1 目的

CPU のシミュレーションプログラム作成を通し CPU の動作を理解する.

2 実習

2.1 実習 7:一方向の連結リスト

| Address | obj | code | source | code | | | |
|---------|-----|------|--------|---------------------|--------------|-------------------------------|---|
| 00 | 67 | 00 | START: | LD | mem(IX+00H), | ACC | mem(IX+00H)->AC |
| 02 | 6f | 01 | | LD | mem(IX+00H), | IX | $\mathrm{mem}(\mathrm{IX}{+}00\mathrm{H}){-}{>}\mathrm{IX}$ |
| 04 | fa | 00 | | CMP | IX, | 0 | IX-00H |
| 06 | 39 | 11 | | BZ | END: | | ZF=1? |
| 08 | f5 | ff | | CMP | ACC, | $\mathrm{mem}[1\mathrm{ffH}]$ | ACC-mem[1ffH] |
| 0a | 3a | 0e | | BN | P1: | | NF=1? |
| 0c | 75 | ff | | ST | ACC, | $\mathrm{mem}[1\mathrm{ffH}]$ | ACC->mem[1ffH] |
| 0e | 62 | 00 | P1: | LD | 00H | ACC | 00H->ACC |
| 10 | 0b | | | JR | START: | | |
| 11 | 0f | | END: | | | | |

表 1 一方向連結リストソースコード

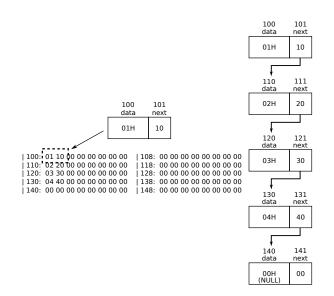


図1 データ構造:リスト

表 1 に一方向連結リストプログラムソースコードを示す.mem[100] へ data,mem[101] へ next として考え. スタート位置は mem[100H] をスタート位置とした.

data が格納されているメモリの隣にアドレスを格納しており、アドレスを IX へ格納して次の data を参照するようになっている.data は ACC へ格納後, これまで参照した最大値が格納されているメモリ (mem[1ffH]) と比較し ACC の方が大きければ入れ替え動作を行う.

NULL は 00H とし next で参照した先が 00 の場合終了する. 表 1 に示すのデータ構造を以下に示す.

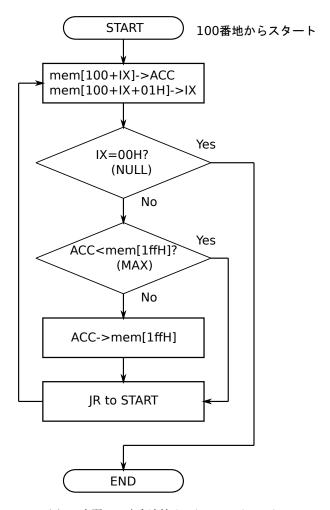


図 2 実習 7:一方向連結リストフローチャート

以下に結果を示す. 結果より mem[1ffH] へ最大値の 04H が格納され終了しているためプログラムは正しく実行されたと確認できる.

```
CPUO,PC=0x0> r 7_list.CPUO,PC=0x0> m 0
    | 000: 67 00 6f 01 fa 00 39 11
                                     | 008: f5 ff 3a 0e 75 ff 62 00
CPU0, PC=0x0> m 10
    | 010: 0b 0f 00 00 00 00 00 00
                                      | 018: 00 00 00 00 00 00 00 00
CPU0, PC=0x0> m 100
    | 100: 01 10 00 00 00 00 00 00
                                       | 108: 00 00 00 00 00 00 00 00
CPU0, PC=0x0> m 110
    | 110: 02 20 00 00 00 00 00 00
                                       | 118:
                                              00 00 00 00 00 00 00
CPUO, PC=0x0> m 120
    | 120: 03 30 00 00 00 00 00 00
                                       | 128: 00 00 00 00 00 00 00 00
CPUO, PC=0x0> m 130
    | 130: 04 40 00 00 00 00 00 00
                                       | 138: 00 00 00 00 00 00 00 00
CPUO, PC=0x0> m 140
    | 140: 00 00 00 00 00 00 00 00
                                       | 148:
                                              00 00 00 00 00 00 00 00
CPUO, PC=0x0> m 1f0
    | 1f0: 00 00 00 00 00 00 00 00
                                      | 1f8: 00 00 00 00 00 00 00 00
CPU0, PC=0x0>c 10
```

```
CPUO, PC=0x10> m 1f0
   | 1f0: 00 00 00 00 00 00 00 00 | 1f8: 00 00 00 00 00 00 01
CPUO, PC=0x10> d
              ix=0x10(16,16) cf=0 vf=0 nf=0 zf=0
acc=0x00(0,0)
ibuf=0:0x00(0,0) obuf=0:0x00(0,0)
CPUO, PC=0x10> i
CPU0, PC=0x0> c 10
CPU0, PC=0x10> m 1f0
    | 1f0: 00 00 00 00 00 00 00 00 | 1f8: 00 00 00 00 00 00 02
CPU0, PC=0x10> d
acc=0x00(0,0) ix=0x20(32,32) cf=0 vf=0 nf=0 zf=0
ibuf=0:0x00(0,0) obuf=0:0x00(0,0)
CPUO, PC=0x10> i
CPU0,PC=0x0> c 10
CPUO, PC=0x10> m 1f0
    | 1f0: 00 00 00 00 00 00 00 00 | 1f8: 00 00 00 00 00 00 03
CPUO, PC=0x10> d
acc=0x00(0,0) ix=0x30(48,48) cf=0 vf=0 nf=0 zf=0
ibuf=0:0x00(0,0) obuf=0:0x00(0,0)
CPUO, PC=0x10> i
CPU0, PC=0x0> c 10
CPUO, PC=0x10> m 1f0
   | 1f0: 00 00 00 00 00 00 00 00 | 1f8: 00 00 00 00 00 00 04
CPUO, PC=0x10> d
acc=0x00(0,0) ix=0x40(64,64) cf=0 vf=0 nf=0 zf=0
ibuf=0:0x00(0,0) obuf=0:0x00(0,0)
CPUO, PC=0x10> i
CPU0, PC=0x0 > c 10
Program Halted.
CPU0, PC=0x12> m 1f0
| 1f0: 00 00 00 00 00 00 00 00 | 1f8: 00 00 00 00 00 00 04
CPUO, PC=0x12> d
acc=0x00(0,0) ix=0x00(0,0) cf=0 vf=0 nf=0 zf=1
ibuf=0:0x00(0,0) obuf=0:0x00(0,0)
CPUO, PC=0x12>
```

