# 计算机组成原理实验报告（Verilog 流水线 plus）

## 一， 设计通路设计

### （1） PC

| 信号名 | 方向 | 描述 |
|---|---|---|
| clk | I | 处理器时钟信号 |
| reset | I | 复位信号 |
| next_PC [31:0] | I | 下一个 PC 的值 |
| PC [31:0] | O | 输出当前指令的地址 |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|
| 1 | 取出指令地址 | 取出将要执行的指令地址 |

### （2） PC_calculator

| 信号名 | 方向 | 描述 |
|---|---|---|
| PC [31:0] | I | 当前 PC 值 |
| PCOp [1:0] | I | 下条 PC 输出控制信号 |
| equal | I | 寄存器值是否相等 |
| instr_index [25:0] | I | 指令的后 26 位 |
| rs [31:0] | I | 寄存器储存的值 |
| imm [31:0] | I | 扩展后的立即数 |
| PC_plus_four [31:0] | O | PC+4 |
| next_PC [31:0] | O | 下条 PC 的值 |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|
| 1 | 计算下一条 PC | 计算下一条指令的地址 |

### （3） im

| 信号名 | 方向 | 描述 |
|---|---|---|
| addr [9:0] | I | 当下 PC 的值 |
| Instr [31:0] | O | 取出的 32 位指令 |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|
| 1 | 取出指令 | 取出将要执行的指令 |

（4） grf

| 信号名 | 方向 | 描述 |
| --- | --- | --- |
| clk | I | 处理器时钟信号 |
| reset | I | 清零信号 |
| RA1[4:0] | I | 读寄存器时第一个寄存器的编号（地址） |
| RA2[4:0] | I | 读寄存器时第二个寄存器的编号（地址） |
| WD[31:0] | I | 寄存器写入数据 |
| WA[4:0] | I | 写寄存器时的编号（地址） |
| RegWrite | I | 寄存器写使能信号 |
| WPC | I | 当前 PC 的值 |
| RD1[31:0] | O | 读寄存器时第一个寄存器的输出数据 |
| RD2[31:0] | O | 读寄存器时第二个寄存器的输出数据 |

| 序号 | 功能名称 | 功能描述 |
| --- | --- | --- |

| | | |
|---|---|---|
| 1 | 读寄存器 | RD1 输出 RA1 所寻址的寄存器中的数据<br>RD2 输出 RA2 所寻址的寄存器中的数据 |
| 2 | 写寄存器 | 当时钟上升沿到来且 RegWrite 信号有效时，<br>WD 被写入 WA 所寻址的寄存器 |

（5） alu

| 信号名 | 方向 | 描述 |
|---|---|---|
| A[31:0] | I | 参与 ALU 计算的第一个值 |
| B[31:0] | I | 参与 ALU 计算的第二个值 |
| ALUOp[2:0] | I | ALU 功能的选择信号：<br>000：ALU 进行加法运算<br>001：ALU 进行减法运算<br>010：ALU 进行或运算<br>011：ALU 进行与运算<br>100：ALU 进行逻辑移位<br>101：ALU 进行算术移位 |
| C[31:0] | O | ALU 的计算结果 |
| Equal | O | 判断两数是否相等：<br>0：A!=B<br>1：A=B |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|
| 1 | 无符号加运算 | Result = A + B |
| 2 | 无符号减运算 | Result = A - B |
| 3 | 或运算 | Result = A \| B |
| 4 | 与运算 | Result = A & B |
| 5 | 算术移位 | Result=A>>B; |
| 6 | 逻辑移位 | Result=$signed(A)>>>B |
| 7 | 判断是否相等 | If(A == B)　Equal=1 |

（6） dm

| 信号名 | 方向 | 描述 |
|---|---|---|
| clk | I | 控制器时钟信号 |
| reset | I | 存储器复位 |
| MemWrite | I | 写使能信号 |
| Addr [9:0] | I | 读或写时对应存储器时地址 |
| WD[31:0] | I | 写存储器时写入数据 |
| PC[31:0] | I | 存储器写使能信号 |
| RD[31:0] | O | 读存储器时的输出 |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|

| | | |
|---|---|---|
| 1 | 读存储器 | RD 输出存储器中地址 Addr 存储的数据 |
| 2 | 写存储器 | 当时钟上升沿到来并且 MemWrite 有效时，WD 被写入存储器中地址 Addr 的位置 |

（7） mux32_4

| 信号名 | 方向 | 描述 |
|---|---|---|
| In0 [31:0] | I | 第一个输入 |
| In1 [31:0] | I | 第二个输入 |
| In2 [31:0] | I | 第三个输入 |
| In3 [31:0] | I | 第四个输入 |
| Select [1:0] | I | 选择信号 |
| Out[31:0] | O | 输出结果 |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|
| 1 | 选择输出 | Select=0：输出 In0<br>Select=1：输出 In1<br>Select=2：输出 In2<br>Select=3：输出 In3 |

（8） mux 5_4

| 信号名 | 方向 | 描述 |
|---|---|---|
| In0 [4:0] | I | 第一个输入 |
| In1 [4:0] | I | 第二个输入 |
| In2 [4:0] | I | 第三个输入 |
| In3 [4:0] | I | 第四个输入 |
| Select [1:0] | I | 选择信号 |
| Out[4:0] | O | 输出结果 |

| 序号 | 功能名称 | 功能描述 |
|---|---|---|
| 1 | 选择输出 | Select=0：输出 In0<br>Select=1：输出 In1<br>Select=2：输出 In2<br>Select=3：输出 In3 |

（9） mux 32_2

| 信号名 | 方向 | 描述 |
| --- | --- | --- |
| In0 [31:0] | I | 第一个输入 |
| In1 [31:0] | I | 第二个输入 |
| Select | I | 选择信号 |
| Out[31:0] | O | 输出结果 |

| 序号 | 功能名称 | 功能描述 |
| --- | --- | --- |
| 1 | 选择输出 | Select=0：输出 In0<br>Select=1：输出 In1 |

（10） ext

| 信号名 | 方向 | 描述 |
| --- | --- | --- |
| imm[15:0] | I | 需要被扩展的 16 位立即数 |
| EOp[1:0] | I | 扩展方式选择信号：<br>00：符号扩展到 32 位<br>01：高位 0 扩展到 32 位<br>10：将立即数加载到高位，低位补 0<br>11：符号扩展之后左移两位 |
| ext_imm | O | 相应扩展后的立即数 |

| 序号 | 功能名称 | 功能描述 |
| --- | --- | --- |
| 1 | 符号扩展 | 将 imm 进行符号扩展到 32 位 |
| 2 | 零扩展 | 将 imm 进行高位补 0 扩展到 32 位 |
| 3 | 加载到高位 | 将 imm 加载到高位，低位补 0 |
| 4 | 符号扩展之后左移 2 位 | 将 imm 进行符号扩展之后左移 2 位 |

（11） D 级流水寄存器

| 信号名 | 方向 | 描述 |
| --- | --- | --- |
| clk | I | 时钟信号 |
| reset | I | 复位信号 |
| Stall | I | 暂停控制信号 |
| IR_F[31:0] | I | 来自 F 级的指令 |

| | | |
|---|---|---|
| PC4_F[31:0] | I | 来自 F 级的 PC+4 |
| IR_D[31:0] | O | D 级指令 |
| PC4_D[31:0] | O | D 级 PC +4 |

（12） E 级流水寄存器

| 信号名 | 方向 | 描述 |
|---|---|---|
| clk | I | 时钟信号 |
| reset | I | 复位信号 |
| Stall | I | 暂停控制信号 |
| IR_D[31:0] | I | 来自 D 级的指令 |
| PC4_D[31:0] | I | 来自 D 级的 PC+4 |
| RD1_D[31:0] | I | 来自 D 级的寄存器第一个输出值 |
| RD2_D[31:0] | I | 来自 D 级的寄存器第二个输出值 |
| Imm_D[31:0] | I | 来自 D 级的扩展后的立即数 |
| RegDst_D[1:0] | I | 来自 D 级的寄存器 WA 选择控制信号 |
| ALUOp_D[2:0] | I | 来自 D 级的 alu 控制信号 |
| MemWrite_D | I | 来自 D 级的存储器写使能信号 |
| RegWrite_D | I | 来自 D 级的寄存器写使能信号 |
| ALUSrc_D | I | 来自 D 级的 alu B 端选择控制信号 |
| MemtoReg_D[1:0] | I | 来自 D 级的寄存器 WD 选择控制信号 |
| IR_E[31:0] | O | 来自 E 级的指令 |
| PC4_E[31:0] | O | 来自 E 级的 PC+4 |
| RD1_E[31:0] | O | 来自 E 级的寄存器第一个输出值 |
| RD2_E[31:0] | O | 来自 E 级的寄存器第二个输出值 |
| Imm_E[31:0] | O | 来自 E 级的扩展后的立即数 |
| RegDst_E[1:0] | O | 来自 E 级的寄存器 WA 选择控制信号 |
| ALUOp_E[2:0] | O | 来自 E 级的 alu 控制信号 |
| MemWrite_E | O | 来自 E 级的存储器写使能信号 |
| RegWrite_E | O | 来自 E 级的寄存器写使能信号 |
| ALUSrc_E | O | 来自 E 级的 alu B 端选择控制信号 |
| MemtoReg_E[1:0] | O | 来自 E 级的寄存器 WD 选择控制信号 |

(13) M 级流水寄存器

| 信号名 | 方向 | 描述 |
|---|---|---|
| clk | I | 时钟信号 |
| reset | I | 复位信号 |
| IR_E[31:0] | I | 来自 E 级的指令 |
| PC4_E[31:0] | I | 来自 E 级的 PC+4 |
| RT_E[31:0] | I | 来自 E 级的寄存器第二个输出值或者转发值 |
| ALUOut_E[31:0] | I | 来自 E 级的 ALU 结果 |
| Imm_E[31:0] | I | 来自 E 级的扩展后的立即数 |
| WA_E[4:0] | I | 来自 E 级的寄存器写入地址 |

| | | |
|---|---|---|
| MemWrite_E | I | 来自 E 级的存储器写使能信号 |
| RegWrite_E | I | 来自 E 级的寄存器写使能信号 |
| MemtoReg_E[1:0] | I | 来自 E 级的寄存器 WD 选择控制信号 |
| IR_M[31:0] | O | 来自 M 级的指令 |
| PC4_M[31:0] | O | 来自 M 级的 PC+4 |
| RT_M[31:0] | O | 来自 M 级的寄存器第二个输出值或者转发值 |
| ALUOut_M[31:0] | O | 来自 M 级的 ALU 结果 |
| Imm_M[31:0] | O | 来自 M 级的扩展后的立即数 |
| WA_M[4:0] | O | 来自 M 级的寄存器写入地址 |
| MemWrite_M | O | 来自 M 级的存储器写使能信号 |
| RegWrite_M | O | 来自 M 级的寄存器写使能信号 |
| MemtoReg_M[1:0] | O | 来自 M 级的寄存器 WD 选择控制信号 |

