RISC-V Reference

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RISC-V Instruction Set

Core Instruction Formats

31 27	26 25	24 20	19 15	14 12	11 7	6 0	
funct7		rs2	rs1	funct3	rd	opcode	R-type
imm[11:0]			rs1	funct3	rd	opcode	I-type
imm[11:5]		rs2	rs1	funct3	imm[4:0]	opcode	S-type
imm[12|10:5]		rs2	rs1	funct3	imm[4:1|11]	opcode	B-type
imm[31:12]					rd	opcode	U-type
imm[20|10:1|11|19:12]					rd	opcode	J-type

RV32I Base Integer Instructions

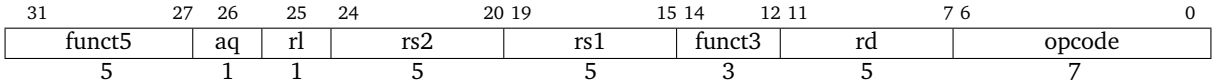
Inst	Name	FMT	Opcode	funct3	funct7	Description (C)	Note
add	ADD	R	0110011	0x0	0x00	rd = rs1 + rs2	
sub	SUB	R	0110011	0x0	0x20	rd = rs1 - rs2	
xor	XOR	R	0110011	0x4	0x00	rd = rs1 ^ rs2	
or	OR	R	0110011	0x6	0x00	rd = rs1 | rs2	
and	AND	R	0110011	0x7	0x00	rd = rs1 & rs2	
sll	Shift Left Logical	R	0110011	0x1	0x00	rd = rs1 << rs2	
srl	Shift Right Logical	R	0110011	0x2	0x00	rd = rs1 >> rs2	
sra	Shift Right Arith*	R	0110011	0x3	0x20	rd = rs1 >> rs2	msb-extends
slt	Set Less Than	R	0110011	0x2		rd = (rs1 < rs2)?1:0	
sltu	Set Less Than (U)	R	0110011	0x3		rd = (rs1 < rs2)?1:0	zero-extends
addi	ADD Immediate	I	0010011	0x0	0x00	rd = rs1 + imm	
xori	XOR Immediate	I	0010011	0x4	0x00	rd = rs1 ^ imm	
ori	OR Immediate	I	0010011	0x6	0x00	rd = rs1 | imm	
andi	AND Immediate	I	0010011	0x7	0x00	rd = rs1 & imm	
slli	Shift Left Logical Imm	I	0010011	0x1	0x00	rd = rs1 << imm	
srli	Shift Right Logical Imm	I	0010011	0x1	0x00	rd = rs1 >> imm	
srai	Shift Right Arith Imm	I	0010011	0x3	0x20	rd = rs1 >> imm	msb-extends
slti	Set Less Than Imm	I	0010011	0x2		rd = (rs1 < imm)?1:0	
sltiu	Set Less Than Imm (U)	I	0010011	0x3		rd = (rs1 < imm)?1:0	zero-extends
lb	Load Byte	I	0000011	0x0		rd = M[rs1+imm][0:7]	
lh	Load Half	I	0000011	0x1		rd = M[rs1+imm][0:15]	
lw	Load Word	I	0000011	0x2		rd = M[rs1+imm][0:31]	
lbu	Load Byte (U)	I	0000011	0x4		rd = M[rs1+imm][0:7]	zero-extends
lhu	Load Half (U)	I	0000011	0x5		rd = M[rs1+imm][0:15]	zero-extends
sb	Store Byte	S	0100011	0x0		M[rs1+imm][0:7] = rs2[0:7]	
sh	Store Half	S	0100011	0x1		M[rs1+imm][0:15] = rs2[0:15]	
sw	Store Word	S	0100011	0x2		M[rs1+imm][0:31] = rs2[0:31]	
beq	Branch ==	B	1100011	0x0		if(rs1 == rs2) PC += imm	
bne	Branch !=	B	1100011	0x1		if(rs1 != rs2) PC += imm	
blt	Branch <	B	1100011	0x4		if(rs1 < rs2) PC += imm	
bge	Branch ≥	B	1100011	0x5		if(rs1 >= rs2) PC += imm	
bltu	Branch < (U)	B	1100011	0x6		if(rs1 < rs2) PC += imm	zero-extends
bgeu	Branch ≥ (U)	B	1100011	0x7		if(rs1 >= rs2) PC += imm	zero-extends
jal	Jump And Link	J	1101111			rd = PC+4; PC += imm	
jalr	Jump And Link Reg	I	1100111	0x0		rd = PC+4; PC = rs1 + imm	
lui	Load Upper Imm	U	0110111			rd = imm << 12	
auipc	Add Upper Imm to PC	U	0010111			rd = PC + (imm << 12)	
ecall	Environment Call	I	1110011	0x0	0x00	Transfer control to OS	imm: 0x000
ebreak	Environment Break	I	1110011	0x0	0x00	Transfer control to debugger	imm: 0x001

