

# Zyelios CPU 10 Handbook

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# Chapter 1

## Processor Features

### 1.1 Introduction

The Zyelios CPU is a virtual processor. It was created so the Wiremod players could include it in their contraptions, automating their contraptions and learning the basics of low-level programming, assembly programming and, with introduction of the HL-ZASM compiler, C programming.

This processor is very similar to the kind of processors all modern complex devices use. Its closest real-world analog is the **x86** architecture, but it has several major distinctions, the most of which is the use of floating-point numbers instead of integers.

It should be noted that the processor is a complex machine, and just like a real vehicle it will require some practice to master. It should be understood, however, that despite large number of possible uses of the processor it's based on a very simple set of logic rules. Only the complex combination of these basic logic rules creates all the behaviour of the processor.

This handbook should serve as a concise documentation that covers all of the ZCPU features and quirks you might encounter during your programming. Just like a car manual for a real car, this book covers all of the controls and features of the ZCPU. This handbook assumes the reader has some basic knowledge of real-world processors.

### 1.2 Theory

The processor was invented as a logical step up from basic analog computers. First processors were tasked with solving mathematical equations, performing simulations, and processing large arrays of statistic data.

The program that the processor must execute is split into instructions. Each instruction is a simple operation, which somehow alters processor state, or state of any external

devices. For example:

```
MOV R0,100 //Move 100 to R0
ADD R0,R1 //Add R0 with R1
```

The extra parameters specified by a programmer to alter the execution of a specific instruction by the processor are called *operands*. All the instructions in ZCPU have zero, one or two operands. The first operand is usually the *destination* operand, and the second one is the *source* operand.

If there is some result after execution the instruction, it is written to the first operand:

```
ADD R0,200; //R0 = R0 + 200
```

A *register* is a variable inside the processor. They are divided into *general purpose* registers and the *special* (internal) registers. Programmer may use general purpose registers as temporary or intermediate storage for any sort of numeric data:

```
MOV R6,100;
MOV R7,R6;
```

The special registers are used to alter the processor execution mode.

The processor may be attached to external devices and external memory via data bus. A *data bus* is a special type of device which allows to connect several other devices together. There are two data buses in ZCPU: the **MemBus** (memory bus), and the **IOBus** (input/output bus). Any memory cell on these buses and in the processors internal memory can be accessed by an *address* - an integer value. There is no principal difference between how the two buses operate, although it is possible to use memory cells located on the IOBus in an easy to understand way - by addressing them as ports:

```
MOV R0,PORT0 //Read cell 0 via I/O bus
MOV [500],R0 //Write to cell 500 via memory bus
```

There are several memory models provided by the ZCPU - these specify how much internal memory the ZCPU has (it may either have some memory and ROM, like a microcontroller, or not use any internal memory at all, similarly to common processors).

## 1.3 General Purpose Registers

There are 40 general purpose registers in the ZCPU. They are divided into the *main* and the *extended* set. The registers from the main set are called EAX, EBX, ECX, EDX, ESI, EDI,

ESP and EBP (named similarly to the x86 architecture registers). The registers from the extended set are called R0, R1, ..., R31.

You can use any of these for any arithmetics purposes (that means they only hold numerical values), apart from the ESP register, which is reserved as the stack pointer (see page 15 for more information on the processor stack). When programming using C syntax the EBP register is also used for storing stack frame pointer, and must not be altered to avoid program crash.

Every register is a single 64-bit floating point value. It can contain any value between  $-10^{3000}$  and  $10^{3000}$ , but the precision in digits is limited to 48 bits. This is a simplification that differs ZCPU from any other real-world processor.

Registers are *a lot faster* than using memory. In the version 10 of the processor 32 more general purpose registers were added to speed up the program execution.

When the CPU is reset, all registers (except for ESP) will be set to 0. If the current ZCPU memory model includes RAM space, then ESP will be reset to the CPU internal RAM size minus one (e.g. 65535 for 64k memory model).

## 1.4 Execution

The Zyelios CPU has a special register called the instruction pointer (IP). IP points to the currently executed instruction and is incremented every time a new instruction is read.

Instructions can be either variable sized or fixed-sized, depending on the local execution mode (see page 53), so the IP may increment in varying steps. It is possible to set IP explicitly by using any of the branching opcodes (see page 16)

The following is the internal execution flow for fetching and executing an instruction:

1. Fetch instruction number (so the processor would know what instruction it is going to execute, and how much operands will the instruction have)
2. If the instruction has operands, then fetch the RM byte (see **rmbyte**). If the instruction has no operands and the next byte is zero it will be skipped (this behaviour assures that the processor is backwards compatible).
3. Processor decodes instruction number and fetches segment prefix bytes (if required, this provides support for segment prefixes. See page 49 for more information on the instruction format).
4. If RM byte requires an immediate value to follow, it will be fetched too.

5. The processor executes the instruction microcode, which somehow alters the processor state (but does not touch the values which are explicitly stated in the operation).
6. All values that must be written are written back to registers, memory, etc.

For the purpose of optimization, one or more of these steps might be cached by the processor and omitted from actual execution. See page 47 for more information on this behaviour.

The processor will run a specific amount of cycles per second. The amount of cycles required for executing each instruction may vary, and it is counted by the **TMR** register. Most instructions are only 1 cycle long, although internal caching or memory access may consume additional cycles.

See page 29 more information on the execution process.

## 1.5 Interrupts

When a certain exceptional event occurs (external signal, error in arithmetics, memory error, etc), the ZCPU will generate an interrupt. Interrupts are special events which will temporarily "interrupt" or change flow of the program and branch to execute the appropriate interrupt handler code. This means that whenever the ZCPU encounters an interrupt it will remember its current state, store it on the processor stack (see page 15) and change IP to the first opcode of the interrupt handler.

In extended mode the processor stores an interrupt table - a table which holds pointers to all interrupt handlers. If extended mode is not enabled, any interrupts called will stop the processor execution.

After the interrupt handler has finished running, it can restore the ZCPU state and the previously executed code will continue executing from where it was interrupted.

For example, if this was the stack state before an interrupt call, and current value of IP is 157:

```
.....  
65304: ...  
65306: 181  
65305: -94
```

ESP = 65304

then the stack state will be altered to this after an interrupt call (and IP will be set to interrupt handler endpoint):



```

.....
65304: ...
65306: 181
65305: -94
65304: 0    CS
65303: 157 IP

```

ESP = 65302

Interrupts are very similar to normal calls (see page 16), but instead of using a memory pointer an interrupt number is given. Also unlike the regular calls a special return instruction `IRET` must be used in place of `RET`. Any interrupt can be called using the `INT` instruction. For example:

```

interrupt_handler:
    ....
    iret;

```

There are two types of interrupts: internal interrupts, and external interrupts. The external interrupts will push the entire ZCPU state (along with the return data internal interrupt would push) to stack before entering the interrupt handler. They can only be triggered via external interrupt pin, or by using the `EXTINT` instruction. The external interrupts require `EXTRET` instruction instead of the `IRET` to restore the processor state.

There are several static interrupts. These interrupts are executed when certain exceptional conditions happen internally. All interrupt numbers less than 32 are reserved by the processor. In addition, interrupts 0 and 1 have special meanings and are handled internally. The user program can only use the interrupts 32..255. See page 19 for more information on the error interrupts.

The following table describes all of the reserved interrupt numbers:

Number	Description
0	<i>Reset</i>
1	<i>Halt</i>
2	End of program execution
3	Division by zero
4	Unknown opcode
5	Internal processor error
6	Stack error (overflow/underflow)
7	Memory read/write fault
8	MemBus fault

9	Write access violation (page protection)
10	Port read/write fault
11	Page access violation (page protection)
12	Read access violation (page protection)
13	General processor fault
14	Execute access violation (page protection)
15	Address space violation
17	Frame instruction limit ( <i>GPU only</i> )
23	String read error ( <i>GPU only</i> )
28	<i>Page read access trap</i>
29	<i>Page write access trap</i>
30	<i>Page access trap</i>
31	<i>Debug trap</i>

The reset interrupt (0) will reset the processor state, and restart code execution from the top of memory. The halt interrupt (1) will stop execution until the processor is reset externally. The `int 1` and `int 0` instructions will work as long as the interrupts are not handled by the software (as long as they are disabled in the interrupt table, or interrupt table is not used):

```
INT 1; //Stop execution
```

```
INT 0; //Reset the processor
```

If extended mode is not enabled, *all the interrupts* will work similarly to the halt interrupt (`int 1`) when triggered. The error code will be set on the error output.

Interrupt handling can be disabled using the IF flag. It is not directly writeable, but it can be changed using the special instructions. *When setting the flag, the value will only become updated after the next instruction.* For example:

```
STI;          //Set interrupt flag
MOV EAX,123; //IF = 0
ADD EAX,123; //IF = 1 (flag updated)
CLI;          //Clear interrupt flag
SUB EAX,123; //IF = 0 (flag clear on this instruction)
RET;          //IF = 0
```

This assures that for example in this situation the interrupt will not occur between the `RET` and the `STI`:

```
ContextSwitch:
```

```

CLI;

... thread switcher code ...

STI; //An interrupt will never occur between this
EXTRET; //STI instruction and the NMIRET

```

For information on using the interrupt table, consult the advanced interrupts chapter (see page 40).

## 1.6 Memory Segmenting and Segment Registers

There are 8 segment registers in the ZCPU. They are CS, SS, DS, ES, GS, FS, KS and LS. They are used by the ZCPU to support certain memory models. Additionally any of the 40 general purpose registers can be used as segment registers.

Every segment register can contain a 48-bit integer. This value can be used for specifying an offset for a pointer to memory. The ZCPU always uses segments when referencing memory: it translates the local address (the memory address explicitly written by the user, it's important to remember that any variable or label has a certain memory address) into the absolute address (the physical address, which serves as a command to direct ZCPU towards where the real data is located).

The formula used for the address translation is:

$$AbsoluteAddress = LocalAddress + SegmentOffset$$

The user can specify which register to use for offsets by prefixing the operand with the segment name followed by a semicolon. If a segment is not specified, DS is used.

Both segment and general purpose registers can be used for segment prefixing. It is not possible to use a constant value for segment prefix. Here is an example of various ZASM syntax for reading memory:

```

MOV EAX,#EBX      //Address: DS+EBX
MOV EAX,ES:#EBX   //Address: ES+EBX
MOV EAX,[EBX]     //Address: DS+EBX
MOV EAX,[ES:EBX]  //Address: ES+EBX
MOV EAX,[ES+EBX]  //Address: ES+EBX

MOV EAX,EBX:ECX   //Address: EBX+ECX

```

```

MOV EAX,[EBX+ECX] //Address: EBX+ECX
MOV EAX,[EBX:100] //Address: EBX+100
MOV EAX,[100:EBX] //This is not valid

```

With some clever programming the segment prefixes can be used for quick array access, typically by using the prefix as the array pointer and the base as the index into the array:

```

MOV ES,ArrayStart
MOV EAX,ES:#0 //EAX = 10
MOV EBX,ES:#2 //EBX = 30
MOV ECX,ES:#1 //ECX = 50

MOV EAX,0
MOV EBX,EAX:#ArrayStart //EBX = 10
INC EAX
MOV EBX,EAX:#ArrayStart //EBX = 50
INC EAX
MOV EBX,EAX:#ArrayStart //EBX = 30

```

```

ArrayStart: db 10,50,30

```

Some of the segment registers are used by the processor for specific tasks, as per the following table:

Register	Name	Description
CS	Code segment	Processor fetches code from this segment
SS	Data segment	Default segment for data
DS	Stack segment	Processor stack is located in this segment
ES	Extra segment	User segment
GS	G segment	User segment
FS	F segment	User segment
KS	Key segment	User segment
LS	Library segment	User segment

All segment registers other than **CS** can be directly set by using the **MOV** operation. The only way to modify the **CS** is to execute **CALLF** or **JMPF** instructions (see page 16 for more information):

```

//CS = 0
//IP = 928

```

```
JMPF 500,100;
```

```
//CS = 100
```

```
//IP = 500
```

Attempting to set **CS** directly will trigger interrupt 13:1 (general processor fault). For example:

```
MOV DS,100
```

```
MOV ES,KS
```

```
MOV CS,1000 //Will generate interrupt 13:1
```

After CPU reset all segment registers will be initialized to 0.

## 1.7 Memory Models

The ZCPU is capable of working in several different memory modes. Linear addressing mode is the default mode, and it is the mode in use when the CPU is reset.

Different modes require different use of registers and provide different execution features. Each mode will usually require extended processor mode to be active, enabling some advanced memory protection features such as page permissions and memory mapping.

It is important to be aware of how memory access actually works. When a memory request occurs (read or write) these are the actions that will be undertaken by the CPU:

1. Check **BusLock** register. If this register is set to 1 the request will fail.
2. Validate the address. The address must be a 48-bit integer value.
3. Fetch page that corresponds to the requested address.
4. If **EF** flag is set check if current runlevel is less or equal to target page runlevel and check if it's possible to read/write on the page.
5. If page has **Mapped** flag set then change the address accordingly.
6. Perform the I/O operation.

### 1.7.1 Linear Address Mode

This is the default address mode when all segment registers are initialized to 0. This mode is available after the initial processor startup. Since all registers are set to zero, in this mode the code, data and stack are all located in same address space.

No segment prefixes are required in this mode. For example you can access the processor stack without specifying the SS prefix:

```
MOV EAX,#0 //EAX will be equal to 14 (MOV opcode no)
MOV #ESP,100 //Same as PUSH 100
DEC ESP
POP EAX //EAX will be equal to 100
```

### 1.7.2 Segmented Address Mode

This is the most common addressing mode when segment registers are used differently. For example, the code, data and stack might all be located in different areas of memory. This has certain benefits:

- Allows to prevent accidental data/code corruption
- Same code can be used for different blocks of data
- Programs can run in local address space, not aware of different programs (for example BIOS)

Example:

```
MOV DS,1000 //Set first data block
MOV SS,2000 //Set first stack block
CALLF 0,500 //Call the routine (CS will be set to 500, IP to 0)

MOV DS,3000 //Set second data block
MOV SS,4000 //Set second stack block
CALLF 0,500 //Call the same routine, but now
           //working on different data block
```

This will run the same routine (located at physical offset 500) on two different sets of data. Thus the same subprogram can be reused for different sets of variables.

### 1.7.3 Mapped Memory Mode

Mapped memory mode uses the memory mapping features of the processor to reroute memory addresses in order to create the appearance of a single continuous address space for the user program. This mode allows user programs to dynamically allocate blocks of data, which can themselves be physically located in different areas of memory. This also allows use of dynamic libraries, where single library loaded once can be used in many programs while remaining in a single place in physical memory.

See page 33 for more information.

## 1.8 Stack

The Zyelios CPU has a built-in hardware processor stack. Stack operation is controlled by the current stack pointer register (ESP), the stack size register (ESZ) and the stack segment register (SS) Stack data is located in physical RAM.

ESP points to the *next free value on the stack*. The stack grows *down*.

PUSH and POP are used to push or pop values to or from the stack, respectively. Stack overflow or underflow is indicated by the interrupt 6:ESP (stack error). The interrupt parameter will be set to the value of ESP. For example:

```
MOV SS,5000    //Stack starts at offset 5000
MOV ESP,2999   //Stack is 3000 bytes in size
               //Next free offset in segment is 2999
CPUSET 9,3000 //Set ESZ register

PUSH 200
PUSH 100
POP EAX //EAX = 100
POP EBX //EBX = 200

//PUSH X is same as the following (but with error checks):
MOV SS:#ESP,X
DEC ESP

//POP Y is same as the following (but with error checks):
INC ESP
MOV Y,SS:#ESP
```

Additionally, the `RSTACK` and `SSTACK` instructions allow the user to read or write an arbitrary position on the stack. These instructions may also trigger stack underflow or overflow interrupts. The following example illustrates the use of `RSTACK` and `SSTACK`:

```
RSTACK X,Y //X = MEMORY[SS+Y]
SSTACK X,Y //MEMORY[SS+X] = Y

RSTACK EAX,ESP:1 //Read stack top
RSTACK EAX,ESP:2 //Read value under stack top

PUSH 100 //
PUSH 200 //Value under top value
PUSH 300 //Value on top

SSTACK ESP:2,123 //Set value under stack top
POP EAX //EAX = 300
POP EBX //EBX = 123
POP ECX //ECX = 100
```

## 1.9 Branching

The Zyelios CPU supports various kinds of branching: conditional or unconditional, absolute or relative. The instruction pointer (IP) points to the currently executing instruction. All branching instructions modify IP; some also modify CS (see page 11).

The simplest type of branching is absolute unconditional. To perform an unconditional jump, `JMP` or `JMPF` are used (the latter also modifies CS).

Program subroutines can be called by using `CALL` or `CALLF`. This will save current the instruction pointer (and CS when `CALLF` is used) to the processor stack. The instruction pointer (and code segment if required) can be restored from the stack by using `RET` or `RETF` accordingly.

The following example illustrates creating routines and jumping:

```
JMPF MAIN,CODE_SEGMENT //Syntax is JMPF IP,CS

.....

MAIN: //A label
    CALL SUBROUTINE
```



```
JMP EXIT
```

```
SUBROUTINE:
```

```
    CALL SUBROUTINE2
```

```
RET //Exit subroutine
```

```
SUBROUTINE2: //Called inside SUBROUTINE
```

```
    ... do something ...
```

```
RET
```

```
.....
```

```
EXIT:
```

It is possible to perform a relative jump. To do this, **JMPR** (jump relative) is used. This instruction adds or subtracts IP by a certain amount instead of giving a specific number. For example example:

```
JMPR +10 //Jump 10 bytes forward
```

```
JMPR -10 //Jump 10 bytes backward
```

```
JMPR LABEL-__PTR__ //Jump to label
```

```
    //__PTR__ label always points
```

```
    //to current write pointer
```

```
.....
```

```
LABEL:
```

Conditional branching allows program flow to be changed depending on certain conditions. **CMP** is used to compare two values, and instructions from the following table react accordingly:

Instruction	Operation	Description
JNE	$X \neq Y$	Jump if not equal
JNZ	$X - Y \neq 0$	Jump if not zero
JG	$X > Y$	Jump if greater than
JNLE	$\text{NOT } X \leq Y$	Jump if not less or equal
JGE	$X \geq Y$	Jump if greater or equal
JNL	$\text{NOT } X < Y$	Jump if not less than

JL	$X < Y$	Jump if less than
JNGE	NOT $X \geq Y$	Jump if not greater or equal
JLE	$X \leq Y$	Jump if less or equal
JNG	NOT $X > Y$	Jump if not greater than
JE	$X = Y$	Jump if equal
JZ	$X - Y = 0$	Jump if zero
CNE	$X \neq Y$	Call if not equal
CNZ	$X - Y \neq 0$	Call if not zero
CG	$X > Y$	Call if greater than
CNLE	NOT $X \leq Y$	Call if not less or equal
CGE	$X \geq Y$	Call if greater or equal
CNL	NOT $X < Y$	Call if not less than
CL	$X < Y$	Call if less than
CNGE	NOT $X \geq Y$	Call if not greater or equal
CLE	$X \leq Y$	Call if less or equal
CNG	NOT $X > Y$	Call if not greater than
CE	$X = Y$	Call if equal
CZ	$X - Y = 0$	Call if zero
JNER	$X \neq Y$	Jump relative if not equal
JNZR	$X - Y \neq 0$	Jump relative if not zero
JGR	$X > Y$	Jump relative if greater than
JNLER	NOT $X \leq Y$	Jump relative if not less or equal
JGER	$X \geq Y$	Jump relative if greater or equal
JNLR	NOT $X < Y$	Jump relative if not less than
JLR	$X < Y$	Jump relative if less than
JNGER	NOT $X \geq Y$	Jump relative if not greater or equal
JLER	$X \leq Y$	Jump relative if less or equal
JNGR	NOT $X > Y$	Jump relative if not greater than
JER	$X = Y$	Jump relative if equal
JZR	$X - Y = 0$	Jump relative if zero

There are other instruction which perform branch testing, such as BIT, which tests specific bits of a given value. For example:

```

CMP EAX,EBX
JG LABEL1 //Jump if EAX > EBX
JLE LABEL2 //Jump if EAX <= EBX
JE LABEL3 //Jump if EAX = EBX
CL LABEL4 //Call if EAX < EBX
CGE LABEL5 //Call if EAX >= EBX

BIT EAX,4 //Test 5th bit of EAX

```

```
JZ LABEL1 //Jump if 5th bit is 0
JNZ LABEL1 //Jump if 5th bit is 1
```

## 1.10 Processor Error Codes

There are several error codes that might be generated during program execution. Each error condition generates an interrupt.

If processor is not in extended mode, code execution will halt when the error is generated. Upon encountering an error, the processor will halt and output the error code to **ERROR** processor output. It will also emit a secondary error code in the fraction part of the **ERROR** processor output. If the processor is in extended mode, the corresponding interrupt will be called instead.

For example, a typical output might be 7.65536, which would indicate a memory read/write fault at address 65536.

