

Number Systems

System	Value	-x	Negation	Addition	Overflow
Sign & Magnitude			Invert first bit		
1s Complement	+ve: same as 2s -ve: 2s + 1	$2^n - x - 1$	Invert all bits	Ignore MSB carry out	MSB carry in != MSB carry out Result opposite sign of A and B
2s Complement	if $x[n-1]: -= 2^{(n-1)}$ for i in $[n-2..0]$: if $x[i]: += 2^i$	$2^n - x$	Invert all bits + 1	If MSB carry out: +=1	Result opposite sign of A and B
Excess-n	x-n				
IEEE 754	(Sign) (1.Mantissa) x 2^{Exponent}		Invert first bit	1: Sign 8: Ex-127 Exp	--- 23: Mantissa

MIPS

Operation	RR1	RR2	WR	WD	Opr1	Opr2	Address	Write Data
lw \$a, x(\$b)	\$b	\$a	\$a	Mem([\$b] + x)	\$b	x	\$b + x	\$a
beq \$a,\$b, immd	\$a	\$b	\$b	?	\$a	\$b	\$a - \$b	\$b
sub \$a, \$b, \$c	\$b	\$c	\$a	\$b - \$c	\$b	\$c	\$b - \$c	\$c
addi \$a, \$b, immd	\$b	\$a	\$a	\$b + immd	\$b	immd	\$b + immd	\$a

MIPS Reference Data

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CORE INSTRUCTION SET

NAME, MNEMONIC	FOR-MAT	OPERATION (in Verilog)	OPCODE / FUNCT (Hex)
Add	add R	$R[rd] = R[rs] + R[rt]$	(1) 0/20 _{hex}
Add Immediate	addi I	$R[rt] = R[rs] + \text{SignExtImm}$	(1,2) 8 _{hex}
Add Imm. Unsigned	addiu I	$R[rt] = R[rs] + \text{SignExtImm}$	(2) 9 _{hex}
Add Unsigned	addu R	$R[rd] = R[rs] + R[rt]$	0/21 _{hex}
And	and R	$R[rd] = R[rs] \& R[rt]$	0/24 _{hex}
And Immediate	andi I	$R[rt] = R[rs] \& \text{ZeroExtImm}$	(3) c _{hex}
Branch On Equal	beq I	if($R[rs] == R[rt]$) $PC = PC + 4 + \text{BranchAddr}$	(4) 4 _{hex}
Branch On Not Equal	bne I	if($R[rs] != R[rt]$) $PC = PC + 4 + \text{BranchAddr}$	(4) 5 _{hex}
Jump	j J	$PC = \text{JumpAddr}$	(5) 2 _{hex}
Jump And Link	jal J	$R[31] = PC + 8; PC = \text{JumpAddr}$	(5) 3 _{hex}
Jump Register	jr R	$PC = R[rs]$	0/08 _{hex}
Load Byte Unsigned	lbu I	$R[rt] = \{24'b0, M[R[rs]](7:0) + \text{SignExtImm}\}$	(2) 24 _{hex}
Load Halfword Unsigned	lhu I	$R[rt] = \{16'b0, M[R[rs]](15:0) + \text{SignExtImm}\}$	(2) 25 _{hex}
Load Linked	ll I	$R[rt] = M[R[rs] + \text{SignExtImm}]$	(2,7) 30 _{hex}
Load Upper Imm.	lui I	$R[rt] = \{\text{imm}, 16'b0\}$	f _{hex}
Load Word	lw I	$R[rt] = M[R[rs] + \text{SignExtImm}]$	(2) 23 _{hex}
Nor	nor R	$R[rd] = \sim (R[rs] R[rt])$	0/27 _{hex}
Or	or R	$R[rd] = R[rs] R[rt]$	0/25 _{hex}
Or Immediate	ori I	$R[rt] = R[rs] \text{ZeroExtImm}$	(3) d _{hex}
Set Less Than	slt R	$R[rd] = (R[rs] < R[rt]) ? 1 : 0$	0/2a _{hex}
Set Less Than Imm.	slti I	$R[rt] = (R[rs] < \text{SignExtImm}) ? 1 : 0$	a _{hex}
Set Less Than Imm. Unsigned	sltiu I	$R[rt] = (R[rs] < \text{SignExtImm}) ? 1 : 0$	(2,6) b _{hex}
Set Less Than Unsig.	sltu R	$R[rd] = (R[rs] < R[rt]) ? 1 : 0$	(6) 0/2b _{hex}
Shift Left Logical	sll R	$R[rd] = R[rt] \ll \text{shamt}$	0/00 _{hex}
Shift Right Logical	srl R	$R[rd] = R[rt] \gg \text{shamt}$	0/02 _{hex}
Store Byte	sb I	$M[R[rs] + \text{SignExtImm}](7:0) = R[rt](7:0)$	(2) 28 _{hex}
Store Conditional	sc I	$M[R[rs] + \text{SignExtImm}] = R[rt];$ $R[rt] = (\text{atomic}) ? 1 : 0$	(2,7) 38 _{hex}
Store Halfword	sh I	$M[R[rs] + \text{SignExtImm}](15:0) = R[rt](15:0)$	(2) 29 _{hex}
Store Word	sw I	$M[R[rs] + \text{SignExtImm}] = R[rt]$	(2) 2b _{hex}
Subtract	sub R	$R[rd] = R[rs] - R[rt]$	(1) 0/22 _{hex}
Subtract Unsigned	subu R	$R[rd] = R[rs] - R[rt]$	0/23 _{hex}