Standard Extensions

RV32M Multiply Extension

Inst	Name	FMT	Opcode	funct3	funct7	Description (C)
mul	MUL	R	0110011	0x0	0x01	rd = (rs1 * rs2)[31:0]
mulh	MUL High	R	0110011	0x1	0x01	rd = (rs1 * rs2)[63:32]
mulsu	MUL High (S) (U)	R	0110011	0x2	0x01	rd = (rs1 * rs2)[63:32]
mulu	MUL High (U)	R	0110011	0x3	0x01	rd = (rs1 * rs2)[63:32]
div	DIV	R	0110011	0x4	0x01	rd = rs1 / rs2
divu	DIV (U)	R	0110011	0x5	0x01	rd = rs1 / rs2
rem	Remainder	R	0110011	0x6	0x01	rd = rs1 % rs2
remu	Remainder (U)	R	0110011	0x7	0x01	rd = rs1 % rs2

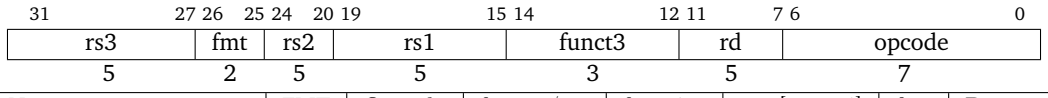
RV32A Atomic Extension



Inst	Name	FMT	Opcode	funct3	funct5	Description (C)
lr.w	Load Reserved	R	0101111	0x2	0x02	rd = M[rs1], reserve M[rs1]
sc.w	Store Conditional	R	0101111	0x2	0x03	if (reserved) { M[rs1] = rs2; rd = 0 } else { rd = 1 }
amoswap.w	Atomic Swap	R	0101111	0x2	0x01	rd = M[rs1]; swap(rd, rs2); M[rs1] = rd
amoadd.w	Atomic ADD	R	0101111	0x2	0x00	rd = M[rs1] + rs2; M[rs1] = rd
amoand.w	Atomic AND	R	0101111	0x2	0x0C	rd = M[rs1] & rs2; M[rs1] = rd
amoor.w	Atomic OR	R	0101111	0x2	0x0A	rd = M[rs1] | rs2; M[rs1] = rd
amoxor.w	Atomix XOR	R	0101111	0x2	0x04	rd = M[rs1] ^ rs2; M[rs1] = rd
amomax.w	Atomic MAX	R	0101111	0x2	0x14	rd = max(M[rs1], rs2); M[rs1] = rd
amomin.w	Atomic MIN	R	0101111	0x2	0x10	rd = min(M[rs1], rs2); M[rs1] = rd