(14) W 级流水寄存器

| 信号名 | 方向 | 描述 |
|---|---|---|
| clk | I | 时钟信号 |
| reset | I | 复位信号 |
| IR_E[31:0] | I | 来自 E 级的指令 |
| PC4_E[31:0] | I | 来自 E 级的 PC+4 |
| RT_E[31:0] | I | 来自 E 级的寄存器第二个输出值或者转发值 |
| ALUOut_E[31:0] | I | 来自 E 级的 ALU 结果 |
| Imm_E[31:0] | I | 来自 E 级的扩展后的立即数 |
| WA_E[4:0] | I | 来自 E 级的寄存器写入地址 |
| MemWrite_E | I | 来自 E 级的存储器写使能信号 |
| RegWrite_E | I | 来自 E 级的寄存器写使能信号 |
| MemtoReg_E[1:0] | I | 来自 E 级的寄存器 WD 选择控制信号 |
| IR_M[31:0] | O | 来自 M 级的指令 |
| PC4_M[31:0] | O | 来自 M 级的 PC+4 |
| RT_M[31:0] | O | 来自 M 级的寄存器第二个输出值或者转发值 |
| ALUOut_M[31:0] | O | 来自 M 级的 ALU 结果 |
| Imm_M[31:0] | O | 来自 M 级的扩展后的立即数 |
| WA_M[4:0] | O | 来自 M 级的寄存器写入地址 |
| MemWrite_M | O | 来自 M 级的存储器写使能信号 |
| RegWrite_M | O | 来自 M 级的寄存器写使能信号 |
| MemtoReg_M[1:0] | O | 来自 M 级的寄存器 WD 选择控制信号 |

## 二， 控制器设计

**详细见 excel**

## 三， 测试程序与结果

观察方法：
1，通过观察转发信号（五个 Forward）
2，grf 与 dm 的 display

暂停测试代码：

```
addu $1,$2,$3   #Stall
beq $1,$4,label1
nop
label1:
nop
nop
nop
addu $1,$2,$3   #Stall
beq $4,$1,label2
nop
label2:
nop
nop
nop
ori $1,$2,100   #Stall
beq $3,$1,label3
nop
label3:
nop
nop
nop
ori $1,$2,100   #Stall
beq $1,$3,label4
nop
label4:
nop
nop
nop
######################
lw $1,($0)   #Stall
```

```
beq $1,$2,label9
nop
label9:
nop
nop
nop
lw $1,($0)   #Stall
beq $2,$1,label10
nop
label10:
nop
nop
nop
lw $1,($0)   #Stall
addu $2,$1,$3
nop
nop
nop
lw $1,($0)   #Stall
subu $2,$3,$1
nop
nop
nop
lw $1,($0)   #Stall
lw $2,($1)
nop
nop
nop
lw $1,($0)   #Stall
sw $2,($1)
nop
nop
nop
lw $1,($0)   #Stall
sw $1,($2)
nop
nop
nop
lw $1,($0)   #Stall
nop
beq $1,$2,label11
nop
label11:
nop
```

```
nop
nop
lw $1,($0)   #Stall
nop
beq $2,$1,label12
nop
label12:
nop
nop
nop
```

测试结果：
（注意这里输出只是参考，更重要的是查看波形，Stall=1 的峰数是否与注释个数一致）

```
9@00003000: $ 1 <= 00000000
23@00003018: $ 1 <= 00000000
37@00003030: $ 1 <= 00000064
51@00003048: $ 1 <= 00000064
65@00003060: $ 1 <= 00000000
81@00003078: $ 1 <= 00000000
97@00003090: $ 1 <= 00000000
101@00003094: $ 2 <= 00000000
109@000030a4: $ 1 <= 00000000
113@000030a8: $ 2 <= 00000000
121@000030b8: $ 1 <= 00000000
125@000030bc: $ 2 <= 00000000
133@000030cc: $ 1 <= 00000000
135@000030d0: *00000000 <= 00000000
145@000030e0: $ 1 <= 00000000
147@000030e4: *00000000 <= 00000000
157@000030f4: $ 1 <= 00000000
173@00003110: $ 1 <= 00000000
```

RS_D 测试代码：

```
lui $1,100   #5
beq $1,$2,label1
nop
label1:
nop
nop
nop
jal label2   #3
label2:
beq $31,$1,label3
```

```
nop
label3:
nop
nop
nop
addu $1,$2,$3   #1
nop
beq $1,$2,label4
nop
label4:
nop
nop
nop
ori $1,$2,100   #1
nop
beq $1,$2,label5
nop
label5:
nop
nop
nop
lui $1,100   #4
nop
beq $1,$2,label6
nop
label6:
nop
nop
nop
jal label7   #2
label7:
nop
beq $31,$1,label8
nop
label8:
nop
nop
nop
lw $1,($0)   #1
nop
beq $1,$2,label9
nop
label9:
nop
```

```
nop
nop
```

测试结果：

```
9@00003000: $ 1 <= 00640000
21@00003018: $31 <= 00003020
35@00003030: $ 1 <= 00000000
49@0000304c: $ 1 <= 00000064
63@00003068: $ 1 <= 00640000
77@00003084: $31 <= 0000308c
93@000030a0: $ 1 <= 00000000
```

RS_E 测试代码：

```
addu $1,$2,$3  #RS_E
subu $5,$1,$4
nop
nop
nop
addu $1,$2,$3  #RS_E
ori $4,$1,7
nop
nop
nop
addu $1,$2,$3  #RS_E
lw $4,($1)
nop
nop
nop
addu $1,$2,$3  #RS_E
sw $4,($1)
nop
nop
nop
ori $1,$2,100  #RS_E
subu $5,$1,$4
nop
nop
nop
ori $1,$2,100  #RS_E
ori $4,$1,7
nop
nop
nop
ori $1,$2,100  #RS_E
```

```
lw $4,($1)
nop
nop
nop
ori $1,$2,100  #RS_E
sw $4,($1)
nop
nop
nop
jal label      #RS_E
subu $5,$31,$4
nop
nop
nop
jal label      #RS_E
ori $4,$31,7
nop
nop
nop
jal label      #RS_E
lw $4,($31)
nop
nop
nop
jal label      #RS_E
sw $4,($31)
nop
nop
nop
lui $1,100     #RS_E
subu $5,$1,$4
nop
nop
nop
lui $1,100     #RS_E
ori $4,$1,7
nop
nop
nop
lui $1,100     #RS_E
lw $4,($1)
nop
nop
nop
```

```
lui $1,100    #RS_E
sw $4,($1)
nop
nop
nop
addu $1,$2,$3  #RS_E
nop
subu $5,$1,$4
nop
nop
nop
addu $1,$2,$3  #RS_E
nop
ori $4,$1,7
nop
nop
nop
addu $1,$2,$3  #RS_E
nop
lw $4,($1)
nop
nop
nop
addu $1,$2,$3  #RS_E
nop
sw $4,($1)
nop
nop
nop
ori $1,$2,100  #RS_E
nop
subu $5,$1,$4
nop
nop
nop
ori $1,$2,100  #RS_E
nop
ori $4,$1,7
nop
nop
nop
ori $1,$2,100  #RS_E
nop
lw $4,($1)
```

```
nop
nop
nop
ori $1,$2,100  #RS_E
nop
sw $4,($1)
nop
nop
nop
jal label      #RS_E
nop
subu $5,$31,$4
nop
nop
nop
jal label      #RS_E
nop
ori $4,$31,7
nop
nop
nop
jal label      #RS_E
nop
lw $4,($31)
nop
nop
nop
jal label      #RS_E
nop
sw $4,($31)
nop
nop
nop
lui $1,100     #RS_E
nop
subu $5,$1,$4
nop
nop
nop
lui $1,100     #RS_E
nop
ori $4,$1,7
nop
nop
```

```
nop
lui $1,100     #RS_E
nop
lw $4,($1)
nop
nop
nop
lui $1,100     #RS_E
nop
sw $4,($1)
nop
nop
nop
nop
nop
nop
nop
nop
nop
nop
label:
jr $31
```

测试结果：

```
9@00003000: $ 1 <= 00000000
11@00003004: $ 5 <= 00000000
19@00003014: $ 1 <= 00000000
21@00003018: $ 4 <= 00000007
29@00003028: $ 1 <= 00000000
31@0000302c: $ 4 <= 00000000
39@0000303c: $ 1 <= 00000000
39@00003040: *00000000 <= 00000000
49@00003050: $ 1 <= 00000064
51@00003054: $ 5 <= 00000064
59@00003064: $ 1 <= 00000064
61@00003068: $ 4 <= 00000067
69@00003078: $ 1 <= 00000064
71@0000307c: $ 4 <= 00000000
79@0000308c: $ 1 <= 00000064
79@00003090: *00000064 <= 00000000
89@000030a0: $31 <= 000030a8
91@000030a4: $ 5 <= 000030a8
105@000030b4: $31 <= 000030bc
107@000030b8: $ 4 <= 000030bf
121@000030c8: $31 <= 000030d0
```

123@000030cc: $ 4 <= 00000000
139@000030dc: $31 <= 000030e4
139@000030e0: *000030e4 <= 00000000
155@000030f0: $ 1 <= 00640000
157@000030f4: $ 5 <= 00640000
165@00003104: $ 1 <= 00640000
167@00003108: $ 4 <= 00640007
175@00003118: $ 1 <= 00640000
177@0000311c: $ 4 <= 00000000
185@0000312c: $ 1 <= 00640000
185@00003130: *00000000 <= 00000000
195@00003140: $ 1 <= 00000000
199@00003148: $ 5 <= 00000000
207@00003158: $ 1 <= 00000000
211@00003160: $ 4 <= 00000007
219@00003170: $ 1 <= 00000000
223@00003178: $ 4 <= 00000000
231@00003188: $ 1 <= 00000000
233@00003190: *00000000 <= 00000000
243@000031a0: $ 1 <= 00000064
247@000031a8: $ 5 <= 00000064
255@000031b8: $ 1 <= 00000064
259@000031c0: $ 4 <= 00000067
267@000031d0: $ 1 <= 00000064
271@000031d8: $ 4 <= 00000000
279@000031e8: $ 1 <= 00000064
281@000031f0: *00000064 <= 00000000
291@00003200: $31 <= 00003208
299@00003208: $ 5 <= 00003208
309@00003218: $31 <= 00003220
317@00003220: $ 4 <= 00003227
327@00003230: $31 <= 00003238
335@00003238: $ 4 <= 00000000
345@00003248: $31 <= 00003250
351@00003250: *00003250 <= 00000000
363@00003260: $ 1 <= 00640000
367@00003268: $ 5 <= 00640000
375@00003278: $ 1 <= 00640000
379@00003280: $ 4 <= 00640007
387@00003290: $ 1 <= 00640000
391@00003298: $ 4 <= 00000000
399@000032a8: $ 1 <= 00640000
401@000032b0: *00000000 <= 00000000
425@00003250: *00003250 <= 00000000

