PeANUt assembly language

- Motivation
- Addressing modes revisited
- Assembly language format
- Translating C into PeANUt
- Reference:
  - Specification of the PeANUt computer (Section 4)

Motivation for assembly language

- Assembly language is 'next level' of abstract machine (after conventional machine and operating system) [Tanenbaum, Figure 1-2]
- Implemented via translation rather than interpretation
- Example machine language file:

```
START a20              ; start address
AT a10
d3                     ; L
d4                     ; M
d2                     ; N
AT a20
o1 o1 a10              ; a20: load L into AC
o1 o6 a11              ; a21: multiply by M
o1 o7 a12              ; a22: compare with N
o53   a25              ; a23: branch a25 if L*M > N
o1 o2 a13              ; a24: store L*M into a13
o65    a1              ; a25: trap 1 (halt)
```

Problems with machine language

- What if we have to
  - replace instruction a24 with two new instructions?
  - need to insert a large string at the beginning of the program?
  - use an addressing mode which is not supported by the machine?
- Does this express a good algorithm?
- Can we (easily) write much larger programs in this way?

Solutions

- Symbol names for addresses (variables, branch targets) needed
- We also need symbol names for opcodes and modes
- We need a way of defining more complex operations (macros)
- Separate converting (mli $\rightarrow$ img) of program modules will be useful
- We can document assembly language code with high level language code to express a (structured) algorithm

Review: PeANUt addressing modes

- Corresponding to most instructions is an operand (**OP**)
- **OP** is sometimes derived from the corresponding address (**AOP**), e.g. `OP = Memory[AOP]`
- **AOP** is generally derived from the lowest 10 bits of the instruction (**opspec**)
- PeANUt has five addressing modes:
  - immediate (#)
  - direct
  - indirect (@)
  - indexed (*)
  - stack (!)

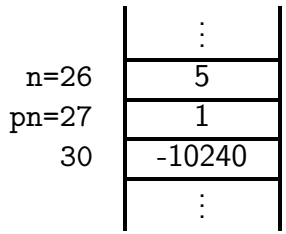
PeANUt addressing modes – 1

- **Immediate**: (#) `OP = <opspec>`

```
load   #6     ; OP = 6    AOP is undefined
mul    #-2    ; OP = -2   AOP is undefined
```

- **Direct**: `AOP = <opspec>` `OP = Memory[AOP]`

```
load  n       ; AOP = 26  OP = 5
mul   pn      ; AOP = 27  OP = 1
add   27      ; AOP = 27  OP = 1
sub   30      ; AOP = 30  OP = -10240
add   1       ; AOP = 1   OP = ?
```



PeANUt addressing modes – 2

- **Indirect**: (**@**) `AOP = Memory[<opspec>]`

```
load  @10      ; AOP = 12  OP = 42
```

	⋮
10	12
11	-1
12	42
	⋮

- **Indexed**: (*) `AOP = <opspec> + XR` (normally <opspec> is a label) (base address + index)

  if **XR** = 1:

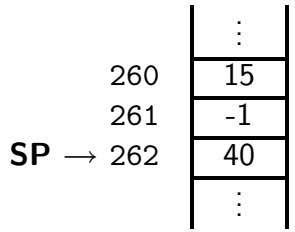
```
load  *a       ; AOP = 15  OP = -1
add   *a+1     ; AOP = 16  OP = 7
```

	⋮
a=14	45
15	-1
16	7
	⋮

PeANUt addressing modes – 3

- **Stack**: (**!**) AOP = <opspec> + SP (normally <opspec> ≤ 0)

```
load  !0      ; AOP = 262  OP = 40
mul   !-2     ; AOP = 260  OP = 15
store !-3     ; AOP = 257  OP = 600
```



- Review: Different addressing modes have very different effects

- The modes correspond to some high level language construct

PeANUt assembly language format

`<label>:`	`operation`	`operand` (e.g. `=<mode><opspec>`)
↑	↑	↑
optional,	e.g.	e.g.
defines a	`load`	`*<number>`
symbolic	`store`	`<label>`
address	add	`*<label>`
	sub	`<label>+<number>`
	mul	`!<number>`
	dvd	`@<number>`
	cmp	
	jmp	
	beq	
	...	

