

7th RISC-V Workshop

REGISTER NAME, USE, CALLING CONVENTION

REGISTER	NAME	USE	SAVER
x0	zero	The constant value 0	N.A.
x1	ra	Return address	Caller
x2	sp	Stack pointer	Callee
x3	gp	Global pointer	--
x4	tp	Thread pointer	--
x5-x7	t0-t2	Temporaries	Caller
x8	s0/fp	Saved register/Frame pointer	Callee
x9	s1	Saved register	Callee
x10-x11	a0-a1	Function arguments/Return values	Caller
x12-x17	a2-a7	Function arguments	Caller
x18-x27	s2-s11	Saved registers	Callee
x28-x31	t3-t6	Temporaries	Caller
f0-f7	ft0-ft7	FP Temporaries	Caller
f8-f9	fs0-fs1	FP Saved registers	Callee
f10-f11	fa0-fa1	FP Function arguments/Return values	Caller
f12-f17	fa2-fa7	FP Function arguments	Caller
f18-f27	fs2-fs11	FP Saved registers	Callee
f28-f31	ft8-ft11	R[rd] = R[rs1] + R[rs2]	Caller

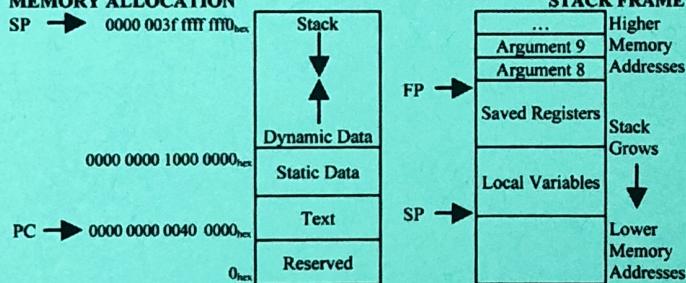
IEEE 754 FLOATING-POINT STANDARD

 $(-1)^S \times (1 + Fraction) \times 2^{(Exponent - Bias)}$ where Half-Precision Bias = 15, Single-Precision Bias = 127,
Double-Precision Bias = 1023, Quad-Precision Bias = 16383

IEEE Half-, Single-, Double-, and Quad-Precision Formats:

S	Exponent	Fraction	
15	14	10 9	0
S	Exponent	Fraction	
31	30	23 22	0
S	Exponent	Fraction	
63	62	52 51	0
S	Exponent	Fraction	
127	126	112 111	0

MEMORY ALLOCATION



SIZE PREFIXES AND SYMBOLS

SIZE	PREFIX	SYMBOL	SIZE	PREFIX	SYMBOL
10^3	Kilo-	K	2^{10}	Kibi-	Ki
10^6	Mega-	M	2^{20}	Mebi-	Mi
10^9	Giga-	G	2^{30}	Gibi-	Gi
10^{12}	Tera-	T	2^{40}	Tebi-	Ti
10^{15}	Peta-	P	2^{50}	Pebi-	Pi
10^{18}	Exa-	E	2^{60}	Exbi-	Ei
10^{21}	Zetta-	Z	2^{70}	Zebi-	Zi
10^{24}	Yotta-	Y	2^{80}	Yobi-	Yi
10^{-3}	milli-	m	10^{-15}	femto-	f
10^{-6}	micro-	μ	10^{-18}	atto-	a
10^{-9}	nano-	n	10^{-21}	zepto-	z
10^{-12}	pico-	p	10^{-24}	yocto-	y

