UnB Departamento de Ciência da Computação

RISC-V

Reference Data v2.3

MNEMONIC	FMT	NAME	DESCRIPTION (in Verilog)	Note	SYNTAX	OPCODE	FUNCT3	FUNCT7	RS2	HEX
lb	I	Load Byte	R[rd]={24'bM[](7),M[R[rs1]+ imm](7:0)}	4)	lb rd,imm(rs1)	0000011	000			03/0
lh	I	Load Halfword	R[rd]={16'bM[](15),M[R[rs1]+ imm](15:0)}	4)	lh rd,imm(rs1)	0000011	001			03/1
lw	I	Load Word	R[rd]=M[R[rs1]+imm]		lw rd,imm(rs1)	0000011	010			03/2
lbu	I	Load Byte Unsigned	R[rd]={24'b0,M[R[rs1]+imm](7:0)}		lbu rd,imm(rs1)	0000011	100			03/4
lhu	I	Load Halfword Unsigned	R[rd]={16'b0,M[R[rs1]+ imm](15:0)}		lhu rd,imm(rs1)	0000011	101			03/5
addi	I	Add Immediate	R[rd]=R[rs1]+imm		addi rd,rs1,imm	0010011	000			13/0
slli	I	Shift Left Logical Imm	R[rd]=R[rs1]<<imm[4:0]		slli rd,rs1,imm	0010011	001	0000000	shamt	13/1/00
slti	I	Set Less Than Immediate	R[rd]=(R[rs1]<imm)?1:0		slti rd,rs1,imm	0010011	010			13/2
sltiu	I	Set Less Than Imm Unsig	R[rd]=(R[rs1]<imm)?1:0	2)	sltiu rd,rs1,imm	0010011	011			13/3
xori	I	XOR Immediate	R[rd]=R[rs1]^imm		xori rd,rs1,imm	0010011	100			13/4
srli	I	Shift Right Logical Imm	R[rd]=R[rs1]>>imm[4:0]		srli rd,rs1,imm	0010011	101	0000000	shamt	13/5/00
srai	I	Shift Right Arith Imm	R[rd]=R[rs1]>>>imm[4:0]	5)	srai rd,rs1,imm	0010011	101	0100000	shamt	13/5/20
ori	I	OR Immediate	R[rd]=R[rs1]|imm		ori rd,rs1,imm	0010011	110			13/6
andi	I	AND Immediate	R[rd]=R[rs1] & imm		andi rd,rs1,imm	0010011	111			13/7
auipc	U	Add Upper Immediate to PC	R[rd]=PC+{imm,12'b0}		auipc rd,imm	0010111				17
sb	S	Store Byte	M[R[rs1]+imm](7:0)=R[rs2](7:0)		sb rs2,imm(rs1)	0100011	000			23/0
sh	S	Store Halfword	M[R[rs1]+imm](15:0)=R[rs2](15:0)		sh rs2,imm(rs1)	0100011	001			23/1
sw	S	Store Word	M[R[rs1]+imm]=R[rs2]		sw rs2,imm(rs1)	0100011	010			23/2
add	R	Add	R[rd]=R[rs1]+R[rs2]		add rd,rs1,rs2	0110011	000	0000000		33/0/00
sub	R	Subtract	R[rd]=R[rs1]-R[rs2]		sub rd,rs1,rs2	0110011	000	0100000		33/0/20
sll	R	Shift Left Logical	R[rd]=R[rs1]<<R[rs2]		sll rd,rs1,rs2	0110011	001	0000000		33/1/00
slt	R	Set Less Than	R[rd]=(R[rs1]<R[rs2])?1:0		slt rd,rs1,rs2	0110011	010	0000000		33/2/00
sltu	R	Set Less Than Unsigned	R[rd]=(R[rs1]<R[rs2])?1:0	2)	sltu rd,rs1,rs2	0110011	011	0000000		33/3/00
xor	R	XOR	R[rd]=R[rs1]^R[rs2]		xor rd,rs1,rs2	0110011	100	0000000		33/4/00
srl	R	Shift Right Logical	R[rd]=R[rs1]>>R[rs2]		srl rd,rs1,rs2	0110011	101	0000000		33/5/00
sra	R	Shift Right Arithmetic	R[rd]=R[rs1]>>>R[rs2]	5)	sra rd,rs1,rs2	0110011	101	0100000		33/5/20
or	R	OR	R[rd]=R[rs1]|R[rs2]		or rd,rs1,rs2	0110011	110	0000000		33/6/00
and	R	AND	R[rd]=R[rs1] & R[rs2]		and rd,rs1,rs2	0110011	111	0000000		33/7/00
lui	U	Load Upper Immediate	R[rd]={imm,12'b0}		lui rd,imm	0110111				37
beq	B	Branch if Equal	if(R[rs1]=R[rs2]) PC=PC+{imm,1'b0}		beq rs1,rs2,imm	1100011	000			63/0
bne	B	Branch if Not Equal	if(R[rs1]!=R[rs2]) PC=PC+{imm,1'b0}		bne rs1,rs2,imm	1100011	001			63/1
blt	B	Branch if Less Than	if(R[rs1]<R[rs2]) PC=PC+{imm,1'b0}		blt rs1,rs2,imm	1100011	100			63/4
bge	B	Branch Greater or Equal	if(R[rs1]>=R[rs2]) PC=PC+{imm,1'b0}		bge rs1,rs2,imm	1100011	101			63/5
bltu	B	Branch Less Than Unsign	if(R[rs1]<R[rs2]) PC=PC+{imm,1'b0}	2)	bltu rs1,rs2,imm	1100011	110			63/6
bgeu	B	Branch Great or Eq Unsign	if(R[rs1]>=R[rs2]) PC=PC+{imm,1'b0}	2)	bgeu rs1,rs2,imm	1100011	111			63/7
jalr	I	Jump & Link Register	R[rd]=PC+4; PC=(R[rs1]+imm)&(!1)	3)	jalr rd,rs1,imm	1100111	000			67/0
jal	J	Jump & Link	R[rd]=PC+4; PC=PC+{imm,1'b0}		jal rd,imm	1101111				6F
ecall	I	Environment CALL	Transfer control to environment system		ecall	1110011	000	0000000	00000	73/0/000
csrrw	I	CSR Read & Write	R[rd]=C[CSR]; C[CSR]=R[rs1]		csrrw rd,CSR,rs1	1110011	001			73/1