437@00003260: $ 1 <= 00640000
441@00003268: $ 5 <= 00640000
449@00003278: $ 1 <= 00640000
453@00003280: $ 4 <= 00640007
461@00003290: $ 1 <= 00640000
465@00003298: $ 4 <= 00000000
473@000032a8: $ 1 <= 00640000
475@000032b0: *00000000 <= 00000000
499@00003250: *00003250 <= 00000000
511@00003260: $ 1 <= 00640000
515@00003268: $ 5 <= 00640000
523@00003278: $ 1 <= 00640000
527@00003280: $ 4 <= 00640007
535@00003290: $ 1 <= 00640000
539@00003298: $ 4 <= 00000000
547@000032a8: $ 1 <= 00640000
549@000032b0: *00000000 <= 00000000
573@00003250: *00003250 <= 00000000
585@00003260: $ 1 <= 00640000
589@00003268: $ 5 <= 00640000
597@00003278: $ 1 <= 00640000
601@00003280: $ 4 <= 00640007
609@00003290: $ 1 <= 00640000
613@00003298: $ 4 <= 00000000
621@000032a8: $ 1 <= 00640000
623@000032b0: *00000000 <= 00000000
647@00003250: *00003250 <= 00000000
659@00003260: $ 1 <= 00640000
663@00003268: $ 5 <= 00640000
671@00003278: $ 1 <= 00640000
675@00003280: $ 4 <= 00640007
683@00003290: $ 1 <= 00640000
687@00003298: $ 4 <= 00000000
695@000032a8: $ 1 <= 00640000
697@000032b0: *00000000 <= 00000000
721@00003250: *00003250 <= 00000000
733@00003260: $ 1 <= 00640000
737@00003268: $ 5 <= 00640000
745@00003278: $ 1 <= 00640000
749@00003280: $ 4 <= 00640007
757@00003290: $ 1 <= 00640000
761@00003298: $ 4 <= 00000000
769@000032a8: $ 1 <= 00640000
771@000032b0: *00000000 <= 00000000

```
795@00003250: *00003250 <= 00000000
807@00003260: $ 1 <= 00640000
811@00003268: $ 5 <= 00640000
819@00003278: $ 1 <= 00640000
823@00003280: $ 4 <= 00640007
831@00003290: $ 1 <= 00640000
835@00003298: $ 4 <= 00000000
843@000032a8: $ 1 <= 00640000
845@000032b0: *00000000 <= 00000000
869@00003250: *00003250 <= 00000000
881@00003260: $ 1 <= 00640000
885@00003268: $ 5 <= 00640000
893@00003278: $ 1 <= 00640000
897@00003280: $ 4 <= 00640007
905@00003290: $ 1 <= 00640000
909@00003298: $ 4 <= 00000000
917@000032a8: $ 1 <= 00640000
919@000032b0: *00000000 <= 00000000
943@00003250: *00003250 <= 00000000
955@00003260: $ 1 <= 00640000
959@00003268: $ 5 <= 00640000
967@00003278: $ 1 <= 00640000
971@00003280: $ 4 <= 00640007
979@00003290: $ 1 <= 00640000
983@00003298: $ 4 <= 00000000
991@000032a8: $ 1 <= 00640000
993@000032b0: *00000000 <= 00000000
```

RT_D 测试代码：

```
lui $1,100
beq $2,$1,label1
nop
label1:
nop
nop
nop
jal label2   #3
label2:
beq $1,$31,label3
nop
label3:
nop
nop
nop
```

```
addu $1,$2,$3   #1
nop
beq $2,$1,label4
nop
label4:
nop
nop
nop
ori $1,$2,100   #1
nop
beq $2,$1,label5
nop
label5:
nop
nop
nop
lui $1,100   #4
nop
beq $2,$1,label6
nop
label6:
nop
nop
nop
jal label7   #2
label7:
nop
beq $1,$31,label8
nop
label8:
nop
nop
nop
lw $1,($0)   #1
nop
beq $2,$1,label9
nop
label9:
nop
nop
nop
```

测试结果：

9@00003000: $ 1 <= 00640000

```
21@00003018: $31 <= 00003020
35@00003030: $ 1 <= 00000000
49@0000304c: $ 1 <= 00000064
63@00003068: $ 1 <= 00640000
77@00003084: $31 <= 0000308c
93@000030a0: $ 1 <= 00000000
```

RT_E 测试代码：

```
addu $1,$2,$3  #RT_E
subu $5,$4,$1
nop
nop
nop
ori $1,$2,100  #RT_E
subu $5,$4,$1
nop
nop
nop
jal label      #RT_E
subu $5,$4,$31
nop
nop
nop
lui $1,100     #RT_E
subu $5,$4,$1
nop
nop
nop
addu $1,$2,$3  #RT_E
nop
subu $5,$4,$1
nop
nop
nop
ori $1,$2,100  #RT_E
nop
subu $5,$4,$1
nop
nop
nop
jal label      #RT_E
nop
subu $5,$4,$31
nop
```

```
nop
nop
lui $1,100     #RT_E
nop
subu $5,$4,$1
nop
nop
nop
addu $1,$2,$3  #RT_E
nop
sw $1,($0)
nop
nop
nop
ori $1,$2,100  #RT_E
nop
sw $1,($0)
nop
nop
nop
jal label      #RT_E
nop
sw $1,($0)
nop
nop
nop
lui $1,100     #RT_E
nop
sw $1,($0)
nop
nop
nop
nop
nop
nop
nop
nop
nop
nop
label:
jr $31
```

测试结果：

```
9@00003000: $ 1 <= 00000000
11@00003004: $ 5 <= 00000000
```

19@00003014: $ 1 <= 00000064
21@00003018: $ 5 <= ffffff9c
29@00003028: $31 <= 00003030
31@0000302c: $ 5 <= ffffcfd0
45@0000303c: $ 1 <= 00640000
47@00003040: $ 5 <= ff9c0000
55@00003050: $ 1 <= 00000000
59@00003058: $ 5 <= 00000000
67@00003068: $ 1 <= 00000064
71@00003070: $ 5 <= ffffff9c
79@00003080: $31 <= 00003088
87@00003088: $ 5 <= ffffcf78
97@00003098: $ 1 <= 00640000
101@000030a0: $ 5 <= ff9c0000
109@000030b0: $ 1 <= 00000000
111@000030b8: *00000000 <= 00000000
121@000030c8: $ 1 <= 00000064
123@000030d0: *00000000 <= 00000064
133@000030e0: $31 <= 000030e8
139@000030e8: *00000000 <= 00000064
151@000030f8: $ 1 <= 00640000
153@00003100: *00000000 <= 00640000
177@000030e8: *00000000 <= 00640000
189@000030f8: $ 1 <= 00640000
191@00003100: *00000000 <= 00640000
215@000030e8: *00000000 <= 00640000
227@000030f8: $ 1 <= 00640000
229@00003100: *00000000 <= 00640000
253@000030e8: *00000000 <= 00640000
265@000030f8: $ 1 <= 00640000
267@00003100: *00000000 <= 00640000
291@000030e8: *00000000 <= 00640000
303@000030f8: $ 1 <= 00640000
305@00003100: *00000000 <= 00640000
329@000030e8: *00000000 <= 00640000
341@000030f8: $ 1 <= 00640000
343@00003100: *00000000 <= 00640000
367@000030e8: *00000000 <= 00640000
379@000030f8: $ 1 <= 00640000
381@00003100: *00000000 <= 00640000
405@000030e8: *00000000 <= 00640000
417@000030f8: $ 1 <= 00640000
419@00003100: *00000000 <= 00640000
443@000030e8: *00000000 <= 00640000

455@000030f8: $ 1 <= 00640000
457@00003100: *00000000 <= 00640000
481@000030e8: *00000000 <= 00640000
493@000030f8: $ 1 <= 00640000
495@00003100: *00000000 <= 00640000
519@000030e8: *00000000 <= 00640000
531@000030f8: $ 1 <= 00640000
533@00003100: *00000000 <= 00640000
557@000030e8: *00000000 <= 00640000
569@000030f8: $ 1 <= 00640000
571@00003100: *00000000 <= 00640000
595@000030e8: *00000000 <= 00640000
607@000030f8: $ 1 <= 00640000
609@00003100: *00000000 <= 00640000
633@000030e8: *00000000 <= 00640000
645@000030f8: $ 1 <= 00640000
647@00003100: *00000000 <= 00640000
671@000030e8: *00000000 <= 00640000
683@000030f8: $ 1 <= 00640000
685@00003100: *00000000 <= 00640000
709@000030e8: *00000000 <= 00640000
721@000030f8: $ 1 <= 00640000
723@00003100: *00000000 <= 00640000
747@000030e8: *00000000 <= 00640000
759@000030f8: $ 1 <= 00640000
761@00003100: *00000000 <= 00640000
785@000030e8: *00000000 <= 00640000
797@000030f8: $ 1 <= 00640000
799@00003100: *00000000 <= 00640000
823@000030e8: *00000000 <= 00640000
835@000030f8: $ 1 <= 00640000
837@00003100: *00000000 <= 00640000
861@000030e8: *00000000 <= 00640000
873@000030f8: $ 1 <= 00640000
875@00003100: *00000000 <= 00640000
899@000030e8: *00000000 <= 00640000
911@000030f8: $ 1 <= 00640000
913@00003100: *00000000 <= 00640000
937@000030e8: *00000000 <= 00640000
949@000030f8: $ 1 <= 00640000
951@00003100: *00000000 <= 00640000
975@000030e8: *00000000 <= 00640000
987@000030f8: $ 1 <= 00640000
989@00003100: *00000000 <= 00640000

跳转指令强测：

```
jal label1  #Stall
nop

jal label2  #Stall
nop

jal label3  #Stall
nop

jal label4  #Stall
nop

beq $5,$6,end

addu $5,$6,$7
addu $6,$7,$8
label4:
sw $31,($0)
lw $31,($0)
nop
jr $31
nop

addu $5,$6,$7
addu $6,$7,$8
label3:
sw $31,($0)
lw $31,($0)
jr $31
nop

addu $5,$6,$7
addu $6,$7,$8
label2:
ori $31,$31,0
jr $31
nop

addu $5,$6,$7
addu $6,$7,$8
label1:
addu $31,$31,$0
```

```
jr $31
nop

end:
addu $1,$0,$0
nop
nop
nop
nop
nop
nop
```

测试结果：

```
9@00003000: $31 <= 00003008
13@00003074: $31 <= 00003008
21@00003008: $31 <= 00003010
25@00003060: $31 <= 00003010
33@00003010: $31 <= 00003018
35@00003048: *00000000 <= 00003018
39@0000304c: $31 <= 00003018
49@00003018: $31 <= 00003020
51@0000302c: *00000000 <= 00003020
55@00003030: $31 <= 00003020
67@00003024: $ 5 <= 00000000
69@00003080: $ 1 <= 00000000
```

乘除模块测试：

```
li $t0, 0x7fffffff
li $t1, 0xffffffff
li $t2, 0x80000000
mult $t0, $t0
mfhi $s0
mflo $s1
multu $t0, $t0
mfhi $s2
mfhi $s3
mult $t1, $t1
mfhi $s4
mflo $s5
multu $t1, $t1
mfhi $s6
mflo $s7
mult $t2, $t2
mfhi $s0
```

```
mflo $s1
multu $t2, $t2
mfhi $s2
mflo $s3
mult $t0, $t1
mfhi $s0
mflo $s1
multu $t0, $t1
mfhi $s2
mflo $s3
mult $t0, $t2
mfhi $s4
mflo $s5
multu $t0, $t2
mfhi $s6
mflo $s7
mult $t1, $t2
mfhi $s0
mflo $s1
multu $t1, $t2
mfhi $s2
mflo $s3
mult $0, $t1
mfhi $s2
mflo $s3
multu $t1, $0
mfhi $s4
mflo $s5
div $t0, $t0
mfhi $s0
mflo $s1
divu $t0, $t0
mfhi $s2
mflo $s3
div $t1, $t1
mfhi $s4
mflo $s5
divu $t1, $t1
mfhi $s6
mflo $s7
div $t2, $t2
mfhi $s0
mflo $s1
divu $t2, $t2
```

```
mfhi $s2
mflo $s3
div $t0, $t1
mfhi $s0
mflo $s1
div $t1, $t0
mfhi $s2
mflo $s3
divu $t0, $t1
mfhi $s4
mflo $s5
divu $t1, $t0
mfhi $s6
mflo $s7
div $t0, $t2
mfhi $s0
mflo $s1
div $t2, $t0
mfhi $s2
mfhi $s3
divu $t0, $t2
mfhi $s4
mflo $s5
divu $t2, $t0
mfhi $s6
mflo $s7
div $t1, $t2
mfhi $s0
mflo $s1
div $t2, $t1
mfhi $s2
mflo $s3
divu $t1, $t2
mfhi $s4
mflo $s5
divu $t2, $t1
mfhi $s6
mflo $s7
div $0, $t1
mfhi $s0
mflo $s1
divu $0, $t1
mfhi $s0
mflo $s1
```

```
ori $t1, 1234
add $t0, $0, $t1
mthi $t0
mtlo $t0
mfhi $s0
mflo $s1
add $t0, $0, $t1
mtlo $t0
mthi $t0
mfhi $s2
mflo $s3
ori $t0 $0, 423
nop
mthi $t0
mtlo $t1
mfhi $s4
mflo $s5
ori $t0, $0, 8765
nop
nop
mthi $t0
mtlo $t0
mflo $s6
mfhi $s7
ori $t0, $0, 6543
nop
nop
nop
mthi $t0
mtlo $t0
mflo $s0
mfhi $s1
```