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Reference Data

RV64I BASE INTEGER INSTRUCTIONS, in alphabetical order

MNEMONIC	FMT	NAME	DESCRIPTION (in Verilog)	NOTE
add, addw	R	ADD (Word)	R[rd] = R[rs1] + R[rs2]	1)
addi, addiw	I	ADD Immediate (Word)	R[rd] = R[rs1] + imm	1)
and	R	AND	R[rd] = R[rs1] & R[rs2]	
andi	I	AND Immediate	R[rd] = R[rs1] & imm	
auipc	U	Add Upper Immediate to PC	R[rd] = PC + (imm, 12'b0)	
beq	SB	Branch EQUAL	if(R[rs1]==R[rs2])	
bge	SB	Branch Greater than or Equal	PC=PC+(imm, 1b'0)	
bgeu	SB	Branch ≥ Unsigned	if(R[rs1]>=R[rs2])	2)
blt	SB	Branch Less Than	if(R[rs1]<R[rs2])	
bltu	SB	Branch Less Than Unsigned	PC=PC+(imm, 1b'0)	
bne	SB	Branch Not Equal	if(R[rs1]!=R[rs2])	
csrrc	I	Cont./Stat.RegRead&Clear	R[rd] = CSR; CSR = CSR & ~R[rs1]	
csrrci	I	Cont./Stat.RegRead&Clear	R[rd] = CSR; CSR = CSR & ~imm	
csrrs	I	Cont./Stat.RegRead&Set	R[rd] = CSR; CSR = CSR R[rs1]	
csrrsi	I	Cont./Stat.RegRead&Set	R[rd] = CSR; CSR = CSR imm	
csrrw	I	Cont./Stat.RegRead&Write	R[rd] = CSR; CSR = R[rs1]	
csrrwi	I	Cont./Stat.Reg Read&Write	R[rd] = CSR; CSR = imm	
ebreak	I	Environment BREAK	Transfer control to debugger	
ecall	I	Environment CALL	Transfer control to operating system	
fence	I	Synch thread	Synchronizes threads	
fence.i	I	Synch Instr & Data	Synchronizes writes to instruction stream	
jal	UJ	Jump & Link	R[rd] = PC+4; PC = PC + {imm, 1b'0}	
jalr	I	Jump & Link Register	R[rd] = PC+4; PC = R[rs1]+imm	3)
lb	I	Load Byte	R[rd] = {56'bM[1:7],M[R[rs1]+imm](7:0)}	4)
lbu	I	Load Byte Unsigned	R[rd] = {56'b0,M[R[rs1]+imm](7:0)}	
ld	I	Load Doubleword	R[rd] = M[R[rs1]+imm](63:0)	
lh	I	Load Halfword	R[rd] = {48'bM[15:1],M[R[rs1]+imm](15:0)}	
lhu	I	Load Halfword Unsigned	R[rd] = {48'b0,M[R[rs1]+imm](15:0)}	
lui	U	Load Upper Immediate	R[rd] = {32'bimm<31>, imm, 12'b0}	
lw	I	Load Word	R[rd] = {32'bM[1:31],M[R[rs1]+imm](31:0)}	4)
lwu	I	Load Word Unsigned	R[rd] = {32'b0,M[R[rs1]+imm](31:0)}	
or	R	OR	R[rd] = R[rs1] R[rs2]	
ori	I	OR Immediate	R[rd] = R[rs1] imm	
sb	S	Store Byte	M[R[rs1]+imm](7:0) = R[rs2](7:0)	
sd	S	Store Doubleword	M[R[rs1]+imm](63:0) = R[rs2](63:0)	
sh	S	Store Halfword	M[R[rs1]+imm](15:0) = R[rs2](15:0)	
sll, sllw	R	Shift Left (Word)	R[rd] = R[rs1] << R[rs2]	1)
slli, slliw	I	Shift Left Immediate (Word)	R[rd] = R[rs1] << imm	1)
slt	R	Set Less Than	R[rd] = (R[rs1] < R[rs2]) ? 1 : 0	
slti	I	Set Less Than Immediate	R[rd] = (R[rs1] < imm) ? 1 : 0	
sltiu	I	Set < Immediate Unsigned	R[rd] = (R[rs1] < imm) ? 1 : 0	2)
sltu	R	Set Less Than Unsigned	R[rd] = (R[rs1] < R[rs2]) ? 1 : 0	2)
sra, sraw	R	Shift Right Arithmetic (Word)	R[rd] = R[rs1] >> R[rs2]	1,5)
srai, sraw	I	Shift Right Arith Imm (Word)	R[rd] = R[rs1] >> imm	1,5)
srl, srw	R	Shift Right (Word)	R[rd] = R[rs1] >> R[rs2]	1)
srl, srlw	I	Shift Right Immediate (Word)	R[rd] = R[rs1] >> imm	1)
sub, subw	R	SUBtract (Word)	R[rd] = R[rs1] - R[rs2]	1)
sw	S	Store Word	M[R[rs1]+imm](31:0) = R[rs2](31:0)	
xor	R	XOR	R[rd] = R[rs1] ^ R[rs2]	
xori	I	XOR Immediate	R[rd] = R[rs1] ^ imm	

