



Computer Organization

Lab11 CPU Design(3)

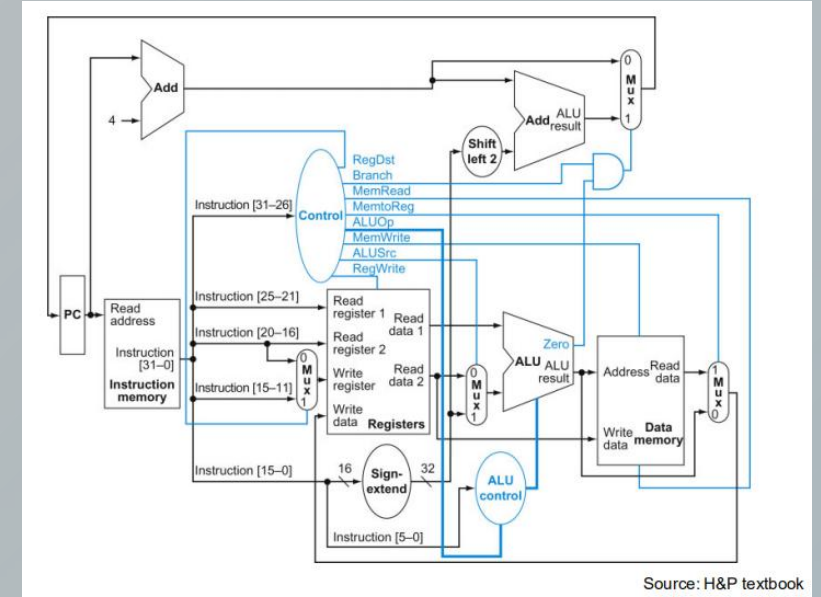
‘single’ cycle CPU
clock, I/O



Topic

➤ CPU Design(3)

- A 'single' cycle CPU
- Clock (IP core)



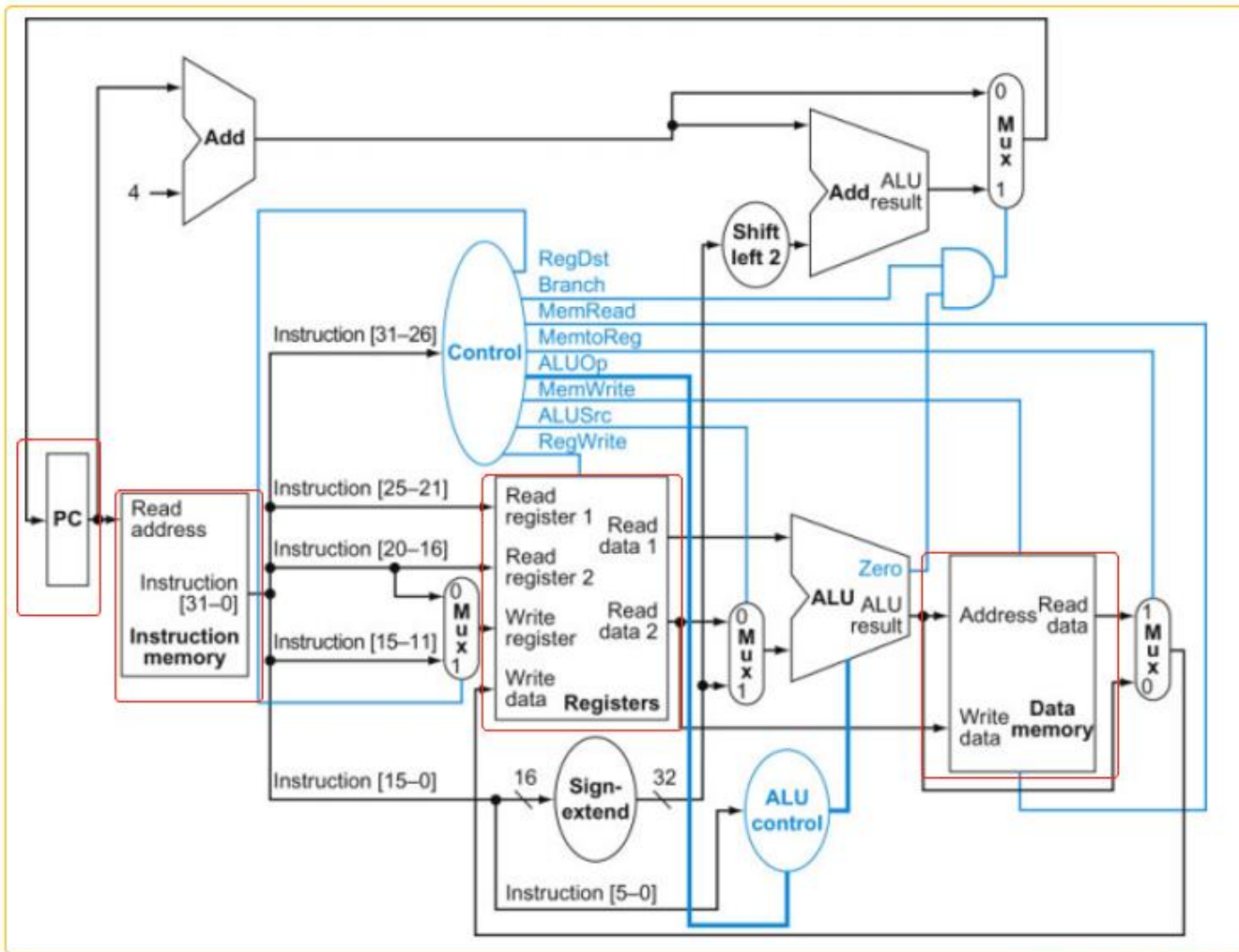
➤ CPU work with I/O device

- MemOrIO
- Controller +





A 'single' cycle CPU



Source: H&P textbook

Q1. Does it **take time** for signals to be processed and transmitted within the module, as well as between modules?