2.2 実習 8:データ通信プログラム

| Address | obj | code | source | code | | | |
|---------|-----|------|--------|------|-----------|-----|---------------------|
| 00 | 62 | 03 | START: | LD | 03H(要素数), | ACC | 03H->ACC |
| 02 | 10 | | | OUT | | | ACC->OBUF |
| 03 | 3c | 03 | WAIT: | BNO | WAIT: | | OBUF_FLG_IN=1? |
| 05 | 6a | 00 | | LD | 01H, | IX | 01H->IX |
| 07 | 62 | 01 | | LD | 01H, | ACC | 01H->ACC |
| 09 | 10 | | | OUT | | | ACC->OBUF |
| 0a | 3c | 0a | WAIT2: | BNO | WAIT2: | | OBUF_FLG_IN=1? |
| 0c | ba | 01 | | ADD | IX, | 01H | IX+01H->IX |
| 0e | b2 | 01 | | ADD | ACC, | 01H | ACC+01H->ACC |
| 10 | fa | 03 | | CMP | IX, | 03H | IX-03H |
| 12 | 31 | 09 | | BNZ | WAIT2: | | $(NF \ v \ ZF) = 1$ |
| 14 | Of | | | HLT | | | |

表 2 データ通信プログラム送信側

表 3 データ通信プログラム受信側

| Address | obj | code | source | code | | | |
|---------|-----|------|--------|----------------------|-------|--|----------------------|
| 00 | 34 | 00 | WAIT: | BNI | WAIT: | | $IBUF_F LG_I N = 0?$ |
| 02 | 1f | | | IN | | | IBUF->ACC |
| 03 | 75 | c0 | | ST | ACC, | $\mathrm{mem}[1\mathrm{C}0\mathrm{H}]$ | ACC->mem[1c0H] |
| 05 | 6a | 00 | | LD | 00H | IX, | 00H->IX |
| 07 | 34 | 07 | LOOP: | BNI | LOOP: | | IBUF_FLG_IN=0? |
| 09 | 1f | | | IN | | | IBUF->ACC |
| 0a | b5 | 03 | | ADD | ACC, | $\mathrm{mem}[103\mathrm{H}]$ | ACC+mem[103H]->ACC |
| 0c | 75 | 03 | | ST | ACC, | $\mathrm{mem}[103\mathrm{H}]$ | ACC+mem[103H]->ACC |
| 0e | ba | 01 | | ADD | IX, | 01H | IX+01H->IX |
| 10 | fd | c0 | | CMP | IX, | mem[1C0H] | IX+mem[1c0H] |
| 12 | 31 | 07 | | BNZ | LOOP: | | ZF=0? |
| 14 | Of | | | HLT | | | |

表 2,3 にデータ通信プログラムソースコードを示す. 表 2 では要素数を即値を用いて通信相手の受け取りが確認できるまで WAIT でループ待機する.