Notes: 1) The Word version only operates on the rightmost 32 bits of a 64-bit register

2) Operation assumes unsigned integers (instead of 2's complement)

3) The least significant bit of the branch address in jalr is set to 0

4) (signed) Load instructions extend the sign bit of data to fill the 64-bit register

5) Replicates the sign bit to fill in the leftmost bits of the result during right shift

6) Multiply with one operand signed and one unsigned

7) The Single version does a single-precision operation using the rightmost 32 bits of a 64-bit F register

8) Classify writes a 10-bit mask to show which properties are true (e.g., -inf, +0, +inf, denorm, ...)

9) Atomic memory operation; nothing else can interpose itself between the read and the write of the memory location

The immediate field is sign-extended in RISC-V

ARITHMETIC CORE INSTRUCTION SET

RV64M Multiply Extension

MNEMONIC	FMT NAME	DESCRIPTION (in Verilog)	NOTE
mul, mulw	R MULtiply (Word)	$R[rd] = R[rs1] * R[rs2](63:0)$	1)
mult	R MULtiply High	$R[rd] = (R[rs1] * R[rs2])(127:64)$	
mulhu	R MULtiply High Unsigned	$R[rd] = (R[rs1] * R[rs2])(127:64)$	2)
mulhsu	R MULtiply upper Half Signs/Ums	$R[rd] = (R[rs1] * R[rs2])(127:64)$	6)
div, divw	R DIVide (Word)	$R[rd] = (R[rs1] / R[rs2])$	1)
divu	R DIVide Unsigned	$R[rd] = (R[rs1] / R[rs2])$	2)
rem, remw	R REMainder (Word)	$R[rd] = (R[rs1] % R[rs2])$	1)
remu, remuw	R REMainder Unsigned (Word)	$R[rd] = (R[rs1] % R[rs2])$	1,2)