测试结果：

```
9@00003000: $ 1 <= 7fff0000
11@00003004: $ 8 <= 7fffffff
13@00003008: $ 9 <= ffffffff
15@0000300c: $ 1 <= 80000000
17@00003010: $10 <= 80000000
33@00003018: $16 <= 3fffffff
35@0000301c: $17 <= 00000001
51@00003024: $18 <= 3fffffff
53@00003028: $19 <= 3fffffff
69@00003030: $20 <= 00000000
```

71@00003034: $21 <= 00000001
87@0000303c: $22 <= fffffffe
89@00003040: $23 <= 00000001
105@00003048: $16 <= 40000000
107@0000304c: $17 <= 00000000
123@00003054: $18 <= 40000000
125@00003058: $19 <= 00000000
141@00003060: $16 <= ffffffff
143@00003064: $17 <= 80000001
159@0000306c: $18 <= 7ffffffe
161@00003070: $19 <= 80000001
177@00003078: $20 <= c0000000
179@0000307c: $21 <= 80000000
195@00003084: $22 <= 3fffffff
197@00003088: $23 <= 80000000
213@00003090: $16 <= 00000000
215@00003094: $17 <= 80000000
231@0000309c: $18 <= 7fffffff
233@000030a0: $19 <= 80000000
249@000030a8: $18 <= 00000000
251@000030ac: $19 <= 00000000
267@000030b4: $20 <= 00000000
269@000030b8: $21 <= 00000000
295@000030c0: $16 <= 00000000
297@000030c4: $17 <= 00000001
323@000030cc: $18 <= 00000000
325@000030d0: $19 <= 00000001
351@000030d8: $20 <= 00000000
353@000030dc: $21 <= 00000001
379@000030e4: $22 <= 00000000
381@000030e8: $23 <= 00000001
407@000030f0: $16 <= 00000000
409@000030f4: $17 <= 00000001
435@000030fc: $18 <= 00000000
437@00003100: $19 <= 00000001
463@00003108: $16 <= 00000000
465@0000310c: $17 <= 80000001
491@00003114: $18 <= ffffffff
493@00003118: $19 <= 00000000
519@00003120: $20 <= 7fffffff
521@00003124: $21 <= 00000000
547@0000312c: $22 <= 00000001
549@00003130: $23 <= 00000002
575@00003138: $16 <= 7fffffff

```
577@0000313c: $17 <= 00000000
603@00003144: $18 <= ffffffff
605@00003148: $19 <= ffffffff
631@00003150: $20 <= 7fffffff
633@00003154: $21 <= 00000000
659@0000315c: $22 <= 00000001
661@00003160: $23 <= 00000001
687@00003168: $16 <= ffffffff
689@0000316c: $17 <= 00000000
715@00003174: $18 <= 00000000
717@00003178: $19 <= 80000000
743@00003180: $20 <= 7fffffff
745@00003184: $21 <= 00000001
771@0000318c: $22 <= 80000000
773@00003190: $23 <= 00000000
799@00003198: $16 <= 00000000
801@0000319c: $17 <= 00000000
827@000031a4: $16 <= 00000000
829@000031a8: $17 <= 00000000
831@000031ac: $ 9 <= ffffffff
833@000031b0: $ 8 <= ffffffff
843@000031bc: $16 <= ffffffff
845@000031c0: $17 <= ffffffff
847@000031c4: $ 8 <= ffffffff
857@000031d0: $18 <= ffffffff
859@000031d4: $19 <= ffffffff
861@000031d8: $ 8 <= 000001a7
873@000031e8: $20 <= 000001a7
875@000031ec: $21 <= ffffffff
877@000031f0: $ 8 <= 0000223d
891@00003204: $22 <= 0000223d
893@00003208: $23 <= 0000223d
895@0000320c: $ 8 <= 0000198f
911@00003224: $16 <= 0000198f
913@00003228: $17 <= 0000198f
```