CPUO,PC=0x0> r 8_out.txt

CPUO,PC=0x0> t

CPU1,PC=0x0> r 8_sum_calc.txt

CPU1,PC=0x0> i CPU1,PC=0x0> i CPU1,PC=0x0> t CPU0,PC=0x0> i

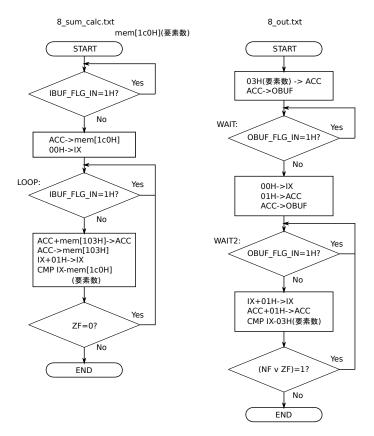


図3 実習8:データ通信プログラムソースコード

```
CPUO, PC=0x2> i
CPUO, PC=0x3> t
CPU1, PC=0x0> i
CPU1, PC=0x2> d
acc=0x00(0,0)
                  ix=0x00(0,0)
                                  cf=0 vf=0 nf=0 zf=0
ibuf=1:0x03(3,3)
                     obuf=0:0x00(0,0)
CPU1, PC=0x2> m
    000:
            34 00 1f 75 c0 6a 00 34
                                        | 008:
                                                07 1f b5 03 75 03 ba 01
    | 010:
            fd c0 31 07 0f 00 00 00
                                        | 018:
                                                00 00 00 00 00 00 00 00
     020:
            00 00 00 00 00 00 00 00
                                          028:
                                                00 00 00 00 00 00 00 00
    030:
            00 00 00 00 00 00 00 00
                                        038:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        1 048:
    1 040:
                                                00 00 00 00 00 00 00 00
    | 050:
            00 00 00 00 00 00 00 00
                                         058:
                                                00 00 00 00 00 00 00 00
    | 060:
            00 00 00 00 00 00 00 00
                                        | 068:
                                                00 00 00 00 00 00 00 00
    | 070:
            00 00 00 00 00 00 00 00
                                        | 078:
                                                00 00 00 00 00 00 00 00
    080:
            00 00 00 00 00 00 00 00
                                        088:
                                                00 00 00 00 00 00 00 00
     090:
            00 00 00 00 00 00 00 00
                                          098:
                                                00 00 00 00 00 00 00 00
    | 0a0:
            00 00 00 00 00 00 00 00
                                        | 0a8:
                                                00 00 00 00 00 00 00 00
    | 0b0:
            00 00 00 00 00 00 00 00
                                        | 0b8:
                                                00 00 00 00 00 00 00 00
     0c0:
            00 00 00 00 00 00 00 00
                                          0c8:
                                                00 00 00 00 00 00 00 00
    | 0d0:
            00 00 00 00 00 00 00 00
                                        | 0d8:
                                                00 00 00 00 00 00 00 00
     0e0:
            00 00 00 00 00 00 00 00
                                          0e8:
                                                00 00 00 00 00 00 00 00
    | Of0:
            00 00 00 00 00 00 00
                                        | 0f8:
                                                00 00 00 00 00 00 00
```

```
l 100:
            00 00 00 00 00 00 00 00
                                        | 108:
                                                00 00 00 00 00 00 00 00
    I 110:
            00 00 00 00 00 00 00 00
                                        | 118:
                                                00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 128:
                                                00 00 00 00 00 00 00 00
    | 120:
    | 130:
            00 00 00 00 00 00 00 00
                                        | 138:
                                                00 00 00 00 00 00 00 00
    | 140:
            00 00 00 00 00 00 00 00
                                        | 148:
                                                00 00 00 00 00 00 00 00
    I 150:
            00 00 00 00 00 00 00 00
                                        I 158:
                                                00 00 00 00 00 00 00 00
    | 160:
            00 00 00 00 00 00 00 00
                                        | 168:
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    | 170:
            00 00 00 00 00 00 00 00
                                        | 178:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 188:
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    | 180:
    | 190:
            00 00 00 00 00 00 00 00
                                        | 198:
                                                00 00 00 00 00 00 00 00
    l 1a0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        l 1a8:
    | 1b0:
            00 00 00 00 00 00 00 00
                                        | 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            00 00 00 00 00 00 00 00
                                        | 1c8:
                                                00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 1d0:
            00 00 00 00 00 00 00 00
                                        | 1d8:
    l 1e0:
            00 00 00 00 00 00 00 00
                                        l 1e8:
                                                00 00 00 00 00 00 00 00
    | 1f0:
            00 00 00 00 00 00 00
                                        | 1f8:
                                                00 00 00 00 00 00 00 00
CPU1, PC=0x2> i
CPU1, PC=0x3> i
CPU1, PC=0x5> m
    1 000:
            34 00 1f 75 c0 6a 00 34
                                        008:
                                                07 1f b5 03 75 03 ba 01
    | 010:
            fd c0 31 07 0f 00 00 00
                                        | 018:
                                                00 00 00 00 00 00 00 00
    1 020:
            00 00 00 00 00 00 00 00
                                        028:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 038:
    | 030:
                                                00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 048:
    | 040:
    | 050:
            00 00 00 00 00 00 00 00
                                        | 058:
                                                00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 060:
            00 00 00 00 00 00 00 00
                                        068:
    | 070:
            00 00 00 00 00 00 00 00
                                        | 078:
                                                00 00 00 00 00 00 00 00
    080:
            00 00 00 00 00 00 00 00
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    090:
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    | 0a0:
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    | 0b0:
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                                        | 0b8:
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    | 0c0:
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                                        | 0c8:
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                                        | 0d8:
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    1 0d0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 0e0:
                                        | 0e8:
    | Of0:
            00 00 00 00 00 00 00 00
                                        | 0f8:
                                                00 00 00 00 00 00 00 00
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                                        | 108:
                                                00 00 00 00 00 00 00 00
    I 100:
    | 110:
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    | 120:
            00 00 00 00 00 00 00 00
                                        | 128:
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                                        | 138:
    I 130:
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    | 140:
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    I 150:
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                                        l 158:
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    | 160:
            00 00 00 00 00 00 00 00
                                        | 168:
                                                00 00 00 00 00 00 00 00
    | 170:
            00 00 00 00 00 00 00 00
                                        | 178:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 180:
                                        | 188:
```

| 190:

00 00 00 00 00 00 00 00

| 198:

00 00 00 00 00 00 00 00

```
| 1a0:
            00 00 00 00 00 00 00 00
                                        | 1a8:
                                                00 00 00 00 00 00 00 00
    | 1b0:
            00 00 00 00 00 00 00 00
                                        | 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            03 00 00 00 00 00 00 00
                                                 00 00 00 00 00 00 00 00
                                        | 1c8:
    | 1d0:
            00 00 00 00 00 00 00 00
                                        | 1d8:
                                                00 00 00 00 00 00 00 00
    | 1e0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        | 1e8:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    l 1f0:
                                        l 1f8:
CPU1, PC=0x5> i
CPU1,PC=0x7> t
CPUO, PC=0x3> i
CPUO, PC=0x5> i
CPUO, PC=0x7 > i
CPUO, PC=0x9> i
CPUO, PC=0xa> i
CPUO, PC=0xa> t
CPU1,PC=0x7> i
CPU1, PC=0x9> i
CPU1, PC=0xa> i
CPU1, PC=0xc> i
CPU1, PC=0xe> i
CPU1, PC=0x10> m
    000:
            34 00 1f 75 c0 6a 00 34
                                        1 008:
                                                07 1f b5 03 75 03 ba 01
    I 010:
            fd c0 31 07 0f 00 00 00
                                        | 018:
                                                 00 00 00 00 00 00 00 00
    | 020:
            00 00 00 00 00 00 00 00
                                        | 028:
                                                 00 00 00 00 00 00 00 00
    1 030:
            00 00 00 00 00 00 00 00
                                        038:
                                                00 00 00 00 00 00 00 00
    | 040:
            00 00 00 00 00 00 00 00
                                        | 048:
                                                 00 00 00 00 00 00 00 00
    | 050:
            00 00 00 00 00 00 00 00
                                        | 058:
                                                00 00 00 00 00 00 00 00
    | 060:
            00 00 00 00 00 00 00 00
                                        068:
                                                 00 00 00 00 00 00 00 00
    | 070:
            00 00 00 00 00 00 00 00
                                        | 078:
                                                 00 00 00 00 00 00 00 00
    080:
            00 00 00 00 00 00 00 00
                                        088:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        098:
    090:
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            00 00 00 00 00 00 00 00
    | 0a0:
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                                                 00 00 00 00 00 00 00 00
    | 0b0:
            00 00 00 00 00 00 00 00
                                        | 0b8:
                                                 00 00 00 00 00 00 00 00
    | 0c0:
            00 00 00 00 00 00 00 00
                                        | 0c8:
                                                00 00 00 00 00 00 00 00
    | 0d0:
            00 00 00 00 00 00 00 00
                                        | 0d8:
                                                 00 00 00 00 00 00 00 00
    | 0e0:
            00 00 00 00 00 00 00 00
                                        | 0e8:
                                                 00 00 00 00 00 00 00 00
    | Of0:
            00 00 00 00 00 00 00 00
                                        | 0f8:
                                                00 00 00 00 00 00 00 00
    1 100:
            00 00 00 01 00 00 00 00
                                        I 108:
                                                 00 00 00 00 00 00 00 00
    | 110:
            00 00 00 00 00 00 00 00
                                        | 118:
                                                00 00 00 00 00 00 00 00
    l 120:
                                        | 128:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 130:
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    I 140:
            00 00 00 00 00 00 00 00
                                        l 148:
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    | 150:
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                                        | 158:
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    | 160:
            00 00 00 00 00 00 00 00
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    | 170:
            00 00 00 00 00 00 00 00
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            00 00 00 00 00 00 00 00
                                        | 188:
    | 180:
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```

```
| 190:
            00 00 00 00 00 00 00 00
                                        | 198:
                                                00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 1a0:
                                        | 1a8:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 1b0:
                                        | 1b8:
    | 1c0:
            03 00 00 00 00 00 00 00
                                        | 1c8:
                                                00 00 00 00 00 00 00 00
    | 1d0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        l 1d8:
    l 1e0:
            00 00 00 00 00 00 00 00
                                        l 1e8:
                                                00 00 00 00 00 00 00 00
    | 1f0:
            00 00 00 00 00 00 00 00
                                        | 1f8:
                                                00 00 00 00 00 00 00 00
CPU1, PC=0x10> i
CPU1, PC=0x12> i
CPU1,PC=0x7>i
CPU1, PC=0x7> m
    | 000: 34 00 1f 75 c0 6a 00 34
                                        1 008:
                                                07 1f b5 03 75 03 ba 01
    | 010:
            fd c0 31 07 0f 00 00 00
                                        | 018:
                                                00 00 00 00 00 00 00 00
    1 020:
            00 00 00 00 00 00 00 00
                                        028:
                                                00 00 00 00 00 00 00 00
    I 030:
            00 00 00 00 00 00 00 00
                                        1 038:
                                                00 00 00 00 00 00 00 00
    1 040:
            00 00 00 00 00 00 00 00
                                        048:
                                                00 00 00 00 00 00 00 00
    050:
            00 00 00 00 00 00 00 00
                                        | 058:
                                                00 00 00 00 00 00 00 00
    I 060:
            00 00 00 00 00 00 00 00
                                        1 068:
                                                00 00 00 00 00 00 00 00
    070:
            00 00 00 00 00 00 00 00
                                        | 078:
                                                00 00 00 00 00 00 00 00
    1 080:
            00 00 00 00 00 00 00
                                        088:
                                                00 00 00 00 00 00 00 00
    090:
            00 00 00 00 00 00 00 00
                                        098:
                                                00 00 00 00 00 00 00 00
    | 0a0:
            00 00 00 00 00 00 00 00
                                        | 0a8:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
    | 0b0:
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                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    1 0c0:
                                        | 0c8:
    | 0d0:
            00 00 00 00 00 00 00 00
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                                                00 00 00 00 00 00 00 00
                                        I 0e8:
    | 0e0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | Of0:
            00 00 00 00 00 00 00 00
                                        | 0f8:
                                                00 00 00 00 00 00 00 00
    | 100:
            00 00 00 01 00 00 00 00
                                        | 108:
                                                00 00 00 00 00 00 00 00
    | 110:
            00 00 00 00 00 00 00 00
                                        | 118:
                                                00 00 00 00 00 00 00 00
    I 120:
            00 00 00 00 00 00 00 00
                                        | 128:
                                                00 00 00 00 00 00 00 00
    | 130:
            00 00 00 00 00 00 00 00
                                        | 138:
                                                00 00 00 00 00 00 00 00
    I 140:
            00 00 00 00 00 00 00
                                        | 148:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        l 158:
                                                00 00 00 00 00 00 00 00
    l 150:
            00 00 00 00 00 00 00 00
    | 160:
                                        | 168:
                                                00 00 00 00 00 00 00 00
    | 170:
            00 00 00 00 00 00 00 00
                                        | 178:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 188:
                                                00 00 00 00 00 00 00 00
    l 180:
    I 190:
            00 00 00 00 00 00 00 00
                                        l 198:
                                                00 00 00 00 00 00 00 00
    | 1a0:
            00 00 00 00 00 00 00 00
                                        | 1a8:
                                                00 00 00 00 00 00 00 00
    | 1b0:
            00 00 00 00 00 00 00 00
                                        | 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            03 00 00 00 00 00 00 00
                                        | 1c8:
                                                00 00 00 00 00 00 00 00
    l 1d0:
            00 00 00 00 00 00 00 00
                                        l 1d8:
                                                00 00 00 00 00 00 00 00
    l 1e0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        | 1e8:
    | 1f0:
            00 00 00 00 00 00 00 00
                                        | 1f8:
                                                00 00 00 00 00 00 00 00
CPU1, PC=0x7> i
CPUO, PC=0xa> i
```

