Final Project – Progress Report 2

CS 385 – Computer Architecture

Daniel Kostecki, Thi Nguyen, and Sonia Leonato Soiras

**Tasks:**

Daniel Kostecki:

* Gate level conversions in the regfile
* Regfile implementation in project
* Report and adjusted diagrams
* Code comments
* Testing program

Thi Nguyen:

* 16-bit implementation of multiplexors using 4x1 mux
* Regfile D-flip-flops
* CPU module
* Main Control Unit
* I-type operations for Report 2
* Testing program

Sonia Leonato Soiras:

* ALU conversions to 16-bit
* Gate level conversions in the ALU (4x1 mux and 2x1 mux)
* Truth table
* Code debugging
* Testing program

**Descriptions:**

The instruction set architecture currently in place for our 16-bit machine allows for R-type and I-type instructions. The list of R-type instructions that are currently supported and their respective opcode are and(0000), sub(0001), add(0010), or(0011), and slt(0111). The opcodes of the I-type instructions are addi(0100), lw(0101), sw(0110), beq(1000), bne(1001).

R-type format: I-type format:

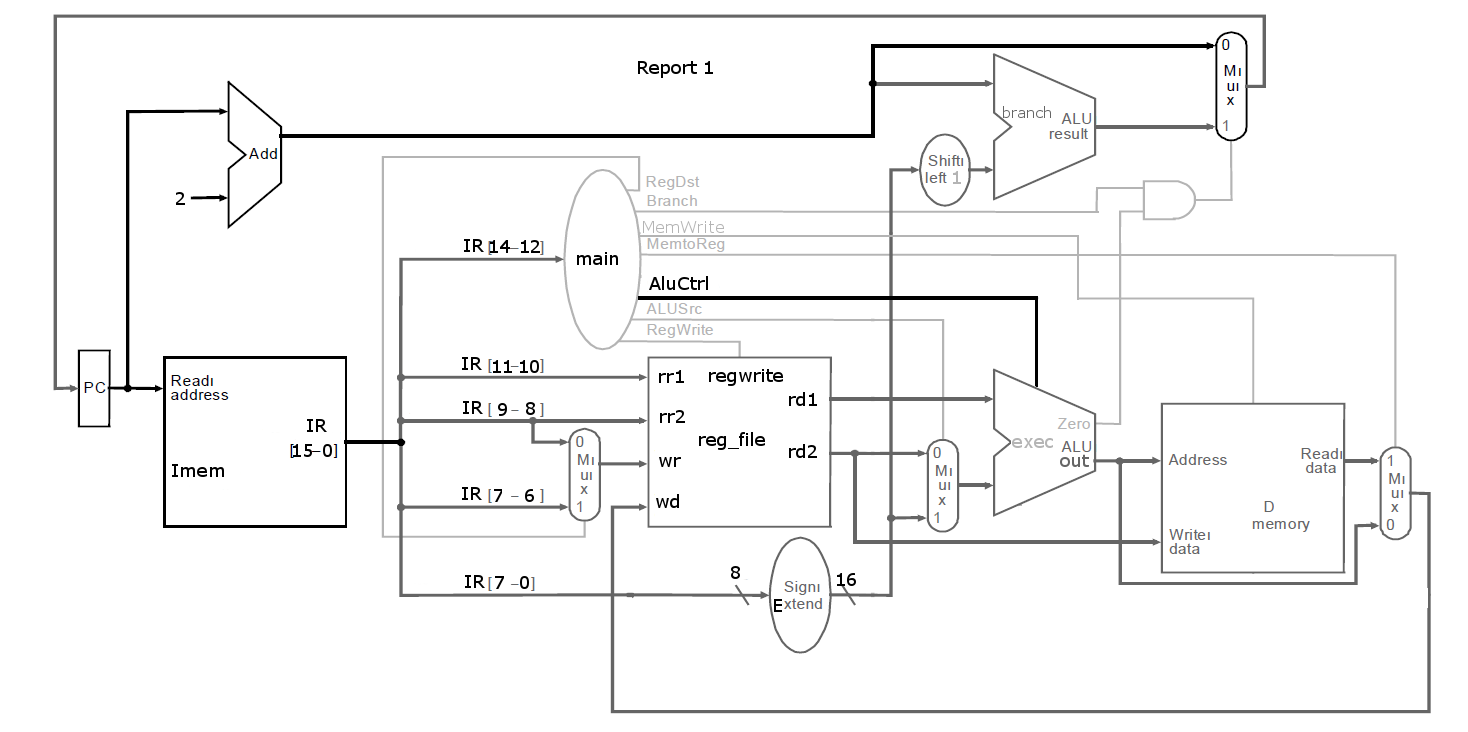
|  |  |  |  |
| --- | --- | --- | --- |
| Op | Rs | Rt | Address/Value |
| 4 | 2 | 2 | 8 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Op | Rs | Rt | Rd | Unused |
| 4 | 2 | 2 | 2 | 6 |

