Implementation of Languages

SIMPLESEM

specify semantics in an abstract assembler language

static structure: data memory D, code memory C, instruction pointer ip

instructions:

set target, source
set 10, D[20]
set 15, read
set write, D[50]
set 99, D[15]+D[33∗C[41]]−8
set D[10], D[20]
jump 47
jumpt 47, D[3]>D[8]
jump D[13]
halt

Language with Simple Statements

```
main()
{
   int i, j;
   get(i, j);
   while (i != j)
      if (i > j)
         i -= j;
      else
         j -= i;
   print(i);
}
```

```
code memory                    data memory
+----------------------        +------------
|0  set 0, read                |0  cell for i
|1  set 1, read                |1  cell for j
|2  jumpt 8, D[0] = D[1]
|3  jumpt 6, D[0] <= D[1]
|4  set 0, D[0] - D[1]
|5  jump 7
|6  set 1, D[1] - D[0]
|7  jump 2
|8  set write, D[0]
|9  halt
```

Simple Routines

```
int i=1, j=2, k=3;

alpha()
{
   int i=4, l=5;
   ...
   i += k + l;
   ...
};
```

```
beta()
{
   int k=6;
   ...
   i = j + k;
   alpha();
   ...
};
```

```
main()
{
   ...
   beta();
   ...
}
```

Memory Layout (Simple Routines)

```
code memory                                  data memory
+-----------------------------------------   +--------------------
|     ...                          // main    |0   8  //i    global
|014  set 6, 16                               |1   2  //j
|015  jump 100                                |2   3  //k
|     ...                                     |3 125  //ret. alpha
|049  halt                                    |4  12  //i
|     ...                          // alpha   |5   5  //l
|058  set 4, D[4]+D[2]+D[5]                   |6  16  //ret. beta
|     ...                                     |7   6  //k
|099  jump D[3]                               |  ...
|     ...                          // beta
|122  set 0, D[1]+D[7]
|123  set 3, 125
|124  jump 50                                      ip = 59
|     ...
|149  jump D[6]
|     ...                          // ...
```

Separate Compilation

```
/* file 1 */

int i=1, j=2, k=3;
extern beta();
main()
{
   ...
   beta();
   ...
}
```

```
/* file 2 */

extern int k;
alpha()
{
   int i=4, l=5;
   ...
   i += k + l;
   ...
}
```

```
/* file 3 */

extern int i,j;
extern alpha();
beta()
{
   int k = 6;
   ...
   i = j + k;
   alpha();
   ...
}
```

Recursion and Result Values

```
int n;
int fact()
{
   int loc;
   if (n > 1) {
      loc = n--;
      return loc * fact();
   }
   else
      return 1;
}
```

```
main()
{
   get(n);
   if (n >= 0)
      print(fact());
   else
      print("input error");
}
```

Stack with Dynamic Link

```
data memory
+-------------------------------------------------------
|0  B    //CURRENT
|1  C    //FREE
|   ...                    stack grows downwards
|                                holds activation records
|
|A  ...  //return pointer (caller's activation record)
|   ...  //dynamic link
|   ...  //local variables
|
|B  ...  //return pointer (current activation record)
|   A    //dynamic link
|   ...  //local variables
|
|C  ...  //free memory
|
```

Invocation and Return

`set 1, D[1]+1`	allocate memory for result
`set D[1], ip+4`	set return pointer
`set D[1]+1, D[0]`	set dynamic link
`set 0, D[1]`	set CURRENT
`set 1, D[1]+AR`	set FREE
`jump addr`	jump to routine

`set 1, D[0]`	set FREE
`set 0, D[D[0]+1]`	set CURRENT
`jump D[D[1]]`	jump to stored return pointer

Nested Blocks

```
int f() {
  int x,y,w;          //1
  while(...) {
    int x,z;          //2
    while(...) {
      int y; ...      //3
    }
    if(...) {
      int x,w; ...    //4
    }
  }
  if(...) {
    int a,b,c,d;      //5
    ...
  }
}
```

```
activation record of f
+------------------------------
|  return pointer
|  dynamic link
|  x in //1
|  y in //1
|  w in //1
|  x in //2, a in //5
|  z in //2, b in //5
|  y in //3, x in //4, c in //5
|  w in //4, d in //5
+------------------------------
```

Nested Routines and Static Link

```
int x,y,z;
void f1() {
  int t,u;
  void f2() {
    int x,w;
    void f3() {
      int y,w,t;
      ...
    }
    ...
  }
  ...
}
```

```
sketch of run-time stack
+---------------------------------
|A  global environment (x,y,z),
|     no dyn.link, stat.link needed
|B  act.record for f1 (t,u) with
|     dyn.link: A, stat.link: A
|C  act.record for f2 (x,w) with
|     dyn.link: B, stat.link: B
|D  act.record for f3 (y,w,t) with
|     dyn.link: C, stat.link: C
|E  act.record for f2 (x,w) with
|     dyn.link: D, stat.link: B !!
|
```

