

MC100 Certification Requirements Document

Table of Contents

Revision History	27
Typographic Conventions	29
1. Introduction	29
1.1. MC Naming Scheme	30
1.2. MC Class Description	30
1.3. MC100 Description	30
1.4. Related Specifications	31
1.5. Privileged Modes	31
2. Extensions	32
2.1. Mandatory Extensions	32
2.2. Optional Extensions	32
3. Implementation-dependencies	33
3.1. IN-SCOPE Parameters	33
3.2. OUT-OF-SCOPE Parameters	34
4. Instruction Summary	34
5. CSR Summary	38
5.1. By Name	38
5.2. By Address	39
Appendix A: Extension Details	41
A.1. Extension C	41
A.1.1. Synopsis	41
A.1.2. Overview	41
A.1.3. Compressed Instruction Formats	44
A.1.4. Instructions	45
A.1.5. OUT-OF-SCOPE Parameters	46
A.2. Extension I	46
A.2.1. Synopsis	47
A.2.2. Instructions	47
A.3. Extension M	48
A.3.1. Synopsis	49
A.3.2. Instructions	49
A.3.3. OUT-OF-SCOPE Parameters	49
A.4. Extension Sm	50
A.4.1. Synopsis	52

A.4.2. Instructions	52
A.4.3. IN-SCOPE Parameters	52
A.4.4. OUT-OF-SCOPE Parameters	55
A.5. Extension Zicntr	57
A.5.1. Synopsis	57
A.5.2. IN-SCOPE Parameters	57
A.6. Extension Zicsr	57
A.6.1. Instructions	58
Appendix B: Instruction Details	59
B.1. add	60
B.1.1. Encoding	60
B.1.2. Synopsis	60
B.1.3. Access	60
B.1.4. Decode Variables	60
B.1.5. Execution	60
B.1.6. Exceptions	60
B.2. addi	61
B.2.1. Encoding	61
B.2.2. Synopsis	61
B.2.3. Access	61
B.2.4. Decode Variables	61
B.2.5. Execution	61
B.2.6. Exceptions	61
B.3. addiw	62
B.3.1. Encoding	62
B.3.2. Synopsis	62
B.3.3. Access	62
B.3.4. Decode Variables	62
B.3.5. Execution	62
B.3.6. Exceptions	62
B.4. addw	63
B.4.1. Encoding	63
B.4.2. Synopsis	63
B.4.3. Access	63
B.4.4. Decode Variables	63
B.4.5. Execution	63
B.4.6. Exceptions	63
B.5. and	64
B.5.1. Encoding	64
B.5.2. Synopsis	64
B.5.3. Access	64

B.5.4. Decode Variables	64
B.5.5. Execution	64
B.5.6. Exceptions	64
B.6. andi	65
B.6.1. Encoding	65
B.6.2. Synopsis	65
B.6.3. Access	65
B.6.4. Decode Variables	65
B.6.5. Execution	65
B.6.6. Exceptions	65
B.7. auipc	66
B.7.1. Encoding	66
B.7.2. Synopsis	66
B.7.3. Access	66
B.7.4. Decode Variables	66
B.7.5. Execution	66
B.7.6. Exceptions	66
B.8. beq	67
B.8.1. Encoding	67
B.8.2. Synopsis	67
B.8.3. Access	67
B.8.4. Decode Variables	67
B.8.5. Execution	67
B.8.6. Exceptions	67
B.9. bge	68
B.9.1. Encoding	68
B.9.2. Synopsis	68
B.9.3. Access	68
B.9.4. Decode Variables	68
B.9.5. Execution	68
B.9.6. Exceptions	68
B.10. bgeu	69
B.10.1. Encoding	69
B.10.2. Synopsis	69
B.10.3. Access	69
B.10.4. Decode Variables	69
B.10.5. Execution	69
B.10.6. Exceptions	69
B.11. blt	70
B.11.1. Encoding	70
B.11.2. Synopsis	70

B.11.3. Access	70
B.11.4. Decode Variables	70
B.11.5. Execution	70
B.11.6. Exceptions	70
B.12. bltu	71
B.12.1. Encoding	71
B.12.2. Synopsis	71
B.12.3. Access	71
B.12.4. Decode Variables	71
B.12.5. Execution	71
B.12.6. Exceptions	71
B.13. bne	72
B.13.1. Encoding	72
B.13.2. Synopsis	72
B.13.3. Access	72
B.13.4. Decode Variables	72
B.13.5. Execution	72
B.13.6. Exceptions	72
B.14. c.add	73
B.14.1. Encoding	73
B.14.2. Synopsis	73
B.14.3. Access	73
B.14.4. Decode Variables	73
B.14.5. Execution	73
B.14.6. Exceptions	73
B.15. c.addi	74
B.15.1. Encoding	74
B.15.2. Synopsis	74
B.15.3. Access	74
B.15.4. Decode Variables	74
B.15.5. Execution	74
B.15.6. Exceptions	74
B.16. c.addi16sp	75
B.16.1. Encoding	75
B.16.2. Synopsis	75
B.16.3. Access	75
B.16.4. Decode Variables	75
B.16.5. Execution	75
B.16.6. Exceptions	75
B.17. c.addi4spn	76
B.17.1. Encoding	76

B.17.2. Synopsis	76
B.17.3. Access	76
B.17.4. Decode Variables	76
B.17.5. Execution	76
B.17.6. Exceptions	76
B.18. c.addiw	77
B.18.1. Encoding	77
B.18.2. Synopsis	77
B.18.3. Access	77
B.18.4. Decode Variables	77
B.18.5. Execution	77
B.18.6. Exceptions	77
B.19. c.addw	78
B.19.1. Encoding	78
B.19.2. Synopsis	78
B.19.3. Access	78
B.19.4. Decode Variables	78
B.19.5. Execution	78
B.19.6. Exceptions	78
B.20. c.and	79
B.20.1. Encoding	79
B.20.2. Synopsis	79
B.20.3. Access	79
B.20.4. Decode Variables	79
B.20.5. Execution	79
B.20.6. Exceptions	79
B.21. c.andi	80
B.21.1. Encoding	80
B.21.2. Synopsis	80
B.21.3. Access	80
B.21.4. Decode Variables	80
B.21.5. Execution	80
B.21.6. Exceptions	80
B.22. c.beqz	81
B.22.1. Encoding	81
B.22.2. Synopsis	81
B.22.3. Access	81
B.22.4. Decode Variables	81
B.22.5. Execution	81
B.22.6. Exceptions	82
B.23. c.bnez	83

B.23.1. Encoding	83
B.23.2. Synopsis	83
B.23.3. Access	83
B.23.4. Decode Variables	83
B.23.5. Execution	83
B.23.6. Exceptions	84
B.24. c.ebreak	85
B.24.1. Encoding	85
B.24.2. Synopsis	85
B.24.3. Access	85
B.24.4. Decode Variables	85
B.24.5. Execution	85
B.24.6. Exceptions	86
B.25. c.j	87
B.25.1. Encoding	87
B.25.2. Synopsis	87
B.25.3. Access	87
B.25.4. Decode Variables	87
B.25.5. Execution	87
B.25.6. Exceptions	87
B.26. c.jal	88
B.26.1. Encoding	88
B.26.2. Synopsis	88
B.26.3. Access	88
B.26.4. Decode Variables	88
B.26.5. Execution	88
B.26.6. Exceptions	88
B.27. c.jalr	90
B.27.1. Encoding	90
B.27.2. Synopsis	90
B.27.3. Access	90
B.27.4. Decode Variables	90
B.27.5. Execution	90
B.27.6. Exceptions	90
B.28. c.jr	92
B.28.1. Encoding	92
B.28.2. Synopsis	92
B.28.3. Access	92
B.28.4. Decode Variables	92
B.28.5. Execution	92
B.28.6. Exceptions	92

B.29. c.ld	93
B.29.1. Encoding	93
B.29.2. Synopsis	93
B.29.3. Access	93
B.29.4. Decode Variables	93
B.29.5. Execution	93
B.29.6. Exceptions	93
B.30. c.ldsp	95
B.30.1. Encoding	95
B.30.2. Synopsis	95
B.30.3. Access	95
B.30.4. Decode Variables	95
B.30.5. Execution	95
B.30.6. Exceptions	95
B.31. c.li	97
B.31.1. Encoding	97
B.31.2. Synopsis	97
B.31.3. Access	97
B.31.4. Decode Variables	97
B.31.5. Execution	97
B.31.6. Exceptions	97
B.32. c.lq	98
B.32.1. Encoding	98
B.32.2. Synopsis	98
B.32.3. Access	98
B.32.4. Decode Variables	98
B.32.5. Execution	98
B.32.6. Exceptions	98
B.33. c.lqsp	100
B.33.1. Encoding	100
B.33.2. Synopsis	100
B.33.3. Access	100
B.33.4. Decode Variables	100
B.33.5. Execution	100
B.33.6. Exceptions	100
B.34. c.lui	102
B.34.1. Encoding	102
B.34.2. Synopsis	102
B.34.3. Access	102
B.34.4. Decode Variables	102
B.34.5. Execution	102

B.34.6. Exceptions	102
B.35. c.lw	104
B.35.1. Encoding	104
B.35.2. Synopsis	104
B.35.3. Access	104
B.35.4. Decode Variables	104
B.35.5. Execution	104
B.35.6. Exceptions	104
B.36. c.lwsp	106
B.36.1. Encoding	106
B.36.2. Synopsis	106
B.36.3. Access	106
B.36.4. Decode Variables	106
B.36.5. Execution	106
B.36.6. Exceptions	106
B.37. c.mv	108
B.37.1. Encoding	108
B.37.2. Synopsis	108
B.37.3. Access	108
B.37.4. Decode Variables	108
B.37.5. Execution	108
B.37.6. Exceptions	108
B.38. c.nop	109
B.38.1. Encoding	109
B.38.2. Synopsis	109
B.38.3. Access	109
B.38.4. Decode Variables	109
B.38.5. Execution	109
B.38.6. Exceptions	109
B.39. c.or	110
B.39.1. Encoding	110
B.39.2. Synopsis	110
B.39.3. Access	110
B.39.4. Decode Variables	110
B.39.5. Execution	110
B.39.6. Exceptions	110
B.40. c.sd	111
B.40.1. Encoding	111
B.40.2. Synopsis	111
B.40.3. Access	111
B.40.4. Decode Variables	111

B.40.5. Execution	111
B.40.6. Exceptions	111
B.41. c.sdsp	113
B.41.1. Encoding	113
B.41.2. Synopsis	113
B.41.3. Access	113
B.41.4. Decode Variables	113
B.41.5. Execution	113
B.41.6. Exceptions	113
B.42. c.slli	115
B.42.1. Encoding	115
B.42.2. Synopsis	115
B.42.3. Access	115
B.42.4. Decode Variables	115
B.42.5. Execution	115
B.42.6. Exceptions	115
B.43. c.sq	116
B.43.1. Encoding	116
B.43.2. Synopsis	116
B.43.3. Access	116
B.43.4. Decode Variables	116
B.43.5. Execution	116
B.43.6. Exceptions	116
B.44. c.sqsp	118
B.44.1. Encoding	118
B.44.2. Synopsis	118
B.44.3. Access	118
B.44.4. Decode Variables	118
B.44.5. Execution	118
B.44.6. Exceptions	118
B.45. c.srai	120
B.45.1. Encoding	120
B.45.2. Synopsis	120
B.45.3. Access	120
B.45.4. Decode Variables	120
B.45.5. Execution	120
B.45.6. Exceptions	120
B.46. c.srli	121
B.46.1. Encoding	121
B.46.2. Synopsis	121
B.46.3. Access	121

B.46.4. Decode Variables	121
B.46.5. Execution	121
B.46.6. Exceptions	121
B.47. c.sub	122
B.47.1. Encoding	122
B.47.2. Synopsis	122
B.47.3. Access	122
B.47.4. Decode Variables	122
B.47.5. Execution	122
B.47.6. Exceptions	122
B.48. c.subw	123
B.48.1. Encoding	123
B.48.2. Synopsis	123
B.48.3. Access	123
B.48.4. Decode Variables	123
B.48.5. Execution	123
B.48.6. Exceptions	123
B.49. c.sw	124
B.49.1. Encoding	124
B.49.2. Synopsis	124
B.49.3. Access	124
B.49.4. Decode Variables	124
B.49.5. Execution	124
B.49.6. Exceptions	124
B.50. c.swsp	126
B.50.1. Encoding	126
B.50.2. Synopsis	126
B.50.3. Access	126
B.50.4. Decode Variables	126
B.50.5. Execution	126
B.50.6. Exceptions	126
B.51. c.xor	128
B.51.1. Encoding	128
B.51.2. Synopsis	128
B.51.3. Access	128
B.51.4. Decode Variables	128
B.51.5. Execution	128
B.51.6. Exceptions	128
B.52. csrrc	129
B.52.1. Encoding	129
B.52.2. Synopsis	129

B.52.3. Access	129
B.52.4. Decode Variables	129
B.52.5. Execution	129
B.52.6. Exceptions	129
B.53. csrrci	130
B.53.1. Encoding	130
B.53.2. Synopsis	130
B.53.3. Access	130
B.53.4. Decode Variables	130
B.53.5. Execution	130
B.53.6. Exceptions	130
B.54. csrrs	131
B.54.1. Encoding	131
B.54.2. Synopsis	131
B.54.3. Access	131
B.54.4. Decode Variables	131
B.54.5. Execution	131
B.54.6. Exceptions	131
B.55. csrrsi	132
B.55.1. Encoding	132
B.55.2. Synopsis	132
B.55.3. Access	132
B.55.4. Decode Variables	132
B.55.5. Execution	132
B.55.6. Exceptions	132
B.56. csrrw	133
B.56.1. Encoding	133
B.56.2. Synopsis	133
B.56.3. Access	133
B.56.4. Decode Variables	133
B.56.5. Execution	133
B.56.6. Exceptions	133
B.57. csrrwi	134
B.57.1. Encoding	134
B.57.2. Synopsis	134
B.57.3. Access	134
B.57.4. Decode Variables	134
B.57.5. Execution	134
B.57.6. Exceptions	134
B.58. div	135
B.58.1. Encoding	135

B.58.2. Synopsis	135
B.58.3. Access	135
B.58.4. Decode Variables	135
B.58.5. Execution	135
B.58.6. Exceptions	136
B.59. divu	137
B.59.1. Encoding	137
B.59.2. Synopsis	137
B.59.3. Access	137
B.59.4. Decode Variables	137
B.59.5. Execution	137
B.59.6. Exceptions	138
B.60. divuw	139
B.60.1. Encoding	139
B.60.2. Synopsis	139
B.60.3. Access	139
B.60.4. Decode Variables	139
B.60.5. Execution	139
B.60.6. Exceptions	140
B.61. divw	141
B.61.1. Encoding	141
B.61.2. Synopsis	141
B.61.3. Access	141
B.61.4. Decode Variables	141
B.61.5. Execution	141
B.61.6. Exceptions	142
B.62. ebreak	143
B.62.1. Encoding	143
B.62.2. Synopsis	143
B.62.3. Access	143
B.62.4. Decode Variables	143
B.62.5. Execution	143
B.62.6. Exceptions	143
B.63. ecall	145
B.63.1. Encoding	145
B.63.2. Synopsis	145
B.63.3. Access	145
B.63.4. Decode Variables	145
B.63.5. Execution	145
B.63.6. Exceptions	146
B.64. fence	147

B.64.1. Encoding	147
B.64.2. Synopsis	147
B.64.3. Access	148
B.64.4. Decode Variables	149
B.64.5. Execution	149
B.64.6. Exceptions	150
B.65. jal	151
B.65.1. Encoding	151
B.65.2. Synopsis	151
B.65.3. Access	151
B.65.4. Decode Variables	151
B.65.5. Execution	151
B.65.6. Exceptions	151
B.66. jalr	152
B.66.1. Encoding	152
B.66.2. Synopsis	152
B.66.3. Access	152
B.66.4. Decode Variables	152
B.66.5. Execution	152
B.66.6. Exceptions	152
B.67. lb	153
B.67.1. Encoding	153
B.67.2. Synopsis	153
B.67.3. Access	153
B.67.4. Decode Variables	153
B.67.5. Execution	153
B.67.6. Exceptions	153
B.68. lbu	154
B.68.1. Encoding	154
B.68.2. Synopsis	154
B.68.3. Access	154
B.68.4. Decode Variables	154
B.68.5. Execution	154
B.68.6. Exceptions	154
B.69. ld	155
B.69.1. Encoding	155
B.69.2. Synopsis	155
B.69.3. Access	155
B.69.4. Decode Variables	155
B.69.5. Execution	155
B.69.6. Exceptions	155

B.70. lh	156
B.70.1. Encoding	156
B.70.2. Synopsis	156
B.70.3. Access	156
B.70.4. Decode Variables	156
B.70.5. Execution	156
B.70.6. Exceptions	156
B.71. lhu	157
B.71.1. Encoding	157
B.71.2. Synopsis	157
B.71.3. Access	157
B.71.4. Decode Variables	157
B.71.5. Execution	157
B.71.6. Exceptions	157
B.72. lui	158
B.72.1. Encoding	158
B.72.2. Synopsis	158
B.72.3. Access	158
B.72.4. Decode Variables	158
B.72.5. Execution	158
B.72.6. Exceptions	158
B.73. lw	159
B.73.1. Encoding	159
B.73.2. Synopsis	159
B.73.3. Access	159
B.73.4. Decode Variables	159
B.73.5. Execution	159
B.73.6. Exceptions	159
B.74. lwu	160
B.74.1. Encoding	160
B.74.2. Synopsis	160
B.74.3. Access	160
B.74.4. Decode Variables	160
B.74.5. Execution	160
B.74.6. Exceptions	160
B.75. mret	161
B.75.1. Encoding	161
B.75.2. Synopsis	161
B.75.3. Access	161
B.75.4. Decode Variables	161
B.75.5. Execution	161

B.75.6. Exceptions	161
B.76. mul	162
B.76.1. Encoding	162
B.76.2. Synopsis	162
B.76.3. Access	162
B.76.4. Decode Variables	162
B.76.5. Execution	162
B.76.6. Exceptions	163
B.77. mulh	164
B.77.1. Encoding	164
B.77.2. Synopsis	164
B.77.3. Access	164
B.77.4. Decode Variables	164
B.77.5. Execution	164
B.77.6. Exceptions	165
B.78. mulhsu	166
B.78.1. Encoding	166
B.78.2. Synopsis	166
B.78.3. Access	166
B.78.4. Decode Variables	166
B.78.5. Execution	166
B.78.6. Exceptions	167
B.79. mulhu	168
B.79.1. Encoding	168
B.79.2. Synopsis	168
B.79.3. Access	168
B.79.4. Decode Variables	168
B.79.5. Execution	168
B.79.6. Exceptions	169
B.80. mulw	170
B.80.1. Encoding	170
B.80.2. Synopsis	170
B.80.3. Access	170
B.80.4. Decode Variables	170
B.80.5. Execution	170
B.80.6. Exceptions	171
B.81. or	172
B.81.1. Encoding	172
B.81.2. Synopsis	172
B.81.3. Access	172
B.81.4. Decode Variables	172

B.81.5. Execution	172
B.81.6. Exceptions	172
B.82. ori	173
B.82.1. Encoding	173
B.82.2. Synopsis	173
B.82.3. Access	173
B.82.4. Decode Variables	173
B.82.5. Execution	173
B.82.6. Exceptions	174
B.83. rem	175
B.83.1. Encoding	175
B.83.2. Synopsis	175
B.83.3. Access	175
B.83.4. Decode Variables	175
B.83.5. Execution	175
B.83.6. Exceptions	176
B.84. remu	177
B.84.1. Encoding	177
B.84.2. Synopsis	177
B.84.3. Access	177
B.84.4. Decode Variables	177
B.84.5. Execution	177
B.84.6. Exceptions	177
B.85. remuw	178
B.85.1. Encoding	178
B.85.2. Synopsis	178
B.85.3. Access	178
B.85.4. Decode Variables	178
B.85.5. Execution	178
B.85.6. Exceptions	179
B.86. remw	180
B.86.1. Encoding	180
B.86.2. Synopsis	180
B.86.3. Access	180
B.86.4. Decode Variables	180
B.86.5. Execution	180
B.86.6. Exceptions	181
B.87. sb	182
B.87.1. Encoding	182
B.87.2. Synopsis	182
B.87.3. Access	182

B.87.4. Decode Variables	182
B.87.5. Execution	182
B.87.6. Exceptions	182
B.88. sd	183
B.88.1. Encoding	183
B.88.2. Synopsis	183
B.88.3. Access	183
B.88.4. Decode Variables	183
B.88.5. Execution	183
B.88.6. Exceptions	183
B.89. sh	184
B.89.1. Encoding	184
B.89.2. Synopsis	184
B.89.3. Access	184
B.89.4. Decode Variables	184
B.89.5. Execution	184
B.89.6. Exceptions	184
B.90. sll	185
B.90.1. Encoding	185
B.90.2. Synopsis	185
B.90.3. Access	185
B.90.4. Decode Variables	185
B.90.5. Execution	185
B.90.6. Exceptions	185
B.91. slli	186
B.91.1. Encoding	186
B.91.2. Synopsis	186
B.91.3. Access	186
B.91.4. Decode Variables	186
B.91.5. Execution	187
B.91.6. Exceptions	187
B.92. slliw	188
B.92.1. Encoding	188
B.92.2. Synopsis	188
B.92.3. Access	188
B.92.4. Decode Variables	188
B.92.5. Execution	188
B.92.6. Exceptions	188
B.93. sllw	189
B.93.1. Encoding	189
B.93.2. Synopsis	189

B.93.3. Access	189
B.93.4. Decode Variables	189
B.93.5. Execution	189
B.93.6. Exceptions	189
B.94. slt	190
B.94.1. Encoding	190
B.94.2. Synopsis	190
B.94.3. Access	190
B.94.4. Decode Variables	190
B.94.5. Execution	190
B.94.6. Exceptions	190
B.95. slti	191
B.95.1. Encoding	191
B.95.2. Synopsis	191
B.95.3. Access	191
B.95.4. Decode Variables	191
B.95.5. Execution	191
B.95.6. Exceptions	191
B.96. sltiu	192
B.96.1. Encoding	192
B.96.2. Synopsis	192
B.96.3. Access	192
B.96.4. Decode Variables	192
B.96.5. Execution	192
B.96.6. Exceptions	192
B.97. sltu	193
B.97.1. Encoding	193
B.97.2. Synopsis	193
B.97.3. Access	193
B.97.4. Decode Variables	193
B.97.5. Execution	193
B.97.6. Exceptions	193
B.98. sra	194
B.98.1. Encoding	194
B.98.2. Synopsis	194
B.98.3. Access	194
B.98.4. Decode Variables	194
B.98.5. Execution	194
B.98.6. Exceptions	194
B.99. srai	195
B.99.1. Encoding	195

B.99.2. Synopsis	195
B.99.3. Access	195
B.99.4. Decode Variables	195
B.99.5. Execution	196
B.99.6. Exceptions	196
B.100. sraiw	197
B.100.1. Encoding	197
B.100.2. Synopsis	197
B.100.3. Access	197
B.100.4. Decode Variables	197
B.100.5. Execution	197
B.100.6. Exceptions	197
B.101. srav	198
B.101.1. Encoding	198
B.101.2. Synopsis	198
B.101.3. Access	198
B.101.4. Decode Variables	198
B.101.5. Execution	198
B.101.6. Exceptions	198
B.102. srl	199
B.102.1. Encoding	199
B.102.2. Synopsis	199
B.102.3. Access	199
B.102.4. Decode Variables	199
B.102.5. Execution	199
B.102.6. Exceptions	199
B.103. srli	200
B.103.1. Encoding	200
B.103.2. Synopsis	200
B.103.3. Access	200
B.103.4. Decode Variables	200
B.103.5. Execution	201
B.103.6. Exceptions	201
B.104. srliw	202
B.104.1. Encoding	202
B.104.2. Synopsis	202
B.104.3. Access	202
B.104.4. Decode Variables	202
B.104.5. Execution	202
B.104.6. Exceptions	202
B.105. srlw	203

B.105.1. Encoding	203
B.105.2. Synopsis	203
B.105.3. Access	203
B.105.4. Decode Variables	203
B.105.5. Execution	203
B.105.6. Exceptions	203
B.106. sub	204
B.106.1. Encoding	204
B.106.2. Synopsis	204
B.106.3. Access	204
B.106.4. Decode Variables	204
B.106.5. Execution	204
B.106.6. Exceptions	204
B.107. subw	205
B.107.1. Encoding	205
B.107.2. Synopsis	205
B.107.3. Access	205
B.107.4. Decode Variables	205
B.107.5. Execution	205
B.107.6. Exceptions	205
B.108. sw	206
B.108.1. Encoding	206
B.108.2. Synopsis	206
B.108.3. Access	206
B.108.4. Decode Variables	206
B.108.5. Execution	206
B.108.6. Exceptions	206
B.109. wfi	207
B.109.1. Encoding	207
B.109.2. Synopsis	207
B.109.3. Access	207
B.109.4. Decode Variables	208
B.109.5. Execution	208
B.109.6. Exceptions	209
B.110. xor	210
B.110.1. Encoding	210
B.110.2. Synopsis	210
B.110.3. Access	210
B.110.4. Decode Variables	210
B.110.5. Execution	210
B.110.6. Exceptions	210

B.111. xori	211
B.111.1. Encoding	211
B.111.2. Synopsis	211
B.111.3. Access	211
B.111.4. Decode Variables	211
B.111.5. Execution	211
B.111.6. Exceptions	211
Appendix C: CSR Details	212
C.1. cycle	213
C.1.1. Attributes	213
C.1.2. Format	213
C.1.3. Field Summary	213
C.1.4. Fields	214
COUNT	214
C.1.5. Software read	214
C.2. cycleh	216
C.2.1. Attributes	216
C.2.2. Format	216
C.2.3. Field Summary	216
C.2.4. Fields	217
COUNT	217
C.2.5. Software read	217
C.3. instret	219
C.3.1. Attributes	219
C.3.2. Format	219
C.3.3. Field Summary	219
C.3.4. Fields	220
COUNT	220
C.3.5. Software read	220
C.4. instreth	222
C.4.1. Attributes	222
C.4.2. Format	222
C.4.3. Field Summary	222
C.4.4. Fields	223
COUNT	223
C.4.5. Software read	223
C.5. marchid	225
C.5.1. Attributes	225
C.5.2. Format	225
C.5.3. Field Summary	226
C.5.4. Fields	226

Architecture	226
C.6. mcause	227
C.6.1. Attributes	227
C.6.2. Format	227
C.6.3. Field Summary	227
C.6.4. Fields	227
INT	227
CODE	228
C.6.5. Software write	229
C.7. mcountinhibit	230
C.7.1. Attributes	230
C.7.2. Format	230
C.7.3. Field Summary	231
C.7.4. Fields	233
CY	233
IR	233
HPM3	234
HPM4	234
HPM5	235
HPM6	235
HPM7	236
HPM8	236
HPM9	237
HPM10	237
HPM11	238
HPM12	238
HPM13	239
HPM14	239
HPM15	240
HPM16	240
HPM17	241
HPM18	241
HPM19	242
HPM20	242
HPM21	243
HPM22	243
HPM23	244
HPM24	244
HPM25	245
HPM26	245
HPM27	246

HPM28	246
HPM29	247
HPM30	247
HPM31	248
C.8. mcycle	249
C.8.1. Attributes	249
C.8.2. Format	249
C.8.3. Field Summary	249
C.8.4. Fields	249
COUNT	249
C.8.5. Software write	250
C.8.6. Software read	251
C.9. mcycleh	252
C.9.1. Attributes	252
C.9.2. Format	252
C.9.3. Field Summary	252
C.9.4. Fields	252
COUNT	252
C.9.5. Software write	253
C.9.6. Software read	253
C.10. mepc	254
C.10.1. Attributes	254
C.10.2. Format	254
C.10.3. Field Summary	254
C.10.4. Fields	254
PC	254
C.10.5. Software write	255
C.10.6. Software read	255
C.11. mhartid	256
C.11.1. Attributes	256
C.11.2. Format	256
C.11.3. Field Summary	256
C.11.4. Fields	256
ID	256
C.11.5. Software read	257
C.12. mie	258
C.12.1. Attributes	260
C.12.2. Format	260
C.12.3. Field Summary	260
C.12.4. Fields	261
SSIE	261

VSSIE	261
MSIE	262
STIE	262
VSTIE	262
MTIE	263
SEIE	263
VSEIE	264
MEIE	264
SGEIE	264
LCOFIE	265
C.13. minpid	266
C.13.1. Attributes	266
C.13.2. Format	266
C.13.3. Field Summary	266
C.13.4. Fields	266
Implementation	266
C.14. minstret	268
C.14.1. Attributes	268
C.14.2. Format	268
C.14.3. Field Summary	268
C.14.4. Fields	268
COUNT	268
C.15. minstreth	270
C.15.1. Attributes	270
C.15.2. Format	270
C.15.3. Field Summary	270
C.15.4. Fields	270
COUNT	270
C.15.5. Software write	271
C.15.6. Software read	271
C.16. mip	272
C.16.1. Attributes	274
C.16.2. Format	274
C.16.3. Field Summary	274
C.16.4. Fields	275
SSIP	275
VSSIP	276
MSIP	276
STIP	277
VSTIP	278
MTIP	279

SEIP	279
VSEIP	280
MEIP	280
SGEIP	281
LCOFIP	281
C.17. misa	283
C.17.1. Attributes	283
C.17.2. Format	283
C.17.3. Field Summary	283
C.17.4. Fields	284
MXL	284
A	284
B	285
C	285
D	286
F	286
G	287
H	287
I	288
M	288
S	288
U	289
V	289
C.17.5. Software write	290
C.17.6. Software read	290
C.18. mscratch	291
C.18.1. Attributes	291
C.18.2. Format	291
C.18.3. Field Summary	291
C.18.4. Fields	291
SCRATCH	291
C.19. mstatus	292
C.19.1. Attributes	292
C.19.2. Format	292
C.19.3. Field Summary	292
C.19.4. Fields	293
SD	293
TSR	294
TW	294
TVM	295
MXR	295

SUM	296
MPRV	296
XS	297
FS	297
MPP	298
VS	299
SPP	299
MPIE	300
UBE	300
SPIE	301
MIE	302
SIE	302
C.19.5. Software write	303
C.20. mtval	305
C.20.1. Attributes	305
C.20.2. Format	305
C.20.3. Field Summary	305
C.20.4. Fields	305
VALUE	305
C.21. mtvec	308
C.21.1. Attributes	308
C.21.2. Format	308
C.21.3. Field Summary	308
C.21.4. Fields	308
BASE	308
MODE	309
C.21.5. Software write	309
C.22. mvendorid	311
C.22.1. Attributes	311
C.22.2. Format	311
C.22.3. Field Summary	311
C.22.4. Fields	311
Bank	311
Offset	312
C.23. time	313
C.23.1. Attributes	313
C.23.2. Format	313
C.23.3. Field Summary	314
C.23.4. Fields	314
COUNT	314
C.23.5. Software read	314

C.24. timeh	316
C.24.1. Attributes	316
C.24.2. Format	316
C.24.3. Field Summary	316
C.24.4. Fields	317
COUNT	317
C.24.5. Software read	317

Revision History

History of documentation changes that eventually lead to releases.

Date	Revision	Changes
2024-07-29	0.7.0	<ul style="list-style-type: none"> • First version after moving non-microcontroller content in this document to a new document called "RISC-V CRDs (Certification Requirement Documents)" • Change MC100 Unpriv ISA spec from "riscv-spec-v2.1, May 31, 2016" to https://github.com/riscv/riscv-isa-manual/releases/tag/Ratified-IMAFDQC since the former isn't ratified by the latter is the oldest ratified version. • Added requirements for WFI instruction • Added requirements related to msip memory-mapped register

Date	Revision	Changes
2024-07-11	0.6.0	<ul style="list-style-type: none"> • Supporting multiple MC versions to support customers wanting to certify existing microcontrollers not using the latest version of ratified standards. • Changed versioning scheme to use major.minor.patch instead of 3-digit major & minor. • Added a table showing the mapping from MC version to ISA manuals. • Reluctantly made interrupts OUT OF SCOPE for MC100 since only the CLINT interrupt controller was ratified at that time and isn't anticipated to be the interrupt controller used by MC100 implementations. • Clarified MANDATORY behaviors for mie and mip CSRs • Removed canonical discovery recipe because the OPT-* options directly inform the certification tests and certification reference model of the status of the various options. Also, canonical discovery recipes (e.g., probing for CLIC) violate the certification approach of avoiding writing potentially illegal values to CSR fields. • Added more options for interrupts • Moved non-microcontroller content in this document to a new document called "RISC-V Certification Plans"
2024-06-03	0.5.0	<ul style="list-style-type: none"> • Renamed to "RISC-V Microcontroller Certification Plan" based on Jason's recommendation • Added mvendorid, marchid, mimpid, and mhardid read-only priv CSRs because Allen pointed out these are mandatory in M-mode v1.13 (probably older versions too, haven't looked yet). • Added table showing mapping of MC versions to associated RISC-V specifications
2024-06-03	0.4.0	<ul style="list-style-type: none"> • Added M-mode instruction requirements • Made Zicntr MANDATORY due to very low cost for implementations to support (in the spirit of minimizing options). • Removed OPT-CNTR-PREC since minstret and mcycle must be a full 64 bits to be standard-compliant.
2024-05-25	0.3.0	<ul style="list-style-type: none"> • Includes Zicntr as OPTIONAL and then has only 32-bit counters for instret and cycle.
2024-05-20	0.2.0	<ul style="list-style-type: none"> • Very early draft
2024-05-16	0.1.0	<ul style="list-style-type: none"> • Initial version

Typographic Conventions

CSR field colors

- Grey fields are reserved (WPRI)
- Green fields are present
- Red fields are defined by the RISC-V ISA but not present

CSR field types

Abbreviation	Description
RO	Read-Only Field has a hardwired value that does not change. Writes to an RO field are ignored.
RO-H	Read-Only with Hardware update Writes are ignored. Reads reflect a value dynamically generated by hardware.
RW	Read-Write Field is writable by software. Any value that fits in the field is acceptable and shall be retained for subsequent reads.
RW-R	Read-Write Restricted Field is writable by software. Only certain values are legal. Writing an illegal value into the field is ignored, and the field retains its prior state.
RW-H	Read-Write with Hardware update Field is writable by software. Any value that fits in the field is acceptable. Hardware also updates the field without an explicit software write.
RW-RH	Read-Write Restricted with Hardware update Field is writeable by software. Only certain values are legal. Writing an illegal value into the field is ignored, such that the field retains its prior state. Hardware also updates the field without an explicit software write.)

1. Introduction

This certification class specifies requirements for microcontrollers. It targets microcontrollers running low-level software on an RTOS or bare-metal. This CRD is not intended for the smallest possible microcontrollers but rather for applications benefiting from a standardized microcontroller. See the [RISC-V CRDs](#) document for information relevant to all RISC-V CRDs.

1.1. MC Naming Scheme

The MC (M = Microcontroller, C = Certificate) has the following naming scheme (suffixes after MC are optional but in the below order):

```
MC<model>[v<version>]
```

Where:

- Left & right square braces denote optional.
- `\<model>` is a 3 digit integer. It is changed only when mandatory extensions are added to a CRD.
 - The one's digit is incremented when a small mandatory extension is added (e.g., Zicond)
 - The ten's digit is incremented when a medium mandatory extension is added (e.g., PMP)
 - The hundreds's digit is incremented when a large mandatory extension is added (e.g., V or H)
- `\<version>` is a semantic version (see semver.org) formatted as `<major>[.<minor>.[patch]]`. If `\<version>` is omitted, the reference applies equally to all versions.
 - A `<major>` release indicates support for a new optional extension.
 - A `<minor>` release indicates one or more of the following changes to the certification tests associated with the CRD.
 - Fix test bug or increase test coverage
 - Add more allowed parameter values
 - Support new extension version
 - A `<patch>` release indicates just CRD specification changes without any difference in functional behavior

1.2. MC Class Description

1.3. MC100 Description

MC100 can be thought of as minimal 32-bit RISC-V processors with M-mode support:

- The Unprivileged ISA is RV32I with a few extensions suitable for a basic microcontroller
- The M-mode features are those listed as mandatory in the associated RISC-V Privileged ISA manual

Key features not included in MC100 (i.e., OUT OF SCOPE):

- Interrupt Controller (e.g., CLIC, CLINT, PLIC)
- Features for modes other than M-mode
- PMP

- Debug & trace (TBD)

1.4. Related Specifications

Certificate Model	TSC Profile	Unpriv ISA Manual	Priv ISA Manual	Debug Manual
MC100	No profile	20191213	20190608-Priv-MSU-Ratified	0.13.2

1.5. Privileged Modes

M	S	U	VS	VU
MANDATORY	OUT-OF-SCOPE	OUT-OF-SCOPE	OUT-OF-SCOPE	OUT-OF-SCOPE

2. Extensions

Any RISC-V extension not listed in this section is OUT-OF-SCOPE so the MC100 certificate doesn't cover its associated behaviors.

2.1. Mandatory Extensions

Requirement ID	Extension	Version	Long Name	Note
REQ-EXT-C	C	~> 2.2	Compressed instructions	
REQ-EXT-I	I	~> 2.1	Base integer ISA (RV32I or RV64I)	
REQ-EXT-M	M	~> 2.0	Integer multiply and divide instructions	
REQ-EXT-Sm	Sm	~> 1.11.0	Machine mode	
REQ-EXT-Zicntr	Zicntr	~> 2.0	Architectural performance counters	
REQ-EXT-Zicsr	Zicsr	~> 2.0	Control and status registers	

2.2. Optional Extensions

None

3. Implementation-dependencies

RISC-V standards support many implementation-defined parameters. In many cases, there are no names associated with these parameters. Names are defined in this section when not provided in the associated standard.

3.1. IN-SCOPE Parameters

These implementation-dependent options defined by MANDATORY or OPTIONAL extensions are IN-SCOPE. An implementation must abide by the "Allowed Value(s)" to obtain a certificate. If the "Allowed Value(s)" is "Any" then any value allowed by the type is acceptable.