The error code will be reset to zero when the CPU is reset. The following are error codes are defined by the current version of the processor:

Code	Description
02	End of program execution
03	Division by zero
04	Unknown opcode
05	Internal processor error
06	Stack error (overflow/underflow)
07	Memory read/write fault
08	MemBus fault
09	Write access violation (page protection)
10	Port read/write fault
11	Page access violation (page protection)
12	Read access violation (page protection)
13	General processor fault
14	Execute access violation (page protection)
15	Address space violation

### 1.10.1 End of program execution (02)

**Error message:** STOP detected

**Occurs when:** STOP/OPCODE 0 is executed

**Cause:** Abnomal program end

**Result:** None

**Error message:** Invalid opcode

**Occurs when:** Any of the branching instructions is executed (JMP, CALL, etc)

**Cause:** Jumping by offset that does not point to valid ZCPU instruction

**Result:** None

### 1.10.2 Division By Zero (03)

**Error message:** Unable to divide by zero

**Occurs when:** Second operand for DIV opcode is zero

**Cause:** User error

**Result:** LADD = 1

**Error message:** Unable to perform inversion on a zero

**Occurs when:** Calling FINV opcode with zero operand

**Cause:** User error

**Result:** LADD = 2

### 1.10.3 Unknown Opcode (04)

**Error message:** Unknown opcode detected in the instruction stream

**Occurs when:** Next executed instruction is not one of the recognized instructions

**Cause:** Invalid branching operation is performed (processor attempts to execute data)

**Result:** LADD = OPCODE NUMBER

### 1.10.4 Internal Processor Error (05)

**Error message:** Unable to execute instruction (microcode error)

**Occurs when:** An internal error has occurred while executing microcode

**Cause:** Encountering a bug in processor

**Result:** LADD = 01

**Error message:** Unknown internal error

**Occurs when:** Never

**Cause:** None

**Result:** LADD = 02

**Error message:** Read error while fetching the instruction

**Occurs when:** Instruction decoder was not able to fetch all of the instruction bytes

**Cause:** JMP or CALL to a memory location outside of physical/logical range

**Result:** LADD = 12

**Error message:** Could not fetch an immediate byte for operand 1

**Occurs when:** Instruction decoder was not able to fetch an immediate byte for the first operand

**Cause:** JMP or CALL to a memory location outside of physical/logical range

**Result:** LADD = 22

**Error message:** Could not fetch an immediate byte for operand 2

**Occurs when:** Instruction decoder was not able to fetch an immediate byte for the second operand

**Cause:** JMP or CALL to a memory location outside of physical/logical range

**Result:** LADD = 32

**Error message:** Invalid RM parameter for operand 1

**Occurs when:** Never

**Cause:** None

**Result:** LADD = 42

**Error message:** Invalid RM parameter for operand 2

**Occurs when:** Never

**Cause:** None

**Result:** LADD = 52

**Error message:** Target operand not writeable

**Occurs when:** Never

**Cause:** None

**Result:** LADD = 62

**Error message:** Source operand not writeable (XCHG instruction only)

**Occurs when:** Never

**Cause:** None

**Result:** LADD = 72

**Error message:** Unknown opcode

**Occurs when:** Never

**Cause:** None

**Result:** LADD = 82

### 1.10.5 Stack Error (06)

**Error message:** Stack overflow error

**Occurs when:** PUSH is executed

**Cause:** ESP register value becomes negative

**Result:** LADD = 0

**Error message:** Stack underflow error

**Occurs when:** POP is executed

**Cause:** ESP register is greater than ESZ

**Result:** LADD = ESZ

**Error message:** Stack read error

**Occurs when:** POP is executed

**Cause:** Unable to read value from memory

**Result:** LADD = ESP

**Error message:** Stack out of bounds error

**Occurs when:** RSTACK or SSTACK is executed

**Cause:** Requested value out of stack bounds

**Result:** LADD equals to requested index on stack

### 1.10.6 Memory Read/Write Fault (07)

**Error message:** Read error: address does not exist

**Occurs when:** Processor attempts to read a value from outside of the internal RAM

**Cause:** No device is attached to the MemBus

**Result:** LADD equals to faulty address in memory

**Error message:** Read error: unable to read memory location

**Occurs when:** Processor attempts to read a value from outside of the internal RAM

**Cause:** A failure has occurred while attempting to read a value (value out of the device address range)

**Result:** LADD equals to faulty address in memory

**Error message:** Write error: address does not exist

**Occurs when:** Processor attempts to write a value to outside of the internal RAM

**Cause:** No device is attached to the MemBus

**Result:** LADD equals to faulty address in memory

**Error message:** Write error: unable to write to memory location

**Occurs when:** Processor attempts to write a value to outside of the internal RAM

**Cause:** A failure has occurred while attempting to write a value (value out of the device address range)

**Result:** LADD equals to faulty address in memory

### 1.10.7 MemBus Fault (08)

**Error message:** MemBus device error

**Occurs when:** Processor attempts to read a value from outside of the internal RAM

**Cause:** Device currently attached to MemBus does not support hispeed interface

**Result:** LADD equals to faulty address in memory

**Error message:** IOBus device error

**Occurs when:** Processor attempts to read a value from a port

**Cause:** Device currently attached to IOBus does not support hispeed interface

**Result:** LADD = -PORT\_NUMBER

### 1.10.8 Write Access Violation (09)

**Error message:** Access violation

**Occurs when:** Attempting to write a value

**Cause:** EF flag set to 1, no write permission on referenced page, and referenced by the address has a smaller runlevel than the current one.

**Result:** LADD equals to faulty address in memory

### 1.10.9 Port Read/Write Fault (10)

**Error message:** Read error: unable to read a port

**Occurs when:** Processor attempts to read a value from a port

**Cause:** A failure has occurred while attempting to read a value (value out of the device address range)

**Result:** LADD equals to faulty address in memory

**Error message:** Write error: unable to write to a port

**Occurs when:** Processor attempts to write a value to a port

**Cause:** A failure has occurred while attempting to write a value (value out of the device address range)

**Result:** LADD equals to faulty address in memory

### 1.10.10 Page access violation (11)

**Error message:** Unable to set page readonly

**Occurs when:** SPG opcode is executed

**Cause:** Current runlevel greater than runlevel of the referenced page

**Result:** LADD points to referenced page

**Error message:** Unable to set page read- and writeable

**Occurs when:** CPG opcode is executed

**Cause:** Current runlevel greater than runlevel of the referenced page

**Result:** LADD points to referenced page

**Error message:** Unable to set page flag

**Occurs when:** SPP opcode is executed

**Cause:** Current runlevel greater than runlevel of the referenced page

**Result:** LADD points to referenced page

**Error message:** Unable to clear page flag

**Occurs when:** CPP opcode is executed

**Cause:** Current runlevel greater than runlevel of the referenced page

**Result:** LADD points to referenced page

**Error message:** Unable to set page runlevel

**Occurs when:** SRL opcode is executed

**Cause:** Current runlevel greater than runlevel of the referenced page

**Result:** LADD points to referenced page

**Error message:** Unable to set page mapping

**Occurs when:** SMAP opcode is executed

**Cause:** Current runlevel greater than runlevel of the referenced page

**Result:** LADD points to referenced page

### 1.10.11 Read access violation (12)

**Error message:** Access violation

**Occurs when:** Attempting to read a value

**Cause:** EF flag set to 1, no read permission on referenced page, and referenced by the address has a smaller runlevel than the current one.

**Result:** LADD equals to faulty address in memory

**Error message:** Referenced page outside ROM



**Occurs when:** ERPG opcode executed

**Cause:** Page referenced by the instruction could not be erased, because it lies outside the processor ROM

**Result:** LADD = 0

**Error message:** Referenced page outside ROM

**Occurs when:** WRPG opcode executed

**Cause:** Page referenced by the instruction could not be written, because it lies outside the processor ROM

**Result:** LADD = 0

**Error message:** Referenced page outside ROM

**Occurs when:** RDPG opcode executed

**Cause:** Page referenced by the instruction could not be read, because it lies outside the processor ROM

**Result:** LADD = 0

### 1.10.12 General Processor Fault (13)

**Error message:** Code segment write violation

**Occurs when:** CS value is being used as a target operand

**Cause:** An attempt is being made to set a read-only segment register. Use CALLF or JMPF instructions to modify the CS register

**Result:** LADD = 1

**Error message:** Unable to read interrupt table

**Occurs when:** Could not fetch entry from interrupt table

**Cause:** Invalid interrupt table location set with LIDTR

**Result:** LADD = 2

**Error message:** Invalid interrupt number

**Occurs when:** Interrupt outside of the acceptable boundary (0..255) is called

**Cause:** Misuse of the INT or the EXTINT instructions

**Result:** LADD = 3

**Error message:** Unprivileged external interrupt call

**Occurs when:** External interrupt was called while the appropriate flag was not set in the interrupt table

**Cause:** 6th bit not set for the external interrupt in the interrupt table, and the external interrupt is called

**Result:** LADD = 4

**Error message:** Incompatible mode

**Occurs when:** Interrupt call in protected (compatibility) mode with less than 512 bytes of RAM

**Cause:** Not enough RAM to contain a complete interrupt table

**Result:** LADD = 5

**Error message:** Unable to push return data

**Occurs when:** Interrupt handler was unable to push return data onto the processor stack

**Cause:** Interrupt was called with no stack space available

**Result:** LADD = 6

**Error message:** Unable to call an interrupt

**Occurs when:** Interrupt is called without sufficient rights

**Cause:** Interrupt is called without sufficient rights to complete the jump

**Result:** LADD = 7

**Error message:** Unable to read page table

**Occurs when:** Page table is not located in valid memory range

**Cause:** Page table is not located in valid memory range

**Result:** LADD = 8

**Error message:** Attempting to execute a privileged instruction

**Occurs when:** Could not execute a privileged instruction due to runlevel

**Cause:** Calling one of the following instructions without sufficient rights: RD, WD, SPG, CPG, STI, CLI, STP, CLP, STEF, CLEF, EXTINT, ERPG, WRPG, RDPG, LIDTR, EXTRET, IDLE, STD2, STM, CLM, CPUGET, CPUSET, CPP, SPP, SRL, GRL, SMAP, GMAP

**Result:** LADD = Opcode number

### 1.10.13 Execute Access Violation (14)

**Error message:** Access violation

**Occurs when:** Execution is attempted on a memory page that does not allow execution

**Cause:** Invalid branching into the protected memory areas

**Result:** LADD = Page number

**Error message:** Access violation

**Occurs when:** Execution is attempted on a memory page that does not allow execution

**Cause:** Code execution has entered page that does not allow execution

**Result:** LADD = Page number

#### **1.10.14 Address space violation (15)**

**Error message:** Address space violation

**Occurs when:** Memory is accessed by an invalid address

**Cause:** Address is not a 48-bit signed integer

**Result:** LADD = Referenced invalid address



# Chapter 2

## Advanced Processor Features

### 2.1 Advanced Execution Control

This section describes instruction execution in complete detail. The processor will fetch instructions sequentially, decode them, and then execute.

During execution the **XEIP** register points to the instruction start address in global memory space, while the **IP** register is incremented as the instruction bytes are fetched in sequence.

The execution will also increment **TMR** register by amount of cycles that have been required to complete this instruction. The **CODEBYTES** register is incremented each time next byte is fetched by the instruction decoder (so the **CODEBYTES** register counts the total size of executable code executed so far).

```
//TMR = 170
```

```
MOV EAX,10; //1-cycle instructions  
ADD EAX,EBX;
```

```
//TMR = 172
```

The instruction decoder will set **CPAGE** register to number of the current page (the page that fetched instruction is located on), and **PPAGE** to number of the page previous instruction was located on. *Current page is determined by the location of the first fetched byte of the currently executed instruction.*

When **CPAGE** and **PPAGE** values mismatch the permission check logic is triggered. Performing a jump of any sort will run a different check logic, and will reset both **CPAGE** and **PPAGE** to page the target jump offset is located on.

The instructions can be either fixed-sized or variable-sized, see page 53.

This is the psuedocode for the instruction decoding procedure:

```
// Calculate absolute execution address and set current page
XEIP = IP + CS
SetCurrentPage(floor(XEIP/128))

// Do not allow execution if we are not on kernel
// page, or not calling from kernel page
if (PCAP == 1) and (CurrentPage.Execute == 0) and
    (PreviousPage.RunLevel <> 0) then
    Interrupt(14,CPAGE)
end

// Reset interrupts flags
INTR = 0
if NIF <> undefined then
    IF = NIF
    NIF = undefined
end

// Fetch instruction and RM byte
Opcode = Fetch()
RM = 0
isFixedSize = false

// Check if it is a fixed-size instruction
if ((Opcode >= 2000) and (Opcode < 4000)) or
    ((Opcode >= 12000) and (Opcode < 14000)) then
    Opcode = Opcode - 2000
    isFixedSize = true
end

// Fetch RM if required
if (OperandCount > 0) or
    (Precompile_Peek() == 0) or
    (isFixedSize) then
    RM = Fetch()
end

// If failed to fetch opcode/RM then report an error
if INTR == 1 then
    IF = 1
    Interrupt(5,12)
end

// Check opcode runlevel
```

```

if (PCAP == 1) and (CurrentPage.Runlevel > RunLevel[Opcode]) then
    Interrupt(13,Opcode)
end

// Decode RM byte
dRM2 = floor(RM / 10000)
dRM1 = RM - dRM2*10000

// Default segment offsets
Segment1 = -4
Segment2 = -4

// Decode segment offsets
if Opcode > 1000 then
    if Opcode > 10000 then
        Segment2 = Fetch()

        Opcode = Opcode-10000
        if Opcode > 1000 then
            Segment1 = Fetch()

            Opcode = Opcode-1000
            Segment1 <> Segment 2
        else
            if isFixedSize then
                Fetch()
            end
        end
    else
        Segment1 = Fetch()
        Opcode = Opcode-1000
        if isFixedSize then
            Fetch()
        end
    end
elseif isFixedSize then
    Fetch()
    Fetch()
end

// If failed to fetch segment prefix then report an error
if INTR == 1 then
    Interrupt(5,12)
end

// Check if opcode is invalid

```

```

if opcode is not valid then
    Interrupt(4,Opcode)
else
    // Fetch immediate values if required
    if isFixedSize then
        OperandByte1 = Fetch()
        if INTR == 1 then
            Interrupt(5,22)
        end
        OperandByte2 = Fetch()
        if INTR == 1 then
            Interrupt(5,32)
        end
    end
    else
        if OperandCount > 0 then
            if NeedFetchByte1 then
                OperandByte1 = Fetch()
                // If failed to read the byte, report an error
                if INTR == 1 then
                    Interrupt(5,22)
                end
            end
            if OperandCount > 1 then
                if NeedFetchByte2 then
                    OperandByte2 = Precompile_Fetch() or 0
                    // If failed to read the byte, report an error
                    if INTR == 1 then
                        Interrupt(5,32)
                    end
                end
            end
        end
    end
end

// Execute instruction
Execute()

// Write back the values
if OperandCount > 0 then
    WriteBack(1)
    if OperandCount > 1 then
        WriteBack(2)
    end
end
end
end

```



```
// Advance timers and counters
CODEBYTES = CODEBYTES + Instruction_Size
TMR = TMR + Instrucion_Cycles
TIMER = TIMER + TimerDT

// Set this page as previous (if it is executable)
XEIP = IP + CS
SetPreviousPage(floor(XEIP/128))
```

## 2.2 Paging System

The Zyelios CPU divides the entire accessible memory space into pages. Every page is 128 bytes in size. Pages are numbered sequentially; This means that addresses 0, 1, ... 127 belong to page 0, addresses 128 .. 255 belong to page 1, 256 .. 383 belong to page 2 and so on.

Every page can have a separate permission mask (read permission, write permission, execute permission) and runlevel.

Runlevel is a number that can be used to divide code into different permission levels, with higher levels reflecting kernel-mode code and lower levels reflecting user-level code. Each runlevel is a number between 0 and 255 inclusive. Higher permission levels are those that are closer to 0. Lower permission levels are those that are closer to 255. Code executing from a page with a higher permission level can read or write pages of a lower runlevel, but the opposite cannot occur.

```
SRL 1,12 //Set page 1 runlevel to 12
//Page 1 is addresses 128..255
```

```
SPP 5,0 //Set page 5 to be readable
CPP 6,1 //Make page 6 non-writeable
CPP 7,2 //Prevent code execution on page 7
```

Runlevel 0 is a special runlevel which will ignore all permission settings. This runlevel is also capable of running several privileged instructions such as **CPUSET**. All others runlevels follow page permissions.

When a page is marked non-readable, it can only be read from a page with a higher runlevel. When a page is marked non-writeable it can only be written from a page with smaller runlevel. When a page is marked non-executable, then only code from runlevel 0 can branch into this page.

Every page can also be remapped to any other page in memory. This means that every time the processor accessess target page, the data will be read from a different

physical address. Any page can be remapped, even if the page already points to valid memory.

```
MOV #130,1234 //Set cell 2 of page 1 to 1234
SMAP 0,1 //Remap page 0 to page 1
MOV EAX,#2 //Read cell 2 of page 0 (but really read from page 1)
//EAX is now set to 1234
```

Page mapping and permissions settings are stored in the *page table*. The page table is active when the processor has the extended memory mode enabled (MF set to 1). If MF is set to 0 the page table will be stored internally; if it is set to 1 the page table will be stored in RAM. The actual permission checks are being made only when EF flag is set to 1, and the processor is running in the extended mode.

The PTBL internal register is an *absolute* pointer to the table start, and PTBE holds the number of entries in the table. It is possible to switch page tables during execution.

Every page table entry is 2 bytes in size. The first entry (entry number 0) is the default page. All other pages in the table correspond to memory pages.

If the address being accessed is not covered by any page listed in the page table, it will use the permissions set on the default page entry. You cannot perform memory mapping on pages which do not have entry in page table.

The first byte of every entry holds the runlevel and permission flags. The second byte holds index of page this page should be remapped to. Note that permission flags in the page table entry are *inverted*; 1 means the permission is restricted and 0 means that it is not.

Example on how to setup a page table:

PageTable:

```
alloc 513*2 //512 page entries + default for 64KB of RAM
```

```
.....
```

```
//Setup page table
```

```
CPUSET 37,PageTable //PTBL
```

```
CPUSET 38,512 //PTBE
```

```
//Enable extended memory mode
```

```
STM
```

```
//Indirect table manipulation
```

```

SMAP 0,1 //Map page 0 to 1
SPP 5,0 //Set page 5 to be readable

//Direct table manipulation
MOV ESI,PageTable; //Table offset
MOV ESI:#0,0xE0; //Set default page permissions to not allow anything
MOV ESI:#2,0; //Disable page 0
MOV ESI:#5,10; //Remap page 1 to page 10

```

The layout of the first byte of each entry is as follows:

Bit	Description
00	Is page disabled? Set to 1 to disable this page
01	Is page remapped? Set to 1 to remap this page
02	Page must generate external interrupt 30 (page trap) upon access
03	Page trap overrides read/write (generates external interrupts 28, 29)
04	Reserved
05	Read permissions (0: allowed, 1: disabled)
06	Write permissions (0: allowed, 1: disabled)
07	Execute permissions (0: allowed, 1: disabled)
08..15	Runlevel

Disabled pages will cause a memory fault when a read is attempted to any address in its range (as if page wasn't in the address space). Remapped pages will use the second byte in the entry as the index for the *physical* page this page must be remapped to.

It is possible to trap page accesses by setting bits 2 and/or 3. This will cause any access to this page to generate external interrupt 28 (read), 29 (write), or 30 (access) with the page number being accessed as the parameter.

If bit 2 and is set, the external interrupt 30 will be generated on memory access attempt. If bit 3 is also set then the external interrupts 28 or 29 will be generated instead of the interrupt 30, and it will be possible to override the result of the memory read/write access (see page 45 for more info).

There are special rules when handling interrupts. Permissions to call the interrupts are defined by runlevel of the interrupt table. This means you can restrict the user program from calling certain interrupts, but the user program would be able to call lower runlevel code using other (non-restricted) interrupts. You can imagine it as if you were **CALLing** your interrupt routine from the interrupt table (and not from user program). This is the way you can protect your kernel code from reading/writing/executing while

retaining the ability to run the code (via calling interrupts).

```
STEF //Enable extended mode
LIDTR 2048 //Interrupt table at pages 16-23

SRL 16,0 //Set runlevel of interrupts 0..31 to 0
SRL 17,1 //Set runlevel of interrupts 32..63 to 1
SRL 18,2 //Set runlevel of interrupts 64..95 to 2
SRL 19,3 //Set runlevel of interrupts 96..127 to 3
```

Current page when executing the instructions is determined by the **CPAGE** register. *The actual current page is determined by the location of the first fetched byte of the currently executed instruction.* The paging system performs permissions checks whenever **PPAGE** (page the previously executed instruction was located on) and **CPAGE** register values mismatch (which corresponds to crossing the page boundary).

Performing a jump of any sort will run permission check logic, and will reset both **CPAGE** and **PPAGE** to page the target jump offset is located on.

It is only possible to cross page boundary or perform a jump if execute flag of the next (target) page is set to 1, or if it is set to 0 and previous page has runlevel 0.

All external access to the ZCPU inside memory will trigger the corresponding read/write permission checks. The runlevel for the external access is equal to the value of the **XTRL** register (external runlevel). By default the external memory access operations have a runlevel of 0.

To sum it up, these are all the permission and logic checks performed by the paging system:

- Boundary permission check (when execution crosses boundary between two pages)
- Jump permission check (execution jumps to a new offset)
- Interrupt table permission checks
- Read/write memory access (to any location)
- External read/write memory access (accessing CPU address space from outside)
- Read/write address remapping logic
- Page access trapping logic

## 2.3 Internal ROM

The Zyelios CPU can be configured to have built-in ROM and RAM. This allows you to store some program code right on the processor chip. The contents of ROM will be written into RAM every time the processor is reset. The ROM can be read from and written to in software.

There are three opcodes to work with the internal ROM: **ERPG** (erase ROM page), **WRPG** (write ROM page), **RDPG** (read ROM page).

See example of use:

```
ERPG 4 //Erase some data from ROM
WRPG 4 //Write this block of data to ROM
      //After CPU reset it will be still preserved
RDPG 4 //Restore this page from ROM

ORG 512 //Put on page 4
SOME_AREA:
    ... some data ...
```

## 2.4 Bitwise Operations

The ZCPU can work with integer values of variable bit width. It supports 8, 16, 32, and 48 bit integers, and has a complete instruction set to work with them.

There are bitwise logic instructions which work on all bits of the integer number. They are **BAND**, **BOR**, **BXOR**, **BSHL**, **BSHR**, **BNOT**. For example:

```
MOV  EAX,105 //1101001
BAND EAX,24  //0011000
//EAX = 8      0001000

BOR  EAX,67  //1000011
//EAX = 75   //1001011

BXOR EAX,15  //0001111
//EAX = 68   //1000100

BSHL EAX,2
//EAX = 272  //100010000
```

```
BSHR EAX,4
//EAX = 17    //0010001
```

```
BNOT EAX
//EAX = -18   //1111111111111111111101110
```

Also there are additional operations that work on separate bits of the number. They are BIT, SBIT, TBIT, CBIT.

The BIT operation tests whether specific bit of the number is set. It is possible to check result of this comparison by using a conditional jump:

```
MOV EAX,105
BIT EAX,0
JNZ LABEL //Jump succeeds (bit is not zero)
```

```
BIT EAX,1
JNZ LABEL //Jump fails (bit is zero)
```

The SBIT and CBIT clear and set the specific bit of the number. TBIT instruction will toggle that bit:

```
MOV EAX,105 //1101001
SBIT EAX,1
//EAX = 107   1101011
```

```
CBIT EAX,6
//EAX = 43    0101011
```

```
TBIT EAX,0
//EAX = 42    0101010
```

## 2.5 Memory Blocks Support

Certain instructions in the ZCPU support using the BLOCK instruction before them to specify a memory block the instruction must be executed on. For example it is possible to set permissions of an entire memory block at once:

```
BLOCK 1024,8192 //A 8KB block at offset 1024
SRL 0,4 //Set runlevel of all pages in this block to 4
```

The first operand of the **BLOCK** instruction is the memory offset the block must start from (must be aligned on page boundary for the paging instructions), and the second operand is the block size (the size must be divisible by 128 if this is a block for the page permission instructions).

The **BLOCK** instruction sets the two internal registers **BlockStart**, **BlockSize**. After the instruction that supports memory blocks has executed, it will reset block size back to zero.

The block size must be non-zero for the instruction to work on that block.

*It is possible that an interrupt will occur between the **BLOCK** instruction and the target instruction.* It is advised against using **BLOCK** instruction inside an interrupt handler!

The following instructions support this psuedo-prefix: **SPP**, **CPP**, **SRL**, **SMAP**.

## 2.6 Copying, Shifting, Swapping Large Blocks of Data

There are built-in instructions in the ZCPU for quickly moving and working with large arrays of data in an easy way.

It's possible to copy one area of memory to another using the **MCOPY** instruction:

```
mov ESI,source_data;
mov EDI,dest_data;
mcopy 5; //Copy 5 bytes
```

```
string source_data,"Apple";
string dest_data,"A quick fox";
```

After running this code "dest\_data" string will be equal to "Appleck fox".

Two blocks of memory can be swapped using the **MXCHG** instruction:

```
mov ESI,source_data;
mov EDI,dest_data;
mxchg 5; //Swap 5 bytes
```

```
string source_data,"Apple";
string dest_data,"A quick fox";
```

After running this code "dest\_data" string will be equal to "Appleck fox", and "source\_data" will be equal to "A qui".