RV32F Single-Precision Floating-Point Extension

R4-type instructions



Inst	Name	FMT	Opcode	funct3/rm	funct7	rs2 [20...24]	fmt	Description (C)
flw	Flt Load Word	I	0000111	010				rd = M[rs1 + imm]
fsw	Flt Store Word	I	0100111	010				M[rs1 + imm] = rs2
fadd.s	Flt Add	R	1010011		0000000			rd = rs1 + rs2
fsub.s	Flt Sub	R	1010011		0000010			rd = rs1 - rs2
fmul.s	Flt Mul	R	1010011		0000100			rd = rs1 * rs2
fdiv.s	Flt Div	R	1010011		0000110			rd = rs1 / rs2
fsgnj.s	Flt Sign Injection	R	1010011	000	0001000			rd = abs(rs1) * sgn(rs2)
fsgnjn.s	Flt Sign Neg Injection	R	1010011	001	0001000			rd = abs(rs1) * -sgn(rs2)
fsgnjx.s	Flt Sign Xor Injection	R	1010011	010	0001000			rd = rs1 * sgn(rs2)
fmin.s	Flt Minimum	R	1010011		0001100			rd = min(rs1, rs2)
fmax.s	Flt Maximum	R	1010011		0001100			rd = max(rs1, rs2)
fsqrt.s	Flt Square Root	R	1010011		0101100	00000		rd = sqrt(rs1)
fle.s	Float Less / Equal	R	1010011	000	0101000			rd = (rs1 <= rs2) ? 1 : 0
flt.s	Float Less Than	R	1010011	001	0101000			rd = (rs1 < rs2) ? 1 : 0
feq.s	Float Equality	R	1010011	010	0101000			rd = (rs1 == rs2) ? 1 : 0
fcvt.w.s	Flt Convert to Int	R	1010011		0110000	00000		rd = (int32_t) rs1
fcvt.wu.s	Flt Convert to Int	R	1010011		0110000	00001		rd = (uint32_t) rs1
fmv.x.w	Move Float to Int	R	1010011	000	0111000	00000		rd = *((int*) &rs1)
fclass.s	Float Classify	R	1010011	001	0111000	00000		rd = 0..9
fcvt.s.w	Flt Conv from Sign Int	R	1010011		0110100	00000		rd = (float) rs1
fcvt.s.wu	Flt Conv from Uns Int	R	1010011		0110100	00001		rd = (float) rs1
fmv.w.x	Move Int to Float	R	1010011	000	0111100	00000		rd = *((float*) &rs1)
fmadd.s	Flt Fused Mul-Add	R4	1000011				00	rd = rs1 * rs2 + rs3
fmsub.s	Flt Fused Mul-Sub	R4	1000111				00	rd = rs1 * rs2 - rs3
fnmadd.s	Flt Neg Fused Mul-Add	R4	1001011				00	rd = -rs1 * rs2 + rs3
fnmsub.s	Flt Neg Fused Mul-Sub	R4	1001111				00	rd = -rs1 * rs2 - rs3

RV32D Double-Precision Floating-Point Extension

Inst	Name	FMT	Opcode	funct3/rm	funct7	rs2 [20...24]	fmt	Description (C)
fld	Flt Load Word	I	0000111	011				rd = M[rs1 + imm]
fsd	Flt Store Word	I	0100111	011				M[rs1 + imm] = rs2
fadd.d	Flt Add	R	1010011		0000001			rd = rs1 + rs2
fsub.d	Flt Sub	R	1010011		0000011			rd = rs1 - rs2
fmul.d	Flt Mul	R	1010011		0000101			rd = rs1 * rs2
fdiv.d	Flt Div	R	1010011		0000111			rd = rs1 / rs2
fsgnj.d	Flt Sign Injection	R	1010011	000	0001001			rd = abs(rs1) * sgn(rs2)
fsgnjn.d	Flt Sign Neg Injection	R	1010011	001	0001001			rd = abs(rs1) * -sgn(rs2)
fsgnjx.d	Flt Sign Xor Injection	R	1010011	010	0001001			rd = rs1 * sgn(rs2)
fmin.d	Flt Minimum	R	1010011		0001101			rd = min(rs1, rs2)
fmax.d	Flt Maximum	R	1010011		0001101			rd = max(rs1, rs2)
fsqrt.d	Flt Square Root	R	1010011		0101101	00000		rd = sqrt(rs1)
fle.d	Float Less / Equal	R	1010011	000	0101001			rd = (rs1 <= rs2) ? 1 : 0
flt.d	Float Less Than	R	1010011	001	0101001			rd = (rs1 < rs2) ? 1 : 0
feq.d	Float Equality	R	1010011	010	0101001			rd = (rs1 == rs2) ? 1 : 0
fcvt.w.d	Flt Convert to Int	R	1010011		0110001	00000		rd = (int32_t) rs1
fcvt.wu.d	Flt Convert to Int	R	1010011		0110001	00001		rd = (uint32_t) rs1
fcvt.s.d	Double Flt to Single	R	1010011	000	0010000	00001		rd = *((float*) &rs1)
fmv.x.d	Move Int to Float	R	1010011	000	0111101	00000		rd = *((float*) &rs1)
fclass.d	Float Classify	R	1010011	001	0111001	00000		rd = 0..9
fcvt.d.w	Flt Conv from Sign Int	R	1010011		0110101	00000		rd = (float) rs1
fcvt.d.wu	Flt Conv from Uns Int	R	1010011		0110101	00001		rd = (float) rs1
fcvt.d.s	Single Flt to Double	R	1010011	000	0010001	00001		rd = *((float*) &rs1)
fmadd.d	Flt Fused Mul-Add	R4	1000011				01	rd = rs1 * rs2 + rs3
fmsub.d	Flt Fused Mul-Sub	R4	1000111				01	rd = rs1 * rs2 - rs3
fnmadd.d	Flt Neg Fused Mul-Add	R4	1001011				01	rd = -rs1 * rs2 + rs3
fnmsub.d	Flt Neg Fused Mul-Sub	R4	1001111				01	rd = -rs1 * rs2 - rs3

