✎ Resumo 1.0

sexta-feira, 10 de setembro de 2021 22:19

- Arquitetura Poxim
  - *Complexity-Reduced Instruction Set Processor* (CRISP)
  - Didática, hipotética e simples com 32 bits
  - Memória Von Neumann de 32 KiB
  - 3 formatos de instruções

CISC tem operando de memoria
RISC só usa resgistradores

MEMORIA

Memória de 4 GiB

0x00000000	B_1	B_2	B_3	B_4
0x00000004	B_5	B_6	B_7	B_8
⋮	⋮	⋮	⋮	⋮
0xFFFFFFF8	B_{n-7}	B_{n-6}	B_{n-5}	B_{n-4}
0xFFFFFFFC	B_{n-3}	B_{n-2}	B_{n-1}	B_n

32 bits (4 bytes)

CUSTO

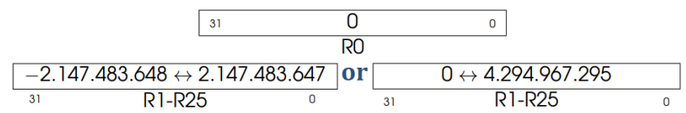
Capacidade × Custo × Latência

Tipo	Capacidade	Custo	Latência
Imediato	1 ↔ 3 bytes	-	-
SRAM	2 KiB ↔ 32 Mbit	≈US$ 5.000 / GiB	0,20 ↔ 2 ns
DRAM	1 ↔ 16 GiB	≈US$ 3 / GiB	≈10 ns

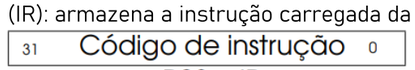
Registrador

Propósito geral (R0-R25)

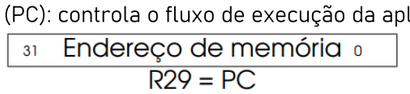
R0 possui valor constante 0 e os demais registradores podem armazenar valores de 32 bits com ou sem signal



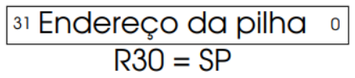
- (IR): armazena a instrução carregada da memória e em execução



- (PC): controla o fluxo de execução da aplicação apontando para as instruções

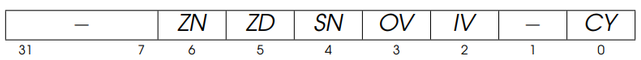


- (SP): referencia o topo da pilha na memória (alocação estática e subrotinas)



- (SR): controle de configurações e status das operações do processador

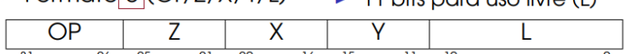
Registrador de status (SR) R31 = SR



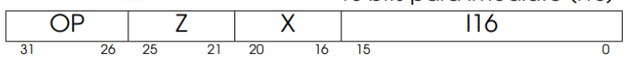
- *ZN* (zero): igual a 0
- *ZD* (divisão por zero): divisor $B = 0$
- *SN* (sinal): sinal negativo
- *OV* (*overflow*): extrapolação de capacidade
- *IV* (instrução inválida): código de operação inválido
- *CY* (*carry*): vai a um aritmético

OPERATIONS

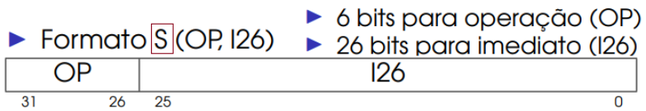
- Formato U (OP, Z, X, Y, L)
  - 6 bits para operação (OP)
  - 5 bits para operandos (Z, X, Y)
  - 11 bits para uso livre (L)



- Formato F (OP, Z, X, I16)
  - 6 bits para operação (OP)
  - 5 bits para operandos (Z, X)
  - 16 bits para imediato (I16)



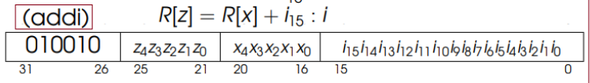
- Formato S (OP, I26)
  - 6 bits para operação (OP)
  - 26 bits para imediato (I26)



Tipo F:

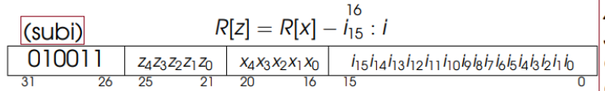
ADIÇÃO IMEDIATA:

(addi) $R[z] = R[x] + \overset{16}{i_{15}} : i$



$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$
$OV \leftarrow (R[x]_{31} = i_{15}) \wedge (R[z]_{31} \neq R[x]_{31})$
$CY \leftarrow (R[z]_{32} = 1)$

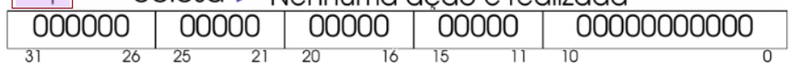
(subi) $R[z] = R[x] - \overset{16}{i_{15}} : i$



$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$
$OV \leftarrow (R[x]_{31} \neq i_{15}) \wedge (R[z]_{31} \neq R[x]_{31})$
$CY \leftarrow (R[z]_{32} = 1)$

Tipo U:

nop ociosa ► Nenhuma ação é realizada



atribuição imediata

(muli) $R[z] = R[x] \times \overset{16}{i_{15}} : i$ Com sinal

010100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

$ZN \leftarrow (R[z] = 0)$
$OV \leftarrow (R[z]_{63:32} \neq 0)$

(divi) $R[z] = R[x] \div \overset{16}{i_{15}} : i$ Com sinal

010101	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

$ZN \leftarrow (R[z] = 0)$
$ZD \leftarrow (i = 0)$
$OV \leftarrow 0$

(remi) $R[z] = R[x] \bmod \overset{16}{i_{15}} : i$ Com sinal

010110	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

$ZN \leftarrow (R[z] = 0)$
$ZD \leftarrow (i = 0)$
$OV \leftarrow 0$

(cmpi) $CMPI = R[x] - \overset{16}{i_{15}} : i$

010111	–	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

$ZN \leftarrow (CMPI = 0)$
$SN \leftarrow (CMPI_{31} = 1)$
$OV \leftarrow (R[x]_{31} \neq i_{15}) \wedge (CMPI_{31} \neq R[x]_{31})$
$CY \leftarrow (CMPI_{32} = 1)$

Tipo F:

Operações de leitura/escrita da memória I
8 bits (I8, s8) I 16 bits (I16, s16) I 32 bits (I32, s32)

(I8) $R[z] = MEM\left[R[x] + \overset{16}{i_{15}} : i\right]$

011000	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

(I16) $R[z] = MEM\left[\left(R[x] + \overset{16}{i_{15}} : i\right) \ll 1\right]$

011001	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

(I32) $R[z] = MEM\left[\left(R[x] + \overset{16}{i_{15}} : i\right) \ll 2\right]$

011010	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

ESCRITA:

(s8) $MEM\left[R[x] + \overset{16}{i_{15}} : i\right] = R[z]$

011011	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

(s16) $MEM\left[\left(R[x] + \overset{16}{i_{15}} : i\right) \ll 1\right] = R[z]$

011100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

(s32) $MEM\left[\left(R[x] + \overset{16}{i_{15}} : i\right) \ll 2\right] = R[z]$

011101	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

(call) $PC = \left(R[x] + \overset{16}{i_{15}} : i\right) \ll 2$ $MEM[SP] = PC + 4, SP = SP - 4$

011110	–	$x_4x_3x_2x_1x_0$	$i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–21	20–16	15–0

(ret) $SP = SP + 4, PC = MEM[SP]$

(mov) ▶ $R[z] = 0 : x : y : I$ ▶ Sem extensão de sinal

000000	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$I_{10}I_9I_8I_7I_6I_5I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

(movs) ▶ $R[z] = \overset{11}{x_4} : x : y : I$ ▶ Com extensão de sinal

000001	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$I_{10}I_9I_8I_7I_6I_5I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

com registradores:

adição:

(add) ▶ $R[z] = R[x] + R[y]$

000010	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	–
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$
$OV \leftarrow (R[x]_{31} = R[y]_{31} \wedge R[z]_{31} \neq R[x]_{31})$
$CY \leftarrow (R[z]_{32} = 1)$