And it's also possible to shift all values in block of data:

```

mov ESI,source_data;

mshift 13,2; //Shift 13 bytes by 2 cells to the right
//source_data = "quick foxA "

mshift 13,-4; //Shift 13 bytes by 4 cells to the left
//source_data = "oxA quick f"

string source_data,"A quick fox";

```

The offset by which data is shifted must be less or equal to amount of bytes that are being shifted. But it is possible to specify offsets larger than the data size, and that will reverse the direction of shift, and will not wrap the data around.

All of these instructions can work on up to 8192 bytes in a memory block.

## 2.7 Stack Frame Support

The ZCPU processor has two extra instructions to provide stack frame support. Stack frame allows to prevent stack corruption by individual subroutines, and it also provides an easy way to create local variables on stack, and pass values to the subroutine via stack.

ENTER X instruction is same as the following code:

```

Push(EBP)
EBP = ESP + 1
ESP = ESP - X

```

It will set EBP register to stack frame base (value of stack pointer at function entrypoint), and add some empty space on stack for the local variables.

LEAVE instruction corresponds to the following code:

```

ESP = EBP - 1
EBP = Pop()

```

It will restore the stack frame base of the previous function (if it exists), and restore stack.

## 2.8 Interrupts/Extended Mode

Interrupts work in a way similar to processor subroutines, but they can also be triggered if an error occurs while executing an instruction. In this case the instruction execution will not be completed, and the processor will attempt to handle this interrupt.



Interrupt handling is only available in extended mode of the processor. If interrupt occurs with extended mode disabled the processor will halt its execution and report error code to the external output:

```
lidtr interrupt_table; //Load interrupt table
stef; //Enable extended mode

int 40; //Handle interrupt 40
mov #0.123,10; //Handle interrupt 15 (address space violation)

clef; //Disable extended mode
int 40; //Will halt processor execution
```

The processor determines which subroutine it must call by checking the interrupt descriptor table/interrupt table. It's a table located somewhere in the processor memory which holds addresses to all interrupt handlers, and extra flags that alter the way the interrupt is handled.

The pointer to this table must be specified using the LIDTR instruction. The interrupt table usually has 256 entries for 256 possible interrupts, but it may have less entries if NIDT (interrupt table entry count) register is changed. If processor attempts to handle an interrupt which is not in the table, it will skip it:

```
cpuset 52,32; //Only have 32 entries
lidtr interrupt_table; //Load interrupt table
stef; //Enable extended mode

int 31; //Will be handled
int 32; //Will be skipped
```

Each entry in the interrupt table has the following format:

Byte	Description
0	Interrupt handler IP
1	Interrupt handler CS (if required, see flags)
2	Reserved (must be 0)
3	Flags

There are the following flags that can be set:

Bit	Description
-----	-------------

3	CMPR register will be set to 1 if an interrupt has occurred
4	1 if interrupt should <i>not</i> set CS
5	Interrupt enabled (active)
6	This interrupt is an external interrupt
0	Interrupt handler IP

If bit 3 is set, the interrupt will set CMPR register to 1. This can be used for making simple exception handlers:

If bit 4 is set, the interrupt will not set the code segment (it sets it by default). The interrupt will only be called if bit 5 is set, if it's clear then it will be ignored (unless it's the interrupt 0 or 1, if so, then they will act as if called without extended mode enabled).

This interrupt can only be called as an external interrupt if bit 6 is set. Otherwise it will generate interrupt 13 (general processor fault) instead.

There are special rules for using the interrupt table if paging is used. See page 35 for more information on how permissions will work if that's the case.

The interrupt handler is fairly complex. The psuedocode for the interrupt handler is listed below:

```
// Interrupt is active, lock the bus to prevent any further read/write
INTR = 1
BusLock = 1

// Set registers
LINT = interruptNo
LADD = interruptParameter or XEIP

// Output the error externally
SignalError(interruptNo,LADD)

if IF == 1 then
  if EF == 1 then // Extended mode
    // Boundary check
    if (interruptNo < 0) or (interruptNo > 255) then
      if not cascadeInterrupt then Interrupt(13,3) end
    end

    // Check against boundaries of the interrupt table
    if interruptNo > NIDT-1 then
      if interruptNo == 0 then Reset = 1 end
      if interruptNo == 1 then Clk = 0 end
    end

    // Calculate absolute offset in the interrupt table
```

```

interruptOffset = IDTR + interruptNo*4

// Disable bus lock, set the current page for read operations
BusLock = 0
SetCurrentPage(interruptOffset)

IF = 0
INTR = 0
IP    = ReadCell(interruptOffset+0)
CS    = ReadCell(interruptOffset+1)
      ReadCell(interruptOffset+2)
FLAGS = ReadCell(interruptOffset+3)
IF = 1

if INTR == 1 then
  if not cascadeInterrupt then Interrupt(13,2) end
else
  INTR = 1
end

// Set previous page to trigger same logic as if
// CALL-ing from a privileged page
SetCurrentPage(XEIP)
SetPrevPage(interruptOffset)
BusLock = 1

if isExternal and (FLAGS[6] <> 1) then
  if not cascadeInterrupt then Interrupt(13,4) end
end

if FLAGS[5] == 1 then
  // Push return data
  BusLock = 0
  IF = 0
  INTR = 0
  Push(IP)
  Push(CS)
  IF = 1

  if INTR == 1 then
    if not cascadeInterrupt then Interrupt(13,6) end
  else
    INTR = 1
  end
  BusLock = 1

```

```

// Perform a short or a long jump
IF = 0
INTR = 0
if FLAGS[4] == 0
then Jump(IP,CS)
else Jump(IP)
end
IF = 1

if INTR == 1 then
  if not cascadeInterrupt then Interrupt(13,7) end
else
  INTR = 1
end

// Set CMPR
if FLAGS[3] == 1 then
  CMPR = 1
end
else
  if interruptNo == 0 then
    Reset()
  end
  if interruptNo == 1 then
    Clk = 0
  end
  if FLAGS[3] == 1 then
    CMPR = 1
  end
end
end
end

if (EF == 0) then // Normal mode
  if (interruptNo < 0) or
    (interruptNo > 255) or
    (interruptNo > NIDT-1) then
    // Interrupt not handled
    Exit()
  end
  if interruptNo == 0 then Reset = 1 end
  if interruptNo ~= 31 then Clk = 0 end
end
end

// Unlock the bus
BusLock = 0

```

## 2.9 External Interrupts

(no chapter)

## 2.10 Memory Access Overriding

(no chapter)

## 2.11 Internal Timer

The ZCPU has an internal timer which can be used for precise time measurements during the code execution. The timer can also be used for triggering interrupts at precise time intervals.

The `TIMER` instruction can be used to fetch the internal timer value in seconds:

```
TIMER EAX
```

```
//EAX is now equal to amount of seconds since CPU startup
```

It is possible to configure the timer to trigger external interrupt after certain amount of seconds, or a certain amount of cycles has passed by configuring one of the special registers.

`TimerMode` register controls the timer mode. If it's set to 0 the timer will be disabled. If `TimerMode` is set to 1 the timer will use `TMR` register as counter source, and if `TimerMode` is set to 2 the timer will use the `TIMER` register as the source.

`TimerRate` sets the number of cycles, or the number of seconds that must pass before the timer will trigger. `TimerPrevTime` register stores value of the `TMR` or the `TIMER` register when timer fired the last time.

`TimerAddress` is the number of the interrupt that will be called when the timer fires. The interrupt call will be an external interrupt call.

Changing value of the `TimerMode` register will reset the `TimerPrevTime` register.

This is an example of how to setup timer:

```
CPUSET 65,90; //Trigger once per 90 cycles
```

```
CPUSET 67,40; //Trigger external interrupt #40
```

```
CPUSET 64,1; //Enable timer to count cycles
```

It could also be initialized for an interval in seconds:

```

CPUSET 65,1.5; //Trigger once per 1.5 seconds
CPUSET 67,40;  //Trigger external interrupt #40

CPUSET 64,2;   //Enable timer to count seconds

```

If precision in intervals between timer firing is required, the timer can be reset in the interrupt caller (if required):

```

ExternalInterrupt:
    CLI; //Disable interrupts

    .....

    CPUGET EAX,29; //Read cycles counter
    ADD EAX,4;     //Account for 4 'missing' cycles
    CPUSET 66,EAX; //Write last timer fire time

    STI; //Enable interrupts
EXTRET;

```

Or alternatively it's possible to reset it by swapping the timer mode:

```

ExternalInterrupt:
    CLI; //Disable interrupts

    .....

    CPUSET 64,1; //Restart timer
    STI; //Enable interrupts
EXTRET;

```

## 2.12 Vector Extension

(using VMODE,VADD,etc)

## 2.13 Hardware Debug Mode

(Using hardware debug mode)

## 2.14 Caching and Runtime Optimization

The Zyelios CPU will cache executed microcode for faster execution. This increases code execution speed, but some penalties apply. The processor will decode instructions the first time they are encountered, and all subsequent executions will use the cached execution information.

The Zyelios CPU will cache executed microcode for faster execution. The processor will decode instructions the first time they are encountered, and all subsequent executions will use the cached execution information. The cache will provide very little benefit for code that is executed infrequently, but code that is executed frequently will run much faster.

The penalties caused by caching system mostly concern the flow of execution and the internal optimizations the processor makes:

1. While executing a single cached block of microcode the processor uses fast-access cached registers. This means that register values are not changed until the block finishes executing.
2. The processor only caches instructions the first time they are decoded. It will invalidate cache if the processor itself writes or reads to the memory, but it does not invalidate cache if any other device writes to an external source.
3. Cached microcode blocks contain up to 8 instructions each. They will end prematurely on unconditional branches and jumps.
4. All reading and writing operations might be delayed by several instructions until they actually happen. There are only very specific ways to make sure your I/O operation really happens.





# Chapter 3

## Instruction Format

### 3.1 Format

Each instruction in the ZCPU begins with a single byte which identifies the instruction to be executed. If the instruction has operands, then a *RM byte* (register/memory selector byte) follows. This extra byte specifies what kind of operands are being passed to the instruction.

Instruction number may also encode information about use of segment prefix, or about the local execution mode (see page 53). The instruction number can fall into one of the following ranges:

- 000 - 999: variable size instructions
- 1000 - 1999: variable size instructions with segment prefix for 1st operand
- 10000 - 10999: variable size instructions with segment prefix for 2nd operand
- 11000 - 11999: variable size instructions with segment prefixes for both operands
- 2000 - 2999: fixed size instructions
- 3000 - 3999: fixed size instructions with segment prefix for 1st operand
- 12000 - 12999: fixed size instructions with segment prefix for 2nd operand
- 13000 - 13999: fixed size instructions with segment prefixes for both operands

The instruction may be followed by several extra bytes that specify segment prefix, constant values, etc. The constant values are always the last bytes in the instruction data. Here's an example of a wide variety of different instructions:

STEF	48
INC EAX	20, 1
MOV EAX,10	14, 1, 10
ADD EAX,ESP	10, 70001
DIV EBX,ES:ECX	10013, 290002, 4
ADD R0,#R2	10, 20822048
MOV #100,#500	14, 250025, 100, 500
MOV EAX:#50,GS	1014, 130025, 9, 50

## 3.2 Register-Memory Modifier Byte

The RM byte consists of two parts - the RM selector for the first and the second operand:  
 $RM = RM_1 + 10000 \cdot RM_2$ .

For example RM bytes from the example in the previous chapter could be decoded like this:

	RM	RM1	RM2
STEF	n/a	n/a	n/a
INC EAX	1	1	n/a
MOV EAX,10	1	1	0
ADD EAX,ESP	70001	1	7
DIV EBX,ES:ECX	290002	2	29
ADD R0,#R2	20822048	2048	2082
MOV #100,#500	250025	25	25
MOV EAX:#50,GS	130025	25	13

These RM selectors are supported right now:

Selector	Operand	Source/target
0	123	Constant value
1	EAX	Register EAX
2	EBX	Register EBX
3	ECX	Register ECX
4	EDX	Register EDX
5	ESI	Register ESI
6	EDI	Register EDI
7	ESP	Register ESP
8	EBP	Register EBP
9	CS	Register CS
10	SS	Register SS

11	DS	Register DS
12	ES	Register ES
13	GS	Register GS
14	FS	Register FS
15	KS	Register KS
16	LS	Register LS
17	#EAX, ES:#EAX	Memory cell EAX + segment
18	#EBX, ES:#EBX	Memory cell EBX + segment
19	#ECX, ES:#ECX	Memory cell ECX + segment
20	#EDX, ES:#EDX	Memory cell EDX + segment
21	#ESI, ES:#ESI	Memory cell ESI + segment
22	#EDI, ES:#EDI	Memory cell EDI + segment
23	#ESP, ES:#ESP	Memory cell ESP + segment
24	#EBP, ES:#EBP	Memory cell EBP + segment
25	#123, ES:#123	Memory cell by constant value
26	ES:EAX	Register EAX + segment
27	ES:EBX	Register EBX + segment
28	ES:ECX	Register ECX + segment
29	ES:EDX	Register EDX + segment
30	ES:ESI	Register ESI + segment
31	ES:EDI	Register EDI + segment
32	ES:ESP	Register ESP + segment
33	ES:EBP	Register EBP + segment
34	No syntax	Memory cell EAX + constant
35	No syntax	Memory cell EBX + constant
36	No syntax	Memory cell ECX + constant
37	No syntax	Memory cell EDX + constant
38	No syntax	Memory cell ESI + constant
39	No syntax	Memory cell EDI + constant
40	No syntax	Memory cell ESP + constant
41	No syntax	Memory cell EBP + constant
42	No syntax	Register EAX + constant
43	No syntax	Register EBX + constant
44	No syntax	Register ECX + constant
45	No syntax	Register EDX + constant
46	No syntax	Register ESI + constant
47	No syntax	Register EDI + constant
48	No syntax	Register ESP + constant
49	No syntax	Register EBP + constant
50	ES:123	Constant value plus segment
1000	PORT0	Port 0
1001	PORT1	Port 1
....	....	....
2023	PORT1023	Port 1023

2048	R0	Extended register R0
....	....	....
2079	R31	Extended register R31
2080	#R0, ES:#R0	Memory cell R0 + segment
....	....	....
2111	#R31, ES:#R31	Memory cell R31 + segment
2112	ES:R0	Extended register R0 + segment
....	....	....
2143	ES:R31	Extended register R31 + segment
2144	No syntax	Memory cell R0 + constant
....	....	....
2175	No syntax	Memory cell R31 + constant
2176	No syntax	Extended register R0 + constant
....	....	....
2207	No syntax	Extended register R31 + constant

### 3.3 Segment Offsets

Segment offset is specified by a byte that follows the RM byte. For example, here is how the same instruction is encoded with different segment prefixes:

```

MOV EAX,EBX      14,20001
MOV LS:EAX,EBX   1014,20027,8
MOV EAX,LS:EBX   10014,280001,8
MOV LS:EAX,LS:EBX 11014,280027,8,8
MOV R0:EAX,EBX   1014,20027,17
MOV EAX,R0:EBX   10014,280001,17
MOV R0:EAX,R0:EBX 11014,280027,17,17

```

There can be the following segment prefixes. The negative-value prefixes are obsolete now, and are only preserved for backwards compatibility:

Value	Register	Value	Register
-02	CS	01	CS
-03	SS	02	SS
-04	DS	03	DS
-05	ES	04	ES
-06	GS	05	GS
-07	FS	06	FS
-08	KS	07	KS
-09	LS	08	LS
-10	EAX	09	EAX
-11	EBX	10	EBX
-12	ECX	11	ECX
-13	EDX	12	EDX
-14	ESI	13	ESI
-15	EDI	14	EDI
-16	ESP	15	ESP
-17	EBP	16	EBP
17	R0		
...	...		
47	R32		

### 3.4 Local Execution Mode

The Zyelios CPU supports two machine code formats: fixed-length and variable-length. The CPU automatically determines which type is in use in order to retain binary compatibility. Several simple rules are employed for this detection.

Example of instructions in the default mode:

```

STEF                48
INC EAX             20, 1
MOV EAX,10          14, 1, 10
ADD EAX,ESP         10, 70001
DIV EBX,ES:ECX      10013, 290002, 4
ADD R0,#R2          10, 20822048
MOV #100,#500       14, 250025, 100, 500
MOV EAX:#50,GS      1014, 130025, 9, 50

```

Example of instructions encoded in fixed-size mode:

```

STEF                2048,0,-4,-4,0,0
INC EAX             2020,1,-4,-4,0,0
MOV EAX,10          2014,1,-4,-4,0,10
ADD EAX,ESP         2010,70001,-4,-4,0,0

```

```

DIV EBX,ES:ECX  12013,290002,-4,4,0,0
ADD R0,#R2      2010,20822048,-4,-4,0,0
MOV #100,#500   2014,250025,-4,-4,100,500
MOV EAX:#50,GS  3014,130025,9,-4,50,0

```

Same instructions in the ZCPU compatibility mode:

```

STEF           48, 0
INC EAX        20, 1
MOV EAX,10     14, 1, 10
ADD EAX,ESP    10, 70001
DIV EBX,ES:ECX 10013, 290002, 4
ADD R0,#R2     10, 20822048
MOV #100,#500  14, 250025, 100, 500
MOV EAX:#50,GS 1014, 130025, 9, 50

```

# Chapter 4

## Internal Registers

The processor has several internal registers which are used to store the internal processor state or control advanced processor features. It is possible to read or write most of these registers using CPUSET and CPUGET.

For example:

```
CPUGET EAX,24 //Read register 24 into EAX
                //24 is the interrupt descriptor table pointer
CPUSET 9,EBX //Set register 9 (stack size) to EBX

CPUGET EAX,1000 //Invalid register will set EAX to 0
```

The registers XEIP, CPAGE, PPAGE, SerialNo, CODEBYTES, TimerDT, RAMSize are read-only - it is not possible to change their value by any means.

Changing value of the IP or the CS register is possible, and will be handled as a far jump.

See the section 2 for description of how some of the registers are used.

Mnemonic	Number	Description
IP	00	Instruction pointer
EAX	01	General purpose register A
EBX	02	General purpose register B
ECX	03	General purpose register C
EDX	04	General purpose register D
ESI	05	Source index
EDI	06	Destanation index
ESP	07	Stack pointer
EBP	08	Base pointer
ESZ	09	Stack size

CS	16	Code segment
SS	17	Stack segment
DS	18	Data segment
ES	19	Extra segment
GS	20	User segment
FS	21	User segment
KS	22	Key segment
LS	23	Library segment
IDTR	24	Interrupt descriptor table pointer
CMRPR	25	Comparison result register
XEIP	26	Pointer to start of currently executed instruction
LADD	27	Current interrupt code
LINT	28	Current interrupt number
TMR	29	Instruction/cycle counter
TIMER	30	Internal precise timer
CPAGE	31	Current page number
IF	32	Interrupts enabled flag
PF	33	Protected mode flag
EF	34	Extended mode flag
NIF	35	Next cycle interrupt enabled flag state
MF	36	Extended memory mapping flag
PTBL	37	Page table offset
PTBE	38	Page table number of entries
PCAP	39	Processor paging system capability
RQCAP	40	Processor delayed memory request capability
PPAGE	41	Previous page ID
MEMRQ	42	Type of the memory request
RAMSize	43	Amount of internal memory
External	44	External I/O operation
BusLock	45	Is bus locked for read/write
Idle	46	Should CPU skip some cycles
INTR	47	Handling an interrupt
SerialNo	48	Processor serial number
CODEBYTES	49	Amount of bytes executed so far
BPREC	50	Binary precision level
IPREC	51	Integer precision level
NIDT	52	Number of interrupt descriptor table entries
BlockStart	53	Start offset of the block
BlockSize	54	Block size
VMODE	55	Vector mode (2: 2D, 3: 3D)
XTRL	56	Runlevel for external memory access
HaltPort	57	Halt until this port changes value
HWDEBUG	58	Hardware debug mode active
DBGSTATE	59	Hardware debug mode state



DBGADDR	60	Hardware debug mode address/parameter
CRL	61	Current runlevel
TimerDT	62	Current timer discrete step
MEMADDR	63	Address requested by the memory operation
TimerMode	64	Timer mode (off, instructions, seconds)
TimerRate	65	Timer rate
TimerPrevTime	66	Previous timer fire time
TimerAddress	67	Number of external interrupt to call when timer fires



# Chapter 5

## Instruction Set Reference

### 5.1 ZCPU Instruction Set

This section describes the primary set of opcodes available in the ZCPU. Not all of these are present in ZGPU or ZSPU though. The following primary set instructions are not available in those architectures: SPG, CPG, HALT, IRET, STI, CLI, STEF, CLEF, EXTINT, ERPG, WRPG, RDPG, LIDTR, EXTRET, STM, CLM, SPP, CPP, SRL, GRL, SMAP, GMAP.

### 5.1.1 000 STOP

**Mnemonic:** STOP

**Encoding:** 000

Triggers interrupt #2 (equivalent to INT 2). Will stop the processor execution if extended mode is not enabled.

Used by the processor to detect end of program/invalid jump error, because this instruction is usually the result of invalid jump. Acts as NOP if interrupts are disabled.

**Pseudocode:**

Interrupt(2,0)

### 5.1.2 001 JNE/JNZ

**Mnemonic:** JNE/JNZ X

**Encoding:** 001 RM [Segment1] [Constant1]

Jumps to the specified address if in previous comparison two values were not equal to each other.

Can also be used to check if result of the previous bit operation was not zero:

```
BIT EAX,2  
JNZ LABEL
```

This code will jump to a label if the second bit is set to 1.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

```
if CMPR <> 0 then  
    Jump(X)  
end
```

### 5.1.3 002 JMP

**Mnemonic:** JMP X

**Encoding:** 002 RM [Segment1] [Constant1]

Unconditional jump to the specified address.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

Jump(X)

### 5.1.4 003 JG/JNLE

**Mnemonic:** JG/JNLE X

**Encoding:** 003 RM [Segment1] [Constant1]

Jumps to target address if the previous comparison resulted in greater, or not less or equal result.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

```
if CMPR > 0 then
  Jump(X)
end
```

### 5.1.5 004 JGE/JNL

**Mnemonic:** JGE/JNL X

**Encoding:** 004 RM [Segment1] [Constant1]

Jumps to target address if the previous comparison resulted in greater or equal, or not less result.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

```
if CMPR >= 0 then
  Jump(X)
end
```



### 5.1.6 005 JL/JNGE

**Mnemonic:** JL/JNGE X

**Encoding:** 005 RM [Segment1] [Constant1]

Jumps to target address if the previous comparison resulted in less, or not greater or equal result.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

```
if CMPR < 0 then
  Jump(X)
end
```

### 5.1.7 006 JLE/JNG

**Mnemonic:** JLE/JNG X

**Encoding:** 006 RM [Segment1] [Constant1]

Jumps to target address if the previous comparison resulted in less or equal, or not greater result.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

```
if CMPR <= 0 then
  Jump(X)
end
```

### 5.1.8 007 JE/JZ

**Mnemonic:** JE/JZ X

**Encoding:** 007 RM [Segment1] [Constant1]

Jumps to the specified address if in previous comparison two values were equal to each other.