Computing Frame Pointer

each variable statically bound to a pair $\langle d, o \rangle$ where

d is the **distance** between current and addressed static scope

e.g., d=2 when accessing u (defined in f1) within f3,

o is the **offset** of the variable within the activation record

computing the **frame pointer**:

$$fp(d) = \text{if } d{=}0 \text{ then } D[0] \text{ else } D[fp(d{-}1){+}stat.link.offset]$$

examples: $fp(0) = D[0]$,
$fp(1) = D[D[0]{+}stat.link.offset]$,
$fp(2) = D[D[D[0]{+}stat.link.offset]{+}stat.link.offset]$

addresse of variable bound to $\langle d, o \rangle$ is $D[fp(d){+}o]$

Routine Invocation with Static Link

`set 1, D[1]+1`	allocate memory for result
`set D[1], ip+5`	set return pointer
`set D[1]+1, D[0]`	set dynamic link
`set D[1]+2, fp(d)`	set static link (stat.link.offset = 2)
`set 0, D[1]`	set CURRENT
`set 1, D[1]+AR`	set FREE
`jump addr`	jump to routine

Dynamic Array

example in Ada: `type V is array (Integer range <>) of Integer;`
`A: V(1..N);  -- N not statically known`

compiler allocates in activation record space for **descriptor**
(holds index range and pointer to memory of array)

when executing the array declaration at run-time:

> extend current activation record with space for array,
> initialize descriptor appropriately

example for access A(I) := 0;

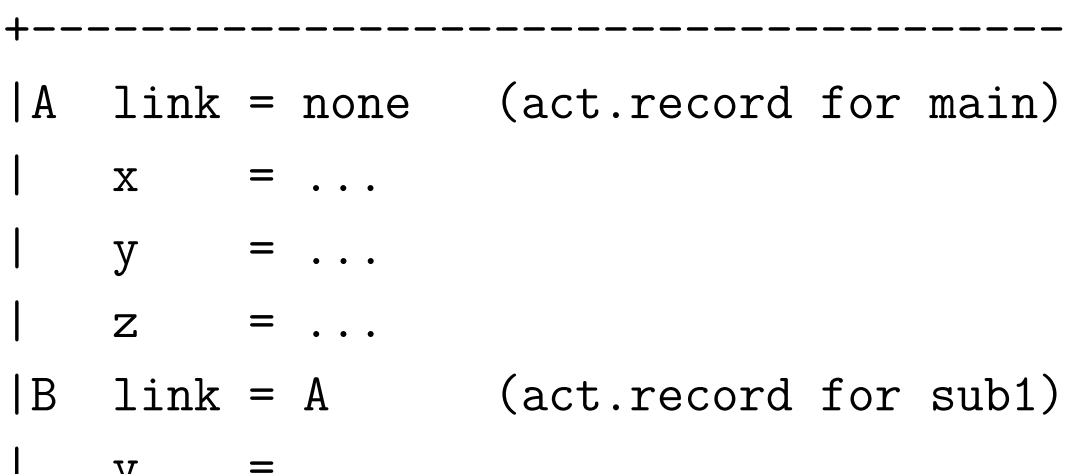
> set[D[D[0]+m] + D[D[0]+s]], 0

(m = offset of descriptor of A; s = offset of local variable I)

Dynamic Scoping

```
void sub2() {
  declare x;
  ...
}
void sub1() {
  declare y;
  sub2();
  ...
}
void main() {
  declare x,y,z;
  sub1();
  sub2();
}
```

sketch of run-time stack



dynamic search for name along link

Heap

local data on stack are lost when returning from a routine invocation

non-local data needed after return must be allocated on the **heap**

```
data memory
+-----------------------------------------------
|  stack: grows downwards,
|         holds activation records removed on return
|
|
|  heap:  grows upwards,
|         holds data alive until program termination
+-----------------------------------------------
```

Parameter Passing

call by reference: pass l-value of actual parameter to callee

call by copy: parameter is local variable of callee

- **call by value:** copy r-value into variable of callee
- **call by result:** copy result back into variable of caller
- **call by value-result:**] call by value on invocation
  and call by result on return (value copied twice)

call by name: substitute actual parameter
for each occurrence of formal parameter in callee

Implementation of Call by Reference

formal parameter is reference to actual parameter in callee's activation record (offest off)

pass l-value if actual parameter is a variable $\langle d, o \rangle$ in caller:

set D[0]+off, fp(d)+o

pass r-value if actual parameter is call-by-reference parameter $\langle d, o \rangle$ in caller:

set D[0]+off, D[fp(d)+o]

assignment to a call-by-reference parameter: x = 0;

set D[D[0]+off], 0

Call by Reference vs. Value Result

these calling conventions differ if

two formal parameters are aliases

example:
actual parameters:	a[i] und a[j]
formal parameters:	x und y
body of routine:	x = 0; y++;

a formal parameter and a variable visible to both (caller and callee) are alias

example:
actual parameter:	a
formal parameter:	x
body of routine:	a = 1; x = x + a;

Call by Name

```
                                |   int c; /* global variable */
swap(int a, b) {                |   swap(int a, b) {
   int temp = a;                |      int temp = a; a = b;
   a = b;                       |      b = temp; c++;
   b = temp;                    |   };
};                              |   y() {
   ...                          |     int c, d;
   swap(i, a[i]);               |     swap(c, d);
   ...                          |   };

temp = i;                       |   temp = c; c = d;
i = a[i];                       |   d = temp;
a[i] = temp;                    |   c++;                  !!
```

Routine as Parameter

```
1  int u, v;
2  void a()
3  {
4     int y;
5     ...
6  };
```

```
 7  void b(routine x)
 8  {
 9     int u, v, y;
10     void c() {
11        ...
12        y = ...;
13        ...
14     };
15     x();
16     b(c);
17     ...
18  }
```

```
19  void main()
20  {
21     b(a);
22  };
```

routine parameter must include static link