综合测试：

```
init_1:j init_44
   lui $0, 58479
init_2:j init_61
   lui $26, 40699
init_3:nop
j init_26
   ori $29, 12340
```

```
init_4:j init_21
   lui $9, 18793
init_5:nop
j init_9
   ori $13, 19610
init_6:j init_38
   ori $28, 17819
init_7:nop
j init_37
   ori $27, 17810
init_8:j init_48
   ori $14, 1324
init_9:j init_8
   lui $14, 20958
init_10:j init_31
   lui $4, 28505
init_11:nop
j init_13
   ori $23, 24263
init_12:j init_16
   ori $12, 2525
init_13:j init_62
   lui $24, 49213
init_14:j init_59
   ori $6, 27235
init_15:j init_52
   ori $16, 28030
init_16:j init_5
   lui $13, 39021
init_17:j init_23
   lui $20, 45636
init_18:nop
j init_57
   ori $7, 34738
init_19:j init_56
   lui $22, 48232
init_20:j init_7
   lui $27, 21269
init_21:nop
j init_24
   ori $9, 60940
init_22:j init_47
   lui $19, 24579
init_23:j init_53
```

```
   ori $20, 23617
init_24:j init_27
   lui $10, 4700
init_25:nop
j init_60
   ori $5, 25135
init_26:j init_34
   lui $30, 14559
init_27:j init_29
   ori $10, 45253
init_28:j init_12
   lui $12, 55820
init_29:j init_36
   lui $11, 49875
init_30:j init_25
   lui $5, 35220
init_31:j init_30
   ori $4, 7615
init_32:j begin
   lui $31, 60984
init_33:j init_43
   ori $2, 18084
init_34:j init_63
   ori $30, 41019
init_35:j init_15
   lui $16, 54272
init_36:nop
j init_28
   ori $11, 2111
init_37:j init_6
   lui $28, 33755
init_38:j init_3
   lui $29, 26291
init_39:nop
j init_2
   ori $25, 48740
init_40:j init_42
   lui $1, 43965
init_41:nop
j init_19
   ori $21, 27953
init_42:nop
j init_50
   ori $1, 18337
```

```
init_43:j init_54
   lui $3, 36555
init_44:j init_40
   ori $0, 39840
init_45:j init_22
   ori $18, 28396
init_46:j init_4
   ori $8, 13173
init_47:nop
j init_17
   ori $19, 60189
init_48:j init_49
   lui $15, 28446
init_49:nop
j init_35
   ori $15, 43996
init_50:j init_33
   lui $2, 50534
init_51:j init_45
   lui $18, 47692
init_52:j init_58
   lui $17, 18098
init_53:j init_41
   lui $21, 23125
init_54:nop
j init_10
   ori $3, 34935
init_55:j init_39
   lui $25, 37200
init_56:j init_64
   ori $22, 41245
init_57:j init_46
   lui $8, 16690
init_58:nop
j init_51
   ori $17, 23659
init_59:j init_18
   lui $7, 16431
init_60:j init_14
   lui $6, 20586
init_61:j init_20
   ori $26, 21724
init_62:j init_55
   ori $24, 64211
```

```
init_63:j init_32
   lui $31, 32491
init_64:j init_11
   lui $23, 36591
begin:
   ori $11, $11, 39941
   sw $11, 0($0)
   ori $22, $22, 13378
   nop
   sw $22, 4($0)
   addu $8, $31, $16
   nop
   nop
   sw $8, 8($0)
   subu $20, $16, $6
   sw $20, 12($0)
   addu $9, $15, $7
   nop
   sw $9, 16($0)
   addu $19, $23, $27
   nop
   nop
   sw $19, 20($0)
   subu $5, $1, $31
   sw $5, 24($0)
   addu $22, $6, $26
   nop
   sw $22, 28($0)
   addu $10, $4, $18
   nop
   nop
   sw $10, 32($0)
   subu $19, $3, $0
   sw $19, 36($0)
   subu $22, $24, $1
   nop
   sw $22, 40($0)
   subu $19, $10, $14
   nop
   nop
   sw $19, 44($0)
   subu $0, $19, $15
   sw $0, 48($0)
   ori $21, $21, 728
```

```
nop
sw $21, 52($0)
subu $13, $29, $4
nop
nop
sw $13, 56($0)
addu $11, $3, $1
sw $11, 60($0)
addu $27, $19, $11
nop
sw $27, 64($0)
addu $27, $16, $28
nop
nop
sw $27, 68($0)
ori $25, $25, 7272
sw $25, 72($0)
ori $31, $31, 65375
nop
sw $31, 76($0)
ori $13, $13, 65318
nop
nop
sw $13, 80($0)
ori $5, $5, 27677
sw $5, 84($0)
ori $13, $13, 30209
nop
sw $13, 88($0)
subu $16, $28, $20
nop
nop
sw $16, 92($0)
addu $6, $16, $21
sw $6, 96($0)
subu $22, $11, $31
nop
sw $22, 100($0)
subu $25, $23, $19
nop
nop
sw $25, 104($0)
ori $0, $0, 8927
sw $0, 108($0)
```

```
ori $24, $24, 21563
nop
sw $24, 112($0)
addu $13, $16, $11
nop
nop
sw $13, 116($0)
subu $14, $12, $27
sw $14, 120($0)
addu $15, $24, $27
nop
sw $15, 124($0)
subu $20, $1, $24
nop
nop
sw $20, 128($0)
subu $13, $28, $15
sw $13, 132($0)
ori $28, $28, 56842
nop
sw $28, 136($0)
addu $31, $6, $23
nop
nop
sw $31, 140($0)
ori $10, $10, 11112
sw $10, 144($0)
addu $21, $23, $9
nop
sw $21, 148($0)
subu $22, $16, $29
nop
nop
sw $22, 152($0)
addu $16, $1, $31
sw $16, 156($0)
subu $12, $15, $28
nop
sw $12, 160($0)
addu $6, $10, $22
nop
nop
sw $6, 164($0)
ori $12, $12, 14691
```

```
    sw $12, 168($0)
    ori $16, $16, 34145
    nop
    sw $16, 172($0)
    ori $11, $11, 18551
    nop
    nop
    sw $11, 176($0)
    sw $sp, 180($0)
    sw $ra, 184($0)
    sw $at, 188($0)
    ori $sp, $0, 4060
    ori $1, $0, 32
    jal foo1
    nop
    lui $1, 0
    ori $1, 0
    beq $1, $0, skip_manual1
    nop
    j dl
    nop
skip_manual1:
    lui $1, 10994
    lui $2, 10994
    beq $1, $2, skip_manual2
    nop
    j dl
    nop
skip_manual2:
    lui $3, 10995
    nop
    nop
    beq $1, $3, dl
    addu $4, $4, $3
    lui $1, 0x6183
    addu $2, $2, $1
    lui $5, 0x8124
    addu $4, $5, $1
    subu $6, $6, $5
    jal skip_manual3
    nop
    sw $0, 4($0)
skip_manual3:
    sw $7, -0x3000($ra)
```

```
    lw $ra, -0x3000($ra)
    ori $ra, $0, 0
    jal skip_manual4
    nop
    sw $0, 8($0)
skip_manual4:
    beq $ra, $0, dl
    nop
    ori $ra, $0, 0
    jal skip_manual5
    nop
    sw $ra, 12($0)
skip_manual5:
    nop
    beq $ra, $0, dl
    nop
    ori $4, $0, 4
    ori $5, $0, 5
    ori $1, $0, 1
    addu $4, $4, $1
    nop
    nop
    beq $4, $5, skip_manual6
    nop
    sw $0, 16($0)
skip_manual6:
    ori $1, $0, 1
    ori $2, $0, 2
    ori $3, $0, 3
    ori $4, $0, 4
    ori $5, $0, 6
    ori $6, $0, 5
    subu $5, $5, $1
    addu $6, $2, $1
    beq $5, $6, dl
    nop
    jal skip_manual8
    nop
skip_manual8:
    addu $3, $3, $ra
    subu $4, $4, $ra
    jal foo
    nop
    jal fooo
```

```
    nop
    bgezal $0, foooo
    nop
    bgezal $0, fooooo
    nop
sw $0, 192($0)
sw $1, 196($0)
sw $2, 200($0)
sw $3, 204($0)
sw $4, 208($0)
sw $5, 212($0)
sw $6, 216($0)
sw $7, 220($0)
sw $8, 224($0)
sw $9, 228($0)
sw $10, 232($0)
sw $11, 236($0)
sw $12, 240($0)
sw $13, 244($0)
sw $14, 248($0)
sw $15, 252($0)
sw $16, 256($0)
sw $17, 260($0)
sw $18, 264($0)
sw $19, 268($0)
sw $20, 272($0)
sw $21, 276($0)
sw $22, 280($0)
sw $23, 284($0)
sw $24, 288($0)
sw $25, 292($0)
sw $26, 296($0)
sw $27, 300($0)
sw $28, 304($0)
sw $29, 308($0)
sw $30, 312($0)
sw $31, 316($0)
    lui $31, 63605
    bgezal $31, tag_0
    nop
    ori $ra, $0, 2
tag_0:sw $ra, 320($0)
    addu $14, $13, $7
    bgezal $14, tag_1
```

```
    nop
    ori $ra, $0, 2
tag_1:sw $ra, 324($0)
    lw $25, 12($0)
    bgezal $25, tag_2
    nop
    ori $ra, $0, 2
tag_2:sw $ra, 328($0)
    lui $29, 14949
    nop
    bgezal $29, tag_3
    nop
    ori $ra, $0, 2
tag_3:sw $ra, 332($0)
    addu $10, $24, $1
    nop
    bgezal $10, tag_4
    nop
    ori $ra, $0, 2
tag_4:sw $ra, 336($0)
    lw $12, 164($0)
    nop
    bgezal $12, tag_5
    nop
    ori $ra, $0, 2
tag_5:sw $ra, 340($0)
    lui $31, 58593
    nop
    nop
    bgezal $31, tag_6
    nop
    ori $ra, $0, 2
tag_6:sw $ra, 344($0)
    addu $1, $7, $12
    nop
    nop
    bgezal $1, tag_7
    nop
    ori $ra, $0, 2
tag_7:sw $ra, 348($0)
    lw $20, 256($0)
    nop
    nop
    bgezal $20, tag_8
```

```
    nop
    ori $ra, $0, 2
tag_8:sw $ra, 352($0)
    lui $17, 19367
    bgezal $17, tag_9
    nop
    ori $ra, $0, 2
tag_9:sw $ra, 356($0)
    addu $8, $11, $11
    bgezal $8, tag_10
    nop
    ori $ra, $0, 2
tag_10:sw $ra, 360($0)
    lw $1, 132($0)
    bgezal $1, tag_11
    nop
    ori $ra, $0, 2
tag_11:sw $ra, 364($0)
    lui $18, 56313
    nop
    bgezal $18, tag_12
    nop
    ori $ra, $0, 2
tag_12:sw $ra, 368($0)
    addu $23, $25, $24
    nop
    bgezal $23, tag_13
    nop
    ori $ra, $0, 2
tag_13:sw $ra, 372($0)
    lw $20, 368($0)
    nop
    bgezal $20, tag_14
    nop
    ori $ra, $0, 2
tag_14:sw $ra, 376($0)
    lui $21, 22951
    nop
    nop
    bgezal $21, tag_15
    nop
    ori $ra, $0, 2
tag_15:sw $ra, 380($0)
    addu $8, $10, $1
```

```
    nop
    nop
    bgezal $8, tag_16
    nop
    ori $ra, $0, 2
tag_16:sw $ra, 384($0)
    lw $4, 88($0)
    nop
    nop
    bgezal $4, tag_17
    nop
    ori $ra, $0, 2
tag_17:sw $ra, 388($0)
    ori $4, $0, 12
    jal skip_manual7
    nop
skip_manual7:
    addu $ra, $ra, $4
    jr $ra
    ori $4, $0, 8
    addu $ra, $ra, $4
    nop
    jr $ra
    nop
dl:addu $ra, $0, $0
    beq $0, $0, dl
    nop
foo:  jr $ra
    ori $ra, $ra, 0xff
fooo: ori $6, $ra, 0xa
    jr $ra
    nop
foooo: jr $ra
    ori $t8, $ra, 0xff
fooooo:  ori $t9, $ra, 0xa
    jr $ra
    nop
foo1:
    sw $a0, 0($sp)
    sw $ra, 16($sp)
    sw $a1, 4($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
```

```
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 84
    ori $s2, $0, 220
    lw $t0, -40($s1)
    lw $t1, -88($s2)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 11072
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 30986
    ori $a2, $a1, 0xf0
    nop
    beq $a2, $a1, skip1
    nop
    jal foo2
    subu $sp, $sp, $1
skip1: lw $a3, 16($sp)
    addu $sp, $sp, $1
    nop
    jr $a3
    nop
foo2:
    sw $a0, 0($sp)
    sw $a1, 4($sp)
    sw $ra, 16($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 152
    ori $s2, $0, 54
    lw $t1, 326($s2)
    lw $t0, 160($s1)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 21109
    addu $t2, $t2, $t2
```

```
   addu $t2, $t2, $t2
   ori $a1, $t2, 60683
   ori $a2, $a1, 0xf0
   beq $a2, $a1, skip2
   nop
   jal foo3
   subu $sp, $sp, $1
skip2: lw $a3, 16($sp)
   jr $a3
   addu $sp, $sp, $1
foo3:
   sw $ra, 16($sp)
   sw $a0, 0($sp)
   sw $a1, 4($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
   ori $s1, $0, 139
   ori $s2, $0, 302
   lw $t0, -35($s1)
   lw $t1, -34($s2)
   addu $a3, $t0, $t1
   addu $a0, $a0, $t0
   addu $a1, $a1, $t1
   addu $t2, $a0, $a1
   ori $a0, $t2, 29202
   addu $t2, $t2, $t2
   addu $t2, $t2, $t2
   ori $a1, $t2, 43269
   ori $a2, $a1, 0xf0
   nop
   beq $a2, $a1, skip3
   nop
   jal foo13
   subu $sp, $sp, $1
skip3: lw $a3, 16($sp)
   addu $sp, $sp, $1
   jr $a3
   nop
foo4:
   sw $a0, 0($sp)
   sw $ra, 16($sp)
```

```
    sw $a1, 4($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 297
    ori $s2, $0, 96
    lw $t1, 104($s2)
    lw $t0, -197($s1)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 14171
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 18179
    ori $a2, $a1, 0xf0
    beq $a2, $a1, skip4
    nop
    jal foo11
    subu $sp, $sp, $1
skip4: lw $a3, 16($sp)
    addu $sp, $sp, $1
    nop
    jr $a3
    nop
foo5:
    sw $a0, 0($sp)
    sw $a1, 4($sp)
    sw $ra, 16($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 106
    ori $s2, $0, 190
    lw $t0, -26($s1)
    lw $t1, -82($s2)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
```

```
    addu $t2, $a0, $a1
    ori $a0, $t2, 49045
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 36619
    ori $a2, $a1, 0xf0
    nop
    beq $a2, $a1, skip5
    nop
    jal foo1
    subu $sp, $sp, $1
skip5: lw $a3, 16($sp)
    jr $a3
    addu $sp, $sp, $1
foo6:
    sw $ra, 16($sp)
    sw $a0, 0($sp)
    sw $a1, 4($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 345
    ori $s2, $0, 52
    lw $t1, -32($s2)
    lw $t0, 15($s1)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 25874
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 45316
    ori $a2, $a1, 0xf0
    beq $a2, $a1, skip6
    nop
    jal foo4
    subu $sp, $sp, $1
skip6: lw $a3, 16($sp)
    addu $sp, $sp, $1
    jr $a3
    nop
```

```
foo7:
   sw $a0, 0($sp)
   sw $ra, 16($sp)
   sw $a1, 4($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
   ori $s1, $0, 319
   ori $s2, $0, 212
   lw $t0, -167($s1)
   lw $t1, 120($s2)
   addu $a3, $t0, $t1
   addu $a0, $a0, $t0
   addu $a1, $a1, $t1
   addu $t2, $a0, $a1
   ori $a0, $t2, 44079
   addu $t2, $t2, $t2
   addu $t2, $t2, $t2
   ori $a1, $t2, 38407
   ori $a2, $a1, 0xf0
   nop
   beq $a2, $a1, skip7
   nop
   jal foo10
   subu $sp, $sp, $1
skip7: lw $a3, 16($sp)
   addu $sp, $sp, $1
   nop
   jr $a3
   nop
foo8:
   sw $a0, 0($sp)
   sw $a1, 4($sp)
   sw $ra, 16($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
   ori $s1, $0, 366
   ori $s2, $0, 244
   lw $t1, -116($s2)
```

```
    lw $t0, -290($s1)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 20552
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 22025
    ori $a2, $a1, 0xf0
    beq $a2, $a1, skip8
    nop
    jal foo5
    subu $sp, $sp, $1
skip8: lw $a3, 16($sp)
    jr $a3
    addu $sp, $sp, $1
foo9:
    sw $ra, 16($sp)
    sw $a0, 0($sp)
    sw $a1, 4($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 223
    ori $s2, $0, 283
    lw $t0, 13($s1)
    lw $t1, -27($s2)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 28872
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 52993
    ori $a2, $a1, 0xf0
    nop
    beq $a2, $a1, skip9
    nop
    jal foo15
    subu $sp, $sp, $1
```

```
skip9: lw $a3, 16($sp)
   addu $sp, $sp, $1
   jr $a3
   nop
foo10:
   sw $a0, 0($sp)
   sw $ra, 16($sp)
   sw $a1, 4($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
   ori $s1, $0, 228
   ori $s2, $0, 255
   lw $t1, -155($s2)
   lw $t0, 12($s1)
   addu $a3, $t0, $t1
   addu $a0, $a0, $t0
   addu $a1, $a1, $t1
   addu $t2, $a0, $a1
   ori $a0, $t2, 56866
   addu $t2, $t2, $t2
   addu $t2, $t2, $t2
   ori $a1, $t2, 21770
   ori $a2, $a1, 0xf0
   beq $a2, $a1, skip10
   nop
   jal foo12
   subu $sp, $sp, $1
skip10:  lw $a3, 16($sp)
   addu $sp, $sp, $1
   nop
   jr $a3
   nop
foo11:
   sw $a0, 0($sp)
   sw $a1, 4($sp)
   sw $ra, 16($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
```

```
    ori $s1, $0, 54
    ori $s2, $0, 306
    lw $t0, 278($s1)
    lw $t1, -238($s2)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 34513
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 36103
    ori $a2, $a1, 0xf0
    nop
    beq $a2, $a1, skip11
    nop
    jal foo8
    subu $sp, $sp, $1
skip11:   lw $a3, 16($sp)
    jr $a3
    addu $sp, $sp, $1
foo12:
    sw $ra, 16($sp)
    sw $a0, 0($sp)
    sw $a1, 4($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 248
    ori $s2, $0, 72
    lw $t1, 152($s2)
    lw $t0, 76($s1)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 1104
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 24322
    ori $a2, $a1, 0xf0
    beq $a2, $a1, skip12
```

```
   nop
   jal foo9
   subu $sp, $sp, $1
skip12:  lw $a3, 16($sp)
   addu $sp, $sp, $1
   jr $a3
   nop
foo13:
   sw $a0, 0($sp)
   sw $ra, 16($sp)
   sw $a1, 4($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
   ori $s1, $0, 386
   ori $s2, $0, 194
   lw $t0, -82($s1)
   lw $t1, -142($s2)
   addu $a3, $t0, $t1
   addu $a0, $a0, $t0
   addu $a1, $a1, $t1
   addu $t2, $a0, $a1
   ori $a0, $t2, 18477
   addu $t2, $t2, $t2
   addu $t2, $t2, $t2
   ori $a1, $t2, 2816
   ori $a2, $a1, 0xf0
   nop
   beq $a2, $a1, skip13
   nop
   jal foo7
   subu $sp, $sp, $1
skip13:  lw $a3, 16($sp)
   addu $sp, $sp, $1
   nop
   jr $a3
   nop
foo14:
   sw $a0, 0($sp)
   sw $a1, 4($sp)
   sw $ra, 16($sp)
   sw $a2, 8($sp)
```

```
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 184
    ori $s2, $0, 255
    lw $t1, 13($s2)
    lw $t0, -88($s1)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 26871
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
    ori $a1, $t2, 23821
    ori $a2, $a1, 0xf0
    beq $a2, $a1, skip14
    nop
    jal foo16
    subu $sp, $sp, $1
skip14:   lw $a3, 16($sp)
    jr $a3
    addu $sp, $sp, $1
foo15:
    sw $ra, 16($sp)
    sw $a0, 0($sp)
    sw $a1, 4($sp)
    sw $a2, 8($sp)
    sw $a3, 12($sp)
    sw $t0, 20($sp)
    sw $t1, 24($sp)
    sw $t2, 28($sp)
    ori $s1, $0, 264
    ori $s2, $0, 366
    lw $t0, -212($s1)
    lw $t1, -2($s2)
    addu $a3, $t0, $t1
    addu $a0, $a0, $t0
    addu $a1, $a1, $t1
    addu $t2, $a0, $a1
    ori $a0, $t2, 36680
    addu $t2, $t2, $t2
    addu $t2, $t2, $t2
```

```
   ori $a1, $t2, 1289
   ori $a2, $a1, 0xf0
   nop
   beq $a2, $a1, skip15
   nop
   jal foo14
   subu $sp, $sp, $1
skip15:  lw $a3, 16($sp)
   addu $sp, $sp, $1
   jr $a3
   nop
foo16:
   sw $a0, 0($sp)
   sw $ra, 16($sp)
   sw $a1, 4($sp)
   sw $a2, 8($sp)
   sw $a3, 12($sp)
   sw $t0, 20($sp)
   sw $t1, 24($sp)
   sw $t2, 28($sp)
   ori $s1, $0, 39
   ori $s2, $0, 301
   lw $t1, -17($s2)
   lw $t0, 317($s1)
   addu $a3, $t0, $t1
   addu $a0, $a0, $t0
   addu $a1, $a1, $t1
   addu $t2, $a0, $a1
   ori $a0, $t2, 706
   addu $t2, $t2, $t2
   addu $t2, $t2, $t2
   ori $a1, $t2, 2561
   ori $a2, $a1, 0xf0
   beq $a2, $a1, skip16
   nop
   jal foo6
   subu $sp, $sp, $1
skip16:  lw $a3, 16($sp)
   addu $sp, $sp, $1
   nop
   jr $a3
   nop
```