Can also be used to check if result of the previous bit operation was zero:

```
BIT EAX,2
```

```
JZ LABEL
```

This code will jump to a label if the second bit is set to 0.

May trigger error 14 (execution access violation) if instruction execution moves into a restricted memory area when extended mode is enabled. See page 33 for information about memory protection and paging.

**Pseudocode:**

```
if CMPR <> 0 then
```

```
    Jump(X)
```

```
end
```

### 5.1.9 008 CUID

**Mnemonic:** CUID X

**Encoding:** 008 RM [Segment1] [Constant1]

The CUID instruction will write various information about the processor itself into the EAX register. This can be used to check for the processor capabilities.

The first parameter passed into the instruction defines what kind of the information is required:

Operand	Description
0	Processor version (current version: 10.00, reported as 1000)
1	Amount of internal RAM
2	Processor type
3	Amount of internal ROM

The result will be written into the EAX register. Processor type can be one of the following:

EAX	Description
0	ZCPU
1	ZGPU beta version
2	ZSPU
3	ZGPU

**Pseudocode:**

EAX = CUID[X]

### 5.1.10 009 PUSH

**Mnemonic:** PUSH X

**Encoding:** 009 RM [Segment1] [Constant1]

Pushes a value to the processor stack (see page 15 for more information on the processor stack). Will check for interrupt overflow by comparing the new stack pointer to zero.

Uses the ESP register as the stack pointer, and the ESZ register as the stack size pointer.

Example of use:

```
PUSH 10
```

```
PUSH 20
```

```
POP EAX //EAX is now 20
```

May trigger error 6 (stack overflow/underflow) if the stack pointer goes outside the allowable limits.

May trigger error 7 (memory read/write fault) if the instruction was not able to perform a memory write/read operation due to an error.

**Pseudocode:**

```
MEMORY[ESP+SS] = X
```

```
ESP = ESP - 1
```

```
if ESP < 0 then
```

```
    ESP = 0
```

```
    Interrupt(6,ESP)
```

```
end
```

### 5.1.11 010 ADD

**Mnemonic:** ADD X,Y

**Encoding:** 010 RM [Segment1] [Segment2] [Constant1] [Constant2]

Adds two values together, and writes the result to the first operand.

**Pseudocode:**

$X = X + Y$

### 5.1.12 011 SUB

**Mnemonic:** SUB X,Y

**Encoding:** 011 RM [Segment1] [Segment2] [Constant1] [Constant2]

Subtracts second operand from the first one, and writes the result to the first operand.

**Pseudocode:**

$X = X - Y$

### 5.1.13 012 MUL

**Mnemonic:** MUL X,Y

**Encoding:** 012 RM [Segment1] [Segment2] [Constant1] [Constant2]

Multiples two values together, and writes the result to the first operand.

**Pseudocode:**

$X = X * Y$



### 5.1.14 013 DIV

**Mnemonic:** DIV X,Y

**Encoding:** 013 RM [Segment1] [Segment2] [Constant1] [Constant2]

Divides the first operand by the second operand, and writes the result to the first operand. Checks for the division by zero error.

May trigger error 3 (division by zero) if the second operand was equal to zero.

Will not trigger division by zero error if interrupt flag register IF is set to 0.

**Pseudocode:**

```
if Y <> 0 then
    X = X / Y
else
    Interrupt(3,0)
end
```

### 5.1.15 014 MOV

**Mnemonic:** MOV X,Y

**Encoding:** 014 RM [Segment1] [Segment2] [Constant1] [Constant2]

Copies the contents of the second operand to the first operand.

**Pseudocode:**

$X = Y$

### 5.1.16 015 CMP

**Mnemonic:** CMP X,Y

**Encoding:** 015 RM [Segment1] [Segment2] [Constant1] [Constant2]

Compares the two operands together, and remembers the result of this comparison.

This instruction is used in conjunction with the conditional branching instructions (see 16), for example:

```
CMP EAX,EBX
JG LABEL1 //Jump if EAX > EBX
JLE LABEL2 //Jump if EAX <= EBX
JE LABEL3 //Jump if EAX = EBX
```

**Pseudocode:**

CMPR = X - Y

### 5.1.17 018 MIN

**Mnemonic:** MIN X,Y

**Encoding:** 018 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds the smaller of the two values, and writes it to the first operand. For example:

```
MOV EAX,100
MOV EBX,200
MIN EBX,EAX //Sets EBX to 100
```

**Psuedocode:**

```
if X > Y then
    X = Y
end
```

### 5.1.18 019 MAX

**Mnemonic:** MAX X,Y

**Encoding:** 019 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds the bigger of the two values, and writes it to the first operand. For example:

```
MOV EAX,100
MOV EBX,200
MAX EAX,EBX //Sets EAX to 200
```

**Pseudocode:**

```
if X < Y then
    X = Y
end
```

### 5.1.19 020 INC

**Mnemonic:** INC X

**Encoding:** 020 RM [Segment1] [Constant1]

Increments the target operand by one. For example:

```
MOV EAX,100
```

```
INC EAX //EAX is now 101
```

**Psuedocode:**

```
X = X + 1
```

### 5.1.20 021 DEC

**Mnemonic:** DEC X

**Encoding:** 021 RM [Segment1] [Constant1]

Decrements the target operand by one. For example:

```
MOV EAX,100
```

```
DEC EAX //EAX is now 99
```

**Pseudocode:**

$$X = X - 1$$

### 5.1.21 022 NEG

**Mnemonic:** NEG X

**Encoding:** 022 RM [Segment1] [Constant1]

Negates the target operand (changes its sign). For example:

```
MOV EAX,123
```

```
NEG EAX //EAX is now -123
```

```
MOV EBX,0
```

```
NEG EBX //EBX is now -0, signed zero
```

**Pseudocode:**

```
X = -X
```



### 5.1.22 023 RAND

**Mnemonic:** RAND X

**Encoding:** 023 RM [Segment1] [Constant1]

Generates a random value between 0.0 and 1.0. The random seed is automatically generated by the processor hardware.

Range inclusive of 0.0 and 1.0.

**Pseudocode:**

X = RANDOM(0.0,1.0)

### 5.1.23 024 LOOP

**Mnemonic:** LOOP X

**Encoding:** 024 RM [Segment1] [Constant1]

Performs a conditional jump to a certain label as long as ECX does not equal zero.  
Is usually used for creating loops in programs:

```
MOV ECX,100;
LABEL:
    <...>
LOOP ECX; //Repeats 100 times
```

Will only terminate when ECX is equal to zero.

**Pseudocode:**

```
if ECX <> 0 then
    ECX = ECX - 1
    IP = X
end
```

### 5.1.24 025 LOOPA

**Mnemonic:** LOOPA X

**Encoding:** 025 RM [Segment1] [Constant1]

Performs a conditional jump to a certain label as long as EAX does not equal zero. Is usually used for creating loops in programs:

```
MOV EAX,100;
LABEL:
    <...>
LOOP EAX; //Repeats 100 times
```

Will only terminate when EAX is equal to zero. Similar to the LOOP instruction.

**Pseudocode:**

```
if EAX <> 0 then
    EAX = EAX - 1
    IP = X
end
```

### 5.1.25 026 LOOPB

**Mnemonic:** LOOPB X

**Encoding:** 026 RM [Segment1] [Constant1]

Performs a conditional jump to a certain label as long as EBX does not equal zero. Is usually used for creating loops in programs:

```
MOV EBX,100;
LABEL:
    <...>
LOOP EBX; //Repeats 100 times
```

Will only terminate when EBX is equal to zero. Similar to the LOOP instruction.

**Pseudocode:**

```
if EBX <> 0 then
    EBX = EBX - 1
    IP = X
end
```

### 5.1.26 027 LOOPD

**Mnemonic:** LOOPD X

**Encoding:** 027 RM [Segment1] [Constant1]

Performs a conditional jump to a certain label as long as EDX does not equal zero. Is usually used for creating loops in programs:

```
MOV EDX,100;
LABEL:
    <...>
LOOP EDX; //Repeats 100 times
```

Will only terminate when EDX is equal to zero. Similar to the LOOP instruction.

**Pseudocode:**

```
if EDX <> 0 then
    EDX = EDX - 1
    IP = X
end
```

### 5.1.27 028 SPG

**Mnemonic:** SPG X

**Encoding:** 028 RM [Segment1] [Constant1]

Makes the specific page read-only. It will clear the write flag of the page specified by the operand, and also set the read flag of the page specified by the operand. See page 33 for more information on the paging system.

Example of use:

```
SPG 1 //Set addresses 128..255 read-only
```

```
SPG 2 //Set addresses 256..511 read-only
```

```
CPG 1 //Make the 128..255 range writeable again
```

May trigger error 11 (page access violation) if the instruction attempts to access a page, and the target page runlevel is greater than the current page runlevel.

This instruction is privileged, meaning it can only be executed from the code page which has runlevel of 0.

In case of an error it will pass the target page number as an interrupt parameter.

**Pseudocode:**

```
if CurrentPage.Runlevel < Page[X].Runlevel then
  Page[X].Read = 1
  Page[X].Write = 0
else
  Interrupt(11,X)
end
```

### 5.1.28 029 CPG

**Mnemonic:** CPG X

**Encoding:** 029 RM [Segment1] [Constant1]

Makes the specific page readable and writeable. It will set the write flag of the page specified by the operand, and also set the read flag of the page specified by the operand. See page 33 for more information on the paging system.

Example of use:

```
SPG 1 //Set addresses 128..255 read-only
```

```
SPG 2 //Set addresses 256..511 read-only
```

```
CPG 1 //Make the 128..255 range writeable again
```

May trigger error 11 (page access violation) if the instruction attempts to access a page, and the target page runlevel is greater than the current page runlevel.

This instruction is privileged, meaning it can only be executed from the code page which has runlevel of 0.

In case of an error it will pass the target page number as an interrupt parameter.

**Pseudocode:**

```
if CurrentPage.Runlevel < Page[X].Runlevel then
  Page[X].Read = 1
  Page[X].Write = 1
else
  Interrupt(11,X)
end
```

### 5.1.29 030 POP

**Mnemonic:** POP X

**Encoding:** 030 RM [Segment1] [Constant1]

Pops a value off the processor stack (see page 15 for more information on the processor stack). Will check for underflow by comparing the new stack pointer to the stack size register.

Uses the ESP register as the stack pointer, and the ESZ register as the stack size pointer.

Example of use:

```
PUSH 10
```

```
PUSH 20
```

```
POP EAX //EAX is now 20
```

May trigger error 6 (stack overflow/underflow) if the stack pointer goes outside the allowable limits.

**Pseudocode:**

```
ESP = ESP + 1
```

```
if ESP > ESZ then
```

```
    ESP = ESZ
```

```
    Interrupt(6,ESP)
```

```
end
```



### 5.1.30 031 CALL

**Mnemonic:** CALL X

**Encoding:** 031 RM [Segment1] [Constant1]

Calls a subroutine of the program. The subroutine will return to this point of execution by executing the **RET** instruction.

This instruction pushes the current instruction pointer to stack, and will restore it upon executing the **RET** instruction. Any damage to the stack data might cause subroutine to fail to return to the original calling point.

The opcode may trigger stack-related errors.

For example:

```
CALL SUBROUTINE0;  
CALL SUBROUTINE1;
```

```
SUBROUTINE0:
```

```
<...>
```

```
RET
```

```
SUBROUTINE1:
```

```
<...>
```

```
CALL SUBROUTINE0;
```

```
RET
```

May trigger error 6 (stack overflow/underflow) if the stack pointer goes outside the allowable limits.

**Pseudocode:**

```
Push(IP)  
if NoInterrupts then  
    IP = X  
end
```

### 5.1.31 032 BNOT

**Mnemonic:** BNOT X

**Encoding:** 032 RM [Segment1] [Constant1]

Toggles all bits in the number. The number of bits affected by the operation depend on the current setting of the BPREC register (binary precision).

For example:

```
CPUSET 50,8 //Set 8-bit precision
```

```
MOV EAX,1
```

```
BNOT EAX //EAX is now 254
```

**Psuedocode:**

```
X = NOT X
```

### 5.1.32 033 FINT

**Mnemonic:** FINT X

**Encoding:** 033 RM [Segment1] [Constant1]

Rounds down the value. Will round down to the lower integer:

```
MOV EAX,1.9
```

```
FINT EAX //EAX = 1.0
```

```
MOV EAX,4.21
```

```
FINT EAX //EAX = 4.0
```

```
MOV EAX,1520.101
```

```
FINT EAX //EAX = 1520.0
```

**Pseudocode:**

```
X = FLOOR(X)
```

### 5.1.33 034 FRND

**Mnemonic:** FRND X

**Encoding:** 034 RM [Segment1] [Constant1]

Rounds the value to the nearest integer:

```
MOV EAX,1.9
```

```
FRND EAX //EAX = 2.0
```

```
MOV EAX,4.21
```

```
FRND EAX //EAX = 4.0
```

```
MOV EAX,1520.101
```

```
FRND EAX //EAX = 1520.0
```

**Psuedocode:**

```
X = ROUND(X)
```

### 5.1.34 035 FFRAC

**Mnemonic:** FFRAC X

**Encoding:** 035 RM [Segment1] [Constant1]

Returns the fractional value of the operand:

```
MOV EAX,1.9
```

```
FRND EAX //EAX = 0.9
```

```
MOV EAX,4.21
```

```
FRND EAX //EAX = 0.21
```

```
MOV EAX,1520.101
```

```
FRND EAX //EAX = 0.101
```

**Pseudocode:**

```
X = FRAC(X)
```

### 5.1.35 036 FINV

**Mnemonic:** FINV X

**Encoding:** 036 RM [Segment1] [Constant1]

Finds the inverse of the operand. Checks for the division by zero error.

May trigger error 3 (division by zero) if the second operand was equal to zero.

Will not trigger division by zero error if interrupt flag register IF is set to 0.

**Pseudocode:**

```
if X <> 0 then
    X = 1 / X
else
    Interrupt(3,1)
end
```

### 5.1.36 038 FSHL

**Mnemonic:** FSHL X

**Encoding:** 038 RM [Segment1] [Constant1]

Performs an arithmetic shift-left by multiplying the input number by two. The result might be a floating-point value:

```
MOV EAX,100  
FSHL EAX //EAX = 200
```

```
MOV EAX,8  
FSHL EAX //EAX = 16
```

```
MOV EAX,4.2  
FSHL EAX //EAX = 8.2
```

**Pseudocode:**

```
X = X * 2
```

### 5.1.37 039 FSHR

**Mnemonic:** FSHR X

**Encoding:** 039 RM [Segment1] [Constant1]

Performs an arithmetic shift-right by dividing the input number by two. The result might be a floating-point value:

```
MOV EAX,100
```

```
FSHR EAX //EAX = 50
```

```
MOV EAX,8
```

```
FSHR EAX //EAX = 4
```

```
MOV EAX,4.2
```

```
FSHR EAX //EAX = 2.1
```

**Pseudocode:**

```
X = X / 2
```



### 5.1.38 040 RET

**Mnemonic:** RET

**Encoding:** 040

Returns from a subroutine previous called by **CALL** instruction. This instruction will pop a value off the stack, and use it as a return address.

It can be used for creating subroutines:

```
CALL SUBROUTINE0;
```

```
CALL SUBROUTINE1;
```

```
SUBROUTINE0:
```

```
<...>
```

```
RET
```

```
SUBROUTINE1:
```

```
<...>
```

```
CALL SUBROUTINE0;
```

```
RET
```

May trigger error 6 (stack overflow/underflow) if the stack pointer goes outside the allowable limits.

**Pseudocode:**

```
IP = POP()
```

### 5.1.39 041 IRET

**Mnemonic:** IRET

**Encoding:** 041

Returns from an interrupt call. This instruction is very similar to the RET instruction, except it restores both the code segment CS and the instruction pointer IP. It will pop both values off the stack.

The code segment that will be restored correspond to the code segment that the execution was in when the interrupt occurred. It is *not* affected by the IF flag (interrupt flag).

For example, a typical interrupt body would be:

```
INTERRUPT_HANDLER:
```

```
<...>
```

```
IRET;
```

**Pseudocode:**

```
if EF = 0 then
```

```
    IP = Pop()
```

```
end
```

```
if EF = 1 then
```

```
    CS = Pop()
```

```
    IP = Pop()
```

```
end
```

### 5.1.40 042 STI

**Mnemonic:** STI

**Encoding:** 042

Set interrupt flag **IF** to 1 *after the next instruction*. This will enable triggering the interrupts (without the **IF** flag interrupts are ignored).

The delay of one instruction is so it would be possible to combine **STI** instruction with an **IRET** or **EXTRET** instruction to provide an atomic interrupt handler (preventing any other interrupts from happening during this interrupt). It's most efficiently used to prevent external interrupts from happening.

For example:

```
INTERRUPT_HANDLER:
```

```
    CLI;
```

```
    <...>
```

```
    STI;
```

```
EXTRET;
```

This instruction is privileged, meaning it can only be executed from the code page which has runlevel of 0.

**Pseudocode:**

```
NextIF = 1
```

### 5.1.41 043 CLI

**Mnemonic:** CLI

**Encoding:** 043

Clears the interrupt flag IF. This will prevent any interrupts from being triggered, and the errors raised by the processor will be ignored. The interrupts can be turned back on using the STI instruction.

This instruction is privileged, meaning it can only be executed from the code page which has runlevel of 0.

**Pseudocode:**

IF = 0

### 5.1.42 047 RETF

**Mnemonic:** RETF

**Encoding:** 047

Performs a return from a far subroutine call via the **CALLF** instruction. Works similarly to the **IRET** instruction, but does not check for the extended mode.

Will set code segment and instruction pointer to values popped off the stack.

**Pseudocode:**

CS = Pop()

IP = Pop()

### 5.1.43 048 STEF

**Mnemonic:** STEF

**Encoding:** 048

Enable the extended mode of the processor. This mode will enable the interrupt table support, and permission checks for the paging system.

The paging system is independant of the extended mode, and can function with or without the extended mode enabled.

It's possible to disable the extended mode by using the **CLEF** instruction.

This instruction is privileged, meaning it can only be executed from the code page which has runlevel of 0.

**Pseudocode:**

EF = 1

#### 5.1.44 049 CLEF

**Mnemonic:** CLEF

**Encoding:** 049

Disables the extended mode which was enabled by the **STEF** instruction. This will disable interrupt table, and disable the permission checks in the paging system.

The paging system is independant of the extended mode, and can function with or without the extended mode enabled.

This instruction is privileged, meaning it can only be executed from the code page which has runlevel of 0.

**Psuedocode:**

EF = 0

### 5.1.45 050 AND

**Mnemonic:** AND X,Y

**Encoding:** 050 RM [Segment1] [Segment2] [Constant1] [Constant2]

Performs a logical AND operation on the two operands, and writes the result back to the first operand. The result will be 1 if both operands are greater or equal to 1.

**Pseudocode:**

$X = X \text{ AND } Y$



### 5.1.46 051 OR

**Mnemonic:** OR X,Y

**Encoding:** 051 RM [Segment1] [Segment2] [Constant1] [Constant2]

Performs a logical OR operation on the two operands, and writes the result back to the first operand. The result will be 1 if either of the operands is greater or equal to 1.

**Pseudocode:**

$X = X \text{ OR } Y$

### 5.1.47 052 XOR

**Mnemonic:** XOR X,Y

**Encoding:** 052 RM [Segment1] [Segment2] [Constant1] [Constant2]

Performs a logical XOR operation on the two operands, and writes the result back to the first operand. The result will be 1 if just one of operands is greater or equal to 1 (but not two of them at once).

**Pseudocode:**

$X = X \text{ XOR } Y$

### 5.1.48 053 FSIN

**Mnemonic:** FSIN X,Y

**Encoding:** 053 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds sine of the second operand, and writes it into the first operand.

**Pseudocode:**

$X = \text{Sin}(Y)$

### 5.1.49 054 FCOS

**Mnemonic:** FCOS X,Y

**Encoding:** 054 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds cosine of the second operand, and writes it into the first operand.

**Pseudocode:**

$X = \text{Cos}(Y)$

### 5.1.50 055 FTAN

**Mnemonic:** FTAN X,Y

**Encoding:** 055 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds tangent of the second operand, and writes it into the first operand.

**Pseudocode:**

$X = \text{Tan}(Y)$

### 5.1.51 056 FASIN

**Mnemonic:** FASIN X,Y

**Encoding:** 056 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds arcsine of the second operand, and writes it into the first operand.

**Pseudocode:**

$X = \text{ArcSin}(Y)$

### 5.1.52 057 FACOS

**Mnemonic:** FACOS X,Y

**Encoding:** 057 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds arccosine of the second operand, and writes it into the first operand.

**Pseudocode:**

$X = \text{ArcCos}(Y)$

### 5.1.53 058 FATAN

**Mnemonic:** FATAN X,Y

**Encoding:** 058 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds arctangent of the second operand, and writes it into the first operand.

**Pseudocode:**

$X = \text{ArcTan}(Y)$



### 5.1.54 059 MOD

**Mnemonic:** MOD X,Y

**Encoding:** 059 RM [Segment1] [Segment2] [Constant1] [Constant2]

Finds a remainder after the first operand was divided by the second operand, and returns the result to the first operand. If the input is a floating-point value, then it will return the value of  $X - n * Y$ , where  $n$  is the quotient of  $X/Y$ , rounded toward zero to an integer.