csrrs	I	CSR Read & Set	R[rd]=C[CSR]; C[CSR]=C[CSR]|R[rs1]		csrrs rd,CSR,rs1	1110011	010			73/2
csrrc	I	CSR Read & Clear	R[rd]=C[CSR]; C[CSR]=C[CSR]&!R[rs1]		csrrc rd,CSR,rs1	1110011	011			73/3
csrrwi	I	CSR Read & Write Imm	R[rd]=C[CSR]; C[CSR]=imm		csrrwi rd,CSR,imm	1110011	101			73/5
csrrsi	I	CSR Read & Set Imm	R[rd]=C[CSR]; C[CSR]=C[CSR]|imm		csrrsi rd,CSR,imm	1110011	110			73/6
csrrci	I	CSR Read & Clear Imm	R[rd]=C[CSR]; C[CSR]=C[CSR]&!imm		csrrci rd,CSR,imm	1110011	111			73/7
mul	R	Multiply	R[rd]=R[rs1]*R[rs2](31:0)		mul rd,rs1,rs2	0110011	000	0000001		33/0/01
mulh	R	Multiply upper Half	R[rd]=R[rs1]*R[rs2](63:32)		mulh rd,rs1,rs2	0110011	001	0000001		33/1/01
mulhsu	R	Mult upper Half Sign/Uns	R[rd]=R[rs1]*R[rs2](63:32)	6)	mulhsu rd,rs1,rs2	0110011	010	0000001		33/2/01
mulhu	R	Mult upper Half Unsig	R[rd]=R[rs1]*R[rs2](63:32)	2)	mulhu rd,rs1,rs2	0110011	011	0000001		33/3/01
div	R	Divide	R[rd]=(R[rs1]/R[rs2])		div rd,rs1,rs2	0110011	100	0000001		33/4/01
divu	R	Divide Unsigned	R[rd]=(R[rs1]/R[rs2])	2)	divu rd,rs1,rs2	0110011	101	0000001		33/5/01
rem	R	Remainder	R[rd]=(R[rs1]%R[rs2])		rem rd,rs1,rs2	0110011	110	0000001		33/6/01
remu	R	Remainder Unsigned	R[rd]=(R[rs1]%R[rs2])	2)	remu rd,rs1,rs2	0110011	111	0000001		33/7/01
fadd.s	R	Float Point Add	F[rd]=F[rs1]+F[rs2]		fadd.s rd,rs1,rs2	1010011	rm	0000000		53/rm/00
fclass.s	R	Classify type	R[rd]=class(F[rs1])	8)	fclass.s rd,rs1	1010011	001	1110000		53/1/E0
fcvt.s.w	R	Convert from Integer	F[rd]=float(R[rs1])		fcvt.s.w rd,rs1	1010011	rm	1101000	00000	53/rm/D00
fcvt.s.wu	R	Conv from Unsign Integer	F[rd]=float(R[rs1])	2)	fcvt.s.wu rd,rs1	1010011	rm	1101000	00001	53/rm/D01
fcvt.w.s	R	Convert to Integer	R[rd]=integer(F[rs1])		fcvt.w.s rd,rs1	1010011	rm	1100000	00000	53/rm/C00
fcvt.wu.s	R	Convert to Unsign Integer	R[rd]=integer(F[rs1])	2)	fcvt.wu.s rd,rs1	1010011	rm	1100000	00001	53/rm/C01
fdiv.s	R	Float Point Divide	F[rd]=F[rs1]/F[rs2]		fdiv.s rd,rs1,rs2	1010011	rm	0001100		53/rm/0C
feq.s	R	Compare Float Equal	R[rd]=(F[rs1]==F[rs2])?1:0		feq.s rd,rs1,rs2	1010011	010	1010000		53/2/50
fle.s	R	Comp Float Less or Equal	R[rd]=(F[rs1]<=F[rs2])?1:0		fle.s rd,rs1,rs2	1010011	000	1010000		53/0/50
flt.s	R	Compare Float Less Than	R[rd]=(F[rs1]<F[rs2])?1:0		flt.s rd,rs1,rs2	1010011	001	1010000		53/1/50
flw	I	Float Point Load	F[rd]=M[R[rs1]+imm]		flw rd,imm(rs1)	0000111	010			07/2
fmax.s	R	FP Maximum	F[rd]=(F[rs1]>F[rs2])?F[rs1]: F[rs2]		fmax.s rd,rs1,rs2	1010011	001	0010100		53/1/14
fmin.s	R	FP Minimum	F[rd]=(F[rs1]<F[rs2])?F[rs1]: F[rs2]		fmin.s rd,rs1,rs2	1010011	000	0010100		53/0/14
fmul.s	R	Float Point Multiply	F[rd]=F[rs1]*F[rs2]		fmul.s rd,rs1,rs2	1010011	rm	0001000		53/rm/08
fmv.s.x	R	Move from Integer	F[rd]=R[rs1]		fmv.s.x rd,rs1	1010011	000	1111000	00000	53/0/F00
fmv.x.s	R	Move to Integer	R[rd]=F[rs1]		fmv.x.s rd,rs1	1010011	000	1110000	00000	53/0/E00
fsgnj.s	R	Sign source	F[rd]={F[rs2](31),F[rs1](30:0)}		fsgnj.s rd,rs1,rs2	1010011	000	0010000		53/0/10
fsgnjn.s	R	Negative Sign source	F[rd]={!F[rs2](31),F[rs1](30:0)}		fsgnjn.s rd,rs1,rs2	1010011	001	0010000		53/1/10
fsgnjx.s	R	XOR Sign source	F[rd]={F[rs2](31)^F[rs1](31), F[rs1](30:0)}		fsgnjx.s rd,rs1,rs2	1010011	010	0010000		53/2/10
fsqrt.s	R	FP Square Root	F[rd]=sqrt(F[rs1])		fsqrt.s rd,rs1	1010011	rm	0101100	00000	53/rm/580
fsub.s	R	Float Point Subtract	F[rd]=F[rs1]-F[rs2]		fsub.s rd,rs1,rs2	1010011	rm	0000100		53/rm/04
fsw	S	Float Point Store	M[R[rs1]+imm]=F[rs2]		fsw rs2,imm(rs1)	0100111	010			27/2
uret	R	User Return	PC=CSR[UEPC] and other settings		uret	1110011	000	0000000	00010	73/0/200