The format of the instructions is dependent on the type if instruction. For example, in the r-type format we first get the op code (listed above). This is followed by the two registers which are being used. The final register is the destination. Because we have a 4-bit opcode followed by 3 2-bit registers this leaves us with 6-bits at the end of every r-type that is unused. For the i-type format this changes. The op code is still 4-bit, and there are still two registers (rs being used and rt being destination) but this is followed by an 8-bit value or address.

**Logic Diagrams/Truth Tables:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Instr** | **RegDst** | **ALUSrc** | **MemReg** | **RegWrite** | **MemWrite** | **Branch** | **ALUCtrl** |
| **add** | 1 | 0 | 0 | 1 | 0 | 00 | 010 |
| **sub** | 1 | 0 | 0 | 1 | 0 | 00 | 110 |
| **and** | 1 | 0 | 0 | 1 | 0 | 00 | 000 |
| **or** | 1 | 0 | 0 | 1 | 0 | 00 | 001 |
| **slt** | 1 | 0 | 0 | 1 | 0 | 00 | 111 |
| **lw** | 0 | 1 | 1 | 1 | 0 | 00 | 010 |
| **sw** | 0 | 1 | 0 | 0 | 1 | 00 | 010 |
| **beq** | 0 | 0 | 0 | 0 | 0 | 01 | 110 |
| **bne** | 0 | 0 | 0 | 0 | 0 | 10 | 110 |
| **addi** | 0 | 1 | 0 | 1 | 0 | 00 | 010 |



**Verilog Code:**

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Class: CS 385

Progress Report 2 - Implementing a 16-bit MIPS machine in Verilog

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16-bit register file with input of read register 1(rr1),

read register 2 (rr2), write register (wr), write data (wd),

regwrite, and clock. The outputs are read data 1 (rd1),

and read data 2 (rd2). The register file relies on registers,

a 16 bit mux, and a decoder.

\*/

module reg\_file (rr1,rr2,wr,wd,regwrite,rd1,rd2,clock);

input [1:0] rr1,rr2,wr;

input [15:0] wd;

input regwrite,clock;

output [15:0] rd1,rd2;

wire [15:0] q1, q2, q3;

//registers

register r1 (wd,c1,q1),

r2 (wd,c2,q2),

r3 (wd,c3,q3);

//output port

mux4x1\_16bit mux1 (16'b0,q1,q2,q3,rr1,rd1),

mux2 (16'b0,q1,q2,q3,rr2,rd2);

//input port

decoder dec (wr[1],wr[0],w3,w2,w1,w0);

and a (regwrite\_and\_clock,regwrite,clock);

and a1 (c1,regwrite\_and\_clock,w1),

a2 (c2,regwrite\_and\_clock,w2),

a3 (c3,regwrite\_and\_clock,w3);

endmodule

// The register module is implemented using 16 D-flip-flops.

module register(D,CLK,Q);

input [15:0]D;

input CLK;

output [15:0]Q;

