More PeANUt assembly language

- Loops in assembly code
- Arrays in assembly
- Evaluating complex expressions
- Reference:
  - Specification of the PeANUt computer (Section 4)
- Additional reading: Section 3.8 in Bryant and O'Hallaron

Translating loops into assembly code

- Iteration is required for most (non-trivial) computations
- While loop: Test is at the top of the loop
- Example: `while (condition) {...}`

```
while1:  load n      ;  while (n != 0) {
         cmp #0      ;
         beq endwh1  ;
         load pn     ;    pn = pn*2;
         mul #2      ;
         store pn    ;
         load n      ;    n = n-1;
         sub #1      ;
         store n     ;
         jmp while1  ;  }
endwh1:  ...
```


While loop in assembly

- Body of **if** is executed zero or one time, but body of **while** is executed zero, one or many times
- The difference: A unconditional backward branch (**jmp**) at the bottom
- Example: Assume first instruction is at address **a6**
- What happens to the **PSW** (n = 1)?

```
load n       GT=0  EQ=0  PC=a7
cmp #0       GT=1  EQ=0  PC=a10
beq endwh1   GT=1  EQ=0  PC=a11
```


Do ... while loop in assembly

- Test is at the bottom of the loop
- Example: `do {...} while (condition)`

```
EOL = 10              ;  #define EOL 10 /* new line */
repeat1:              ;  do {
         trap #2      ;    scanf("%c", &n);
         store n      ;
         ...
         load n       ;  } while (n != EOL);
         cmp #EOL     ;
         bne  repeat1 ;
```

- Review:
  - **while** → Like **if** with **jmp** at end
  - **do ... while** → Like **if** in reverse order
  - **for** loop translates into **while** loop
  - For loops the machine needs a backwards branch capability

Arrays in assembly

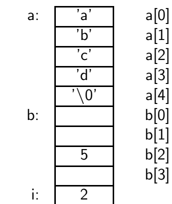
- Iterative computations normally require an iterative data structure
  → **Array** is the most fundamental
- How is defining / access different from normal variables?
- Easiest to use lower bound of **0** (zero), like in C

Array example in assembly

```
N = 4                   ;  #define N 4;
                        ;
a:      block N         ;  char a[N+1];
        block 1         ;
b:      block N         ;  int b[N];
i:      block 1         ;  int i;
                        ;
...
load i                  ;  printf("%c", a[i]);
storexr                 ;          /* XR = AC */
load *a                 ;          /* AC = Memory[a+XR] */
trap #3                 ;
load i                  ;  b[i] = 5;
storexr                 ;          /* XR = AC */
load #5                 ;          /* AC = 5 */
store *b                ;          /* Memory[b+XR] = AC */
```


Array example memory layout

- The memory layout of the previous example is



- General method: Put the value of the index in **XR** (via accumulator), then simply use indexed addressing mode
- Strings: Position of the first NULL ('\0') character defines the length of a string

Another array example

```
        load #0      ;  i = 0;
        store i      ;
repeat1:             ;  do {
        load i       ;    b[i] = a[i+1];  /* AC = Memory[i] */
        storexr      ;                    /* XR = AC */
        load *a+1    ;                    /* AC = Memory[a+1+XR] */
        store *b     ;                    /* Memory[b+XR] = AC */
        load i       ;    i = i+1;
        add #1       ;
        store i      ;
        load #N      ;  while (i < N);
        cmp i        ;
        bgt repeat1  ;
```

Conditions and arrays

- Just set up **XR** before evaluating

```
        load i       ;  if (b[i] > 0) {
        storexr      ;
        load *b      ;      /* AC = Memory[b+XR] */
        cmp #0       ;
        ble endif1   ;
        load x       ;    x = x + b[i];  /* AC = Memory[x] */
        add *b       ;           /* AC = AC + Memory[b+XR] */
        store x      ;  }
endif1:              ;
```


XR as index variable

- One can use **XR** as index variable

```
        load #0      ;  i = 0;        /* AC = 0 */
        storexr      ;                /* XR = AC */
repeat1:             ;  do {
        load *a+1    ;    b[i] = a[i+1];
        store *b     ;
        incxr #1     ;    i = i+1;
        loadxr       ;                /* AC = XR */
        cmp #N       ;  } while (i != N);
        bne repeat1  ;
```


Arrays in assembly - Review

- More difficult if two different indices are used
  Example: `b[j] = a[i]+42;`
- Define an array using **block** *array_length*
- Set **XR** to value of the index (usually start at 0)
- For arrays, the machine needs an indexing address mode to efficiently access individual elements

Evaluating complex expressions

- Compound conditions may be joined by **AND** or **OR**
- Example: Skip characters until a digit is found

```
while1:              ;  do {
        trap #2      ;    scanf("%c", &ch);
        store ch     ;
        load #'0'    ;  } while (('0' > ch) || (ch > '9'));
        cmp ch       ;
        bgt while1   ;
        load ch      ;    /* (ch > '9') */
        cmp #'9'     ;
        bgt while1   ;
        ...
```

Evaluating complex expressions (2)

- Example: Skip characters until a non-digit is found

```
           trap #2        ;  scanf("%c", &ch);
           store ch       ;
while1:    load #'0'      ;  while (('0' <= ch) && (ch <= '9')) {
           cmp ch         ;
           bgt endwhile1  ;
           load ch        ;    /* (ch <= '9') */
           cmp #'9'       ;
           bgt endwhile1  ;
           trap #2        ;    scanf("%c", &ch);
           store ch       ;
           jmp while1     ;  }
endwhile1: ...
```


Direct evaluation if right-simple

- If the right-hand side of every arithmetic operator is a variable or a constant

```
load #10      ;  x = x*10
mul x         ;
add ch        ;          + ch
sub #'0'      ;          - ord('0');
store x       ;
```

- Evaluation is similar for **if**

```
load x        ;  if ((x+1) <= 0) {
add #1        ;
cmp #0        ;
bgt ...       ;
```


Use stack for complex expressions

- Use stack to store temporary variables
- **incsp #***n*, then access **!0, !-1, !-2, ... !***(n-1)*
- Example: **d = v - (v / 10) * 10 + x;**

```
incsp #1      ;    /* Allocate stack space for t1 */
t1 = 0        ;    /* Define relative place for t1 */
load v        ;  t1 = (v / 10)
dvd #10       ;
mul #10       ;      * 10
store !t1     ;
load v        ;  d = v - t1
sub !t1       ;
add x         ;      + x;
store d       ;
incsp #-1     ;    /* Deallocate stack space for t1 */
```

- Important: Don't forget **incsp#**-*n* at the end!