RV32C Compressed Extension

15 14 13	12	11 10	9 8 7	6 5	4 3 2	1 0	
funct4		rd/rs1		rs2		op	CR-type
funct3	imm	rd/rs1		imm		op	CI-type
funct3	imm			rs2		op	CSS-type
funct3	imm				rd’	op	CIW-type
funct3	imm		rs1’	imm	rd’	op	CL-type
funct3	imm		rd’/rs1’	imm	rs2’	op	CS-type
funct3	imm		rs1’	imm		op	CB-type
funct3	offset					op	CJ-type

Inst	Name	FMT	OP	Funct	Description
c.lwsp	Load Word from SP	CI	10	010	lw rd, (4*imm)(sp)
c.swsp	Store Word to SP	CSS	10	110	sw rs2, (4*imm)(sp)
c.lw	Load Word	CL	00	010	lw rd’, (4*imm)(rs1’)
c.sw	Store Word	CS	00	110	sw rs1’, (4*imm)(rs2’)
c.j	Jump	CJ	01	101	jal x0, 2*offset
c.jal	Jump And Link	CJ	01	001	jal ra, 2*offset
c.jr	Jump Reg	CR	10	1000	jalr x0, rs1, 0
c.jalr	Jump And Link Reg	CR	10	1001	jalr ra, rs1, 0
c.beqz	Branch == 0	CB	01	110	beq rs’, x0, 2*imm
c.bnez	Branch != 0	CB	01	111	bne rs’, x0, 2*imm
c.li	Load Immediate	CI	01	010	addi rd, x0, imm
c.lui	Load Upper Imm	CI	01	011	lui rd, imm
c.addi	ADD Immediate	CI	01	000	addi rd, rd, imm
c.addi16sp	ADD Imm * 16 to SP	CI	01	011	addi sp, sp, 16*imm
c.addi4spn	ADD Imm * 4 + SP	CIW	00	000	addi rd’, sp, 4*imm
c.slli	Shift Left Logical Imm	CI	10	000	slli rd, rd, imm
c.srli	Shift Right Logical Imm	CB	01	100x00	srli rd’, rd’, imm
c.srai	Shift Right Arith Imm	CB	01	100x01	srai rd’, rd’, imm
c.andi	AND Imm	CB	01	100x10	andi rd’, rd’, imm
c.mv	MoVe	CR	10	1000	add rd, x0, rs2
c.add	ADD	CR	10	1001	add rd, rd, rs2
c.and	AND	CS	01	10001111	and rd’, rd’, rs2’
c.or	OR	CS	01	10001110	or rd’, rd’, rs2’
c.xor	XOR	CS	01	10001101	xor rd’, rd’, rs2’
c.sub	SUB	CS	01	10001100	sub rd’, rd’, rs2’
c.nop	No OPeration	CI	01	000	addi x0, x0, 0
c.ebreak	Environment BREAK	CR	10	1001	ebreak

