

CS 61C Reference Card

Version 5.0.2

	Instruction	Name	Description	Type	Opcode	Funct3	Funct7
Arithmetic	add rd rs1 rs2	ADD	$R[rd] = R[rs1] + R[rs2]$	R	011 0011	000	000 0000
	sub rd rs1 rs2	SUBtract	$R[rd] = R[rs1] - R[rs2]$	R	011 0011	000	010 0000
	and rd rs1 rs2	bitwise AND	$R[rd] = R[rs1] \& R[rs2]$	R	011 0011	111	000 0000
	or rd rs1 rs2	bitwise OR	$R[rd] = R[rs1] | R[rs2]$	R	011 0011	110	000 0000
	xor rd rs1 rs2	bitwise XOR	$R[rd] = R[rs1] \wedge R[rs2]$	R	011 0011	100	000 0000
	sll rd rs1 rs2	Shift Left Logical	$R[rd] = R[rs1] \ll R[rs2]$	R	011 0011	001	000 0000
	sr1 rd rs1 rs2	Shift Right Logical	$R[rd] = R[rs1] \gg R[rs2]$ (Zero-extend)	R	011 0011	101	000 0000
	sra rd rs1 rs2	Shift Right Arithmetic	$R[rd] = R[rs1] \gg R[rs2]$ (Sign-extend)	R	011 0011	101	010 0000
	slt rd rs1 rs2	Set Less Than (signed)	if ($R[rs1] < R[rs2]$) { $R[rd] = 1$; } else { $R[rd] = 0$; }	R	011 0011	010	000 0000
	sltu rd rs1 rs2	Set Less Than (Unsigned)		R	011 0011	011	000 0000
	addi rd rs1 imm	ADD Immediate	$R[rd] = R[rs1] + \text{imm}$	I	001 0011	000	
	andi rd rs1 imm	bitwise AND Immediate	$R[rd] = R[rs1] \& \text{imm}$	I	001 0011	111	
	ori rd rs1 imm	bitwise OR Immediate	$R[rd] = R[rs1] | \text{imm}$	I	001 0011	110	
	xori rd rs1 imm	bitwise XOR Immediate	$R[rd] = R[rs1] \wedge \text{imm}$	I	001 0011	100	
	slli rd rs1 imm	Shift Left Logical Immediate	$R[rd] = R[rs1] \ll \text{imm}$	I*	001 0011	001	000 0000
	srli rd rs1 imm	Shift Right Logical Immediate	$R[rd] = R[rs1] \gg \text{imm}$ (Zero-extend)	I*	001 0011	101	000 0000
	srai rd rs1 imm	Shift Right Arithmetic Immediate	$R[rd] = R[rs1] \gg \text{imm}$ (Sign-extend)	I*	001 0011	101	010 0000
	slti rd rs1 imm	Set Less Than Immediate (signed)	if ($R[rs1] < \text{imm}$) { $R[rd] = 1$; } else { $R[rd] = 0$; }	I	001 0011	010	
	sltiu rd rs1 imm	Set Less Than Immediate (Unsigned)		I	001 0011	011	
Memory	lb rd imm(rs1)	Load Byte	$R[rd] = M[R[rs1] + \text{imm}][7:0]$ (Sign-extend)	I	000 0011	000	
	lbu rd imm(rs1)	Load Byte (Unsigned)	$R[rd] = M[R[rs1] + \text{imm}][7:0]$ (Zero-extend)	I	000 0011	100	
	lh rd imm(rs1)	Load Half-word	$R[rd] = M[R[rs1] + \text{imm}][15:0]$ (Sign-extend)	I	000 0011	001	
	lhu rd imm(rs1)	Load Half-word (Unsigned)	$R[rd] = M[R[rs1] + \text{imm}][15:0]$ (Zero-extend)	I	000 0011	101	
	lw rd imm(rs1)	Load Word	$R[rd] = M[R[rs1] + \text{imm}][31:0]$	I	000 0011	010	
	sb rs2 imm(rs1)	Store Byte	$M[R[rs1] + \text{imm}][7:0] = R[rs2][7:0]$	S	010 0011	000	
	sh rs2 imm(rs1)	Store Half-word	$M[R[rs1] + \text{imm}][15:0] = R[rs2][15:0]$	S	010 0011	001	
	sw rs2 imm(rs1)	Store Word	$M[R[rs1] + \text{imm}][31:0] = R[rs2][31:0]$	S	010 0011	010	