Q2. Which sub modules within CPU **need the trigger from the clock**? When does the following event occur in a clock cycle?

- 1-1) **IFetch: update** the value of PC register
- 1-2) **IFetch: fetch** the instruction according to the value of PC
- 2-1-1) **Controller: generate the control signals**
- 2-2-1) **Decoder: get the value of register(s)**
- 2-2-2) **Decoder: generate the extended immediate**
- 3-1) **ALU: get the operands**
- 3-2) **ALU: generate the calculation result**
- 4-1) **Dmemory: get the address**(from ALU) and **data**(from Decoder)
- 4-2) **Dmemory: read out the data**
- 5-1) **Decoder: write back the data**

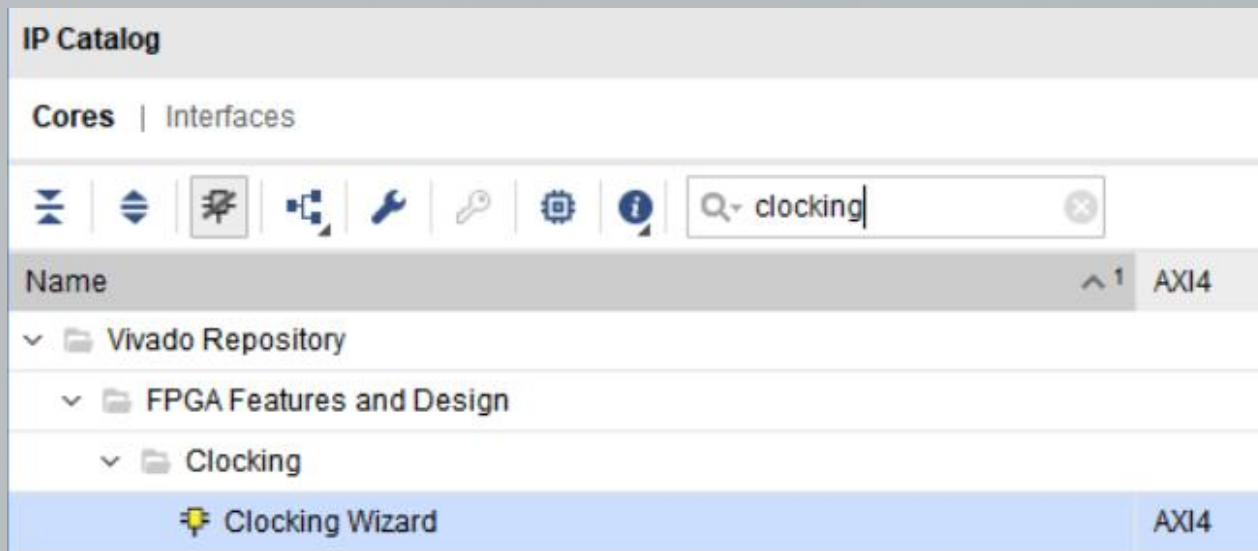


Clock

➤ Add **PLL clock IP core** to generate the needed clock:

1. The clock on the Minisys/EGO1 development board is **100Mhz** *(clk_in1)*
➤ 100Mhz is too fast for a 'single' clock CPU

2. A clock of 23Mhz is more suitable for the 'single' clock CPU *(clk_out1)*





Clock continued

Custom the IP core, set its **name**, **Primitive**, **Output Freq** and **with out the reset and locked**. Then **generate** the IP core with the settings.

Component Name **cpuck**

Clocking Options | Output Clocks | Port Renaming | PLL2 Settings | Summary

Clock Monitor

☐ Enable Clock Monitoring

Primitive

☐ MMCM ☒ **PLL**

Clocking Features

☒ Frequency Synthesis ☐ Minimize Power

☒ Phase Alignment

☐ Dynamic Reconfig

☐ Safe Clock Startup

Jitter Optimization

☒ Balanced

☐ Minimize Output Jitter

☐ Maximize Input Jitter filtering

Clocking Options | **Output Clocks** | Port Renaming | PLL2 Settings

The phase is calculated relative to the active input clock.

Output Clock	Port Name	Output Freq (MHz)	
		Requested	Actual
<input checked="" type="checkbox"/> clk_out1	clk_out1	23.000	23.000

Component Name cpuck

Clocking Options | **Output Clocks** | Port Renaming | PLL2 Settings | Summary

Enable Optional Inputs / Outputs for MMCM/PLL

☐ reset ☐ power_down

☐ locked

Reset Type

☒ Active High ☐ Active Low



The Function Verification of “cpuckl”

Functional Verification by **testbench** and **simulator**

1) Create a verilog **testbench** module to instance the IP core “**cpuckl**” and bind its ports. set the frequency of the input on “cpuckl” as **100Mhz**.