D\_flip\_flop d1 (D[0],CLK,Q[0]),

d2 (D[1],CLK,Q[1]),

d3 (D[2],CLK,Q[2]),

d4 (D[3],CLK,Q[3]),

d5 (D[4],CLK,Q[4]),

d6 (D[5],CLK,Q[5]),

d7 (D[6],CLK,Q[6]),

d8 (D[7],CLK,Q[7]),

d9 (D[8],CLK,Q[8]),

d10(D[9],CLK,Q[9]),

d11(D[10],CLK,Q[10]),

d12(D[11],CLK,Q[11]),

d13(D[12],CLK,Q[12]),

d14(D[13],CLK,Q[13]),

d15(D[14],CLK,Q[14]),

d16(D[15],CLK,Q[15]);

endmodule

// The D-flip-flop module implemented using d-latches.

module D\_flip\_flop (D,CLK,Q);

input D,CLK;

output Q;

wire CLK1, Y;

not not1 (CLK1,CLK);

D\_latch D1(D,CLK, Y),

D2(Y,CLK1,Q);

endmodule

// The d-latch module.

module D\_latch (D,C,Q);

input D,C;

output Q;

wire x,y,D1,Q1;

nand nand1 (x,D, C),

nand2 (y,D1,C),

nand3 (Q,x,Q1),

nand4 (Q1,y,Q);

not not1 (D1,D);

endmodule

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The 16-bit ALU which takes an operation (op) input as well as

an 'a' and 'b' input. What is returned is reult which is sent

to the write data (wd) of the register file, and zero.

\*/

module ALU (op,a,b,result,zero);

input [15:0] a;

input [15:0] b;

input [2:0] op;

output [15:0] result;

output zero;

wire c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,c11,c12,c13,c14,c15,c16;

ALU1 alu0 (a[0],b[0],op[2],op[1:0],set,op[2],c1,result[0]);

ALU1 alu1 (a[1],b[1],op[2],op[1:0],0,c1,c2,result[1]);

ALU1 alu2 (a[2],b[2],op[2],op[1:0],0,c2,c3,result[2]);

ALU1 alu3 (a[3],b[3],op[2],op[1:0],0,c3,c4,result[3]);

ALU1 alu4 (a[4],b[4],op[2],op[1:0],0,c4,c5,result[4]);

ALU1 alu5 (a[5],b[5],op[2],op[1:0],0,c5,c6,result[5]);

ALU1 alu6 (a[6],b[6],op[2],op[1:0],0,c6,c7,result[6]);

ALU1 alu7 (a[7],b[7],op[2],op[1:0],0,c7,c8,result[7]);

ALU1 alu8 (a[8],b[8],op[2],op[1:0],0,c8,c9,result[8]);

ALU1 alu9 (a[9],b[9],op[2],op[1:0],0,c9,c10,result[9]);

ALU1 alu10(a[10],b[10],op[2],op[1:0],0,c10,c11,result[10]);

ALU1 alu11(a[11],b[11],op[2],op[1:0],0,c11,c12,result[11]);

ALU1 alu12(a[12],b[12],op[2],op[1:0],0,c12,c13,result[12]);

ALU1 alu13(a[13],b[13],op[2],op[1:0],0,c13,c14,result[13]);

ALU1 alu14(a[14],b[14],op[2],op[1:0],0,c14,c15,result[14]);

ALUmsb alu15(a[15],b[15],op[2],op[1:0],0,c15,c16,result[15],set);

// If result = 0 then zero = 1

check\_zero cz(zero,result);

endmodule

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1-bit ALU used to handle bits 0-14 (least significant bits) using a

2x1 and 4x1 multiplexor as well as a full adder.

\*/

module ALU1 (a,b,binvert,op,less,carryin,carryout,result);

input a,b,less,carryin,binvert;

input [1:0] op;

output carryout,result;

wire sum, a\_and\_b, a\_or\_b, b\_inv;

not not1(b\_inv, b);

mux2x1 mux1(b,b\_inv,binvert,b1);

and and1(a\_and\_b, a, b);

or or1(a\_or\_b, a, b);

fulladder adder1(sum,carryout,a,b1,carryin);

mux4x1 mux2(a\_and\_b,a\_or\_b,sum,less,op[1:0],result);

endmodule

/\*

1-bit ALU used to handle bit 15 (the most significant bit)

using a 2x1 and 4x1 multiplexor as well as a full adder.