**Pseudocode:**

$X = X \text{ FMOD } Y$

### 5.1.55 060 BIT

**Mnemonic:** BIT X,Y

**Encoding:** 060 RM [Segment1] [Segment2] [Constant1] [Constant2]

Tests whether specific bit is set in the given number, and writes the result to the **CMPR** register. It's possible to check the result of this operation using the conditional branching opcodes (see pages 18, 37):

```
BIT EAX,4 //Test 5th bit of EAX
JZ LABEL1 //Jump if 5th bit is 0
JNZ LABEL1 //Jump if 5th bit is 1
```

**Pseudocode:**

```
CMPR = Yth bit of X
```

### 5.1.56 061 SBIT

**Mnemonic:** SBIT X,Y

**Encoding:** 061 RM [Segment1] [Segment2] [Constant1] [Constant2]

Sets specific bit of the first operand (see page 37):

```
MOV EAX,105 //1101001
```

```
SBIT EAX,1
```

```
//EAX = 107 1101011
```

**Pseudocode:**

```
Yth bit of X = 1
```

### 5.1.57 062 CBIT

**Mnemonic:** CBIT X,Y

**Encoding:** 062 RM [Segment1] [Segment2] [Constant1] [Constant2]

Clears specific bit of the first operand (see page 37):

```
MOV EAX,107 //1101011
```

```
CBIT EAX,6
```

```
//EAX = 43 0101011
```

**Pseudocode:**

Yth bit of X = 0

### 5.1.58 063 TBIT

**Mnemonic:** TBIT X,Y

**Encoding:** 063 RM [Segment1] [Segment2] [Constant1] [Constant2]

Toggles specific bit of the first operand (see page 37):

```
MOV EAX,43 //0101011
```

```
TBIT EAX,0
```

```
//EAX = 42 0101010
```

**Pseudocode:**

Yth bit of X = 1 - Yth bit of X

### 5.1.59 064 BAND

**Mnemonic:** BAND X,Y

**Encoding:** 064 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.60 065 BOR

**Mnemonic:** BOR X,Y

**Encoding:** 065 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.61 066 BXOR

**Mnemonic:** BXOR X,Y

**Encoding:** 066 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**



### 5.1.62 067 BSHL

**Mnemonic:** BSHL X,Y

**Encoding:** 067 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.63 068 BSHR

**Mnemonic:** BSHR X,Y

**Encoding:** 068 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.64 069 JMPF

**Mnemonic:** JMPF X,Y

**Encoding:** 069 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.65    070 EXTINT**

**Mnemonic:** EXTINT X

**Encoding:** 070 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.66 071 CNE**

**Mnemonic:** CNE X

**Encoding:** 071 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.67 071 CNZ**

**Mnemonic:** CNZ X

**Encoding:** 071 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.68 073 CG**

**Mnemonic:** CG X

**Encoding:** 073 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.69    073 CNLE**

**Mnemonic:** CNLE X

**Encoding:** 073 RM [Segment1] [Constant1]

**Psuedocode:**



### **5.1.70    074 CGE**

**Mnemonic:** CGE X

**Encoding:** 074 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.71    074 CNL**

**Mnemonic:** CNL X

**Encoding:** 074 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.72   075 CL**

**Mnemonic:** CL X

**Encoding:** 075 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.73 075 CNGE**

**Mnemonic:** CNGE X

**Encoding:** 075 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.74 076 CLE**

**Mnemonic:** CLE X

**Encoding:** 076 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.75    076 CNG**

**Mnemonic:** CNG X

**Encoding:** 076 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.76    077 CE**

**Mnemonic:** CE X

**Encoding:** 077 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.77 077 CZ**

**Mnemonic:** CZ X

**Encoding:** 077 RM [Segment1] [Constant1]

**Psuedocode:**



### **5.1.78    078 MCOPY**

**Mnemonic:** MCOPY X

**Encoding:** 078 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.79    078 MCOPY**

**Mnemonic:** MCOPY X

**Encoding:** 078 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.80 079 MXCHG**

**Mnemonic:** MXCHG X

**Encoding:** 079 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.81 079 MXCHG**

**Mnemonic:** MXCHG X

**Encoding:** 079 RM [Segment1] [Constant1]

**Psuedocode:**

### 5.1.82 080 FPWR

**Mnemonic:** FPWR X,Y

**Encoding:** 080 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.83 081 XCHG

**Mnemonic:** XCHG X,Y

**Encoding:** 081 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.84 082 FLN

**Mnemonic:** FLN X,Y

**Encoding:** 082 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.85 083 FLOG10

**Mnemonic:** FLOG10 X,Y

**Encoding:** 083 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**



### **5.1.86    084 IN**

**Mnemonic:** IN X,Y

**Encoding:** 084 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.87 085 OUT

**Mnemonic:** OUT X,Y

**Encoding:** 085 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.88 086 FABS

**Mnemonic:** FABS X,Y

**Encoding:** 086 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.89 087 FSGN

**Mnemonic:** FSGN X,Y

**Encoding:** 087 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.90 088 FEXP**

**Mnemonic:** FEXP X,Y

**Encoding:** 088 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.91 089 CALLF

**Mnemonic:** CALLF X,Y

**Encoding:** 089 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.92 090 FPI**

**Mnemonic:** FPI X

**Encoding:** 090 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.93 091 FE**

**Mnemonic:** FE X

**Encoding:** 091 RM [Segment1] [Constant1]

**Psuedocode:**



### **5.1.94 092 INT**

**Mnemonic:** INT X

**Encoding:** 092 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.95 093 TPG**

**Mnemonic:** TPG X

**Encoding:** 093 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.96    094 FCEIL**

**Mnemonic:** FCEIL X

**Encoding:** 094 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.97 095 ERPG**

**Mnemonic:** ERPG X

**Encoding:** 095 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.98 096 WRPB**

**Mnemonic:** WRPB X

**Encoding:** 096 RM [Segment1] [Constant1]

**Pseudocode:**

### **5.1.99 097 RDPG**

**Mnemonic:** RDPG X

**Encoding:** 097 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.100 098 TIMER**

**Mnemonic:** TIMER X

**Encoding:** 098 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.101 099 LIDTR**

**Mnemonic:** LIDTR X

**Encoding:** 099 RM [Segment1] [Constant1]

**Psuedocode:**



### **5.1.102    101 JNER**

**Mnemonic:** JNER X

**Encoding:** 101 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.103    101 JNZR**

**Mnemonic:** JNZR X

**Encoding:** 101 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.104    102 JMPR**

**Mnemonic:** JMPR X

**Encoding:** 102 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.105    103 JGR**

**Mnemonic:** JGR X

**Encoding:** 103 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.106    103 JNLER**

**Mnemonic:** JNLER X

**Encoding:** 103 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.107 104 JGER**

**Mnemonic:** JGER X

**Encoding:** 104 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.108    104 JNLR**

**Mnemonic:** JNLR X

**Encoding:** 104 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.109    105 JLR**

**Mnemonic:** JLR X

**Encoding:** 105 RM [Segment1] [Constant1]

**Psuedocode:**



### **5.1.110    105 JNGER**

**Mnemonic:** JNGER X

**Encoding:** 105 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.111    106 JLER**

**Mnemonic:** JLER X

**Encoding:** 106 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.112    106 JNGR**

**Mnemonic:** JNGR X

**Encoding:** 106 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.113    107 JER**

**Mnemonic:** JER X

**Encoding:** 107 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.114    107 JZR**

**Mnemonic:** JZR X

**Encoding:** 107 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.115    108 LNEG**

**Mnemonic:** LNEG X

**Encoding:** 108 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.116   110 EXTRET**

**Mnemonic:** EXTRET

**Encoding:** 110

**Psuedocode:**

### **5.1.117 111 IDLE**

**Mnemonic:** IDLE

**Encoding:** 111

**Psuedocode:**



### 5.1.118 112 NOP

**Mnemonic:** NOP

**Encoding:** 112

**Pseudocode:**

### **5.1.119    114 PUSHB**

**Mnemonic:** PUSHB

**Encoding:** 114

**Pseudocode:**

### **5.1.120 115 POPA**

**Mnemonic:** POPA

**Encoding:** 115

**Psuedocode:**

### **5.1.121 116 STD2**

**Mnemonic:** STD2

**Encoding:** 116

**Psuedocode:**

### **5.1.122   117 LEAVE**

**Mnemonic:** LEAVE

**Encoding:** 117

**Psuedocode:**

### **5.1.123 118 STM**

**Mnemonic:** STM

**Encoding:** 118

**Psuedocode:**

### **5.1.124   119   CLM**

**Mnemonic:** CLM

**Encoding:** 119

**Psuedocode:**

### **5.1.125    120 CPUGET**

**Mnemonic:** CPUGET X,Y

**Encoding:** 120 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**



### **5.1.126    121 CPUSET**

**Mnemonic:** CPUSET X,Y

**Encoding:** 121 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.127 122 SPP

**Mnemonic:** SPP X,Y

**Encoding:** 122 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.128   123 CPP**

**Mnemonic:** CPP X,Y

**Encoding:** 123 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.129 124 SRL

**Mnemonic:** SRL X,Y

**Encoding:** 124 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.130    125 GRL**

**Mnemonic:** GRL X,Y

**Encoding:** 125 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.131    126 LEA**

**Mnemonic:** LEA X,Y

**Encoding:** 126 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.132 127 BLOCK

**Mnemonic:** BLOCK X,Y

**Encoding:** 127 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.133 128 CMPAND

**Mnemonic:** CMPAND X,Y

**Encoding:** 128 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**



### 5.1.134 129 CMPOR

**Mnemonic:** CMPOR X,Y

**Encoding:** 129 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.135    130 MSHIFT**

**Mnemonic:** MSHIFT X,Y

**Encoding:** 130 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.136    131 SMAP**

**Mnemonic:** SMAP X,Y

**Encoding:** 131 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.137 132 GMAP

**Mnemonic:** GMAP X,Y

**Encoding:** 132 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.138    133 RSTACK**

**Mnemonic:** RSTACK X,Y

**Encoding:** 133 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.139    134 SSTACK**

**Mnemonic:** SSTACK X,Y

**Encoding:** 134 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.140    135 ENTER**

**Mnemonic:** ENTER X

**Encoding:** 135 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.141    250 VADD**

**Mnemonic:** VADD X,Y

**Encoding:** 250 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**



### **5.1.142    251   VSUB**

**Mnemonic:** VSUB X,Y

**Encoding:** 251 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.143 252 VMUL

**Mnemonic:** VMUL X,Y

**Encoding:** 252 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.144    253 VDOT**

**Mnemonic:** VDOT X,Y

**Encoding:** 253 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.145    254 VCROSS**

**Mnemonic:** VCROSS X,Y

**Encoding:** 254 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.146    255 VMOV**

**Mnemonic:** VMOV X,Y

**Encoding:** 255 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.147 256 VNORM

**Mnemonic:** VNORM X,Y

**Encoding:** 256 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

## 5.1.148 257 VCOLORNORM

**Mnemonic:** VCOLORNORM X,Y

**Encoding:** 257 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 5.1.149 259 LOOPXY

**Mnemonic:** LOOPXY X,Y

**Encoding:** 259 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

```
    IF EDX > 0 THEN
IP = X
    IF ECX > 0 THEN
ECX = ECX - 1
    ELSE
EDX = EDX - 1
ECX = Y
    END
END
```



### 5.1.150 260 MADD

**Mnemonic:** MADD X,Y

**Encoding:** 260 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### **5.1.151    261 MSUB**

**Mnemonic:** MSUB X,Y

**Encoding:** 261 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.152 262 MMUL

**Mnemonic:** MMUL X,Y

**Encoding:** 262 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.153    263 MROTATE**

**Mnemonic:** MROTATE X,Y

**Encoding:** 263 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.154    264 MSCALE**

**Mnemonic:** MSCALE X,Y

**Encoding:** 264 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.155 265 MPERSPECTIVE

**Mnemonic:** MPERSPECTIVE X,Y

**Encoding:** 265 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.156    266 MTRANSLATE**

**Mnemonic:** MTRANSLATE X,Y

**Encoding:** 266 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 5.1.157 267 MLOOKAT

**Mnemonic:** MLOOKAT X,Y

**Encoding:** 267 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**



### 5.1.158 268 MMOV

**Mnemonic:** MMOV X,Y

**Encoding:** 268 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.159    269 VLEN**

**Mnemonic:** VLEN X,Y

**Encoding:** 269 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.160    270 MIDENT**

**Mnemonic:** MIDENT X

**Encoding:** 270 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.161    273 VMODE**

**Mnemonic:** VMODE X

**Encoding:** 273 RM [Segment1] [Constant1]

**Psuedocode:**

### **5.1.162    295 VDIV**

**Mnemonic:** VDIV X,Y

**Encoding:** 295 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### **5.1.163    296 VTRANSFORM**

**Mnemonic:** VTRANSFORM X,Y

**Encoding:** 296 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

# Chapter 6

## HL-ZASM

### 6.1 Description

HL-ZASM is a high-level assembler compiler and a programming language. It provides support for all the basic C high-level structures, while retaining compatibility with ZASM2 assembly code.

### 6.2 Keywords

There are certain characters and keywords that are reserved in the HL-ZASM compiler, and cannot be used as, for example, variable names. A variable name/function name/identifier can be any alphanumeric character, underscore (`_`). In some cases the dot (`.`) symbol can be part of a label name.

The following keywords are reserved: `GOTO`, `FOR`, `IF`, `ELSE`, `WHILE`, `DO`, `SWITCH`, `CASE`, `CONST`, `RETURN`, `BREAK`, `CONTINUE`, `EXPORT`, `FORWARD`, `DB`, `ALLOC`, `SCALAR`, `VECTOR1F`, `VECTOR2F`, `UV`, `VECTOR3F`, `VECTOR4F`, `COLOR`, `VEC1F`, `VEC2F`, `VEC3F`, `VEC4F`, `MATRIX`, `STRING`, `DB`, `DEFINE`, `CODE`, `DATA`, `ORG`, `OFFSET`, `VOID`, `FLOAT`, `CHAR`, `INT48`, `VECTOR`, `PRESERVE`, `ZAP`.

The exact meaning and use of these keywords is detailed in the following chapters.

### 6.3 Assembler Syntax

#### 6.3.1 Basic Assembly

HL-ZASM supports the following common assembly syntax (Intel-like):

```
mov eax,123; //Moving constant into register
mov eax,ebx; //Moving register into register
```

```
add eax,123; //2-operand instruction
jmp 123; //1-operand instruction on constant
jmp eax; //1-operand instruction on register
```

The two operands always follow the instruction. The first one is always the destination operand, and the second one is the source operand.

### 6.3.2 Memory Access and Segments

It is possible to use both the traditional ZASM memory access symbol (#) or the more common square brackets ([]). Both are considered valid.

The CPU also supports segment prefixes to offset memory reads (see page 11 for more information on segments). It is possible to use any general-purpose or segment register as a segment prefix to any common operand.

HL-ZASM allows for an 'inverted' syntax, which is when a segment prefix follows the operand itself (for example 'es:eax' instead of 'eax:es').

When using common syntax for reading a value from memory, a segment prefix must be included inside the brackets. It is possible to use the plus sign (+) instead of a colon (:), but the common memory access syntax must be used.

It is also possible to use a constant value as a segment prefix for a register via inverted syntax support. It is currently not possible to access a memory cell using a constant offset by a constant, but this will be fixed later.

The following syntax for using memory access and segments is supported:

```
//ZASM2-style reading from memory
mov eax,#100;
mov eax,#eax;
mov eax,es:#100;
mov eax,es:#eax;
mov eax,es:#100;
//mov eax,es:#es; //Invalid: cannot use segment register as pointer

//Common-style reading from memory
mov eax,[100];
mov eax,[eax];
mov eax,[es:eax];
mov eax,[es+eax];
//mov eax,[eax:es]; //Invalid: cannot use segment register as pointer
```



```
//mov eax,[eax+es]; //Invalid: cannot use segment register as pointer

//Using constants with segments
mov eax,es:100;
mov eax,eax:100;
mov eax,100:es;
mov eax,100:eax;
//mov eax,100:200; //Invalid

//Using registers with segments
mov eax,ebx:ecx;
mov eax,es:ebx;
mov eax,ebx:es; //Invalid, but translated into the valid 'es:ebx'
//mov eax,fs:es; //Invalid, as no valid syntax is possible
```

### 6.3.3 Constants

It is possible to use constant expressions, hexadecimal values and label values in HL-ZASM:

```
//Constant integers
mov eax,255;    //EAX = 255
mov eax,0255;   //EAX = 255
mov eax,0x1FF;  //EAX = 511

//Negative integers
mov eax,-255;    //EAX = -255
mov eax,-0x1FF;  //EAX = -511

//Floating point numbers and expressions
mov eax,1e4;      //EAX = 10000
mov eax,1.53e-3;   //EAX = 0.00153
mov eax,1.284;     //EAX = 1.248
mov eax,2.592+3.583; //EAX = 6.175
mov eax,1e2+15;    //EAX = 115
//mov eax,1e-5+0.034; //Does not parse (bug)
mov eax,0xFF+100;  //EAX = 355
```

```
//Complex expressions
define labelname,512;
mov eax,10+15;           //EAX = 25
mov eax,10*(15+17*24); //EAX = 4230
mov eax,10+labelname*53-10*(17-labelname); //EAX = 32096
```

### 6.3.4 Labels And Variables

Labels are used to branch to specific portions of code. Each label name is actually a number with a name assigned to it. That means that variable names and label names all have valid constant values, and can be used in expressions as parameters for various macros:

```
labelname:
    jmp labelname;
    mov eax,labelname+3;

labelName: //case sensitive
    jmp labelName;
```

The `define` macro allow a label name to be assigned to any constant expression:

```
define defVar1,120;
define defVar2,50+defVar1;
//define defVar3,labelname2*10; //Does not parse, bug

labelname2:
    mov eax,defVar1; //120
    mov eax,defVar2; //170
//mov eax,defVar3; //170
```

The `db` macro is used to write specific values to memory, bypassing any preprocessing. They will be written into the code segment:

```
db 100; //Outputs 100
db 0xFF; //Outputs 255
db labelname2+10;
db 'This is a string',0;
db 15,28,595,'string',35,29;
```

The `alloc` macro allocates space and allows it to be accessed by name, if one is given. It will be located at the current position in memory (if data and code are located in the same segment), or in a separate data segment, depending on the compiler preferences. The first parameter must either be a valid ident or a constant expression that does not start with an ident:

```
alloc var1,100,72; //alloc label,size,value, same as 'var1: db 72,72,72,...'
alloc var2,100;    //alloc label,value, same as 'var2: db 100'
alloc var3;        //alloc label, same as 'var3: db 0'
alloc 120;          //alloc size, same as 'db 0,0,0,0,0....'
```

```
define allocsize,120;
alloc 0+allocsize; //must not start with an ident name
```

There are also special macros for defining vector variables and string variables. The basic syntax is `VECTOR_MACRO NAME,DEFAULT_VALUE`. These are the examples of all available vector macros:

```
scalar name,...; //For example "scalar x,10"
vector1f name,...;
vector2f name,...;
vector3f name,...;
vector4f name,...;
vec1f name,...;
vec2f name,...;
vec3f name,...;
vec4f name,...;
uv name,...;
color name,...;
matrix name; //No default initializer
```

It's possible to get pointer to each of the members of the vector variable:

```
vector3f vec1;
mov #vec1.x,10;
mov #vec1.y,20;
*(vec1.z) = 30;

uv texcoord1;
mov #texcoord1.u,10;
```

```
mov #texcoord1.v,20;
```

```
color col1;  
mov #col1.r,10;  
mov #col1.g,20;  
mov #col1.b,30;  
mov #col1.a,40;
```

Matrix and vector variables can be used along with the vector extension of the ZCPU:

```
matrix m1;  
matrix m2;  
vector4f rot,0,0,1,45;  
  
mident m1; //Load identity matrix  
mrotate m2,rot; //Load rotation matrix  
  
mmul m1,m2; //Multiply two matrices
```

There's also an additional macro which is not directly connected to creating variables, but it allows to change the current write pointer of the program (the location in memory at which program is being written). The macro is called `ORG`:

```
//Write pointer 0  
alloc 64;  
//Write pointer is now 64  
alloc 1;  
//Write pointer is now 65  
  
ORG 1000;  
//Write pointer is now 1000
```

This macro can be used for slightly more advanced management of the code generation.

There are also two special helper macros available that can be used to simplify variable declaration in the simple program: the `DATA` and the `CODE` macros. They are used like this:

```
DATA; //Data section  
    alloc var1;
```

```

    alloc var2;
    .....
    subroutine1:
        ....
    ret
    ....
CODE; //Main code section
    call subroutine1;
    call subroutine2;
    .....

```

These macros are expanded into the following code:

```

//DATA
jmp _code;

//CODE
_code:

```

## 6.4 Expression Generator

HL-ZASM has a built-in expression generator. It is possible to generate complex expressions that can involve function calls, registers, variables in a similar way as they are generated in the C code.

Here are the several examples of various expressions:

```

EAX = 0 //Same as "mov eax,0"
EAX += EBX //Same as "add EAX,EBX"

```

```

main()
print("text",999)
R17 = solve("sol1",50,R5)
R2 = R0 + R1*128
c = *ptr++;

```

```

R0 = (noise(x-1, y) + noise(x+1, y) + noise(x, y-1) + noise(x, y+1)) / 8
Offset = 65536+32+MAX_DEVICES+udhBusOffset[busIndex*2]

```

Extra care must be taken while using the expression generator, since it will use the 6 general purpose registers (EAX .. EDI) as temporary storage for evaluating the expressions.

There is support for parsing constant expressions, which are reduced to a single constant value during compile time. It is possible to use the following syntax features in the expression parser:

Syntax	Description
<code>-X, +X</code>	Specify value sign, or negate the value
<code>&amp;globalvar</code>	Pointer to a global variable (always constant)
<code>&amp;stackvar</code>	Pointer to a stack variable (always dynamic)
<code>&amp;globalvar[...]</code>	Pointer to an element of a global array
<code>&amp;stackvar[...]</code>	Pointer to an element of a stack-based array
<code>1234</code>	Constant value
<code>"string"</code>	Pointer to a constant string, can be only used inside functions
<code>'c'</code>	Single character
<code>pointervar</code>	Constant pointer (or a label)
<code>EAX</code>	Register
<code>func(...)</code>	Function call
<code>var[...]</code>	Array access
<code>*var</code>	Read variable by pointer
<code>expr + expr</code>	Addition
<code>expr - expr</code>	Subtraction
<code>expr * expr</code>	Product
<code>expr / expr</code>	Division
<code>expr ^^expr</code>	Raising to power
<code>expr &amp;expr</code>	Binary AND
<code>expr  expr</code>	Binary OR
<code>expr ^expr</code>	Binary XOR
<code>expr &amp;&amp;expr</code>	Logic AND
<code>expr   expr</code>	Logic OR
<code>expr = expr</code>	Assign (returns value of left side AFTER assigning)
<code>expr &gt; expr</code>	Greater than
<code>expr &gt;= expr</code>	Greater or equal than
<code>expr == expr</code>	Equal
<code>expr &lt;= expr</code>	Less or equal than
<code>expr &lt; expr</code>	Less than
<code>expr++</code>	Increment (returns value BEFORE incrementing)
<code>expr--</code>	Decrement (returns value BEFORE decrementing)
<code>++expr</code>	Increment (returns value AFTER incrementing)
<code>--expr</code>	Decrement (returns value AFTER decrementing)

Expression generator supports expressions inside opcodes as well.

## 6.5 Declaring Variables

It's possible to declare variables in HL-ZASM the same way they are declared in the C programming language. It must be noted, however, that there is a difference between variables declared with this way, and variables declared using ZASM2 macros. It will be detailed a bit more on this problem further down.

Variables may be declared either in global space (data segment), or local space (stack segment/stack frame). The variables declared in the global space are created at compile-time, while the stack-based variables are allocated runtime.

*Take note that variable declarations and variable definitions are two different things.* Variables are declared as shown below, but they can be defined using ZASM2 macros. Consider the following code:

```
float x;
mov x,10; //Set variable X to 10
mov #x,10; //Same as '*(x) = 10'

scalar y;
mov y,10; //Does nothing, same as 'mov 123,10'
mov #y,10; //Sets variable Y to 10
```

There are three types supported by the compiler right now: `float` (64-bit floating point variable), `char` (64-bit floating point character code), `void` (undeclared type/no assigned behaviour). Unlike the usual compilers, all three types work the same way, and are essentially the same thing:

```
float x;
float y,z;
char* w;
char** u; //Pointer to a pointer

//In all of these examples 'a' is a pointer to a character
char * a;
char* a;
char *a;
char b,*a;
```

It's possible to use `*` symbol to create pointers to variables. There is no difference on whether there are any whitespaces between the asterisk and the variable name (the asterisk belongs to the variable name).

Arrays of constant size may be declared as variables. If array is located in global scope, *all members will usually default to zero, although this is might not be the case if program is dynamically loaded by the OS*. If the array is declared in local scope, the contents of it may be undeclared. :

```
float arr[256];

arr[100] = 123;
R0 = arr[R1];
```

There is no way to declare 2-dimensional arrays right now, but there will be support for that feature at some point.