- A `<number>` is $+/-$ decimal or binary integer or a symbol
- Operations are either instructions or directives

Directives

- **block** n
  Allocates n memory cells (words) initialised to 0
  Example: `i:  block 1`

- **data** n
  data <*label*>
  data "*string*" (one cell per character)
  Allocates the appropriate number of cells and initialises them
  Example: `text:  data "Hello"`

- **end** <*label*>
  End program here, <*label*> is start address of the program
  (each PeANUt assembly program must have exactly one
  end directive at the end of the program)

Translating C into PeANUt – Assignments

- Variable declarations and simple assignments **n = 1;** or **i = n;**

```
n:  block 1     ;   int n;
i:  block 1     ;   int i;
    ...

    load  #1    ;   n = 1;   /* AC = 1 */
    store n     ;            /* Memory[n] = AC */

    load  n     ;   i = n;   /* AC = Memory[n] */
    store i     ;            /* Memory[i] = AC */
```

- More complex assignment **n = n - 1;**

```
                ;   n = n - 1;
    load  n     ;            /* AC = Memory[n] */
    sub   #1    ;            /* AC = AC-1 */
    store n     ;            /* Memory[n] = AC */
```

Translating C into PeANUt – Variable declarations

- Variable declarations and simple calculations

```
sal: block 1     ;   int sal;
tax: block 1     ;   int tax;
     ...

                 ;   tax = sal / 12;
     load sal    ;         /* AC = Memory[sal] */
     dvd  #12    ;         /* AC = AC/12 */
     store tax   ;         /* Memory[tax] = AC */
```

- What if an assignment is even more complex?
  Example: `x = val - q*42 + x*x;`

Translating C into PeANUt – Simple `if`

- Simple `IF` (assume first instruction is at address a20)

```
        load #0     ;   if (0 > x) {
        cmp  x      ;
        ble  endif1 ;
        load #0     ;     x = 0 - x;
        sub  x      ;
        store x     ;
    endif1:         ;   }
```

- What happens to the PSW (for x=3)?

  `load #0` → `GT=0, EQ=0, PC=21`

  `cmp x` → `GT=0, EQ=0, PC=22`

  `ble endif1` → `GT=0, EQ=0, PC=26`

  (`ble` sets `PC` to `endif1` if `GT=0`)

Translating C into PeANUt – `if .. else if .. else ..`

```
        load sal    ;  if (sal <= 250) {
        cmp #250    ;
        bgt elsif2  ;
        load #0     ;    tax = 0;
        store tax   ;
        jmp endif2  ;  }
elsif2: load sal    ;  else if (sal <= 500) {
        cmp #500    ;
        bgt else2   ;
        load sal    ;    tax = sal*20;
        mul #20     ;
        store tax   ;
        jmp endif2  ;  }
else2:              ;  else {
        load sal    ;    tax = sal*30;
        mul #30     ;
        store tax   ;
endif2: ...         ;  }
```

Translating C into PeANUt – Some remarks

- For simple C, we have standard translation patterns
- Expression evaluation similar like assignment, except use **cmp** instead of **add, sub** etc.
- Use the **opposite** branch instruction to the condition
- Use systematically named branch targets
- For **if** we need to be able to do a **conditional** forward branch
- for **else if**/**else** we also need an **unconditional** forward branch (**jmp**)
- The **PSW** plays an important role in all control structures

Translation of simple I/O into PeANUt

- Scan and print characters

```
ch:  block 1     ;   char ch;   /* 16 bits! */
                 ;
     trap #2     ;   scanf("%c", &ch);
     store ch    ;
                 ;
     load ch     ;   printf("%c", ch);
     trap #3     ;
```

- Basic I/O is via traps, i.e. the operating system
- Always make sure you print ASCII values (not integer numbers)
- In PeANUt, the value -1 (`hFFFF`) gets stored to signify EOF
- Question: How do we do more complex I/O in PeANUt?