- (1) May cause overflow exception
- (2) $\text{SignExtImm} = \{16\{\text{immediate}[15]\}, \text{immediate}\}$
- (3) $\text{ZeroExtImm} = \{16\{1'b0\}, \text{immediate}\}$
- (4) $\text{BranchAddr} = \{14\{\text{immediate}[15]\}, \text{immediate}, 2'b0\}$
- (5) $\text{JumpAddr} = \{PC + 4[31:28], \text{address}, 2'b0\}$
- (6) Operands considered unsigned numbers (vs. 2's comp.)
- (7) Atomic test&set pair; $R[rt] = 1$ if pair atomic, 0 if not atomic

BASIC INSTRUCTION FORMATS

R	opcode	rs	rt	rd	shamt	funct
	31 26 25	21 20	16 15	11 10	6 5	0
I	opcode	rs	rt	immediate		
	31 26 25	21 20	16 15	0		
J	opcode	address				
	31 26 25	0				

ARITHMETIC CORE INSTRUCTION SET

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OPCODE / FMT / FT / FUNCT (Hex)

NAME, MNEMONIC	FOR-MAT	OPERATION	OPCODE / FMT / FT / FUNCT (Hex)
Branch On FP True	bclt FI	if(FPcond) $PC = PC + 4 + \text{BranchAddr}$	(4) 11/8/1/--
Branch On FP False	bclt FI	if(!FPcond) $PC = PC + 4 + \text{BranchAddr}$	(4) 11/8/0/--
Divide	div R	$Lo = R[rs]/R[rt]; Hi = R[rs]\%R[rt]$	0/--/--1a
Divide Unsigned	divu R	$Lo = R[rs]/R[rt]; Hi = R[rs]\%R[rt]$	(6) 0/--/--1b
FP Add Single	add.s FR	$F[fd] = F[fs] + F[ft]$	11/10/--/0
FP Add Double	add.d FR	$\{F[fd], F[fd+1]\} = \{F[fs], F[fs+1]\} + \{F[ft], F[ft+1]\}$	11/11/--/0
FP Compare Single	c.x.s* FR	$FPcond = (F[fs] \text{ op } F[ft]) ? 1 : 0$	11/10/--/y
FP Compare Double	c.x.d* FR	$FPcond = (\{F[fs], F[fs+1]\} \text{ op } \{F[ft], F[ft+1]\}) ? 1 : 0$	11/11/--/y
* (x is eq, lt, or le) (op is ==, <, or <=) (y is 32, 3c, or 3e)			
FP Divide Single	div.s FR	$F[fd] = F[fs] / F[ft]$	11/10/--/3
FP Divide Double	div.d FR	$\{F[fd], F[fd+1]\} = \{F[fs], F[fs+1]\} / \{F[ft], F[ft+1]\}$	11/11/--/3
FP Multiply Single	mul.s FR	$F[fd] = F[fs] * F[ft]$	11/10/--/2
FP Multiply Double	mul.d FR	$\{F[fd], F[fd+1]\} = \{F[fs], F[fs+1]\} * \{F[ft], F[ft+1]\}$	11/11/--/2
FP Subtract Single	sub.s FR	$F[fd] = F[fs] - F[ft]$	11/10/--/1
FP Subtract Double	sub.d FR	$\{F[fd], F[fd+1]\} = \{F[fs], F[fs+1]\} - \{F[ft], F[ft+1]\}$	11/11/--/1
Load FP Single	lwc1 I	$F[rt] = M[R[rs] + \text{SignExtImm}]$	(2) 31/--/--
Load FP Double	ldc1 I	$F[rt] = M[R[rs] + \text{SignExtImm}];$ $F[rt+1] = M[R[rs] + \text{SignExtImm} + 4]$	(2) 35/--/--
Move From Hi	mfmhi R	$R[rd] = Hi$	0/--/--/10
Move From Lo	mfmlo R	$R[rd] = Lo$	0/--/--/12
Move From Control	mfc0 R	$R[rd] = CR[rs]$	10/0/--/0
Multiply	mult R	$\{Hi, Lo\} = R[rs] * R[rt]$	0/--/--/18
Multiply Unsigned	multu R	$\{Hi, Lo\} = R[rs] * R[rt]$	(6) 0/--/--/19
Shift Right Arith.	sra R	$R[rd] = R[rt] \gg \text{shamt}$	0/--/--/3
Store FP Single	swc1 I	$M[R[rs] + \text{SignExtImm}] = F[rt]$	(2) 39/--/--
Store FP Double	sdc1 I	$M[R[rs] + \text{SignExtImm}] = F[rt];$ $M[R[rs] + \text{SignExtImm} + 4] = F[rt+1]$	(2) 3d/--/--