\*/

module ALUmsb (a,b,binvert,op,less,carryin,carryout,result,sum);

input a,b,less,carryin,binvert;

input [1:0] op;

output carryout,result,sum;

wire sum, a\_and\_b, a\_or\_b, b\_inv;

not not1(b\_inv, b);

mux2x1 mux1(b,b\_inv,binvert,b1);

and and1(a\_and\_b, a, b);

or or1(a\_or\_b, a, b);

fulladder adder1(sum,carryout,a,b1,carryin);

mux4x1 mux2(a\_and\_b,a\_or\_b,sum,less,op[1:0],result);

endmodule

// Module to check zero returned by the ALU

module check\_zero (zero,result);

input [15:0] result;

wire z[14:0];

output zero;

or g5(z[0],result[0],result[1]);

or g6(z[1],result[2],result[3]);

or g7(z[2],result[4],result[5]);

or g8(z[3],result[6],result[7]);

or g9(z[4],result[8],result[9]);

or g1(z[5],result[10],result[11]);

or g2(z[6],result[12],result[13]);

or g3(z[7],result[14],result[15]);

or g4(z[8],z[0],z[1]);

or g10(z[9],z[2],z[3]);

or g11(z[10],z[4],z[5]);

or g12(z[11],z[6],z[7]);

or g13(z[12],z[8],z[9]);

or g14(z[13],z[10],z[11]);

or g15(z[14],z[12],z[13]);

xnor g8(zero,z[14],0);

endmodule

// Half adder module used twice in the implementation of the full adder.

module halfadder (S,C,x,y);

input x,y;

output S,C;

xor (S,x,y);

and (C,x,y);

endmodule

// Full adder module using two half adders.

module fulladder (S,C,x,y,z);

input x,y,z;

output S,C;

wire S1,D1,D2;

halfadder HA1 (S1,D1,x,y),

HA2 (S,D2,S1,z);

or g1(C,D2,D1);

endmodule

// 4x1 multiplexor module.

module mux4x1 (a\_and\_b, a\_or\_b,sum, less, op[1:0], result);

input a\_and\_b,a\_or\_b,sum,less;

input [1:0] op;

wire a,b,c,d,notOp0,notOp1;

output result;

not g1(notOp0,op[0]); // S0

not g2(notOp1,op[1]); // S1

and g3(a,a\_and\_b,notOp1,notOp0), // AND operation - 00

g4(b,a\_or\_b,notOp1,op[0]), // OR operation - 01

g5(c,sum,op[1],notOp0), // ADD operation - 10

g6(d,less,op[1],op[0]); // SLT operation - 11

or g7(result,a,b,c,d);

endmodule

// 16-bit 4x1 multiplexor module.

module mux4x1\_16bit (i0,i1,i2,i3,select,y);

input [15:0] i0,i1,i2,i3;

input [1:0] select;

output [15:0] y;

mux4x1 m1(i0[0], i1[0], i2[0], i3[0], select,y[0]);

mux4x1 m2(i0[1], i1[1], i2[1], i3[1], select,y[1]);

mux4x1 m3(i0[2], i1[2], i2[2], i3[2], select,y[2]);

mux4x1 m4(i0[3], i1[3], i2[3], i3[3], select,y[3]);

mux4x1 m5(i0[4], i1[4], i2[4], i3[4], select,y[4]);

mux4x1 m6(i0[5], i1[5], i2[5], i3[5], select,y[5]);

mux4x1 m7(i0[6], i1[6], i2[6], i3[6], select,y[6]);

mux4x1 m8(i0[7], i1[7], i2[7], i3[7], select,y[7]);

mux4x1 m9(i0[8], i1[8], i2[8], i3[8], select,y[8]);

mux4x1 m10(i0[9], i1[9], i2[9], i3[9], select,y[9]);

mux4x1 m11(i0[10],i1[10],i2[10],i3[10], select,y[10]);

mux4x1 m12(i0[11],i1[11],i2[11],i3[11],select,y[11]);

mux4x1 m13(i0[12],i1[12],i2[12],i3[12],select,y[12]);

mux4x1 m14(i0[13],i1[13],i2[13],i3[13],select,y[13]);

mux4x1 m15(i0[14],i1[14],i2[14],i3[14],select,y[14]);

mux4x1 m16(i0[15],i1[15],i2[15],i3[15],select,y[15]);

endmodule

// 2x1 multiplexor module.