Parameter	Type	Allowed Value(s)	Extension(s)	Note
ARCH_ID	64-bit integer	Any	Sm	
IMP_ID	64-bit integer	Any	Sm	
MISALIGNED_LDST	boolean	Any	Sm	
MISALIGNED_LDST_EXCEPTION_PRIORITY	[low, high]	Any	Sm	
MISALIGNED_MAX_ATOMICITY_GRANULE_SIZE	[0, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096]	Any	Sm	
MISALIGNED_SPLIT_STRATEGY	[by_byte, custom]	by_byte	Sm	
MISA_CSR_IMPLEMENTED	boolean	Any	Sm	
MTVAL_WIDTH	≤ 64	Any	Sm	
MTVEC_BASE_ALIGNMENT_DIRECT	≥ 4	Any	Sm	
MTVEC_BASE_ALIGNMENT_VECTORED	≥ 4	Any	Sm	
MTVEC_MODES	1-element to 2-element array of [0, 1]	Any	Sm	
M_MODE_ENDIANNESS	[little, big, dynamic]	little	Sm	
PHYS_ADDR_WIDTH	≤ 64	Any	Sm	
PRECISE_SYNCHRONOUS_EXCEPTIONS	boolean	true	Sm	
TIME_CSR_IMPLEMENTED	boolean	Any	Zicntr	
TRAP_ON_EBREAK	boolean	true	Sm	
TRAP_ON_ECALL_FROM_M	boolean	true	Sm	
VENDOR_ID_BANK	25-bit integer	Any	Sm	

Parameter	Type	Allowed Value(s)	Extension(s)	Note
VENDOR_ID_OFFSET	7-bit integer	Any	Sm	
XLEN	[32, 64]	32	Sm	

3.2. OUT-OF-SCOPE Parameters

These implementation-dependent options defined by MANDATORY or OPTIONAL extensions are OUT-OF-SCOPE. There are no restrictions on their values for certification purposes because the certificate doesn't cover the behavior of the associated RISC-V standard as a function of these parameters.

Parameters	Type	Extension(s)
MUTABLE_MISA_C	boolean	C
MUTABLE_MISA_M	boolean	M
PMA_GRANULARITY	2 to 66	Sm
REPORT_ENCODING_IN_MTVAl_ON_ILLEGAL_INSTRUCTION	boolean	Sm
REPORT_VA_IN_MTVAl_ON_BREAKPOINT	boolean	Sm
REPORT_VA_IN_MTVAl_ON_INSTRUCTION_ACCESS_FAULT	boolean	Sm
REPORT_VA_IN_MTVAl_ON_INSTRUCTION_MISALIGNED	boolean	Sm
REPORT_VA_IN_MTVAl_ON_INSTRUCTION_PAGE_FAULT	boolean	Sm
REPORT_VA_IN_MTVAl_ON_LOAD_ACCESS_FAULT	boolean	Sm
REPORT_VA_IN_MTVAl_ON_LOAD_MISALIGNED	boolean	Sm
REPORT_VA_IN_MTVAl_ON_LOAD_PAGE_FAULT	boolean	Sm
REPORT_VA_IN_MTVAl_ON_STORE_AMO_ACCESS_FAULT	boolean	Sm
REPORT_VA_IN_MTVAl_ON_STORE_AMO_MISALIGNED	boolean	Sm
REPORT_VA_IN_MTVAl_ON_STORE_AMO_PAGE_FAULT	boolean	Sm
TRAP_ON_ILLEGAL_WLRL	boolean	Sm
TRAP_ON_RESERVED_INSTRUCTION	boolean	Sm
TRAP_ON_UNIMPLEMENTED_CSR	boolean	Sm
TRAP_ON_UNIMPLEMENTED_INSTRUCTION	boolean	Sm

4. Instruction Summary

Name	Long Name
add	Integer add
addi	Add immediate

Name	Long Name
addiw	Add immediate word
addw	Add word
and	And
andi	And immediate
auipc	Add upper immediate to pc
beq	Branch if equal
bge	Branch if greater than or equal
bgeu	Branch if greater than or equal unsigned
blt	Branch if less than
bltu	Branch if less than unsigned
bne	Branch if not equal
c.add	Add
c.addi	Add a sign-extended non-zero immediate
c.addi16sp	Add a sign-extended non-zero immediate
c.addi4spn	Add a zero-extended non-zero immediate, scaled by 4, to the stack pointer
c.addiw	Add a sign-extended non-zero immediate
c.addw	Add word
c.and	And
c.andi	And immediate
c.beqz	Branch if Equal Zero
c.bnez	Branch if NOT Equal Zero
c.ebreak	Breakpoint exception.
c.j	Jump
c.jal	Jump and Link
c.jalr	Jump and Link Register.
c.jr	Jump Register
c.ld	Load double
c.ldsp	Load doubleword from stack pointer
c.li	Load the sign-extended 6-bit immediate
c.lq	Load quadruple
c.lqsp	Load quadruple word from stack pointer
c.lui	Load the non-zero 6-bit immediate field into bits 17-12 of the destination register
c.lw	Load word

Name	Long Name
c.lwsp	Load word from stack pointer
c.mv	Move Register
c.nop	Non-operation
c.or	Or
c.sd	Store double
c.sdsp	Store doubleword to stack
c.slli	Shift left logical immediate
c.sq	Store quadruple
c.sqsp	Store quadruple word to stack
c.srai	Shift right arithmetical immediate
c.srli	Shift right logical immediate
c.sub	Subtract
c.subw	Subtract word
c.sw	Store word
c.swsp	Store word to stack
c.xor	Exclusive Or
csrrc	No synopsis available.
csrrci	No synopsis available.
csrrs	Atomic Read and Set Bits in CSR
csrrsi	No synopsis available.
csrrw	Atomic Read/Write CSR
csrrwi	Atomic Read/Write CSR Immediate
div	Signed division
divu	Unsigned division
divuw	Unsigned 32-bit division
divw	Signed 32-bit division
ebreak	Breakpoint exception
ecall	Environment call
fence	Memory ordering fence
jal	Jump and link
jalr	Jump and link register
lb	Load byte
lbu	Load byte unsigned

Name	Long Name
ld	Load doubleword
lh	Load halfword
lhu	Load halfword unsigned
lui	Load upper immediate
lw	Load word
lwu	Load word unsigned
mret	Machine Exception Return
mul	Signed multiply
mulh	Signed multiply high
mulhsu	Signed/unsigned multiply high
mulhu	Unsigned multiply high
mulw	Signed 32-bit multiply
or	Or
ori	Or immediate
rem	Signed remainder
remu	Unsigned remainder
remuw	Unsigned 32-bit remainder
remw	Signed 32-bit remainder
sb	Store byte
sd	Store doubleword
sh	Store halfword
sll	Shift left logical
slli	Shift left logical immediate
slliw	Shift left logical immediate word
sllw	Shift left logical word
slt	Set on less than
slti	Set on less than immediate
sltiu	Set on less than immediate unsigned
sltu	Set on less than unsigned
sra	Shift right arithmetic
srai	Shift right arithmetic immediate
sraiw	Shift right arithmetic immediate word
sraw	Shift right arithmetic word

Name	Long Name
srl	Shift right logical
srli	Shift right logical immediate
srliw	Shift right logical immediate word
srlw	Shift right logical word
sub	Subtract
subw	Subtract word
sw	Store word
wfi	Wait for interrupt
xor	Exclusive Or
xori	Exclusive Or immediate

5. CSR Summary

5.1. By Name

Name	Long Name	Address	Mode	Primary Extension
cycle	Cycle counter for RDCYCLE Instruction	0xc00	U	Zicntr
cycleh	High-half cycle counter for RDCYCLE Instruction	0xc80	U	Zicntr
instret	Instructions retired counter for RDINSTRET Instruction	0xc02	U	Zicntr
instreth	Instructions retired counter, high bits	0xc82	U	Zicntr
marchid	Machine Architecture ID	0xf12	M	Sm
mcause	Machine Cause	0x342	M	Sm
mcountinhibit	Machine Counter Inhibit	0x320	M	Sm
mcycle	Machine Cycle Counter	0xb00	M	Zicntr
mcycleh	High-half machine Cycle Counter	0xb80	M	Zicntr
mepc	Machine Exception Program Counter	0x341	M	Sm
mhartid	Machine Hart ID	0xf14	M	Sm
mie	Machine Interrupt Enable	0x304	M	Sm
mimpid	Machine Implementation ID	0xf13	M	Sm
minstret	Machine Instructions Retired Counter	0xb02	M	Zicntr
minstreth	Machine Instructions Retired Counter	0xb02	M	Zicntr
mip	Machine Interrupt Pending	0x344	M	Sm

Name	Long Name	Address	Mode	Primary Extension
misa	Machine ISA Control	0x301	M	Sm
mscratch	Machine Scratch Register	0x340	M	Sm
mstatus	Machine Status	0x300	M	Sm
mtval	Machine Trap Value	0x343	M	Sm
mtvec	Machine Trap Vector Control	0x305	M	Sm
mvendorid	Machine Vendor ID	0xf11	M	Sm
time	Timer for RDTIME Instruction	0xc01	U	Zicntr
timeh	High-half timer for RDTIME Instruction	0xc81	U	Zicntr

5.2. By Address

Address	Mode	Name	Long Name	Primary Extension
0x300	M	mstatus	Machine Status	Sm
0x301	M	misa	Machine ISA Control	Sm
0x304	M	mie	Machine Interrupt Enable	Sm
0x305	M	mtvec	Machine Trap Vector Control	Sm
0x320	M	mcountinhibit	Machine Counter Inhibit	Sm
0x340	M	mscratch	Machine Scratch Register	Sm
0x341	M	mepc	Machine Exception Program Counter	Sm
0x342	M	mcause	Machine Cause	Sm
0x343	M	mtval	Machine Trap Value	Sm
0x344	M	mip	Machine Interrupt Pending	Sm
0xb00	M	mcycle	Machine Cycle Counter	Zicntr
0xb02	M	minstret	Machine Instructions Retired Counter	Zicntr
0xb02	M	minstreth	Machine Instructions Retired Counter	Zicntr
0xb80	M	mcycleh	High-half machine Cycle Counter	Zicntr
0xc00	U	cycle	Cycle counter for RDCYCLE Instruction	Zicntr
0xc01	U	time	Timer for RDTIME Instruction	Zicntr
0xc02	U	instret	Instructions retired counter for RDINSTRET Instruction	Zicntr
0xc80	U	cycleh	High-half cycle counter for RDCYCLE Instruction	Zicntr
0xc81	U	timeh	High-half timer for RDTIME Instruction	Zicntr

Addresses	Mode	Name	Long Name	Primary Extension
0xc82	U	instreth	Instructions retired counter, high bits	Zicntr
0xf11	M	mvendorid	Machine Vendor ID	Sm
0xf12	M	marchid	Machine Architecture ID	Sm
0xf13	M	mimpid	Machine Implementation ID	Sm
0xf14	M	mhartid	Machine Hart ID	Sm

Appendix A: Extension Details

A.1. Extension C

Long Name: Compressed instructions

Version Requirement: ~> 2.2

2.2.0

State

ratified

Ratification date

2019-12

A.1.1. Synopsis

The C extension reduces static and dynamic code size by adding short 16-bit instruction encodings for common operations. The C extension can be added to any of the base ISAs (RV32, RV64, RV128), and we use the generic term "RVC" to cover any of these. Typically, 50%-60% of the RISC-V instructions in a program can be replaced with RVC instructions, resulting in a 25%-30% code-size reduction.

A.1.2. Overview

RVC uses a simple compression scheme that offers shorter 16-bit versions of common 32-bit RISC-V instructions when:

- the immediate or address offset is small, or
- one of the registers is the zero register (`x0`), the ABI link register (`x1`), or the ABI stack pointer (`x2`), or
- the destination register and the first source register are identical, or
- the registers used are the 8 most popular ones.

The C extension is compatible with all other standard instruction extensions. The C extension allows 16-bit instructions to be freely intermixed with 32-bit instructions, with the latter now able to start on any 16-bit boundary, i.e., `IALIGN=16`. With the addition of the C extension, no instructions can raise instruction-address-misaligned exceptions.

NOTE

Removing the 32-bit alignment constraint on the original 32-bit instructions allows significantly greater code density.

The compressed instruction encodings are mostly common across RV32C, RV64C, and RV128C, but as shown in [Table 34](#), a few opcodes are used for different purposes depending on base ISA. For example, the wider address-space RV64C and RV128C variants require additional opcodes to compress loads and stores of 64-bit integer values, while RV32C uses the same opcodes to compress

loads and stores of single-precision floating-point values. Similarly, RV128C requires additional opcodes to capture loads and stores of 128-bit integer values, while these same opcodes are used for loads and stores of double-precision floating-point values in RV32C and RV64C. If the C extension is implemented, the appropriate compressed floating-point load and store instructions must be provided whenever the relevant standard floating-point extension (F and/or D) is also implemented. In addition, RV32C includes a compressed jump and link instruction to compress short-range subroutine calls, where the same opcode is used to compress ADDIW for RV64C and RV128C.

Double-precision loads and stores are a significant fraction of static and dynamic instructions, hence the motivation to include them in the RV32C and RV64C encoding.

Although single-precision loads and stores are not a significant source of static or dynamic compression for benchmarks compiled for the currently supported ABIs, for microcontrollers that only provide hardware single-precision floating-point units and have an ABI that only supports single-precision floating-point numbers, the single-precision loads and stores will be used at least as frequently as double-precision loads and stores in the measured benchmarks. Hence, the motivation to provide compressed support for these in RV32C.

TIP

Short-range subroutine calls are more likely in small binaries for microcontrollers, hence the motivation to include these in RV32C.

Although reusing opcodes for different purposes for different base ISAs adds some complexity to documentation, the impact on implementation complexity is small even for designs that support multiple base ISAs. The compressed floating-point load and store variants use the same instruction format with the same register specifiers as the wider integer loads and stores.

RVC was designed under the constraint that each RVC instruction expands into a single 32-bit instruction in either the base ISA (RV32I/E, RV64I/E, or RV128I) or the F and D standard extensions where present. Adopting this constraint has two main benefits:

- Hardware designs can simply expand RVC instructions during decode, simplifying verification and minimizing modifications to existing microarchitectures.
- Compilers can be unaware of the RVC extension and leave code compression to the assembler and linker, although a compression-aware compiler will generally be able to produce better results.

NOTE

We felt the multiple complexity reductions of a simple one-one mapping between C and base IFD instructions far outweighed the potential gains of a slightly denser encoding that added additional instructions only supported in the C extension, or that allowed encoding of multiple IFD instructions in one C instruction.

It is important to note that the C extension is not designed to be a stand-alone ISA, and is meant to be used alongside a base ISA.

TIP

Variable-length instruction sets have long been used to improve code density. For

example, the IBM Stretch [cite:\[stretch\]](#), developed in the late 1950s, had an ISA with 32-bit and 64-bit instructions, where some of the 32-bit instructions were compressed versions of the full 64-bit instructions. Stretch also employed the concept of limiting the set of registers that were addressable in some of the shorter instruction formats, with short branch instructions that could only refer to one of the index registers. The later IBM 360 architecture [cite:\[ibm360\]](#) supported a simple variable-length instruction encoding with 16-bit, 32-bit, or 48-bit instruction formats.

In 1963, CDC introduced the Cray-designed CDC 6600 [cite:\[cdc6600\]](#), a precursor to RISC architectures, that introduced a register-rich load-store architecture with instructions of two lengths, 15-bits and 30-bits. The later Cray-1 design used a very similar instruction format, with 16-bit and 32-bit instruction lengths.

The initial RISC ISAs from the 1980s all picked performance over code size, which was reasonable for a workstation environment, but not for embedded systems. Hence, both ARM and MIPS subsequently made versions of the ISAs that offered smaller code size by offering an alternative 16-bit wide instruction set instead of the standard 32-bit wide instructions. The compressed RISC ISAs reduced code size relative to their starting points by about 25-30%, yielding code that was significantly smaller than 80x86. This result surprised some, as their intuition was that the variable-length CISC ISA should be smaller than RISC ISAs that offered only 16-bit and 32-bit formats.

Since the original RISC ISAs did not leave sufficient opcode space free to include these unplanned compressed instructions, they were instead developed as complete new ISAs. This meant compilers needed different code generators for the separate compressed ISAs. The first compressed RISC ISA extensions (e.g., ARM Thumb and MIPS16) used only a fixed 16-bit instruction size, which gave good reductions in static code size but caused an increase in dynamic instruction count, which led to lower performance compared to the original fixed-width 32-bit instruction size. This led to the development of a second generation of compressed RISC ISA designs with mixed 16-bit and 32-bit instruction lengths (e.g., ARM Thumb2, microMIPS, PowerPC VLE), so that performance was similar to pure 32-bit instructions but with significant code size savings. Unfortunately, these different generations of compressed ISAs are incompatible with each other and with the original uncompressed ISA, leading to significant complexity in documentation, implementations, and software tools support.

Of the commonly used 64-bit ISAs, only PowerPC and microMIPS currently supports a compressed instruction format. It is surprising that the most popular 64-bit ISA for mobile platforms (ARM v8) does not include a compressed instruction format given that static code size and dynamic instruction fetch bandwidth are important metrics. Although static code size is not a major concern in larger systems, instruction fetch bandwidth can be a major bottleneck in servers running commercial workloads, which often have a large instruction working set.

Benefiting from 25 years of hindsight, RISC-V was designed to support compressed instructions from the outset, leaving enough opcode space for RVC to be added as a simple extension on top of the base ISA (along with many other extensions). The philosophy of RVC is to reduce code size for embedded applications *and* to improve

performance and energy-efficiency for all applications due to fewer misses in the instruction cache. Waterman shows that RVC fetches 25%-30% fewer instruction bits, which reduces instruction cache misses by 20%-25%, or roughly the same performance impact as doubling the instruction cache size. cite:[waterman-ms]

A.1.3. Compressed Instruction Formats

[Compressed 16-bit RVC instruction formats](#) shows the nine compressed instruction formats. CR, CI, and CSS can use any of the 32 RVI registers, but CIW, CL, CS, CA, and CB are limited to just 8 of them. [Registers specified by the three-bit *rs1'*, *rs2'*, and *rd'* fields of the CIW, CL, CS, CA, and CB formats.](#) lists these popular registers, which correspond to registers *x8* to *x15*. Note that there is a separate version of load and store instructions that use the stack pointer as the base address register, since saving to and restoring from the stack are so prevalent, and that they use the CI and CSS formats to allow access to all 32 data registers. CIW supplies an 8-bit immediate for the ADDI4SPN instruction.

NOTE

The RISC-V ABI was changed to make the frequently used registers map to registers 'x8-x15'. This simplifies the decompression decoder by having a contiguous naturally aligned set of register numbers, and is also compatible with the RV32E and RV64E base ISAs, which only have 16 integer registers.

Compressed register-based floating-point loads and stores also use the CL and CS formats respectively, with the eight registers mapping to *f8* to *f15*.

NOTE

*The standard RISC-V calling convention maps the most frequently used floating-point registers to registers *f8* to *f15*, which allows the same register decompression decoding as for integer register numbers.*

The formats were designed to keep bits for the two register source specifiers in the same place in all instructions, while the destination register field can move. When the full 5-bit destination register specifier is present, it is in the same place as in the 32-bit RISC-V encoding. Where immediates are sign-extended, the sign extension is always from bit 12. Immediate fields have been scrambled, as in the base specification, to reduce the number of immediate muxes required.

NOTE

The immediate fields are scrambled in the instruction formats instead of in sequential order so that as many bits as possible are in the same position in every instruction, thereby simplifying implementations.

For many RVC instructions, zero-valued immediates are disallowed and *x0* is not a valid 5-bit register specifier. These restrictions free up encoding space for other instructions requiring fewer operand bits.

Table 1. Compressed 16-bit RVC instruction formats

Format	Meaning	15 14 13 12	11 10 9 8 7	6 5 4 3 2	1 0		
CR	Register	funct4		rd/rs1	rs2	op	
CI	Immediate	funct3	imm	rd/rs1	imm	op	
CSS	Stack-relative Store	funct3	imm		rs2	op	
CIW	Wide Immediate	funct3	imm			rd'	op
CL	Load	funct3	imm	rs1'	imm	rd'	op
CS	Store	funct3	imm	rs1'	imm	rs2'	op
CA	Arithmetic	funct6		rd'/rs1'	funct2	rs2'	op
CB	Branch/Arithmetic	funct3	offset	rd'/rs1'	offset		op
CJ	Jump	funct3	jump target			op	

Table 2. Registers specified by the three-bit $rs1'$, $rs2'$, and rd' fields of the CIW, CL, CS, CA, and CB formats.

RVC Register Number	000	001	010	011	100	101	110	111
Integer Register Number	x8	x9	x10	x11	x12	x13	x14	x15
Integer Register ABI Name	s0	s1	a0	a1	a2	a3	a4	a5
Floating-Point Register Number	f8	f9	f10	f11	f12	f13	f14	f15
Floating-Point Register ABI Name	fs0	fs1	fa0	fa1	fa2	fa3	fa4	fa5

A.1.4. Instructions

The following instructions are added by this extension:

c.add	Add
c.addi	Add a sign-extended non-zero immediate
c.addi16sp	Add a sign-extended non-zero immediate
c.addi4spn	Add a zero-extended non-zero immediate, scaled by 4, to the stack pointer
c.addiw	Add a sign-extended non-zero immediate
c.addw	Add word
c.and	And
c.andi	And immediate
c.beqz	Branch if Equal Zero
c.bnez	Branch if NOT Equal Zero
c.ebreak	Breakpoint exception.
c.j	Jump
c.jal	Jump and Link

c.jalr	Jump and Link Register.
c.jr	Jump Register
c.ld	Load double
c.ldsp	Load doubleword from stack pointer
c.li	Load the sign-extended 6-bit immediate
c.lq	Load quadruple
c.lqsp	Load quadruple word from stack pointer
c.lui	Load the non-zero 6-bit immediate field into bits 17-12 of the destination register
c.lw	Load word
c.lwsp	Load word from stack pointer
c.mv	Move Register
c.nop	Non-operation
c.or	Or
c.sd	Store double
c.sdsp	Store doubleword to stack
c.slli	Shift left logical immediate
c.sq	Store quadruple
c.sqsp	Store quadruple word to stack
c.srai	Shift right arithmetical immediate
c.srli	Shift right logical immediate
c.sub	Subtract
c.subw	Subtract word
c.sw	Store word
c.swsp	Store word to stack
c.xor	Exclusive Or

A.1.5. OUT-OF-SCOPE Parameters

MUTABLE_MISA_C ⇒ boolean

Indicates whether or not the C extension can be disabled with the misa.C bit.

A.2. Extension I

Long Name: Base integer ISA (RV32I or RV64I)

Version Requirement: ~> 2.1

2.1.0

State

ratified

Ratification date

2019-06

Changes

- ratified RVWMO memory model and exclusion of FENCE.I, counters, and CSR instructions that were in previous base ISA

A.2.1. Synopsis

Base integer instructions — TODO

A.2.2. Instructions

The following instructions are added by this extension:

add	Integer add
addi	Add immediate
addiw	Add immediate word
addw	Add word
and	And
andi	And immediate
auipc	Add upper immediate to pc
beq	Branch if equal
bge	Branch if greater than or equal
bgeu	Branch if greater than or equal unsigned
blt	Branch if less than
bltu	Branch if less than unsigned
bne	Branch if not equal
ebreak	Breakpoint exception
ecall	Environment call
fence	Memory ordering fence
jal	Jump and link
jalr	Jump and link register
lb	Load byte
lbu	Load byte unsigned
ld	Load doubleword

lh	Load halfword
lhu	Load halfword unsigned
lui	Load upper immediate
lw	Load word
lwu	Load word unsigned
or	Or
ori	Or immediate
sb	Store byte
sd	Store doubleword
sh	Store halfword
sll	Shift left logical
slli	Shift left logical immediate
slliw	Shift left logical immediate word
sllw	Shift left logical word
slt	Set on less than
slti	Set on less than immediate
sltiu	Set on less than immediate unsigned
sltu	Set on less than unsigned
sra	Shift right arithmetic
srai	Shift right arithmetic immediate
sraiw	Shift right arithmetic immediate word
sraw	Shift right arithmetic word
srl	Shift right logical
srli	Shift right logical immediate
srliw	Shift right logical immediate word
srlw	Shift right logical word
sub	Subtract
subw	Subtract word
sw	Store word
xor	Exclusive Or
xori	Exclusive Or immediate

A.3. Extension M

Long Name: Integer multiply and divide instructions

Version Requirement: ~> 2.0

2.0.0

State

ratified

Ratification date

2019-12

A.3.1. Synopsis

This chapter describes the standard integer multiplication and division instruction extension, which is named M and contains instructions that multiply or divide values held in two integer registers.

TIP

We separate integer multiply and divide out from the base to simplify low-end implementations, or for applications where integer multiply and divide operations are either infrequent or better handled in attached accelerators.

A.3.2. Instructions

The following instructions are added by this extension:

div	Signed division
divu	Unsigned division
divuw	Unsigned 32-bit division
divw	Signed 32-bit division
mul	Signed multiply
mulh	Signed multiply high
mulhsu	Signed/unsigned multiply high
mulhu	Unsigned multiply high
mulw	Signed 32-bit multiply
rem	Signed remainder
remu	Unsigned remainder
remuw	Unsigned 32-bit remainder
remw	Signed 32-bit remainder

A.3.3. OUT-OF-SCOPE Parameters

MUTABLE_MISA_M ⇒ **boolean**

Indicates whether or not the M extension can be disabled with the misa.M bit.

A.4. Extension Sm

Long Name: Machine mode

Version Requirement: ~> 1.11.0

1.11.0

State

ratified

Ratification date

2019-12

Changes

- Moved Machine spec to **Ratified** status.
- Improvements to the description and commentary.
- Specified which interrupt sources are reserved for standard use.
- Allocated some synchronous exception causes for custom use.
- Specified the priority ordering of synchronous exceptions.
- Added specification that xRET instructions may, but are not required to, clear LR reservations if A extension present.
- Made the [mstatus](#).MPP field **WARL**, rather than **WLRL**.
- Made the unused [xip](#) fields **WPRI**, rather than **WIRI**.
- Made the unused [misa](#) fields **WARL**, rather than **WIRI**.
- Rectified an editing error that misdescribed the mechanism by which [mstatus](#) is written upon an exception.
- Described scheme for emulating misaligned AMOs.
- Specified the behavior of the [misa](#) and [xepc](#) registers in systems with variable IALIGN.
- Specified the behavior of writing self-contradictory values to the [misa](#) register.
- Specified contents of CSRs across XLEN modification.
- Moved PLIC chapter into its own document.

1.12.0

State

ratified

Ratification date

2021-12

Changes

- Changed MRET to clear [mstatus](#).MPRV when leaving M-mode.
- Relaxed I/O regions have been specified to follow RVWMO. The previous specification

implied that PPO rules other than fences and acquire/release annotations did not apply.

- Constrained the LR/SC reservation set size and shape when using page-based virtual memory.
- PMP changes require an SFENCE.VMA on any hart that implements page-based virtual memory, even if VM is not currently enabled.
- Removed the N extension.
- Defined the mandatory RV32-only CSR `mstatush`, which contains most of the same fields as the upper 32 bits of RV64's `mstatus`.
- Defined the mandatory CSR `mconfigptr`, which if nonzero contains the address of a configuration data structure.
- Defined optional `mseccfg` and `mseccfgh` CSRs, which control the machine's security configuration.
- Defined `menvcfg` CSR (and RV32-only `menvcfgh`), which control various characteristics of the execution environment.
- Designated part of SYSTEM major opcode for custom use.
- Permitted the unconditional delegation of less-privileged interrupts.
- Added optional big-endian and bi-endian support.
- Made priority of load/store/AMO address-misaligned exceptions implementation-defined relative to load/store/AMO page-fault and access-fault exceptions.
- Software breakpoint exceptions are permitted to write either 0 or the `pc` to `xtval`.
- Specified relaxed constraints for implicit reads of non-idempotent regions.

1.13.0

State

frozen

Changes

- Redefined `misa.MXL` to be read-only, making `MXLEN` a constant.
- Defined the `misa.B` field to reflect that the B extension has been implemented.
- Defined the `misa.V` field to reflect that the V extension has been implemented.
- Defined the RV32-only `medeleg` CSR.
- Defined the misaligned atomicity granule PMA, superseding the proposed Zam extension.
- Defined hardware error and software check exception codes.
- Specified synchronization requirements when changing the PBMTE fields in `menvcfg` and `henvcfg`.
- Exposed count-overflow interrupts to VS-mode via the `Shlcofideleg` extension.
- Relaxed behavior of some HINTs when `MXLEN > XLEN`.
- Transliterated the document from LaTeX into AsciiDoc.
- Included all ratified extensions through March 2024.

- Clarified that "platform- or custom-use" interrupts are actually "platform-use interrupts", where the platform can choose to make some custom.
- Clarified semantics of explicit accesses to CSRs wider than XLEN bits.
- Clarified that $MXLEN \geq SXLEN$.
- Clarified that WFI is not a HINT instruction.
- Clarified that, for a given exception cause, `xtval` might sometimes be set to a nonzero value but sometimes not.
- Clarified exception behavior of unimplemented or inaccessible CSRs.
- Replaced the concept of vacant memory regions with inaccessible memory or I/O regions.
- Clarified that timer and count-overflow interrupts' arrival in interrupt-pending registers is not immediate.
- Clarified that MXR affects only explicit memory accesses.

A.4.1. Synopsis

This chapter describes the machine-level operations available in machine-mode (M-mode), which is the highest privilege mode in a RISC-V hart. M-mode is used for low-level access to a hardware platform and is the first mode entered at reset. M-mode can also be used to implement features that are too difficult or expensive to implement in hardware directly. The RISC-V machine-level ISA contains a common core that is extended depending on which other privilege levels are supported and other details of the hardware implementation. This chapter describes the RISC-V machine-level architecture, which contains a common core that is used with various supervisor-level address translation and protection schemes.

A.4.2. Instructions

The following instructions are added by this extension:

<code>mret</code>	Machine Exception Return
<code>wfi</code>	Wait for interrupt

A.4.3. IN-SCOPE Parameters

ARCH_ID ⇒ 64-bit integer

Vendor-specific architecture ID in `marchid`

IMP_ID ⇒ 64-bit integer

Vendor-specific implementation ID in `mimpid`

MISALIGNED_LDST ⇒ boolean

Does the implementation perform non-atomic misaligned loads and stores to main memory (does **not** affect misaligned support to device memory)? If not, the implementation always throws a misaligned exception.

MISALIGNED_LDST_EXCEPTION_PRIORITY ⇒ [low, high]

The relative priority of a load/store/AMO exception vs. load/store/AMO page-fault or access-fault exceptions.

May be one of:

low	Misaligned load/store/AMO exceptions are always lower priority than load/store/AMO page-fault and access-fault exceptions.
high	Misaligned load/store/AMO exceptions are always higher priority than load/store/AMO page-fault and access-fault exceptions.

MISALIGNED_LDST_EXCEPTION_PRIORITY cannot be "high" when MISALIGNED_MAX_ATOMICITY_GRANULE_SIZE is non-zero, since the atomicity of an access cannot be determined in that case until after address translation.

MISALIGNED_MAX_ATOMICITY_GRANULE_SIZE ⇒ [0, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096]

The maximum granule size, in bytes, that the hart can atomically perform a misaligned load/store/AMO without raising a Misaligned exception. When MISALIGNED_MAX_ATOMICITY_GRANULE_SIZE is 0, the hart cannot atomically perform a misaligned load/store/AMO. When a power of two, the hart can atomically load/store/AMO a misaligned access that is fully contained in a MISALIGNED_MAX_ATOMICITY_GRANULE_SIZE-aligned region.

NOTE

Even if the hart is capable of performing a misaligned load/store/AMO atomically, a misaligned exception may still occur if the access does not have the appropriate Misaligned Atomicity Granule PMA set.

MISALIGNED_SPLIT_STRATEGY ⇒ [by_byte, custom]

When misaligned accesses are supported, this determines the **order** in the implementation appears to process the load/store, which determines how/which exceptions will be reported

Options:

- **by_byte**: The load/store appears to be broken into byte-sized accesses that processed sequentially from smallest address to largest address
- **custom**: Something else. Will result in a call to `unpredictable()` in the execution

MISA_CSR_IMPLEMENTED ⇒ boolean

Whether or not the [misa](#) CSR returns zero or a non-zero value.

Possible values:

true

The [misa](#) CSR returns a non-zero value.

false

The `misa` CSR is read-only-0.

MTVAL_WIDTH ⇒ ≤ 64

The number of implemented bits in the `mtval` CSR. This is the CSR that may be written when a trap is taken into M-mode with exception-specific information to assist software in handling the trap (e.g., address associated with exception).

Must be greater than or equal to $\max(\text{PHYS_ADDR_WIDTH}, \text{VA_SIZE})$

MTVEC_BASE_ALIGNMENT_DIRECT ⇒ ≥ 4

Byte alignment for `mtvec.BASE` when `mtvec.MODE` is Direct.

Cannot be less than 4-byte alignment.

MTVEC_BASE_ALIGNMENT_VECTORED ⇒ ≥ 4

Byte alignment for `mtvec.BASE` when `mtvec.MODE` is Vectored.

Cannot be less than 4-byte alignment.

MTVEC_MODES ⇒ 1-element to 2-element array of [0, 1]

Modes supported by `mtvec.MODE`. If only one, it is assumed to be read-only with that value.

M_MODE_ENDIANESS ⇒ [little, big, dynamic]

Endianess of data in M-mode. Can be one of:

little	M-mode data is always little endian
big	M-mode data is always big endian
dynamic	M-mode data can be either little or big endian, depending on the CSR field <code>mstatus.MBE</code>

PHYS_ADDR_WIDTH ⇒ ≤ 64

Number of bits in the physical address space.

PRECISE_SYNCHRONOUS_EXCEPTIONS ⇒ **boolean**

Whether or not all synchronous exceptions are precise.

If false, any exception not otherwise mandated to be precise (e.g., PMP violation) will cause execution to enter an unpredictable state.

TRAP_ON_EBREAK ⇒ **boolean**

Whether or not an EBREAK causes a synchronous exception.

The spec states that implementations may handle EBREAKs transparently without raising a trap, in which case the EEI must provide a builtin.

TRAP_ON_ECALL_FROM_M ⇒ **boolean**

Whether or not an ECALL-from-M-mode causes a synchronous exception.

The spec states that implementations may handle ECALLs transparently without raising a trap, in which case the EEI must provide a builtin.

VENDOR_ID_BANK ⇒ 25-bit integer

JEDEC Vendor ID bank, for [mvendorid](#)

VENDOR_ID_OFFSET ⇒ 7-bit integer

Vendor JEDEC code offset, for [mvendorid](#)

XLEN ⇒ [32, 64]

XLEN in M-mode (AKA MXLEN, tracked by issue #52)

A.4.4. OUT-OF-SCOPE Parameters

PMA_GRANULARITY ⇒ 2 to 66

log2 of the smallest supported PMA region.

Generally, for systems with an MMU, should not be smaller than 12, as that would preclude caching PMP results in the TLB along with virtual memory translations

REPORT_ENCODING_IN_MTVAL_ON_ILLEGAL_INSTRUCTION ⇒ boolean

When true, [mtval](#) is written with the encoding of an instruction that causes an [IllegalInstruction](#) exception.

When false [mtval](#) is written with 0 when an [IllegalInstruction](#) exception occurs.

REPORT_VA_IN_MTVAL_ON_BREAKPOINT ⇒ boolean

When true, [mtval](#) is written with the virtual PC of the EBREAK instruction (same information as [mepc](#)).

When false, [mtval](#) is written with 0 on an EBREAK instruction.

Regardless, [mtval](#) is always written with a virtual PC when an external breakpoint is generated

REPORT_VA_IN_MTVAL_ON_INSTRUCTION_ACCESS_FAULT ⇒ boolean

When true, [mtval](#) is written with the virtual PC of an instruction when fetch causes an [InstructionAccessFault](#).

When false, [mtval](#) is written with 0 when an instruction fetch causes an [InstructionAccessFault](#).

REPORT_VA_IN_MTVAL_ON_INSTRUCTION_MISALIGNED ⇒ boolean

When true, [mtval](#) is written with the virtual PC when an instruction fetch is misaligned.

When false, [mtval](#) is written with 0 when an instruction fetch is misaligned.

Note that when IALIGN=16 (i.e., when the C or one of the [Zc*](#) extensions are implemented), it is impossible to generate a misaligned fetch, and so this parameter has no effect.

REPORT_VA_IN_MTVAL_ON_INSTRUCTION_PAGE_FAULT ⇒ boolean

When true, [mtval](#) is written with the virtual PC of an instruction when fetch causes an

`InstructionPageFault`.

When false, `mtval` is written with 0 when an instruction fetch causes an `InstructionPageFault`.

REPORT_VA_IN_MTVAl_ON_LOAD_ACCESS_FAULT ⇒ boolean

When true, `mtval` is written with the virtual address of a load when it causes a `LoadAccessFault`.

When false, `mtval` is written with 0 when a load causes a `LoadAccessFault`.

REPORT_VA_IN_MTVAl_ON_LOAD_MISALIGNED ⇒ boolean

When true, `mtval` is written with the virtual address of a load instruction when the address is misaligned and `MISALIGNED_LDST` is false.

When false, `mtval` is written with 0 when a load address is misaligned and `MISALIGNED_LDST` is false.

REPORT_VA_IN_MTVAl_ON_LOAD_PAGE_FAULT ⇒ boolean

When true, `mtval` is written with the virtual address of a load when it causes a `LoadPageFault`.

When false, `mtval` is written with 0 when a load causes a `LoadPageFault`.

REPORT_VA_IN_MTVAl_ON_STORE_AMO_ACCESS_FAULT ⇒ boolean

When true, `mtval` is written with the virtual address of a store when it causes a `StoreAmoAccessFault`.

When false, `mtval` is written with 0 when a store causes a `StoreAmoAccessFault`.

REPORT_VA_IN_MTVAl_ON_STORE_AMO_MISALIGNED ⇒ boolean

When true, `mtval` is written with the virtual address of a store instruction when the address is misaligned and `MISALIGNED_LDST` is false.

When false, `mtval` is written with 0 when a store address is misaligned and `MISALIGNED_LDST` is false.

REPORT_VA_IN_MTVAl_ON_STORE_AMO_PAGE_FAULT ⇒ boolean

When true, `mtval` is written with the virtual address of a store when it causes a `StoreAmoPageFault`.

When false, `mtval` is written with 0 when a store causes a `StoreAmoPageFault`.