```
CPUO, PC=0xc> i
CPUO, PC=0xe> i
CPUO, PC=0x10 > i
CPUO, PC=0x12> i
CPUO, PC=0x9> i
CPUO, PC=0xa> i
CPUO, PC=0xa> m
                                        008:
    | 000:
            62 03 10 3c 03 6a 00 62
                                                01 10 3c 0a ba 01 b2 01
            fa 03 31 09 0f 00 00 00
                                        | 018:
                                                00 00 00 00 00 00 00 00
    | 010:
    020:
            00 00 00 00 00 00 00 00
                                        028:
                                                00 00 00 00 00 00 00 00
    1 030:
            00 00 00 00 00 00 00 00
                                        1 038:
                                                00 00 00 00 00 00 00 00
    | 040:
            00 00 00 00 00 00 00 00
                                        | 048:
                                                00 00 00 00 00 00 00 00
    | 050:
            00 00 00 00 00 00 00 00
                                        | 058:
                                                00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 060:
            00 00 00 00 00 00 00 00
                                        068:
    1 070:
            00 00 00 00 00 00 00 00
                                        1 078:
                                                00 00 00 00 00 00 00 00
    080:
            00 00 00 00 00 00 00 00
                                        088:
                                                00 00 00 00 00 00 00 00
    090:
            00 00 00 00 00 00 00 00
                                        098:
                                                00 00 00 00 00 00 00 00
    I 0a0:
            00 00 00 00 00 00 00 00
                                        I 0a8:
                                                00 00 00 00 00 00 00 00
    | 0b0:
            00 00 00 00 00 00 00 00
                                        | 0b8:
                                                00 00 00 00 00 00 00 00
    | 0c0:
            00 00 00 00 00 00 00 00
                                        | 0c8:
                                                00 00 00 00 00 00 00 00
    | 0d0:
            00 00 00 00 00 00 00 00
                                        | 0d8:
                                                00 00 00 00 00 00 00 00
    I 0e0:
            00 00 00 00 00 00 00 00
                                        | 0e8:
                                                00 00 00 00 00 00 00 00
    | Of0:
            00 00 00 00 00 00 00 00
                                        | 0f8:
                                                00 00 00 00 00 00 00 00
                                        | 108:
    l 100:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    l 110:
            00 00 00 00 00 00 00 00
                                        | 118:
                                                00 00 00 00 00 00 00 00
    l 120:
            00 00 00 00 00 00 00 00
                                        l 128:
                                                00 00 00 00 00 00 00 00
    | 130:
            00 00 00 00 00 00 00 00
                                        | 138:
                                                00 00 00 00 00 00 00 00
    | 140:
            00 00 00 00 00 00 00 00
                                        | 148:
                                                00 00 00 00 00 00 00 00
    | 150:
            00 00 00 00 00 00 00 00
                                        | 158:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
    I 160:
                                        | 168:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 178:
                                                00 00 00 00 00 00 00 00
    | 170:
            00 00 00 00 00 00 00 00
                                        | 188:
    | 180:
                                                00 00 00 00 00 00 00 00
                                        l 198:
    l 190:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 1a0:
                                        | 1a8:
    | 1b0:
            00 00 00 00 00 00 00 00
                                        | 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        | 1c8:
    l 1d0:
            00 00 00 00 00 00 00 00
                                        l 1d8:
                                                00 00 00 00 00 00 00 00
    | 1e0:
            00 00 00 00 00 00 00 00
                                        | 1e8:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00
                                        | 1f8:
                                                00 00 00 00 00 00 00 00
    | 1f0:
CPUO, PC=0xa> i
CPU1,PC=0x7> i
CPU1, PC=0x9> i
CPU1, PC=0xa> i
CPU1, PC=0xc> m
    | 000: 34 00 1f 75 c0 6a 00 34
                                        | 008: 07 1f b5 03 75 03 ba 01
```