module mux2x1 (A,B,select,OUT);

input A,B,select;

output OUT;

wire notS,andA,andB;

not g1(notS,select);

and g2(andA,A,notS),

g3(andB,B,select);

or g4(OUT,andA,andB);

endmodule

// 2-bit 2x1 multiplexor module.

module mux2x1\_2bit (A,B,select,y);

input [1:0] A,B;

input select;

output [1:0] y;

mux2x1 mux1(A[0], B[0], select, y[0]),

mux2(A[1], B[1], select, y[1]);

endmodule

// 16-bit 2x1 multiplexor module.

module mux2x1\_16bit (A, B, select, y);

input [15:0] A,B;

input select;

output [15:0] y;

mux2x1 mux1(A[0], B[0], select, y[0]),

mux2(A[1], B[1], select, y[1]),

mux3(A[2], B[2], select, y[2]),

mux4(A[3], B[3], select, y[3]),

mux5(A[4], B[4], select, y[4]),

mux6(A[5], B[5], select, y[5]),

mux7(A[6], B[6], select, y[6]),

mux8(A[7], B[7], select, y[7]),

mux9(A[8], B[8], select, y[8]),

mux10(A[9], B[9], select, y[9]),

mux11(A[10], B[10], select, y[10]),

mux12(A[11], B[11], select, y[11]),

mux13(A[12], B[12], select, y[12]),

mux14(A[13], B[13], select, y[13]),

mux15(A[14], B[14], select, y[14]),

mux16(A[15], B[15], select, y[15]);

endmodule

// Decoder module.

module decoder (S1,S0,D3,D2,D1,D0);

input S0,S1;

output D0,D1,D2,D3;

not n1 (notS0,S0),

n2 (notS1,S1);

and a0 (D0,notS1,notS0),

a1 (D1,notS1, S0),

a2 (D2, S1,notS0),

a3 (D3, S1, S0);

endmodule

// #### Branch Control ####

module BranchCtrl(Op, Zero, Out);

input [1:0] Op;

input Zero;

output Out;

wire pZero, i0,i1;

not n(pZero, Zero);

and a1(i0, Op[0], Zero),

a2(i1, Op[1], pZero);

or o(Out,i0,i1);

endmodule

// Main Control Unit module.

module MainControl (op,control);

input [3:0] op;

output reg [9:0] control;

//Control is in the format of: RegDst, AluSrc, MemtoReg, RegWrite, MemWrite, Branch, AluCtrl

always @(op) case (op)

//R-types

4'b0000: control <= 10'b1001000010; // ADD

4'b0001: control <= 10'b1001000110; // SUB

4'b0010: control <= 10'b1001000000; // AND

4'b0011: control <= 10'b1001000001; // OR

4'b0111: control <= 10'b1001000111; // SLT

//I-type

4'b0100: control <= 10'b0101000010; // ADDI

4'b0101: control <= 10'b0111000010; // LW (added for report 2)

4'b0110: control <= 10'b0100100010; // SW (added for report 2)

4'b1000: control <= 10'b0000001110; // BEQ (added for report 2)

4'b1001: control <= 10'b0000010110; // BNE (added for report 2)

endcase

endmodule

/\*

CPU module which implements the other major components (ALU, Register,

and control unit).

\*/

module CPU (clk, WD, IR);

input clk;

output [15:0] AluOut, IR, WD;

reg[15:0] PC;

reg[15:0] Imem[0:1023], DMemory[0:1023];

wire [15:0] IR, NextPC, A, B, AluOut, RD2, SignExtend, PC2, Target;

wire [2:0] AluCtrl;

wire [1:0] WR, Branch;

//To test

initial begin

//r-type = op(4),rs(2), rt(2), rd(2), unused(6)

//i-type = op(4), rs(2), rt(2), address/value(8)

//#### not finished. missing add and bne

Imem[0] = 16'b0101000100000000; // lw $1, 0($0) #$1 = DMemory[0]