测试结果：

11@00003004: $ 0 <= e46f0000
15@00003188: $ 0 <= 00009ba0
19@00003160: $ 1 <= abbd0000
25@00003178: $ 1 <= abbd47a1
29@000031c0: $ 2 <= c5660000
33@00003120: $ 2 <= c56646a4
37@00003180: $ 3 <= 8ecb0000
43@000031e4: $ 3 <= 8ecb8877
47@00003058: $ 4 <= 6f590000
51@00003110: $ 4 <= 6f591dbf
55@00003108: $ 5 <= 89940000
61@000030e0: $ 5 <= 8994622f
65@00003218: $ 6 <= 506a0000
69@0000307c: $ 6 <= 506a6a63
73@00003210: $ 7 <= 402f0000
79@000030a0: $ 7 <= 402f87b2
83@000031fc: $ 8 <= 41320000
87@00003198: $ 8 <= 41323375
91@00003020: $ 9 <= 49690000
97@000030bc: $ 9 <= 4969ee0c
101@000030d4: $10 <= 125c0000
105@000030f0: $10 <= 125cb0c5
109@00003100: $11 <= c2d30000
115@0000313c: $11 <= c2d3083f
119@000030f8: $12 <= da0c0000
123@0000306c: $12 <= da0c09dd
127@0000308c: $13 <= 986d0000
133@0000302c: $13 <= 986d4c9a
137@00003050: $14 <= 51de0000
141@00003048: $14 <= 51de052c
145@000031ac: $15 <= 6f1e0000
151@000031b8: $15 <= 6f1eabdc
155@00003130: $16 <= d4000000
159@00003084: $16 <= d4006d7e
163@000031d0: $17 <= 46b20000
169@00003208: $17 <= 46b25c6b
173@000031c8: $18 <= ba4c0000
177@00003190: $18 <= ba4c6eec
181@000030c4: $19 <= 60030000
187@000031a4: $19 <= 6003eb1d
191@00003094: $20 <= b2440000
195@000030cc: $20 <= b2445c41
199@000031d8: $21 <= 5a550000
205@0000316c: $21 <= 5a556d31

```
209@000030a8: $22 <= bc680000
213@000031f4: $22 <= bc68a11d
217@00003238: $23 <= 8eef0000
223@00003064: $23 <= 8eef5ec7
227@00003074: $24 <= c03d0000
231@00003228: $24 <= c03dfad3
235@000031ec: $25 <= 91500000
241@00003158: $25 <= 9150be64
245@0000300c: $26 <= 9efb0000
249@00003220: $26 <= 9efb54dc
253@000030b0: $27 <= 53150000
259@00003040: $27 <= 53154592
263@00003144: $28 <= 83db0000
267@00003034: $28 <= 83db459b
271@0000314c: $29 <= 66b30000
277@00003018: $29 <= 66b33034
281@000030e8: $30 <= 38df0000
285@00003128: $30 <= 38dfa03b
289@00003230: $31 <= 7eeb0000
293@00003118: $31 <= ee380000
295@0000323c: $11 <= c2d39c3f
295@00003240: *00000000 <= c2d39c3f
299@00003244: $22 <= bc68b55f
301@0000324c: *00000004 <= bc68b55f
305@00003250: $ 8 <= c2386d7e
309@0000325c: *00000008 <= c2386d7e
313@00003260: $20 <= 8396031b
313@00003264: *0000000c <= 8396031b
317@00003268: $ 9 <= af4e338e
319@00003270: *00000010 <= af4e338e
323@00003274: $19 <= e204a459
327@00003280: *00000014 <= e204a459
331@00003284: $ 5 <= bd8547a1
331@00003288: *00000018 <= bd8547a1
335@0000328c: $22 <= ef65bf3f
337@00003294: *0000001c <= ef65bf3f
341@00003298: $10 <= 29a58cab
345@000032a4: *00000020 <= 29a58cab
349@000032a8: $19 <= 8ecb8877
349@000032ac: *00000024 <= 8ecb8877
353@000032b0: $22 <= 1480b332
355@000032b8: *00000028 <= 1480b332
359@000032bc: $19 <= d7c7877f
363@000032c8: *0000002c <= d7c7877f
```

```
367@000032cc: $ 0 <= 68a8dba3
367@000032d0: *00000030 <= 00000000
371@000032d4: $21 <= 5a556ff9
373@000032dc: *00000034 <= 5a556ff9
377@000032e0: $13 <= f75a1275
381@000032ec: *00000038 <= f75a1275
385@000032f0: $11 <= 3a88d018
385@000032f4: *0000003c <= 3a88d018
389@000032f8: $27 <= 12505797
391@00003300: *00000040 <= 12505797
395@00003304: $27 <= 57dbb319
399@00003310: *00000044 <= 57dbb319
403@00003314: $25 <= 9150be6c
403@00003318: *00000048 <= 9150be6c
407@0000331c: $31 <= ee38ff5f
409@00003324: *0000004c <= ee38ff5f
413@00003328: $13 <= f75aff77
417@00003334: *00000050 <= f75aff77
421@00003338: $ 5 <= bd856fbd
421@0000333c: *00000054 <= bd856fbd
425@00003340: $13 <= f75aff77
427@00003348: *00000058 <= f75aff77
431@0000334c: $16 <= 00454280
435@00003358: *0000005c <= 00454280
439@0000335c: $ 6 <= 5a9ab279
439@00003360: *00000060 <= 5a9ab279
443@00003364: $22 <= 4c4fd0b9
445@0000336c: *00000064 <= 4c4fd0b9
449@00003370: $25 <= b727d748
453@0000337c: *00000068 <= b727d748
457@00003380: $ 0 <= 000022df
457@00003384: *0000006c <= 00000000
461@00003388: $24 <= c03dfefb
463@00003390: *00000070 <= c03dfefb
467@00003394: $13 <= 3ace1298
471@000033a0: *00000074 <= 3ace1298
475@000033a4: $14 <= 823056c4
475@000033a8: *00000078 <= 823056c4
479@000033ac: $15 <= 1819b214
481@000033b4: *0000007c <= 1819b214
485@000033b8: $20 <= eb7f48a6
489@000033c4: *00000080 <= eb7f48a6
493@000033c8: $13 <= 6bc19387
493@000033cc: *00000084 <= 6bc19387
```

```
497@000033d0: $28 <= 83dbdf9b
499@000033d8: *00000088 <= 83dbdf9b
503@000033dc: $31 <= e98a1140
507@000033e8: *0000008c <= e98a1140
511@000033ec: $10 <= 29a5afeb
511@000033f0: *00000090 <= 29a5afeb
515@000033f4: $21 <= 3e3d9255
517@000033fc: *00000094 <= 3e3d9255
521@00003400: $22 <= 9992124c
525@0000340c: *00000098 <= 9992124c
529@00003410: $16 <= 954758e1
529@00003414: *0000009c <= 954758e1
533@00003418: $12 <= 943dd279
535@00003420: *000000a0 <= 943dd279
539@00003424: $ 6 <= c337c237
543@00003430: *000000a4 <= c337c237
547@00003434: $12 <= 943dfb7b
547@00003438: *000000a8 <= 943dfb7b
551@0000343c: $16 <= 9547dde1
553@00003444: *000000ac <= 9547dde1
557@00003448: $11 <= 3a88d87f
561@00003454: *000000b0 <= 3a88d87f
563@00003458: *000000b4 <= 66b33034
565@0000345c: *000000b8 <= e98a1140
567@00003460: *000000bc <= abbd47a1
571@00003464: $29 <= 00000fdc
573@00003468: $ 1 <= 00000020
575@0000346c: $31 <= 00003474
577@0000381c: *00000fdc <= 6f591dbf
579@00003820: *00000fec <= 00003474
581@00003824: *00000fe0 <= bd856fbd
583@00003828: *00000fe4 <= c337c237
585@0000382c: *00000fe8 <= 402f87b2
587@00003830: *00000ff0 <= c2386d7e
589@00003834: *00000ff4 <= af4e338e
591@00003838: *00000ff8 <= 29a5afeb
595@0000383c: $17 <= 00000054
597@00003840: $18 <= 000000dc
599@00003844: $ 8 <= d7c7877f
601@00003848: $ 9 <= 6bc19387
605@0000384c: $ 7 <= 43891b06
607@00003850: $ 4 <= 4720a53e
609@00003854: $ 5 <= 29470344
611@00003858: $10 <= 7067a882
```

```
613@0000385c: $ 4 <= 7067abc2
615@00003860: $10 <= e0cf5104
617@00003864: $10 <= c19ea208
619@00003868: $ 5 <= c19efb0a
621@0000386c: $ 6 <= c19efbfa
629@0000387c: $31 <= 00003884
631@00003880: $29 <= 00000fbc
631@00003898: *00000fbc <= 7067abc2
633@0000389c: *00000fc0 <= c19efb0a
635@000038a0: *00000fcc <= 00003884
637@000038a4: *00000fc4 <= c19efbfa
639@000038a8: *00000fc8 <= 43891b06
641@000038ac: *00000fd0 <= d7c7877f
643@000038b0: *00000fd4 <= 6bc19387
645@000038b4: *00000fd8 <= c19ea208
649@000038b8: $17 <= 00000098
651@000038bc: $18 <= 00000036
653@000038c0: $ 9 <= 00000000
655@000038c4: $ 8 <= 00000000
659@000038c8: $ 7 <= 00000000
661@000038cc: $ 4 <= 7067abc2
663@000038d0: $ 5 <= c19efb0a
665@000038d4: $10 <= 3206a6cc
667@000038d8: $ 4 <= 3206f6fd
669@000038dc: $10 <= 640d4d98
671@000038e0: $10 <= c81a9b30
673@000038e4: $ 5 <= c81aff3b
675@000038e8: $ 6 <= c81afffb
683@000038f4: $31 <= 000038fc
685@000038f8: $29 <= 00000f9c
685@00003908: *00000fac <= 000038fc
687@0000390c: *00000f9c <= 3206f6fd
689@00003910: *00000fa0 <= c81aff3b
691@00003914: *00000fa4 <= c81afffb
693@00003918: *00000fa8 <= 00000000
695@0000391c: *00000fb0 <= 00000000
697@00003920: *00000fb4 <= 00000000
699@00003924: *00000fb8 <= c81a9b30
703@00003928: $17 <= 0000008b
705@0000392c: $18 <= 0000012e
707@00003930: $ 8 <= b727d748
709@00003934: $ 9 <= 00000000
713@00003938: $ 7 <= b727d748
715@0000393c: $ 4 <= e92ece45
```

```
717@00003940: $ 5 <= c81aff3b
719@00003944: $10 <= b149cd80
721@00003948: $ 4 <= b149ff92
723@0000394c: $10 <= 62939b00
725@00003950: $10 <= c5273600
727@00003954: $ 5 <= c527bf05
729@00003958: $ 6 <= c527bff5
737@00003968: $31 <= 00003970
739@0000396c: $29 <= 00000f7c
739@00003da4: *00000f7c <= b149ff92
741@00003da8: *00000f8c <= 00003970
743@00003dac: *00000f80 <= c527bf05
745@00003db0: *00000f84 <= c527bff5
747@00003db4: *00000f88 <= b727d748
749@00003db8: *00000f90 <= b727d748
751@00003dbc: *00000f94 <= 00000000
753@00003dc0: *00000f98 <= c5273600
757@00003dc4: $17 <= 00000182
759@00003dc8: $18 <= 000000c2
761@00003dcc: $ 8 <= 00000000
763@00003dd0: $ 9 <= 5a556ff9
767@00003dd4: $ 7 <= 5a556ff9
769@00003dd8: $ 4 <= b149ff92
771@00003ddc: $ 5 <= 1f7d2efe
773@00003de0: $10 <= d0c72e90
775@00003de4: $ 4 <= d0c76ebd
777@00003de8: $10 <= a18e5d20
779@00003dec: $10 <= 431cba40
781@00003df0: $ 5 <= 431cbb40
783@00003df4: $ 6 <= 431cbbf0
791@00003e04: $31 <= 00003e0c
793@00003e08: $29 <= 00000f5c
793@00003ae0: *00000f5c <= d0c76ebd
795@00003ae4: *00000f6c <= 00003e0c
797@00003ae8: *00000f60 <= 431cbb40
799@00003aec: *00000f64 <= 431cbbf0
801@00003af0: *00000f68 <= 5a556ff9
803@00003af4: *00000f70 <= 00000000
805@00003af8: *00000f74 <= 5a556ff9
807@00003afc: *00000f78 <= 431cba40
811@00003b00: $17 <= 0000013f
813@00003b04: $18 <= 000000d4
815@00003b08: $ 8 <= 9992124c
817@00003b0c: $ 9 <= 00000000
```

```
821@00003b10: $ 7 <= 9992124c
823@00003b14: $ 4 <= 6a598109
825@00003b18: $ 5 <= 431cbb40
827@00003b1c: $10 <= ad763c49
829@00003b20: $ 4 <= ad76bc6f
831@00003b24: $10 <= 5aec7892
833@00003b28: $10 <= b5d8f124
835@00003b2c: $ 5 <= b5d8f727
837@00003b30: $ 6 <= b5d8f7f7
845@00003b40: $31 <= 00003b48
847@00003b44: $29 <= 00000f3c
847@00003c44: *00000f3c <= ad76bc6f
849@00003c48: *00000f4c <= 00003b48
851@00003c4c: *00000f40 <= b5d8f727
853@00003c50: *00000f44 <= b5d8f7f7
855@00003c54: *00000f48 <= 9992124c
857@00003c58: *00000f50 <= 9992124c
859@00003c5c: *00000f54 <= 00000000
861@00003c60: *00000f58 <= b5d8f124
865@00003c64: $17 <= 000000e4
867@00003c68: $18 <= 000000ff
869@00003c6c: $ 9 <= 4c4fd0b9