FLOATING-POINT INSTRUCTION FORMATS

FR	opcode	fnt	ft	fs	fd	funct
	31	26 25	21 20	16 15	11 10	6 5
FI	opcode	fnt	ft	immediate		
	31	26 25	21 20	16 15		

PSEUDOINSTRUCTION SET

NAME	MNEMONIC	OPERATION
Branch Less Than	blt	if($R[rs] < R[rt]$) $PC = \text{Label}$
Branch Greater Than	bgt	if($R[rs] > R[rt]$) $PC = \text{Label}$
Branch Less Than or Equal	bte	if($R[rs] \leq R[rt]$) $PC = \text{Label}$
Branch Greater Than or Equal	bge	if($R[rs] \geq R[rt]$) $PC = \text{Label}$
Load Immediate	li	$R[rd] = \text{immediate}$
Move	move	$R[rd] = R[rs]$

REGISTER NAME, NUMBER, USE, CALL CONVENTION

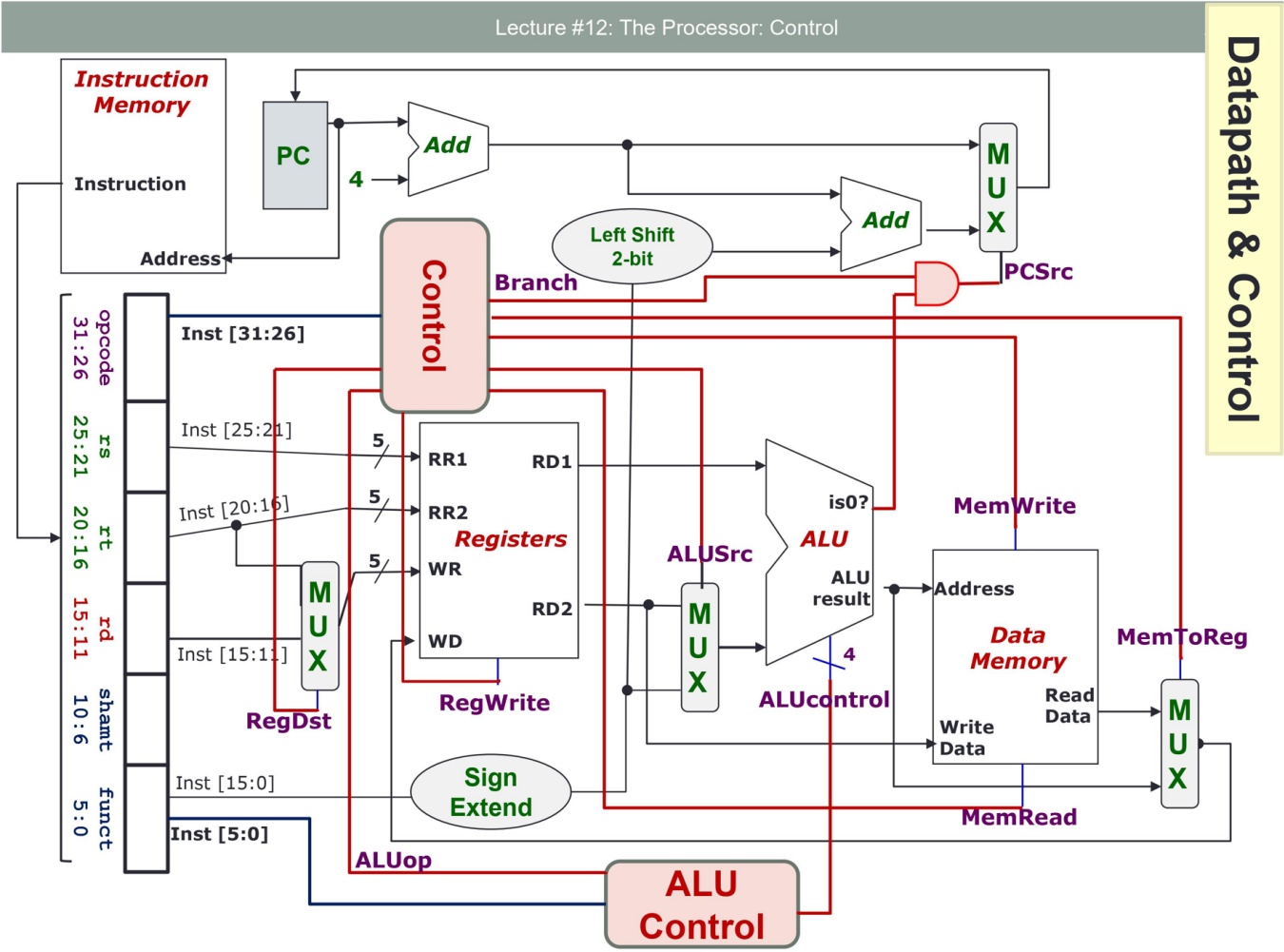
NAME	NUMBER	USE	PRESERVED ACROSS A CALL?
\$zero	0	The Constant Value 0	N.A.
\$at	1	Assembler Temporary	No
\$v0-\$v1	2-3	Values for Function Results and Expression Evaluation	No
\$a0-\$a3	4-7	Arguments	No
\$t0-\$t7	8-15	Temporaries	No
\$s0-\$s7	16-23	Saved Temporaries	Yes
\$t8-\$t9	24-25	Temporaries	No
\$k0-\$k1	26-27	Reserved for OS Kernel	No
\$gp	28	Global Pointer	Yes
\$sp	29	Stack Pointer	Yes
\$fp	30	Frame Pointer	Yes
\$ra	31	Return Address	Yes