RV64F and RV64D Floating-Point Extensions

MNEMONIC	FMT NAME	DESCRIPTION (in Verilog)	NOTE
fld, flw	I Load (Word)	$F[rd] = M[R[rs1]+imm]$	1)
fsd, fsw	S Store (Word)	$M[R[rs1]+imm] = F[rd]$	1)
fadd.s, fadd.d	R ADD	$F[rd] = F[rs1] + F[rs2]$	7)
fsub.s, fsub.d	R SUBtract	$F[rd] = F[rs1] - F[rs2]$	7)
fmul.s, fmul.d	R MULtiply	$F[rd] = F[rs1] * F[rs2]$	7)
fdiv.s, fdiv.d	R DIVide	$F[rd] = F[rs1] / F[rs2]$	7)
fsqrts, fsqrtd	R SQUare Root	$F[rd] = \sqrt{F[rs1]}$	7)
fmadd.s, fmadd.d	R Multiply-ADD	$F[rd] = F[rs1] * F[rs2] + F[rs3]$	7)
fmsub.s, fmsub.d	R Multiply-SUBtract	$F[rd] = F[rs1] * F[rs2] - F[rs3]$	7)
fmnadd.s, fmnadd.d	R Negative Multiply-ADD	$F[rd] = -(F[rs1] * F[rs2] + F[rs3])$	7)
fnmsub.s, fnmsub.d	R Negative Multiply-SUBtract	$F[rd] = -(F[rs1] * F[rs2] - F[rs3])$	7)
fsgnj.s, fsgnj.d	R SIGN source	$F[rd] = ((F[rs2]<63), F[rs1]<62:0>)$	7)
fsgnjn.s, fsgnjn.d	R Negative SIGN source	$F[rd] = ((-F[rs2]<63>, F[rs1]<62:0>)$	7)
fsgnjx.s, fsgnjx.d	R Xor SIGN source	$F[rd] = (F[rs2]<63>^F[rs1]<63>, F[rs1]<62:0>)$	7)
fmin.s, fmin.d	R MINimum	$F[rd] = (F[rs1] < F[rs2]) ? F[rs1] : F[rs2]$	7)
fmax.s, fmax.d	R MAXimum	$F[rd] = (F[rs1] > F[rs2]) ? F[rs1] : F[rs2]$	7)
feq.s, feq.d	R Compare Float EQUAL	$R[rd] = (F[rs1]==F[rs2]) ? 1 : 0$	7)
flt.s, flt.d	R Compare Float Less Than	$R[rd] = (F[rs1]<F[rs2]) ? 1 : 0$	7)
fle.s, fle.d	R Compare Float Less than or Equal	$R[rd] = (F[rs1]≤F[rs2]) ? 1 : 0$	7)
fclass.s, fclass.d	R Classify Type	$R[rd] = \text{class}(F[rs1])$	7,8)
fmv.s.x, fmvd.x	R Move from Integer	$F[rd] = R[rs1]$	7)
fmv.x.s, fmvd.x	R Move to Integer	$R[rd] = F[rs1]$	7)
fcvt.s.d	R Convert to SP from DP	$F[rd] = \text{single}(F[rs1])$	
fcvt.d.s	R Convert to DP from SP	$F[rd] = \text{double}(F[rs1])$	
fcvt.s.w, fcvt.d.w	R Convert from 32b Integer	$F[rd] = \text{float}(R[rs1](31:0))$	7)
fcvt.s.l, fcvt.d.l	R Convert from 64b Integer	$F[rd] = \text{float}(R[rs1](63:0))$	7)
fcvt.s.wu, fcvt.d.wu	R Convert from 32b Int Unsigned	$F[rd] = \text{float}(R[rs1](31:0))$	2,7)
fcvt.s.lu, fcvt.d.lu	R Convert from 64b Int Unsigned	$F[rd] = \text{float}(R[rs1](63:0))$	2,7)
fcvt.w.s, fcvt.w.d	R Convert to 32b Integer	$R[rd](31:0) = \text{integer}(F[rs1])$	7)
fcvt.l.s, fcvt.l.d	R Convert to 64b Integer	$R[rd](63:0) = \text{integer}(F[rs1])$	7)
fcvt.w.u, fcvt.w.d	R Convert to 32b Int Unsigned	$R[rd](31:0) = \text{integer}(F[rs1])$	2,7)
fcvt.lu.s, fcvt.lu.d	R Convert to 64b Int Unsigned	$R[rd](63:0) = \text{integer}(F[rs1])$	2,7)

RV64A Atomic Extension

amoadd.w, amoadd.d	R ADD	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] + R[rs2]$	9)
amoand.w, amoand.d	R AND	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] \& R[rs2]$	9)
amamax.w, amamax.d	R MAXimum	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] \& R[rs2]$	9)
amomaxu.w, amomaxu.d	R MAXimum Unsigned	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] \& R[rs2]$	2,9)
amomin.w, amomin.d	R MINimum	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] \& R[rs2]$	9)
amominu.w, amominu.d	R MINimum Unsigned	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] \& R[rs2]$	2,9)
amoor.w, amoor.d	R OR	$R[rd] = M[R[rs1]], M[R[rs1]] = M[R[rs1]] R[rs2]$	9)
amoswap.w, amoswap.d	R SWAP	$R[rd] = M[R[rs1]], M[R[rs1]] = R[rs2]$	9)
amoxor.w, amoxor.d	R XOR	$R[rd] = M[R[rs1]], M[R[rs1]] = R[rs2]$	9)
lr.w, lr.d	R Load Reserved	$R[rd] = M[R[rs1]], reservation on M[R[rs1]]$	
sc.w, sc.d	R Store Conditional	$\text{if reserved, } M[R[rs1]] = R[rs2], R[rd] = 0; \text{ else } R[rd] = 1$	