It's possible to use initializers for the arrays and the variables. It's only possible to use constant expressions as initializers for the global scope variables and arrays (there is no limit on what expressions may be used in the stack-based mode):

```
//Global scope
float x = 10;
float garr1[4] = { 0, 5, 7, 2 };
float garr2[8] = { 1, 2 }; //Missing entries filled with zeroes
float garr3[8] = { 1, 2, 0, 0, 0, 0, 0, 0 }; //Same as garr2

//Local scope
void func(float x,y) {
    float z = x + y * 128;
    float larr1[4] = { x, y, 0, 0 };
    float larr2[16] = { x, 0, y }; //Missing entries filled with zeroes
}
```

There is also support for creating variables, which are stored in the processors registers. To do this their type must be prepended with the **register** keyword. Local variables in registers work much faster than the stack-based local variables, but they cannot be an array type (they can be a pointer though):

```
void strfunc(char *str) {
    register char *ptr = str;
    *ptr++ = 'A';
}
```

There is a limit on how much local register variables there can be.



## 6.6 Declaring Functions

It's possible to use C-style function declaration syntax, although only one style is currently supported:

```
return_type function_name(param_type1 name1, name2, param_type2 name3) {  
    ....  
    code  
    ....  
}
```

Parameters are defined the same way the variables are defined, see page 231. It's possible to use constant-size arrays as variables into function, but *there is no way to actually pass them into the function right now*. It's also possible to use sizeless array as a parameter (see examples).

Examples of declaring functions:

```
void main() { .. }  
float func1() { .. }  
float func2(float x, y, float z) { .. }  
  
char strcmp(char* str1, char* str2) { .. }  
float strlen(char str[]) { .. } //'char str[]' is same as 'char* str'  
  
//no way to actually pass an array like this:  
void dowork(char str[256]) { .. }
```

There are two kinds of function declarations - normal declarations, and forward declarations. Normal function declarations can be anywhere in the code, and there's no restriction on using them from any other part of the program. Forward function declarations must always precede the function use (or they must be declared beforehand without the function body).

The forward function declarations allow to perform strict arguments check, and they allow overriding the function to have different parameter lists while having the same name. A function can be forward-declared by using the **FORWARD** keyword before the function type:

```
//Forward declarations before use  
forward void func(); //First function  
forward void func(float x); //Second function
```

```

forward void func(float x, *y);

func(); //Calls first function
func(10); //Calls second function

func2(); //COMPILE ERROR: function 'func2' is not declared

//Actual function bodies
forward void func() { //First function
    ...
}
forward void func(float x) { //Second function
    ...
}
forward void func(float x, *y) {
    ...
}
forward void func2() {
    ...
}

```

Unlike the forward function declarations, the normal functions can be used from anywhere in the code, but they do not provide strict argument type checks:

```

void func1() { .. }

func1();
func2(); //Works even though it's not yet declared

void func2() { .. }

```

There's also an additional keyword that can be used when defining functions - **EXPORT**. If this keyword is used, the function name will be preserved in the generated library (see page 242 for more information on how to generate libraries). The compiler will also add a declaration for this function automatically in the generated library file:

```

export void func1() { .. }
void func2() { .. } //Function name will be mangled in the resulting file

```

## 6.7 Function Calling

### 6.7.1 Calling Convention

HL-ZASM uses the `cdecl` calling convention. The function result is passed via the EAX register. If the function is not forward-declared, or if it has variable argument count, then the ECX register must be set to the parameter count:

```
R0 = func(a,b,c);

//Same as:
push c;
push b;
push a;
mov ecx,3; //Optional if forward-declared
call func;
add esp,3; //Must clean up stack
mov r0,eax; //Return result

main();

//Same as:
mov ecx,0;
call func;
```

The function will modify EAX, ECX, EBP registers (along with the ESP register), and may modify all other registers unless they are marked as preserved (see 237).

### 6.7.2 Stack Frame

The HL-ZASM uses the ZCPU stack frame management instructions (`ENTER`, `LEAVE`) for creating a stack frame for the function. It will pass number of local variables into the `ENTER` instruction, so it will create a stack frame with pre-allocated space for local variables.

The function would generate such code:

```
void func(float x,y) {
    float z,w;
    ...
}
```

```
//Generates:
func:
    enter 2;
    ....
    leave;
    ret
```

All the access to variables on stack is done via the `RSTACK`, `SSTACK` instructions. The compiler will use `EBP:X` as the stack offset, where `EBP` is the stack frame base register, and `X` is the offset of the target value on stack. For example:

```
void func(float x,y) {
    float z,w;
}
```

```
//These values would be laying on stack
//[ 3] Y
//[ 2] X
//[ 1] Return address
//[ 0] Saved value of EBP (at function call)
//[-1] Z
//[-1] Z
```

```
//Therefore this would be valid:
rstack R0,EBP:2 //R0 = X
rstack R1,EBP:3 //R1 = Y
rstack R2,EBP:-1 //R2 = Z
rstack R3,EBP:-2 //R3 = W
```

Therefore it's possible to generate a stack trace using the following code:

```
void stack_trace() {
    char* returnAddress,savedEBP;

    R0 = EBP; //'Current' EBP
    while ((R0 > 0) && (R0 < 65535)) {
        rstack returnAddress,R0:1;
        rstack savedEBP,R0:0;
```

```

    add_to_trace(returnAddress);
    R0 = savedEBP;
}
}

```

### 6.7.3 Preserving Registers

If the current program makes use of any ZCPU registers, it must mark them as preserved so the expression generator does not use those registers for purpose of calculating expressions.

The compiler will give out warning when unpreserved registers are being used. Right now only EAX-EDI registers must be marked as preserved (since only those are used for expression generator):

```

void func(float x,y) {
    preserve EAX, EBX;

    //Expression generator will never change EAX or EBX registers
    EAX = 123;
    EBX = x*10 + y;
}

```

## 6.8 Control Structures

The HL-ZASM compiler supports common C control structures, although right now the support is limited.

The conditional branching can be done via the `if` construct. The `else` clause, and the `else if` are supported. It's possible to branch into a single expression, or into an entire block of code too:

```

//Can use blocks
if (expression) {
    ....
} else if (expression) {
    ....
} else {
    ....
}

```

```
//Can avoid using blocks:
if (expression) expression;
if (expression) expression1 else expression2;
```

HL-ZASM supports for loops. The syntax is:

```
for (initializer; condition; step) { ... }
```

where **initializer** is the expression that will be executed to setup the loop, **condition** is the condition that is tested on each step, and **step** is the expression executed after each step. For example:

```
float x;
for (x = 0; x < 128; x++) { .. } //Loop for X from 0 to 127
for (x = 128; x > 0; x--) { .. } //Loop for X from 128 to 1
for (;;) { .. } //Infinite loop
```

It's possible to use the **while** loop (but no support for **do - while** loops yet):

```
while (expression) { ... }
while ((x < y) && (x > 0)) { ... }
while (1) { ... } //Infinite loop
```

The **break** keyword can be used to end the currently executed loop, for example:

```
while(1) {
    if (condition) {
        break;
    }
    ....
}
```

It's possible to use the **continue** keyword to go on to the next step in the loop. For example:

```
float x;
for (x = 0; x < 128; x++) {
    if (x == 50) { //Skip iteration 50
        continue;
    }
}
```

## 6.9 Preprocessor

The HL-ZASM preprocessor supports C-style preprocessor macros. Preprocessor macros are always last on the current line (it is not possible to write two preprocessor macros on same line).

### 6.9.1 C Runtime Library Macros

By default programs compiled with HL-ZASM have no attached runtime library, and would require rewriting all the basic routines. It is possible to link to a runtime library of a choice though. The default runtime library is called ZCRT, and it allows to boot up the ZCPU without any additional software.

The CRT library can be picked with the following preprocessor macro. It must be located in the first line of code, before any other code is generated, otherwise it will not work correctly (macro is case-insensitive):

```
#pragma CRT ZCRT
```

This macro will add CRT folder as one of the search paths, and include the main CRT file:

```
#pragma SearchPath lib\zcert\  
#include <zcert\main.txt>
```

This makes it possible to use the default libraries that belong to that runtime library. See page ?? for more information on the ZCRT library.

### 6.9.2 Definition And Conditional Macros

It is possible to use the C style definition preprocessor macros (it is not possible to define preprocessor functions yet though). It supports the `#define`, `#ifdef`, `#elseif`, `#else`, `#endif` and the `#undef` macros:

```
#define DEF1  
#define DEF2 1234  
  
#ifdef DEF1  
    func(DEF2) //same as func(1234)  
    ...  
#elseif DEF2  
    ....
```

```
#else
...
#endif

#undef DEF1
```

### 6.9.3 File Inclusion Macros

The preprocessor supports including external files using the `#include` macro:

```
#include "filename"
#include <filename>
```

The `#include "filename"` macro will include file from the current working directory. This is the same directory the main (first) compiled source file is located in. The other version of this macro includes file relative to the base directory (`CPUChip`).

If file is not found, it will also be searched on one of the search paths.

The preprocessor also supports the ZASM2 file include syntax:

```
##include## filename
same as
#include <filename>
```

### 6.9.4 Special Compiler Commands

There are several special compiler commands available through the `#pragma` macro.

The `#pragma set` macro allows user to modify settings of the compiler. Example of the syntax (everything is case-sensitive):

```
#pragma set OutputResolveListing true
```

There are the following settings available:

Name	Default	Description
CurrentLanguage	HLZASM	Current compiler language. Can be HLZASM or ZASM2
CurrentPlatform	CPU	Target platform. Defines the feature set, cannot be modified
MagicValue	-700500	The magic value is used in place of an erroneous constant value
OptimizeLevel	0	Optimizer level. 0 is none, 1 is low, 2 is high. Not supported right now.



OutputCodeTree	false	Output code tree
OutputResolveListing	false	Output code listing for resolve stage
OutputFinalListing	false	Output code listing for final stage
OutputTokenListing	false	Output tokenized sourcecode
OutputBinaryListing	false	Output final binary dump as listing
OutputDebugListing	false	Output the debug data as listing
OutputToFile	false	Output listings to files instead of to the console
OutputOffsetsInListing	true	Output binary offsets in listings
OutputLabelsInListing	true	Output label names in final listing
GenerateComments	true	Generate extra comments in output listing
FixedSizeOutput	false	Output fixed-size instructions (can be toggled at any time)
SeparateDataSegment	false	Puts all variables into separate data segment Not supported right now.
GenerateLibrary	false	Generate a precompiled library. See page 242
AlwaysEnterLeave	false	Always generate the enter/leave blocks in functions
NoUnreferencedLeaves	true	Do not compile functions and variables which are not used by the program

The `#pragma language` macro can be used in place of setting the language via changing the compiler variables:

```
#pragma language zasm
#pragma set CurrentLanguage ZASM2
```

The `#pragma crt` macro can be used to attach a C runtime library. See page 239 for more information.

The `#pragma cpuname` macro is used to assign a specific name to the target processor:

```
#pragma CPUName ACPI Power Controller
```

### 6.9.5 Preprocessor Definitions

There are several preprocessor definitions and special labels available for use by the programmer:

Bit	Description
<code>__PTR__</code>	Current write pointer
<code>__LINE__</code>	Current line number
<code>__FILE__</code>	Current file name (a string)

<code>__DATE_YEAR__</code>	Current year (at compile time)
<code>__DATE_MONTH__</code>	Current month (at compile time)
<code>__DATE_DAY__</code>	Current day (at compile time)
<code>__DATE_HOUR__</code>	Current hour (at compile time)
<code>__DATE_MINUTE__</code>	Current minute (at compile time)
<code>__DATE_SECOND__</code>	Current second (at compile time)
<code>__PROGRAMSIZE__</code>	Total size of the program in bytes
<code>programsize</code>	Total size of the program in bytes (ZASM2 compatibility macro)

## 6.10 Advanced Features

### 6.10.1 Generating Libraries

no chapter

### 6.10.2 Optimizer

no chapter

## 6.11 List Of Errors

### 6.11.1 General Compiler Errors

#### Undefined label

Previously unknown label, variable, or function call was never declared in the current scope.

#### Variable redefined

Variable or function with this name was already defined previously in the scope. Error message will point to initial definition.

#### Identifier expected

Expression generator expects identifier to follow (variable/function name, etc).

### **Expression expected, got ...**

There was something unexpected in the source code at that position. Can also indicate invalid expression syntax.

### **Ident ... is not a variable/pointer/array**

Unable to get pointer of the given identifier.

### **Invalid instruction operand**

The ZCPU does not support the given instruction operand. Can indicate that segment prefix is used for segment register access, or for port access.

### **Undefined opcode**

Given opcode is not supported by the current architecture.

### **Array size must be constant**

It's only possible to define arrays which have constant size. There is no support for declaring variable-sized arrays.

### **Cannot have expressions in global initializers**

There is no support for having complex expressions as variable initializers right now.

### **Can only zap/preserve registers inside functions/local blocks**

Compiler does not support preserving registers in global scope right now.

### **... must be constant**

A constant value is expected, and it must not rely on values of any unknown variables or labels.

### **Expected ... got ... instead**

Invalid syntax is being used for some specific language structure.

### **Out of free registers**

This error indicates one of the following things:

- There are no more free registers to use due to too much local register variables allocated.
- The expression being generated was too complex (there are not enough unallocated registers).
- Internal compiler error.

### **Unable to include CRT library**

Invalid runtime library name/library is not found.

### **Cannot open file**

File was not found in the specified folder, and it was not found on one of the search paths.

### **Internal error ...**

Internal compiler error (is not an error that can be worked around).

# Chapter 7

## Zylios GPU

### 7.1 General Information

#### 7.1.1 Basics

ZGPU is a vector graphics processor, which runs a certain set of instructions to display an image on screen. It has two basic modes of operation - frame-based mode, in which the processor core will execute a certain subprogram each time the new frame must be drawn to screen, and asynchronous mode, which allows to run ZGPU instructions without being tied to screen refreshes.

Even though ZGPU works with vector graphics the final result is being rasterized into one of two buffers. These two buffers are called the *front* buffer, and the *texture* buffer. Both buffers are 512x512 pixels in size, and can be used by the programmer. There is support for a native vertex mode for drawing graphics, but it has certain limitations.

By default the ZGPU runs the frame-based mode, which makes use of the *front* buffer to store data, which will then

#### 7.1.2 Memory Layout

be displayed on screen. When running in asynchronous mode the graphics are drawn to one of the two buffers, and are then being output to screen.

#### 7.1.3 Features

Most of the features in the ZGPU are controlled via internal registers (see 252 for a complete list of all the registers). They are located in the register memory, which starts at addresses 63488 and ends at 65535.

The memory area between addresses 65536 and 131071 (inclusive) is reserved as an additional external memory bus. It is very slow, but it allows GPU to communicate with other devices. If several GPU's are running at the same time, the access to these memory areas will be concurrent, and so additional synchronization is required to prevent race conditions or collisions of any sort.

The simplest program GPU can execute is the following (it makes use of the frame-based mode of execution):

```
dtest; //Output test pattern to screen
dexit; //Finish execution
```

It's possible to setup asynchronous rendering instead of frame-based rendering:

```
//Setup entrypoints
dentrypoint 0,DrawThread;
dentrypoint 4,AsyncThread;

//Disable hardware clear so drawing thread does not wipe
//the image on screen
mov #regHWClear,0;
//Set asynchronous thread frequency (speed)
mov #regAsyncFreq,200000;
//Run the thread
mov #regAsyncClk,1;
dexit;

DrawThread: //Do nothing
dexit;

AsyncThread:
    dbegin;
    dtest;
    dend;

    dvsync; //Add frame synchronization
    jmp AsyncThread;
```

ZGPU makes use of the vector extension (see page ??) which allows it to work with matrices and vectors:

```

//Generate rotation, translation matrices
mrotate mRotateMatrix,vRotate;
mtranslate mTranslateMatrix,vTranslate;

//Create model matrix
mmov mModelMatrix,mRotateMatrix;
mmul mModelMatrix,mTranslateMatrix;

```

The ZGPU supports 2D and 3D graphics , which must be drawn as polygons:

```

dvxdata_2f polydata,4; //4 vertices
dvxdata_3f cubedata,12; //12 triangles

```

```

....

```

```

polydata:

```

```

db 0, 0;
db 10, 0;
db 10, 10;
db 0, 10;

```

```

cubedata:

```

```

db -1,-1,-1; //Triangle 1
db 1,-1,-1;
db 1, 1,-1;

```

```

db -1,-1,-1; //Triangle 2
db 1, 1,-1;
db -1, 1,-1;

```

```

...

```

Polygons can be drawn in both normal mode, and indexed mode. They can also be drawn solid-colored, textured, or wireframe:

```

//Load array of vertices
mov #regVertexArray,cube_varray;
dvxdata_3f cube_idxarray,12; //Draw all faces
dvxdata_3f_wf cube_idxarray,6; //Draw faces 1-3 as wireframe

```

```
//Load array of vertices with texture coords
mov #regVertexArray,cube_varray_tex;
dvxdata_3f_tex cube_idxarray,12; //Draw all faces, textured
```

```
cube_varray:
    db -1,-1,-1; //0
    db -1,-1, 1; //1
    db -1, 1,-1; //2
    db -1, 1, 1; //3
    db  1,-1,-1; //4
    db  1,-1, 1; //5
    db  1, 1,-1; //6
    db  1, 1, 1; //7
```

```
cube_idx:
    db 0,4,6;  db 0,6,2; //Face 1
    db 5,1,7;  db 1,3,7; //Face 2
    db 4,0,5;  db 0,1,5; //Face 3
    db 2,6,7;  db 3,2,7; //Face 4
    db 0,2,3;  db 1,0,3; //Face 5
    db 6,4,7;  db 4,5,7; //Face 6
```

It supports vertex buffer, which serves as temporary storage for 2D/3D data before it's rendered on screen. This allows to provide depth-sorting within the buffer, and other features:

```
//Enable vertex buffer features
denable 0; //Vertex buffer
denable 1; //ZSorting
denable 2; //Lighting
```

```
//Add commands to vertex buffer
dcolor cube_color;
dvxdata_3f cube_data,12;
```

```
//Flush vertex buffer
dvxflush;
```



```
//Disable vertex buffer and its features
ddisable 0;
```

There is support for texturing using both custom textures, and textures available externally:

```
mov #regVertexMode,1; //Enable vertex mode
mov #regTexSize,128; //Texture size
denable 5; //Enable custom texture mapping
dcolor white; //Set color to white

dtexture 2; //Pick texture #2
directwh rect_pos,rect_size;

...
ddisable 5; //Disable custom texture mapping

dtexture texture_name; //Pick texture
directwh rect_pos,rect_size;

....
string texture_name,"brick/brickfloor001a";
```

ZGPU supports various 2D transformations to move shapes on screen:

```
dmove target_pos; //move to position
drotatescale 1.23,2; //Rotate by 1.23 radians, and scale up twice
direct rect_pos1,rect_pos2; //Draw rectangle around 0,0 point

....
vector2f target_pos,256,256; //Screen center

vector2f rect_pos1,-50,-50; //Two endpoints for rectangle
vector2f rect_pos2, 50, 50;
```

There is also support for performing similar transformations on the textures, independently of the previous transformations (rotation is performed around texture centerpoint usually):

```
denable 5; //Enable custom texturing
```

```

mov #regTexRotation,1.23; //Rotate texture by 1.23 radians
mov #regTexOffsetV,0.2; //Offset V coordinates by 0.2
dvxtexpoly horizon_polygon,4;

```

## 7.2 Features Reference

### 7.2.1 Basic Graphics

The basic graphics output in GPU makes use of the few control instructions (such as `DCOLOR`, which changes the current drawing color), and the few drawing instructions (for example `DRECT`, `DLINE`, etc).

The basic graphics output only requires use of the frame-based drawing mode. The GPU will clear the screen to black each frame, and set the current color to black too. To draw something the color must first be set to wanted color, and then some drawing instructions must be executed:

```

dcolor white;
direct rect_point1,rect_point2;
dexit; //Program must be correctly terminated

//Compiler macros for data:
color white,255,255,255;

vec2f rect_point1,50,50;
vec2f rect_point2,100,150;

```

These are all the basic drawing instruction that can be used:

Instruction	Description
<code>DRECT</code>	Draw a rectangle between two endpoints
<code>DRECTWH</code>	Draw a rectangle at some point (first operand), with some size (second operand)
<code>DORECT</code>	Similar to <code>DRECT</code> , but draws a rectangle outline
<code>DORECTWH</code>	Similar to <code>DRECTWH</code> , but draws a rectangle outline
<code>DCIRCLE</code>	Draw a circle at some point (first operand), with some radius (second operand)
<code>DLINE</code>	Draws a line between two points. Width specified with the <code>DSETWIDTH</code> instruction
<code>DVXPOLY</code>	Draw a custom polygon

It's possible to specify quality at which the circle is drawn:

```
dcolor white;
mov #regCircleQuality,8; //8 vertices in the circle
dcircle pos,256; //Draw a circle in middle of the screen,
                //and covering the entire screen
dexit;

//Compiler macros for data:
color white,255,255,255;
vec2f pos,256,256;
```

It's also possible to draw 2D polygons (each polygon may have up to 128 vertices in it):

```
dcolor white;
dvxpoly polygon_data,4;
dexit;

//Compiler macros for data:
color white,255,255,255;

polygon_data: //Polygon for a distorted rectangle
    db 50,50;
    db 190,50;
    db 120,190;
    db 50,120;
```

It's possible to use all of these instructions to draw textured data (see page ??)

## 7.2.2 Asynchronous Thread

Asynchronous thread runs in parallel to the main frame-based rendering thread, but it is not synchronized to frame boundaries (while the normal frame-based mode will restart execution each time it must render a new frame). It's possible to use both at the same time, or use just one of two.

Asynchronous thread is not active by default, but it can be started up using the following code:

```
//Setup entrypoints
```

```

dentrypoint 0,DrawThread;
dentrypoint 4,AsyncThread;

//Set asynchronous thread frequency (speed)
mov #regAsyncFreq,200000;
//Run the thread
mov #regAsyncClk,1;
dexit;

DrawThread: //Do nothing
dexit;

AsyncThread:
    ...
    jmp AsyncThread;

```

Asynchronous thread frequency may be set up to 1,200,000. If asynchronous thread encounters an error, and there is no specified error handler, it will simply shut down (and reset **AsyncClk** register back to 0).

It's possible to perform rendering in asynchronous thread in two ways. There are built-in opcodes which allow to draw to texture buffer, and then copy that image back into the front buffer. They require the hardware clear feature to be disabled though:

```

mov #regHWClear,0;
....

AsyncThread:
    dbegin; //Start drawing
    ... //Drawing code of any length
    dend; //Copy the image to front buffer

    dvsync; //If rendering is too fast, it can be synchronized with frame
            //generation, making it less resource intensive
    jmp AsyncThread;

```

It's also possible to manually switch buffers for drawing. See page ?? for more information on that.