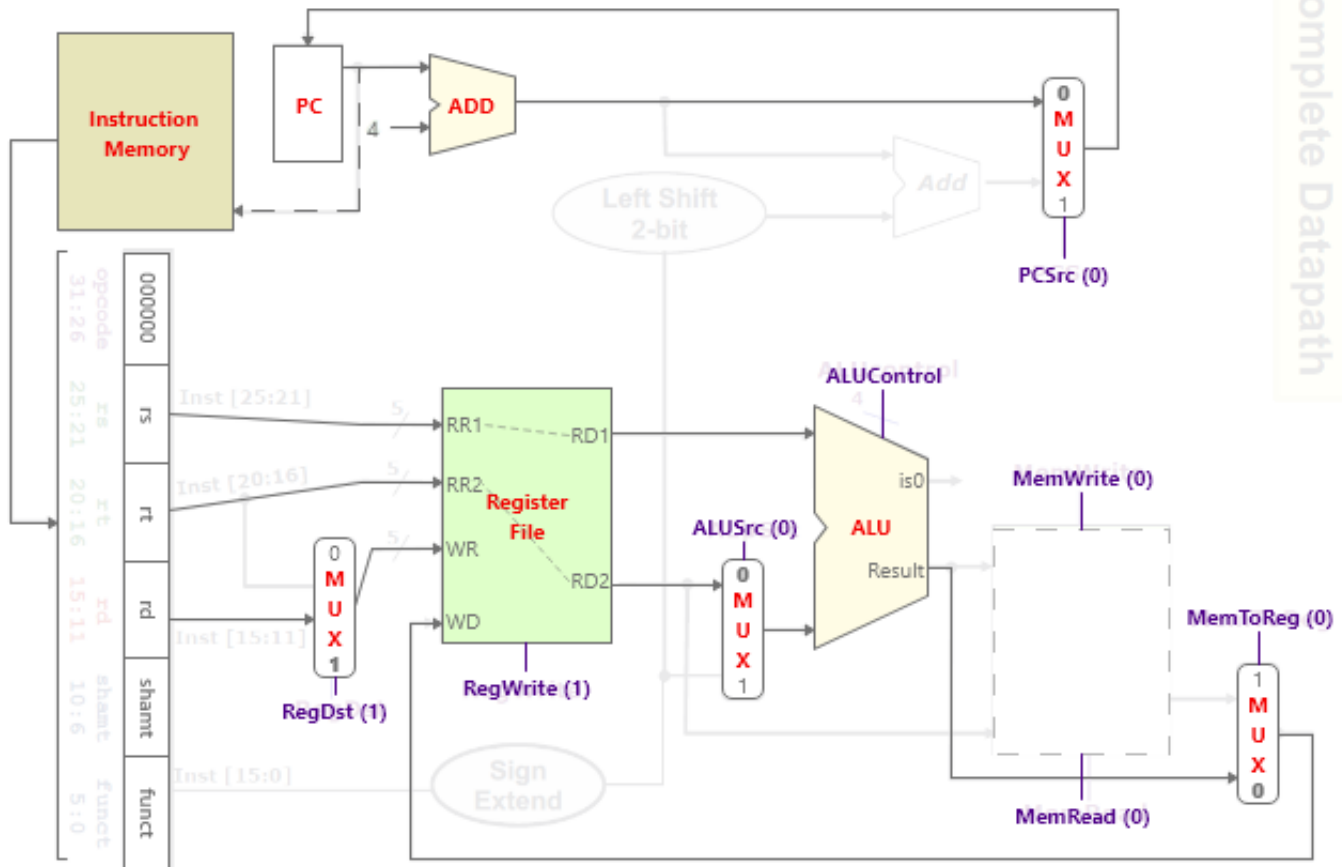
Control Design: Outputs

	RegDst	ALUSrc	MemTo Reg	Reg Write	Mem Read	Mem Write	Branch	ALUop	
								op1	op0
R-type	1	0	0	1	0	0	0	1	0
lw	0	1	1	1	1	0	0	0	0
sw	X	1	X	0	0	1	0	0	0
beq	X	0	X	0	0	0	1	0	1