TRAP_ON_ILLEGAL_WLRL ⇒ boolean

When true, writing an illegal value to a WLRL CSR field raises an `IllegalInstruction` exception.

When false, writing an illegal value to a WLRL CSR field is `unpredictable`.

TRAP_ON_RESERVED_INSTRUCTION ⇒ boolean

When true, fetching an unimplemented and/or undefined instruction from the standard/reserved encoding space will cause an `IllegalInstruction` exception.

When false, fetching such an instruction is `UNPREDICTABLE`.

TRAP_ON_UNIMPLEMENTED_CSR ⇒ **boolean**

When true, accessing an unimplemented CSR (via a Zicsr instruction) will cause an **IllegalInstruction** exception.

When false, accessing an unimplemented CSR (via a Zicsr instruction) is **unpredictable**.

TRAP_ON_UNIMPLEMENTED_INSTRUCTION ⇒ **boolean**

When true, fetching an unimplemented instruction from the custom encoding space will cause an **IllegalInstruction** exception.

When false, fetching an unimplemented instruction is **UNPREDICTABLE**.

A.5. Extension Zicntr

Long Name: Architectural performance counters

Version Requirement: ~> 2.0

2.0.0

State

ratified

Ratification date

2019-12

A.5.1. Synopsis

Architectural performance counters

A.5.2. IN-SCOPE Parameters

TIME_CSR_IMPLEMENTED ⇒ **boolean**

Whether or not a real hardware **time** CSR exists. Implementations can either provide a real CSR or emulate access at M-mode.

Possible values:

true

time/timeh exists, and accessing it will not cause an **IllegalInstruction** trap

false

time/timeh does not exist. Accessing the CSR will cause an **IllegalInstruction** trap or enter an unpredictable state, depending on **TRAP_ON_UNIMPLEMENTED_CSR**. Privileged software may emulate the **time** CSR, or may pass the exception to a lower level.

A.6. Extension Zicsr

Long Name: Control and status registers

Version Requirement: ~> 2.0

2.0.0

State

ratified

Ratification date

==== Synopsis

Control and status registers

A.6.1. Instructions

The following instructions are added by this extension:

csrrc	No synopsis available.
csrrci	No synopsis available.
csrrs	Atomic Read and Set Bits in CSR
csrrsi	No synopsis available.
csrrw	Atomic Read/Write CSR
csrrwi	Atomic Read/Write CSR Immediate

Appendix B: Instruction Details

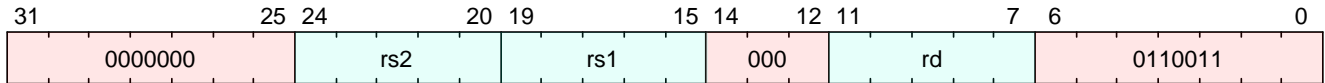
B.1. add

Integer add

This instruction is defined by:

- I, version ≥ 0

B.1.1. Encoding



B.1.2. Synopsis

Add the value in rs1 to rs2, and store the result in rd. Any overflow is thrown away.

B.1.3. Access

M	S	U
Always	Always	Always

B.1.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.1.5. Execution

```
X[rd] = X[rs1] + X[rs2];
```

B.1.6. Exceptions

This instruction does not generate synchronous exceptions.

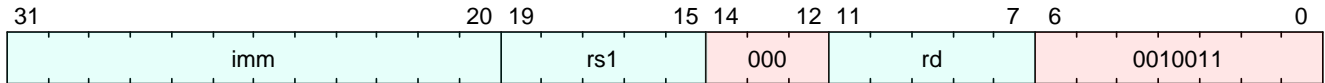
B.2. addi

Add immediate

This instruction is defined by:

- I, version ≥ 0

B.2.1. Encoding



B.2.2. Synopsis

Add an immediate to the value in rs1, and store the result in rd

B.2.3. Access

M	S	U
Always	Always	Always

B.2.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.2.5. Execution

```
X[rd] = X[rs1] + imm;
```

B.2.6. Exceptions

This instruction does not generate synchronous exceptions.

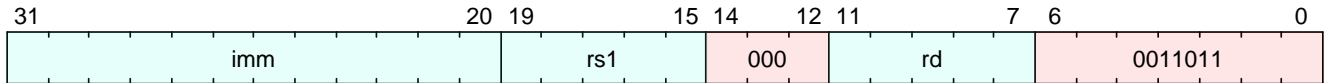
B.3. addiw

Add immediate word

This instruction is defined by:

- I, version ≥ 0

B.3.1. Encoding



B.3.2. Synopsis

Add an immediate to the 32-bit value in rs1, and store the sign extended result in rd

B.3.3. Access

M	S	U
Always	Always	Always

B.3.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.3.5. Execution

```
XReg operand = sext(X[rs1], 31);  
X[rd] = sext(operand + imm, 31);
```

B.3.6. Exceptions

This instruction does not generate synchronous exceptions.

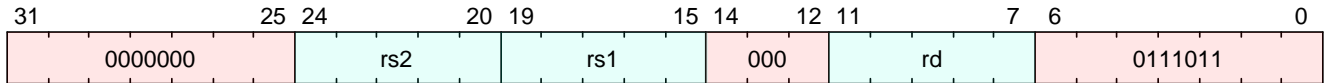
B.4. addw

Add word

This instruction is defined by:

- I, version ≥ 0

B.4.1. Encoding



B.4.2. Synopsis

Add the 32-bit values in rs1 to rs2, and store the sign-extended result in rd. Any overflow is thrown away.

B.4.3. Access

M	S	U
Always	Always	Always

B.4.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.4.5. Execution

```
XReg operand1 = sext(X[rs1], 31);  
XReg operand2 = sext(X[rs2], 31);  
X[rd] = sext(operand1 + operand2, 31);
```

B.4.6. Exceptions

This instruction does not generate synchronous exceptions.

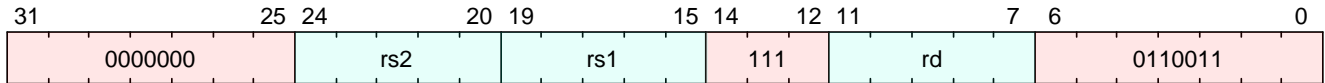
B.5. and

And

This instruction is defined by:

- I, version ≥ 0

B.5.1. Encoding



B.5.2. Synopsis

And rs1 with rs2, and store the result in rd

B.5.3. Access

M	S	U
Always	Always	Always

B.5.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.5.5. Execution

```
X[rd] = X[rs1] & X[rs2];
```

B.5.6. Exceptions

This instruction does not generate synchronous exceptions.

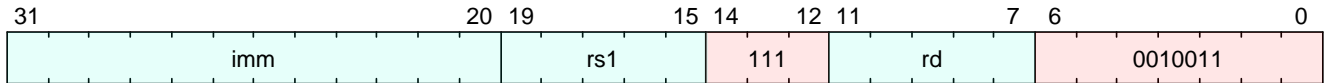
B.6. andi

And immediate

This instruction is defined by:

- I, version ≥ 0

B.6.1. Encoding



B.6.2. Synopsis

And an immediate to the value in rs1, and store the result in rd

B.6.3. Access

M	S	U
Always	Always	Always

B.6.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.6.5. Execution

```
X[rd] = X[rs1] & imm;
```

B.6.6. Exceptions

This instruction does not generate synchronous exceptions.

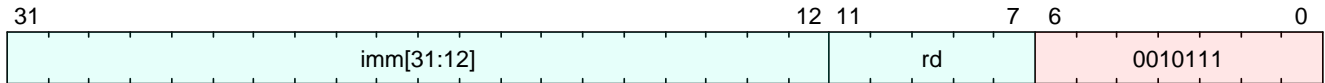
B.7. auipc

Add upper immediate to pc

This instruction is defined by:

- I, version ≥ 0

B.7.1. Encoding



B.7.2. Synopsis

Add an immediate to the current PC.

B.7.3. Access

M	S	U
Always	Always	Always

B.7.4. Decode Variables

```
Bits<32> imm = {$encoding[31:12], 12'd0};  
Bits<5> rd = $encoding[11:7];
```

B.7.5. Execution

```
X[rd] = $pc + imm;
```

B.7.6. Exceptions

This instruction does not generate synchronous exceptions.

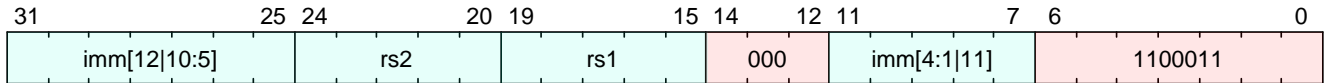
B.8. beq

Branch if equal

This instruction is defined by:

- I, version ≥ 0

B.8.1. Encoding



B.8.2. Synopsis

Branch to PC + imm if the value in register rs1 is equal to the value in register rs2.

Raise a **MisalignedAddress** exception if PC + imm is misaligned.

B.8.3. Access

M	S	U
Always	Always	Always

B.8.4. Decode Variables

```
Bits<13> imm = {$encoding[31], $encoding[7], $encoding[30:25], $encoding[11:8], 1'd0};  
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];
```

B.8.5. Execution

```
XReg lhs = X[rs1];  
XReg rhs = X[rs2];  
if (lhs == rhs) {  
    jump_halfword($pc + imm);  
}
```

B.8.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

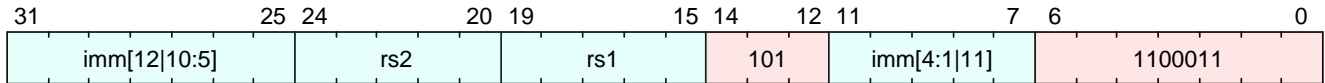
B.9. bge

Branch if greater than or equal

This instruction is defined by:

- I, version ≥ 0

B.9.1. Encoding



B.9.2. Synopsis

Branch to PC + imm if the signed value in register rs1 is greater than or equal to the signed value in register rs2.

Raise a **MisalignedAddress** exception if PC + imm is misaligned.

B.9.3. Access

M	S	U
Always	Always	Always

B.9.4. Decode Variables

```
Bits<13> imm = {$encoding[31], $encoding[7], $encoding[30:25], $encoding[11:8], 1'd0};
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
```

B.9.5. Execution

```
XReg lhs = X[rs1];
XReg rhs = X[rs2];
if ($signed(lhs) >= $signed(rhs)) {
    jump_halfword($pc + imm);
}
```

B.9.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

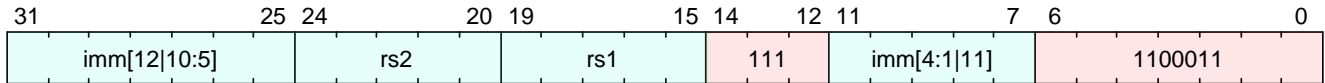
B.10. bgeu

Branch if greater than or equal unsigned

This instruction is defined by:

- I, version ≥ 0

B.10.1. Encoding



B.10.2. Synopsis

Branch to PC + imm if the unsigned value in register rs1 is greater than or equal to the unsigned value in register rs2.

Raise a **MisalignedAddress** exception if PC + imm is misaligned.

B.10.3. Access

M	S	U
Always	Always	Always

B.10.4. Decode Variables

```
Bits<13> imm = {$encoding[31], $encoding[7], $encoding[30:25], $encoding[11:8], 1'd0};  
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];
```

B.10.5. Execution

```
XReg lhs = X[rs1];  
XReg rhs = X[rs2];  
if (lhs >= rhs) {  
    jump_halfword($pc + imm);  
}
```

B.10.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

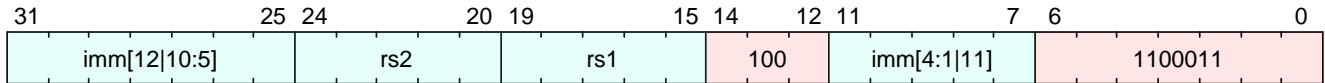
B.11. blt

Branch if less than

This instruction is defined by:

- I, version ≥ 0

B.11.1. Encoding



B.11.2. Synopsis

Branch to PC + imm if the signed value in register rs1 is less than the signed value in register rs2.

Raise a **MisalignedAddress** exception if PC + imm is misaligned.

B.11.3. Access

M	S	U
Always	Always	Always

B.11.4. Decode Variables

```
Bits<13> imm = {$encoding[31], $encoding[7], $encoding[30:25], $encoding[11:8], 1'd0};
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
```

B.11.5. Execution

```
XReg lhs = X[rs1];
XReg rhs = X[rs2];
if ($signed(lhs) < $signed(rhs)) {
    jump_halfword($pc + imm);
}
```

B.11.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

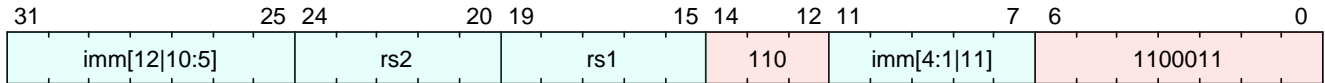
B.12. bltu

Branch if less than unsigned

This instruction is defined by:

- I, version ≥ 0

B.12.1. Encoding



B.12.2. Synopsis

Branch to PC + imm if the unsigned value in register rs1 is less than the unsigned value in register rs2.

Raise a **MisalignedAddress** exception if PC + imm is misaligned.

B.12.3. Access

M	S	U
Always	Always	Always

B.12.4. Decode Variables

```
Bits<13> imm = {$encoding[31], $encoding[7], $encoding[30:25], $encoding[11:8], 1'd0};
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
```

B.12.5. Execution

```
XReg lhs = X[rs1];
XReg rhs = X[rs2];
if (lhs < rhs) {
    jump_halfword($pc + imm);
}
```

B.12.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

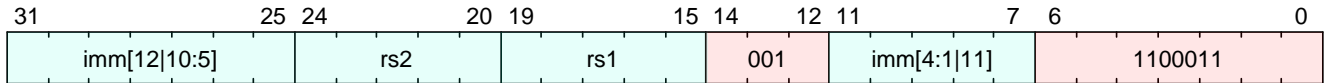
B.13. bne

Branch if not equal

This instruction is defined by:

- I, version ≥ 0

B.13.1. Encoding



B.13.2. Synopsis

Branch to PC + imm if the value in register rs1 is not equal to the value in register rs2.

Raise a **MisalignedAddress** exception if PC + imm is misaligned.

B.13.3. Access

M	S	U
Always	Always	Always

B.13.4. Decode Variables

```
Bits<13> imm = {$encoding[31], $encoding[7], $encoding[30:25], $encoding[11:8], 1'd0};  
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];
```

B.13.5. Execution

```
XReg lhs = X[rs1];  
XReg rhs = X[rs2];  
if (lhs != rhs) {  
    jump_halfword($pc + imm);  
}
```

B.13.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

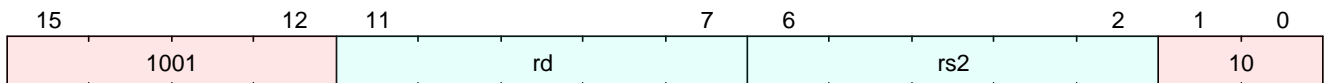
B.14. c.add

Add

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.14.1. Encoding



B.14.2. Synopsis

Add the value in rs2 to rd, and store the result in rd. C.ADD expands into `add rd, rd, rs2`.

B.14.3. Access

M	S	U
Always	Always	Always

B.14.4. Decode Variables

```
Bits<5> rs2 = $encoding[6:2];  
Bits<5> rd = $encoding[11:7];
```

B.14.5. Execution

```
XReg t0 = X[rd];  
XReg t1 = X[rs2];  
X[rd] = t0 + t1;
```

B.14.6. Exceptions

This instruction does not generate synchronous exceptions.

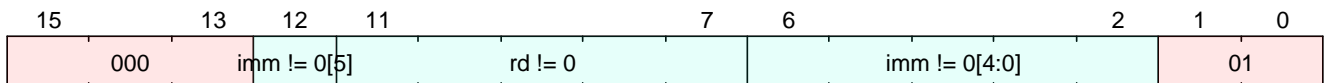
B.15. c.addi

Add a sign-extended non-zero immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.15.1. Encoding



B.15.2. Synopsis

C.ADDI adds the non-zero sign-extended 6-bit immediate to the value in register `rd` then writes the result to `rd`. C.ADDI expands into `<code>addi rd, rd, imm</code>`. C.ADDI is only valid when `rd` \neq `x0` and `imm` \neq 0. The code points with `rd=x0` encode the C.NOP instruction; the remaining code points with `imm=0` encode HINTs.

B.15.3. Access

M	S	U
Always	Always	Always

B.15.4. Decode Variables

```
Bits<6> imm = { $encoding[12], $encoding[6:2] };  
Bits<5> rd = $encoding[11:7];
```

B.15.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
X[rd] = X[rd] + imm;
```

B.15.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

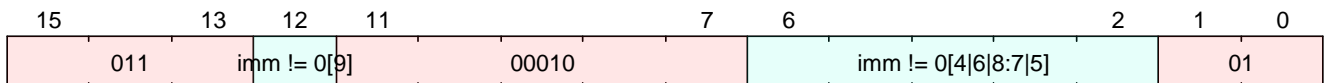
B.16. c.addi16sp

Add a sign-extended non-zero immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.16.1. Encoding



B.16.2. Synopsis

C.ADDI16SP adds the non-zero sign-extended 6-bit immediate to the value in the stack pointer ($sp=x2$), where the immediate is scaled to represent multiples of 16 in the range (-512,496). C.ADDI16SP is used to adjust the stack pointer in procedure prologues and epilogues. It expands into `addi x2, x2, nzimm[9:4]`. C.ADDI16SP is only valid when $nzimm \neq 0$; the code point with $nzimm=0$ is reserved.

B.16.3. Access

M	S	U
Always	Always	Always

B.16.4. Decode Variables

```
Bits<10> imm = { $encoding[12], $encoding[4:3], $encoding[5], $encoding[2],  
$encoding[6], 4'd0};
```

B.16.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
X[2] = X[2] + imm;
```

B.16.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

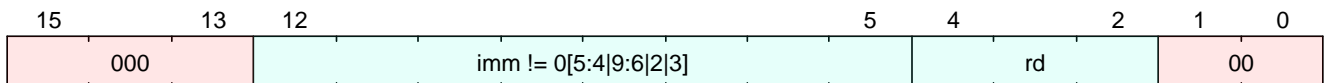
B.17. c.addi4spn

Add a zero-extended non-zero immediate, scaled by 4, to the stack pointer

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.17.1. Encoding



B.17.2. Synopsis

Adds a zero-extended non-zero immediate, scaled by 4, to the stack pointer, x2, and writes the result to rd'. This instruction is used to generate pointers to stack-allocated variables. It expands to `addi rd', x2, nzuimm[9:2]`. C.ADDI4SPN is only valid when nzuimm \neq 0; the code points with nzuimm=0 are reserved.

B.17.3. Access

M	S	U
Always	Always	Always

B.17.4. Decode Variables

```
Bits<10> imm = {$encoding[10:7], $encoding[12:11], $encoding[5], $encoding[6], 2'd0};  
Bits<3> rd = $encoding[4:2];
```

B.17.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
X[rd + 8] = X[2] + imm;
```

B.17.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

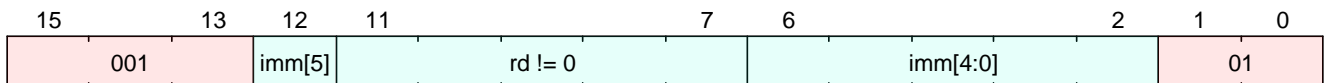
B.18. c.addiw

Add a sign-extended non-zero immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.18.1. Encoding



B.18.2. Synopsis

C.ADDIW is an RV64C/RV128C-only instruction that performs the same computation as C.ADDI but produces a 32-bit result, then sign-extends result to 64 bits. C.ADDIW expands into `addiw rd, rd, imm`. The immediate can be zero for C.ADDIW, where this corresponds to `sext.w rd`. C.ADDIW is only valid when `rd != x0`; the code points with `rd=x0` are reserved.

B.18.3. Access

M	S	U
Always	Always	Always

B.18.4. Decode Variables

```
Bits<6> imm = {$encoding[12], $encoding[6:2]};  
Bits<5> rd = $encoding[11:7];
```

B.18.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
X[rd] = sext((X[rd] + imm), 32);
```

B.18.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

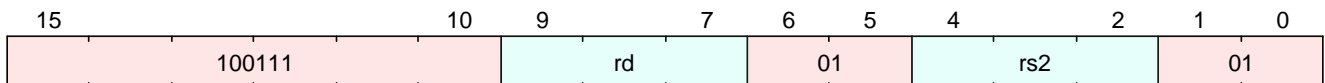
B.19. c.addw

Add word

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.19.1. Encoding



B.19.2. Synopsis

Add the 32-bit values in rs2 from rd, and store the result in rd. The rd and rs2 register indexes should be used as rd+8 and rs2+8 (registers x8-x15). C.ADDW expands into `addw rd, rd, rs2`.

B.19.3. Access

M	S	U
Always	Always	Always

B.19.4. Decode Variables

```
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rd = $encoding[9:7];
```

B.19.5. Execution

```
Bits<32> t0 = X[rd + 8][31:0];  
Bits<32> t1 = X[rs2 + 8][31:0];  
X[rd + 8] = sext(t0 + t1, 31);
```

B.19.6. Exceptions

This instruction does not generate synchronous exceptions.

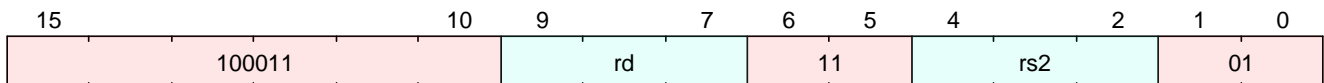
B.20. c.and

And

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.20.1. Encoding



B.20.2. Synopsis

And rd with rs2, and store the result in rd. The rd and rs2 register indexes should be used as rd+8 and rs2+8 (registers x8-x15). C.AND expands into `and rd, rd, rs2`.

B.20.3. Access

M	S	U
Always	Always	Always

B.20.4. Decode Variables

```
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rd = $encoding[9:7];
```

B.20.5. Execution

```
XReg t0 = X[rd + 8];  
XReg t1 = X[rs2 + 8];  
X[rd + 8] = t0 & t1;
```

B.20.6. Exceptions

This instruction does not generate synchronous exceptions.

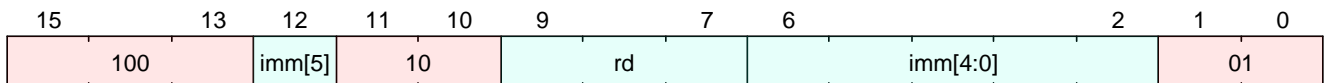
B.21. c.andi

And immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.21.1. Encoding



B.21.2. Synopsis

And an immediate to the value in rd, and store the result in rd. The rd register index should be used as rd+8 (registers x8-x15). C.ANDI expands into `andi rd, rd, imm`.

B.21.3. Access

M	S	U
Always	Always	Always

B.21.4. Decode Variables

```
Bits<6> imm = { $encoding[12], $encoding[6:2] };  
Bits<3> rd = $encoding[9:7];
```

B.21.5. Execution

```
X[rd + 8] = X[rd + 8] & imm;
```

B.21.6. Exceptions

This instruction does not generate synchronous exceptions.

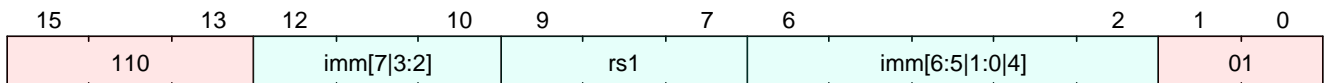
B.22. c.beqz

Branch if Equal Zero

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.22.1. Encoding



B.22.2. Synopsis

C.BEQZ performs conditional control transfers. The offset is sign-extended and added to the pc to form the branch target address. It can therefore target a ± 256 B range. C.BEQZ takes the branch if the value in register rs1' is zero. It expands to `beq <code>rs1, x0, offset</code>`.

B.22.3. Access

M	S	U
Always	Always	Always

B.22.4. Decode Variables

```
Bits<8> imm = { $encoding[12], $encoding[6:5], $encoding[2], $encoding[11:10],  
$encoding[4:3] };  
Bits<3> rs1 = $encoding[9:7];
```

B.22.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
if (X[rs1] != 0) {  
  jump($pc + imm);  
}
```

B.22.6. Exceptions

This instruction may result in the following synchronous exceptions:

- `IllegalInstruction`
- `InstructionAddressMisaligned`

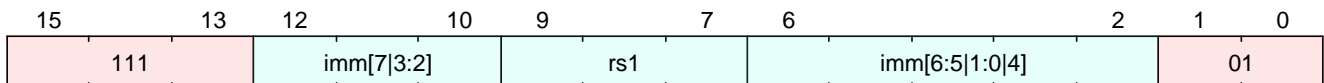
B.23. c.bnez

Branch if NOT Equal Zero

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.23.1. Encoding



B.23.2. Synopsis

C.BEQZ performs conditional control transfers. The offset is sign-extended and added to the pc to form the branch target address. It can therefore target a ± 256 B range. C.BEQZ takes the branch if the value in register rs1' is NOT zero. It expands to `beq <code>rs1, x0, offset</code>`.

B.23.3. Access

M	S	U
Always	Always	Always

B.23.4. Decode Variables

```
Bits<8> imm = { $encoding[12], $encoding[6:5], $encoding[2], $encoding[11:10],  
$encoding[4:3] };  
Bits<3> rs1 = $encoding[9:7];
```

B.23.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
if (X[rs1] != 0) {  
  jump($pc + imm);  
}
```

B.23.6. Exceptions

This instruction may result in the following synchronous exceptions:

- `IllegalInstruction`
- `InstructionAddressMisaligned`

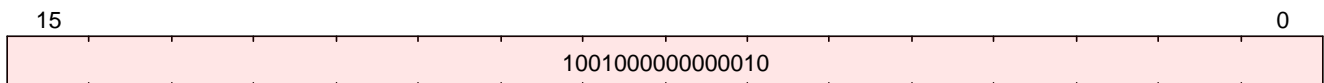
B.24. c.ebreak

Breakpoint exception.

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.24.1. Encoding



B.24.2. Synopsis

The C.EBREAK instruction is used by debuggers to cause control to be transferred back to a debugging environment. Unless overridden by an external debug environment, C.EBREAK raises a breakpoint exception and performs no other operation.

NOTE As described in the C Standard Extension for Compressed Instructions, the [c.ebreak](#) instruction performs the same operation as the EBREAK instruction.

EBREAK causes the receiving privilege mode's epc register to be set to the address of the EBREAK instruction itself, not the address of the following instruction. As EBREAK causes a synchronous exception, it is not considered to retire, and should not increment the [minstret](#) CSR.

B.24.3. Access

M	S	U
Always	Always	Always

B.24.4. Decode Variables

B.24.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
if (TRAP_ON_EBREAK) {
    raise_precise(ExceptionCode::Breakpoint, mode(), $pc);
} else {
    eei_ebreak();
}
```

```
}
```

B.24.6. Exceptions

This instruction may result in the following synchronous exceptions:

- Breakpoint
- IllegalInstruction

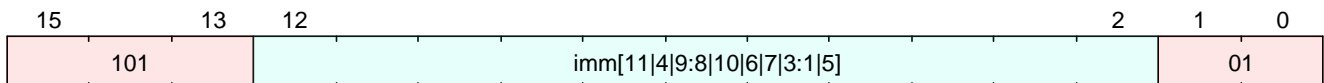
B.25. c.j

Jump

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.25.1. Encoding



B.25.2. Synopsis

C.J performs an unconditional control transfer. The offset is sign-extended and added to the pc to form the jump target address. C.J can therefore target a ± 2 KiB range. It expands to `jal <code>x0, offset</code>`.

B.25.3. Access

M	S	U
Always	Always	Always

B.25.4. Decode Variables

```
signed Bits<12> imm = sext({$encoding[12], $encoding[8], $encoding[10:9],  
$encoding[6], $encoding[7], $encoding[2], $encoding[11], $encoding[5:3], 1'd0});
```

B.25.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
jump($pc + imm);
```

B.25.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction
- InstructionAddressMisaligned

- InstructionAddressMisaligned

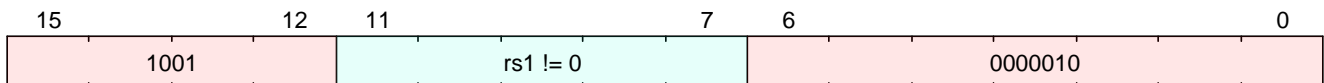
B.27. c.jalr

Jump and Link Register.

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.27.1. Encoding



B.27.2. Synopsis

C.JALR (jump and link register) performs the same operation as C.JR, but additionally writes the address of the instruction following the jump (pc+2) to the link register, x1. C.JALR expands to jalr x1, 0(rs1).

B.27.3. Access

M	S	U
Always	Always	Always

B.27.4. Decode Variables

```
Bits<5> rs1 = $encoding[11:7];
```

B.27.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg returnaddr;  
returnaddr = $pc + 2;  
jump(X[rs1]);  
X[1] = returnaddr;
```

B.27.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- InstructionAddressMisaligned

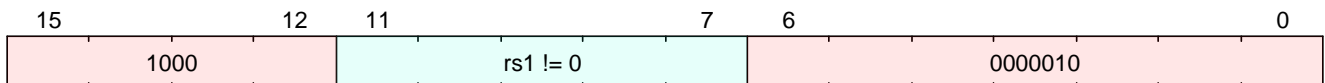
B.28. c.jr

Jump Register

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.28.1. Encoding



B.28.2. Synopsis

C.JR (jump register) performs an unconditional control transfer to the address in register rs1. C.JR expands to jalr x0, 0(rs1).

B.28.3. Access

M	S	U
Always	Always	Always

B.28.4. Decode Variables

```
Bits<5> rs1 = $encoding[11:7];
```

B.28.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
jump(X[rs1]);
```

B.28.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction
- InstructionAddressMisaligned

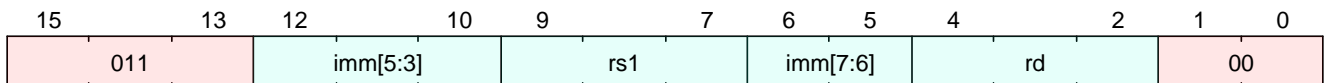
B.29. c.ld

Load double

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.29.1. Encoding



B.29.2. Synopsis

Loads a 64-bit value from memory into register `rd`. It computes an effective address by adding the zero-extended offset, scaled by 8, to the base address in register `rs1`. It expands to `ld rd, offset(rs1)`.

B.29.3. Access

M	S	U
Always	Always	Always

B.29.4. Decode Variables

```
Bits<8> imm = {$encoding[6:5], $encoding[12:10], 3'd0};  
Bits<3> rd = $encoding[4:2];  
Bits<3> rs1 = $encoding[9:7];
```

B.29.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg virtual_address = X[rs1] + imm;  
X[rd] = sext(read_memory<64>(virtual_address, $encoding), 64);
```

B.29.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault
- StoreAmoAccessFault

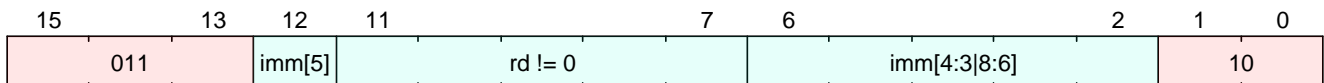
B.30. c.ldsp

Load doubleword from stack pointer

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.30.1. Encoding



B.30.2. Synopsis

C.LDSP is an RV64C/RV128C-only instruction that loads a 64-bit value from memory into register rd. It computes its effective address by adding the zero-extended offset, scaled by 8, to the stack pointer, x2. It expands to `ld <code>rd, offset(x2)</code>`. C.LDSP is only valid when rd \neq x0 the code points with rd=x0 are reserved.

B.30.3. Access

M	S	U
Always	Always	Always

B.30.4. Decode Variables

```
Bits<9> imm = {$encoding[4:2], $encoding[12], $encoding[6:5], 3'd0};  
Bits<5> rd = $encoding[11:7];
```

B.30.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg virtual_address = X[2] + imm;  
X[rd] = read_memory<64>(virtual_address, $encoding);
```

B.30.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

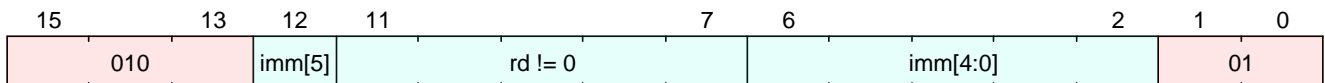
B.31. c.li

Load the sign-extended 6-bit immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.31.1. Encoding



B.31.2. Synopsis

C.LI loads the sign-extended 6-bit immediate, `imm`, into register `rd`. C.LI expands into `<code>addi rd, x0, imm</code>`. C.LI is only valid when `rd` \neq `x0`; the code points with `rd=x0` encode HINTs.

B.31.3. Access

M	S	U
Always	Always	Always

B.31.4. Decode Variables

```
Bits<6> imm = { $encoding[12], $encoding[6:2] };
Bits<5> rd = $encoding[11:7];
```

B.31.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
X[rd] = imm;
```

B.31.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

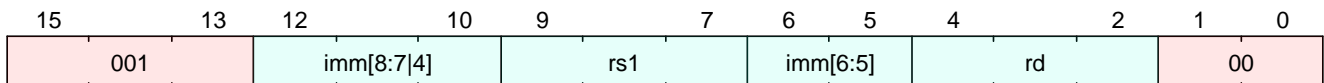
B.32. c.lq

Load quadruple

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.32.1. Encoding



B.32.2. Synopsis

Loads a 128-bit value from memory into register rd. It computes an effective address by adding the zero-extended offset, scaled by 16, to the base address in register rs1. It expands to `lq rd, offset(rs1)`.

B.32.3. Access

M	S	U
Always	Always	Always

B.32.4. Decode Variables

```
Bits<9> imm = {$encoding[12:11], $encoding[6:5], $encoding[10], 4'd0};
Bits<3> rd = $encoding[4:2];
Bits<3> rs1 = $encoding[9:7];
```

B.32.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[rs1] + imm;
X[rd] = sext(read_memory<128>(virtual_address, $encoding), 128);
```

B.32.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

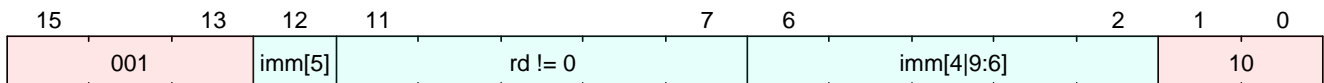
B.33. c.lqsp

Load quadruple word from stack pointer

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.33.1. Encoding



B.33.2. Synopsis

C.LQSP is an RV128C-only instruction that loads a 128-bit value from memory into register rd. It computes its effective address by adding the zero-extended offset, scaled by 16, to the stack pointer, x2. It expands to `<code>lq</code> <code>rd, offset(x2)</code>. C.LQSP is only valid when rd \neq x0; the code points with rd=x0 are reserved.`

B.33.3. Access

M	S	U
Always	Always	Always

B.33.4. Decode Variables

```
Bits<10> imm = {$encoding[5:2], $encoding[12], $encoding[6], 4'd0};
Bits<5> rd = $encoding[11:7];
```

B.33.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[2] + imm;
X[rd] = read_memory<128>(virtual_address, $encoding);
```

B.33.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

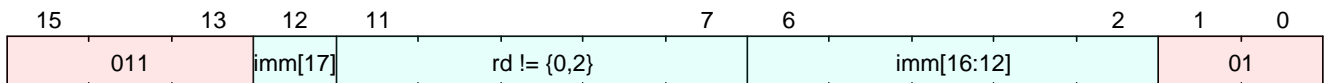
B.34. c.lui

Load the non-zero 6-bit immediate field into bits 17-12 of the destination register

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.34.1. Encoding



B.34.2. Synopsis

C.LUI loads the non-zero 6-bit immediate field into bits 17-12 of the destination register, clears the bottom 12 bits, and sign-extends bit 17 into all higher bits of the destination. C.LUI expands into `lui rd, imm`. C.LUI is only valid when $rd \neq x0$ and $rd \neq x2$, and when the immediate is not equal to zero. The code points with $imm=0$ are reserved; the remaining code points with $rd=x0$ are HINTs; and the remaining code points with $rd=x2$ correspond to the C.ADDI16SP instruction

B.34.3. Access

M	S	U
Always	Always	Always

B.34.4. Decode Variables

```
Bits<18> imm = { $encoding[12], $encoding[6:2], 12'd0 };
Bits<5> rd = $encoding[11:7];
```

B.34.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
X[rd] = imm;
```

B.34.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

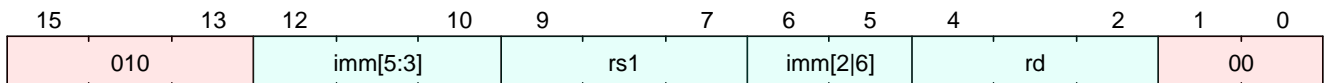
B.35. c.lw

Load word

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.35.1. Encoding



B.35.2. Synopsis

Loads a 32-bit value from memory into register rd. It computes an effective address by adding the zero-extended offset, scaled by 4, to the base address in register rs1. It expands to `lw rd, offset(rs1)`.

B.35.3. Access

M	S	U
Always	Always	Always

B.35.4. Decode Variables

```
Bits<7> imm = {$encoding[5], $encoding[12:10], $encoding[6], 2'd0};
Bits<3> rd = $encoding[4:2];
Bits<3> rs1 = $encoding[9:7];
```

B.35.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[rs1] + imm;
X[rd] = sext(read_memory<32>(virtual_address, $encoding), 32);
```

B.35.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

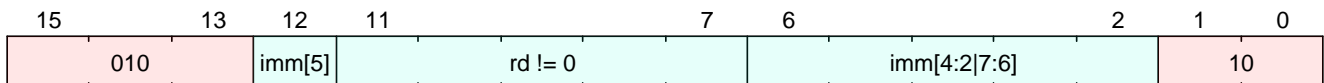
B.36. c.lwsp

Load word from stack pointer

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.36.1. Encoding



B.36.2. Synopsis

Loads a 32-bit value from memory into register `rd`. It computes an effective address by adding the zero-extended offset, scaled by 4, to the stack pointer, `x2`. It expands to `lw <code>rd, offset(x2)</code>`. C.LWSP is only valid when `rd` \neq `x0`. The code points with `rd=x0` are reserved.

B.36.3. Access

M	S	U
Always	Always	Always

B.36.4. Decode Variables

```
Bits<8> imm = {$encoding[3:2], $encoding[12], $encoding[6:4], 2'd0};  
Bits<5> rd = $encoding[11:7];
```

B.36.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg virtual_address = X[2] + imm;  
X[rd] = sext(read_memory<32>(virtual_address, $encoding), 32);
```

B.36.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

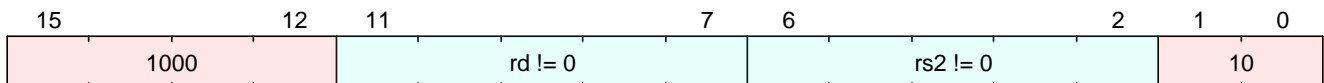
B.37. c.mv

Move Register

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.37.1. Encoding



B.37.2. Synopsis

C.MV (move register) performs copy of the data in register rs2 to register rd. C.MV expands to `addi rd, x0, rs2`.