```
00 00 00 00 00 00 00 00
    | 010:
            fd c0 31 07 0f 00 00 00
                                        | 018:
    | 020:
            00 00 00 00 00 00 00 00
                                        028:
                                                00 00 00 00 00 00 00
    030:
            00 00 00 00 00 00 00 00
                                        038:
                                                00 00 00 00 00 00 00 00
    | 040:
            00 00 00 00 00 00 00 00
                                        | 048:
                                                00 00 00 00 00 00 00 00
    | 050:
            00 00 00 00 00 00 00 00
                                        | 058:
                                                00 00 00 00 00 00 00 00
    1 060:
            00 00 00 00 00 00 00 00
                                        1 068:
                                                00 00 00 00 00 00 00 00
                                        | 078:
    | 070:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        | 088:
    080:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        098:
                                                00 00 00 00 00 00 00 00
    090:
    | 0a0:
            00 00 00 00 00 00 00 00
                                        | 0a8:
                                                00 00 00 00 00 00 00 00
    I 0b0:
            00 00 00 00 00 00 00 00
                                        I 0b8:
                                                00 00 00 00 00 00 00 00
    | 0c0:
            00 00 00 00 00 00 00 00
                                        | 0c8:
                                                00 00 00 00 00 00 00 00
    | 0d0:
            00 00 00 00 00 00 00 00
                                        | 0d8:
                                                00 00 00 00 00 00 00 00
    | 0e0:
            00 00 00 00 00 00 00 00
                                        | 0e8:
                                                00 00 00 00 00 00 00 00
    I 0f0:
            00 00 00 00 00 00 00 00
                                        I 0f8:
                                                00 00 00 00 00 00 00 00
    | 100:
            00 00 00 01 00 00 00 00
                                        | 108:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
    | 110:
                                        | 118:
                                                00 00 00 00 00 00 00 00
    1 120:
            00 00 00 00 00 00 00 00
                                        1 128:
                                                00 00 00 00 00 00 00 00
    | 130:
            00 00 00 00 00 00 00 00
                                        | 138:
                                                00 00 00 00 00 00 00 00
    | 140:
            00 00 00 00 00 00 00 00
                                        | 148:
                                                00 00 00 00 00 00 00 00
    | 150:
            00 00 00 00 00 00 00 00
                                        | 158:
                                                00 00 00 00 00 00 00 00
    l 160:
            00 00 00 00 00 00 00 00
                                        | 168:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 178:
    l 170:
                                                00 00 00 00 00 00 00 00
                                        | 188:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    I 180:
    | 190:
            00 00 00 00 00 00 00 00
                                        | 198:
                                                00 00 00 00 00 00 00 00
    | 1a0:
            00 00 00 00 00 00 00 00
                                        | 1a8:
                                                00 00 00 00 00 00 00 00
    | 1b0:
            00 00 00 00 00 00 00 00
                                        | 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            03 00 00 00 00 00 00 00
                                        | 1c8:
                                                00 00 00 00 00 00 00 00
    | 1d0:
            00 00 00 00 00 00 00 00
                                        | 1d8:
                                                00 00 00 00 00 00 00 00
    l 1e0:
            00 00 00 00 00 00 00 00
                                        l 1e8:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 1f0:
                                        | 1f8:
CPU1, PC=0xc> i
CPU1, PC=0xe> i
CPU1, PC=0x10> i
CPU1, PC=0x12> i
CPU1, PC=0x7> i
CPU1.PC=0x7> m
    000:
            34 00 1f 75 c0 6a 00 34
                                        | 008:
                                                07 1f b5 03 75 03 ba 01
            fd c0 31 07 0f 00 00 00
                                                00 00 00 00 00 00 00 00
    | 010:
                                        | 018:
    1 020:
            00 00 00 00 00 00 00 00
                                        028:
                                                00 00 00 00 00 00 00 00
    I 030:
            00 00 00 00 00 00 00 00
                                        1 038:
                                                00 00 00 00 00 00 00 00
    | 040:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
                                        | 048:
    | 050:
            00 00 00 00 00 00 00 00
                                        | 058:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    1 060:
                                        1 068:
    070:
            00 00 00 00 00 00 00 00
                                        078:
                                                00 00 00 00 00 00 00
```