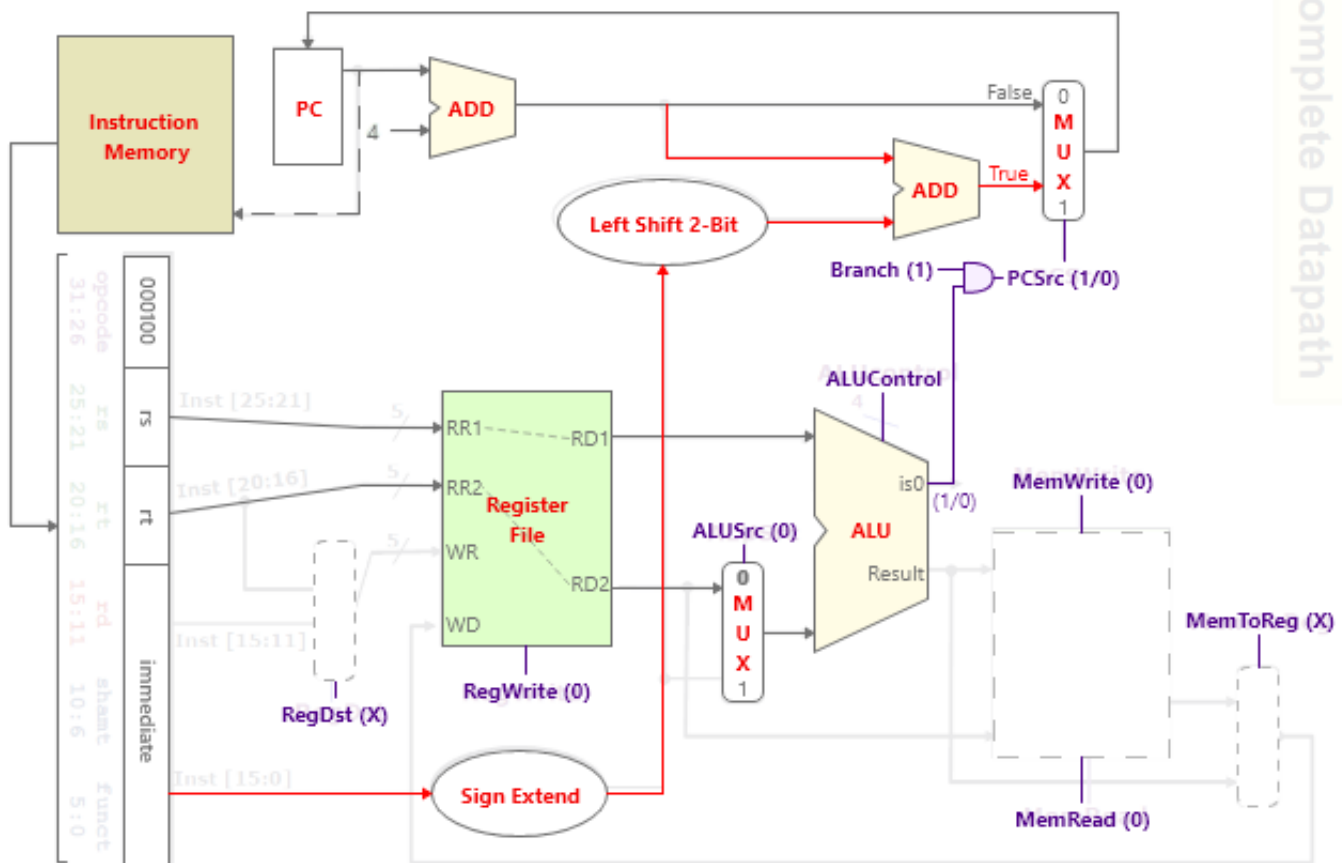
Control Design: Inputs

	Opcode (Op[5:0] == Inst[31:26])						
	Op5	Op4	Op3	Op2	Op1	Op0	Value in Hexadecimal
R-type	0	0	0	0	0	0	0
lw	1	0	0	0	1	1	23
sw	1	0	1	0	1	1	2B
beq	0	0	0	1	0	0	4