### **7.2.3 Error Handling**

no chapter

### **7.2.4 Using Coordinate Transformations**

no chapter

### **7.2.5 Using Vertex Transformations**

no chapter

### **7.2.6 Drawing 3D Graphics**

no chapter

### **7.2.7 Coordinate Transformations**

no chapter

### **7.2.8 Rasterizer Control**

no chapter

### **7.2.9 Cursor Control**

no chapter

### **7.2.10 Color Transformation Control**

no chapter

### **7.2.11 Font Rendering**

no chapter paramlist

### **7.2.12 3D Rendering Control**

no chapter

### 7.2.13 Indexed Rendering

no chapter

### 7.2.14 Switching buffers

no chapter

### 7.2.15 Texturing

no chapter

### 7.2.16 Texture Transformations

no chapter

### 7.2.17 Advanced Rendering Instructions

no chapter DDFRAME, DDTErrain

## 7.3 Internal Registers

The internal registers of the ZGPU are mapped to the memory, and are available as memory locations. They can be read and written to at any time, and they control various aspects of the ZGPU operation.

All of these registers are available in the HL-ZASM compiler by prepending **reg** prefix to the registers name.

Memory offsets 63488..64511 are mapped to the IOBus (external ports). The memory offsets 65536..131071 are mapped to the MemBus, allowing for access to external devices from the GPU. There is support for both reading and writing this memory, although at very low speed.

Name	Address	Description
Clk	65535	Current GPU power state (if set to 0, the GPU will be shut down)
Reset	65534	Reset the GPU state
HWClear	65533	Enables or disables the hardware clear (front buffer filling to black)
VertexMode	65532	Enables or disables the vertex mode (raw vertex output instead of rasterizing)

Halt	65531	Halts the current GPU execution, and preserves image in the front buffer
RAMReset	65530	Clears the GPU RAM
AsyncReset	65529	Reset the asynchronous thread state
AsyncClk	65528	Asynchronous thread execution state
AsyncFreq	65527	Asynchronous thread frequency
Index	65526	GPU index, can be between 0 and 31
HScale	65525	Horizontal image scale (for rasterized output)
VScale	65524	Vertical image scale (for rasterized output)
HWScale	65523	Hardware image scale
Rotation	65522	Rotation of the rasterized image. 0 for 0 deg, 1 for 90 deg, 2 for 180 deg, 3 for 270 deg
TexSize	65521	Subtexture size
TexDataPtr	65520	Pointer to texture data for load by the GPU
TexDataSz	65519	Size of the texture data for load by the GPU
RasterQ	65518	Rasterizer quality
TexBuffer	65517	Buffer used for the texturing (0: front buffer, 1: texture buffer)
Width	65515	Screen width (resolution)
Height	65514	Screen height (resolution)
Ratio	65513	Current screen ratio (physical)
ParamList	65512	Pointer to list of parameters for the DWRITEFMT instruction, or 0 if unused
CursorX	65505	X coordinate of the cursor (0..1)
CursorY	65504	Y coordinate of the cursor (0..1)
Cursor	65503	Should the cursor be drawn on screen
CursorButtons	65502	State of the cursor buttons
BrightnessW	65495	Total screen brightness
BrightnessR	65494	R component brightness
BrightnessG	65493	G component brightness
BrightnessB	65492	B component brightness
ContrastW	65491	Total screen contrast
ContrastR	65490	R component contrast
ContrastG	65489	G component contrast
ContrastB	65488	B component contrast
CircleQuality	65485	Circle output quality (number of vertices). Can be between 3 and 128
OffsetX	65484	X offset for screen coordinates of all drawn graphics
OffsetY	65483	Y offset for screen coordinates of all drawn graphics
Rotation	65482	Rotation in radians for screen coordinates of all drawn graphics

Scale	65481	Scale (1 is normal scale) for screen coordinates of all drawn graphics
CenterX	65480	X coordinate of centerpoint of rotation (see <b>Rotation</b> register)
CenterY	65479	Y coordinate of centerpoint of rotation (see <b>Rotation</b> register)
CircleStart	65478	Circle start angle (in radians)
CircleEnd	65477	Circle end angle (in radians)
LineWidth	65476	Line width
ScaleX	65475	X component of the scale for screen coordinates of all drawn graphics
ScaleY	65474	Y component of the scale for screen coordinates of all drawn graphics
FontHalign	65473	Font horizontal align mode
Zoffset	65472	Extra Z offset for all coordinates passed into vertex pipe
FontValign	65471	Font vertical align mode
CullDistance	65470	Culling distance
CullMode	65469	Face culling mode (0: front, 1: back)
LightMode	65468	Lighting mode (0: two-side, 1: front, -1: back)
VertexArray	65467	Pointer to array of vertices for indexed rendering
TexRotation	65466	Texture rotation in radians
TexScale	65465	Texture scale (1 is normal)
TexCenterU	65464	U component of centerpoint of texture rotation
TexCenterV	65463	V component of centerpoint of texture rotation
TexOffsetU	65462	U offset for the texture output
TexOffsetV	65461	V offset for the texture output



## 7.4 Instruction Set Reference

### 7.4.1 200 DTEST

**Mnemonic:** DTEST

**Encoding:** 200

This opcode generates a test pattern image on the GPU screen, somewhat similar to the PAL TV test pattern. It ignores any coordinate or texture transformations, and ignores all previous color commands/settings.

The rightmost left black bar will be left transparent.

**Pseudocode:**

W = ScreenWidth

H = ScreenHeight

```
for bar=0,6 do
```

```
    SetColor(TEST_PATTERN_COLOR[bar])
```

```
    Rectangle(W*0.125*bar,0,W*0.125,H*0.80)
```

```
end
```

```
for gray=0,7 do
```

```
    SetColor(31*gray,31*gray,31*gray,255)
```

```
    Rectangle(W*0.125*gray,H*0.80,W*0.125,H*0.20)
```

```
end
```

## 7.4.2 201 DEXIT/DVSYNC

**Mnemonic:** DEXIT/DVSYNC

**Encoding:** 201

Finishes drawing the current frame (used only in the frame-based mode). This must be the last instruction in any program that makes use of the frame-based mode.

The execution may be terminated before this instruction if amount of cycles spent drawing the current frame exceeds total limit

It's implementation is exactly same as that of the IDLE instruction (while in the frame-based mode).

**Pseudocode:**

INTR = 1

### 7.4.3 202 DCLR

**Mnemonic:** DCLR

**Encoding:** 202

Clears screen/current buffer by filling it with black background.

**Pseudocode:**

```
SetColor(0,0,0,0)
```

```
Rectangle(0,0,ScreenWidth,ScreenHeight)
```

#### 7.4.4 203 DCLRTEX

**Mnemonic:** DCLRTEX

**Encoding:** 203

Clears screen/current buffer by filling it with a texture.

If vertex texturing is enabled, it will use the texture specified by the DTEXTURE opcode. Otherwise it will use the texture specified by the DXTEXTURE opcode.

If no texture was defined, it will fill buffer with solid black color.

**Psuedocode:**

```
BindState()
```

```
SetColor(0,0,0,255)
```

```
Rectangle(0,0,ScreenWidth,ScreenHeight)
```

### 7.4.5 204 DVXFLUSH

**Mnemonic:** DVXFLUSH

**Encoding:** 204

Draws all the pending polygons in the vertex buffer to screen, and clears the buffer.

This instruction is used with vertex buffer enabled. It will perform Z-sorting, clipping, etc, and draw the output to screen.

**Pseudocode:**

`FlushBuffer()`

### **7.4.6 205 DVXCLEAR**

**Mnemonic:** DVXCLEAR

**Encoding:** 205

Clears any pending polygons from the vertex buffer.

**Pseudocode:**

`ClearBuffer()`

### 7.4.7 206 DSETBUF\_VX

**Mnemonic:** DSETBUF\_VX

**Encoding:** 206

Sets the current drawing target to the raw vertex output. This opcode can only be used when vertex mode is active, and it is the default target for the vertex mode.

**Pseudocode:**

SetRendertarget(2)

### 7.4.8 207 DSETBUF\_SPR

**Mnemonic:** DSETBUF\_SPR

**Encoding:** 207

Sets current drawing target to the texture buffer. Also known as DBACKBUF.

**Psuedocode:**

```
SetRenderTarget(1)
```



### 7.4.9 208 DSETBUF\_FBO

**Mnemonic:** DSETBUF\_FBO

**Encoding:** 208

Sets current drawing target to the front/main buffer. Also known as DFRONTBUF.

**Pseudocode:**

```
SetRenderTarget(0)
```

### 7.4.10 209 DSWAP

**Mnemonic:** DSWAP

**Encoding:** 209

Copies contents of the texture buffer into the front buffer.

**Pseudocode:**

```
Copy(RenderTarget(1),RenderTarget(0))
```

### 7.4.11 210 DVXPIPE

**Mnemonic:** DVXPIPE X

**Encoding:** 210 RM [Segment1] [Constant1]

Selects the current vertex pipe/vertex transformation mode. This controls the transformation that brings world-space coordinates into screen coordinates. X can be one of the following pipes:

- 0: X, Y coordinates are used as the screen coordinates
- 1: Y, Z coordinates are used as the screen coordinates
- 2: X, Z coordinates are used as the screen coordinates
- 3: Uses basic 3D perspective projection (Z: depth)
- 4: Transforms X, Y coordinates with the current model matrix
- 5: Performs 3D transformation with projection and model matrices

**Pseudocode:**

VertexPipe = X

## 7.4.12 211 DCPIPE

**Mnemonic:** DCPIPE X

**Encoding:** 211 RM [Segment1] [Constant1]

Selects the current coordinate pipe/coordinate transformation mode. This controls the transformation that converts the screen coordinates into true coordinates, which are correctly mapped to the buffer. X can be one of the following pipes:

- 0: No transformation
- 1: Mapped to screen using the `Width` and `Height` registers.
- 2: Coordinates are transformed from 0..1 range.
- 3: Coordinates are transformed from -1..1 range.
- 4: Coordinates are relative to the screen center (and not the top-left corner).

**Pseudocode:**

`CoordinatePipe = X`

### 7.4.13 212 DENABLE

**Mnemonic:** DENABLE X

**Encoding:** 212 RM [Segment1] [Constant1]

Enables one of the internal GPU modes/switches. X can be one of the following:

- 0: Vertex buffer
- 1: Z-Sorting for the triangles in the vertex buffer.
- 2: Flat face lighting using the internal lighting system
- 3: Front/back face culling
- 4: Distance-based culling
- 5: Texturing using the internal GPU buffers

For example:

```
//Prepare 3D drawing
mov #regCullingDistance,4.0; //Setup culling distance
denable 0; //Vertex buffer
denable 1; //ZSorting
denable 2; //Lighting
denable 3; //Face culling
denable 4; //Distance-based culling
```

**Psuedocode:**

```
MODE_SWITCH[X] = 1
```

### 7.4.14 213 DDISABLE

**Mnemonic:** DDISABLE X

**Encoding:** 213 RM [Segment1] [Constant1]

Disables one of the internal GPU modes/switches. X can be one of the following:

- 0: Vertex buffer
- 1: Z-Sorting for the triangles in the vertex buffer.
- 2: Flat face lighting using the internal lighting system
- 3: Front/back face culling
- 4: Distance-based culling
- 5: Texturing using the internal GPU buffers

For example:

```
//Finish 3D drawing
ddisable 0; //Vertex buffer
ddisable 1; //ZSorting
ddisable 2; //Lighting
ddisable 3; //Face culling
ddisable 4; //Distance-based culling
```

**Pseudocode:**

```
MODE_SWITCH[X] = 0
```

### 7.4.15 214 DCLRSCR

**Mnemonic:** DCLRSCR X

**Encoding:** 214 RM [Segment1] [Constant1]

Clears screen with the specified color.

**Pseudocode:**

SetColor(X)

Rectangle(0,0,ScreenWidth,ScreenHeight)

## 7.4.16 215 DCOLOR

**Mnemonic:** DCOLOR X

**Encoding:** 215 RM [Segment1] [Constant1]

Sets the current drawing color.

If the vertex buffer is enabled, it will change the color of all the following polygons in the buffer (until the next DCOLOR command, or end of buffer).

**Pseudocode:**

SetColor(X)



### 7.4.17 216 DTEXTURE

**Mnemonic:** DTEXTURE X

**Encoding:** 216 RM [Segment1] [Constant1]

Sets a texture out of one of the internal buffers. The buffer texture data is taken from is specified by the `TexBuffer` register.

By default it will take the entire buffer as the texture, but it is possible to specify smaller subtextures of the buffer. For example, it's possible to use four 256x256 textures, or 16 128x128 textures. If it is done so, the X parameter will specify which subtexture must be used.

Example:

```
mov #regTexBuffer,0; //Select front buffer
mov #regTexSize,128; //128x128 subtextures
dtexture 2; //Bind subtexture #2
```

**Pseudocode:**

`SetBufferTexture(X)`

## 7.4.18 217 DSETFONT

**Mnemonic:** DSETFONT X

**Encoding:** 217 RM [Segment1] [Constant1]

Set the current font for all operations which output text. There are 8 fonts available:

- 0: Letter Gothic (Lucida Console)
- 1: Courier New
- 2: Trebuchet
- 3: Arial
- 4: Times New Roman
- 5: Coolvetica
- 6: Akbar
- 7: CSD

**Psuedocode:**

Font = X

### 7.4.19 218 DSETSIZE

**Mnemonic:** DSETSIZE X

**Encoding:** 218 RM [Segment1] [Constant1]

Set the current font size for all operations which output text. Size can be any integer value between 4 and 200.

**Pseudocode:**

## 7.4.20 219 DMOVE

**Mnemonic:** DMOVE X

**Encoding:** 219 RM [Segment1] [Constant1]

Set the offset for 2D drawing. This instruction will offset all screen coordinates of next rendering instructions by the given vector.

X must be a pointer to vector, or it can be 0. If X is equal to zero then offset will be removed.

**Pseudocode:**

Registers[OffsetX] = X.x

Registers[OffsetY] = X.y

### 7.4.21 220 DVXDATA\_\_2F

**Mnemonic:** DVXDATA\_2F X,Y

**Encoding:** 220 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draw a single 2D polygon with up to 128 vertices. Also known as DVXPOLY.

If vertex array mode is not used, X points to an array of polygon vertex coordinates, and Y specifies the total count of vertices.

In vertex array mode, X points to an array of indexes into the vertex array, and Y specifies the total count of vertices.

**Pseudocode:**

```
VDATA = Registers[VertexArray]
for IDX=1,MIN(128,Y) do
  if VDATA > 0 then
    VIDX = ReadCell(X+IDX-1)
    VD[IDX] = {
      x = ReadCell(VDATA+VIDX*2+0),
      y = ReadCell(VDATA+VIDX*2+1)}
  else
    VD[IDX] = {
      x = ReadCell(X+(IDX-1)*2+0),
      y = ReadCell(X+(IDX-1)*2+1)}
  end
  ComputeTextureUV(VD[IDX],VD[IDX].x/512,VD[IDX].y/512)
end
DrawToBuffer(VD)
```

## 7.4.22 221 DVXDATA\_2F\_TEX

**Mnemonic:** DVXDATA\_2F\_TEX X,Y

**Encoding:** 221 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draw a single textured 2D polygon with up to 128 vertices. Also known as DVXTEXPOLY.

If vertex array mode is not used, X points to an array of polygon vertex coordinates and texture coordinates, and Y specifies the total count of vertices.

In vertex array mode, X points to an array of indexes into the vertex array, and Y specifies the total count of vertices.

**Pseudocode:**

```
VDATA = Registers[VertexArray]
for IDX=1,MIN(128,Y) do
  if VDATA > 0 then
    VIDX = ReadCell(X+IDX-1)
    VD[IDX] = {
      x = ReadCell(VDATA+VIDX*4+0),
      y = ReadCell(VDATA+VIDX*4+1)}
    ComputeTextureUV(VD[IDX],
      ReadCell(VDATA+VIDX*4+2),
      ReadCell(VDATA+VIDX*4+3))
  else
    VD[IDX] = {
      x = ReadCell(X+(IDX-1)*4+0),
      y = ReadCell(X+(IDX-1)*4+1)}
    ComputeTextureUV(VD[IDX],
      ReadCell(X+(IDX-1)*4+2),
      ReadCell(X+(IDX-1)*4+3))
  end
end
DrawToBuffer(VD)
```

### 7.4.23 222 DVXDATA\_\_3F

**Mnemonic:** DVXDATA\_3F X,Y

**Encoding:** 222 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draw a single 3D polygon with up to 128 triangles.

If vertex array mode is not used, X points to an array of triangle vertex coordinates, and Y specifies the total count of triangles.

In vertex array mode, X points to an array of indexes into the vertex array, and Y specifies the total count of triangles.

**Pseudocode:**

```
VDATA = Registers[VertexArray]
for IDX=1,MIN(128,Y) do
  if VDATA > 0 then
    VIDX1 = ReadCell(X+(IDX-1)*3+0)
    VIDX2 = ReadCell(X+(IDX-1)*3+1)
    VIDX3 = ReadCell(X+(IDX-1)*3+2)
    VD[1] = {
      x = ReadCell(VDATA+VIDX1*3+0),
      y = ReadCell(VDATA+VIDX1*3+1),
      z = ReadCell(VDATA+VIDX1*3+2)}
    VD[2] = {
      x = ReadCell(VDATA+VIDX2*3+0),
      y = ReadCell(VDATA+VIDX2*3+1),
      z = ReadCell(VDATA+VIDX2*3+2)}
    VD[3] = {
      x = ReadCell(VDATA+VIDX3*3+0),
      y = ReadCell(VDATA+VIDX3*3+1),
      z = ReadCell(VDATA+VIDX3*3+2)}
  else
    VD[1] = {
      x = ReadCell(X+(IDX-1)*9+0),
      y = ReadCell(X+(IDX-1)*9+1),
      z = ReadCell(X+(IDX-1)*9+2)}
    VD[2] = {
      x = ReadCell(X+(IDX-1)*9+3),
```

```

        y = ReadCell(X+(IDX-1)*9+4),
        z = ReadCell(X+(IDX-1)*9+5)}
    VD[3] = {
        x = ReadCell(X+(IDX-1)*9+6),
        y = ReadCell(X+(IDX-1)*9+7),
        z = ReadCell(X+(IDX-1)*9+8)}
end

ComputeTextureUV(VD[1],0,0)
ComputeTextureUV(VD[2],1,0)
ComputeTextureUV(VD[3],1,1)

DrawToBuffer(VD)
end

```



## 7.4.24 223 DVXDATA\_3F\_TEX

**Mnemonic:** DVXDATA\_3F\_TEX X,Y

**Encoding:** 223 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draw a single textured 3D polygon with up to 128 triangles.

If vertex array mode is not used, X points to an array of triangle vertex coordinates and texture coordinates, and Y specifies the total count of triangles.

In vertex array mode, X points to an array of indexes into the vertex array, and Y specifies the total count of triangles.

**Pseudocode:**

```
VDATA = Registers[VertexArray]
for IDX=1,MIN(128,Y) do
  if VDATA > 0 then
    $L VIDX1 = ReadCell(X+(IDX-1)*3+0)
    $L VIDX2 = ReadCell(X+(IDX-1)*3+1)
    $L VIDX3 = ReadCell(X+(IDX-1)*3+2)
    VD[1] = {
      x = ReadCell(VDATA+VIDX1*5+0),
      y = ReadCell(VDATA+VIDX1*5+1),
      z = ReadCell(VDATA+VIDX1*5+2),
    }
    VD[2] = {
      x = ReadCell(VDATA+VIDX2*5+0),
      y = ReadCell(VDATA+VIDX2*5+1),
      z = ReadCell(VDATA+VIDX2*5+2),
    }
    VD[3] = {
      x = ReadCell(VDATA+VIDX3*5+0),
      y = ReadCell(VDATA+VIDX3*5+1),
      z = ReadCell(VDATA+VIDX3*5+2),
    }

    ComputeTextureUV(VD[1],
      ReadCell(VDATA+VIDX1*5+3),
      ReadCell(VDATA+VIDX1*5+4))
```

```

    ComputeTextureUV(VD[2],
        ReadCell(VDATA+VIDX2*5+3),
        ReadCell(VDATA+VIDX2*5+4))
    ComputeTextureUV(VD[3],
        ReadCell(VDATA+VIDX3*5+3),
        ReadCell(VDATA+VIDX3*5+4))
else
    VD[1] = {
        x = ReadCell(X+(IDX-1)*15+0),
        y = ReadCell(X+(IDX-1)*15+1),
        z = ReadCell(X+(IDX-1)*15+2),
    }
    VD[2] = {
        x = ReadCell(X+(IDX-1)*15+5),
        y = ReadCell(X+(IDX-1)*15+6),
        z = ReadCell(X+(IDX-1)*15+7),
    }
    VD[3] = {
        x = ReadCell(X+(IDX-1)*15+10),
        y = ReadCell(X+(IDX-1)*15+11),
        z = ReadCell(X+(IDX-1)*15+12),
    }

    ComputeTextureUV(VD[1],
        ReadCell(X+(IDX-1)*15+ 3),
        ReadCell(X+(IDX-1)*15+ 4))
    ComputeTextureUV(VD[2],
        ReadCell(X+(IDX-1)*15+ 8),
        ReadCell(X+(IDX-1)*15+ 9))
    ComputeTextureUV(VD[3],
        ReadCell(X+(IDX-1)*15+13),
        ReadCell(X+(IDX-1)*15+14))
end

self:Dyn_EmitInterruptCheck()
DrawToBuffer(VD)
end

```

## 7.4.25 224 DVXDATA\_3F\_WF

**Mnemonic:** DVXDATA\_3F\_WF X,Y

**Encoding:** 224 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draw a single wireframe 3D polygon with up to 128 triangles.

If vertex array mode is not used, X points to an array of triangle vertex coordinates and texture coordinates, and Y specifies the total count of triangles.

In vertex array mode, X points to an array of indexes into the vertex array, and Y specifies the total count of triangles.

**Pseudocode:**

```
VDATA = Registers[VertexArray]
for IDX=1,MIN(128,Y) do
  if VDATA > 0 then
    VIDX1 = ReadCell(X+(IDX-1)*3+0)
    VIDX2 = ReadCell(X+(IDX-1)*3+1)
    VIDX3 = ReadCell(X+(IDX-1)*3+2)
    VD[1] = {
      x = ReadCell(VDATA+VIDX1*3+0),
      y = ReadCell(VDATA+VIDX1*3+1),
      z = ReadCell(VDATA+VIDX1*3+2)}
    VD[2] = {
      x = ReadCell(VDATA+VIDX2*3+0),
      y = ReadCell(VDATA+VIDX2*3+1),
      z = ReadCell(VDATA+VIDX2*3+2)}
    VD[3] = {
      x = ReadCell(VDATA+VIDX3*3+0),
      y = ReadCell(VDATA+VIDX3*3+1),
      z = ReadCell(VDATA+VIDX3*3+2)}
  else
    VD[1] = {
      x = ReadCell(X+(IDX-1)*9+0),
      y = ReadCell(X+(IDX-1)*9+1),
      z = ReadCell(X+(IDX-1)*9+2)}
    VD[2] = {
      x = ReadCell(X+(IDX-1)*9+3),
```

```

        y = ReadCell(X+(IDX-1)*9+4),
        z = ReadCell(X+(IDX-1)*9+5)}
    VD[3] = {
        x = ReadCell(X+(IDX-1)*9+6),
        y = ReadCell(X+(IDX-1)*9+7),
        z = ReadCell(X+(IDX-1)*9+8)}
end

ComputeTextureUV(VD[1],0,0)
ComputeTextureUV(VD[2],1,0)
ComputeTextureUV(VD[3],1,1)

DrawToBuffer(VD,WIREFRAME)
end

```

## 7.4.26 225 DIRECT

**Mnemonic:** DIRECT X,Y

**Encoding:** 225 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draws a single rectangle. X is a pointer to vector which specifies the top-left vertex, and Y is a pointer to vector which specifies the bottom-right vertex.