B.37.3. Access

M	S	U
Always	Always	Always

B.37.4. Decode Variables

```
Bits<5> rd = $encoding[11:7];  
Bits<5> rs2 = $encoding[6:2];
```

B.37.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
X[rd] = X[rs2];
```

B.37.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

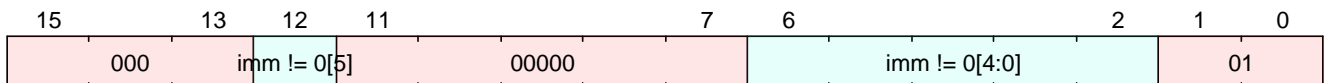
B.38. c.nop

Non-operation

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.38.1. Encoding



B.38.2. Synopsis

C.NOP expands into `addi x0, x0, imm`.

B.38.3. Access

M	S	U
Always	Always	Always

B.38.4. Decode Variables

```
Bits<6> imm = {$encoding[12], $encoding[6:2]};
```

B.38.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}
```

B.38.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

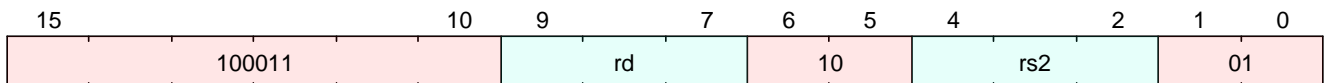
B.39. c.or

Or

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.39.1. Encoding



B.39.2. Synopsis

Or rd with rs2, and store the result in rd. The rd and rs2 register indexes should be used as rd+8 and rs2+8 (registers x8-x15). C.OR expands into `or rd, rd, rs2`.

B.39.3. Access

M	S	U
Always	Always	Always

B.39.4. Decode Variables

```
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rd = $encoding[9:7];
```

B.39.5. Execution

```
XReg t0 = X[rd + 8];  
XReg t1 = X[rs2 + 8];  
X[rd + 8] = t0 | t1;
```

B.39.6. Exceptions

This instruction does not generate synchronous exceptions.

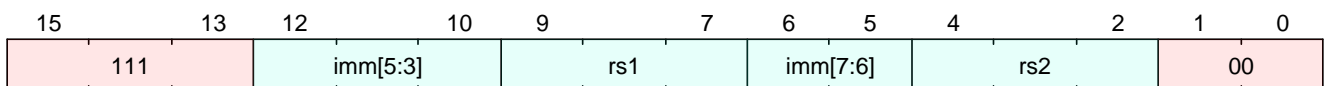
B.40. c.sd

Store double

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.40.1. Encoding



B.40.2. Synopsis

Stores a 64-bit value in register `rs2` to memory. It computes an effective address by adding the zero-extended offset, scaled by 8, to the base address in register `rs1`. It expands to `sd rs2, offset(rs1)`.

B.40.3. Access

M	S	U
Always	Always	Always

B.40.4. Decode Variables

```
Bits<8> imm = {$encoding[6:5], $encoding[12:10], 3'd0};  
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rs1 = $encoding[9:7];
```

B.40.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg virtual_address = X[rs1] + imm;  
write_memory<64>(virtual_address, X[rs2], $encoding);
```

B.40.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

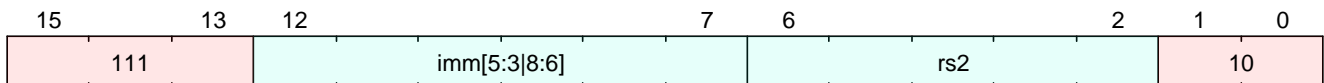
B.41. c.sdsp

Store doubleword to stack

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.41.1. Encoding



B.41.2. Synopsis

Stores a 64-bit value in register `rs2` to memory. It computes an effective address by adding the zero-extended offset, scaled by 8, to the stack pointer, `x2`. It expands to `sd rs2, offset(x2)`.

B.41.3. Access

M	S	U
Always	Always	Always

B.41.4. Decode Variables

```
Bits<9> imm = { $encoding[9:7], $encoding[12:10], 3'd0 };
Bits<5> rs2 = $encoding[6:2];
```

B.41.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[2] + imm;
write_memory<64>(virtual_address, X[rs2], $encoding);
```

B.41.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction
- LoadAccessFault

- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

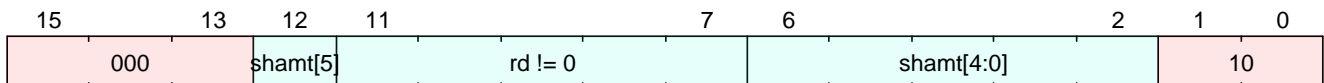
B.42. c.slli

Shift left logical immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.42.1. Encoding



B.42.2. Synopsis

Shift the value in rd left by shamt, and store the result back in rd. C.SLLI expands into `slli rd, rd, shamt`.

B.42.3. Access

M	S	U
Always	Always	Always

B.42.4. Decode Variables

```
Bits<6> shamt = { $encoding[12], $encoding[6:2] };  
Bits<5> rd = $encoding[11:7];
```

B.42.5. Execution

```
X[rd] = X[rd] << shamt;
```

B.42.6. Exceptions

This instruction does not generate synchronous exceptions.

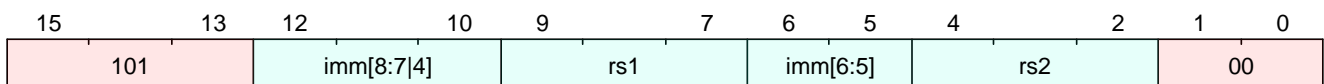
B.43. c.sq

Store quadruple

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.43.1. Encoding



B.43.2. Synopsis

Stores a 128-bit value in register `rs2` to memory. It computes an effective address by adding the zero-extended offset, scaled by 16, to the base address in register `rs1`. It expands to `sq rs2, offset(rs1)`.

B.43.3. Access

M	S	U
Always	Always	Always

B.43.4. Decode Variables

```
Bits<9> imm = {$encoding[12:11], $encoding[6:5], $encoding[10], 4'd0};
Bits<3> rs2 = $encoding[4:2];
Bits<3> rs1 = $encoding[9:7];
```

B.43.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[rs1] + imm;
write_memory<128>(virtual_address, X[rs2], $encoding);
```

B.43.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

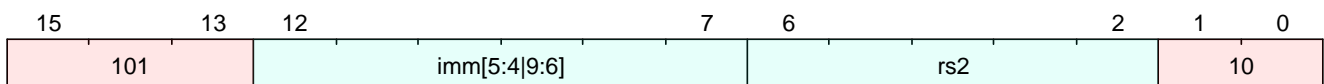
B.44. c.sqsp

Store quadruple word to stack

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.44.1. Encoding



B.44.2. Synopsis

Stores a 128-bit value in register `rs2` to memory. It computes an effective address by adding the zero-extended offset, scaled by 16, to the stack pointer, `x2`. It expands to `sq rs2, offset(x2)`.

B.44.3. Access

M	S	U
Always	Always	Always

B.44.4. Decode Variables

```
Bits<10> imm = {$encoding[10:7], $encoding[12:11], 4'd0};  
Bits<5> rs2 = $encoding[6:2];
```

B.44.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg virtual_address = X[2] + imm;  
write_memory<128>(virtual_address, X[rs2], $encoding);
```

B.44.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction
- LoadAccessFault

- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

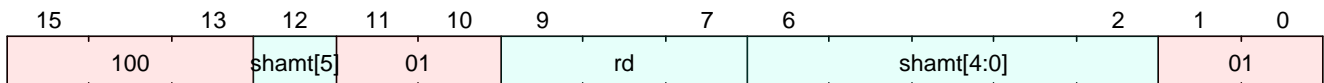
B.45. c.srai

Shift right arithmetical immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.45.1. Encoding



B.45.2. Synopsis

Arithmetic shift (the original sign bit is copied into the vacated upper bits) the value in rd right by shamt, and store the result in rd. The rd register index should be used as rd+8 (registers x8-x15). C.SRAI expands into `srai rd, rd, shamt`.

B.45.3. Access

M	S	U
Always	Always	Always

B.45.4. Decode Variables

```
Bits<6> shamt = {$encoding[12], $encoding[6:2]};  
Bits<3> rd = $encoding[9:7];
```

B.45.5. Execution

```
X[rd + 8] = X[rd + 8] >>> shamt;
```

B.45.6. Exceptions

This instruction does not generate synchronous exceptions.

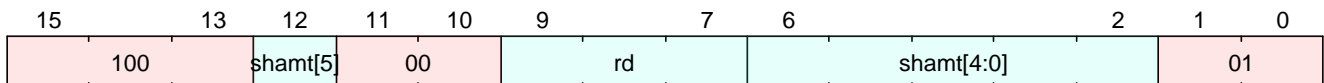
B.46. c.srli

Shift right logical immediate

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.46.1. Encoding



B.46.2. Synopsis

Shift the value in rd right by shamt, and store the result back in rd. The rd register index should be used as rd+8 (registers x8-x15). C.SRLI expands into `srli rd, rd, shamt`.

B.46.3. Access

M	S	U
Always	Always	Always

B.46.4. Decode Variables

```
Bits<6> shamt = { $encoding[12], $encoding[6:2] };
Bits<3> rd = $encoding[9:7];
```

B.46.5. Execution

```
X[rd + 8] = X[rd + 8] >> shamt;
```

B.46.6. Exceptions

This instruction does not generate synchronous exceptions.

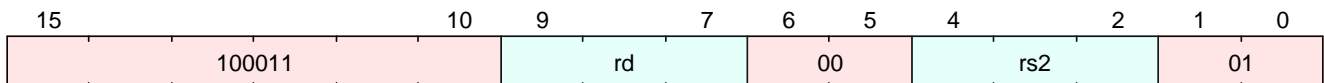
B.47. c.sub

Subtract

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.47.1. Encoding



B.47.2. Synopsis

Subtract the value in rs2 from rd, and store the result in rd. The rd and rs2 register indexes should be used as rd+8 and rs2+8 (registers x8-x15). C.SUB expands into `sub rd, rd, rs2`.

B.47.3. Access

M	S	U
Always	Always	Always

B.47.4. Decode Variables

```
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rd = $encoding[9:7];
```

B.47.5. Execution

```
XReg t0 = X[rd + 8];  
XReg t1 = X[rs2 + 8];  
X[rd + 8] = t0 - t1;
```

B.47.6. Exceptions

This instruction does not generate synchronous exceptions.

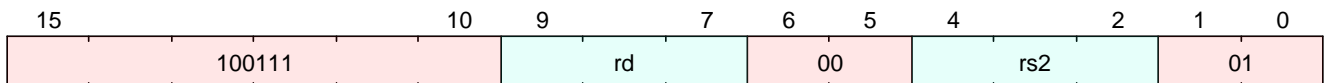
B.48. c.subw

Subtract word

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.48.1. Encoding



B.48.2. Synopsis

Subtract the 32-bit values in rs2 from rd, and store the result in rd. The rd and rs2 register indexes should be used as rd+8 and rs2+8 (registers x8-x15). C.SUBW expands into `subw rd, rd, rs2`.

B.48.3. Access

M	S	U
Always	Always	Always

B.48.4. Decode Variables

```
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rd = $encoding[9:7];
```

B.48.5. Execution

```
Bits<32> t0 = X[rd + 8][31:0];  
Bits<32> t1 = X[rs2 + 8][31:0];  
X[rd + 8] = sext(t0 - t1, 31);
```

B.48.6. Exceptions

This instruction does not generate synchronous exceptions.

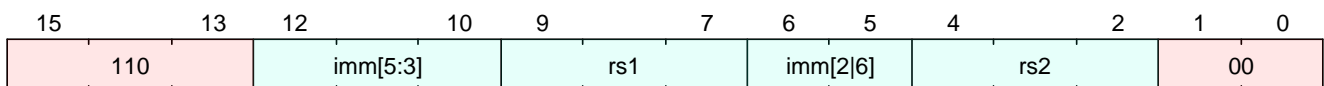
B.49. c.sw

Store word

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.49.1. Encoding



B.49.2. Synopsis

Stores a 32-bit value in register `rs2` to memory. It computes an effective address by adding the zero-extended offset, scaled by 4, to the base address in register `rs1`. It expands to `sw rs2, offset(rs1)`.

B.49.3. Access

M	S	U
Always	Always	Always

B.49.4. Decode Variables

```
Bits<7> imm = {$encoding[5], $encoding[12:10], $encoding[6], 2'd0};
Bits<3> rs2 = $encoding[4:2];
Bits<3> rs1 = $encoding[9:7];
```

B.49.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[rs1] + imm;
write_memory<32>(virtual_address, X[rs2][31:0], $encoding);
```

B.49.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

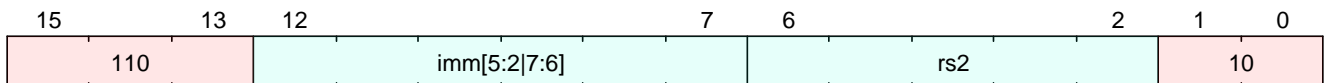
B.50. c.swsp

Store word to stack

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.50.1. Encoding



B.50.2. Synopsis

Stores a 32-bit value in register `rs2` to memory. It computes an effective address by adding the zero-extended offset, scaled by 4, to the stack pointer, `x2`. It expands to `sw rs2, offset(x2)`.

B.50.3. Access

M	S	U
Always	Always	Always

B.50.4. Decode Variables

```
Bits<8> imm = { $encoding[8:7], $encoding[12:9], 2'd0 };
Bits<5> rs2 = $encoding[6:2];
```

B.50.5. Execution

```
if (implemented?(ExtensionName::C) && (CSR[misa].C == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg virtual_address = X[2] + imm;
write_memory<32>(virtual_address, X[rs2][31:0], $encoding);
```

B.50.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction
- LoadAccessFault

- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

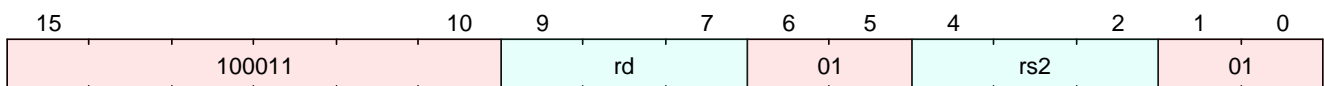
B.51. c.xor

Exclusive Or

This instruction is defined by:

- anyOf:
 - C, version ≥ 0
 - Zca, version ≥ 0

B.51.1. Encoding



B.51.2. Synopsis

Exclusive or rd with rs2, and store the result in rd. The rd and rs2 register indexes should be used as rd+8 and rs2+8 (registers x8-x15). C.XOR expands into `xor rd, rd, rs2`.

B.51.3. Access

M	S	U
Always	Always	Always

B.51.4. Decode Variables

```
Bits<3> rs2 = $encoding[4:2];  
Bits<3> rd = $encoding[9:7];
```

B.51.5. Execution

```
XReg t0 = X[rd + 8];  
XReg t1 = X[rs2 + 8];  
X[rd + 8] = t0 ^ t1;
```

B.51.6. Exceptions

This instruction does not generate synchronous exceptions.

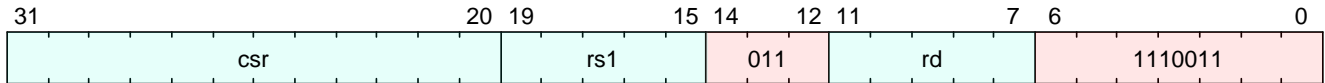
B.52. csrrc

No synopsis available.

This instruction is defined by:

- Zicsr, version ≥ 0

B.52.1. Encoding



B.52.2. Synopsis

No description available.

B.52.3. Access

M	S	U
Always	Always	Always

B.52.4. Decode Variables

```
Bits<12> csr = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.52.5. Execution

B.52.6. Exceptions

This instruction does not generate synchronous exceptions.

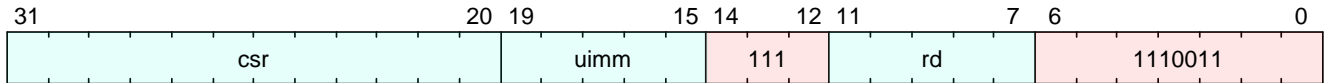
B.53. csrrci

No synopsis available.

This instruction is defined by:

- Zicsr, version ≥ 0

B.53.1. Encoding



B.53.2. Synopsis

No description available.

B.53.3. Access

M	S	U
Always	Always	Always

B.53.4. Decode Variables

```
Bits<12> csr = $encoding[31:20];  
Bits<5> uimm = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.53.5. Execution

B.53.6. Exceptions

This instruction does not generate synchronous exceptions.

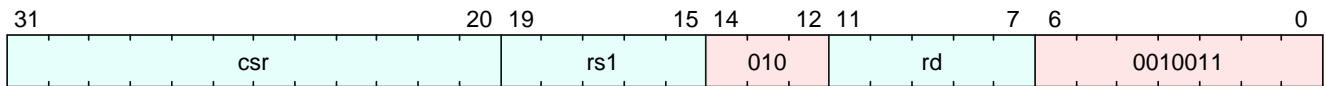
B.54. csrrs

Atomic Read and Set Bits in CSR

This instruction is defined by:

- Zicsr, version ≥ 0

B.54.1. Encoding



B.54.2. Synopsis

Atomically read and set bits in a CSR.

Reads the value of the CSR, zero-extends the value to $XLEN$ bits, and writes it to integer register rd . The initial value in integer register $rs1$ is treated as a bit mask that specifies bit positions to be set in the CSR. Any bit that is high in $rs1$ will cause the corresponding bit to be set in the CSR, if that CSR bit is writable. Other bits in the CSR are not explicitly written.

B.54.3. Access

M	S	U
Always	Always	Always

B.54.4. Decode Variables

```
Bits<12> csr = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.54.5. Execution

```
XReg initial_csr_value = CSR[csr].sw_read();  
XReg mask = X[rs1];  
CSR[csr].sw_write(initial_csr_value | mask);  
X[rd] = initial_csr_value;
```

B.54.6. Exceptions

This instruction does not generate synchronous exceptions.

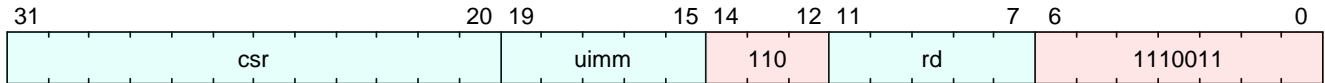
B.55. csrrsi

No synopsis available.

This instruction is defined by:

- Zicsr, version ≥ 0

B.55.1. Encoding



B.55.2. Synopsis

No description available.

B.55.3. Access

M	S	U
Always	Always	Always

B.55.4. Decode Variables

```
Bits<12> csr = $encoding[31:20];  
Bits<5> uimm = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.55.5. Execution

B.55.6. Exceptions

This instruction does not generate synchronous exceptions.

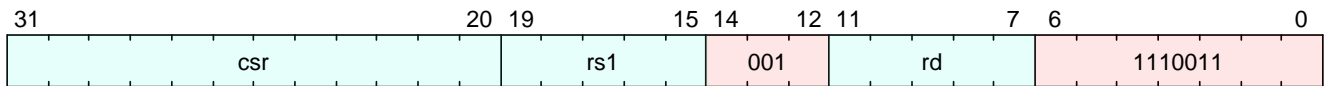
B.56. csrrw

Atomic Read/Write CSR

This instruction is defined by:

- Zicsr, version ≥ 0

B.56.1. Encoding



B.56.2. Synopsis

Atomically swap values in the CSRs and integer registers.

Read the old value of the CSR, zero-extends the value to $XLEN$ bits, and then write it to integer register rd . The initial value in $rs1$ is written to the CSR. If $rd=x0$, then the instruction shall not read the CSR and shall not cause any of the side effects that might occur on a CSR read.

B.56.3. Access

M	S	U
Always	Always	Always

B.56.4. Decode Variables

```
Bits<12> csr = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.56.5. Execution

```
if (rd != 0) {  
    X[rd] = CSR[csr].sw_read();  
}  
CSR[csr].sw_write(X[rs1]);
```

B.56.6. Exceptions

This instruction does not generate synchronous exceptions.

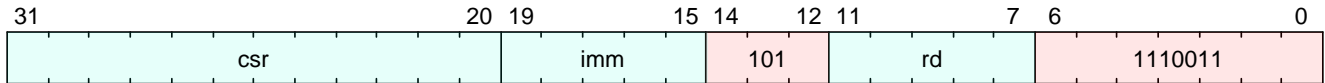
B.57. csrrwi

Atomic Read/Write CSR Immediate

This instruction is defined by:

- Zicsr, version ≥ 0

B.57.1. Encoding



B.57.2. Synopsis

Atomically write CSR using a 5-bit immediate, and load the previous value into 'rd'.

Read the old value of the CSR, zero-extends the value to $XLEN$ bits, and then write it to integer register rd . The 5-bit uimm field is zero-extended and written to the CSR. If $rd=x0$, then the instruction shall not read the CSR and shall not cause any of the side effects that might occur on a CSR read.

B.57.3. Access

M	S	U
Always	Always	Always

B.57.4. Decode Variables

```
Bits<12> csr = $encoding[31:20];  
Bits<5> imm = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.57.5. Execution

```
if (rd != 0) {  
    X[rd] = CSR[csr].sw_read();  
}  
CSR[csr].sw_write({{XLEN - 5{1'b0}}, imm});
```

B.57.6. Exceptions

This instruction does not generate synchronous exceptions.

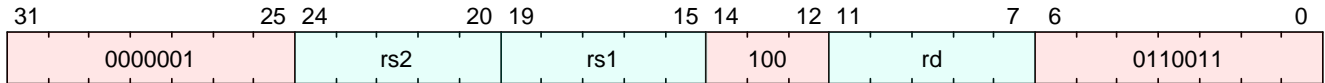
B.58. div

Signed division

This instruction is defined by:

- M, version ≥ 0

B.58.1. Encoding



B.58.2. Synopsis

Divide rs1 by rs2, and store the result in rd. The remainder is discarded.

Division by zero will put -1 into rd.

Division resulting in signed overflow (when most negative number is divided by -1) will put the most negative number into rd;

B.58.3. Access

M	S	U
Always	Always	Always

B.58.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
Bits<5> rd = $encoding[11:7];
```

B.58.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg src1 = X[rs1];
XReg src2 = X[rs2];
if (src2 == 0) {
    X[rd] = {XLEN{1'b1}};
} else if ((src1 == {1'b1, {XLEN - 1{1'b0}}}) && (src2 == {XLEN{1'b1}})) {
    X[rd] = {1'b1, {XLEN - 1{1'b0}}};
} else {
    X[rd] = $signed(src1) / $signed(src2);
}
```

```
}
```

B.58.6. Exceptions

This instruction may result in the following synchronous exceptions:

- `IllegalInstruction`

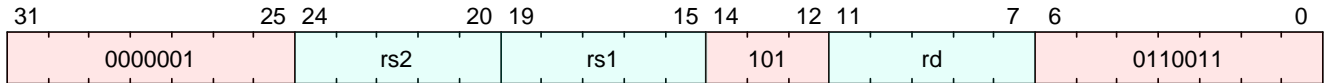
B.59. divu

Unsigned division

This instruction is defined by:

- M, version ≥ 0

B.59.1. Encoding



B.59.2. Synopsis

Divide unsigned values in rs1 by rs2, and store the result in rd.

The remainder is discarded.

If the value in rs2 is zero, rd gets the largest unsigned value.

B.59.3. Access

M	S	U
Always	Always	Always

B.59.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.59.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg src1 = X[rs1];  
XReg src2 = X[rs2];  
if (src2 == 0) {  
    X[rd] = {XLEN{1'b1}};  
} else {  
    X[rd] = src1 / src2;  
}
```

B.59.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

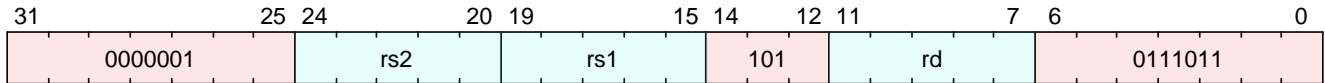
B.60. divuw

Unsigned 32-bit division

This instruction is defined by:

- M, version ≥ 0

B.60.1. Encoding



B.60.2. Synopsis

Divide the unsigned 32-bit values in rs1 and rs2, and store the sign-extended result in rd.

The remainder is discarded.

If the value in rs2 is zero, rd is written with all 1s.

B.60.3. Access

M	S	U
Always	Always	Always

B.60.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.60.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
Bits<32> src1 = X[rs1][31:0];  
Bits<32> src2 = X[rs2][31:0];  
if (src2 == 0) {  
    X[rd] = {64{1'b1}};  
} else {  
    Bits<32> result = src1 / src2;  
    Bits<1> sign_bit = result[31];  
    X[rd] = {{32{sign_bit}}, result};  
}
```

B.60.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

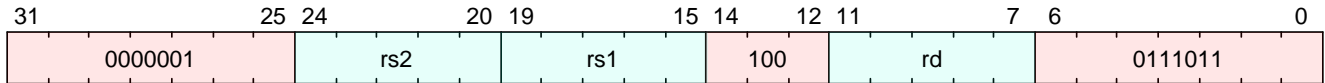
B.61. divw

Signed 32-bit division

This instruction is defined by:

- M, version ≥ 0

B.61.1. Encoding



B.61.2. Synopsis

Divide the lower 32-bits of register rs1 by the lower 32-bits of register rs2, and store the sign-extended result in rd.

The remainder is discarded.

Division by zero will put -1 into rd.

Division resulting in signed overflow (when most negative number is divided by -1) will put the most negative number into rd;

B.61.3. Access

M	S	U
Always	Always	Always

B.61.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.61.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
Bits<32> src1 = X[rs1][31:0];  
Bits<32> src2 = X[rs2][31:0];  
if (src2 == 0) {  
    X[rd] = {XLEN{1'b1}};  
} else if ((src1 == {33'b1, 31'b0}) && (src2 == 32'b1)) {  
    X[rd] = {33'b1, 31'b0};  
}
```

```
} else {  
  Bits<32> result = $signed(src1) / $signed(src2);  
  Bits<1> sign_bit = result[31];  
  X[rd] = {{32{sign_bit}}, result};  
}
```

B.61.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

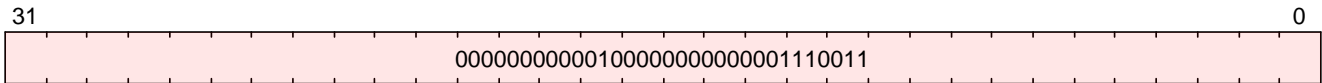
B.62. ebreak

Breakpoint exception

This instruction is defined by:

- I, version ≥ 0

B.62.1. Encoding



B.62.2. Synopsis

The EBREAK instruction is used by debuggers to cause control to be transferred back to a debugging environment. Unless overridden by an external debug environment, EBREAK raises a breakpoint exception and performs no other operation.

NOTE As described in the C Standard Extension for Compressed Instructions, the [c.ebreak](#) instruction performs the same operation as the EBREAK instruction.

EBREAK causes the receiving privilege mode's epc register to be set to the address of the EBREAK instruction itself, not the address of the following instruction. As EBREAK causes a synchronous exception, it is not considered to retire, and should not increment the [minstret](#) CSR.

B.62.3. Access

M	S	U
Always	Always	Always

B.62.4. Decode Variables

B.62.5. Execution

```
if (TRAP_ON_EBREAK) {
    raise_precise(ExceptionCode::Breakpoint, mode(), $pc);
} else {
    eei_ebreak();
}
```

B.62.6. Exceptions

This instruction may result in the following synchronous exceptions:

- Breakpoint

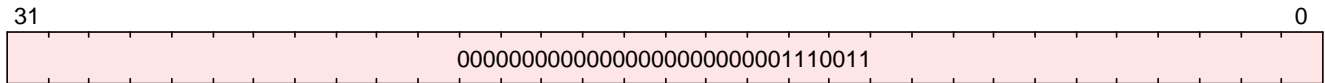
B.63. ecall

Environment call

This instruction is defined by:

- I, version ≥ 0

B.63.1. Encoding



B.63.2. Synopsis

The ECALL instruction is used to make a request to the supporting execution environment. When executed in U-mode, S-mode, or M-mode, it generates an environment-call-from-U-mode exception, environment-call-from-S-mode exception, or environment-call-from-M-mode exception, respectively, and performs no other operation.

NOTE

ECALL generates a different exception for each originating privilege mode so that environment call exceptions can be selectively delegated. A typical use case for Unix-like operating systems is to delegate to S-mode the environment-call-from-U-mode exception but not the others.

ECALL causes the receiving privilege mode's epc register to be set to the address of the ECALL instruction itself, not the address of the following instruction. As ECALL causes a synchronous exception, it is not considered to retire, and should not increment the [minstret](#) CSR.

B.63.3. Access

M	S	U
Always	Always	Always

B.63.4. Decode Variables

B.63.5. Execution

```
if (mode() == PrivilegeMode::M) {
    if (TRAP_ON_ECALL_FROM_M) {
        raise_precise(ExceptionCode::Mcall, PrivilegeMode::M, 0);
    } else {
        eei_ecall_from_m();
    }
} else if (mode() == PrivilegeMode::S) {
```

```

if (TRAP_ON_ECALL_FROM_S) {
    raise_precise(ExceptionCode::Scall, PrivilegeMode::S, 0);
} else {
    eei_ecall_from_s();
}
} else if (mode() == PrivilegeMode::U || mode() == PrivilegeMode::VU) {
    if (TRAP_ON_ECALL_FROM_U) {
        raise_precise(ExceptionCode::Ucall, mode(), 0);
    } else {
        eei_ecall_from_u();
    }
} else if (mode() == PrivilegeMode::VS) {
    if (TRAP_ON_ECALL_FROM_VS) {
        raise_precise(ExceptionCode::VScall, PrivilegeMode::VS, 0);
    } else {
        eei_ecall_from_vs();
    }
}
}

```

B.63.6. Exceptions

This instruction may result in the following synchronous exceptions:

- Mcall
- Scall
- Ucall
- VScall

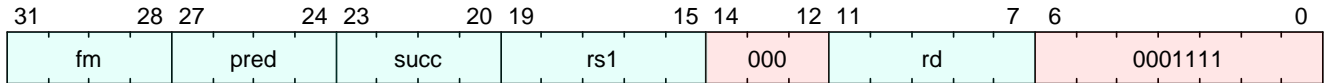
B.64. fence

Memory ordering fence

This instruction is defined by:

- I, version ≥ 0

B.64.1. Encoding



B.64.2. Synopsis

Orders memory operations.

The `fence` instruction is used to order device I/O and memory accesses as viewed by other RISC-V harts and external devices or coprocessors. Any combination of device input (I), device output (O), memory reads (R), and memory writes (W) may be ordered with respect to any combination of the same. Informally, no other RISC-V hart or external device can observe any operation in the *successor* set following a `fence` before any operation in the *predecessor* set preceding the `fence`.

The predecessor and successor fields have the same format to specify operation types:

pred				succ			
27	26	25	24	23	22	21	20
PI	PO	PR	PW	SI	SO	SR	SW

Table 3. Fence mode encoding

<i>fm</i> field	Mnemonic	Meaning
0000	<i>none</i>	Normal Fence
1000	TSO	With FENCE RW, RW : exclude write-to-read ordering; otherwise: <i>Reserved for future use.</i>
<i>other</i>		<i>Reserved for future use.</i>

When the mode field *fm* is `0001` and both the predecessor and successor sets are 'RW', then the instruction acts as a special-case `fence.tso`. `fence.tso` orders all load operations in its predecessor set before all memory operations in its successor set, and all store operations in its predecessor set before all store operations in its successor set. This leaves non-AMO store operations in the 'fence.tso's predecessor set unordered with non-AMO loads in its successor set.

When mode field *fm* is not `0001`, or when mode field *fm* is `0001` but the *pred* and *succ* fields are not both 'RW' (0x3), then the fence acts as a baseline fence (e.g., *fm* is effectively `0000`). This is unaffected by the FIOM bits, described below (implicit promotion does not change how `fence.tso` is decoded).

The `rs1` and `rd` fields are unused and ignored.

In modes other than M-mode, `fence` is further affected by `menvcfg.FIOM`, `senvcfg.FIOM` if `ext?(:H) %>`, and/or `henvcfg.FIOM` if `end %>` as follows:

Table 4. Effective PR/PW/SR/SW in (H)S-mode

<code>menvcfg.FIOM</code>	<code>pred.PI</code> → effective PR <code>pred.PO</code> → effective PW <code>succ.SI</code> → effective SR <code>succ.SO</code> → effective SW	
0	-	from encoding
1	0	from encoding
1	1	1

Table 5. Effective PR/PW/SR/SW in U-mode

<code>menvcfg.FIOM</code>	<code>senvcfg.FIOM</code>	<code>pred.PI</code> → effective PR <code>pred.PO</code> → effective PW <code>succ.SI</code> → effective SR <code>succ.SO</code> → effective SW	
0	0	-	from encoding
0	1	0	from encoding
0	1	1	1
1	-	0	from encoding
1	-	1	1

`<%- if ext?(:H) -%>` .Effective PR/PW/SR/SW in VS-mode and VU-mode

<code>menvcfg.FIOM</code>	<code>henvcfg.FIOM</code>	<code>pred.PI</code> → effective PR <code>pred.PO</code> → effective PW <code>succ.SI</code> → effective SR <code>succ.SO</code> → effective SW	
0	0	-	from encoding
0	1	0	from encoding
0	1	1	1
1	-	0	from encoding
1	-	1	1

`<%- end -%>`

B.64.3. Access

M	S	U
---	---	---

Always

Always

Always

B.64.4. Decode Variables

```
Bits<4> fm = $encoding[31:28];
Bits<4> pred = $encoding[27:24];
Bits<4> succ = $encoding[23:20];
Bits<5> rs1 = $encoding[19:15];
Bits<5> rd = $encoding[11:7];
```

B.64.5. Execution

```
Boolean is_fence_tso;
Boolean is_pause;
if (fm == 1) {
  if (pred == 0x3 && succ == 0x3) {
    is_fence_tso = true;
  }
}
if (implemented?(ExtensionName::Zihintpause)) {
  if ((pred == 1) && (succ == 0) && (fm == 0) && (rd == 0) && (rs1 == 0)) {
    is_pause = true;
  }
}
Boolean pred_i = pred[3] == 1;
Boolean pred_o = pred[2] == 1;
Boolean pred_r = pred[1] == 1;
Boolean pred_w = pred[0] == 1;
Boolean succ_i = succ[3] == 1;
Boolean succ_o = succ[2] == 1;
Boolean succ_r = succ[1] == 1;
Boolean succ_w = succ[0] == 1;
if (is_fence_tso) {
  fence_tso();
} else if (is_pause) {
  pause();
} else {
  if (mode() == PrivilegeMode::S) {
    if (CSR[menvcfg].FIOM == 1) {
      if (pred_i) {
        pred_r = true;
      }
      if (pred_o) {
        pred_w = true;
      }
      if (succ_i) {
        succ_r = true;
      }
    }
  }
}
```

```

    if (succ_o) {
        succ_w = true;
    }
} else if (mode() == PrivilegeMode::U) {
    if ((CSR[menvcfg].FIOM | CSR[senvcfg].FIOM) == 1) {
        if (pred_i) {
            pred_r = true;
        }
        if (pred_o) {
            pred_w = true;
        }
        if (succ_i) {
            succ_r = true;
        }
        if (succ_o) {
            succ_w = true;
        }
    }
} else if (mode() == PrivilegeMode::VS || mode() == PrivilegeMode::VU) {
    if ((CSR[menvcfg].FIOM | CSR[henvcfg].FIOM) == 1) {
        if (pred_i) {
            pred_r = true;
        }
        if (pred_o) {
            pred_w = true;
        }
        if (succ_i) {
            succ_r = true;
        }
        if (succ_o) {
            succ_w = true;
        }
    }
}
fence(pred_i, pred_o, pred_r, pred_w, succ_i, succ_o, succ_r, succ_w);
}

```

B.64.6. Exceptions

This instruction does not generate synchronous exceptions.

B.65. jal

Jump and link

This instruction is defined by:

- I, version ≥ 0

B.65.1. Encoding



B.65.2. Synopsis

Jump to a PC-relative offset and store the return address in rd.

B.65.3. Access

M	S	U
Always	Always	Always

B.65.4. Decode Variables

```
signed Bits<21> imm = sext({$encoding[31], $encoding[19:12], $encoding[20],  
$encoding[30:21], 1'd0});  
Bits<5> rd = $encoding[11:7];
```

B.65.5. Execution

```
XReg retrun_addr = $pc + 4;  
jump_halfword($pc + imm);  
X[rd] = retrun_addr;
```

B.65.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

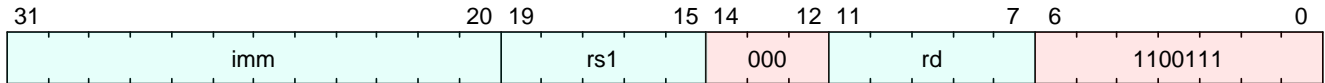
B.66. jalr

Jump and link register

This instruction is defined by:

- I, version ≥ 0

B.66.1. Encoding



B.66.2. Synopsis

Jump to an address formed by adding rs1 to a signed offset, and store the return address in rd.