871@00003c70: $ 8 <= 00000000
875@00003c74: $ 7 <= 4c4fd0b9
877@00003c78: $ 4 <= ad76bc6f
879@00003c7c: $ 5 <= 0228c7e0
881@00003c80: $10 <= af9f844f
883@00003c84: $ 4 <= af9fde6f
885@00003c88: $10 <= 5f3f089e
887@00003c8c: $10 <= be7e113c
889@00003c90: $ 5 <= be7e553e
891@00003c94: $ 6 <= be7e55fe
899@00003ca0: $31 <= 00003ca8
901@00003ca4: $29 <= 00000f1c
901@00003d30: *00000f2c <= 00003ca8
903@00003d34: *00000f1c <= af9fde6f
905@00003d38: *00000f20 <= be7e553e
907@00003d3c: *00000f24 <= be7e55fe
909@00003d40: *00000f28 <= 4c4fd0b9
911@00003d44: *00000f30 <= 00000000
913@00003d48: *00000f34 <= 4c4fd0b9
915@00003d4c: *00000f38 <= be7e113c
919@00003d50: $17 <= 000000f8
921@00003d54: $18 <= 00000048
```

```
923@00003d58: $ 9 <= 00000000
925@00003d5c: $ 8 <= 00000000
929@00003d60: $ 7 <= 00000000
931@00003d64: $ 4 <= af9fde6f
933@00003d68: $ 5 <= be7e553e
935@00003d6c: $10 <= 6e1e33ad
937@00003d70: $ 4 <= 6e1e37fd
939@00003d74: $10 <= dc3c675a
941@00003d78: $10 <= b878ceb4
943@00003d7c: $ 5 <= b878dfb6
945@00003d80: $ 6 <= b878dff6
953@00003d8c: $31 <= 00003d94
955@00003d90: $29 <= 00000efc
955@00003bcc: *00000f0c <= 00003d94
957@00003bd0: *00000efc <= 6e1e37fd
959@00003bd4: *00000f00 <= b878dfb6
961@00003bd8: *00000f04 <= b878dff6
963@00003bdc: *00000f08 <= 00000000
965@00003be0: *00000f10 <= 00000000
967@00003be4: *00000f14 <= 00000000
969@00003be8: *00000f18 <= b878ceb4
973@00003bec: $17 <= 000000df
975@00003bf0: $18 <= 0000011b
977@00003bf4: $ 8 <= 00000000
979@00003bf8: $ 9 <= 00000000
983@00003bfc: $ 7 <= 00000000
985@00003c00: $ 4 <= 6e1e37fd
987@00003c04: $ 5 <= b878dfb6
989@00003c08: $10 <= 269717b3
991@00003c0c: $ 4 <= 269777fb
993@00003c10: $10 <= 4d2e2f66
995@00003c14: $10 <= 9a5c5ecc
997@00003c18: $ 5 <= 9a5cdfcd
999@00003c1c: $ 6 <= 9a5cdffd
1007@00003c2c: $31 <= 00003c34
1009@00003c30: $29 <= 00000edc
1009@00003e90: *00000eec <= 00003c34
1011@00003e94: *00000edc <= 269777fb
1013@00003e98: *00000ee0 <= 9a5cdfcd
1015@00003e9c: *00000ee4 <= 9a5cdffd
1017@00003ea0: *00000ee8 <= 00000000
1019@00003ea4: *00000ef0 <= 00000000
1021@00003ea8: *00000ef4 <= 00000000
1023@00003eac: *00000ef8 <= 9a5c5ecc
```

```
1027@00003eb0: $17 <= 00000108
1029@00003eb4: $18 <= 0000016e
1031@00003eb8: $ 8 <= 5a556ff9
1033@00003ebc: $ 9 <= 00000000
1037@00003ec0: $ 7 <= 5a556ff9
1039@00003ec4: $ 4 <= 80ece7f4
1041@00003ec8: $ 5 <= 9a5cdfcd
1043@00003ecc: $10 <= 1b49c7c1
1045@00003ed0: $ 4 <= 1b49cfc9
1047@00003ed4: $10 <= 36938f82
1049@00003ed8: $10 <= 6d271f04
1051@00003edc: $ 5 <= 6d271f0d
1053@00003ee0: $ 6 <= 6d271ffd
1061@00003ef0: $31 <= 00003ef8
1063@00003ef4: $29 <= 00000ebc
1063@00003e20: *00000ebc <= 1b49cfc9
1065@00003e24: *00000ec0 <= 6d271f0d
1067@00003e28: *00000ecc <= 00003ef8
1069@00003e2c: *00000ec4 <= 6d271ffd
1071@00003e30: *00000ec8 <= 5a556ff9
1073@00003e34: *00000ed0 <= 5a556ff9
1075@00003e38: *00000ed4 <= 00000000
1077@00003e3c: *00000ed8 <= 6d271f04
1081@00003e40: $17 <= 000000b8
1083@00003e44: $18 <= 000000ff
1085@00003e48: $ 9 <= 00000000
1087@00003e4c: $ 8 <= 5a9ab279
1091@00003e50: $ 7 <= 5a9ab279
1093@00003e54: $ 4 <= 75e48242
1095@00003e58: $ 5 <= 6d271f0d
1097@00003e5c: $10 <= e30ba14f
1099@00003e60: $ 4 <= e30be9ff
1101@00003e64: $10 <= c617429e
1103@00003e68: $10 <= 8c2e853c
1105@00003e6c: $ 5 <= 8c2edd3d
1107@00003e70: $ 6 <= 8c2eddfd
1115@00003e7c: $31 <= 00003e84
1117@00003e80: $29 <= 00000e9c
1117@00003f08: *00000e9c <= e30be9ff
1119@00003f0c: *00000eac <= 00003e84
1121@00003f10: *00000ea0 <= 8c2edd3d
1123@00003f14: *00000ea4 <= 8c2eddfd
1125@00003f18: *00000ea8 <= 5a9ab279
1127@00003f1c: *00000eb0 <= 5a9ab279
```

```
1129@00003f20: *00000eb4 <= 00000000
1131@00003f24: *00000eb8 <= 8c2e853c
1135@00003f28: $17 <= 00000027
1137@00003f2c: $18 <= 0000012d
1139@00003f30: $ 9 <= 00000000
1141@00003f34: $ 8 <= 00000000
1145@00003f38: $ 7 <= 00000000
1147@00003f3c: $ 4 <= e30be9ff
1149@00003f40: $ 5 <= 8c2edd3d
1151@00003f44: $10 <= 6f3ac73c
1153@00003f48: $ 4 <= 6f3ac7fe
1155@00003f4c: $10 <= de758e78
1157@00003f50: $10 <= bceb1cf0
1159@00003f54: $ 5 <= bceb1ef1
1161@00003f58: $ 6 <= bceb1ef1
1169@00003f6c: $ 7 <= 00003e84
1171@00003f70: $29 <= 00000ebc
1179@00003e84: $ 7 <= 00003ef8
1187@00003e8c: $29 <= 00000edc
1189@00003ef8: $ 7 <= 00003c34
1191@00003efc: $29 <= 00000efc
1199@00003c34: $ 7 <= 00003d94
1201@00003c38: $29 <= 00000f1c
1209@00003d94: $ 7 <= 00003ca8
1211@00003d98: $29 <= 00000f3c
1219@00003ca8: $ 7 <= 00003b48
1221@00003cac: $29 <= 00000f5c
1229@00003b48: $ 7 <= 00003e0c
1231@00003b4c: $29 <= 00000f7c
1239@00003e0c: $ 7 <= 00003970
1241@00003e10: $29 <= 00000f9c
1249@00003970: $ 7 <= 000038fc
1251@00003974: $29 <= 00000fbc
1259@000038fc: $ 7 <= 00003884
1267@00003904: $29 <= 00000fdc
1269@00003884: $ 7 <= 00003474
1271@00003888: $29 <= 00000ffc
1279@00003474: $ 1 <= 00000000
1281@00003478: $ 1 <= 00000000
1289@0000348c: $ 1 <= 2af20000
1291@00003490: $ 2 <= 2af20000
1297@000034a4: $ 3 <= 2af30000
1305@000034b4: $ 4 <= 9a2dc7fe
1307@000034b8: $ 1 <= 61830000
```

```
1309@000034bc: $ 2 <= 8c750000
1311@000034c0: $ 5 <= 81240000
1313@000034c4: $ 4 <= e2a70000
1315@000034c8: $ 6 <= 3bc71ef1
1317@000034cc: $31 <= 000034d4
1319@000034d8: *000004d4 <= 00003474
1323@000034dc: $31 <= 00003474
1325@000034e0: $31 <= 00000000
1327@000034e4: $31 <= 000034ec
1335@000034f8: $31 <= 00000000
1337@000034fc: $31 <= 00003504
1347@00003514: $ 4 <= 00000004
1349@00003518: $ 5 <= 00000005
1351@0000351c: $ 1 <= 00000001
1353@00003520: $ 4 <= 00000005
1363@00003538: $ 1 <= 00000001
1365@0000353c: $ 2 <= 00000002
1367@00003540: $ 3 <= 00000003
1369@00003544: $ 4 <= 00000004
1371@00003548: $ 5 <= 00000006
1373@0000354c: $ 6 <= 00000005
1375@00003550: $ 5 <= 00000005
1377@00003554: $ 6 <= 00000003
1385@00003560: $31 <= 00003568
1389@00003568: $ 3 <= 0000356b
1391@0000356c: $ 4 <= ffffca9c
1393@00003570: $31 <= 00003578
1399@000037f8: $31 <= 000035ff
1401@00003578: $31 <= 00003580
1405@000037fc: $ 6 <= 0000358a
1411@00003580: $31 <= 00003588
1417@0000380c: $24 <= 000035ff
1419@00003588: $31 <= 00003590
1423@00003810: $25 <= 0000359a
1427@00003590: *000000c0 <= 00000000
1429@00003594: *000000c4 <= 00000001
1431@00003598: *000000c8 <= 00000002
1433@0000359c: *000000cc <= 0000356b
1435@000035a0: *000000d0 <= ffffca9c
1437@000035a4: *000000d4 <= 00000005
1439@000035a8: *000000d8 <= 0000358a
1441@000035ac: *000000dc <= 00003474
1443@000035b0: *000000e0 <= 00000000
1445@000035b4: *000000e4 <= 00000000
```

```
1447@000035b8: *000000e8 <= bceb1cf0
1449@000035bc: *000000ec <= 3a88d87f
1451@000035c0: *000000f0 <= 943dfb7b
1453@000035c4: *000000f4 <= 6bc19387
1455@000035c8: *000000f8 <= 823056c4
1457@000035cc: *000000fc <= 1819b214
1459@000035d0: *00000100 <= 9547dde1
1461@000035d4: *00000104 <= 00000027
1463@000035d8: *00000108 <= 0000012d
1465@000035dc: *0000010c <= d7c7877f
1467@000035e0: *00000110 <= eb7f48a6
1469@000035e4: *00000114 <= 3e3d9255
1471@000035e8: *00000118 <= 9992124c
1473@000035ec: *0000011c <= 8eef5ec7
1475@000035f0: *00000120 <= 000035ff
1477@000035f4: *00000124 <= 0000359a
1479@000035f8: *00000128 <= 9efb54dc
1481@000035fc: *0000012c <= 57dbb319
1483@00003600: *00000130 <= 83dbdf9b
1485@00003604: *00000134 <= 00000ffc
1487@00003608: *00000138 <= 38dfa03b
1489@0000360c: *0000013c <= 00003590
1493@00003610: $31 <= f8750000
1499@0000361c: $31 <= 00000002
1499@00003620: *00000140 <= 00000002
1503@00003624: $14 <= 6bc1c7fb
1507@00003628: $31 <= 00003630
1509@00003634: *00000144 <= 00003630
1513@00003638: $25 <= 8396031b
1523@00003644: $31 <= 00000002
1523@00003648: *00000148 <= 00000002
1527@0000364c: $29 <= 3a650000
1531@00003654: $31 <= 0000365c
1533@00003660: *0000014c <= 0000365c
1537@00003664: $10 <= 00003600
1541@0000366c: $31 <= 00003674
1543@00003678: *00000150 <= 00003674
1547@0000367c: $12 <= c337c237
1557@0000368c: $31 <= 00000002
1557@00003690: *00000154 <= 00000002
1561@00003694: $31 <= e4e10000
1571@000036a8: $31 <= 00000002
1571@000036ac: *00000158 <= 00000002
1575@000036b0: $ 1 <= c337f6ab
```

```
1585@000036c4: $31 <= 00000002
1585@000036c8: *0000015c <= 00000002
1589@000036cc: $20 <= 9547dde1
1599@000036e0: $31 <= 00000002
1599@000036e4: *00000160 <= 00000002
1603@000036e8: $17 <= 4ba70000
1605@000036ec: $31 <= 000036f4
1607@000036f8: *00000164 <= 000036f4
1611@000036fc: $ 8 <= 7511b0fe
1615@00003700: $31 <= 00003708
1617@0000370c: *00000168 <= 00003708
1621@00003710: $ 1 <= 6bc19387
1627@00003714: $31 <= 0000371c
1629@00003720: *0000016c <= 0000371c
1633@00003724: $18 <= dbf90000
1641@00003734: $31 <= 00000002
1641@00003738: *00000170 <= 00000002
1645@0000373c: $23 <= 8396391a
1653@0000374c: $31 <= 00000002
1653@00003750: *00000174 <= 00000002
1657@00003754: $20 <= 00000002
1663@0000375c: $31 <= 00003764
1665@00003768: *00000178 <= 00003764
1669@0000376c: $21 <= 59a70000
1675@00003778: $31 <= 00003780
1677@00003784: *0000017c <= 00003780
1681@00003788: $ 8 <= 6bc1c987
1687@00003794: $31 <= 0000379c
1689@000037a0: *00000180 <= 0000379c
1693@000037a4: $ 4 <= f75aff77
1703@000037b8: $31 <= 00000002
1703@000037bc: *00000184 <= 00000002
1707@000037c0: $ 4 <= 0000000c
1709@000037c4: $31 <= 000037cc
1713@000037cc: $31 <= 000037d8
1719@000037d4: $ 4 <= 00000008
1721@000037d8: $31 <= 000037e0
```