0b00010..
>> 1 = 0b00001..
int instruçao;
$inteiro = \ a_1a_2a_3z_1z_2z_3m_1m_2$
$zr = \ a_1a_2a_3z_1z_2z_3m_1m_2 \ \& \ 00011100$
$a_1a_2a_3z_1z_2z_3m_1m_2$
0 0 0 1 1 1 0 0
zrmask = 0 0 0 z_1 z_2 z_3 0 0
= 0 0 0 z_1 z_2 z_3 0 0 $\gg 2$
rz = 0 0 0 0 0 z_1 z_2 z_3
opmask =11100000

op = (instrução & opmask) >> 26
rz = (instrução & rzmask) >> 21
rx = (instrução & rxmask) >> 16

add, sub

if op == 0b001: // add
  print("ADD, regitrador{rz}, regitraso rx{rx}")
1 and 0 = 0

int op = instrução >> 21
if (OP == 0b00010)
  add(z,x,y)

subtração

(sub) ▶ $R[z] = R[x] - R[y]$

000011	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	–
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$
$OV \leftarrow (R[x]_{31} \neq R[y]_{31} \wedge R[z]_{31} \neq R[x]_{31})$
$CY \leftarrow (R[z]_{32} = 1)$

multiplicação

(mul) $R[I_{4:0}] : R[z] = R[x] \times R[y]$ Sem sinal

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	000– – –$I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[I_{4:0}] : R[z] = 0)$
$CY \leftarrow (R[I_{4:0}] \neq 0)$

(muls) $R[I_{4:0}] : R[z] = R[x] \times R[y]$ Com sinal

(rel)

011111	—	—	—
31–26	25–21	20–16	15–0

I Operações de controle de fluxo I

Desvio condicional:
(**bae, bat, bbe, bbt, beq, bge, bgt, biv, ble, blt, bne, bni, bnz, bzd**)

Desvio incondicional:
(**bun**) I Interrupção (**int**)

Desvio Condicional:

Tipo S:

Condição *AE* (sem signal)

(bae) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

101010	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A \geq B \rightarrow A - B \geq 0 \equiv AE \leftarrow CY = 0$

Condição *AT* (sem signal)

(bat) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

101011	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A > B \rightarrow A - B > 0 \equiv AT \leftarrow (ZN = 0 \wedge CY = 0)$

Condição *BE* (sem signal)

(bbe) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

101100	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A \leq B \rightarrow A - B \leq 0 \equiv BE \leftarrow (ZN = 1 \vee CY = 1)$

Condição *BT* (sem signal)

(bbt) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

101101	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A < B \rightarrow A - B < 0 \equiv BT \leftarrow CY = 1$

Condição *EQ*

(beq) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

101110	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A = B \rightarrow A - B = 0 \equiv EQ \leftarrow ZN = 1$

Condição *GE* (com signal)

(bge) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

101111	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A \geq B \rightarrow A - B \geq 0 \equiv GE \leftarrow SN = OV$

Condição *GT* (com signal)

(bgt) $PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$

110000	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31–26	25–0

$A > B \rightarrow A - B > 0 \equiv GT \leftarrow (ZN = 0 \wedge SN = OV)$

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$010{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[I_{4:0}] : R[z] = 0)$
$OV \leftarrow (R[I_{4:0}] \neq 0)$

divisão:

(div) $R[I_{4:0}] = R[x] \bmod R[y], R[z] = R[x] \div R[y]$ Sem sinal

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$100{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$ZD \leftarrow (R[y] = 0)$
$CY \leftarrow (R[I_{4:0}] \neq 0)$

(divs) $R[I_{4:0}] = R[x] \bmod R[y], R[z] = R[x] \div R[y]$ Com sinal

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$110{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$ZD \leftarrow (R[y] = 0)$
$OV \leftarrow (R[I_{4:0}] \neq 0)$

Deslocamento:

Esquerda lógico:

(sll) $R[z] : R[x] = (R[z] : R[y]) \times 2^{I_{4:0}+1}$ (sem sinal)

