0x00 0x2e 0x64 0x61 0x74 0x61 0x2e 0x44 0x41 0x54
[0x00000020] 0x41 0x32 0x00 0x2e 0x74 0x65 0x78 0x74 0x2e 0x43 0x4f 0x44 0x45 0x32 0x00 0x2e 0x6e 0x6f 0x74 0x65
[0x00000030] 0x74 0x65 0x78 0x74 0x2e 0x43 0x4f 0x44 0x45 0x32 0x00 0x2e 0x6e 0x6f 0x74 0x65

.data.DATA1
[0x00000000] 0x99 0x99 0x99 0x99 0x99 0x00 0x00 0x00 0x48 0x41 0x4c 0x4c 0x4f 0x00 0x00 0x41
[0x00000010] 0x01 0x23 0x45 0x67

.data.DATA2
[0x00000000] 0x01 0x01 0x23 0x00 0x23 0x45 0x67 0x4f 0x00 0x01 0x23 0x45 0x67 0x89 0xab 0xcd
[0x00000010] 0xef

.text.CODE1
[0x00000000] 0x44 0x49 0x00 0x23 0x44 0x49 0x00 0x23 0x40 0x40 0x00 0x2f 0x44 0x54 0x00 0x21
[0x00000010] 0x40 0x44 0x00 0x21 0x44 0xa3 0xff 0xd1 0x80 0x3f 0xff 0xfb 0x80 0x3f 0xff 0xfd
.text.CODE2
[0x00000000] 0x44 0xc9 0x00 0x45 0x40 0x44 0x00 0x21 0x44 0xa3 0xff 0xd1 0x40 0x44 0x00 0x21
.note
[0x00000000] 0x00 0x00 0x00 0x11 0x00 0x00 0x00 0x00 0x00 0x00 0x01 0x43 0x72 0x65 0x61
[0x00000010] 0x74 0x65 0x64 0x20 0x62 0x79 0x20 0x41 0x53 0x4d 0x33 0x32 0x00 0x00 0x00 0x00
[0x00000020] 0x00 0x00 0x00 0x0a 0x00 0x00 0x00 0x00 0x00 0x00 0x01 0x41 0x2e 0x30 0x30
[0x00000030] 0x2e 0x31 0x2e 0x31 0x38 0x00 0x00 0x00

Segment Data:
Segment # 0
[0x00000000] 0x99 0x99 0x99 0x99 0x99 0x00 0x00 0x00 0x48 0x41 0x4c 0x4c 0x4f 0x00 0x00 0x41
[0x00000010] 0x01 0x23 0x45 0x67
Segment # 1
[0x00000000] 0x01 0x01 0x23 0x00 0x23 0x45 0x67 0x4f 0x00 0x01 0x23 0x45 0x67 0x89 0xab 0xcd
[0x00000010] 0xef
Segment # 2
[0x00000000] 0x44 0x49 0x00 0x23 0x44 0x49 0x00 0x23 0x40 0x40 0x00 0x2f 0x44 0x54 0x00 0x21
[0x00000010] 0x40 0x44 0x00 0x21 0x44 0xa3 0xff 0xd1 0x80 0x3f 0xff 0xfb 0x80 0x3f 0xff 0xfd
Segment # 3
[0x00000000] 0x44 0xc9 0x00 0x45 0x40 0x44 0x00 0x21 0x44 0xa3 0xff 0xd1 0x40 0x44 0x00 0x21

```

## 2

# Implementation Status

This temporary chapter documents the actual implementation status of the ASM32 Assembler.

**Version 1 is the standalone program mode.(A.00.1.xx)**

### **Implemented in Version 1**

- Standalone program
- all VCPU32 instructions
- Code-generation
- proper handling underscore in names and addresses
- handling of .CODE and .DATA
- filling structure of ELF file



## 3

# Assembler Processing

The assembler processes the source code within the following steps:

- Main program
- Lexer
- Parser
- Codegen

### 3.1 Main Program

The main program establishes the overall environment, opens the source file, reads the source line and passes into the lexer. It builds a tree structure SRCNode global program source line as a base for printing source lines, binary instructions and error messages. After the lexer the parser is called and finally the coding is copied to the ELF text sections. Data are copied during the parser to the corresponding ELF data sections.

Finally the sections are added to the required segments and the ELF output file is created.

The main program contains a couple of DEBUG Switches, which provide additional 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\_SEGMENT** Prints the segment table.
- **DBG\_SOURCE** Prints a list of address, machine code, source-line number and source text and corresponding errors:
- **DBG\_ELF** Dumps ELF File.

### 3.2 Lexer

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

### 3.3 Parser

Before the Parser is started the structures for the ELF output are prepared. The Parser reads the list of tokens and generates the symbol table (SymNode) and the abstract syntax tree (ASTNode). The parser consists of multiple subprocessing routines for label (ParseLabel), directives (ParseDirectives) and instructions (ParseInstruction).

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

### 3.4 ParseLabel

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

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

### 3.5 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 **FUNCTION** directives and their corresponding end functions build scope levels within 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

**3.5.1 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.

### 3.5.2 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.

### 3.5.3 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 copied to the ELF data section at their corresponding address.

### 3.5.4 EXPORT and IMPORT processing

### **3.6 ParseInstruction**

The tokens identified as instructions are checked against a table opCodeTab. If the opcode 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 same parsing procedure for a group 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 syntax 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
- address of the corresponding 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

**3.7 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.

**3.8 Codegen**

The codegen routine reads the **AST** sequentially, calculates code address and populates the binary word of the instruction. The result is stored in the **SRC** structure

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

### 3.9 Big-Endian Little-Endian

The target architecture VCPU32 is a Big-Endian machine. the host systems Windows and MAC are Little-Endian systems.

The binary machine instructions are already in big-endian format.

All multi-byte metadata fields in the ELF file, in the ELF header, program headers, section headers, symbol tables, relocation entries, dynamic sections, and auxiliary tables — are subject to big-endian encoding as specified in `e_ident[EI_DATA]`. The raw contents of sections (machine instructions, literal data, strings) are stored as-is and are not affected by ELF's endianness rule.