	NOTES
2)	*Operation assumes unsigned integers (instead 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*
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*
8)	*Classify writes a 10-bit mask to show which properties are true (e.g. –inf, -0, +0, +inf, denorm…)*
	The immediate field is sign-extended in RISC-V

CORE INSTRUCTION FORMATS

	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
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

PSEUDO INSTRUCTIONS *non-exhaustive list

MNEMONIC	NAME	DESCRIPTION
beqz	Branch == Zero	If(R[rs1]==0) PC=PC+{imm,1'b0}
bnez	Branch != Zero	If(R[rs1]!=0) PC=PC+{imm,1'b0}
fabs.s	Absolut Value	F[rd]=(F[rs1]<0)?-F[rs1]:F[rs1]
fmv.s	FP move	F[rd]=F[rs1]
fneg.s	FP negate	F[rd]=-F[rs1]
j	Jump	PC={imm,1'b0}
jr	Jump Register	PC=R[rs1]
la	Load Address	R[rd]=address
li	Load Immediate	R[rd]=immediate
mv	Move	R[rd]=R[rs1]
neg	Negate	R[rd]=-R[rs1]
nop	No Operation	R[zero]=R[zero]+zero
not	Not	R[rd]=!R[rs1]
ret	Return	PC=R[ra]
seqz	Set if == Zero	R[rd]=(R[rs1]==0)?1:0
snez	Set if != Zero	R[rd]=(R[rs1]!=0)?1:0