B.66.3. Access

M	S	U
Always	Always	Always

B.66.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.66.5. Execution

```
XReg returnaddr;  
returnaddr = $pc + 4;  
jump(X[rs1] + imm);  
X[rd] = returnaddr;
```

B.66.6. Exceptions

This instruction may result in the following synchronous exceptions:

- InstructionAddressMisaligned

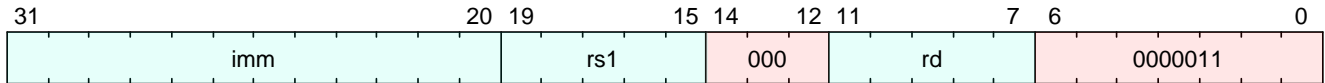
B.67. lb

Load byte

This instruction is defined by:

- I, version ≥ 0

B.67.1. Encoding



B.67.2. Synopsis

Load 8 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset. Sign extend the result.

B.67.3. Access

M	S	U
Always	Always	Always

B.67.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.67.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = sext(read_memory<8>(virtual_address, $encoding), 8);
```

B.67.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

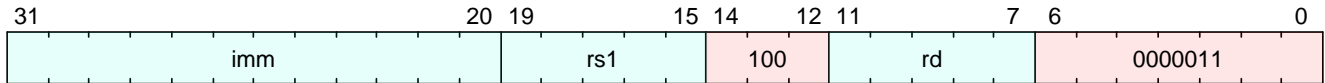
B.68. lbu

Load byte unsigned

This instruction is defined by:

- I, version ≥ 0

B.68.1. Encoding



B.68.2. Synopsis

Load 8 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset. Zero extend the result.

B.68.3. Access

M	S	U
Always	Always	Always

B.68.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.68.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = read_memory<8>(virtual_address, $encoding);
```

B.68.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

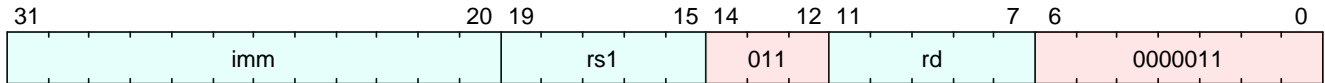
B.69. ld

Load doubleword

This instruction is defined by:

- I, version ≥ 0

B.69.1. Encoding



B.69.2. Synopsis

Load 64 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset.

B.69.3. Access

M	S	U
Always	Always	Always

B.69.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.69.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = read_memory<64>(virtual_address, $encoding);
```

B.69.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

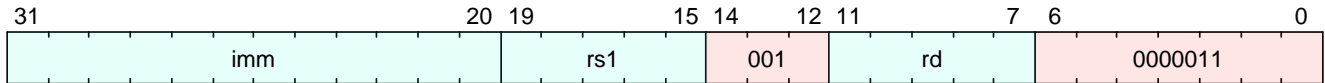
B.70. lh

Load halfword

This instruction is defined by:

- I, version ≥ 0

B.70.1. Encoding



B.70.2. Synopsis

Load 16 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset. Sign extend the result.

B.70.3. Access

M	S	U
Always	Always	Always

B.70.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.70.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = sext(read_memory<16>(virtual_address, $encoding), 16);
```

B.70.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

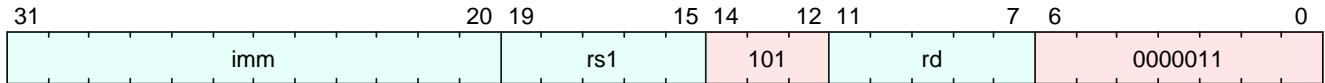
B.71. lhu

Load halfword unsigned

This instruction is defined by:

- I, version ≥ 0

B.71.1. Encoding



B.71.2. Synopsis

Load 16 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset. Zero extend the result.

B.71.3. Access

M	S	U
Always	Always	Always

B.71.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.71.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = read_memory<16>(virtual_address, $encoding);
```

B.71.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

B.72. lui

Load upper immediate

This instruction is defined by:

- I, version ≥ 0

B.72.1. Encoding



B.72.2. Synopsis

Load the zero-extended imm into rd.

B.72.3. Access

M	S	U
Always	Always	Always

B.72.4. Decode Variables

```
Bits<32> imm = {$encoding[31:12], 12'd0};  
Bits<5> rd = $encoding[11:7];
```

B.72.5. Execution

```
X[rd] = imm;
```

B.72.6. Exceptions

This instruction does not generate synchronous exceptions.

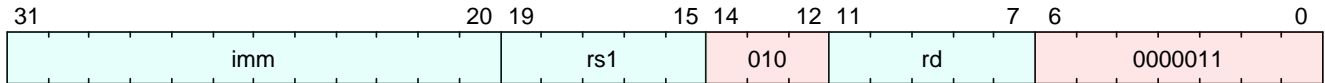
B.73. lw

Load word

This instruction is defined by:

- I, version ≥ 0

B.73.1. Encoding



B.73.2. Synopsis

Load 32 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset. Sign extend the result.

B.73.3. Access

M	S	U
Always	Always	Always

B.73.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.73.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = read_memory<32>(virtual_address, $encoding);
```

B.73.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

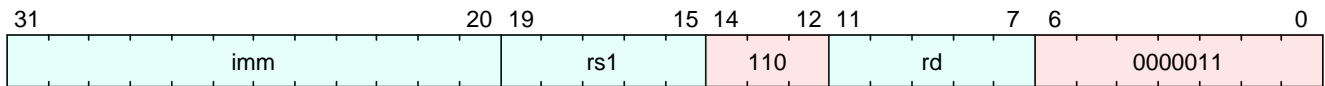
B.74. lwu

Load word unsigned

This instruction is defined by:

- I, version ≥ 0

B.74.1. Encoding



B.74.2. Synopsis

Load 64 bits of data into register `rd` from an address formed by adding `rs1` to a signed offset. Zero extend the result.

B.74.3. Access

M	S	U
Always	Always	Always

B.74.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.74.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
X[rd] = read_memory<32>(virtual_address, $encoding);
```

B.74.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- LoadAddressMisaligned
- LoadPageFault

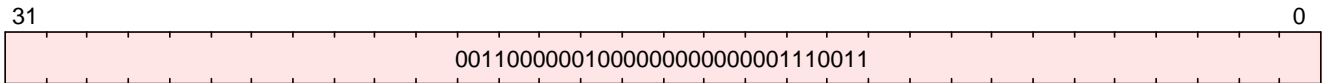
B.75. mret

Machine Exception Return

This instruction is defined by:

- Sm, version ≥ 0

B.75.1. Encoding



B.75.2. Synopsis

Returns from an exception in M-mode.

B.75.3. Access

M	S	U
Always	Never	Never

B.75.4. Decode Variables

B.75.5. Execution

```
if (implemented?(ExtensionName::S) && CSR[mstatus].MPP != 2'b11) {
    CSR[mstatus].MPRV = 0;
}
CSR[mstatus].MIE = CSR[mstatus].MPIE;
CSR[mstatus].MPIE = 1;
if (CSR[mstatus].MPP == 2'b00) {
    set_mode(PrivilegeMode::U);
} else if (CSR[mstatus].MPP == 2'b01) {
    set_mode(PrivilegeMode::S);
} else if (CSR[mstatus].MPP == 2'b11) {
    set_mode(PrivilegeMode::M);
}
CSR[mstatus].MPP = implemented?(ExtensionName::U) ? 2'b00 : 2'b11;
$pc = $bits(CSR[mepc]);
```

B.75.6. Exceptions

This instruction does not generate synchronous exceptions.

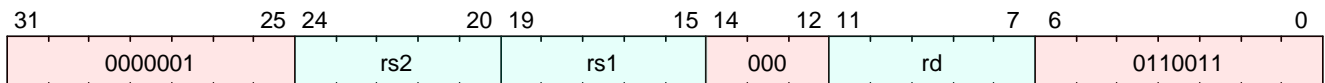
B.76. mul

Signed multiply

This instruction is defined by:

- anyOf:
 - M, version ≥ 0
 - Zmmul, version ≥ 0

B.76.1. Encoding



B.76.2. Synopsis

MUL performs an XLEN-bitxXLEN-bit multiplication of *rs1* by *rs2* and places the lower XLEN bits in the destination register. Any overflow is thrown away.

NOTE

If both the high and low bits of the same product are required, then the recommended code sequence is: MULH[[S]U] rdh, rs1, rs2; MUL rdl, rs1, rs2 (source register specifiers must be in same order and rdh cannot be the same as rs1 or rs2). Microarchitectures can then fuse these into a single multiply operation instead of performing two separate multiplies.

B.76.3. Access

M	S	U
Always	Always	Always

B.76.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.76.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg src1 = X[rs1];  
XReg src2 = X[rs2];
```

```
X[rd] = (src1 * src2)[XLEN - 1:0];
```

B.76.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

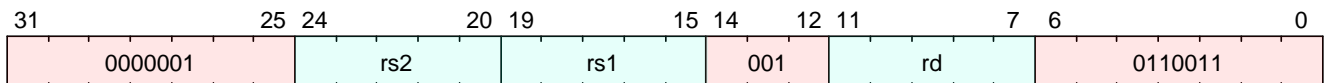
B.77. mulh

Signed multiply high

This instruction is defined by:

- anyOf:
 - M, version ≥ 0
 - Zmmul, version ≥ 0

B.77.1. Encoding



B.77.2. Synopsis

Multiply the signed values in rs1 to rs2, and store the upper half of the result in rd. The lower half is thrown away.

If both the upper and lower halves are needed, it suggested to use the sequence:

```
mulh rdh, rs1, rs2
mul  rdL, rs1, rs2
---
```

Microarchitectures may look for that sequence and fuse the operations.

B.77.3. Access

M	S	U
Always	Always	Always

B.77.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
Bits<5> rd  = $encoding[11:7];
```

B.77.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
```

```
}  
Bits<1> rs1_sign_bit = X[rs1][xlen() - 1];  
Bits<XLEN * 2> src1 = {{xlen(){rs1_sign_bit}}, X[rs1]};  
Bits<1> rs2_sign_bit = X[rs2][xlen() - 1];  
Bits<XLEN * 2> src2 = {{xlen(){rs2_sign_bit}}, X[rs2]};  
X[rd] = (src1 * src2)[(xlen() * 8'd2) - 1:xlen()];
```

B.77.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

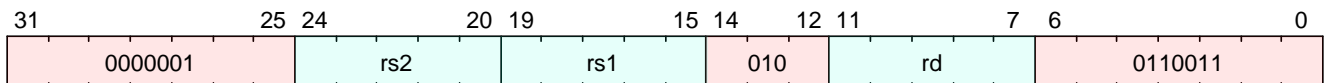
B.78. mulhsu

Signed/unsigned multiply high

This instruction is defined by:

- anyOf:
 - M, version ≥ 0
 - Zmmul, version ≥ 0

B.78.1. Encoding



B.78.2. Synopsis

Multiply the signed value in rs1 by the unsigned value in rs2, and store the upper half of the result in rd. The lower half is thrown away.

If both the upper and lower halves are needed, it is suggested to use the sequence:

```
mulhsu rdh, rs1, rs2
mul    rdl, rs1, rs2
---
```

Microarchitectures may look for that sequence and fuse the operations.

B.78.3. Access

M	S	U
Always	Always	Always

B.78.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
Bits<5> rd  = $encoding[11:7];
```

B.78.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
```

```
}  
Bits<1> rs1_sign_bit = X[rs1][XLEN - 1];  
Bits<XLEN * 8'd2> src1 = {{XLEN{rs1_sign_bit}}, X[rs1]};  
Bits<XLEN * 8'd2> src2 = {{XLEN{1'b0}}, X[rs2]};  
X[rd] = (src1 * src2)[(XLEN * 8'd2) - 1:XLEN];
```

B.78.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

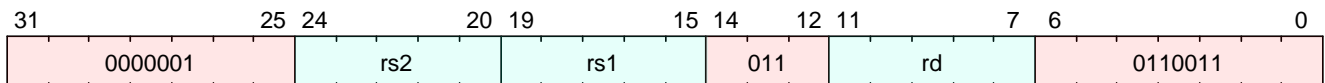
B.79. mulhu

Unsigned multiply high

This instruction is defined by:

- anyOf:
 - M, version ≥ 0
 - Zmmul, version ≥ 0

B.79.1. Encoding



B.79.2. Synopsis

Multiply the unsigned values in rs1 to rs2, and store the upper half of the result in rd. The lower half is thrown away.

If both the upper and lower halves are needed, it suggested to use the sequence:

```
mulhu rdh, rs1, rs2
mul   rdl, rs1, rs2
---
```

Microarchitectures may look for that sequence and fuse the operations.

B.79.3. Access

M	S	U
Always	Always	Always

B.79.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
Bits<5> rd  = $encoding[11:7];
```

B.79.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
```



```
}  
Bits<XLEN * 8'd2> src1 = {{XLEN{1'b0}}, X[rs1]};  
Bits<XLEN * 8'd2> src2 = {{XLEN{1'b0}}, X[rs2]};  
X[rd] = (src1 * src2)[(XLEN * 8'd2) - 1:XLEN];
```

B.79.6. Exceptions

This instruction may result in the following synchronous exceptions:

- `IllegalInstruction`

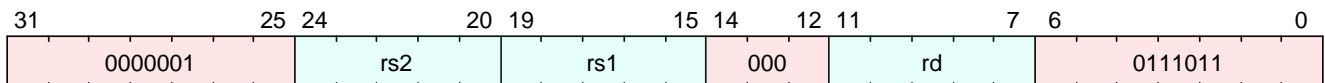
B.80. mulw

Signed 32-bit multiply

This instruction is defined by:

- anyOf:
 - M, version ≥ 0
 - Zmmul, version ≥ 0

B.80.1. Encoding



B.80.2. Synopsis

Multiplies the lower 32 bits of the source registers, placing the sign-extension of the lower 32 bits of the result into the destination register.

Any overflow is thrown away.

NOTE

In RV64, MUL can be used to obtain the upper 32 bits of the 64-bit product, but signed arguments must be proper 32-bit signed values, whereas unsigned arguments must have their upper 32 bits clear. If the arguments are not known to be sign- or zero-extended, an alternative is to shift both arguments left by 32 bits, then use MULH[[S]U].

B.80.3. Access

M	S	U
Always	Always	Always

B.80.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.80.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
Bits<32> src1 = X[rs1][31:0];
```

```
Bits<32> src2 = X[rs2][31:0];  
Bits<32> result = src1 * src2;  
Bits<1> sign_bit = result[31];  
X[rd] = {{32{sign_bit}}, result};
```

B.80.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

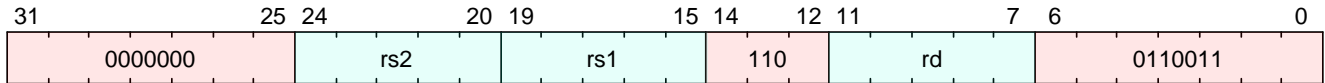
B.81. or

Or

This instruction is defined by:

- I, version ≥ 0

B.81.1. Encoding



B.81.2. Synopsis

Or rs1 with rs2, and store the result in rd

B.81.3. Access

M	S	U
Always	Always	Always

B.81.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.81.5. Execution

```
X[rd] = X[rs1] | X[rs2];
```

B.81.6. Exceptions

This instruction does not generate synchronous exceptions.

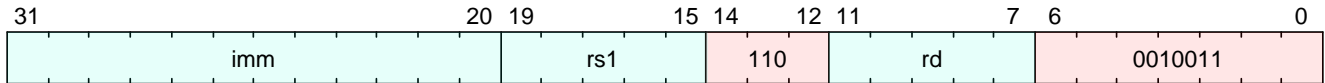
B.82. ori

Or immediate

This instruction is defined by:

- I, version ≥ 0

B.82.1. Encoding



B.82.2. Synopsis

Or an immediate to the value in rs1, and store the result in rd

B.82.3. Access

M	S	U
Always	Always	Always

B.82.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.82.5. Execution

```
if (implemented?(ExtensionName::Zicbop)) {  
  if (rd == 0) {  
    if (imm[4:0] == 0) {  
      Bits<12> offset = {imm[11:5], rd};  
      prefetch_instruction(offset);  
    } else if (imm[4:0] == 1) {  
      Bits<12> offset = {imm[11:5], rd};  
      prefetch_read(offset);  
    } else if (imm[4:0] == 3) {  
      Bits<12> offset = {imm[11:5], rd};  
      prefetch_write(offset);  
    }  
  }  
}  
X[rd] = X[rs1] | imm;
```

B.82.6. Exceptions

This instruction does not generate synchronous exceptions.

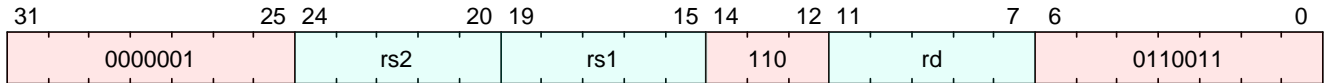
B.83. rem

Signed remainder

This instruction is defined by:

- M, version ≥ 0

B.83.1. Encoding



B.83.2. Synopsis

Calculate the remainder of signed division of rs1 by rs2, and store the result in rd.

If the value in register rs2 is zero, write the value in rs1 into rd;

If the result of the division overflows, write zero into rd;

B.83.3. Access

M	S	U
Always	Always	Always

B.83.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.83.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg src1 = X[rs1];  
XReg src2 = X[rs2];  
if (src2 == 0) {  
    X[rd] = src1;  
} else if ((src1 == {1'b1, {XLEN - 1{1'b0}}}) && (src2 == {XLEN{1'b1}})) {  
    X[rd] = 0;  
} else {  
    X[rd] = $signed(src1) % $signed(src2);  
}
```

B.83.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

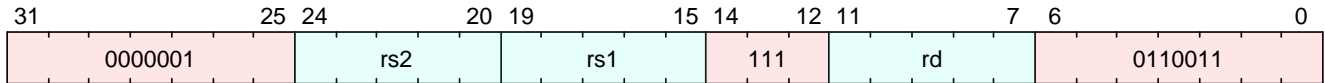
B.84. remu

Unsigned remainder

This instruction is defined by:

- M, version ≥ 0

B.84.1. Encoding



B.84.2. Synopsis

Calculate the remainder of unsigned division of rs1 by rs2, and store the result in rd.

B.84.3. Access

M	S	U
Always	Always	Always

B.84.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.84.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
XReg src1 = X[rs1];  
XReg src2 = X[rs2];  
if (src2 == 0) {  
    X[rd] = src1;  
} else {  
    X[rd] = src1 % src2;  
}
```

B.84.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

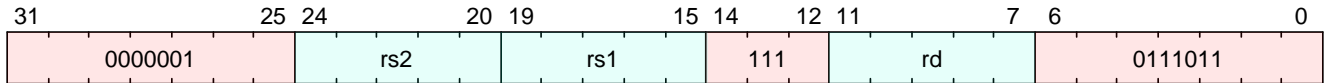
B.85. remuw

Unsigned 32-bit remainder

This instruction is defined by:

- M, version ≥ 0

B.85.1. Encoding



B.85.2. Synopsis

Calculate the remainder of unsigned division of the 32-bit values in rs1 by rs2, and store the sign-extended result in rd.

If the value in rs2 is zero, rd gets the sign-extended value in rs1.

B.85.3. Access

M	S	U
Always	Always	Always

B.85.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.85.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
Bits<32> src1 = X[rs1][31:0];  
Bits<32> src2 = X[rs2][31:0];  
if (src2 == 0) {  
    Bits<1> sign_bit = src1[31];  
    X[rd] = {{32{sign_bit}}, src1};  
} else {  
    Bits<32> result = src1 % src2;  
    Bits<1> sign_bit = result[31];  
    X[rd] = {{32{sign_bit}}, result};  
}
```

B.85.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

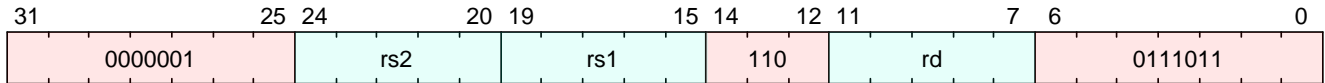
B.86. remw

Signed 32-bit remainder

This instruction is defined by:

- M, version ≥ 0

B.86.1. Encoding



B.86.2. Synopsis

Calculate the remainder of signed division of the 32-bit values rs1 by rs2, and store the sign-extended result in rd.

If the value in register rs2 is zero, write the sign-extended 32-bit value in rs1 into rd;

If the result of the division overflows, write zero into rd;

B.86.3. Access

M	S	U
Always	Always	Always

B.86.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.86.5. Execution

```
if (implemented?(ExtensionName::M) && (CSR[misa].M == 1'b0)) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
Bits<32> src1 = X[rs1][31:0];  
Bits<32> src2 = X[rs2][31:0];  
if (src2 == 0) {  
    Bits<1> sign_bit = src1[31];  
    X[rd] = {{32{sign_bit}}, src1};  
} else if ((src1 == {33'b1, 31'b0}) && (src2 == 32'b1)) {  
    X[rd] = 0;  
} else {  
    Bits<32> result = $signed(src1) % $signed(src2);
```

```
Bits<1> sign_bit = result[31];
X[rd] = {{32{sign_bit}}, result};
}
```

B.86.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction

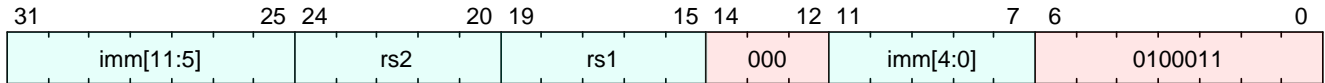
B.87. sb

Store byte

This instruction is defined by:

- I, version ≥ 0

B.87.1. Encoding



B.87.2. Synopsis

Store 8 bits of data from register *rs2* to an address formed by adding *rs1* to a signed offset.

B.87.3. Access

M	S	U
Always	Always	Always

B.87.4. Decode Variables

```
Bits<12> imm = { $encoding[31:25], $encoding[11:7] };  
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];
```

B.87.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
write_memory<8>(virtual_address, X[rs2][7:0], $encoding);
```

B.87.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

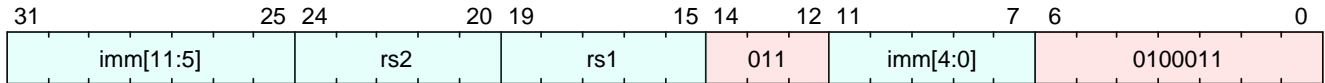
B.88. sd

Store doubleword

This instruction is defined by:

- I, version ≥ 0

B.88.1. Encoding



B.88.2. Synopsis

Store 64 bits of data from register *rs2* to an address formed by adding *rs1* to a signed offset.

B.88.3. Access

M	S	U
Always	Always	Always

B.88.4. Decode Variables

```
signed Bits<12> imm = sext({$encoding[31:25], $encoding[11:7]});  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rs2 = $encoding[24:20];
```

B.88.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
write_memory<64>(virtual_address, X[rs2], $encoding);
```

B.88.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

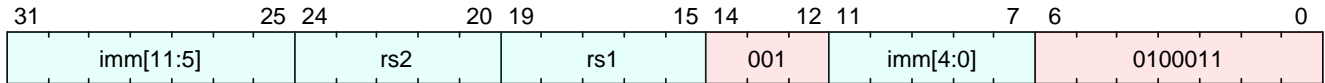
B.89. sh

Store halfword

This instruction is defined by:

- I, version ≥ 0

B.89.1. Encoding



B.89.2. Synopsis

Store 16 bits of data from register *rs2* to an address formed by adding *rs1* to a signed offset.

B.89.3. Access

M	S	U
Always	Always	Always

B.89.4. Decode Variables

```
Bits<12> imm = { $encoding[31:25], $encoding[11:7] };  
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];
```

B.89.5. Execution

```
XReg virtual_address = X[rs1] + imm;  
write_memory<16>(virtual_address, X[rs2][15:0], $encoding);
```

B.89.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

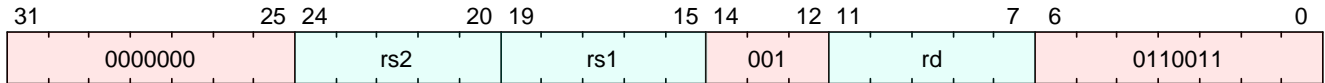
B.90. sll

Shift left logical

This instruction is defined by:

- I, version ≥ 0

B.90.1. Encoding



B.90.2. Synopsis

Shift the value in *rs1* left by the value in the lower 6 bits of *rs2*, and store the result in *rd*.

B.90.3. Access

M	S	U
Always	Always	Always

B.90.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.90.5. Execution

```
if (xlen() == 64) {  
    X[rd] = X[rs1] << X[rs2][5:0];  
} else {  
    X[rd] = X[rs1] << X[rs2][4:0];  
}
```

B.90.6. Exceptions

This instruction does not generate synchronous exceptions.

B.91. slli

Shift left logical immediate

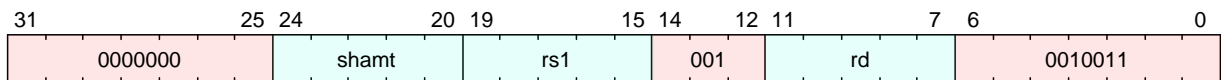
This instruction is defined by:

- I, version ≥ 0

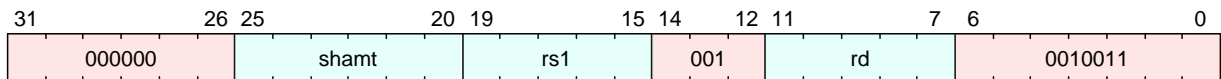
B.91.1. Encoding

NOTE This instruction has different encodings in RV32 and RV64.

RV32



RV64



B.91.2. Synopsis

Shift the value in rs1 left by shamt, and store the result in rd

B.91.3. Access

M	S	U
Always	Always	Always

B.91.4. Decode Variables

RV32

```
Bits<5> shamt = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

RV64

```
Bits<6> shamt = $encoding[25:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.91.5. Execution

```
X[rd] = X[rs1] << shamt;
```

B.91.6. Exceptions

This instruction does not generate synchronous exceptions.

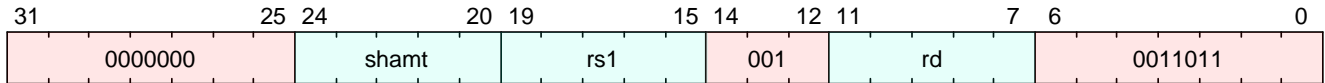
B.92. slliw

Shift left logical immediate word

This instruction is defined by:

- I, version ≥ 0

B.92.1. Encoding



B.92.2. Synopsis

Shift the 32-bit value in rs1 left by shamt, and store the sign-extended result in rd

B.92.3. Access

M	S	U
Always	Always	Always

B.92.4. Decode Variables

```
Bits<5> shamt = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.92.5. Execution

```
X[rd] = sext(X[rs1] << shamt, 31);
```

B.92.6. Exceptions

This instruction does not generate synchronous exceptions.

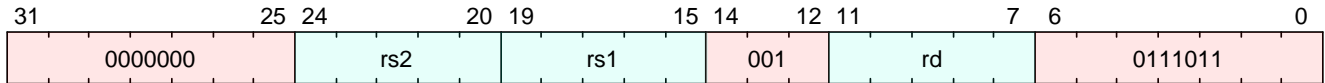
B.93. sllw

Shift left logical word

This instruction is defined by:

- I, version ≥ 0

B.93.1. Encoding



B.93.2. Synopsis

Shift the 32-bit value in *rs1* left by the value in the lower 5 bits of *rs2*, and store the sign-extended result in *rd*.

B.93.3. Access

M	S	U
Always	Always	Always

B.93.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.93.5. Execution

```
X[rd] = sext(X[rs1] << X[rs2][4:0], 31);
```

B.93.6. Exceptions

This instruction does not generate synchronous exceptions.

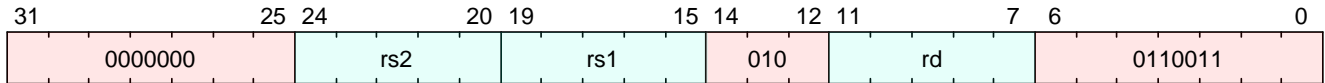
B.94. slt

Set on less than

This instruction is defined by:

- I, version ≥ 0

B.94.1. Encoding



B.94.2. Synopsis

Places the value 1 in register `rd` if register `rs1` is less than the value in register `rs2`, where both sources are treated as signed numbers, else 0 is written to `rd`.

B.94.3. Access

M	S	U
Always	Always	Always

B.94.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.94.5. Execution

```
XReg src1 = X[rs1];  
XReg src2 = X[rs2];  
X[rd] = ($signed(src1) < $signed(src2)) ? '1' : '0';
```

B.94.6. Exceptions

This instruction does not generate synchronous exceptions.

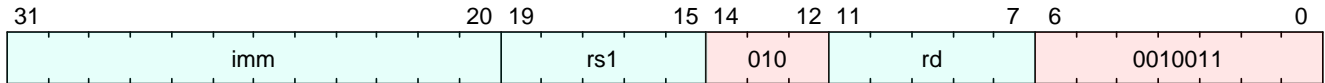
B.95. slti

Set on less than immediate

This instruction is defined by:

- I, version ≥ 0

B.95.1. Encoding



B.95.2. Synopsis

Places the value 1 in register `rd` if register `rs1` is less than the sign-extended immediate when both are treated as signed numbers, else 0 is written to `rd`.

B.95.3. Access

M	S	U
Always	Always	Always

B.95.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.95.5. Execution

```
X[rd] = ($signed(X[rs1]) < $signed(imm)) ? '1' : '0';
```

B.95.6. Exceptions

This instruction does not generate synchronous exceptions.

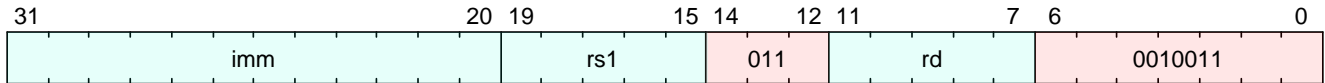
B.96. sltiu

Set on less than immediate unsigned

This instruction is defined by:

- I, version ≥ 0

B.96.1. Encoding



B.96.2. Synopsis

Places the value 1 in register `rd` if register `rs1` is less than the sign-extended immediate when both are treated as unsigned numbers (*i.e.*, the immediate is first sign-extended to XLEN bits then treated as an unsigned number), else 0 is written to `rd`.

NOTE `sltiu rd, rs1, 1` sets `rd` to 1 if `rs1` equals zero, otherwise sets `rd` to 0 (assembler pseudoinstruction `SEQZ rd, rs`).

B.96.3. Access

M	S	U
Always	Always	Always

B.96.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.96.5. Execution

```
X[rd] = (X[rs1] < imm) ? 1 : 0;
```

B.96.6. Exceptions

This instruction does not generate synchronous exceptions.

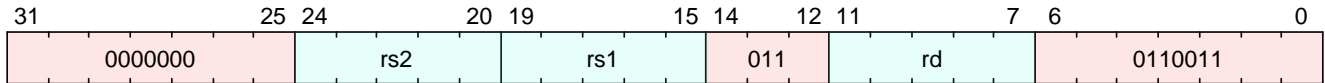
B.97. sltu

Set on less than unsigned

This instruction is defined by:

- I, version ≥ 0

B.97.1. Encoding



B.97.2. Synopsis

Places the value 1 in register `rd` if register `rs1` is less than the value in register `rs2`, where both sources are treated as unsigned numbers, else 0 is written to `rd`.

B.97.3. Access

M	S	U
Always	Always	Always

B.97.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.97.5. Execution

```
X[rd] = (X[rs1] < X[rs2]) ? 1 : 0;
```

B.97.6. Exceptions

This instruction does not generate synchronous exceptions.

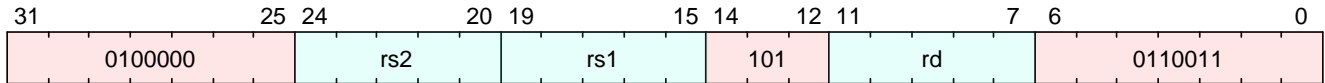
B.98. sra

Shift right arithmetic

This instruction is defined by:

- I, version ≥ 0

B.98.1. Encoding



B.98.2. Synopsis

Arithmetic shift the value in `rs1` right by the value in the lower 5 bits of `rs2`, and store the result in `rd`.

B.98.3. Access

M	S	U
Always	Always	Always

B.98.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.98.5. Execution

```
if (xlen() == 64) {  
    X[rd] = X[rs1] >>> X[rs2][5:0];  
} else {  
    X[rd] = X[rs1] >>> X[rs2][4:0];  
}
```

B.98.6. Exceptions

This instruction does not generate synchronous exceptions.

B.99. srai

Shift right arithmetic immediate

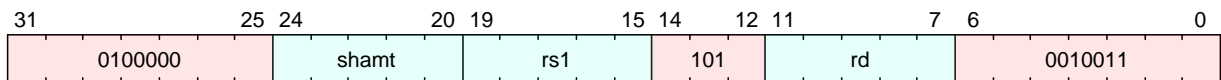
This instruction is defined by:

- I, version ≥ 0

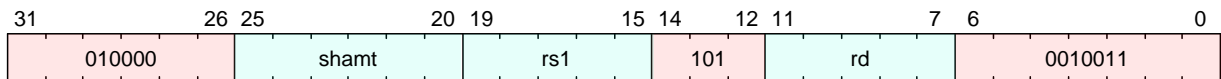
B.99.1. Encoding

NOTE This instruction has different encodings in RV32 and RV64.

RV32



RV64



B.99.2. Synopsis

Arithmetic shift (the original sign bit is copied into the vacated upper bits) the value in rs1 right by shamt, and store the result in rd.

B.99.3. Access

M	S	U
Always	Always	Always

B.99.4. Decode Variables

RV32

```
Bits<5> shamt = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

RV64

```
Bits<6> shamt = $encoding[25:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.99.5. Execution

```
X[rd] = X[rs1] >>> shamt;
```

B.99.6. Exceptions

This instruction does not generate synchronous exceptions.

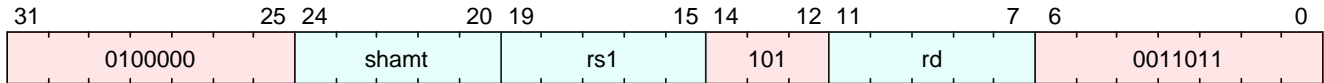
B.100. sraiw

Shift right arithmetic immediate word

This instruction is defined by:

- I, version ≥ 0

B.100.1. Encoding



B.100.2. Synopsis

Arithmetic shift (the original sign bit is copied into the vacated upper bits) the 32-bit value in rs1 right by shamt, and store the sign-extended result in rd.

B.100.3. Access

M	S	U
Always	Always	Always

B.100.4. Decode Variables

```
Bits<5> shamt = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.100.5. Execution

```
XReg operand = sext(X[rs1], 31);  
X[rd] = sext(operand >>> shamt, 31);
```

B.100.6. Exceptions

This instruction does not generate synchronous exceptions.

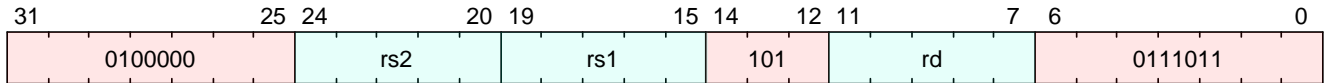
B.101. srar

Shift right arithmetic word

This instruction is defined by:

- I, version ≥ 0

B.101.1. Encoding



B.101.2. Synopsis

Arithmetic shift the 32-bit value in *rs1* right by the value in the lower 5 bits of *rs2*, and store the sign-extended result in *rd*.

B.101.3. Access

M	S	U
Always	Always	Always

B.101.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.101.5. Execution

```
XReg operand1 = sext(X[rs1], 31);  
X[rd] = sext(operand1 >>> X[rs2][4:0], 31);
```

B.101.6. Exceptions

This instruction does not generate synchronous exceptions.

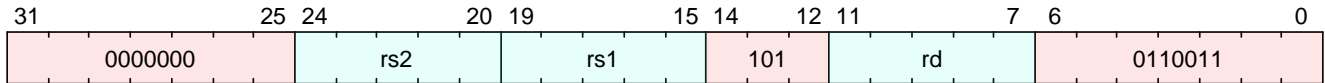
B.102. srl

Shift right logical

This instruction is defined by:

- I, version ≥ 0

B.102.1. Encoding



B.102.2. Synopsis

Logical shift the value in *rs1* right by the value in the lower bits of *rs2*, and store the result in *rd*.

B.102.3. Access

M	S	U
Always	Always	Always

B.102.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.102.5. Execution

```
if (xlen() == 64) {  
    X[rd] = X[rs1] >> X[rs2][5:0];  
} else {  
    X[rd] = X[rs1] >> X[rs2][4:0];  
}
```

B.102.6. Exceptions

This instruction does not generate synchronous exceptions.

B.103. srli

Shift right logical immediate

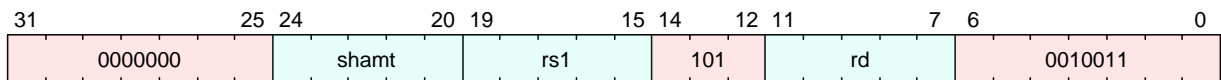
This instruction is defined by:

- I, version ≥ 0

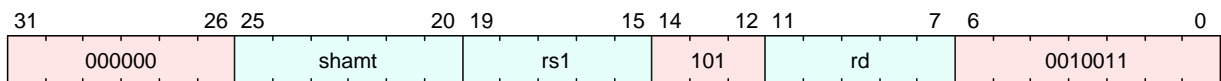
B.103.1. Encoding

NOTE This instruction has different encodings in RV32 and RV64.

RV32



RV64



B.103.2. Synopsis

Shift the value in rs1 right by shamt, and store the result in rd

B.103.3. Access

M	S	U
Always	Always	Always

B.103.4. Decode Variables

RV32

```
Bits<5> shamt = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

RV64

```
Bits<6> shamt = $encoding[25:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```


B.103.5. Execution

```
X[rd] = X[rs1] >> shamt;
```

B.103.6. Exceptions

This instruction does not generate synchronous exceptions.