CORE INSTRUCTION FORMATS

	31	27	26	25	24	20	19	15	14	12	11	7	6	0
R	func7	rs2	rs1	func3		rd		Opcode						
I	imm[11:0]		rs1	func3		rd		Opcode						
S	imm[11:5]	rs2	rs1	func3	imm[4:0]			opcode						
SB	imm[12:10:5]	rs2	rs1	func3	imm[4:1:11]			opcode						
U	imm[31:12]					rd		opcode						
UJ	imm[20:10:11 19:12]					rd		opcode						

PSEUDO INSTRUCTIONS

MNEMONIC	NAME	DESCRIPTION	USES
beq	Branch = zero	$\text{if}(R[rs1]==0) \text{PC}=\text{PC}+\{\text{imm}, \text{lb}'0\}$	bne
bne	Branch ≠ zero	$\text{if}(R[rs1]≠0) \text{PC}=\text{PC}+\{\text{imm}, \text{lb}'0\}$	beq
fabs.s, fabs.d	Absolute Value	$F[rd] = F[rs1] < 0 ? -F[rs1] : F[rs1]$	fsgnx
fmv.s, fmv.d	FP Move	$F[rd] = F[rs1]$	fsgnj
fneg.s, fneg.d	FP negate	$F[rd] = -F[rs1]$	fsgnjn
j	Jump	$\text{PC} = \{\text{imm}, \text{lb}'0\}$	jal
jr	Jump register	$\text{PC} = R[rs1]$	jalr
la	Load address	$R[rd] = \text{address}$	auipc
li	Load imm	$R[rd] = \text{imm}$	addi
mv	Move	$R[rd] = R[rs1]$	add
neg	Negate	$R[rd] = -R[rs1]$	sub
nop	No operation	$R[rd] = R[rd]$	addi
not	Not	$R[rd] = \neg R[rs1]$	xori
ret	Return	$\text{PC} = R[1]$	jalr
seqz	Set = zero	$R[rd] = (R[rs1]==0) ? 1 : 0$	situ
snez	Set ≠ zero	$R[rd] = (R[rs1]≠0) ? 1 : 0$	situ

OPCODES IN NUMERICAL ORDER BY OPCODE

MNEMONIC	FMT	OPCODE	FUNCT3	FUNCT7 OR IMM	HEXADECIMAL
lb	I	0000011	000		03/0
lh	I	0000011	001		03/1
lw	I	0000011	010		03/2
ld	I	0000011	011		03/3
lbu	I	0000011	100		03/4
lhu	I	0000011	101		03/5
lwu	I	0000011	110		03/6
fence	I	0001111	000		0F/0
fence.i	I	0001111	001		0F/1
addi	I	0010011	000		13/0
slli	I	0010011	001	0000000	13/1/00
slti	I	0010011	010		13/2
sltiu	I	0010011	011		13/3
xori	I	0010011	100		13/4
srli	I	0010011	101	0000000	13/5/00
srai	I	0010011	110	0100000	13/5/20
ori	I	0010011	111		13/6
andi	I	0010011	111		13/7
auipc	U	0010111	000		17
addiw	I	0011011	000		1B/0/0
slliw	I	0011011	001	0000000	1B/1/00
srliw	I	0011011	101	0000000	1B/5/00
sraw	R	0110111	101	0100000	1B/5/20
lui	U	0110111	000		37
addw	R	0111011	000	0000000	3B/0/00
subw	R	0111011	000	0100000	3B/0/20
sllw	R	0111011	001	0000000	3B/1/00
srlw	R	0111011	101	0000000	3B/5/00
sraw	R	0111011	101	0100000	3B/5/20
beq	SB	1100011	000		63/0
bne	SB	1100011	001		63/1
blt	SB	1100011	100		63/4
bge	SB	1100011	101		63/5
bltu	SB	1100011	110		63/6
bgeu	SB	1100011	111		63/7
jalr	I	1100111	000		67/0
jal	UJ	1101111			6F
ecall	I	1110011	000	0000000000000	73/0/000
ebreak	I	1110011	000	0000000000001	73/0/001
CSRRW	I	1110011	001		73/1
CSRWS	I	1110011	010		73/2
CSRRC	I	1110011	011		73/3
CSRRWI	I	1110011	101		73/5
CSRWSI	I	1110011	110		73/6
CSRRCI	I	1110011	111		73/7

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