```
080:
            00 00 00 00 00 00 00 00
                                        | 088:
                                                00 00 00 00 00 00 00 00
    090:
            00 00 00 00 00 00 00 00
                                        098:
                                                00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 0a0:
                                        | 0a8:
    | 0b0:
            00 00 00 00 00 00 00 00
                                        | 0b8:
                                                00 00 00 00 00 00 00 00
    | 0c0:
            00 00 00 00 00 00 00 00
                                        | 0c8:
                                                00 00 00 00 00 00 00 00
    I 0d0:
            00 00 00 00 00 00 00 00
                                        I 0d8:
                                                00 00 00 00 00 00 00 00
    | 0e0:
            00 00 00 00 00 00 00 00
                                        | 0e8:
                                                00 00 00 00 00 00 00 00
    | Of0:
            00 00 00 00 00 00 00 00
                                        | 0f8:
                                                00 00 00 00 00 00 00 00
    | 100:
            00 00 00 03 00 00 00 00
                                        | 108:
                                                00 00 00 00 00 00 00 00
    | 110:
            00 00 00 00 00 00 00 00
                                        | 118:
                                                00 00 00 00 00 00 00 00
    l 120:
            00 00 00 00 00 00 00 00
                                        1 128:
                                                00 00 00 00 00 00 00 00
    | 130:
            00 00 00 00 00 00 00 00
                                        | 138:
                                                00 00 00 00 00 00 00 00
    | 140:
            00 00 00 00 00 00 00 00
                                        | 148:
                                                00 00 00 00 00 00 00 00
    | 150:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 158:
    l 160:
            00 00 00 00 00 00 00 00
                                        l 168:
                                                00 00 00 00 00 00 00 00
    | 170:
            00 00 00 00 00 00 00 00
                                        | 178:
                                                00 00 00 00 00 00 00 00
    | 180:
            00 00 00 00 00 00 00 00
                                        | 188:
                                                00 00 00 00 00 00 00 00
    I 190:
            00 00 00 00 00 00 00 00
                                        l 198:
                                                00 00 00 00 00 00 00 00
    | 1a0:
            00 00 00 00 00 00 00 00
                                        | 1a8:
                                                00 00 00 00 00 00 00 00
    | 1b0:
            00 00 00 00 00 00 00 00
                                        | 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            03 00 00 00 00 00 00 00
                                        | 1c8:
                                                00 00 00 00 00 00 00 00
    | 1d0:
            00 00 00 00 00 00 00 00
                                        | 1d8:
                                                00 00 00 00 00 00 00 00
    | 1e0:
            00 00 00 00 00 00 00 00
                                        | 1e8:
                                                00 00 00 00 00 00 00 00
                                        | 1f8:
    | 1f0:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
CPU1, PC=0x7> t
CPUO, PC=0xa> i
CPUO, PC=0xc> i
CPUO, PC=0xe> i
CPUO, PC=0x10> i
CPUO, PC=0x12> i
CPUO, PC=0x9> i
CPUO, PC=0xa> i
CPUO, PC=0xa> t
CPU1,PC=0x7> t
CPUO, PC=0xa> m
    1 000:
            62 03 10 3c 03 6a 00 62
                                        1 008:
                                                01 10 3c 0a ba 01 b2 01
    I 010:
            fa 03 31 09 0f 00 00 00
                                        I 018:
                                                00 00 00 00 00 00 00 00
    020:
            00 00 00 00 00 00 00 00
                                        028:
                                                00 00 00 00 00 00 00 00
    | 030:
                                        | 038:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 040:
            00 00 00 00 00 00 00 00
                                        | 048:
                                                00 00 00 00 00 00 00 00
    I 050:
            00 00 00 00 00 00 00 00
                                        1 058:
                                                00 00 00 00 00 00 00 00
    | 060:
            00 00 00 00 00 00 00 00
                                        068:
                                                00 00 00 00 00 00 00 00
    | 070:
            00 00 00 00 00 00 00 00
                                        | 078:
                                                00 00 00 00 00 00 00 00
    080:
            00 00 00 00 00 00 00 00
                                        088:
                                                00 00 00 00 00 00 00 00
                                        098:
    090:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
```

```
| 0a0:
            00 00 00 00 00 00 00 00
                                        | 0a8:
                                                00 00 00 00 00 00 00 00
    | 0b0:
            00 00 00 00 00 00 00 00
                                        | 0b8:
                                                00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 0c0:
                                        | 0c8:
    | 0d0:
            00 00 00 00 00 00 00 00
                                        | 0d8:
                                                00 00 00 00 00 00 00 00
    | 0e0:
            00 00 00 00 00 00 00 00
                                        | 0e8:
                                                00 00 00 00 00 00 00 00
    I 0f0:
            00 00 00 00 00 00 00 00
                                        I 0f8:
                                                00 00 00 00 00 00 00 00
    | 100:
            00 00 00 00 00 00 00 00
                                        | 108:
                                                00 00 00 00 00 00 00 00
    | 110:
            00 00 00 00 00 00 00 00
                                        | 118:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 128:
                                                00 00 00 00 00 00 00 00
    | 120:
    | 130:
            00 00 00 00 00 00 00 00
                                        | 138:
                                                00 00 00 00 00 00 00 00
    l 140:
            00 00 00 00 00 00 00 00
                                        l 148:
                                                00 00 00 00 00 00 00 00
    | 150:
            00 00 00 00 00 00 00 00
                                        | 158:
                                                00 00 00 00 00 00 00 00
    | 160:
            00 00 00 00 00 00 00 00
                                        | 168:
                                                00 00 00 00 00 00 00 00
    | 170:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                        | 178:
    l 180:
            00 00 00 00 00 00 00 00
                                        l 188:
                                                00 00 00 00 00 00 00 00
    | 190:
            00 00 00 00 00 00 00 00
                                        | 198:
                                                00 00 00 00 00 00 00 00
    | 1a0:
            00 00 00 00 00 00 00 00
                                        | 1a8:
                                                00 00 00 00 00 00 00 00
    l 1b0:
            00 00 00 00 00 00 00 00
                                        l 1b8:
                                                00 00 00 00 00 00 00 00
    | 1c0:
            00 00 00 00 00 00 00 00
                                        | 1c8:
                                                00 00 00 00 00 00 00 00
    | 1d0:
            00 00 00 00 00 00 00 00
                                        | 1d8:
                                                00 00 00 00 00 00 00 00
    | 1e0:
            00 00 00 00 00 00 00 00
                                        | 1e8:
                                                00 00 00 00 00 00 00 00
    | 1f0:
            00 00 00 00 00 00 00 00
                                        l 1f8:
                                                00 00 00 00 00 00 00 00
CPUO, PC=0xa> t
CPU1, PC=0x7> i
CPU1, PC=0x9> i
CPU1, PC=0xa> i
CPU1, PC=0xc> i
CPU1, PC=0xe> i
CPU1,PC=0x10> i
CPU1, PC=0x12> i
CPU1, PC=0x14> i
Program Halted.
CPU1, PC=0x15> m
    000:
            34 00 1f 75 c0 6a 00 34
                                        | 008:
                                                07 1f b5 03 75 03 ba 01
    | 010:
            fd c0 31 07 0f 00 00 00
                                        | 018:
                                                00 00 00 00 00 00 00 00
    020:
            00 00 00 00 00 00 00 00
                                        | 028:
                                                00 00 00 00 00 00 00 00
    1 030:
            00 00 00 00 00 00 00 00
                                        1 038:
                                                00 00 00 00 00 00 00 00
    | 040:
            00 00 00 00 00 00 00 00
                                        | 048:
                                                00 00 00 00 00 00 00 00
    | 050:
                                        | 058:
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 060:
            00 00 00 00 00 00 00 00
                                        068:
                                                00 00 00 00 00 00 00 00
    1 070:
            00 00 00 00 00 00 00 00
                                        1 078:
                                                00 00 00 00 00 00 00 00
    080:
            00 00 00 00 00 00 00 00
                                        088:
                                                00 00 00 00 00 00 00 00
    090:
            00 00 00 00 00 00 00 00
                                        098:
                                                00 00 00 00 00 00 00 00
            00 00 00 00 00 00 00 00
                                                00 00 00 00 00 00 00 00
    | 0a0:
                                        | 0a8:
```

| 0b0:

00 00 00 00 00 00 00 00

| 0b8:

00 00 00 00 00 00 00 00