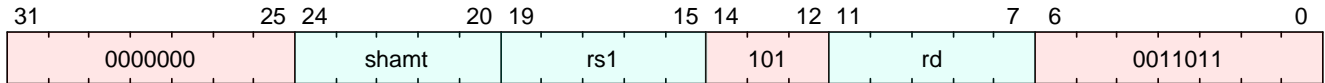
B.104. srlw

Shift right logical immediate word

This instruction is defined by:

- I, version ≥ 0

B.104.1. Encoding



B.104.2. Synopsis

Shift the 32-bit value in rs1 right by shamt, and store the sign-extended result in rd

B.104.3. Access

M	S	U
Always	Always	Always

B.104.4. Decode Variables

```
Bits<5> shamt = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.104.5. Execution

```
XReg operand = X[rs1][31:0];  
X[rd] = sext(operand >> shamt, 31);
```

B.104.6. Exceptions

This instruction does not generate synchronous exceptions.

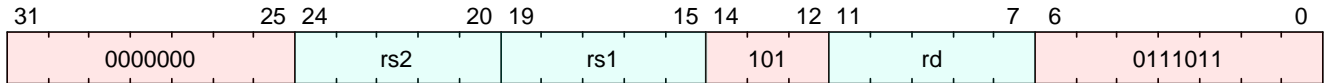
B.105. srlw

Shift right logical word

This instruction is defined by:

- I, version ≥ 0

B.105.1. Encoding



B.105.2. Synopsis

Logical shift the 32-bit value in *rs1* right by the value in the lower 5 bits of *rs2*, and store the sign-extended result in *rd*.

B.105.3. Access

M	S	U
Always	Always	Always

B.105.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.105.5. Execution

```
X[rd] = sext(X[rs1][31:0] >> X[rs2][4:0], 31);
```

B.105.6. Exceptions

This instruction does not generate synchronous exceptions.

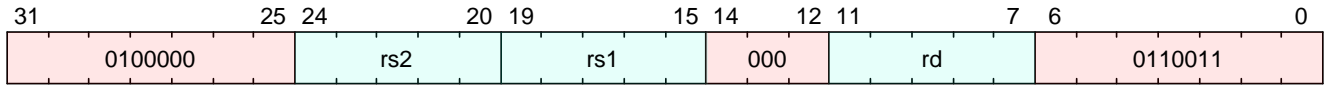
B.106. sub

Subtract

This instruction is defined by:

- I, version ≥ 0

B.106.1. Encoding



B.106.2. Synopsis

Subtract the value in rs2 from rs1, and store the result in rd

B.106.3. Access

M	S	U
Always	Always	Always

B.106.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.106.5. Execution

```
XReg t0 = X[rs1];  
XReg t1 = X[rs2];  
X[rd] = t0 - t1;
```

B.106.6. Exceptions

This instruction does not generate synchronous exceptions.

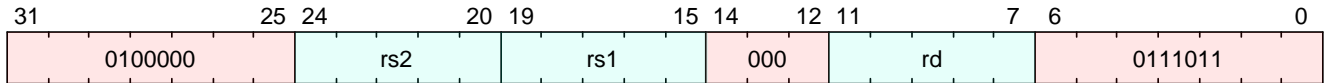
B.107. subw

Subtract word

This instruction is defined by:

- I, version ≥ 0

B.107.1. Encoding



B.107.2. Synopsis

Subtract the 32-bit values in rs2 from rs1, and store the sign-extended result in rd

B.107.3. Access

M	S	U
Always	Always	Always

B.107.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.107.5. Execution

```
Bits<32> t0 = X[rs1][31:0];  
Bits<32> t1 = X[rs2][31:0];  
X[rd] = sext(t0 - t1, 31);
```

B.107.6. Exceptions

This instruction does not generate synchronous exceptions.

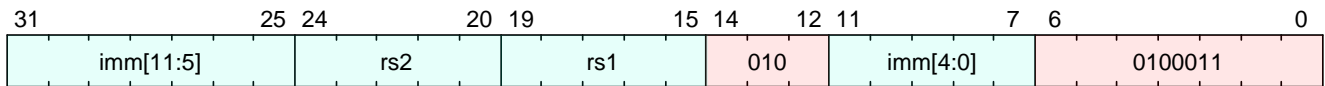
B.108. sw

Store word

This instruction is defined by:

- I, version ≥ 0

B.108.1. Encoding



B.108.2. Synopsis

Store 32 bits of data from register *rs2* to an address formed by adding *rs1* to a signed offset.

B.108.3. Access

M	S	U
Always	Always	Always

B.108.4. Decode Variables

```
Bits<12> imm = { $encoding[31:25], $encoding[11:7] };
Bits<5> rs2 = $encoding[24:20];
Bits<5> rs1 = $encoding[19:15];
```

B.108.5. Execution

```
XReg virtual_address = X[rs1] + imm;
write_memory<32>(virtual_address, X[rs2][31:0], $encoding);
```

B.108.6. Exceptions

This instruction may result in the following synchronous exceptions:

- LoadAccessFault
- StoreAmoAccessFault
- StoreAmoAddressMisaligned
- StoreAmoPageFault

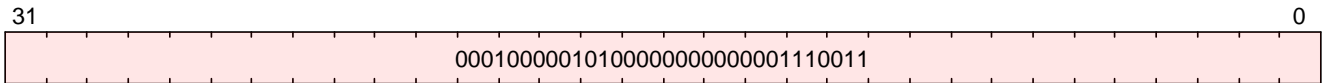
B.109. wfi

Wait for interrupt

This instruction is defined by:

- Sm, version ≥ 0

B.109.1. Encoding



B.109.2. Synopsis

Can causes the processor to enter a low-power state until the next interrupt occurs.

<%- if ext?(:H) -%> The behavior of **wfi** is affected by the `mstatus.TW` and `hstatus.VTW` bits, as summarized below.

mstatus.TW	hstatus.VTW	wfi behavior			
		HS-mode	U-mode	VS-mode	in VU-mode
0	0	Wait	Trap (I)	Wait	Trap (V)
0	1	Wait	Trap (I)	Trap (V)	Trap (V)
1	-	Trap (I)	Trap (I)	Trap (I)	Trap (I)

Trap (I) - Trap with **Illegal Instruction** code
Trap (V) - Trap with **Virtual Instruction** code

<%- else -%> The **wfi** instruction is also affected by `mstatus.TW`, as shown below:

mstatus.TW	wfi behavior	
	S-mode	U-mode
0	Wait	Trap (I)
1	Trap (I)	Trap (I)

Trap (I) - Trap with **Illegal Instruction** code

<%- end -%>

When **wfi** is marked as causing a trap above, the implementation is allowed to wait for an unspecified period of time to see if an interrupt occurs before raising the trap. That period of time can be zero (*i.e.*, **wfi** always causes a trap in the cases identified above).

B.109.3. Access

M	S	U
---	---	---

Always	Sometimes	Sometimes
--------	-----------	-----------

<%- if ext?(:H) -%> The behavior of `wfi` is affected by the `mstatus.TW` and `hstatus.VTW` bits, as summarized below.

mstatus.TW	hstatus.VTW	wfi behavior			
		HS-mode	U-mode	VS-mode	in VU-mode
0	0	Wait	Trap (I)	Wait	Trap (V)
0	1	Wait	Trap (I)	Trap (V)	Trap (V)
1	-	Trap (I)	Trap (I)	Trap (I)	Trap (I)

Trap (I) - Trap with **Illegal Instruction** code
 Trap (V) - Trap with **Virtual Instruction** code

<%- else -%> The `wfi` instruction is also affected by `mstatus.TW`, as shown below:

mstatus.TW	wfi behavior	
	S-mode	U-mode
0	Wait	Trap (I)
1	Trap (I)	Trap (I)

Trap (I) - Trap with **Illegal Instruction** code

<%- end -%>

B.109.4. Decode Variables

B.109.5. Execution

```

if (mode() == PrivilegeMode::U) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
if ((CSR[misa].S == 1) && (CSR[mstatus].TW == 1'b1)) {
  if (mode() != PrivilegeMode::M) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
}
if (CSR[misa].H == 1) {
  if (CSR[hstatus].VTW == 1'b0) {
    if (mode() == PrivilegeMode::VU) {
      raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
    }
  } else if (CSR[hstatus].VTW == 1'b1) {
    if ((mode() == PrivilegeMode::VS) || (mode() == PrivilegeMode::VU)) {

```



```
        raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
    }
}
wfi();
```

B.109.6. Exceptions

This instruction may result in the following synchronous exceptions:

- IllegalInstruction
- VirtualInstruction

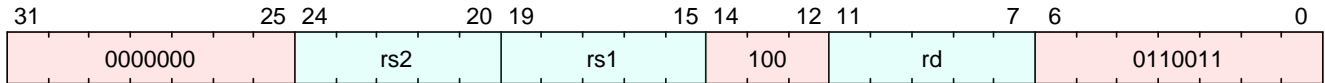
B.110. xor

Exclusive Or

This instruction is defined by:

- I, version ≥ 0

B.110.1. Encoding



B.110.2. Synopsis

Exclusive or rs1 with rs2, and store the result in rd

B.110.3. Access

M	S	U
Always	Always	Always

B.110.4. Decode Variables

```
Bits<5> rs2 = $encoding[24:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.110.5. Execution

```
X[rd] = X[rs1] ^ X[rs2];
```

B.110.6. Exceptions

This instruction does not generate synchronous exceptions.

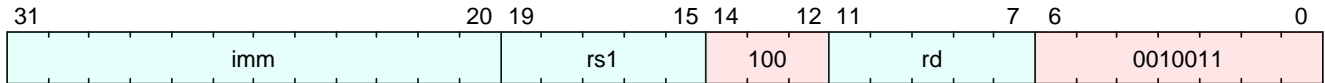
B.111. xori

Exclusive Or immediate

This instruction is defined by:

- I, version ≥ 0

B.111.1. Encoding



B.111.2. Synopsis

Exclusive or an immediate to the value in rs1, and store the result in rd

B.111.3. Access

M	S	U
Always	Always	Always

B.111.4. Decode Variables

```
Bits<12> imm = $encoding[31:20];  
Bits<5> rs1 = $encoding[19:15];  
Bits<5> rd = $encoding[11:7];
```

B.111.5. Execution

```
X[rd] = X[rs1] ^ imm;
```

B.111.6. Exceptions

This instruction does not generate synchronous exceptions.

Appendix C: CSR Details

C.1. cycle

Cycle counter for RDCYCLE Instruction

Alias for M-mode CSR [mcycle](#).

Privilege mode access is controlled with `mcounteren.CY`, `scounteren.CY`, and `hcounteren.CY` as follows:

mcountere n.CY	scountere n.CY	hcountere n.CY	cycle behavior			
			S-mode	U-mode	VS-mode	VU-mode
0	-	-	IllegalInstru ction	IllegalInstru ction	IllegalInstru ction	IllegalInstru ction
1	0	0	read-only	IllegalInstru ction	VirtualInstru ction	VirtualInstru ction
1	1	0	read-only	read-only	VirtualInstru ction	VirtualInstru ction
1	0	1	read-only	IllegalInstru ction	read-only	VirtualInstru ction
1	1	1	read-only	read-only	read-only	read-only

C.1.1. Attributes

CSR Address	0xc00
Defining extension	<ul style="list-style-type: none"> Zicntr, version >= 0
Length	64-bit
Privilege Mode	U

C.1.2. Format

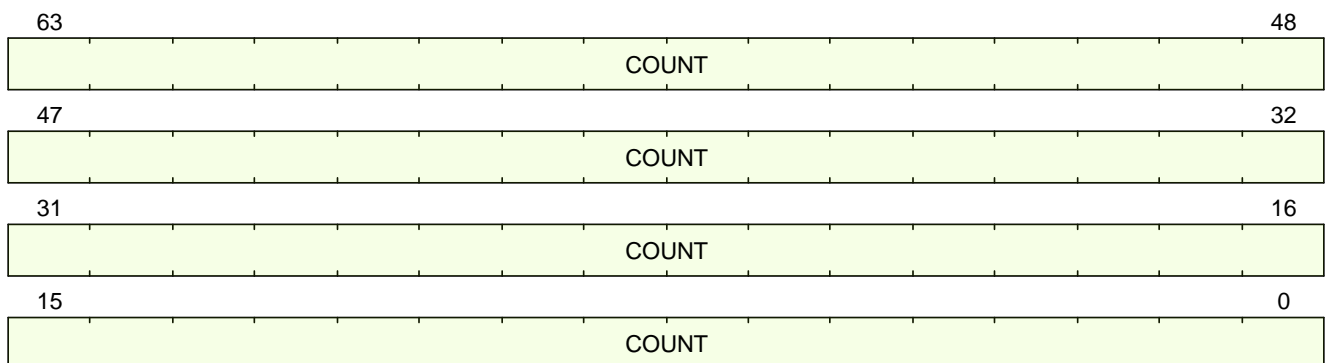


Figure 1. cycle format

C.1.3. Field Summary

Na me	Location	Type	Reset Value
COU NT	63:0	RO-H	UNDEFINED_LEGAL

C.1.4. Fields

COUNT

Location

63:0

Description

Alias of mcycle.COUNT.

Type

RO-H

Reset value

UNDEFINED_LEGAL

C.1.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```

if (mode() == PrivilegeMode::S) {
  if (CSR[mcounteren].CY == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::U) {
  if (CSR[misa].S == 1'b1) {
    if ((CSR[mcounteren].CY & CSR[scounteren].CY) == 1'b0) {
      raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
  } else if (CSR[mcounteren].CY == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VS) {
  if (CSR[hcounteren].CY == 1'b0 && CSR[mcounteren] == 1'b1) {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
  } else if (CSR[mcounteren].CY == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VU) {
  if (CSR[hcounteren].CY & CSR[scounteren].CY == 1'b0 && (CSR[mcounteren].CY ==
1'b1 {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);

```

```
} else if (CSR[mcounteren].CY == 1'b0) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
}  
return read_mcycle();
```

C.2. cycleh

High-half cycle counter for RDCYCLE Instruction

NOTE | `cycleh` is only defined in RV32.

Alias for M-mode CSR `mcycleh`.

Privilege mode access is controlled with `mcounteren.CY`, `scounteren.CY`, and `hcounteren.CY` as follows:

mcounteren.CY	scounteren.CY	hcounteren.CY	cycle behavior			
			S-mode	U-mode	VS-mode	VU-mode
0	-	-	IllegalInstruction	IllegalInstruction	IllegalInstruction	IllegalInstruction
1	0	0	read-only	IllegalInstruction	VirtualInstruction	VirtualInstruction
1	1	0	read-only	read-only	VirtualInstruction	VirtualInstruction
1	0	1	read-only	IllegalInstruction	read-only	VirtualInstruction
1	1	1	read-only	read-only	read-only	read-only

C.2.1. Attributes

CSR Address	0xc80
Defining extension	<ul style="list-style-type: none"> Zicntr, version ≥ 0
Length	32-bit
Privilege Mode	U

C.2.2. Format

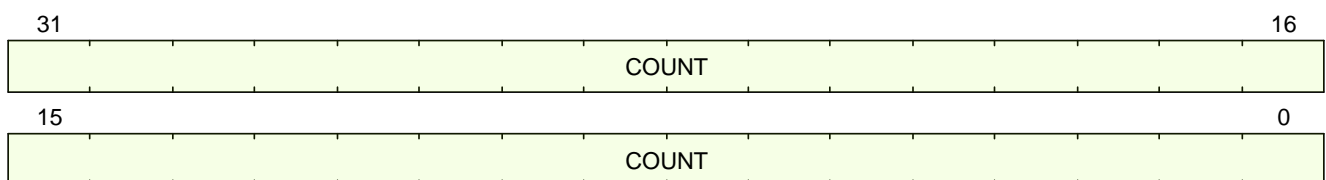


Figure 2. `cycleh` format

C.2.3. Field Summary

Na me	Location	Type	Reset Value
COU NT	31:0	RO-H	UNDEFINED_LEGAL

C.2.4. Fields

COUNT

Location

31:0

Description

Alias of mcycleh.COUNT.

Type

RO-H

Reset value

UNDEFINED_LEGAL

C.2.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```

if (mode() == PrivilegeMode::S) {
  if (CSR[mcounteren].CY == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::U) {
  if (CSR[misa].S == 1'b1) {
    if ((CSR[mcounteren].CY & CSR[scounteren].CY) == 1'b0) {
      raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
  } else if (CSR[mcounteren].CY == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VS) {
  if (CSR[hcounteren].CY == 1'b0 && CSR[mcounteren] == 1'b1) {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
  } else if (CSR[mcounteren].CY == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VU) {
  if (CSR[hcounteren].CY & CSR[scounteren].CY == 1'b0 && (CSR[mcounteren].CY ==
1'b1 {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);

```

```
} else if (CSR[mcounteren].CY == 1'b0) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
}  
return read_mcycle()[63:32];
```

C.3. instret

Instructions retired counter for RDINSTRET Instruction

Alias for M-mode CSR [minstret](#).

Privilege mode access is controlled with `mcounteren.IR`, `scounteren.IR`, and `hcounteren.IR` as follows:

mcounteren.IR	scounteren.IR	hcounteren.IR	instret behavior			
			S-mode	U-mode	VS-mode	VU-mode
0	-	-	IllegalInstruction	IllegalInstruction	IllegalInstruction	IllegalInstruction
1	0	0	read-only	IllegalInstruction	VirtualInstruction	VirtualInstruction
1	1	0	read-only	read-only	VirtualInstruction	VirtualInstruction
1	0	1	read-only	IllegalInstruction	read-only	VirtualInstruction
1	1	1	read-only	read-only	read-only	read-only

C.3.1. Attributes

CSR Address	0xc02
Defining extension	<ul style="list-style-type: none"> Zicntr, version ≥ 0
Length	64-bit
Privilege Mode	U

C.3.2. Format

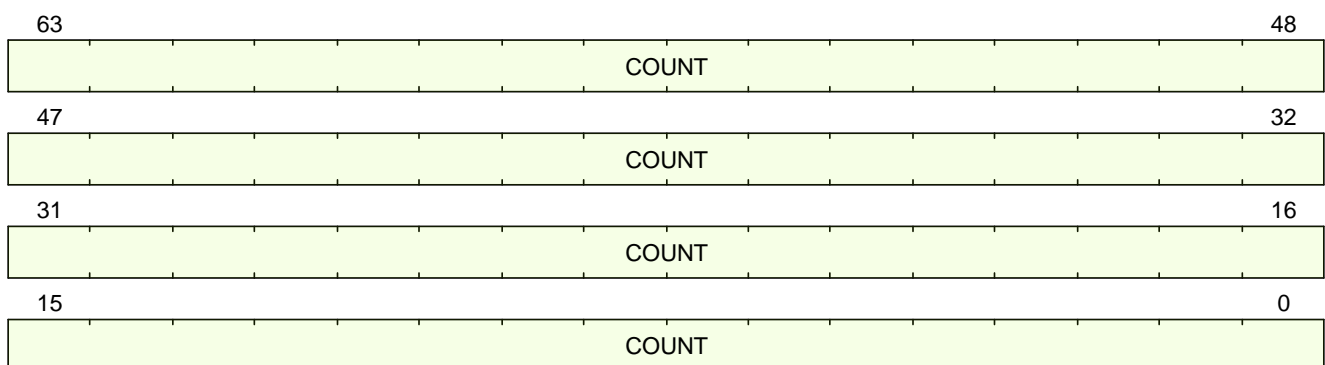


Figure 3. `instret` format

C.3.3. Field Summary

Na me	Location	Type	Reset Value
COU NT	63:0	RO-H	0

C.3.4. Fields

COUNT

Location

63:0

Description

Alias of minstret.COUNT.

Type

RO-H

Reset value

0

C.3.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```

if (mode() == PrivilegeMode::S) {
  if (CSR[mcounteren].IR == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::U) {
  if (CSR[misa].S == 1'b1) {
    if ((CSR[mcounteren].IR & CSR[scounteren].IR) == 1'b0) {
      raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
  } else if (CSR[mcounteren].IR == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VS) {
  if (CSR[hcounteren].IR == 1'b0 && CSR[mcounteren] == 1'b1) {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
  } else if (CSR[mcounteren].IR == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VU) {
  if (CSR[hcounteren].IR & CSR[scounteren].IR == 1'b0 && (CSR[mcounteren].IR ==
1'b1 {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);

```

```
} else if (CSR[mcounteren].IR == 1'b0) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
}  
return CSR[minstret].COUNT;
```

C.4. instreth

Instructions retired counter, high bits

NOTE | `instreth` is only defined in RV32.

Alias for high bits of M-mode CSR `minstret`[63:32].

Privilege mode access is controlled with `mcounteren.IR`, `scounteren.IR`, and `hcounteren.IR` as follows:

mcounteren.IR	scounteren.IR	hcounteren.IR	instret behavior			
			S-mode	U-mode	VS-mode	VU-mode
0	-	-	IllegalInstruction	IllegalInstruction	IllegalInstruction	IllegalInstruction
1	0	0	read-only	IllegalInstruction	VirtualInstruction	VirtualInstruction
1	1	0	read-only	read-only	VirtualInstruction	VirtualInstruction
1	0	1	read-only	IllegalInstruction	read-only	VirtualInstruction
1	1	1	read-only	read-only	read-only	read-only

C.4.1. Attributes

CSR Address	0xc82
Defining extension	<ul style="list-style-type: none"> Zicntr, version ≥ 0
Length	32-bit
Privilege Mode	U

C.4.2. Format

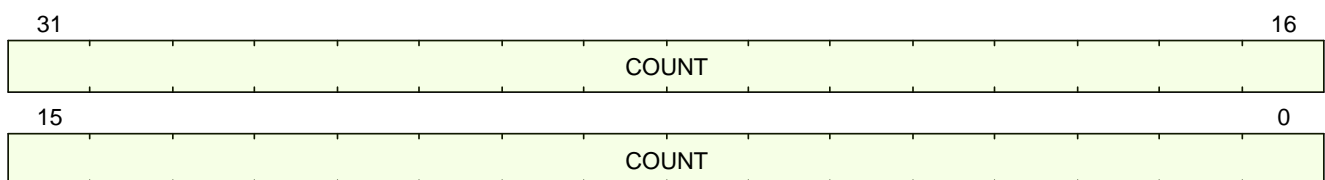


Figure 4. `instreth` format

C.4.3. Field Summary

Na me	Location	Type	Reset Value
COUNT	31:0	RO-H	UNDEFINED_LEGAL

C.4.4. Fields

COUNT

Location

31:0

Description

Alias of minstret.COUNT[63:32].

Type

RO-H

Reset value

UNDEFINED_LEGAL

C.4.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```

if (mode() == PrivilegeMode::S) {
  if (CSR[mcounteren].IR == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::U) {
  if (CSR[misa].S == 1'b1) {
    if ((CSR[mcounteren].IR & CSR[scounteren].IR) == 1'b0) {
      raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
  } else if (CSR[mcounteren].IR == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VS) {
  if (CSR[hcounteren].IR == 1'b0 && CSR[mcounteren] == 1'b1) {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
  } else if (CSR[mcounteren].IR == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
  }
} else if (mode() == PrivilegeMode::VU) {
  if (CSR[hcounteren].IR & CSR[scounteren].IR == 1'b0 && (CSR[mcounteren].IR ==
1'b1 {
    raise(ExceptionCode::VirtualInstruction, mode(), $encoding);

```

```
} else if (CSR[mcounteren].IR == 1'b0) {  
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);  
}  
}  
return read_mcycle();
```


C.5. marchid

Machine Architecture ID

The `marchid` CSR is an MXLEN-bit read-only register encoding the base microarchitecture of the hart. This register must be readable in any implementation, but a value of 0 can be returned to indicate the field is not implemented. The combination of `mvendorid` and `marchid` should uniquely identify the type of hart microarchitecture that is implemented.

Open-source project architecture IDs are allocated globally by RISC-V International, and have non-zero architecture IDs with a zero most-significant-bit (MSB). Commercial architecture IDs are allocated by each commercial vendor independently, but must have the MSB set and cannot contain zero in the remaining MXLEN-1 bits.

NOTE

The intent is for the architecture ID to represent the microarchitecture associated with the repo around which development occurs rather than a particular organization. Commercial fabrications of open-source designs should (and might be required by the license to) retain the original architecture ID. This will aid in reducing fragmentation and tool support costs, as well as provide attribution. Open-source architecture IDs are administered by RISC-V International and should only be allocated to released, functioning open-source projects. Commercial architecture IDs can be managed independently by any registered vendor but are required to have IDs disjoint from the open-source architecture IDs (MSB set) to prevent collisions if a vendor wishes to use both closed-source and open-source microarchitectures.

The convention adopted within the following Implementation field can be used to segregate branches of the same architecture design, including by organization. The `misa` register also helps distinguish different variants of a design.

C.5.1. Attributes

CSR Address	0xf12
Defining extension	<ul style="list-style-type: none"> Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.5.2. Format

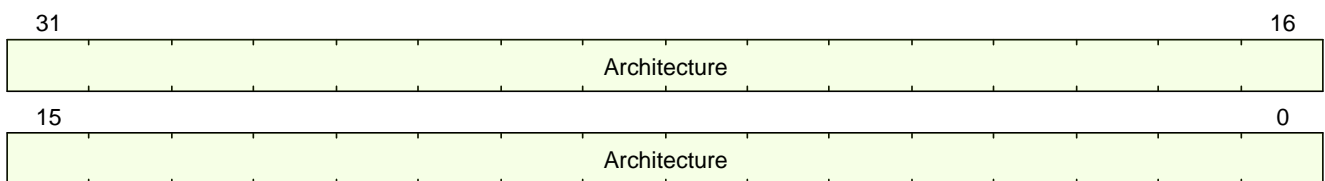


Figure 5. `marchid` format

C.5.3. Field Summary

Name	Location	Type	Reset Value
Architecture	31:0	RO	ARCH_ID

C.5.4. Fields

Architecture

Location

31:0

Description

Vendor-specific microarchitecture ID.

Type

RO

Reset value

ARCH_ID

C.6. mcause

Machine Cause

Reports the cause of the latest exception.

C.6.1. Attributes

CSR Address	0x342
Defining extension	<ul style="list-style-type: none">Sm, version ≥ 0
Length	32-bit
Privilege Mode	M

C.6.2. Format

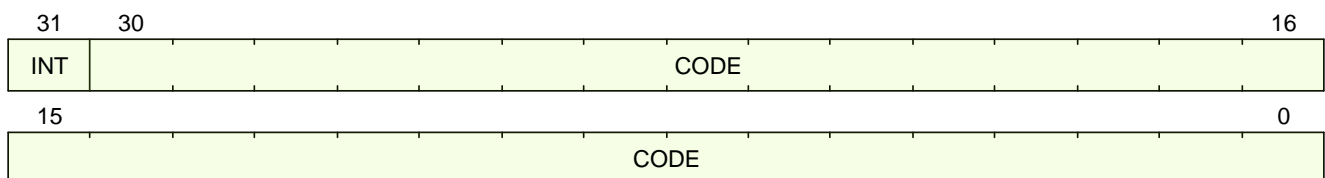


Figure 6. mcause format

C.6.3. Field Summary

Name	Location	Type	Reset Value
INT	31	RW-RH	0
CODE	30:0	RW-RH	0

C.6.4. Fields

INT

Location

31

Description

Written by hardware when a trap is taken into M-mode.

When set, the last exception was caused by an asynchronous Interrupt.

mcause.INT is writeable.

[when, "TRAP_ON_ILLEGAL_WLRL == true"]

If `mcause` is written with an undefined cause (combination of `mcause.INT` and `mcause.CODE`), an **Illegal Instruction** exception occurs.

[when,"TRAP_ON_ILLEGAL_WLRL == false"]

If `mcause` is written with an undefined cause (combination of `mcause.INT` and `mcause.CODE`), neither `mcause.INT` nor `mcause.CODE` are modified.

Type

RW-RH

Reset value

0

CODE

Location

30:0

Description

Written by hardware when a trap is taken into M-mode.

Holds the interrupt or exception code for the last taken trap.

`mcause.CODE` is writeable.

[when,"TRAP_ON_ILLEGAL_WLRL == true"]

If `mcause` is written with an undefined cause (combination of `mcause.INT` and `mcause.CODE`), an **Illegal Instruction** exception occurs.

[when,"TRAP_ON_ILLEGAL_WLRL == false"]

If `mcause` is written with an undefined cause (combination of `mcause.INT` and `mcause.CODE`), neither `mcause.INT` nor `mcause.CODE` are modified.

Valid interrupt codes are:

[separator="!"]

!===

<%- interrupt_codes.sort_by{ |code| code.num }.each do |code| -%>

! <%= code.num %> ! <%= code.name %>

<%- end -%>

!===

Valid exception codes are:

[separator="!"]

!===

<%- exception_codes.sort_by{ |code| code.num }.each do |code| -%>

! <%= code.num %> ! <%= code.name %>

<%- end -%>

!===

Type

RW-RH

Reset value

0

C.6.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (e.g., through `csrrw`), the following determines the written value:

```
INT = # the write only holds if the INT/CODE combination is valid
```

```
if (csr_value.INT == 1) {  
    if (valid_interrupt_code?(csr_value.CODE)) {  
        return 1;  
    }  
    return ILLEGAL_WLRL;  
} else {  
    if (valid_exception_code?(csr_value.CODE)) {  
        return 1;  
    }  
    return ILLEGAL_WLRL;  
}
```

```
CODE = # the write only holds if the INT/CODE combination is valid
```

```
if (csr_value.INT == 1) {  
    if (valid_interrupt_code?(csr_value.CODE)) {  
        return csr_value.CODE;  
    }  
    return ILLEGAL_WLRL;  
} else {  
    if (valid_exception_code?(csr_value.CODE)) {  
        return csr_value.CODE;  
    }  
    return ILLEGAL_WLRL;  
}
```

C.7. mcountinhibit

Machine Counter Inhibit

Bits to inhibit (stops counting) performance counters.

The counter-inhibit register `mcountinhibit` is a **WARL** register that controls which of the hardware performance-monitoring counters increment. The settings in this register only control whether the counters increment; their accessibility is not affected by the setting of this register.

When the `CY`, `IR`, or `HPM n` bit in the `mcountinhibit` register is clear, the `mcycle`, `minstret`, or `mhpmcountern` register increments as usual. When the `CY`, `IR`, or `HPM n _bit` is set, the corresponding counter does not increment.

The `mcycle` CSR may be shared between harts on the same core, in which case the `mcountinhibit.CY` field is also shared between those harts, and so writes to `mcountinhibit.CY` will be visible to those harts.

If the `mcountinhibit` register is not implemented, the implementation behaves as though the register were set to zero.

NOTE

When the `mcycle` and `minstret` counters are not needed, it is desirable to conditionally inhibit them to reduce energy consumption. Providing a single CSR to inhibit all counters also allows the counters to be atomically sampled.

Because the `mtime` counter can be shared between multiple cores, it cannot be inhibited with the `mcountinhibit` mechanism.

C.7.1. Attributes

CSR Address	0x320
Defining extension	<ul style="list-style-type: none"> • anyOf: <ul style="list-style-type: none"> ◦ Sm, version >= 0 ◦ Smhpm, version >= 0
Length	32-bit
Privilege Mode	M

C.7.2. Format

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HPM31	HPM30	HPM29	HPM28	HPM27	HPM26	HPM25	HPM24	HPM23	HPM22	HPM21	HPM20	HPM19	HPM18	HPM17	HPM16
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HPM15	HPM14	HPM13	HPM12	HPM11	HPM10	HPM9	HPM8	HPM7	HPM6	HPM5	HPM4	HPM3	IR		CY

Figure 7. `mcountinhibit` format

C.7.3. Field Summary

Na me	Location	Type	Reset Value
CY	0	RW	UNDEFINED_LEGAL
		RO	0
IR	2	RW	UNDEFINED_LEGAL
		RO	0
HPM 3	3	RW	UNDEFINED_LEGAL
		RO	0
HPM 4	4	RW	UNDEFINED_LEGAL
		RO	0
HPM 5	5	RW	UNDEFINED_LEGAL
		RO	0
HPM 6	6	RW	UNDEFINED_LEGAL
		RO	0
HPM 7	7	RW	UNDEFINED_LEGAL
		RO	0
HPM 8	8	RW	UNDEFINED_LEGAL
		RO	0
HPM 9	9	RW	UNDEFINED_LEGAL
		RO	0
HPM 10	10	RW	UNDEFINED_LEGAL
		RO	0
HPM 11	11	RW	UNDEFINED_LEGAL
		RO	0
HPM 12	12	RW	UNDEFINED_LEGAL
		RO	0
HPM 13	13	RW	UNDEFINED_LEGAL
		RO	0

Na me	Location	Type	Reset Value
HPM 14	14	RW	UNDEFINED_LEGAL
		RO	0
HPM 15	15	RW	UNDEFINED_LEGAL
		RO	0
HPM 16	16	RW	UNDEFINED_LEGAL
		RO	0
HPM 17	17	RW	UNDEFINED_LEGAL
		RO	0
HPM 18	18	RW	UNDEFINED_LEGAL
		RO	0
HPM 19	19	RW	UNDEFINED_LEGAL
		RO	0
HPM 20	20	RW	UNDEFINED_LEGAL
		RO	0
HPM 21	21	RW	UNDEFINED_LEGAL
		RO	0
HPM 22	22	RW	UNDEFINED_LEGAL
		RO	0
HPM 23	23	RW	UNDEFINED_LEGAL
		RO	0
HPM 24	24	RW	UNDEFINED_LEGAL
		RO	0
HPM 25	25	RW	UNDEFINED_LEGAL
		RO	0
HPM 26	26	RW	UNDEFINED_LEGAL
		RO	0
HPM 27	27	RW	UNDEFINED_LEGAL
		RO	0

Na me	Location	Type	Reset Value
HPM 28	28	RW	UNDEFINED_LEGAL
		RO	0
HPM 29	29	RW	UNDEFINED_LEGAL
		RO	0
HPM 30	30	RW	UNDEFINED_LEGAL
		RO	0
HPM 31	31	RW	UNDEFINED_LEGAL
		RO	0

C.7.4. Fields

CY

Location

0

Description

When set, mcycle.COUNT stops counting in all privilege modes.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

IR

Location

2

Description

When set, minstret.COUNT stops counting in all privilege modes.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM3

Location

3

Description

[when="COUNTINHIBIT_EN[3] == true"]

When set, hpmcounter3.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[3] == false"]

Since hpmcounter3 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM4

Location

4

Description

[when="COUNTINHIBIT_EN[4] == true"]

When set, hpmcounter4.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[4] == false"]

Since hpmcounter4 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM5

Location

5

Description

[when="COUNTINHIBIT_EN[5] == true"]

When set, hpmcounter5.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[5] == false"]

Since hpmcounter5 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM6

Location

6

Description

[when="COUNTINHIBIT_EN[6] == true"]

When set, hpmcounter6.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[6] == false"]

Since hpmcounter6 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM7

Location

7

Description

[when="COUNTINHIBIT_EN[7] == true"]

When set, hpmcounter7.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[7] == false"]

Since hpmcounter7 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM8

Location

8

Description

[when="COUNTINHIBIT_EN[8] == true"]

When set, hpmcounter8.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[8] == false"]

Since hpmcounter8 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM9

Location

9

Description

[when="COUNTINHIBIT_EN[9] == true"]

When set, hpmcounter9.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[9] == false"]

Since hpmcounter9 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM10

Location

10

Description

[when="COUNTINHIBIT_EN[10] == true"]

When set, hpmcounter10.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[10] == false"]

Since hpmcounter10 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM11

Location

11

Description

[when="COUNTINHIBIT_EN[11] == true"]

When set, hpmcounter11.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[11] == false"]

Since hpmcounter11 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM12

Location

12

Description

[when="COUNTINHIBIT_EN[12] == true"]

When set, hpmcounter12.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[12] == false"]

Since hpmcounter12 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM13

Location

13

Description

[when="COUNTINHIBIT_EN[13] == true"]

When set, hpmcounter13.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[13] == false"]

Since hpmcounter13 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM14

Location

14

Description

[when="COUNTINHIBIT_EN[14] == true"]

When set, hpmcounter14.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[14] == false"]

Since hpmcounter14 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM15

Location

15

Description

[when="COUNTINHIBIT_EN[15] == true"]

When set, hpmcounter15.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[15] == false"]

Since hpmcounter15 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM16

Location

16

Description

[when="COUNTINHIBIT_EN[16] == true"]

When set, hpmcounter16.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[16] == false"]

Since hpmcounter16 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM17

Location

17

Description

[when="COUNTINHIBIT_EN[17] == true"]

When set, hpmcounter17.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[17] == false"]

Since hpmcounter17 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM18

Location

18

Description

[when="COUNTINHIBIT_EN[18] == true"]

When set, hpmcounter18.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[18] == false"]

Since hpmcounter18 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM19

Location

19

Description

[when="COUNTINHIBIT_EN[19] == true"]

When set, hpmcounter19.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[19] == false"]

Since hpmcounter19 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM20

Location

20

Description

[when="COUNTINHIBIT_EN[20] == true"]

When set, hpmcounter20.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[20] == false"]

Since hpmcounter20 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM21

Location

21

Description

[when="COUNTINHIBIT_EN[21] == true"]

When set, hpmcounter21.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[21] == false"]

Since hpmcounter21 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM22

Location

22

Description

[when="COUNTINHIBIT_EN[22] == true"]

When set, hpmcounter22.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[22] == false"]

Since hpmcounter22 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM23

Location

23

Description

[when="COUNTINHIBIT_EN[23] == true"]

When set, hpmcounter23.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[23] == false"]

Since hpmcounter23 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM24

Location

24

Description

[when="COUNTINHIBIT_EN[24] == true"]

When set, hpmcounter24.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[24] == false"]

Since hpmcounter24 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM25

Location

25

Description

[when="COUNTINHIBIT_EN[25] == true"]

When set, hpmcounter25.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[25] == false"]

Since hpmcounter25 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM26

Location

26

Description

[when="COUNTINHIBIT_EN[26] == true"]

When set, hpmcounter26.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[26] == false"]

Since hpmcounter26 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM27

Location

27

Description

[when="COUNTINHIBIT_EN[27] == true"]

When set, hpmcounter27.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[27] == false"]

Since hpmcounter27 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM28

Location

28

Description

[when="COUNTINHIBIT_EN[28] == true"]

When set, hpmcounter28.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[28] == false"]

Since hpmcounter28 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM29

Location

29

Description

[when="COUNTINHIBIT_EN[29] == true"]

When set, hpmcounter29.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[29] == false"]

Since hpmcounter29 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM30

Location

30

Description

[when="COUNTINHIBIT_EN[30] == true"]

When set, hpmcounter30.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[30] == false"]

Since hpmcounter30 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

HPM31

Location

31

Description

[when="COUNTINHIBIT_EN[31] == true"]

When set, hpmcounter31.COUNT stops counting in all privilege modes.