Imem[1] = 16'b0101001000000010; // lw $2, 2($0) #$2 = DMemory[1]

Imem[2] = 16'b0111011011000000; // slt $3, $1, $2 #$3 = 1 if less than

Imem[3] = 16'b1000110000001000; // beq $3, $0, 4 #not taken

Imem[4] = 16'b0110000100000010; // sw $1, 2($0) #store $1 into DMemory[1]

Imem[5] = 16'b0110001000000000; // sw $2, 0($0) #store $2 into DMemory[0]

Imem[6] = 16'b0101000100000000; // lw $1, 0($0) #$1 = DMemory[0]

Imem[7] = 16'b0101001000000010; // lw $2, 2($0) #$2 = DMemory[1]

Imem[8] = 16'b0001011001000000; // sub $1, $1, $2 #$1 = $1 - $2

Imem[9] = 16'b0100010100000100; // addi $1, $1, 4 #$1 = $1 + 4

Imem[10]= 16'b1001011011111100; // bne $1, $2, -5 #taken first loop, not taken second

Imem[11]= 16'b1000011000000010; // beq $1, $2, 1 #branch over

Imem[12]= 16'b0000010101000000; // add $1, $1, $1 #skip

// Data

DMemory[0] = 16'h5;

DMemory[1] = 16'h7;

end

initial PC = 0;

assign IR = Imem[PC>>1];

mux2x1\_2bit muxWR (IR[9:8], IR[7:6], RegDst, WR);

mux2x1\_16bit muxB (RD2, SignExtend, AluSrc, B);

assign SignExtend = {{8{IR[7]}},IR[7:0]};

reg\_file rf (IR[11:10], IR[9:8], WR, WD, RegWrite, A, RD2, clk);

ALU fetch (3'b010, PC, 16'b10, PC2, Unused);

ALU exec (AluCtrl, A, B, AluOut, Zero);

//#### Added for branching for r2 ####

ALU branch (3'b010, SignExtend<<1, PC2, Target, Unused);

//####### Made changes for report 2 #######

MainControl main (IR[15:12], {RegDst, AluSrc, MemReg, RegWrite, MemWrite, Branch, AluCtrl});

//#### Added for r2 ####

mux2x1\_16bit MemRegs (AluOut, DMemory[AluOut>>1], MemReg, WD);

BranchCtrl BranchControl (Branch, Zero, BCtrlOut);

mux2x1\_16bit muxBranch (PC2, Target, BCtrlOut, NextPC);

// Program counter

always @(negedge clk) begin

PC <= NextPC;

if (MemWrite) DMemory[AluOut>>1] <= RD2; //#### Added for r2 #####

end

endmodule

// Test module using the CPU.

module testing ();

reg clock;

wire [15:0] WD,IR;

CPU test\_cpu(clock,WD,IR);

always #1 clock = ~clock;

//test program

initial begin

$display ("Time Clock IR WD");

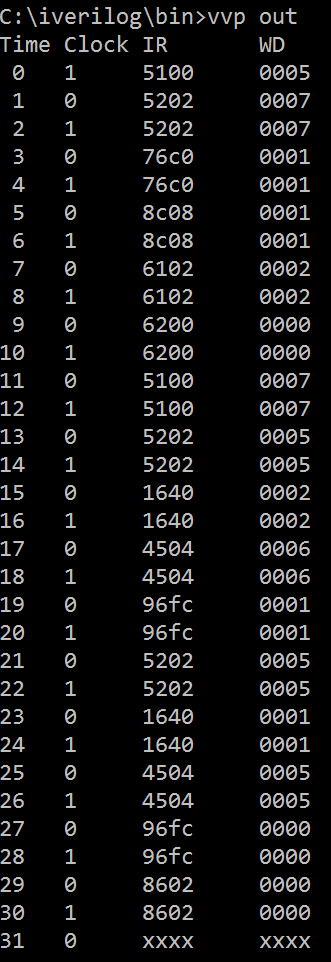
$monitor ("%2d %b %h %h", $time,clock,IR,WD);

clock = 1;

#31 $finish;

End

endmodule

**Test results**