2) Do the simulation to verify whether the output signal is a **23Mhz** clock signal while the input signal is **100Mhz**.

```
module cpuckl_tb( ); // a reference testbench for 'cpuckl'
```

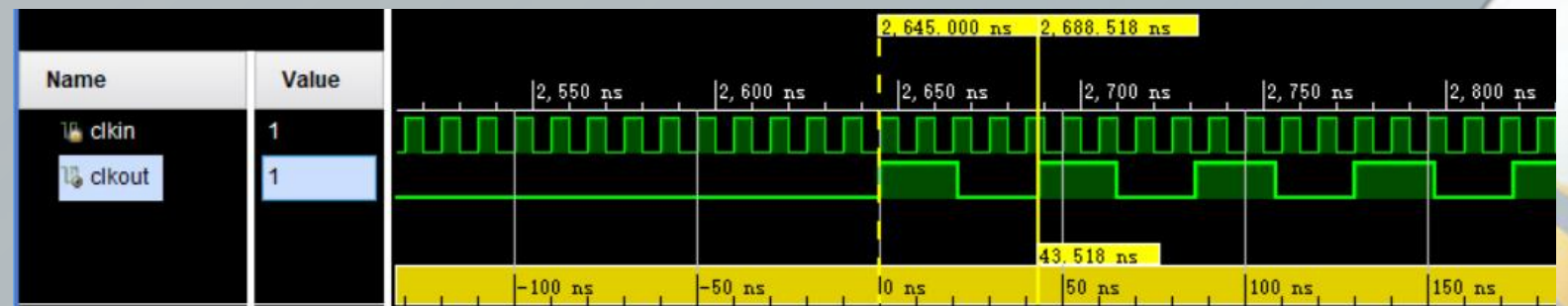
```
    reg clk_in;  
    wire clk_out;
```

```
    cpuckl clk1( .clk_in1(clk_in), .clk_out1(clk_out) );
```

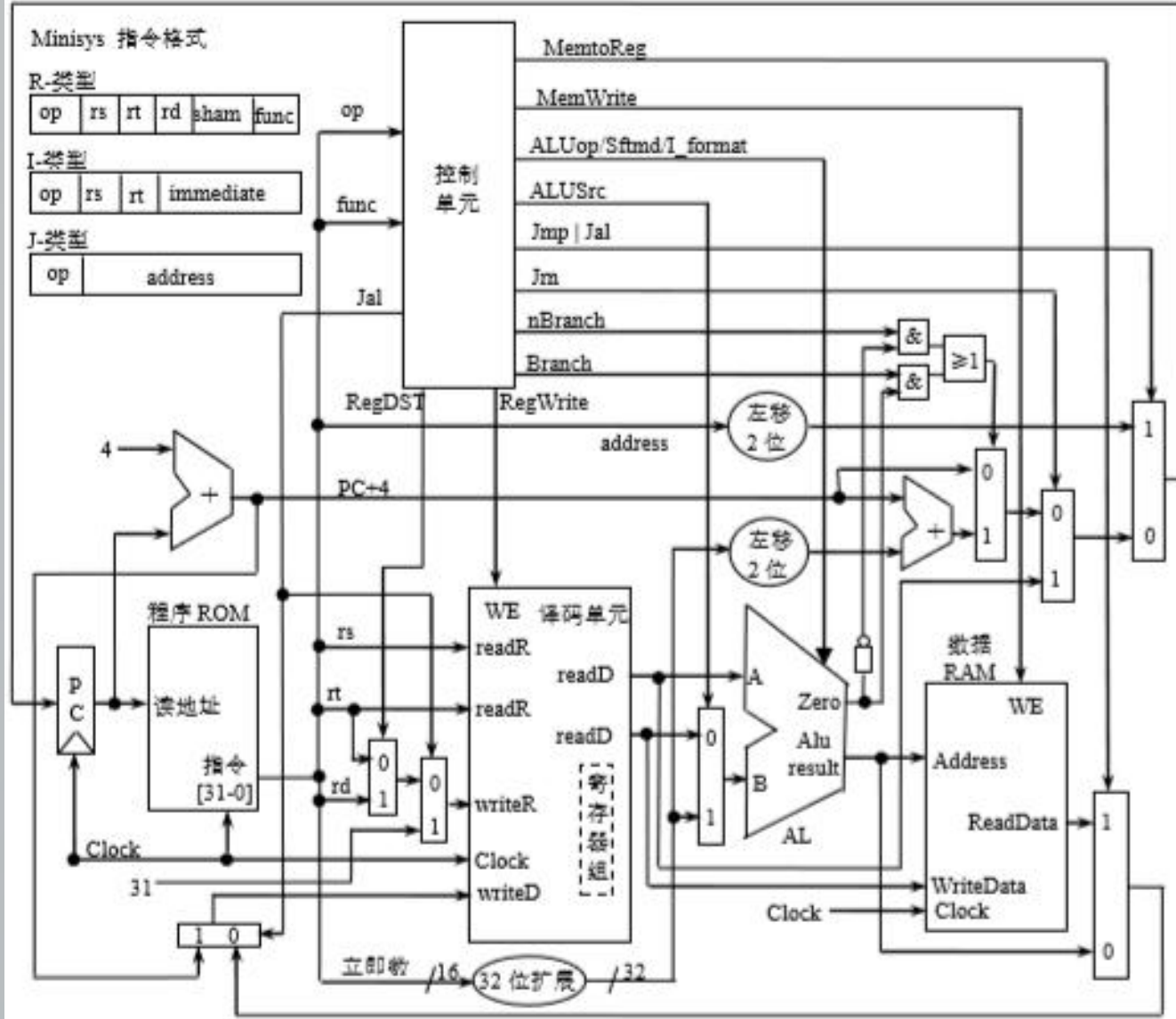
```
    initial      clk_in = 1'b0;
```

```
    always #5 clk_in=~clk_in;  
endmodule
```