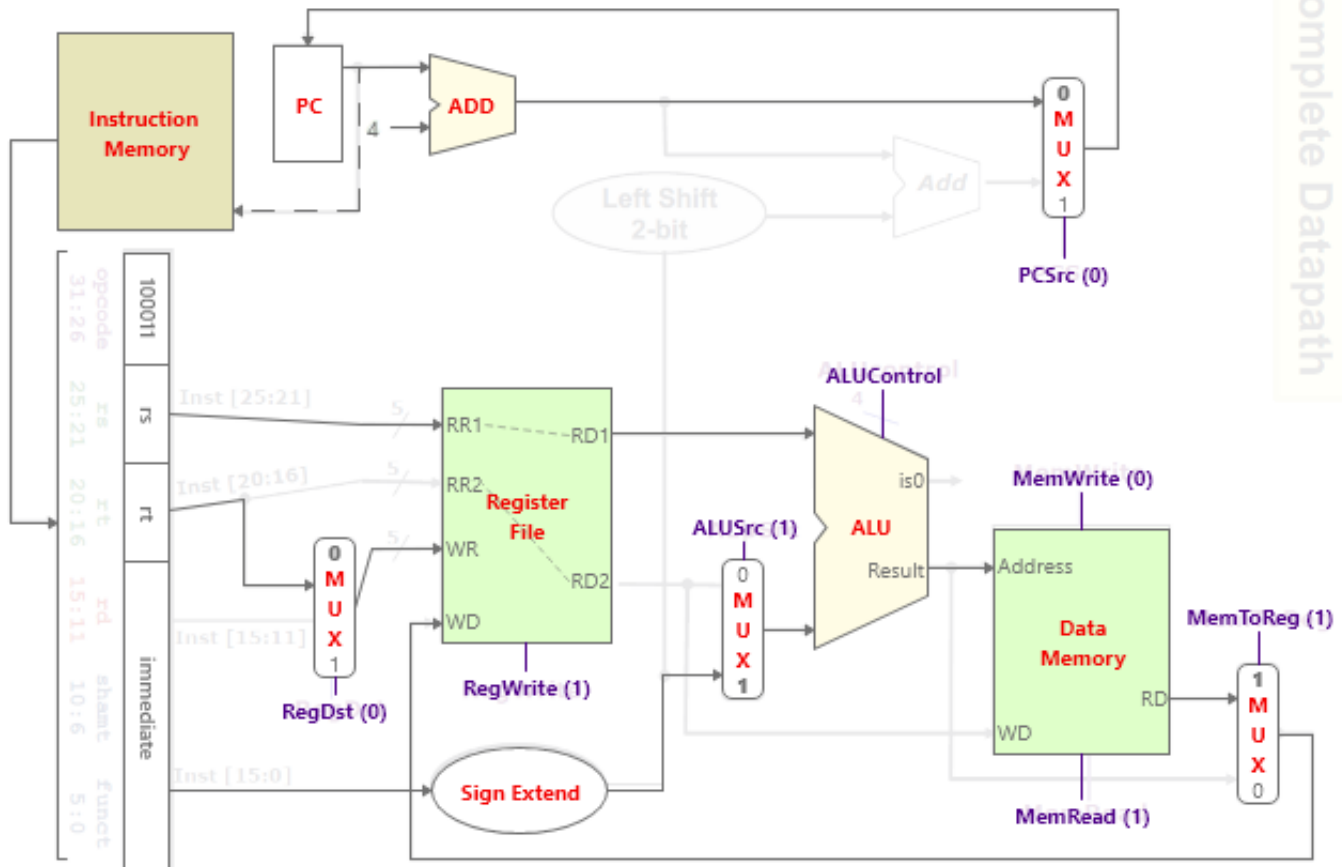




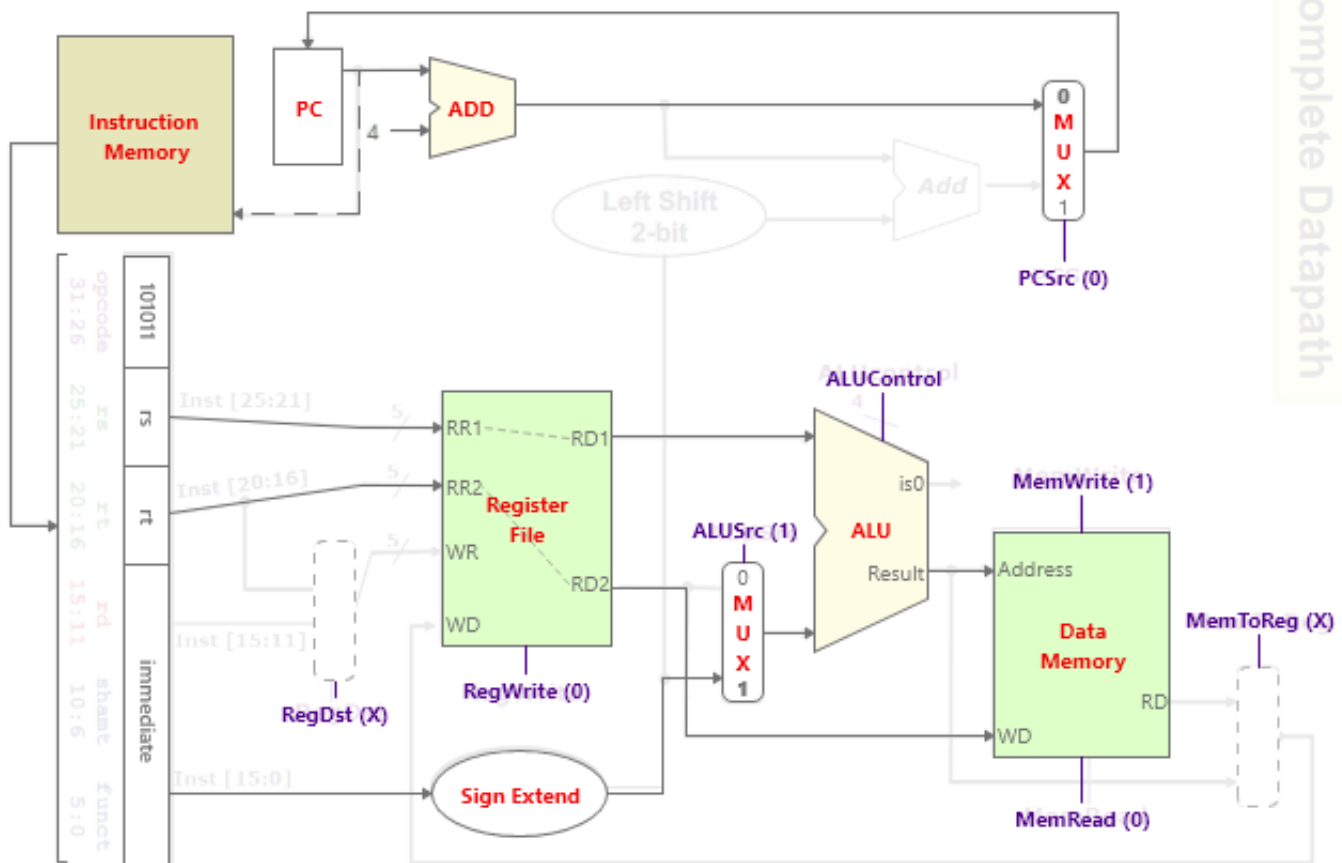
Add



BEQ



Load Word



Store Word

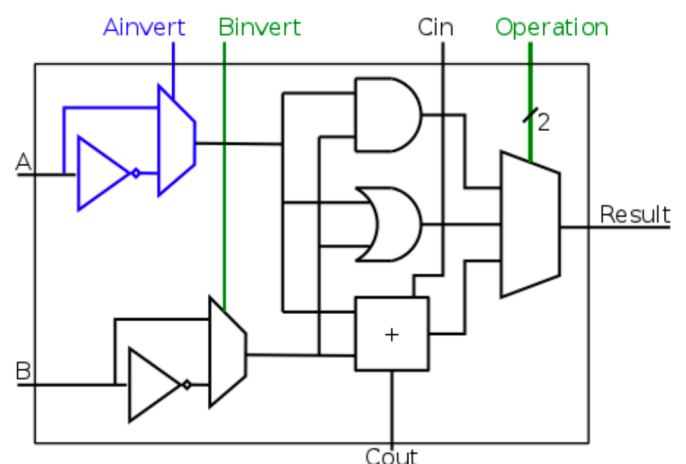
Opcode	ALUop	Instruction Operation	Func field	ALU action	ALU control
lw	00	load word	xxxxxx	add	0010
sw	00	store word	xxxxxx	add	0010
beq	01	branch equal	xxxxxx	subtract	0110
R-type	10	add	10 0000	add	0010
R-type	10	subtract	10 0010	subtract	0110
R-type	10	AND	10 0100	AND	0000
R-type	10	OR	10 0101	OR	0001
R-type	10	set on less than	10 1010	set on less than	0111

Instruction Type	ALUop
lw / sw	00
beq	01
R-type	10

ALUcontrol	Function
0000	AND
0001	OR
0010	add
0110	subtract
0111	slt
1100	NOR

Generation of 2-bit **ALUop** signal will be discussed later

ALUcontrol			Function
Ainvert	Binvert	Operation	
0	0	00	AND
0	0	01	OR
0	0	10	add
0	1	10	subtract
0	1	11	slt
1	1	00	NOR



Links

[Hexadecimal to Float](#)

[Hexadecimal-Binary-Decimal](#)

[XOR](#)

[Bitwise Calculator](#)

[Instructions to Hexadecimal](#)