[when="COUNTINHIBIT_EN[31] == false"]

Since hpmcounter31 is not implemented, this field is read-only zero.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

C.8. mcycle

Machine Cycle Counter

Counts the number of clock cycles executed by the processor core on which the hart is running. The counter has 64-bit precision on all RV32 and RV64 harts.

The `mcycle` CSR may be shared between harts on the same core, in which case writes to `mcycle` will be visible to those harts. The platform should provide a mechanism to indicate which harts share an `mcycle` CSR.

C.8.1. Attributes

CSR Address	0xb00
Defining extension	<ul style="list-style-type: none">Zicntr, version ≥ 0
Length	64-bit
Privilege Mode	M

C.8.2. Format

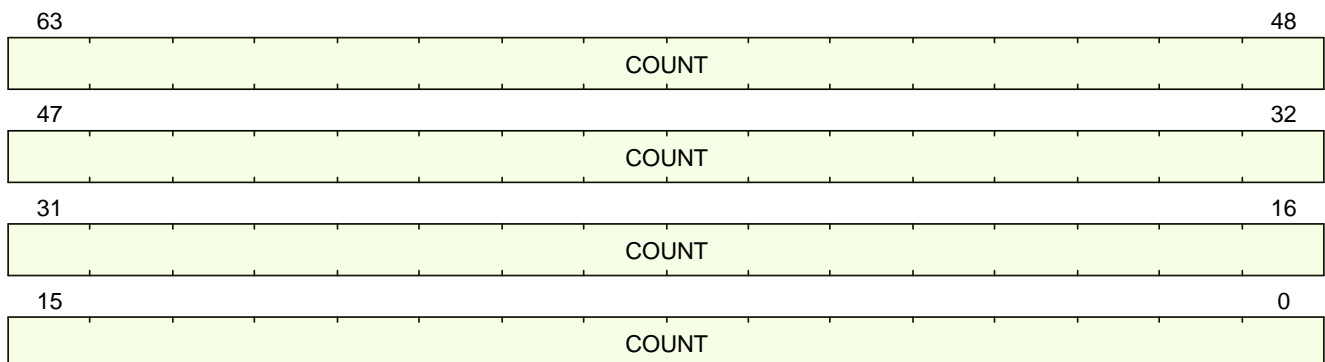


Figure 8. mcycle format

C.8.3. Field Summary

Name	Location	Type	Reset Value
COUNT	63:0	RW-RH	UNDEFINED_LEGAL

C.8.4. Fields

COUNT

Location
63:0

Description

Cycle counter.

```
<%- if ext?(:Zicntr) -%>
```

Aliased as [cycle](#).

```
<%- end -%>
```

Increments every cycle unless:

- `mcountinhibit.CY`

```
<%- if ext?(:Smcdeleg) -%>
```

 or its alias `scountinhibit.CY`

```
<%- end -%>
```

 is set

```
<%- if ext?(:Smcntrpmf) -%>
```
- `mcyclecfg.MINH` is set and the current privilege level is M

```
<%- if ext?(:S) -%>
```
- `mcyclecfg.SINH`

```
<%- if ext?(:Sscfg) -%>
```

 or its alias `instretcfg.SINH`

```
<%- end -%>
```

 is set and the current privilege level is (H)S

```
<%- end -%>
```

```
<%- if ext?(:U) -%>
```
- `mcyclecfg.UINH`

```
<%- if ext?(:Sscfg) -%>
```

 or its alias `instretcfg.SINH`

```
<%- end -%>
```

 is set and the current privilege level is U

```
<%- end -%>
```

```
<%- if ext?(:H) -%>
```
- `mcyclecfg.VSINH`

```
<%- if ext?(:Sscfg) -%>
```

 or its alias `instretcfg.SINH`

```
<%- end -%>
```

 is set and the current privilege level is VS
- `mcyclecfg.VUINH`

```
<%- if ext?(:Sscfg) -%>
```

 or its alias `instretcfg.SINH`

```
<%- end -%>
```

 is set and the current privilege level is VU

```
<%- end -%>
```

```
<%- end -%>
```

Type

RW-RH

Reset value

UNDEFINED_LEGAL

C.8.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (e.g., through [csrrw](#)), the following determines the written value:

```
COUNT = # since writes to this register may not be hart-local, it must be handled
# as a special case
if (xlen() == 32) {
    return sw_write_mcycle({read_mcycle()[63:31], csr_value.COUNT[31:0]});
```

```
} else {  
    return sw_write_mcycle(csr_value.COUNT);  
}
```

C.8.6. Software read

This CSR may return a value that is different from what is stored in hardware.

```
return read_mcycle();
```

C.9. mcycleh

High-half machine Cycle Counter

NOTE | `mcycleh` is only defined in RV32.

High-half alias of `mcycle`.

C.9.1. Attributes

CSR Address	0xb80
Defining extension	<ul style="list-style-type: none">Zicntr, version ≥ 0
Length	32-bit
Privilege Mode	M

C.9.2. Format

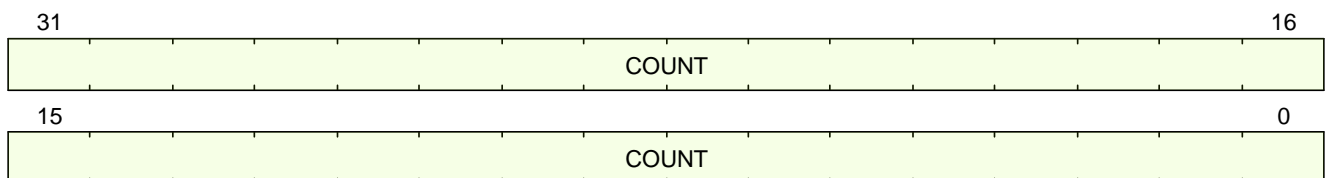


Figure 9. `mcycleh` format

C.9.3. Field Summary

Name	Location	Type	Reset Value
<code>COUNT</code>	31:0	RW-RH	UNDEFINED_LEGAL

C.9.4. Fields

`COUNT`

Location

31:0

Description

Alias of upper half of `mcycle.COUNT`.

Type

RW-RH

Reset value

UNDEFINED_LEGAL

C.9.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (*e.g.*, through `csrrw`), the following determines the written value:

```
COUNT = # since writes to this register may not be hart-local, it must be handled
# as a special case
if (xlen() == 32) {
    return sw_write_mcycle({csr_value.COUNT[31:0], read_mcycle()[31:0]});
} else {
    return sw_write_mcycle(csr_value.COUNT);
}
```

C.9.6. Software read

This CSR may return a value that is different from what is stored in hardware.

```
return read_mcycle()[63:32];
```

C.10. mepc

Machine Exception Program Counter

Written with the PC of an instruction on an exception or interrupt taken in M-mode.

Also controls where the hart jumps on an exception return from M-mode.

C.10.1. Attributes

CSR Address	0x341
Defining extension	<ul style="list-style-type: none">Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.10.2. Format

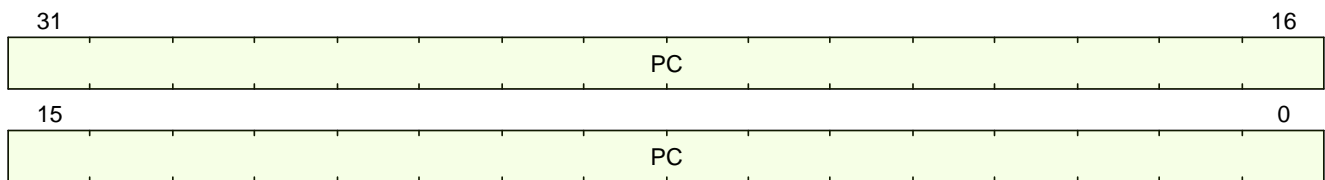


Figure 10. mepc format

C.10.3. Field Summary

Na me	Location	Type	Reset Value
PC	31:0	RW-RH	0

C.10.4. Fields

PC

Location

31:0

Description

When a trap is taken into M-mode, mepc.PC is written with the virtual address of the instruction that was interrupted or that encountered the exception.

Otherwise, mepc.PC is never written by the implementation, though it may be explicitly written by software.

On an exception return from M-mode (from the MRET instruction),

control transfers to the virtual address read out of mepc.PC.

```
[when,"ext?:(C)"]
```

Because PCs are always halfword-aligned, bit 0 of mepc.PC is always read-only 0.

```
[when,"!ext?:(C)"]
```

Because PCs are always word-aligned, bits 1:0 of mepc.PC are always read-only 0.

```
[when,"ext?:(C) && MUTABLE_MISA_C == true"]
```

When misa.C is clear, bit 1 is masked to zero. Writes to bit 1 are still captured, and may be visible on the next read with misa.C is set.

Type

RW-RH

Reset value

0

C.10.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (e.g., through [csrrw](#)), the following determines the written value:

```
PC = return csr_value.PC & ~64'b1;
```

C.10.6. Software read

This CSR may return a value that is different from what is stored in hardware.

```
if (implemented?(ExtensionName::C) && CSR[misa].C == 1'b1) {  
    return CSR[mepc].PC & ~64'b1;  
} else {  
    return CSR[mepc].PC;  
}
```

C.11. mhartid

Machine Hart ID

Reports the unique hart-specific ID in the system.

C.11.1. Attributes

CSR Address	0xf14
Defining extension	<ul style="list-style-type: none">Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.11.2. Format

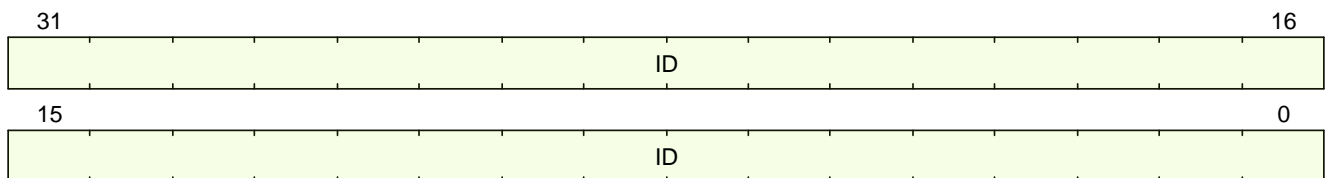


Figure 11. mhartid format

C.11.3. Field Summary

Name	Location	Type	Reset Value
ID	31:0	RO	UNDEFINED_LEGAL

C.11.4. Fields

ID

Location

31:0

Description

hart-specific ID.

Type

RO

Reset value

UNDEFINED_LEGAL

C.11.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```
return hartid();
```

C.12. mie

Machine Interrupt Enable

The `mie` and `mip` CSRs are MXLEN-bit read/write registers used when the CLINT or PLIC interrupt controllers are present. Note that the CLINT refers to an interrupt controller used by some RISC-V implementations but isn't a ratified RISC-V International standard.

The `mip` CSR contains information on pending interrupts, while `mie` is the corresponding CSR containing interrupt enable bits. Interrupt cause number i (as reported in the `mcause` CSR) corresponds to bit i in both `mip` and `mie`. Bits 15:0 are allocated to standard interrupt causes only, while bits 16 and above are designated for platform use.

NOTE Interrupts designated for platform use may be designated for custom use at the platform's discretion.

An interrupt i will trap to M-mode (causing the privilege mode to change to M-mode) if all of the following are true:

- either the current privilege mode is M and the MIE bit in the `mstatus` register is set, or the current privilege mode has less privilege than M-mode;
- bit i is set in both `mip` and `mie`
- if register `mideleg` exists, bit i is not set in `mideleg`.

These conditions for an interrupt trap to occur must be evaluated in a bounded amount of time from when an interrupt becomes, or ceases to be, pending in `mip`, and must also be evaluated immediately following the execution of an `xRET` instruction or an explicit write to a CSR on which these interrupt trap conditions expressly depend (including `mip`, `mie`, `mstatus`, and `mideleg`).

Interrupts to M-mode take priority over any interrupts to lower privilege modes.

Each individual bit in register `mip` may be writable or may be read-only. When bit i in `mip` is writable, a pending interrupt i can be cleared by writing 0 to this bit. If interrupt i can become pending but bit i in `mip` is read-only, the implementation must provide some other mechanism for clearing the pending interrupt.

A bit in `mie` must be writable if the corresponding interrupt can ever become pending. Bits of `mie` that are not writable must be read-only zero.

NOTE The machine-level interrupt registers handle a few root interrupt sources which are assigned a fixed service priority for simplicity, while separate external interrupt controllers can implement a more complex prioritization scheme over a much larger set of interrupts that are then muxed into the machine-level interrupt sources.

The non-maskable interrupt is not made visible via the `mip` register as its presence is implicitly known when executing the NMI trap handler.

If supervisor mode is implemented, bits `mip.SEIP` and `mie.SEIE` are the interrupt-pending and interrupt-enable bits for supervisor-level external interrupts. SEIP is writable in `mip`, and may be written by M-mode software to indicate to S-mode that an external interrupt is pending. Additionally, the platform-level interrupt controller may generate supervisor-level external interrupts. Supervisor-level external interrupts are made pending based on the logical-OR of the software-writable SEIP bit and the signal from the external interrupt controller. When `mip` is read with a CSR instruction, the value of the SEIP bit returned in the `rd` destination register is the logical-OR of the software-writable bit and the interrupt signal from the interrupt controller, but the signal from the interrupt controller is not used to calculate the value written to SEIP. Only the software-writable SEIP bit participates in the read-modify-write sequence of a CSRRS or CSRRC instruction.

For example, if we name the software-writable SEIP bit `B` and the signal from the external interrupt controller `E`, then if `csrrs t0, mip, t1` is executed, `t0[9]` is written with `B || E`, then `B` is written with `B || t1[9]`. If `csrrw t0, mip, t1` is executed, then `t0[9]` is written with `B || E`, and `B` is simply written with `t1[9]`. In neither case does `B` depend upon `E`.

NOTE

The SEIP field behavior is designed to allow a higher privilege layer to mimic external interrupts cleanly, without losing any real external interrupts. The behavior of the CSR instructions is slightly modified from regular CSR accesses as a result.

If supervisor mode is implemented, bits `mip.STIP` and `mie.STIE` are the interrupt-pending and interrupt-enable bits for supervisor-level timer interrupts. STIP is writable in `mip`, and may be written by M-mode software to deliver timer interrupts to S-mode.

If supervisor mode is implemented, bits `mip.SSIP` and `mie.SSIE` are the interrupt-pending and interrupt-enable bits for supervisor-level software interrupts. SSIP is writable in `mip` and may also be set to 1 by a platform-specific interrupt controller.

<% if ext?(:Sscofpmf) -%> bits `mip.LCOFIP` and `mie.LCOFIE` are the interrupt-pending and interrupt-enable bits for local counter-overflow interrupts. LCOFIP is read-write in `mip` and reflects the occurrence of a local counter-overflow overflow interrupt request resulting from any of the `mhpmeventn.OF` bits being set. <% end -%>

Multiple simultaneous interrupts destined for M-mode are handled in the following decreasing priority order: MEI, MSI, MTI, SEI, SSI, STI, LCOFI.

The machine-level interrupt fixed-priority ordering rules were developed with the following rationale.

Interrupts for higher privilege modes must be serviced before interrupts for lower privilege modes to support preemption.

NOTE

The platform-specific machine-level interrupt sources in bits 16 and above have platform-specific priority, but are typically chosen to have the highest service priority to support very fast local vectored interrupts.

External interrupts are handled before internal (timer/software) interrupts as

external interrupts are usually generated by devices that might require low interrupt service times.

Software interrupts are handled before internal timer interrupts, because internal timer interrupts are usually intended for time slicing, where time precision is less important, whereas software interrupts are used for inter-processor messaging. Software interrupts can be avoided when high-precision timing is required, or high-precision timer interrupts can be routed via a different interrupt path. Software interrupts are located in the lowest four bits of `mip` as these are often written by software, and this position allows the use of a single CSR instruction with a five-bit immediate.

Restricted views of the `mip` and `mie` registers appear as the `sip` and `sie` registers for supervisor level. If an interrupt is delegated to S-mode by setting a bit in the `mideleg` register, it becomes visible in the `sip` register and is maskable using the `sie` register. Otherwise, the corresponding bits in `sip` and `sie` are read-only zero.

C.12.1. Attributes

CSR Address	0x304
Defining extension	<ul style="list-style-type: none"> Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.12.2. Format

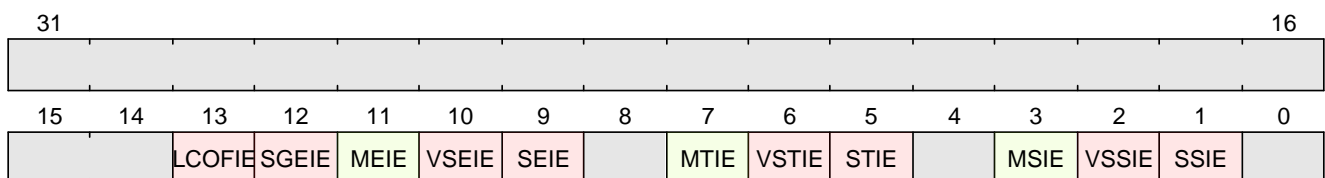


Figure 12. mie format

C.12.3. Field Summary

Name	Location	Type	Reset Value
SSIE	1	RW	0
VSSIE	2	RW	0
MSIE	3	RW	0
STIE	5	RW	0

Na me	Location	Type	Reset Value
VST IE	6	RW	0
MTI E	7	RW	0
SEI E	9	RW	0
VSE IE	10	RW	0
MEI E	11	RW	0
SGE IE	12	RW	0
LCO FIE	13	RW	0

C.12.4. Fields

SSIE

Location

1

Description

Enables Supervisor Software Interrupts.

Alias of `sie.SSIE` when `mideleg.SSI` is set. Otherwise, `sie.SSIE` is read-only 0.

Type

RW

Reset value

0

VSSIE

Location

2

Description

Enables Virtual Supervisor Software Interrupts.

Alias of `hie.VSSIE`.

Alias of `vsie.SSIE` when `hideleg.VSSI` is set. Otherwise, `vseie.SSIE` is read-only 0.

Alias of `sie.SSIE` when `hideleg.VSSI` is set and the current mode is VS or VU (Because `mie` is inaccessible in VS or VU mode, this alias can never be observed by software).

Type

RW

Reset value

0

MSIE

Location

3

Description

Enables Machine Software Interrupts.

Type

RW

Reset value

0

STIE

Location

5

Description

Enables Supervisor Timer Interrupts.

Alias of `sip` when `mideleg.STI` is set. Otherwise, `sip` is read-only 0.

Type

RW

Reset value

0

VSTIE

Location

6

Description

Enables Virtual Supervisor Timer Interrupts.

Alias of `hie.VSTIE`.

Alias of `vsie.STIE` when `hideleg.VSTI` is set. Otherwise, `vseie.STIE` is read-only 0.

Alias of `sie.STIE` when `hideleg.VSTI` is set and the current mode is VS or VU (Because `mie` is inaccessible in VS or VU mode, this alias can never be observed by software).

Type

RW

Reset value

0

MTIE

Location

7

Description

Enables Machine Timer Interrupts.

Type

RW

Reset value

0

SEIE

Location

9

Description

Enables Supervisor External Interrupts.

Alias of `sie.SEIE` when `mideleg.SEI` is set. Otherwise, `sie.SEIE` is read-only 0.

Type

RW

Reset value

0

VSEIE**Location**

10

Description

Enables Virtual Supervisor External Interrupts.

Alias of `hie.VSEIE`.

Alias of `vsie.SEIE` when `hideleg.VSEI` is set. Otherwise, `vseie.SEIE` is read-only 0.

Alias of `sie.SEIE` when `hideleg.VSEI` is set and the current mode is VS or VU (Because `mie` is inaccessible in VS or VU mode, this alias can never be observed by software).

Type

RW

Reset value

0

MEIE**Location**

11

Description

Enables Machine External Interrupts.

Type

RW

Reset value

0

SGEIE**Location**

12

Description

Enables Supervisor Guest External Interrupts

Alias of `hie.SGEIE`.

Type

RW

Reset value

0

LCOFIE**Location**

13

Description

Enables Local Counter Overflow Interrupts.

Alias of `sie.LCOFIE` when `mideleg.LCOFI` is set. Otherwise, `sie.LCOFIE` is an independent writeable bit when `mvien.LCOFI` is set or is read-only 0.

Alias of `vsip.LCOFIE` when `hideleg.LCOFI` is set. Otherwise, `vsip.LCOFIE` is read-only 0.

Type

RW

Reset value

0

C.13. mimpid

Machine Implementation ID

Reports the vendor-specific implementation ID.

The `mimpid` CSR provides a unique encoding of the version of the processor implementation. This register must be readable in any implementation, but a value of 0 can be returned to indicate that the field is not implemented. The Implementation value should reflect the design of the RISC-V processor itself and not any surrounding system.

NOTE

The format of this field is left to the provider of the architecture source code, but will often be printed by standard tools as a hexadecimal string without any leading or trailing zeros, so the Implementation value can be left-justified (i.e., filled in from most-significant nibble down) with subfields aligned on nibble boundaries to ease human readability.

C.13.1. Attributes

CSR Address	0xf13
Defining extension	<ul style="list-style-type: none">Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.13.2. Format

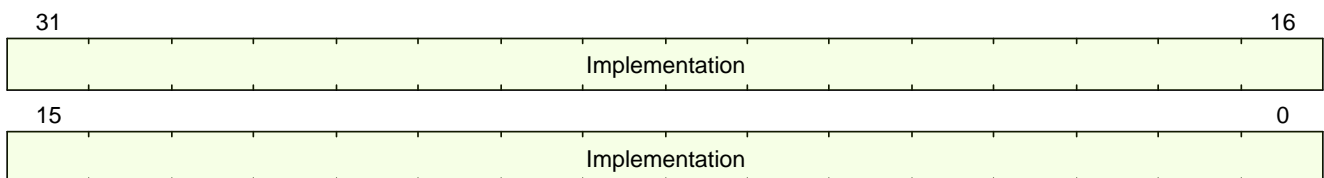


Figure 13. mimpid format

C.13.3. Field Summary

Name	Location	Type	Reset Value
Implementation	31:0	RO	IMP_ID

C.13.4. Fields

Implementation

Location

31:0

Description

Vendor-specific implementation ID.

Type

RO

Reset value

IMP_ID

C.14. minstret

Machine Instructions Retired Counter

Counts the number of instructions retired by this hart from some arbitrary start point in the past.

NOTE Instructions that cause synchronous exceptions, including [ecall](#) and [ebreak](#), are not considered to retire and hence do not increment the [minstret](#) CSR.

C.14.1. Attributes

CSR Address	0xb02
Defining extension	<ul style="list-style-type: none">Zicntr, version ≥ 0
Length	64-bit
Privilege Mode	M

C.14.2. Format

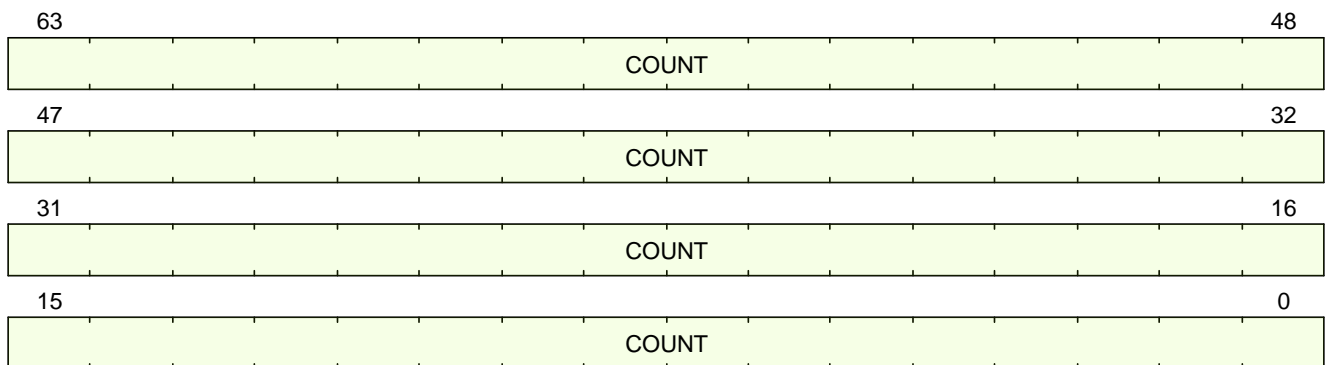


Figure 14. minstret format

C.14.3. Field Summary

Name	Location	Type	Reset Value
COUNT	63:0	RW-H	UNDEFINED_LEGAL

C.14.4. Fields

COUNT

Location

63:0

Description

Instructions retired counter.

<%- if ext?(:Zicntr) -%>

Aliased as instret.COUNT.

<%- end -%>

Increments every time an instruction retires unless:

- `mcountinhibit.IR` <%- if ext?(:Smcdeleg) -%> or its alias `scountinhibit.IR` <%- end -%> is set
<%- if ext?(:Smcntrpmf) -%>
- `minstretcfg.MINH` is set and the current privilege level is M
<%- if ext?(:S) -%>
- `minstretcfg.SINH` <%- if ext?(:Ssccfg) -%> or its alias `instretcfg.SINH` <%- end -%> is set and the current privilege level is (H)S
<%- end -%>
<%- if ext?(:U) -%>
- `minstretcfg.UINH` <%- if ext?(:Ssccfg) -%> or its alias `instretcfg.SINH` <%- end -%> is set and the current privilege level is U
<%- end -%>
<%- if ext?(:H) -%>
- `minstretcfg.VSINH` <%- if ext?(:Ssccfg) -%> or its alias `instretcfg.SINH` <%- end -%> is set and the current privilege level is VS
- `minstretcfg.VUINH` <%- if ext?(:Ssccfg) -%> or its alias `instretcfg.SINH` <%- end -%> is set and the current privilege level is VU
<%- end -%>
<%- end -%>

An instruction that causes an exception, notably including MRET/SRET, does not retire and does not cause `minstret.COUNT` to increment.

Type

RW-H

Reset value

UNDEFINED_LEGAL

C.15. minstreth

Machine Instructions Retired Counter

Upper half of 64-bit instructions retired counters.

See [minstret](#) for details.

C.15.1. Attributes

CSR Address	0xb02
Defining extension	<ul style="list-style-type: none">Zicntr, version >= 0
Length	32-bit
Privilege Mode	M

C.15.2. Format

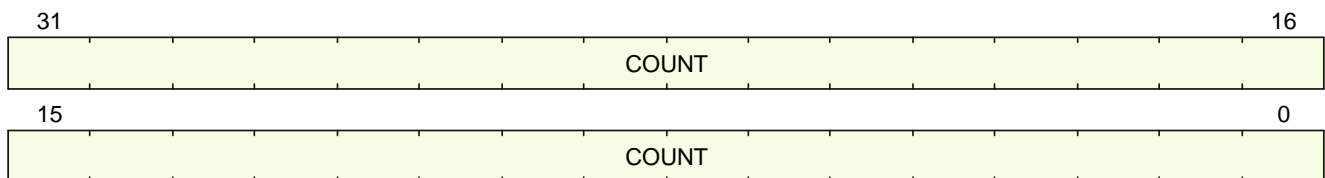


Figure 15. minstreth format

C.15.3. Field Summary

Name	Location	Type	Reset Value
COUNT	31:0	RW-H	UNDEFINED_LEGAL

C.15.4. Fields

COUNT

Location

31:0

Description

Instructions retired counter

Upper half of [minstret](#).

Type

RW-H

Reset value

UNDEFINED_LEGAL

C.15.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (*e.g.*, through [csrrw](#)), the following determines the written value:

```
COUNT = CSR[mcycle].COUNT = {csr_value.COUNT[31:0], CSR[minstret].COUNT[31:0]};  
return csr_value.COUNT;
```

C.15.6. Software read

This CSR may return a value that is different from what is stored in hardware.

```
return CSR[minstret].COUNT[63:32];
```

C.16. mip

Machine Interrupt Pending

The `mie` and `mip` CSRs are MXLEN-bit read/write registers used when the CLINT or PLIC interrupt controllers are present. Note that the CLINT refers to an interrupt controller used by some RISC-V implementations but isn't a ratified RISC-V International standard.

The `mip` CSR contains information on pending interrupts, while `mie` is the corresponding CSR containing interrupt enable bits. Interrupt cause number i (as reported in the `mcause` CSR) corresponds to bit i in both `mip` and `mie`. Bits 15:0 are allocated to standard interrupt causes only, while bits 16 and above are designated for platform use.

NOTE Interrupts designated for platform use may be designated for custom use at the platform's discretion.

An interrupt i will trap to M-mode (causing the privilege mode to change to M-mode) if all of the following are true:

- either the current privilege mode is M and the MIE bit in the `mstatus` register is set, or the current privilege mode has less privilege than M-mode;
- bit i is set in both `mip` and `mie`
- if register `mideleg` exists, bit i is not set in `mideleg`.

These conditions for an interrupt trap to occur must be evaluated in a bounded amount of time from when an interrupt becomes, or ceases to be, pending in `mip`, and must also be evaluated immediately following the execution of an `xRET` instruction or an explicit write to a CSR on which these interrupt trap conditions expressly depend (including `mip`, `mie`, `mstatus`, and `mideleg`).

Interrupts to M-mode take priority over any interrupts to lower privilege modes.

Each individual bit in register `mip` may be writable or may be read-only. When bit i in `mip` is writable, a pending interrupt i can be cleared by writing 0 to this bit. If interrupt i can become pending but bit i in `mip` is read-only, the implementation must provide some other mechanism for clearing the pending interrupt.

A bit in `mie` must be writable if the corresponding interrupt can ever become pending. Bits of `mie` that are not writable must be read-only zero.

NOTE The machine-level interrupt registers handle a few root interrupt sources which are assigned a fixed service priority for simplicity, while separate external interrupt controllers can implement a more complex prioritization scheme over a much larger set of interrupts that are then muxed into the machine-level interrupt sources.

The non-maskable interrupt is not made visible via the `mip` register as its presence is implicitly known when executing the NMI trap handler.

If supervisor mode is implemented, bits `mip.SEIP` and `mie.SEIE` are the interrupt-pending and interrupt-enable bits for supervisor-level external interrupts. SEIP is writable in `mip`, and may be written by M-mode software to indicate to S-mode that an external interrupt is pending. Additionally, the platform-level interrupt controller may generate supervisor-level external interrupts. Supervisor-level external interrupts are made pending based on the logical-OR of the software-writable SEIP bit and the signal from the external interrupt controller. When `mip` is read with a CSR instruction, the value of the SEIP bit returned in the `rd` destination register is the logical-OR of the software-writable bit and the interrupt signal from the interrupt controller, but the signal from the interrupt controller is not used to calculate the value written to SEIP. Only the software-writable SEIP bit participates in the read-modify-write sequence of a CSRRS or CSRRC instruction.

For example, if we name the software-writable SEIP bit `B` and the signal from the external interrupt controller `E`, then if `csrrs t0, mip, t1` is executed, `t0[9]` is written with `B || E`, then `B` is written with `B || t1[9]`. If `csrrw t0, mip, t1` is executed, then `t0[9]` is written with `B || E`, and `B` is simply written with `t1[9]`. In neither case does `B` depend upon `E`.

NOTE

The SEIP field behavior is designed to allow a higher privilege layer to mimic external interrupts cleanly, without losing any real external interrupts. The behavior of the CSR instructions is slightly modified from regular CSR accesses as a result.

If supervisor mode is implemented, bits `mip.STIP` and `mie.STIE` are the interrupt-pending and interrupt-enable bits for supervisor-level timer interrupts. STIP is writable in `mip`, and may be written by M-mode software to deliver timer interrupts to S-mode.

If supervisor mode is implemented, bits `mip.SSIP` and `mie.SSIE` are the interrupt-pending and interrupt-enable bits for supervisor-level software interrupts. SSIP is writable in `mip` and may also be set to 1 by a platform-specific interrupt controller.

<% if ext?(:Sscopmf) -%> bits `mip.LCOFIP` and `mie.LCOFIE` are the interrupt-pending and interrupt-enable bits for local counter-overflow interrupts. LCOFIP is read-write in `mip` and reflects the occurrence of a local counter-overflow overflow interrupt request resulting from any of the `mhpmeventn.OF` bits being set. <% end -%>

Multiple simultaneous interrupts destined for M-mode are handled in the following decreasing priority order: MEI, MSI, MTI, SEI, SSI, STI, LCOFI.

The machine-level interrupt fixed-priority ordering rules were developed with the following rationale.

Interrupts for higher privilege modes must be serviced before interrupts for lower privilege modes to support preemption.

NOTE

The platform-specific machine-level interrupt sources in bits 16 and above have platform-specific priority, but are typically chosen to have the highest service priority to support very fast local vectored interrupts.

External interrupts are handled before internal (timer/software) interrupts as

external interrupts are usually generated by devices that might require low interrupt service times.

Software interrupts are handled before internal timer interrupts, because internal timer interrupts are usually intended for time slicing, where time precision is less important, whereas software interrupts are used for inter-processor messaging. Software interrupts can be avoided when high-precision timing is required, or high-precision timer interrupts can be routed via a different interrupt path. Software interrupts are located in the lowest four bits of `mip` as these are often written by software, and this position allows the use of a single CSR instruction with a five-bit immediate.

Restricted views of the `mip` and `mie` registers appear as the `sip` and `sie` registers for supervisor level. If an interrupt is delegated to S-mode by setting a bit in the `mideleg` register, it becomes visible in the `sip` register and is maskable using the `sie` register. Otherwise, the corresponding bits in `sip` and `sie` are read-only zero.

C.16.1. Attributes

CSR Address	0x344
Defining extension	<ul style="list-style-type: none"> Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.16.2. Format

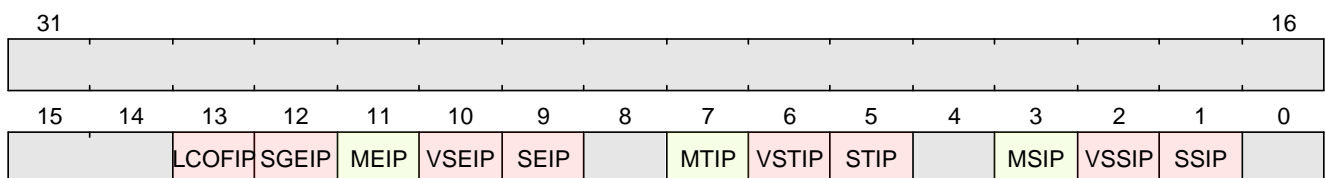


Figure 16. `mip` format

C.16.3. Field Summary

Name	Location	Type	Reset Value
SSIP	1	RW	0
VSSIP	2	RW	0
MSIP	3	RO	0
STIP	5	RW	0

Na me	Location	Type	Reset Value
VST IP	6	RO-H	0
MTI P	7	RO-H	0
SEI P	9	RW-H	0
VSE IP	10	RO-H	0
MEI P	11	RO-H	0
SGE IP	12	RO-H	0
LCO FIP	13	RW-H	0

C.16.4. Fields

SSIP

Location

1

Description

Supervisor Software Interrupt Pending

Reports the current pending state of an (H)S-mode software interrupt, which is generated by writing to this field.

<%- if ext?(:Smaia) -%>

When using AIA/IMSIC, IPIs are expected to be delivered as external interrupts and SSIP is not backed by any hardware update (aside from any aliasing effects). However, SSIP is still writable by M-mode software and, when written, can be used to generate an S-mode Software Interrupt.

<%- end -%>

<% if ext?(:Smaia) %>_Aliases_<% else %>_Alias_<% end %>:

- sip.SSIP when mideleg.SSI is set

<%- if ext?(:Smaia) -%>

- **mvip.SSIP**

<%- end -%>

Type

RW

Reset value

0

VSSIP**Location**

2

Description**Virtual Supervisor Software Interrupt Pending**

Reports the current pending state of a VS-mode software interrupt, which is generated by writing to this field.

<%- if ext?(:Smaia) -%>

When using AIA/IMSIC, IPIs are expected to be delivered as external interrupts and VSSIP is not backed by any hardware update (aside from any aliased writes).

However, VSSIP is still writable by M-mode software and, when written, can be used to generate a VS-mode Software Interrupt.

<%- end -%>

Aliases:

- [hip.VSSIP](#)
- [hvip.VSSIP](#)
- [vsip.SSIP](#) when [hideleg.VSSI](#) is set

Type

RW

Reset value

0

MSIP**Location**

3

Description**Machine Software Interrupt Pending**

Unused field.

<%- if ext?(:Smaia) -%>

With AIA/IMSIC, IPIs are delivered as external interrupts. As a result, this bit is unused and hardwired to 0.

<%- end -%>

Type

RO

Reset value

0

STIP

Location

5

Description

Supervisor Timer Interrupt Pending

Reports the current pending state of an (H)S-mode timer interrupt

<%- if ext?(:Sstc) -%>

, which is normally controlled by the `stimecmp` CSR.

<%- else -%>

, which is generated by software by writing to `mip.STIP`<% if ext?(:Smaia) %>or its alias `mvip.STIP`<% end %>.

<%- end -%>

<%-if ext?(:Sstc) -%>

When `menvcfg.STCE` is set, `mip.STIP` is RO-H, and is completely controlled by the timer interrupt device (using `stimecmp`).

When `menvcfg.STCE` is clear, `mip.STIP` is RW, and M-mode software may write the bit to inject a Supervisor Timer Interrupt.

<%- end -%>

<% if ext?(:Smaia) %>_Aliases_<% else %>_Alias_<% end %>:

- `sip.STIP` when `mideleg.STI` is set (though `sip.STIP` is a read-only view)

<%- if ext?(:Smaia) -%>

- `mvip.STIP` when `menvcfg.STCE` is clear

<%- end -%>

Type

RW

Reset value

0

Location

6

Description**Virtual Supervisor Timer Interrupt Pending**

Reports the current pending state of a VS-mode timer interrupt

<%- if ext?(:Sstc) -%>

, which is normally controlled by the `vstimecmp` CSR, but can also be injected by the hypervisor through `hvip.VSTIP`.

<%- else -%>

, which is generated by M-mode and/or HS-mode software by writing to `hvip.VSTIP`.

<%- end -%>

<%-if ext?(:Sstc) -%>

When `menvcfg.STCE` is set (enabling the Sstc extension), `mip.VSTIP` is the logical OR of `hvip.VSTIP` and the VS-level interrupt signal generated by the timer device (controlled by the value of `vstimecmp`).

When `menvcfg.STCE` is clear (disabling the Sstc extension), `mip.VSTIP` is exactly the value of `hvip.VSTIP`.

<%- end -%>

`mip.VSTIP` is never writable. If VS-mode software wants to clear the bit, it must do so

<%- if ext?(:Sstc) -%>

by writing the `vstimecmp` register or

<%- end -%>

by calling into the hypervisor (which can then clear `hvip.VSTIP`).

Aliases:

- `hip.VSTIP`
- `vsip.STIP` when `hideleg.VSTI` is set
- `hvip.VSTIP` <% if ext?(:Sstc) %>when `menvcfg.STCE` is clear<% end %> (though `hvip.VSTIP` is writable)

Type

RO-H

Reset value

0

MTIP

Location

7

Description

Machine Timer Interrupt Pending

Reports the current pending state of an M-mode timer interrupt.

Bit is controlled by the timer device (using `mtimecmp`), and is not writeable.

Type

RO-H

Reset value

0

SEIP

Location

9

Description

Supervisor External Interrupt Pending

Reports the current pending state of an (H)S-mode external interrupt.

This field has two parts: a software-writeable shadow value and a wire from the interrupt controller.

The value presented to software in the bit on a CSR read is the logical OR of the software-writeable value and the interrupt controller value.

When software writes this bit, only the shadow value is updated (the interrupt controller is not notified of the write).

<%- if ext?(:Smaia) -%>

The software-writeable shadow value is aliased in `mvip.SEIP` (Smaia extension).

<%- end -%>

Alias:

- `sip.SEIP` when `mideleg.SEI` is set (though `sip.SEIP` is read-only)

Type

RW-H

Reset value

0

VSEIP**Location**

10

Description**Virtual Supervisor External Interrupt Pending**

Reports the current pending state of a VS-mode external interrupt.

This field is the logical OR of `hvip.VSEIP` and the wire coming from the interrupt controller.

The field is not writable by software

<%- if ext?(:Smaia) -%>

(i.e., unlike the behavior of `mip.SEIP`/`mvip.SEIP`, attempted writes to `mip.VSEIP` do not propagate to `hvip.VSEIP`)

<%- end -%>

1. +

Aliases:

- `hip.VSEIP`
- `vsip.SEIP` when `hideleg.VSEI` is set

Type

RO-H

Reset value

0

MEIP**Location**

11

Description**Machine External Interrupt Pending**

Reports the current pending state of an M-mode external interrupt.

MEIP is controlled by the external interrupt controller <% if ext?(:Smaia) %>(AIA) <% end %>.

It is not writable by software.

Type

RO-H

Reset value

0

SGEIP

Location

12

Description

Supervisor Guest External Interrupt Pending

Read-only summary of any pending Supervisor Guest External Interrupt Pending, i.e.: the logical-OR reduction of the `hgeip` register.

Alias:

- `hip.SGEIP`

Type

RO-H

Reset value

0

LCOFIP

Location

13

Description

Local Counter Overflow Interrupt pending

<%- if ext?(H) -%>

When `hideleg.LCOFI` is set,

`vsip.LCOFIP`, `sip.LCOFIP`, and `mip.LCOFIP` are all aliases.

<%- end -%>

When a counter overflow interrupt occurs, a hidden sticky bit is set.

Software writes 0 to `mip.LCOFIP` to clear the pending interrupt.