NOTE: The output of IP core 'cpuckl' need to work for a ‘long’ time to achieve stability.



Build and test the CPU



Build a CPU top module

1) **Instantiating** the sub-modules: **clock**, **Decoder**, execution unit/**ALU**, **IFetch**, **Controller** and **Data-Memory**.

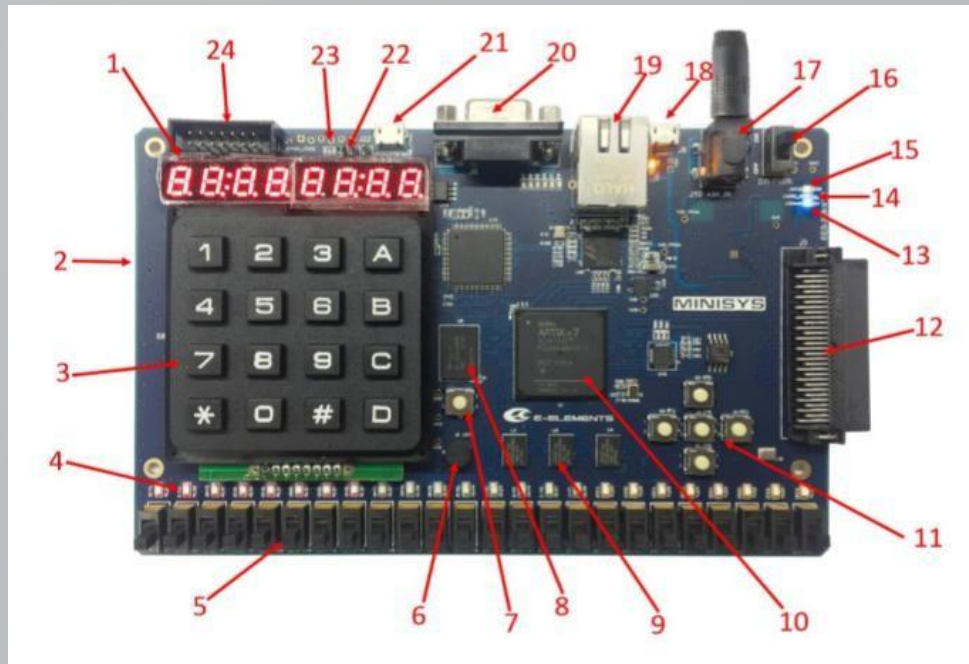
2) Complete the inter-module connection inside the CPU and the **binding** to the CPU port.

Q1. How to test the CPU ?
how to determine the
program, the data, how to
check the result?

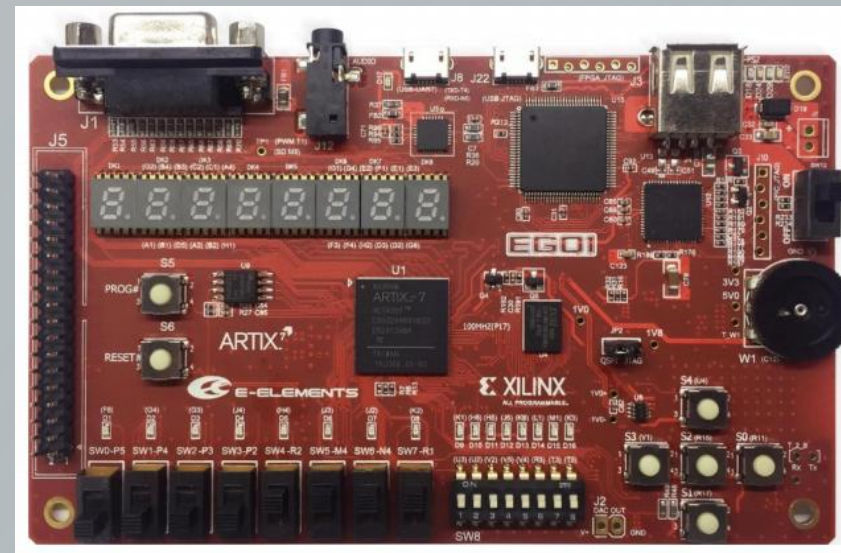


I/O interface

Minisys board with FPGA chip embedded



EGO1 board with FPGA chip embedded



We have practiced a Cropped CPU on EGO1 in lab1



TIPS:

The handbook of board **Minisys** and **EGO1** could be found in the directory "labs\Handbook_of_Minisys_EGO1" on the course **BlackBoard** sit



A Simple Design on the I/O Interface

This part mainly accomplishes the following work:

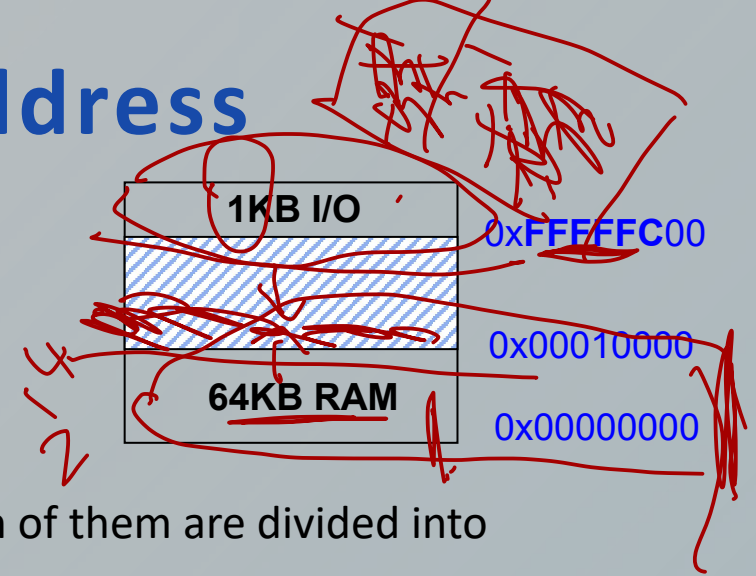
1. Add I/O function
2. 16-bit LED design
3. 16-bit DIP Switch design

This is only one of the design solutions for I/O related data bus. Please develop a solution that suits your design needs!

I/O Share Part of the Data Bus Address

The space of **32** bits address bus is **4GB**(0x0000_0000~0xFFFF_FFFF)

1024 bytes(0xFFFF_FC00~0xFFFF_FFFF) is designed to be allocated for the **I/O**.
Chip **Select** and **address** are specified by specifying **10** IO port lines.



Here is an example for **24 LED lights** and **24 DIP switches** on Minisys board, both of them are divided into two groups, all the ports in one group share the same address.

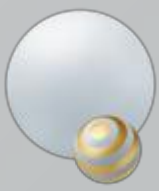
1. The CS(Chip Select) signal of the LED light is **ledCtrl**
2. The CS(Chip Select) signal of the DIP switch is **switchCtrl**

Range	LED(1~16)	LED(17~24)	Switch(1~16)	Switch(17~24)
Address	0xFFFFFC60	0xFFFFFC62	0xFFFFFC70	0xFFFFFC72

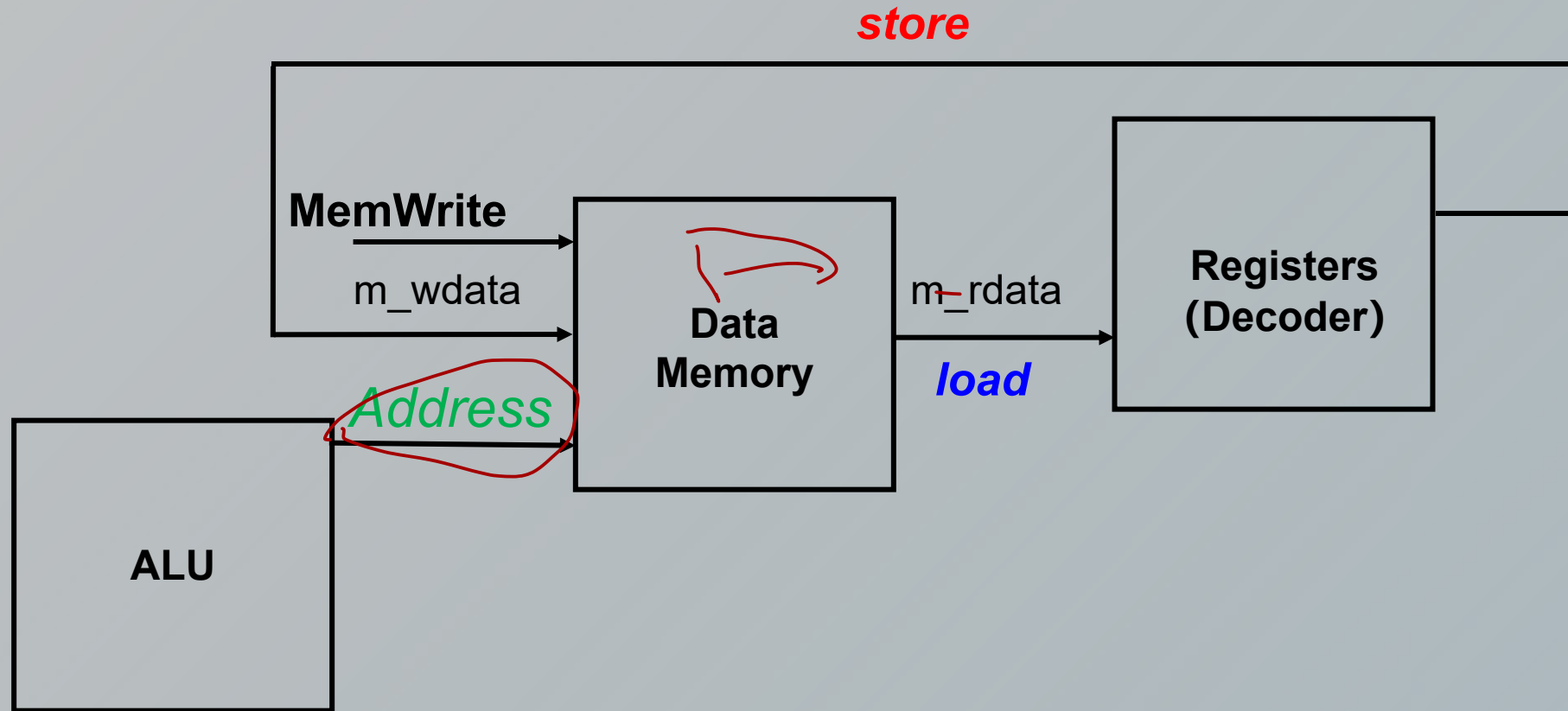
Note:

1. In the computer field, there are usually two schemes for I/O address space design: I/O and memory **unified addressing** or **I/O independent addressing**. However there is no dedicated I/O instruction in current Minisys-1. Here, both LW and SW instructions are used for RAM access and I/O access, which means Minisys-1 can only use I/O unified addressing.

2. It is just a way for IO address implementation (MMIO: Memory-Mapped Input Output) , but not the only choice.



Corresponding Operation of LW/SW

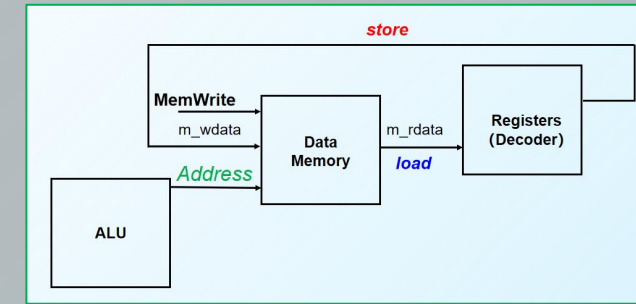
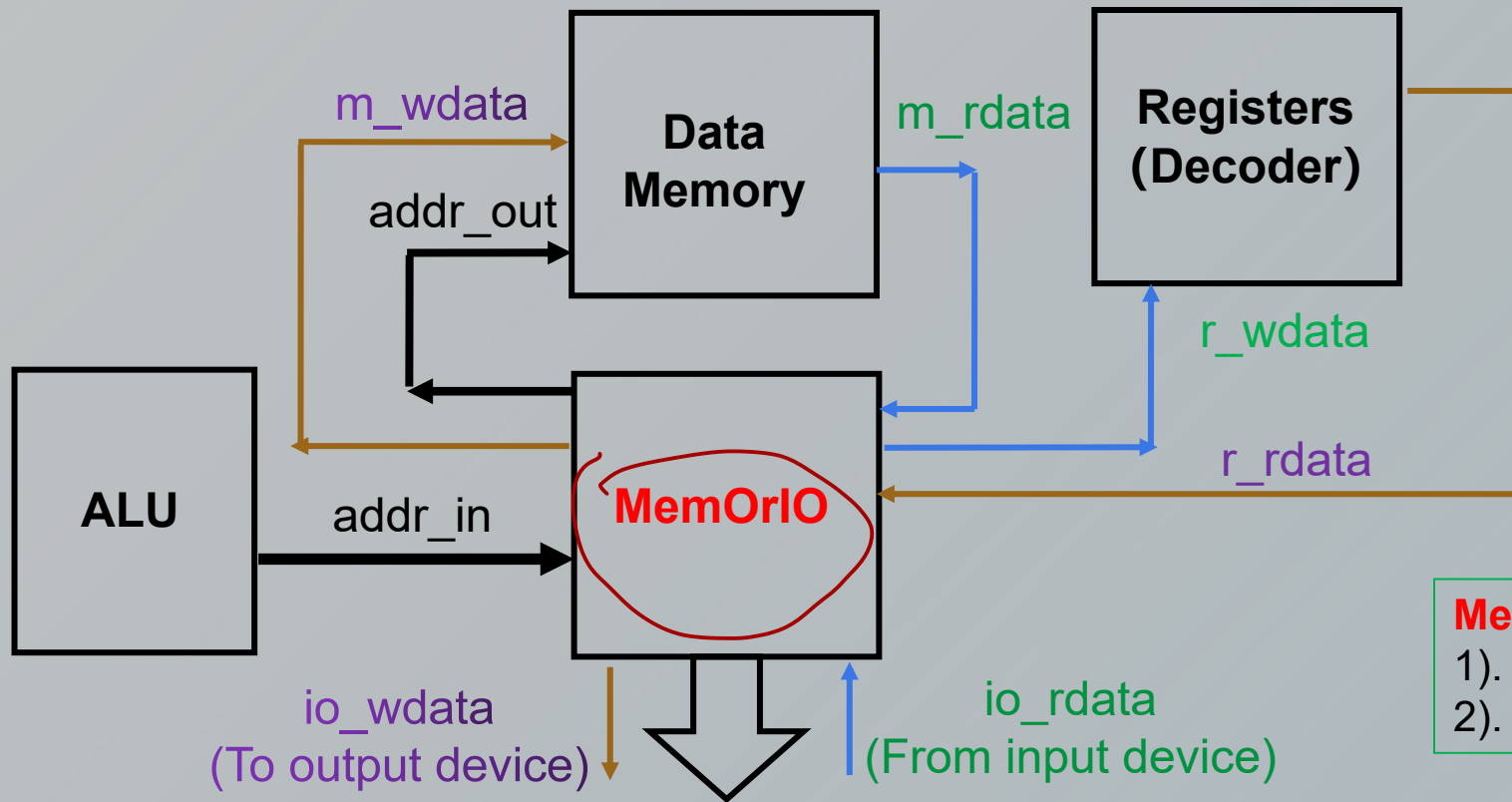