Pseudo Instructions

Pseudoinstruction	Base Instruction(s)	Meaning
`la rd, symbol`	`auipc rd, symbol[31:12]` `addi rd, rd, symbol[11:0]`	Load address
`l{b|h|w|d} rd, symbol`	`auipc rd, symbol[31:12]` `l{b|h|w|d} rd, symbol[11:0](rd)`	Load global
`s{b|h|w|d} rd, symbol, rt`	`auipc rt, symbol[31:12]` `s{b|h|w|d} rd, symbol[11:0](rt)`	Store global
`fl{w|d} rd, symbol, rt`	`auipc rt, symbol[31:12]` `fl{w|d} rd, symbol[11:0](rt)`	Floating-point load global
`fs{w|d} rd, symbol, rt`	`auipc rt, symbol[31:12]` `fs{w|d} rd, symbol[11:0](rt)`	Floating-point store global
`nop`	`addi x0, x0, 0`	No operation
`li rd, immediate`	*Myriad sequences*	Load immediate
`mv rd, rs`	`addi rd, rs, 0`	Copy register
`not rd, rs`	`xori rd, rs, -1`	One's complement
`neg rd, rs`	`sub rd, x0, rs`	Two's complement
`negw rd, rs`	`subw rd, x0, rs`	Two's complement word
`sext.w rd, rs`	`addiw rd, rs, 0`	Sign extend word
`seqz rd, rs`	`sltiu rd, rs, 1`	Set if $=$ zero
`snez rd, rs`	`sltu rd, x0, rs`	Set if $\neq$ zero
`sltz rd, rs`	`slt rd, rs, x0`	Set if $<$ zero
`sgtz rd, rs`	`slt rd, x0, rs`	Set if $>$ zero
`fmv.s rd, rs`	`fsgnj.s rd, rs, rs`	Copy single-precision register
`fabs.s rd, rs`	`fsgnjx.s rd, rs, rs`	Single-precision absolute value
`fneg.s rd, rs`	`fsgnjn.s rd, rs, rs`	Single-precision negate
`fmv.d rd, rs`	`fsgnj.d rd, rs, rs`	Copy double-precision register
`fabs.d rd, rs`	`fsgnjx.d rd, rs, rs`	Double-precision absolute value
`fneg.d rd, rs`	`fsgnjn.d rd, rs, rs`	Double-precision negate
`beqz rs, offset`	`beq rs, x0, offset`	Branch if $=$ zero
`bnez rs, offset`	`bne rs, x0, offset`	Branch if $\neq$ zero
`blez rs, offset`	`bge x0, rs, offset`	Branch if $\leq$ zero
`bgez rs, offset`	`bge rs, x0, offset`	Branch if $\geq$ zero
`bltz rs, offset`	`blt rs, x0, offset`	Branch if $<$ zero
`bgtz rs, offset`	`blt x0, rs, offset`	Branch if $>$ zero
`bgt rs, rt, offset`	`blt rt, rs, offset`	Branch if $>$
`ble rs, rt, offset`	`bge rt, rs, offset`	Branch if $\leq$
`bgtu rs, rt, offset`	`bltu rt, rs, offset`	Branch if $>$, unsigned
`bleu rs, rt, offset`	`bgeu rt, rs, offset`	Branch if $\leq$, unsigned
`j offset`	`jal x0, offset`	Jump
`jal offset`	`jal x1, offset`	Jump and link
`jr rs`	`jalr x0, rs, 0`	Jump register
`jalr rs`	`jalr x1, rs, 0`	Jump and link register
`ret`	`jalr x0, x1, 0`	Return from subroutine
`call offset`	`auipc x1, offset[31:12]` `jalr x1, x1, offset[11:0]`	Call far-away subroutine
`tail offset`	`auipc x6, offset[31:12]` `jalr x0, x6, offset[11:0]`	Tail call far-away subroutine
`fence`	`fence iorw, iorw`	Fence on all memory and I/O

Registers

Register	ABI Name	Description	Saver
x0	zero	Zero constant	—
x1	ra	Return address	Caller
x2	sp	Stack pointer	—
x3	gp	Global pointer	—
x4	tp	Thread pointer	Callee
x5	t0-t2	Temporaries	Caller
x8	s0 / fp	Saved / frame pointer	Callee
x9	s1	Saved register	Callee
x10-x11	a0-a1	Fn args/return values	Caller
x12-x17	a2-a7	Fn args	Caller
x18-x27	s2-s11	Saved registers	Callee
x28-x31	t3-t6	Temporaries	Caller
f0-7	ft0-7	FP temporaries	Caller
f8-9	fs0-1	FP saved registers	Callee
f10-11	fa0-1	FP args/return values	Caller
f12-17	fa2-7	FP args	Caller
f18-27	fs2-11	FP saved registers	Callee
f28-31	ft8-11	FP temporaries	Caller