四， 思考题

1. 乘除法耗时比其他的 ALU 中进行的运算长，整合将会阻塞后续指令，使得 CPU 性能下降。因此将乘除法运算与 ALU 分开有利于 CPU 的整体性能。如果不

单独设置 HI,LO 寄存器，则彼此结果容易混淆，产生混乱

2. 乘除槽就是当乘除运算时，往往有较长的延迟，这时候乘除类型的指令将会被阻塞，而为了不浪费时间周期，因此可以像跳转延迟槽一样，安排一些与乘除无关且不影响结果的指令正常运行。题目中我们已经简单化：不考虑调整指令顺序，只要是乘除就阻塞。

3. 放在 W 级流水寄存器之后而不是 DM 之后的理由：

1) DM 是整个流水线中最慢的模块，因此 M 级周期长短直接决定流水线的周期，如果继续增加其中的元件，将会进一步增加流水线周期，降低流水线的性能。进而拖慢整个流水线，而 W 级本身周期较短，加上也不会对整体性能造成影响。

2) 放在 W 级之后更符合高内聚低耦合的原则，M 级只需做访存的工作，只需要拿出相应的字即可，对于写回信号的分选、处理等工作，更应该是 W 级应该完成的工作。

4. 当向 DM 中存入一个字符串时，更有优势。字符的 ASCII 码仅需 8 位二进制码即可确定，一个 word 中可以放入 4 个 ASCII 字符。如果按字来访问则还需另外的处理才能拿到需要的字节。

5. 我个人属于 Planner 型。主要通过以下方式克服复杂的问题：

（1） 规范加指令的步骤：需不需要增加部件模块？（一般不用）控制信号如何选取？（这是重点）

（2） 处理冒险与暂停：尽量参考已有的，即便不能直接归为一类也依然可以

借鉴。

6. detector 型更适合写代码经验更为丰富的同学，他们经过长期地训练，对编程方面更多地有自己的理解，已经形成了有效的，完备的思考模式，用自己的方式去处理问题，他们更容易得心应手。

而 planner 更适合编程经历，编程感觉不如前者的同学。按照一定的，可以复制的方法论逐步完善设计，同样能达成目标，从结果上来看，降低了流水线 CPU 设计与实现的智力壁垒。此外，planner 的设计更方便广泛的交流，在现实中的工程实践里，这种设计更容易被团队中的其他人，合作伙伴等方所理解，接纳。