```
| OcO: 00 00 00 00 00 00 00
                                  | 0c8: 00 00 00 00 00 00 00 00
| 0d0:
       00 00 00 00 00 00 00 00
                                  | 0d8:
                                          00 00 00 00 00 00 00 00
| 0e0:
       00 00 00 00 00 00 00 00
                                  0e8:
                                          00 00 00 00 00 00 00 00
| Of0:
       00 00 00 00 00 00 00 00
                                  | 0f8:
                                          00 00 00 00 00 00 00 00
                                  | 108:
| 100: 00 00 00 06 00 00 00 00
                                          00 00 00 00 00 00 00 00
l 110:
       00 00 00 00 00 00 00 00
                                  l 118:
                                          00 00 00 00 00 00 00 00
| 120: 00 00 00 00 00 00 00 00
                                  | 128:
                                          00 00 00 00 00 00 00 00
| 130: 00 00 00 00 00 00 00 00
                                  | 138:
                                          00 00 00 00 00 00 00 00
| 140: 00 00 00 00 00 00 00 00
                                  | 148:
                                          00 00 00 00 00 00 00 00
| 150: 00 00 00 00 00 00 00 00
                                  | 158:
                                          00 00 00 00 00 00 00 00
| 160: 00 00 00 00 00 00 00 00
                                  | 168:
                                          00 00 00 00 00 00 00 00
| 170: 00 00 00 00 00 00 00 00
                                  | 178:
                                          00 00 00 00 00 00 00 00
| 180: 00 00 00 00 00 00 00 00
                                  | 188:
                                          00 00 00 00 00 00 00 00
| 190: 00 00 00 00 00 00 00 00
                                  | 198:
                                          00 00 00 00 00 00 00 00
| 1a0: 00 00 00 00 00 00 00 00
                                  l 1a8:
                                          00 00 00 00 00 00 00 00
| 1b0: 00 00 00 00 00 00 00 00
                                  | 1b8:
                                          00 00 00 00 00 00 00
                                  | 1c8: 00 00 00 00 00 00 00 00
| 1c0: 03 00 00 00 00 00 00 00
| 1d0: 00 00 00 00 00 00 00 00
                                  | 1d8:
                                          00 00 00 00 00 00 00 00
| 1e0: 00 00 00 00 00 00 00 00
                                  | 1e8:
                                          00 00 00 00 00 00 00 00
                                  | 1f8: 00 00 00 00 00 00 00 00
| 1f0: 00 00 00 00 00 00 00 00
```

CPU1, PC=0x15>

3 演習

3.1 演習 4

教育用 CPU ボードでも JR,JAL 命令を用いなくてもサブルーチンを実現することは可能だと考える. 理由としては関数に飛ぶ際にフラグ用のメモリを用意し関数 (サブルーチン) を用いる際は 1 にして条件 Branch 命令を用いて関数の動作内容が記述されている部分に PC を変更する. 事前に戻る位置の PC はどこかのメモリに記録しておき, 戻る前にフラグ用のメモリを 0 へ戻して Branch 命令を用い戻るいちを記録したメモリを参照し PC を変更させることにより実現できると考えた.

4 考察

cpu シミュレータ作成実習を通して、各マシン命令を作成することによってフェーズ毎の動作を知ることができた.メモリを意識しながらプログラムを行うことによって C 言語のポインタに対する考えが深まった。普段 python や c 言語などを用いるためマシン語でコーディングする際に理解しにくくミスが増えプログラミングの効率が悪く時間も多くかかってしまった、現在利用されている言語は人間が用いる言葉に近い形で記述することができより良い形に使用される言語も変化しているのだと感じられた。

参考文献

- [1] CPU 実習テキスト
- [2] 教育用 CPU ボードのマニュアル