**Pseudocode:**

```
VD[1] = {  
    x = ReadCell(X+0),  
    y = ReadCell(X+1)}  
VD[2] = {  
    x = ReadCell(Y+0),  
    y = ReadCell(X+1)}  
VD[3] = {  
    x = ReadCell(Y+0),  
    y = ReadCell(Y+1)}  
VD[4] = {  
    x = ReadCell(X+0),  
    y = ReadCell(Y+1)}
```

```
ComputeTextureUV(VD[1],0,0)  
ComputeTextureUV(VD[2],1,0)  
ComputeTextureUV(VD[3],1,1)  
ComputeTextureUV(VD[4],0,1)
```

```
DrawToBuffer(VD)
```

## 7.4.27 226 DCIRCLE

**Mnemonic:** DCIRCLE X,Y

**Encoding:** 226 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draws a circle or a sector with specific radius and angles.

**Pseudocode:**

```
R = Y
SIDES = clamp(ReadCell(65485),3,64)
START = ReadCell(65478)
END = ReadCell(65477)
STEP = (END-START)/SIDES
VEC = ReadVector2f(X)

for IDX=1,SIDES do
    VD[1] = {
        x = VEC.x + R*sin(START+STEP*(IDX+0)),
        y = VEC.y + R*cos(START+STEP*(IDX+0))}
    VD[2] = {
        x = VEC.x,
        y = VEC.y}
    VD[3] = {
        x = VEC.x + R*sin(START+STEP*(IDX+1)),
        y = VEC.y + R*cos(START+STEP*(IDX+1))}

    ComputeTextureUV(VD[1],0,0)
    ComputeTextureUV(VD[2],1,0)
    ComputeTextureUV(VD[3],1,1)

    DrawToBuffer(VD)
end
```

### 7.4.28 227 DLINE

**Mnemonic:** DLINE X,Y

**Encoding:** 227 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draws a line between two points specified by the vectors X and Y.

**Pseudocode:**

```
DrawLine(ReadVector2f($1),ReadVector2f($2))
```

## 7.4.29 228 DRECTWH

**Mnemonic:** DRECTWH X,Y

**Encoding:** 228 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draws a single rectangle. X is a pointer to vector which specifies the top-left corner coordinates, and Y is a pointer to vector which specifies the Rectangle size.

**Pseudocode:**

```
VD[1] = {  
    x = ReadCell(X+0),  
    y = ReadCell(X+1)}  
VD[2] = {  
    x = ReadCell(X+0)+ReadCell(Y+0),  
    y = ReadCell(X+1)}  
VD[3] = {  
    x = ReadCell(X+0)+ReadCell(Y+0),  
    y = ReadCell(X+1)+ReadCell(Y+1)}  
VD[4] = {  
    x = ReadCell(X+0),  
    y = ReadCell(X+1)+ReadCell(Y+1)}
```

```
ComputeTextureUV(VD[1],0,0)
```

```
ComputeTextureUV(VD[2],1,0)
```

```
ComputeTextureUV(VD[3],1,1)
```

```
ComputeTextureUV(VD[4],0,1)
```

```
DrawToBuffer(VD)
```



### 7.4.30 229 DORECT

**Mnemonic:** DORECT X,Y

**Encoding:** 229 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draws an outline of a rectangle. X is a pointer to vector which specifies the top-left vertex, and Y is a pointer to vector which specifies the bottom-right vertex.

The line width can be specified with the DSETWIDTH instruction.

**Pseudocode:**

```
VD[1] = {  
    x = ReadCell(X+0),  
    y = ReadCell(X+1)}  
VD[2] = {  
    x = ReadCell(Y+0),  
    y = ReadCell(X+1)}  
VD[3] = {  
    x = ReadCell(Y+0),  
    y = ReadCell(Y+1)}  
VD[4] = {  
    x = ReadCell(X+0),  
    y = ReadCell(Y+1)}  
  
DrawLine(VD[1],VD[2])  
DrawLine(VD[2],VD[3])  
DrawLine(VD[3],VD[4])  
DrawLine(VD[4],VD[1])
```

### 7.4.31 230 DTRANSFORM2F

**Mnemonic:** DTRANSFORM2F X,Y

**Encoding:** 230 RM [Segment1] [Segment2] [Constant1] [Constant2]

Transforms a 2D vector using the projection and the modelview matrices.

**Psuedocode:**

**Psuedocode:**

### 7.4.32 231 DTRANSFORM3F

**Mnemonic:** DTRANSFORM3F X,Y

**Encoding:** 231 RM [Segment1] [Segment2] [Constant1] [Constant2]

Transforms a 3D vector using the projection and the modelview matrices.

**Pseudocode:**

### 7.4.33 232 DSCRSIZE

**Mnemonic:** DSCRSIZE X,Y

**Encoding:** 232 RM [Segment1] [Segment2] [Constant1] [Constant2]

Sets the current screen size.

**Pseudocode:**

Registers[Width] = X

Registers[Height] = Y

### 7.4.34 233 DROTATESCALE

**Mnemonic:** DROTATESCALE X,Y

**Encoding:** 233 RM [Segment1] [Segment2] [Constant1] [Constant2]

Rotates and scales coordinates of all following graphics instructions. The default centerpoint of rotation is (0,0) which can be changed using the **CenterX** and the **CenterY** registers.

**Pseudocode:**

Registers[Rotation] = X

Registers[Scale] = Y

### 7.4.35 234 DORECTWH

**Mnemonic:** DORECTWH X,Y

**Encoding:** 234 RM [Segment1] [Segment2] [Constant1] [Constant2]

Draws an outline of a rectangle. X is a pointer to vector which specifies the top-left corner coordinates, and Y is a pointer to vector which specifies the Rectangle size.

The line width can be specified with the DSETWIDTH instruction.

**Pseudocode:**

```
VD[1] = {  
    x = ReadCell(X+0),  
    y = ReadCell(X+1)}  
VD[2] = {  
    x = ReadCell(X+0)+ReadCell(Y+0),  
    y = ReadCell(X+1)}  
VD[3] = {  
    x = ReadCell(X+0)+ReadCell(Y+0),  
    y = ReadCell(X+1)+ReadCell(Y+1)}  
VD[4] = {  
    x = ReadCell(X+0),  
    y = ReadCell(X+1)+ReadCell(Y+1)}
```

```
DrawLine(VD[1],VD[2])  
DrawLine(VD[2],VD[3])  
DrawLine(VD[3],VD[4])  
DrawLine(VD[4],VD[1])
```

### 7.4.36 235 DCULLMODE

**Mnemonic:** DCULLMODE X,Y

**Encoding:** 235 RM [Segment1] [Segment2] [Constant1] [Constant2]

Sets the current culling mode and lighting mode.

X sets the culling mode:

- 0: front face culling
- 1: back face culling

Y sets the lighting mode:

- 0: double-side lighting
- 1: front side lighting
- -1: back side lighting

**Pseudocode:**

Register[CullMode] = X

Register[LightMode] = X

### 7.4.37 238 DPIXEL

**Mnemonic:** DPIXEL X,Y

**Encoding:** 238 RM [Segment1] [Segment2] [Constant1] [Constant2]

Outputs a single pixel to screen. X is a pointer to vector which specifies coordinates on screen (can be non-integer, which will cause anti-aliasing effect), and Y is a pointer to color of the pixel.

**Pseudocode:**

SetPixel(X,Y)



### 7.4.38 240 DWRITE

**Mnemonic:** DWRITE X,Y

**Encoding:** 240 RM [Segment1] [Segment2] [Constant1] [Constant2]

Writes a null-terminated string to screen. X is a pointer to vector that specifies the position of string on screen, and Y is the pointer to the first character of the string.

**Pseudocode:**

```
TEXT = VM:ReadString(Y)
FontWrite(X,TEXT)
```

### 7.4.39 241 DWRITEI

**Mnemonic:** DWRITEI X,Y

**Encoding:** 241 RM [Segment1] [Segment2] [Constant1] [Constant2]

Writes a integer value to screen. X is a pointer to vector that specifies the position of string on screen, and Y is the value that must be drawn on screen.

**Psuedocode:**

FontWrite(X,Integer(Y))

#### **7.4.40    242 DWRITEF**

**Mnemonic:** DWRITEF X,Y

**Encoding:** 242 RM [Segment1] [Segment2] [Constant1] [Constant2]

Writes a floating-point value to screen. X is a pointer to vector that specifies the position of string on screen, and Y is the value that must be drawn on screen.

**Psuedocode:**

FontWrite(X,Y)

#### 7.4.41 243 DENTRYPOINT

**Mnemonic:** DENTRYPOINT X,Y

**Encoding:** 243 RM [Segment1] [Segment2] [Constant1] [Constant2]

Sets one of the GPU entrypoints. Each entrypoint corresponds to a specific function, there are the following entrypoints available right now:

**Psuedocode:**

### 7.4.42 244 DSETLIGHT

**Mnemonic:** DSETLIGHT X,Y

**Encoding:** 244 RM [Segment1] [Segment2] [Constant1] [Constant2]

Sets parameters of one of the 8 lights supported by the GPU. X is the light index (0..7), and Y points to the following data structure:

**LightData:**

```
vector4f position,<x>,<y>,<z>,0;  
vector4f color,<r>,<g>,<b>,<brightness>;
```

Light brightness is usually set to 1, but can vary.

**Pseudocode:**

```
if (X < 0) or (X > 7) then  
    Interrupt(19,0)  
else  
    Lights[X] = {  
        Position = ReadVector4f(Y+0),  
        Color    = ReadVector4f(Y+4)}  
end
```

### 7.4.43 245 DGETLIGHT

**Mnemonic:** DGETLIGHT X,Y

**Encoding:** 245 RM [Segment1] [Segment2] [Constant1] [Constant2]

Reads light data for one of the 8 lights supported by the GPU. X is the light index (0..7), and Y points to the following data structure, which will be filled with light data:

**LightData:**

```
vector4f position,<x>,<y>,<z>,0;  
vector4f color,<r>,<g>,<b>,<brightness>;
```

**Psuedocode:**

N/A

#### 7.4.44 246 DWRITEFMT

**Mnemonic:** DWRITEFMT X,Y

**Encoding:** 246 RM [Segment1] [Segment2] [Constant1] [Constant2]

Writes a formatted string to screen. X points to vector that specifies the position of string on screen, and Y is the string that must be drawn on screen.

Variables used in the string format must follow the string data. If **ParamList** register is set, then variables used in the string format start at that offset.

**Pseudocode:**

N/A

#### **7.4.45    247 DWRITEFIX**

**Mnemonic:** DWRITEFIX X,Y

**Encoding:** 247 RM [Segment1] [Segment2] [Constant1] [Constant2]

Writes a fixed-point value to screen. X is a pointer to vector that specifies the position of string on screen, and Y is the value that must be drawn on screen.

**Psuedocode:**

N/A



#### **7.4.46    248 DTEXTWIDTH**

**Mnemonic:** DTEXTWIDTH X,Y

**Encoding:** 248 RM [Segment1] [Segment2] [Constant1] [Constant2]

Returns the width of string using the current font, and writes it to X.

**Pseudocode:**

#### **7.4.47    249 DTEXTHEIGHT**

**Mnemonic:** DTEXTHEIGHT X,Y

**Encoding:** 249 RM [Segment1] [Segment2] [Constant1] [Constant2]

Returns the height of string using the current font, and writes it to X.

**Pseudocode:**

#### 7.4.48 271 MLOADPROJ

**Mnemonic:** MLOADPROJ X

**Encoding:** 271 RM [Segment1] [Constant1]

Loads given matrix into the GPU projection matrix. X points to the matrix.

**Psuedocode:**

```
ProjectionMatrix = ReadMatrix(X)
```

#### 7.4.49 272 MREAD

**Mnemonic:** MREAD X

**Encoding:** 272 RM [Segment1] [Constant1]

Reads GPU model matrix. X points to the matrix into which model matrix will be written.

**Pseudocode:**

```
WriteMatrix(X,ModelMatrix)
```

### 7.4.50 274 DT

**Mnemonic:** DT X

**Encoding:** 274 RM [Segment1] [Constant1]

Returns time passed since last frame (works only in frame-based mode).

**Pseudocode:**

X = TimerDT

### 7.4.51 276 DSHADE

**Mnemonic:** DSHADE X

**Encoding:** 276 RM [Segment1] [Constant1]

Shades the current color by specific amount. **X** is the shading value. A value between 0 and 1 will make the color darker, a value of 1 will not change the current color, while value higher than 1 will make color brighter.

There is no normalization, so values outside of 0..1 range might generate weird colors.

**Pseudocode:**

```
Color.x = Color.x*X  
Color.y = Color.y*X  
Color.z = Color.z*X  
SetColor(Color)
```

### 7.4.52 277 DSETWIDTH

**Mnemonic:** DSETWIDTH X

**Encoding:** 277 RM [Segment1] [Constant1]

Sets line width.

**Pseudocode:**

Register[LineWidth] = X

### 7.4.53 278 MLOAD

**Mnemonic:** MLOAD X

**Encoding:** 278 RM [Segment1] [Constant1]

Loads given matrix into the GPU model matrix. X points to the matrix.

**Pseudocode:**

```
ModelMatrix = ReadMatrix(X)
```



### 7.4.54 279 DSHADENORM

**Mnemonic:** DSHADENORM X

**Encoding:** 279 RM [Segment1] [Constant1]

Shades the current color by specific amount. X is the shading value. A value between 0 and 1 will make the color darker, a value of 1 will not change the current color, while value higher than 1 will make color brighter.

The resulting color is normalized, so it's possible to use values outside of the 0..1 range.

**Pseudocode:**

```
Color.x = Clamp(Color.x*X,0,255)
Color.y = Clamp(Color.y*X,0,255)
Color.z = Clamp(Color.z*X,0,255)
SetColor(Color)
```

## 7.4.55 280 DDFRAME

**Mnemonic:** DDFRAME X

**Encoding:** 280 RM [Segment1] [Constant1]

Draws a framed rectangle. X points to the following data structure:

FrameData:

```
vector2f position,<x>,<y>;  
vector2f size,<w>,<h>;  
vector4f info,<shadow>,<highlight>,<face>,<border size>;
```

The info entry stores pointers to colors that must be used in rendering.

**Pseudocode:**

```
V1 = ReadVector2f(X+0)
```

```
V2 = ReadVector2f(X+2)
```

```
V3 = ReadVector4f(X+4)
```

```
CSHADOW    = ReadVector3f(V3.x)
```

```
CHIGHLIGHT = ReadVector3f(V3.y)
```

```
CFACE      = ReadVector3f(V3.z)
```

```
VD1[1] = {  
    x = V3.w + V1.x,  
    y = V3.w + V1.y}
```

```
VD1[2] = {  
    x = V3.w + V1.x + V2.x,  
    y = V3.w + V1.y}
```

```
VD1[3] = {  
    x = V3.w + V1.x + V2.x,  
    y = V3.w + V1.y + V2.y}
```

```
VD1[4] = {  
    x = V3.w + V1.x,  
    y = V3.w + V1.y + V2.y}
```

```
VD2[1] = {  
    x = -V3.w + V1.x,
```

```

    y = --V3.w + V1.y}
VD2[2] = {
    x = -V3.w + V1.x + V2.x,
    y = -V3.w + V1.y}
VD2[3] = {
    x = -V3.w + V1.x + V2.x,
    y = -V3.w + V1.y + V2.y}
VD2[4] = {
    x = -V3.w + V1.x,
    y = -V3.w + V1.y + V2.y}

VD3[1] = {
    x = V1.x,
    y = V1.y}
VD3[2] = {
    x = V1.x + V2.x,
    y = V1.y}
VD3[3] = {
    x = V1.x + V2.x,
    y = V1.y + V2.y}
VD3[4] = {
    x = V1.x,
    y = V1.y + V2.y}

ComputeTextureUV(VD1[1],0,0)
ComputeTextureUV(VD1[2],1,0)
ComputeTextureUV(VD1[3],1,1)
ComputeTextureUV(VD1[4],0,1)

ComputeTextureUV(VD2[1],0,0)
ComputeTextureUV(VD2[2],1,0)
ComputeTextureUV(VD2[3],1,1)
ComputeTextureUV(VD2[4],0,1)

ComputeTextureUV(VD3[1],0,0)
ComputeTextureUV(VD3[2],1,0)
ComputeTextureUV(VD3[3],1,1)

```

```
ComputeTextureUV(VD3[4],0,1)
```

```
SetColor(CSHADOW)
```

```
DrawToBuffer(VD1)
```

```
SetColor(CHIGHLIGHT)
```

```
DrawToBuffer(VD2)
```

```
SetColor(CFACE)
```

```
DrawToBuffer(VD3)
```

### 7.4.56 283 DRASTER

**Mnemonic:** DRASTER X

**Encoding:** 283 RM [Segment1] [Constant1]

Set raster quality.

**Pseudocode:**

Registers[RasterQ] = X

## 7.4.57 284 DD TERRAIN

**Mnemonic:** DD TERRAIN X

**Encoding:** 284 RM [Segment1] [Constant1]

Draw 3D terrain.

**Pseudocode:**

```
W = ReadCell(X+0)
```

```
H = ReadCell(X+1)
```

```
R = clamp(floor(ReadCell(X+2)),0,16)
```

```
U = ReadCell(X+3)
```

```
V = ReadCell(X+4)
```

```
MinX = clamp(floor(W/2 + U - R),1,W-1)
```

```
MinY = clamp(floor(H/2 + V - R),1,H-1)
```

```
MaxX = clamp(floor(W/2 + U + R),1,W-1)
```

```
MaxY = clamp(floor(H/2 + V + R),1,H-1)
```

```
for X=MinX,MaxX do
```

```
  for Y=MinY,MaxY do
```

```
    XPOS = X - W/2 - U - 0.5
```

```
    YPOS = Y - H/2 - U - 0.5
```

```
    if (X > 0) and (X <= W-1) and (Y > 0) and (Y <= H-1) and (XPOS^2+YPOS^2 <= R^2) t
```

```
      Z1 = ReadCell(X+16+(Y-1)*W+(X-1)
```

```
      Z2 = ReadCell(X+16+(Y-1)*W+(X-0)
```

```
      Z3 = ReadCell(X+16+(Y-0)*W+(X-0)
```

```
      Z4 = ReadCell(X+16+(Y-0)*W+(X-1)
```

```
      VD[1] = { x = XPOS,    y = YPOS,    y = Z1 }
```

```
      VD[2] = { x = XPOS+1, y = YPOS,    y = Z2 }
```

```
      VD[3] = { x = XPOS+1, y = YPOS+1, y = Z3 }
```

```
      ComputeTextureUV(VD[1],0,0)
```

```
      ComputeTextureUV(VD[2],1,0)
```

```
      ComputeTextureUV(VD[3],1,1)
```

```

    DrawToBuffer(VD)

    VD[1] = { x = XPOS,    y = YPOS,    y = Z1}
    VD[2] = { x = XPOS,    y = YPOS+1, y = Z4}
    VD[3] = { x = XPOS+1, y = YPOS+1, y = Z3}

    ComputeTextureUV(VD[1],0,0)
    ComputeTextureUV(VD[2],0,1)
    ComputeTextureUV(VD[3],1,1)
    DrawToBuffer(VD)
end
end
end

```

### 7.4.58 294 DMULDT

**Mnemonic:** DMULDT X,Y

**Encoding:** 294 RM [Segment1] [Segment2] [Constant1] [Constant2]

Multiplies Y by time-step and writes it into X. Used in frame-based mode to provide smooth animations.

**Pseudocode:**

$X = Y * \text{TimerDT}$



### **7.4.59    298 DBEGIN**

**Mnemonic:** DBEGIN

**Encoding:** 298

Starts asynchronous drawing. Used only in asynchronous thread.

**Pseudocode:**

`SetRenderTarget(1)`

### **7.4.60    299 DEND**

**Mnemonic:** DEND

**Encoding:** 299

Ends asynchronous drawing, and outputs the drawn image to screen.

**Psuedocode:**

FlushBuffer()

Copy(1,0)

SetRenderTarget(2)

### 7.4.61 303 DXTEXTURE

**Mnemonic:** DXTEXTURE X

**Encoding:** 303 RM [Segment1] [Constant1]

Binds a predefined texture. X points to the string that contains texture name. If X is equal to 0, texture will be unbound.

**Pseudocode:**

```
if X > 0 then
  NAME = VM:ReadString(X)
  SetTexture(NAME)
else
  SetTexture(0)
end
```



# Chapter 8

## Zylios SPU

### 8.1 General Information

ZSPU is a programmable sequencer and sound synthesizer. It works with waveforms and channels. Each waveform is an unique sound, there can be up to 128 different waveforms loaded, while each channel corresponds to one of the output channels. It's possible to play just one waveform through each channel, although it's possible to use same waveform for many channels.

Each channel has separate pitch, volume settings, and supports hardware ADSR/LFO.

### 8.2 Features Reference

no chapter

### 8.3 Internal Registers

no chapter

### 8.4 Instruction Set Reference

### 8.4.1 320 CHRESET

**Mnemonic:** CHRESET X

**Encoding:** 320 RM [Segment1] [Constant1]

**Psuedocode:**

## 8.4.2 321 CHSTART

**Mnemonic:** CHSTART X

**Encoding:** 321 RM [Segment1] [Constant1]

**Psuedocode:**

### 8.4.3 322 CHSTOP

**Mnemonic:** CHSTOP X

**Encoding:** 322 RM [Segment1] [Constant1]

**Psuedocode:**



#### 8.4.4 330 WSET

**Mnemonic:** WSET X,Y

**Encoding:** 330 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 8.4.5 331 CHWAVE

**Mnemonic:** CHWAVE X,Y

**Encoding:** 331 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 8.4.6 332 CHLOOP

**Mnemonic:** CHLOOP X,Y

**Encoding:** 332 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 8.4.7 333 CHVOLUME

**Mnemonic:** CHVOLUME X,Y

**Encoding:** 333 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 8.4.8 334 CHPITCH

**Mnemonic:** CHPITCH X,Y

**Encoding:** 334 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 8.4.9 335 CHMODT

**Mnemonic:** CHMODT X,Y

**Encoding:** 335 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 8.4.10 336 CHMODA

**Mnemonic:** CHMODA X,Y

**Encoding:** 336 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**

### 8.4.11 337 CHMODF

**Mnemonic:** CHMODF X,Y

**Encoding:** 337 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Psuedocode:**



### 8.4.12 338 CHADSR

**Mnemonic:** CHADSR X,Y

**Encoding:** 338 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**

### 8.4.13 339 WLEN

**Mnemonic:** WLEN X,Y

**Encoding:** 339 RM [Segment1] [Segment2] [Constant1] [Constant2]

**Pseudocode:**