	Instruction	Name	Description	Type	Opcode	Funct3
Control	beq rs1 rs2 label	Branch if Equal	if (R[rs1] == R[rs2]) PC = PC + offset	B	110 0011	000
	bne rs1 rs2 label	Branch if Not Equal	if (R[rs1] != R[rs2]) PC = PC + offset	B	110 0011	001
	blt rs1 rs2 label	Branch if Less Than (signed)	if (R[rs1] < R[rs2]) PC = PC + offset	B	110 0011	100
	bltu rs1 rs2 label	Branch if Less Than (Unsigned)	PC = PC + offset	B	110 0011	110
	bge rs1 rs2 label	Branch if Greater or Equal (signed)	if (R[rs1] >= R[rs2]) PC = PC + offset	B	110 0011	101
	bgeu rs1 rs2 label	Branch if Greater or Equal (Unsigned)	PC = PC + offset	B	110 0011	111
	jal rd label	Jump And Link	R[rd] = PC + 4 PC = PC + offset	J	110 1111	
	jalr rd rs1 imm	Jump And Link Register	R[rd] = PC + 4 PC = R[rs1] + imm	I	110 0111	000
Other	auipc rd immu	Add Upper Immediate to PC	imm = immu << 12 R[rd] = PC + imm	U	001 0111	
	lui rd immu	Load Upper Immediate	imm = immu << 12 R[rd] = imm	U	011 0111	
	ebreak	Environment BREAK	Asks the debugger to do something (imm = 0)	I	111 0011	000
	ecall	Environment CALL	Asks the OS to do something (imm = 1)	I	111 0011	000
Ext	mul rd rs1 rs2	Multiply (part of mul ISA extension)	R[rd] = (R[rs1]) * (R[rs2])	(omitted)		

#	Name	Description	#	Name	Desc
x0	zero	Constant 0	x16	a6	Args
x1	ra	Return Address	x17	a7	
x2	sp	Stack Pointer	x18	s2	Saved Registers
x3	gp	Global Pointer	x19	s3	
x4	tp	Thread Pointer	x20	s4	
x5	t0	Temporary Registers	x21	s5	
x6	t1		x22	s6	
x7	t2		x23	s7	
x8	s0	Saved Registers	x24	s8	
x9	s1		x25	s9	
x10	a0	Function Arguments or Return Values	x26	s10	
x11	a1		x27	s11	
x12	a2	Function Arguments	x28	t3	Temporaries
x13	a3		x29	t4	
x14	a4		x30	t5	
x15	a5		x31	t6	
Caller saved registers					
Callee saved registers (except x0, gp, tp)					

Immediates are sign-extended to 32 bits, except in I* type instructions

Pseudoinstruction	Name	Description	Translation
beqz rs1 label	Branch if Equals Zero	if (R[rs1] == 0) PC = PC + offset	beq rs1 x0 label
bnez rs1 label	Branch if Not Equals Zero	if (R[rs1] != 0) PC = PC + offset	bne rs1 x0 label
j label	Jump	PC = PC + offset	jal x0 label
jal label	Jump and Link	PC = PC + offset R[ra] = PC + 4	jal ra label
jr rs1	Jump Register	PC = R[rs1]	jalr x0 rs1 0
la rd label	Load absolute Address	R[rd] = &label	auipc , addi
li rd imm	Load Immediate	R[rd] = imm	lui (if needed), addi
mv rd rs1	MoVe	R[rd] = R[rs1]	addi rd rs1 0
neg rd rs1	NEGate	R[rd] = -(R[rs1])	sub rd x0 rs1
nop	No OPeration	do nothing	addi x0 x0 0
not rd rs1	bitwise NOT	R[rd] = ~(R[rs1])	xori rd rs1 -1
ret	RETurn	PC = R[ra]	jalr x0 ra 0

	31	25 24	20 19	15 14	12 11	7 6	0
R	funct7	rs2	rs1	funct3	rd	opcode	
I	imm[11:0]		rs1	funct3	rd	opcode	
I*	funct7	imm[4:0]	rs1	funct3	rd	opcode	
S	imm[11:5]	rs2	rs1	funct3	imm[4:0]	opcode	
B	imm[12|10:5]	rs2	rs1	funct3	imm[4:1|11]	opcode	
U	imm[31:12]				rd	opcode	
J	imm[20|10:1|11|19:12]				rd	opcode	