```
<% if ext?(:H) %>_Aliases_<% else %>_Alias_<% end %>:
```

- sip.LCOFIP when mideleg.LCOFI is set
<%- if ext?(:H) -%>
- vsip.LCOFIP when hideleg.LCOFI is set
<%- end -%>

Type

RW-H

Reset value

0

C.17. misa

Machine ISA Control

Reports the XLEN and "major" extensions supported by the ISA.

C.17.1. Attributes

CSR Address	0x301
Defining extension	<ul style="list-style-type: none"> Sm, version ≥ 0
Length	32-bit
Privilege Mode	M

C.17.2. Format

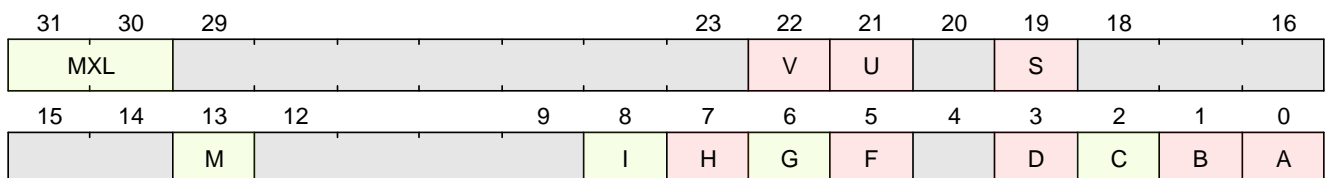


Figure 17. misa format

C.17.3. Field Summary

Name	Location	Type	Reset Value
MXL	31:30	RO	2
A	0	RW RO	1
B	1	RW RO	1
C	2	RW RO	1
D	3	RW RO	1
F	5	RW RO	1

Na me	Location	Type	Reset Value
G	6	RO-H	1
		RO	0
H	7	RW	1
		RO	
I	8	RO	1
M	13	RW	1
		RO	
S	19	RW	1
		RO	
U	21	RW	1
		RO	
V	22	RO	1

C.17.4. Fields

MXL

Location

31:30

Description

XLEN in M-mode.

Type

RO

Reset value

2

A

Location

0

Description

Indicates support for the A (atomic) extension.

[when,"MUTABLE_MISA_A == true"]

Writing 0 to this field will cause all atomic instructions to raise an `IllegalInstruction` exception.

Type

RW

RO

Reset value

1

B

Location

1

Description

Indicates support for the B (bitmanip) extension.

[when,"MUTABLE_MISA_B == true"]

Writing 0 to this field will cause all bitmanip instructions to raise an `IllegalInstruction` exception.

Type

RW

RO

Reset value

1

C

Location

2

Description

Indicates support for the C (compressed) extension.

[when,"MUTABLE_MISA_C == true"]

Writing 0 to this field will cause all compressed instructions to raise an `IllegalInstruction` exception.

Additionally, IALIGN becomes 32.

Type

RW

RO

Reset value

1

D**Location**

3

Description

Indicates support for the D (double precision float) extension.

[when,"MUTABLE_MISA_D == true"] + — + Writing 0 to this field will cause all double-precision floating point instructions to raise an **IllegalInstruction** exception.

Additionally, the upper 32-bits of the f registers will read as zero. + — +

Type

RW

RO

Reset value

1

F**Location**

5

Description

Indicates support for the F (single precision float) extension.

[when,"MUTABLE_MISA_F == true"] + — + Writing 0 to this field will cause all floating point (single and double precision) instructions to raise an **IllegalInstruction** exception.

Writing 0 to this field with misa.D set will result in UNDEFINED behavior. + — +

Type

RW

RO

Reset value

1

G

Location

6

Description

Indicates support for all of the following extensions: I, A, M, F, D.

Type

RO-H

RO

Reset value

1

0

H

Location

7

Description

Indicates support for the H (hypervisor) extension.

[when,"MUTABLE_MISA_H == true"]

Writing 0 to this field will cause all attempts to enter VS- or VU- mode, execute a hypervisor instruction, or access a hypervisor CSR to raise an **IllegalInstruction** fault.

Type

RW

RO

Reset value

1

I

Location

8

Description

Indicates support for the I (base) extension.

Type

RO

Reset value

1

M

Location

13

Description

Indicates support for the M (integer multiply/divide) extension.

[when,"MUTABLE_MISA_M == true"]

Writing 0 to this field will cause all attempts to execute an integer multiply or divide instruction to raise an `IllegalInstruction` exception.

Type

RW

RO

Reset value

1

S

Location

19

Description

Indicates support for the S (supervisor mode) extension.

[when,"MUTABLE_MISA_S == true"]

Writing 0 to this field will cause all attempts to enter S-mode or access S-mode state to

raise an exception.

Type

RW

RO

Reset value

1

U

Location

21

Description

Indicates support for the U (user mode) extension.

[when,"MUTABLE_MISA_U == true"]

Writing 0 to this field will cause all attempts to enter U-mode to raise an exception.

Type

RW

RO

Reset value

1

V

Location

22

Description

Indicates support for the V (vector) extension.

[when,"MUTABLE_MISA_V == true"]

Writing 0 to this field will cause all attempts to execute a vector instruction to raise an **IllegalInstruction** trap.

Type

RO

Reset value

1

C.17.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (e.g., through `csrrw`), the following determines the written value:

```
MXL = csr_value.MXL
A = csr_value.A
B = csr_value.B
C = csr_value.C
D = csr_value.D
F = if (csr_value.F == 0 && csr_value.D == 1) {
    return UNDEFINED_LEGAL_DETERMINISTIC;
}

# fall-through; write the intended value
return csr_value.F;

G = csr_value.G
H = csr_value.H
I = csr_value.I
M = csr_value.M
S = csr_value.S
U = csr_value.U
V = csr_value.V
```

C.17.6. Software read

This CSR may return a value that is different from what is stored in hardware.

```
return ((CSR[misa].MXL << 62) | (CSR[misa].V << 21) | (CSR[misa].U << 20) |
(CSR[misa].S << 18) | (CSR[misa].M << 12) | (CSR[misa].I << 7) | (CSR[misa].H << 6) |
((CSR[misa].A & CSR[misa].M & CSR[misa].F & CSR[misa].D) << 5) | (CSR[misa].F << 4) |
(CSR[misa].D << 3) | (CSR[misa].C << 2) | (CSR[misa].B << 1) | CSR[misa].A);
```

C.18. mscratch

Machine Scratch Register

Scratch register for software use. Bits are not interpreted by hardware.

C.18.1. Attributes

CSR Address	0x340
Defining extension	<ul style="list-style-type: none">• Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.18.2. Format

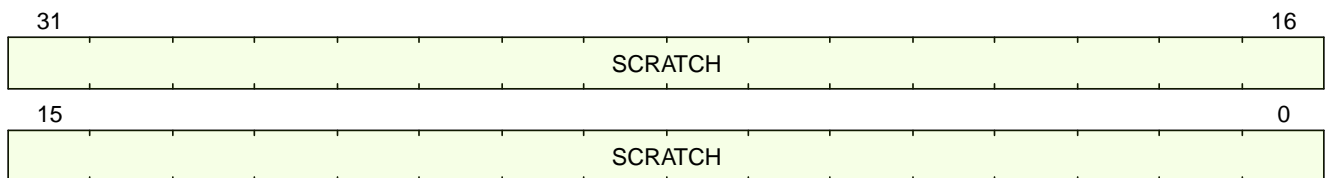


Figure 18. mscratch format

C.18.3. Field Summary

Na me	Location	Type	Reset Value
SCR ATC H	31:0	RW	0

C.18.4. Fields

SCRATCH

Location

31:0

Description

Scratch value

Type

RW

Reset value

0

Na me	Location	Type	Reset Value
MPR V	17	RW-H	0
		RO	
XS	16:15	RO	0
FS	14:13	RW-H	UNDEFINED_LEGAL
		RO	0
		RW	UNDEFINED_LEGAL
		RO	0
MPP	12:11	RW-H	UNDEFINED_LEGAL
VS	10:9	RW-H	UNDEFINED_LEGAL
SPP	8	RW-H	UNDEFINED_LEGAL
MPI E	7	RW-H	UNDEFINED_LEGAL
UBE	6	RW	0
		RO	1
			UNDEFINED_LEGAL
SPI E	5	RW-H	UNDEFINED_LEGAL
		RO	0
MIE	3	RW-H	0
SIE	1	RW-H	UNDEFINED_LEGAL
		RO	0

C.19.4. Fields

SD

Location

31

Description

State Dirty.

Read-only bit that summarizes whether either the FS, XS, or VS fields signal the presence of some dirty state.

Type

RO-H

RO-H

RO

Reset value

mstatus_sd_reset_value()

UNDEFINED_LEGAL

TSR

Location

22

Description

Trap SRET

When 1, attempts to execute the [sret](#) instruction while executing in HS/S-mode will raise an Illegal Instruction exception.

[when,"ext?(:H)"]

Does not affect the behavior of [sret](#) in VS_mode (see hstatus.VTSR).

Type

RW

Reset value

UNDEFINED_LEGAL

TW

Location

21

Description

Timeout Wait

When 1, the WFI instruction will raise an Illegal Instruction trap after an implementation-defined wait period when executed in a mode other than M-mode.

When 0, the [wfi](#) instruction is permitted to wait forever in (H)S-mode but must trap after an implementation-defined wait period in U-mode.

Type

RW

Reset value

UNDEFINED_LEGAL

TVM**Location**

20

Description

Trap Virtual Memory.

When 1, an **Illegal Instruction** trap occurs when

- writing the [satp](#) CSR, executing an [sfence.vma](#), or executing an [sinval.vma](#) while in (H)S-mode (but not VS-mode)
- writing the [hgtap](#) CSR, executing an [hfence.gvma](#), or executing an [hinval.gvma](#) while in HS-mode

Notably, `mstatus.TVM` does **not** cause

[*hfence.vvma](#), [sfence.w.inval](#), or [sfence.inval.ir](#) to trap.

- Any additional traps in VS-mode (controlled via `hstatus.VTVM` instead).

Type

RO

RW

Reset value

0

UNDEFINED_LEGAL

0

MXR**Location**

19

Description

Make eXecutable Readable.

When 1, loads from pages marked readable **or executable** are allowed.

When 0, loads from pages marked executable raise a Page Fault exception.

Type

RW

Reset value

UNDEFINED_LEGAL

SUM

Location

18

Description

permit Supervisor Memory Access.

When 0, an S-mode read or an M-mode read with `mstatus.MPRV=1` and `mstatus.MPP=01` to a 'U' (user) page will cause an ILLEGAL INSTRUCTION exception.

Type

RW

RO

Reset value

UNDEFINED_LEGAL

0

MPRV

Location

17

Description

Modify PRiVilege.

When 1, loads and stores behave as if the current virtualization mode:privilege level was `mstatus.MPV:mstatus.MPP`.

`mstatus.MPRV` is cleared on any exception return (`mret` or `sret` instruction, regardless of

the trap handler privilege mode).

Type

RW-H

RO

Reset value

0

XS

Location

16:15

Description

Custom (X) extension context Status

Summarizes the current state of any custom extension state.

Either 0 - Off, 1 - Initial, 2 - Clean, 3 - Dirty.

Since there are no custom extensions in the base spec, this field is read-only 0.

Type

RO

Reset value

0

FS

Location

14:13

Description

Floating point context status.

When 0, floating point instructions (from F and D extensions) are disabled, and cause **ILLEGAL INSTRUCTION** exceptions.

When a floating point register, or the fCSR register is written, FS obtains the value 3.

Values 1 and 2 are valid write values for software, but are not interpreted by hardware other than to possibly enable a previously-disabled floating point unit.

Type

RW-H

RO

RW

RO

Reset value

UNDEFINED_LEGAL

0

UNDEFINED_LEGAL

0

MPP

Location

12:11

Description

M-mode Previous Privilege.

Written by hardware in two cases:

- Written with the prior nominal privilege level when entering M-mode from an exception/interrupt.
- Written with 0 when executing an [mret](#) instruction to return from an exception in M-mode.

Can also be written by software without immediate side-effect.

Affects execution in two cases:

- On a return from an exception from M-mode, the machine will enter the privilege level stored in MPP before clearing the field.
- When `mstatus.MPRV` is set, loads and stores behave as if the current privilege level were MPP.

Type

RW-H

Reset value

UNDEFINED_LEGAL

VS

Location

10:9

Description

Vector context status.

When 0, vector instructions (from the V extension) are disabled, and cause `ILLEGAL INSTRUCTION` exceptions.

When a vector register or vector CSR is written, VS obtains the value 3.

Values 1 and 2 are valid write values for software, but are not interpreted by hardware other than to possibly enable a previously-disabled vector unit.

Type

RW-H

Reset value

UNDEFINED_LEGAL

SPP

Location

8

Description

S-mode Previous Privilege

Written by hardware in two cases:

- Written with the prior nominal privilege level when entering (H)S-mode from an exception/interrupt.
- Written with 0 when executing an `sret` instruction to return from an exception in (H)S-mode or (unlikely) M-mode.

Can also be written by software without immediate side-effect.

Affects execution in one case:

- On a return from an exception using the `sret` instruction in (H)S-mode or (unlikely) M-mode, the machine will enter the privilege level stored in SPP before clearing the field.

Notably, `mstatus.SPP` does not affect exception return in VS-mode (see `vsstatus.SPP`).

Type

RW-H

Reset value

UNDEFINED_LEGAL

MPIE**Location**

7

Description**M-mode Previous Interrupt Enable**

Written by hardware in two cases:

- Written with prior value of `mstatus.MIE` when entering M-mode from an exception/interrupt.
- Written with the value 1 when returning from an exception in M-mode (via the `mret` instruction).

Can also be written by software without immediate side effect.

Other than serving as a record of nested traps as described above, `mstatus.MPIE` does not affect execution.

Type

RW-H

Reset value

UNDEFINED_LEGAL

UBE**Location**

6

Description**U-mode Big Endian**

Controls the endianness of U-mode (0 = little, 1 = big).
Instructions are always little endian, regardless of the data setting.

[when, "U_MODE_ENDIANESS == 'little'"]

Since the CPU does not support big endian in U-mode, this is hardwired to 0.

```
[when,"U_MODE_ENDIANESS == 'big']
```

Since the CPU does not support little endian in U-mode, this is hardwired to 1.

Type

RW

RO

Reset value

0

1

UNDEFINED_LEGAL

SPIE

Location

5

Description

S-mode Previous Interrupt Enable

Written by hardware in two cases:

- Written with prior value of `mstatus.SIE` when entering (H)S-mode from an exception/interrupt.
- Written with the value 1 when returning from an exception via the `sret` instruction in (H)S-mode or (unlikely) M-mode.

Can also be written by software without immediate side effect.

Other than serving as a record of nested traps as described above, `mstatus.SPIE` does not affect execution.

Type

RW-H

RO

Reset value

UNDEFINED_LEGAL

MIE**Location**

3

Description**M-mode Interrupt Enable**

Written by hardware in two cases:

- Written with the value 0 when entering M-mode from an exception/interrupt.
- Written with the prior value of `mstatus.MPIE` when returning from an exception in M-mode (via [mret](#)).

Affects execution by:

- When 0, all interrupts are disabled when the current privilege level is M.
- When 1, interrupts that are not otherwise disabled with a field in [mie](#) are enabled.

Type

RW-H

Reset value

0

SIE**Location**

1

Description**S-mode Interrupt Enable**

Written by hardware in two cases:

- Written with the value 0 when entering (H)S-mode from an exception/interrupt.
- Written with the prior value of `mstatus.SPIE` when returning from an exception via [sret](#) in (H)S-mode or (unlikely) M-mode.

Affects execution by:

- When 0, all (H)S-mode interrupts are disabled when the current privilege level is (H)S (M-mode interrupts are still enabled).
- When 1, (H)S-mode interrupts that are not otherwise disabled with a field in `sie` are enabled.

Type

RW-H

RO

Reset value

UNDEFINED_LEGAL

0

C.19.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (e.g., through `csrrw`), the following determines the written value:

```
SD = csr_value.SD
TSR = csr_value.TSR
TW = csr_value.TW
TVM = if (CSR[misa].S == 1'b0) {
    return 0;
} else if (MSTATUS_TVM_IMPLEMENTED) {
    return csr_value.TVM;
} else {
    return 0;
}

MXR = csr_value.MXR
SUM = csr_value.SUM
MPRV = csr_value.MPRV
XS = csr_value.XS
FS = if (CSR[misa].F == 1'b1){
    return ary_includes?<$array_size(MSTATUS_FS_LEGAL_VALUES),
2>(MSTATUS_FS_LEGAL_VALUES, csr_value.FS) ? csr_value.FS :
UNDEFINED_LEGAL_DETERMINISTIC;
} else if ((CSR[misa].S == 1'b0) && (CSR[misa].F == 1'b0)) {
    # must be read-only-0
    return 0;
} else {
    # there will be no hardware update in this case because we know the F extension
isn't implemented
    return ary_includes?<$array_size(MSTATUS_FS_LEGAL_VALUES),
2>(MSTATUS_FS_LEGAL_VALUES, csr_value.FS) ? csr_value.FS :
```

```

UNDEFINED_LEGAL_DETERMINISTIC;
}

MPP = if (csr_value.MPP == 2'b01 && !implemented?(ExtensionName::S)) {
    return UNDEFINED_LEGAL_DETERMINISTIC;
} else if (csr_value.MPP == 2'b00 && !implemented?(ExtensionName::U)) {
    return UNDEFINED_LEGAL_DETERMINISTIC;
} else if (csr_value.MPP == 2'b10) {
    # never a valid value
    return UNDEFINED_LEGAL_DETERMINISTIC;
} else {
    return csr_value.MPP;
}

VS = if (CSR[misa].V == 1'b1){
    return ary_includes?<$array_size(MSTATUS_VS_LEGAL_VALUES),
2>(MSTATUS_VS_LEGAL_VALUES, csr_value.FS) ? csr_value.FS :
UNDEFINED_LEGAL_DETERMINISTIC;
} else if ((CSR[misa].S == 1'b0) && (CSR[misa].V == 1'b0)) {
    # must be read-only-0
    return 0;
} else {
    # there will be no hardware update in this case because we know the V extension
isn't implemented
    return ary_includes?<$array_size(MSTATUS_VS_LEGAL_VALUES),
2>(MSTATUS_VS_LEGAL_VALUES, csr_value.FS) ? csr_value.FS :
UNDEFINED_LEGAL_DETERMINISTIC;
}

SPP = if (csr_value.SPP == 2'b10) {
    return UNDEFINED_LEGAL_DETERMINISTIC;
} else {
    return csr_value.SPP;
}

MPIE = csr_value.MPIE
UBE = csr_value.UBE
SPIE = csr_value.SPIE
MIE = csr_value.MIE
SIE = csr_value.SIE

```


C.20. mtval

Machine Trap Value

Holds trap-specific information

C.20.1. Attributes

CSR Address	0x343
Defining extension	<ul style="list-style-type: none">Sm, version ≥ 0
Length	32-bit
Privilege Mode	M

C.20.2. Format

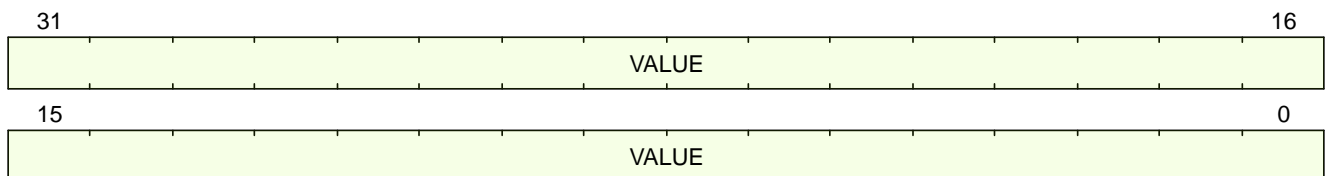


Figure 20. mtval format

C.20.3. Field Summary

Name	Location	Type	Reset Value
VALUE	31:0	RW-H	0

C.20.4. Fields

VALUE

Location

31:0

Description

Written with trap-specific information when a trap is taken into M-mode.

The values are:

[separator="!"]

!===

! Exception type ! Value

! [0] Instruction address misaligned ! The misaligned virtual PC (same as the value written to [mepc](#)).

! [1] Instruction access fault ! The <% if ext?(:C) %> portion of the <% end %> virtual PC causing the access fault <%- unless ext?(:C) -%>(same as the value written to [mepc](#))<%- end -%>.

! [2] Illegal Instruction ! The encoding of the illegal instruction.

! [3] Breakpoint

! [when,"REPORT_VA_IN_MTVAl_ON_BREAKPOINT == true"]

When caused by an EBREAK instruction, the virtual PC of the breakpoint instruction.

[when,"REPORT_VA_IN_MTVAl_ON_BREAKPOINT == false"]

When caused by an EBREAK instruction, zero.

When caused by a data address (*i.e.*, watchpoint) breakpoint, the faulting virtual address.

When caused by an instruction address breakpoint, the faulting virtual PC.

! [4] Load address misaligned ! The misaligned virtual load address.

! [5] Load access fault

! The part of virtual load address causing in the access fault.

When the load is misaligned, the reported value is the smallest address on the page causing a fault

(*e.g.*, if an 8-byte load is equally split across a page and the fault occurs on the second page, address + 4 is reported).

(Even though the access fault arises on a physical address, the virtual address is reported)

! [6] Store/AMO address misaligned ! The misaligned virtual store/AMO address.

! [7] Store/AMO access fault

! The virtual store/AMO address causing the access fault.

When the store/AMO is misaligned, the reported value is the smallest address on the page causing a fault

(*e.g.*, if an 8-byte store is equally split across a page and the fault occurs on the second page, address + 4 is reported).

(Even though the access fault arises on a physical address, the virtual address is reported)

! [8] Environment call from U-mode <% if ext?(:H) %>or VU-mode<% end %> ! Zero

! [9] Environment call from (H)S-mode ! Zero

<%- if ext?(:H) -%>

! [10] Environment call from VS-mode ! Zero

<%- end -%>

! [11] Environment call from M-mode ! Zero

! [12] Instruction page fault

! The <% if ext?(:C) %> portion of the <% end %> virtual PC causing the page fault

<% unless ext?(:C) %>(same as the value written to [mepc](#))<% end %>.

! [13] Load page fault

! The part of the virtual load address causing in the page fault.

When the load is misaligned, the reported value is the smallest address on the page causing a fault

(e.g., if an 8-byte load is equally split across a page and the fault occurs on the second page, address + 4 is reported).

! [15] Store/AMO page fault

! The virtual store/AMO address causing in the page fault.

When the store/AMO is misaligned, the reported value is the smallest address on the page causing a fault

(e.g., if an 8-byte store is equally split across a page and the fault occurs on the second page, address + 4 is reported).

<%- if ext?(:H) -%>

! [20] Instruction guest-page fault

! The <% if ext?(:C) %> portion of the <% end %> virtual PC causing the fault <% unless ext?(:C) %>(same as the value written to [mepc](#))<% end %>.

The guest physical address is reported in [mtval2](#).

! [21] Load guest-page fault

! The part of the virtual address causing the fault.

When the load is misaligned, the reported value is the smallest address on the page causing a fault

(e.g., if an 8-byte load is equally split across a page and the fault occurs on the second page, address + 4 is reported).

The guest physical address is reported in [mtval2](#).

! [22] Virtual instruction

! The encoding of the faulting virtual instruction.

! [23] Store/AMO guest-page fault

! The part of the virtual address causing the fault.

When the store/AMO is misaligned, the reported value is the smallest address on the page causing a fault

(e.g., if an 8-byte store is equally split across a page and the fault occurs on the second page, address + 4 is reported).

The guest physical address is reported in [mtval2](#).

<%- end -%>

!===

Type

RW-H

Reset value

0

C.21. mtvec

Machine Trap Vector Control

Controls where traps jump.

C.21.1. Attributes

CSR Address	0x305
Defining extension	<ul style="list-style-type: none">Sm, version ≥ 0
Length	32-bit
Privilege Mode	M

C.21.2. Format

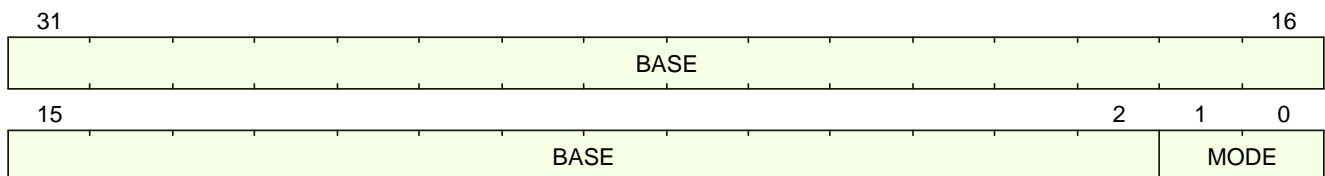


Figure 21. mtvec format

C.21.3. Field Summary

Name	Location	Type	Reset Value
BAS E	31:2	RW-R	0
MOD E	1:0	RW-R	UNDEFINED_LEGAL

C.21.4. Fields

BASE

Location

31:2

Description

Bits [MXLEN-1:2] of the exception vector physical address for any trap taken in M-mode.

The implementation physical memory map may restrict which values are legal in this field.

Type

RW-R

Reset value

0

MODE**Location**

1:0

Description

Vectored mode for asynchronous interrupts.

0 - Direct, 1 - Vectored

When Direct, all synchronous exceptions and asynchronous interrupts jump to $(\text{mtvec.BASE} \ll 2)$.

When Vectored, asynchronous interrupts jump to $(\text{mtvec.BASE} \ll 2 + \text{mcause} * 4)$ while synchronous exceptions continue to jump to $(\text{mtvec.BASE} \ll 2)$.

Type

RW-R

Reset value

UNDEFINED_LEGAL

C.21.5. Software write

This CSR may store a value that is different from what software attempts to write.

When a software write occurs (e.g., through `csrrw`), the following determines the written value:

```

BASE = # Base spec says that BASE must be 4-byte aligned, which will always be the
case
# implementations may put further constraints on BASE when MODE != Direct
# If that is the case, stvec should have an override for the implementation
return csr_value.BASE;

MODE = if (csr_value.MODE == 0) {
  if (ary_includes?<$array_size(MTVEC_MODES), 2>(MTVEC_MODES, 0)) {
    return csr_value.MODE;
  } else {
    return UNDEFINED_LEGAL_DETERMINISTIC;
  }
}

```

```
} else if (csr_value.MODE == 1) {
  if (ary_includes?<$array_size(MTVEC_MODES), 2>(MTVEC_MODES, 1)) {
    return csr_value.MODE;
  } else {
    return UNDEFINED_LEGAL_DETERMINISTIC;
  }
} else {
  return UNDEFINED_LEGAL_DETERMINISTIC;
}
```

C.22. mvendorid

Machine Vendor ID

Reports the JEDEC manufacturer ID of the core.

C.22.1. Attributes

CSR Address	0xf11
Defining extension	<ul style="list-style-type: none">Sm, version >= 0
Length	32-bit
Privilege Mode	M

C.22.2. Format

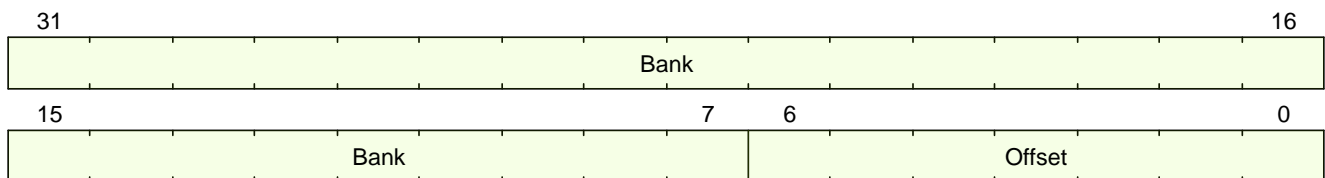


Figure 22. mvendorid format

C.22.3. Field Summary

Name	Location	Type	Reset Value
Bank	31:7	RO	VENDOR_ID_BANK
Offset	6:0	RO	VENDOR_ID_OFFSET

C.22.4. Fields

Bank

Location

31:7

Description

JEDEC manufacturer ID bank minus 1

Type

RO

Reset value

VENDOR_ID_BANK

Offset**Location**

6:0

Description

JEDEC manufacturer ID offset

Type

RO

Reset value

VENDOR_ID_OFFSET

C.23. time

Timer for RDTIME Instruction

This CSR does not exist, and access will cause an IllegalInstruction exception.

Shadow of the memory-mapped M-mode CSR `mtime`.

Privilege mode access is controlled with `mcounteren.TM`, `scounteren.TM`, and `hcounteren.TM` as follows:

mcounteren.TM	scounteren.TM	scouteren.TM	time behavior			
			S-mode	U-mode	VS-mode	VU-mode
0	-	-	Illegal Instruction	Illegal Instruction	Illegal Instruction	Illegal Instruction
1	0	0	read-only	Illegal Instruction	Illegal Instruction	Illegal Instruction
1	1	0	read-only	read-only	Illegal Instruction	Illegal Instruction
1	0	1	read-only	Illegal Instruction	read-only	Illegal Instruction
1	1	1	read-only	read-only	read-only	read-only

C.23.1. Attributes

CSR Address	0xc01
Defining extension	<ul style="list-style-type: none"> Zicntr, version ≥ 0
Length	64-bit
Privilege Mode	U

C.23.2. Format

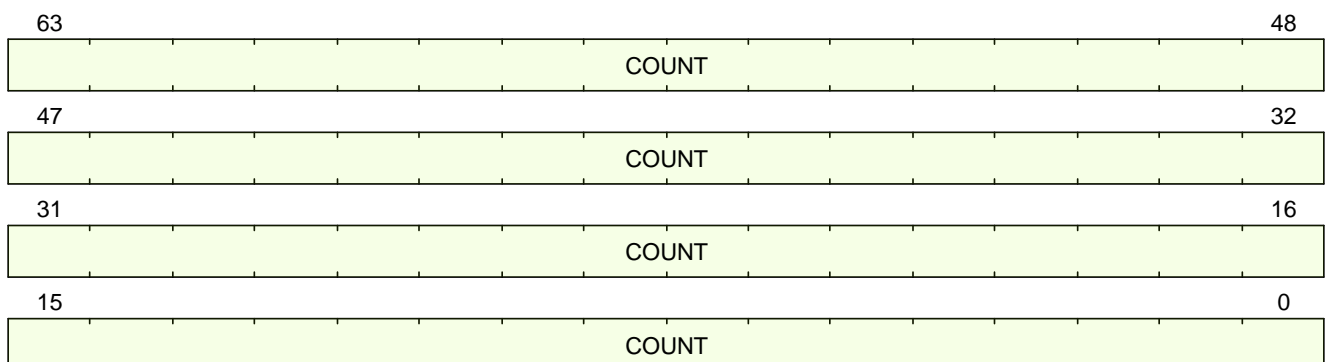


Figure 23. time format

C.23.3. Field Summary

Name	Location	Type	Reset Value
COUNT	63:0	RO-H	UNDEFINED_LEGAL

C.23.4. Fields

COUNT

Location

63:0

Description

Reports the current wall-clock time from the timer device.

Alias of the `mtime` memory-mapped CSR.

Type

RO-H

Reset value

UNDEFINED_LEGAL

C.23.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```
if (!TIME_CSR_IMPLEMENTED) {
    unimplemented_csr($encoding);
}
if (mode() == PrivilegeMode::S) {
    if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
} else if (mode() == PrivilegeMode::U) {
    if (CSR[misa].S == 1'b1) {
        if ((CSR[mcounteren].TM & CSR[scounteren].TM) == 1'b0) {
            raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
        }
    } else if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
} else if (mode() == PrivilegeMode::VS) {
    if (CSR[hcounteren].TM == 1'b0 && CSR[mcounteren] == 1'b1) {
        raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
    }
}
```

```
} else if (CSR[mcounteren].TM == 1'b0) {
    raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
} else if (mode() == PrivilegeMode::VU) {
    if (CSR[hcounteren].TM & CSR[scounteren].TM) == 1'b0) && (CSR[mcounteren].IR ==
1'b1) {
        raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
    } else if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
}
}
return read_mtime();
```

C.24. timeh

High-half timer for RDTIME Instruction

This CSR does not exist, and access will cause an IllegalInstruction exception.

Shadow of the memory-mapped M-mode CSR `mtimeh`.

Privilege mode access is controlled with `mcounteren.TM`, `scounteren.TM`, and `hcounteren.TM` as follows:

mcountere n.TM	scountere n.TM	scountere n.TM	time behavior			
			S-mode	U-mode	VS-mode	VU-mode
0	-	-	Illegal Instruction	Illegal Instruction	Illegal Instruction	Illegal Instruction
1	0	0	read-only	Illegal Instruction	Illegal Instruction	Illegal Instruction
1	1	0	read-only	read-only	Illegal Instruction	Illegal Instruction
1	0	1	read-only	Illegal Instruction	read-only	Illegal Instruction
1	1	1	read-only	read-only	read-only	read-only

C.24.1. Attributes

CSR Address	0xc81
Defining extension	<ul style="list-style-type: none"> Zicntr, version ≥ 0
Length	32-bit
Privilege Mode	U

C.24.2. Format

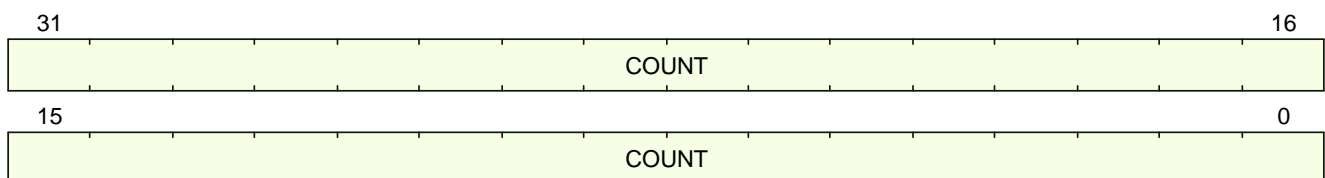


Figure 24. `timeh` format

C.24.3. Field Summary

Name	Location	Type	Reset Value
COUNT	31:0	RO-H	UNDEFINED_LEGAL

C.24.4. Fields

COUNT

Location

31:0

Description

Reports the most significant 32 bits of the current wall-clock time from the timer device.

Type

RO-H

Reset value

UNDEFINED_LEGAL

C.24.5. Software read

This CSR may return a value that is different from what is stored in hardware.

```
if (!TIME_CSR_IMPLEMENTED) {
    unimplemented_csr($encoding);
}
if (mode() == PrivilegeMode::S) {
    if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
} else if (mode() == PrivilegeMode::U) {
    if (CSR[misa].S == 1'b1) {
        if ((CSR[mcounteren].TM & CSR[scounteren].TM) == 1'b0) {
            raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
        }
    } else if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
} else if (mode() == PrivilegeMode::VS) {
    if (CSR[hcounteren].TM == 1'b0 && CSR[mcounteren] == 1'b1) {
        raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
    } else if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
} else if (mode() == PrivilegeMode::VU) {
    if (CSR[hcounteren].TM & CSR[scounteren].TM == 1'b0 && (CSR[mcounteren].IR ==
1'b1) {
        raise(ExceptionCode::VirtualInstruction, mode(), $encoding);
    } else if (CSR[mcounteren].TM == 1'b0) {
        raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
    }
}
```

```
}  
return read_mtime()[63:32];
```