Decimal Prefix				Binary Prefix	
mili(m)	10^{-3}	kilo(k)	10^{3}	kibi(ki)	2^{10}
micro(μ)	10^{-6}	Mega(M)	10^{6}	Mebi(Mi)	2^{20}
nano(n)	10^{-9}	Giga(G)	10^{9}	Gibi(Gi)	2^{30}
pico(p)	10^{-12}	Tera(T)	10^{12}	Tebi(Ti)	2^{40}
femto(f)	10^{-15}	Peta(P)	10^{15}	Pebi(Pi)	2^{50}
atto(a)	10^{-18}	Exa(E)	10^{18}	Exbi(Ei)	2^{60}
zepto(z)	10^{-21}	Zetta(Z)	10^{21}	Zebi(Zi)	2^{70}
yocto(y)	10^{-24}	Yotta(Y)	10^{24}	Yobi(Yi)	2^{80}

CSR Listing

Number	Privilege	Name	Description
0x000	URW	ustatus	Status register
0x001	URW	fflags	FP accrued exceptions
0x002	URW	frm	FP dynamic rounding mode
0x003	URW	fcsr	FP control and status (frm+fflags)
0x004	URW	uie	Interrupt-enable
0x005	URW	utvec	Trap handler base
0x040	URW	uscratch	Scratch register
0x041	URW	uepc	Exception program counter
0x042	URW	ucause	Trap cause
0x043	URW	utval	Bad address or instruction
0x044	URW	uip	Interrupt pending
0xC00	URO	cycle	Cycle counter
0xC01	URO	time	Timer
0xC02	URO	instret	Instruction-retired counter
0xC80	URO	cycleh	Upper 32 bits of cycle
0xC81	URO	timeh	Upper 32 bits time
0xC82	URO	instreth	Upper 32 bits instret

IEEE 754 FLOATING-POINT STANDARD

$(-1)^{S} \times (1 + \text{Fraction}) \times 2^{(\text{Expoent}-\text{Bias})}$

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

FCSR (Float-point Control and Status Register)

31	...	8	7	6	5	4	3	2	1	0
Reserved			Round Mode			NV	DZ	OF	UF	NX

Round Mode(rm)

000	to even
001	to zero
010	to -∞
011	to +∞
100	to max mag
111	N.A. (Rars)

Flags

NV	Invalid Operation
DZ	Divide by Zero
OF	Overflow
UF	Underflow
NX	Inexact

REGISTER NAME, USE, CALLING CONVENTION

REGISTER	NAME	USE	SAVED?
x0	zero	The constant value 0	N.A.
x1	ra	Return Address	No
x2	sp	Stack Pointer	Yes
x3	gp	Global Pointer	--
x4	tp	Thread Pointer	--
x5-x7	t0-t2	Temporaries	No
x8	s0/fp	Saved Register/Frame Pointer	Yes
x9	s1	Saved Register	Yes
x10-x11	a0-a1	Function Arguments/Return Values	No
x12-x17	a2-a7	Function Arguments	No
x18-x27	s2-s11	Saved Registers	Yes
x28-x31	t3-t6	Temporaries	No
f0-f7	ft0-ft7	FP Temporaries	No
f8-f9	fs0-fs1	FP Saved Registers	Yes
f10-f11	fa0-fa1	FP Function Arguments/Return Values	No
f12-f17	fa2-fa7	FP Function Arguments	No
f18-f27	fs2-fs11	Saved Registers	Yes
f28-f31	ft8-ft11	Temporaries	No

Service	a7	Input	Output
Print Integer	1	a0=integer	Print an Integer on console
Print Float	2	fa0=float	Print a Float on console
Print String	4	a0=address of the string	Print a null-terminated string
Read Integer	5		Return in a0 the integer read from console
Read Float	6		Return in fa0 the float read from console
Read String	8	a0=buffer address, a1=max num characters	Return in a0 address the string read from console
Print Char	11	a0=char (ASCII)	Print a char a0 (ASCII)
Exit	10		Return to operational system
Read Char	12		Return in a0 the ASCII code of a pressed key
Time	30		Return in {a1,a0} the system time
Sleep	32	a0=time(ms)	Sleep for a0 milliseconds
Print Int Hex	34	a0=integer	Print an integer a0 in hexadecimal
Rand	41		Return a random number in a0