Selected ASCII values

HEX	DEC	CHAR	HEX	DEC	CHAR	HEX	DEC	CHAR	HEX	DEC	CHAR	HEX	DEC	CHAR	HEX	DEC	CHAR
0x20	32	{SPACE}	0x30	48	0	0x40	64	@	0x50	80	P	0x60	96	`	0x70	112	p
0x21	33	!	0x31	49	1	0x41	65	A	0x51	81	Q	0x61	97	a	0x71	113	q
0x22	34	"	0x32	50	2	0x42	66	B	0x52	82	R	0x62	98	b	0x72	114	r
0x23	35	#	0x33	51	3	0x43	67	C	0x53	83	S	0x63	99	c	0x73	115	s
0x24	36	\$	0x34	52	4	0x44	68	D	0x54	84	T	0x64	100	d	0x74	116	t
0x25	37	%	0x35	53	5	0x45	69	E	0x55	85	U	0x65	101	e	0x75	117	u
0x26	38	&	0x36	54	6	0x46	70	F	0x56	86	V	0x66	102	f	0x76	118	v
0x27	39	'	0x37	55	7	0x47	71	G	0x57	87	W	0x67	103	g	0x77	119	w
0x28	40	(	0x38	56	8	0x48	72	H	0x58	88	X	0x68	104	h	0x78	120	x
0x29	41	)	0x39	57	9	0x49	73	I	0x59	89	Y	0x69	105	i	0x79	121	y
0x2A	42	*	0x3A	58	:	0x4A	74	J	0x5A	90	Z	0x6A	106	j	0x7A	122	z
0x2B	43	+	0x3B	59	;	0x4B	75	K	0x5B	91	[	0x6B	107	k	0x7B	123	{
0x2C	44	,	0x3C	60	<	0x4C	76	L	0x5C	92	\	0x6C	108	l	0x7C	124	|
0x2D	45	-	0x3D	61	=	0x4D	77	M	0x5D	93	]	0x6D	109	m	0x7D	125	}
0x2E	46	.	0x3E	62	>	0x4E	78	N	0x5E	94	^	0x6E	110	n	0x7E	126	~
0x2F	47	/	0x3F	63	?	0x4F	79	O	0x5F	95	_	0x6F	111	o	0x00	0	NULL

IEEE 754 Floating Point Standard

Exponent (pre-bias; binary)	Significand	Meaning	Sign	Exponent	Significand
00...00	Any Value	Denormalized	Single Precision 1 bit	8 bits (bias = -127)	23 bits
00...01 → 11...10	Any Value	Normal	Double Precision 1 bit	11 bits (bias = -1023)	52 bits
11...11	0	±∞			
11...11	Non-zero	NaN			

Standard exponent bias: $-(2^{E-1}-1)$ where E is the number of exponent bits

Normalized floats: Value = $(-1)^{\text{Sign}} \times 2^{\text{Exp} + \text{Bias}} \times 1.\text{Significand}_2$

Denormalized floats: Value = $(-1)^{\text{Sign}} \times 2^{\text{Bias} + 1} \times 0.\text{Significand}_2$

C Format String Specifiers

Specifier	Output
d or i	Signed decimal integer
u	Unsigned decimal integer
o	Unsigned octal
x	Unsigned hexadecimal integer, lowercase
X	Unsigned hexadecimal integer, uppercase
f	Decimal floating point, lowercase
F	Decimal floating point, uppercase
e	Scientific notation (significand/exponent), lowercase
E	Scientific notation (significand/exponent), uppercase
c	Character
s	String of characters
p	Pointer address