NOTE:

- 1) There is no specific instruction in Minisys to read data from input ports and write data to output ports.
- 2) To implement the read/write process on I/O, it needs to **share the load/store instructions** in Minisys.



MemOrIO



MemOrIO determine:

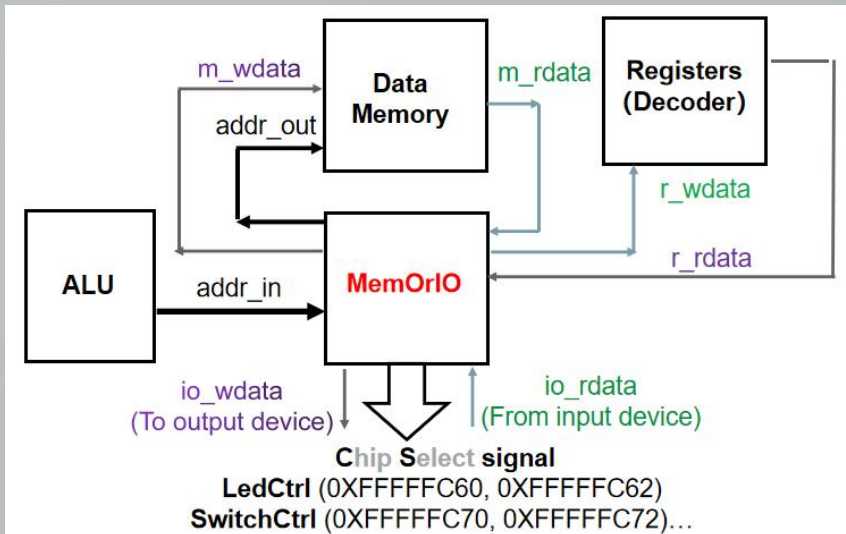
- 1). The source of **r_wdata**
- 2). The destination of **r_rdata**

Chip Select signal

LedCtrl (0xFFFFFC60, 0xFFFFFC62)
SwitchCtrl (0xFFFFFC70, 0xFFFFFC72)...



MemOrIO continued



```
module MemOrIO( mRead, mWrite, ioRead, ioWrite, addr_in, addr_out,
m_rdata, io_rdata, r_wdata, r_rdata, write_data, LEDCtrl, SwitchCtrl);

input mRead; // read memory, from Controller
input mWrite; // write memory, from Controller
input ioRead; // read IO, from Controller
input ioWrite; // write IO, from Controller

input[31:0] addr_in; // from alu_result in ALU
output[31:0] addr_out; // address to Data-Memory

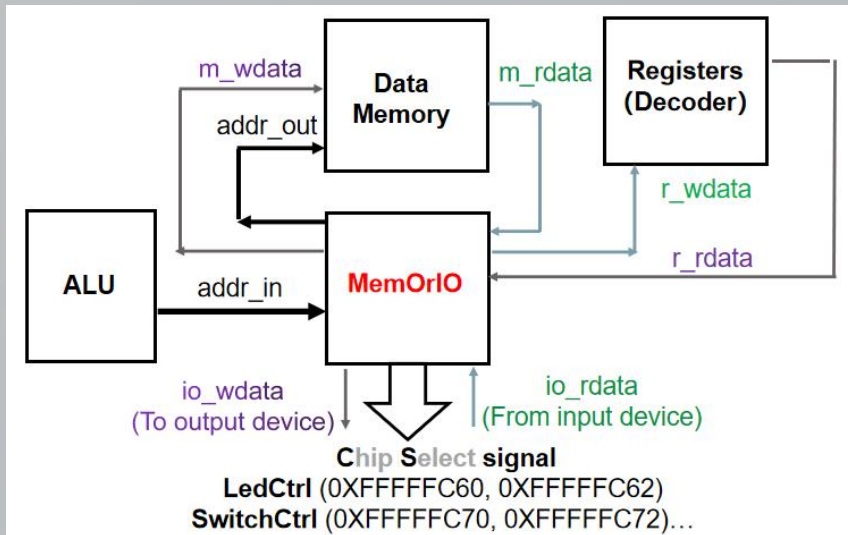
input[31:0] m_rdata; // data read from Data-Memory
input[15:0] io_rdata; // data read from IO, 16 bits
output[31:0] r_wdata; // data to Decoder(register file)

input[31:0] r_rdata; // data read from Decoder(register file)
output reg[31:0] write_data; // data to memory or I/O (m_wdata, io_wdata)
output LEDCtrl; // LED Chip Select
output SwitchCtrl; // Switch Chip Select
```