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$001{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] : R[x] = 0)$
$CY \leftarrow (R[z] \neq 0)$

Esquerda aritmetico:

(sla) $R[z] : R[x] = (R[z] : R[y]) \times 2^{I_{4:0}+1}$ Aritmético (com sinal)

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$011{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] : R[x] = 0)$
$OV \leftarrow (R[z] \neq 0)$

Direito lógico

(srl) $R[z] : R[x] = (R[z] : R[y]) \div 2^{I_{4:0}+1}$ Lógico (sem sinal)

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$101{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] : R[x] = 0)$
$CY \leftarrow (R[z] \neq 0)$

Direito artimetico

(sra) $R[z] : R[x] = (R[z] : R[y]) \div 2^{I_{4:0}+1}$ Aritmético (com sinal)

000100	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$111{-}{-}{-}I_4I_3I_2I_1I_0$
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] : R[x] = 0)$
$OV \leftarrow (R[z] \neq 0)$

Comparação

(cmp) $CMP = R[x] - R[y]$

000101	—	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	—
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (CMP = 0)$
$SN \leftarrow (CMP_{31} = 1)$
$OV \leftarrow (R[x]_{31} \neq R[y]_{31}) \wedge (CMP_{31} \neq R[x]_{31})$
$CY \leftarrow (CMP_{32} = 1)$

BIT A BIT:

(and) $R[z] = R[x]$ **and** $R[y]$

000110	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	—
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$

(or) $R[z] = R[x]$ **or** $R[y]$

000111	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$

(not) $R[z] =$ **not** $R[x]$

001000	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	—	
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$

(xor) $R[z] = R[x]$ **xor** $R[y]$

001001	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	
31–26	25–21	20–16	15–11	10–0

$ZN \leftarrow (R[z] = 0)$
$SN \leftarrow (R[z]_{31} = 1)$

FlowControl

(push)

$i = v, w, x, y, z$
$i \neq 0 \rightarrow MEM[SP] = R[i], SP = SP - 4$

Condição *IV*

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(biv)

110001	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

Condição *LE* (com sinal)

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(ble)

110010	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

$A \leq B \rightarrow A - B \leq 0 \equiv LE \quad \leftarrow \quad (ZN = 1 \vee SN \neq OV)$

Condição *LT* (com sinal)

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(blt)

110011	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

$A < B \rightarrow A - B < 0 \equiv LT \quad \leftarrow \quad SN \neq OV$

Condição *NE*

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(bne)

110100	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

$A \neq B \rightarrow A - B \neq 0 \equiv NE \quad \leftarrow \quad ZN = 0$

Condição *NI*

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(bni)

110101	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

$NI \quad \leftarrow \quad IV = 0$

Condição *NZ*

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(bnz)

110110	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

$NZ \quad \leftarrow \quad ZD = 0$

Desvio Incondicional:

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(bun)

110111	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

Condição *ZD*

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(bzd)

111000	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

(int) interrupção ▸ Se $i = 0$, a execução é finalizada

111111	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

$MEM[SP] = PC + 4, SP = SP - 4$

$$PC = PC + 4 + \left[\left(i_{25}^{6} : i\right) \ll 2\right]$$

(call)

111001	$i_{25}i_{24}i_{23}i_{22}i_{21}i_{20}i_{19}i_{18}i_{17}i_{16}i_{15}i_{14}i_{13}i_{12}i_{11}i_{10}i_9i_8i_7i_6i_5i_4i_3i_2i_1i_0$
31 26	25 0

(qsort)

001010	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$v_4v_3v_2v_1v_0 - w_4w_3w_2w_1w_0$
31 26	25 21	20 16	15 11	10 0

q	

$i = v, w, x, y, z$

$i \neq 0 \rightarrow SP = SP + 4, R[i] = MEM[SP]$

(pop)

001011	$z_4z_3z_2z_1z_0$	$x_4x_3x_2x_1x_0$	$y_4y_3y_2y_1y_0$	$v_4v_3v_2v_1v_0 - w_4w_3w_2w_1w_0$
31 26	25 21	20 16	15 11	10 0