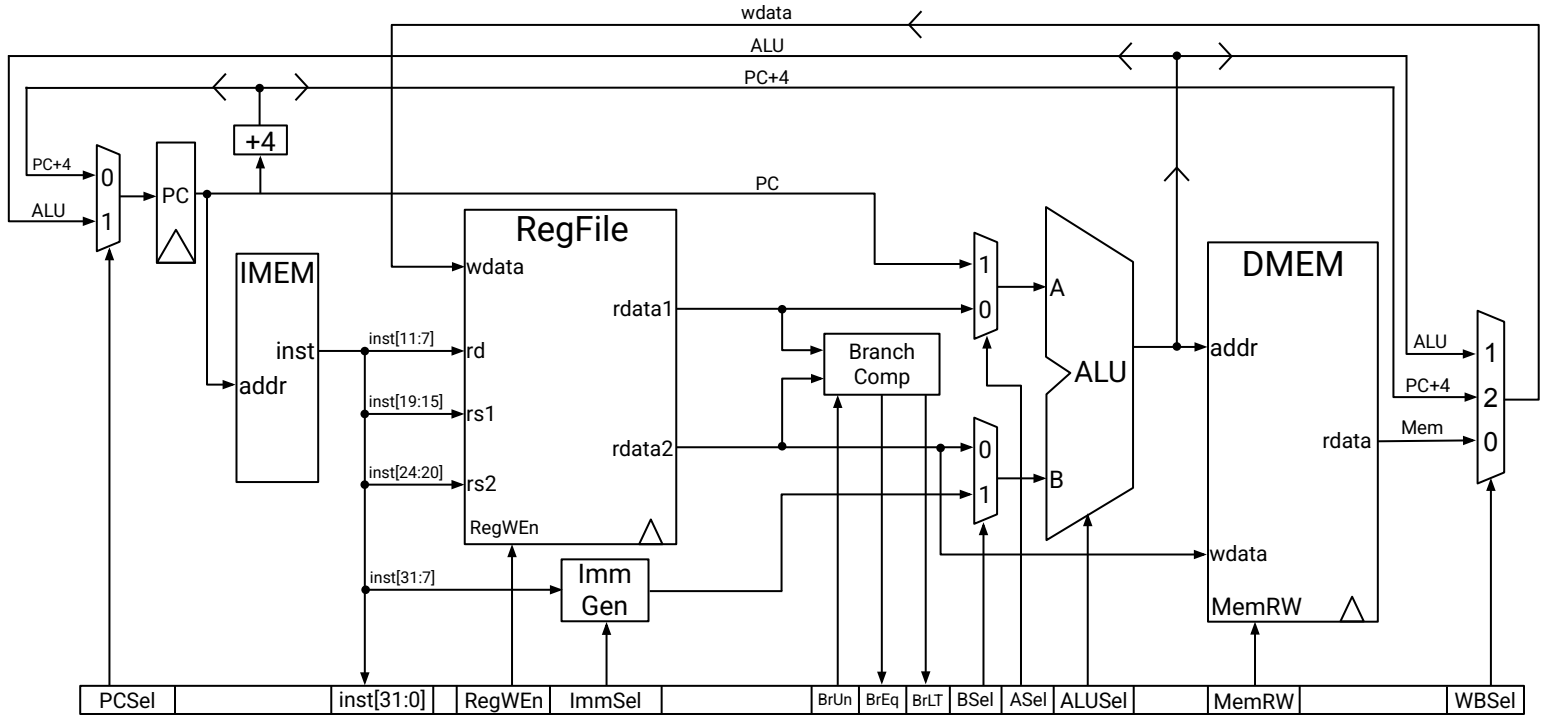
SI Prefixes

Size	Prefix	Symbol	Size	Prefix	Symbol	Size	Prefix	Symbol
10 ⁻³	milli-	m	10 ³	kilo-	k	2 ¹⁰	kibi-	Ki
10 ⁻⁶	micro-	μ	10 ⁶	mega-	M	2 ²⁰	mebi-	Mi
10 ⁻⁹	nano-	n	10 ⁹	giga-	G	2 ³⁰	gibi-	Gi
10 ⁻¹²	pico-	p	10 ¹²	tera-	T	2 ⁴⁰	tebi-	Ti
10 ⁻¹⁵	femto-	f	10 ¹⁵	peta-	P	2 ⁵⁰	pebi-	Pi
10 ⁻¹⁸	atto-	a	10 ¹⁸	exa-	E	2 ⁶⁰	exbi-	Ei
10 ⁻²¹	zepto-	z	10 ²¹	zetta-	Z	2 ⁷⁰	zebi-	Zi
10 ⁻²⁴	yocto-	y	10 ²⁴	yotta-	Y	2 ⁸⁰	yobi-	Yi

Laws of Boolean Algebra

$$\begin{aligned}
 x \cdot \bar{x} &= 0 & x + \bar{x} &= 1 & (xy)z &= x(yz) \\
 x \cdot 0 &= 0 & x + 1 &= 1 & (x + y) + z &= x + (y + z) \\
 x \cdot 1 &= x & x + 0 &= x & x(y + z) &= xy + xz \\
 x \cdot x &= x & x + x &= x & x + yz &= (x + y)(x + z) \\
 x \cdot y &= y \cdot x & x + y &= y + x & \overline{x \cdot y} &= \bar{x} + \bar{y} \\
 xy + x &= x & (x + y)x &= x & \overline{(x + y)} &= \bar{x} \cdot \bar{y}
 \end{aligned}$$

Single-Cycle Datapath Diagram



5-Stage Datapath Diagram