*Tips: A demo about how the **Chip Select** signals work on I/O could be found in **labs/lab11_io** on course BlackBoard site*



MemOrIO continued



```
assign addr_out= addr_in;  
// The data write to register file may be from memory or io.  
// While the data is from io, it should be the lower 16bit of r_wdata.  
assign r_wdata = ? ? ?
```

```
// Chip select signal of Led and Switch are all active high;  
assign LEDCtrl= ? ? ?  
assign SwitchCtrl= ? ? ?
```

```
always @* begin  
    if((mWrite==1)|| (ioWrite==1))  
        //write_data could go to either memory or IO. where is it from?  
        write_data = ? ? ?  
    else  
        write_data = 32'hZZZZZZZZ;  
end  
endmodule
```



The Function Verification of MemOrIO

// a reference for the testbench of MemOrIO

```
module MemOrIO_tb( );  
    reg mRead,mWrite,ioRead,ioWrite;  
    reg[31:0] addr_in,m_rdata,r_rdata;  
    reg[15:0] io_rdata;  
    wire LEDCtrl,SwitchCtrl;  
    wire [31:0] addr_out,r_wdata,write_data;  
  
    MemoryOrIO umio(addr_out, addr_in,  
        mRead, mWrite, ioRead, ioWrite,  
        m_rdata, io_rdata, r_rdata, r_wdata, write_data,  
        LEDCtrl, SwitchCtrl );
```



```
initial begin // r_rdata -> m_wdata(write_data)  
    m_rdata = 32'h0xffff_0001; io_rdata = 16'h0xffff; r_rdata = 32'h0x0f0f_0f0f; addr_in = 32'h4;{mRead,mWrite,ioRead,ioWrite}= 4'b01_00;  
    #10 addr_in = 32'hffff_fc60; {mRead,mWrite,ioRead,ioWrite}= 4'b00_01; // r_rdata -> io_wdata(write_data)  
    #10 addr_in = 32'h0000_0004; {mRead,mWrite,ioRead,ioWrite}= 4'b10_00; // m_rdata -> r_wdata  
    #10 addr_in = 32'hffff_fc70; {mRead,mWrite,ioRead,ioWrite}= 4'b00_10; // io_rdata -> r_wdata(write_data)  
    #10 $finish;  
    end  
endmodule
```



Controller+

Add new ports to Controller for IO reading and writing support.



```
module control32(Opcode,Function_opcode,Jr,Branch,nBranch,Jmp,Jal,
Alu_resultHigh,
RegDST,MemorIOtoReg,RegWrite,
MemRead,MemWrite,
IORead,IOWrite,
ALUSrc,ALUOp,Sftmd,I_format);
...
input[21:0] Alu_resultHigh; // From the execution unit Alu_Result[31..10]
output MemorIOtoReg; // 1 indicates that data needs to be read from memory or I/O to the register
output RegWrite; // 1 indicates that the instruction needs to write to the register
output MemRead; // 1 indicates that the instruction needs to read from the memory
output MemWrite; // 1 indicates that the instruction needs to write to the memory
output IORead; // 1 indicates I/O read
output IOWrite; // 1 indicates I/O write
...
```




Controller+ continued

- 1) **Modify** the logic of the '**MemWrite**'
- 2) **Add** '**MemRead**', '**IORead**' and '**IOWrite**' signals
- 3) **Change** '**MemtoReg**' to '**MemorIotoReg**'.

```
// The real address of LW and SW is Alu_Result, the signal comes from the execution unit
// From the execution unit Alu_Result[31..10], used to help determine whether to process Mem or IO
input[21:0] Alu_resultHigh;

output    MemorIotoReg;    //1 indicates that read data from memory or I/O to write to the register
output    MemRead;        // 1 indicates that reading from the memory to get data
output    IORead;         // 1 indicates I/O read
output    IOWrite;        // 1 indicates I/O write

assign RegWrite = (R_format || Lw || Jal || I_format) && !(Jr) ;    // Write memory or write IO
assign MemWrite = ((sw==1) && (Alu_resultHigh[21:0] != 22'h3FFFFFF)) ? 1'b1:1'b0;
assign MemRead = ? ? ?    // Read memory
assign IORead = ? ? ?    // Read input port
assign IOWrite = ? ? ?    // Write output port

// Read operations require reading data from memory or I/O to write to the register
assign MemorIotoReg = IORead || MemRead;
```



Practice

P1-1. Do the functional verification on the module `cpuclk`(which is introduced in the first part of this lab)

P1-2. Answer the Q2 on page 2 and Q1 on page 7 of this lab slides.

P2. Complete the following modules, do the function verification:

- 1. `MemoryOrIO`
- 2. `Controller+`
- 3. Single cycle CPU with I/O process

P3. Redesign and implement the solution about I/O data bus and I/O addressing that are suitable for your design. Build the single cycle CPU with the updated solution of I/O process and do the function verification.