CS 421 Lecture 12

- Compilation static languages, continued
  - Compiling in context
    - Assignment
    - Break ~~and labeled~~ statements
    - Short-circuit evaluation of boolean expressions
  - Switch statements
  - Arrays
  - Code optimization
- Friday's class: dynamic languages – ~~code generation,~~ garbage collection, reflection

Notation

- [S] = compiled code for S
- [e] = compiled code for e
- Use subscripts on brackets for additional arguments, e.g. $[S]_L$ is compiled code for S, assuming S occurs within a switch statements labeled L.

compile(S) =

Assignment statements

- Old scheme: [x=e] = let (l,t) = [e] in l; x=t.
- Can give poor results: [x=3] = t=3; x=t
  [x=x+1] = t1=1; t2=x+t1; x=t2
- Compile expressions in context of target location:
  $[e]_x$ = code to calculate value of e *and* store it in x. $[e]_x$: instruction list
- [x=e] = $[e]_x$
- $[n]_x$ = "x=n"
- $[y]_x$ = "x=y", if y a different variable from x; ϵ, otherwise
- $[e1+e2]_x$ = let t = new location in $[e1]_t$; $[e2]_x$; x=t+x

$[x=x+1] = [x+1]_x = [x]_t$; $[1]_x$; $x=t+x$ → t=x; x=1; t=t+x

$[x=1+x] = [1+x]_x = [1]_t$; $[x]_x$; $x=t+x$ → t=1; x=t+x

compile (break, L_b, L_c)

Same as [S] for non-break stmts

break statements

- break statement breaks from one level of switch or while. Cannot translate "break" without knowing context.
- $[S]_L$ = code for statement S, given that S occurs inside a switch or while statement, and L is the label just after that enclosing statement.

$[S]_{L_b, L_c}$

$[\text{break}]_{L_b, L_c}$ = JUMP L_b

$[\text{continue}]_{L_b, L_c}$ = JUMP L_c

[while e do S] = JUMP L2
L1: $[S]_{L3, L2}$
L2: [e]
CJUMP t, L1, L3
L3:

Boolean expressions

- Current scheme: boolean expressions evaluated like any other, placing value in a temporary location:

  [e1<e2] = let $(l_1, t1)$ = [e1], $(l_2, t2)$ = [e2], t = newloc()
  in $(l_1; l_2;$ t = t1<t2, t)

  [e1 && e2] = let $(l_1, t1)$ = [e1]
  $(l_2, t2)$ = [e2]
  in $(l_1;$ l2; t = t1 && t2, t)

  [if e then S1 else S2] = let (l, t) = [e]
  in (l; CJUMP t L1 L2; …)

  - *What's wrong?*

x != 0 && y/x ..

x != null && x.t ..

x < n && A[x] == ..

[if (x<y && y<z) then ..]

= t1 = x<y

t2 = y<z

t3 = t1 && t2

CJUMP t3, L1, L2

⋮

Boolean expressions w/ short-circuit evaluation

- Improved scheme:

```
[e1 && e2] = let  t = newlocation()
                  I1 = [e1]t
                  I2 = [e2]t
                  L1, L2 = newlabel()
             in  (I1
                  CJUMP t, L1, L2
             L1:  I2
             L2:        ,       t)
```

if (x<y && y<z) then ...

```
=     t = x<y
      CJUMP t, L1, L2 L3
  L1: t = y<z
  L2: CJUMP t, L2, L3
```

t contains value of e_1 || e_2 and e_2 is evaluated only if needed

- What's wrong now?

Compiling boolean expressions in context

- Get better code if boolean expression can jump to correct label as soon as possible
- $[e]_{Lt,Lf}$ = code that calculates e and jumps to Lt if it is true, Lf if it is false. The code does not save the value anywhere.

- $[true]_{Lt,Lf}$ = JUMP Lt

  $[e1<e2]_{Lt,Lf}$ = let $(I_1, t_1) = [\![e1]\!]$
  $(I_2, t_2) = [\![e2]\!]$
  in I_1
  I_2
  $t = t_1 < t_2$
  CJUMP t, Lt, Lf

Compiling boolean expressions in context

- $[e1 \&\& e2]_{Lt,Lf}$ = $[e_1]_{L1,Lf}$
  L1: $[e_2]_{Lt,Lf}$

[while e do S] =
JUMP L2
L1: [S]
L2: $[e]_{L1,L3}$
L3:

$[!e]_{Lt,Lf} = [e]_{Lf,Lt}$

$[e1 || e2]_{Lt,Lf} = [e1]_{Lt,L1}$
L1: $[e2]_{Lt,Lf}$

[if e then S_1 else S_2]
= $[e]_{L1,L2}$
L1: $[S_1]$
JUMP L3
L2: $[S_2]$
L3:

[if (x<y && y<z) then ...]
= $[x<y \&\& y<z]_{L1,L2}$
= $[x<y]_{L4,L2}$
L4: $[y<z]_{L1,L2}$

L3:

[if (x<y && y<z) then . . .]

= $[x<y \text{ \&\& } y<z]_{L1, L2}$

= $[x<y]_{L4, L2}$

L4: $[y<z]_{L1, L2}$

=
```
    t1 = x<y
    CJUMP t1, L4, L2
L4: t2 = y<z
    CJUMP t2, L1, L2
L1: [S1]
    ⋮
```

good

Compiling switch statement

- Use “jump table” and address calculation

[switch (e){
case 0: S0
break
case 1: S1
break
⋮
}]

= let (I, t) = [e]
in I
o = t * 4
l = table + o
JUMPIND l
L0: [[S0]]
JUMP L
⋮
L:
table: L0, L1, L2, ...

Compiling object references

- In expression e.t:
  - Type of e is known; call its class C
  - Location of field t within C is known; say its offset is o
  - [e] will produce (l, t), where t contains pointer to object
- [e.t] = let (l,t) = [e]
  t1 = newlocation()
  in (l; t1=t+o, t1)
- Method calls e.t(...) more complicated – will discuss in a couple of weeks

address of e.x
To get value, add:
t2 = LOADIND t1

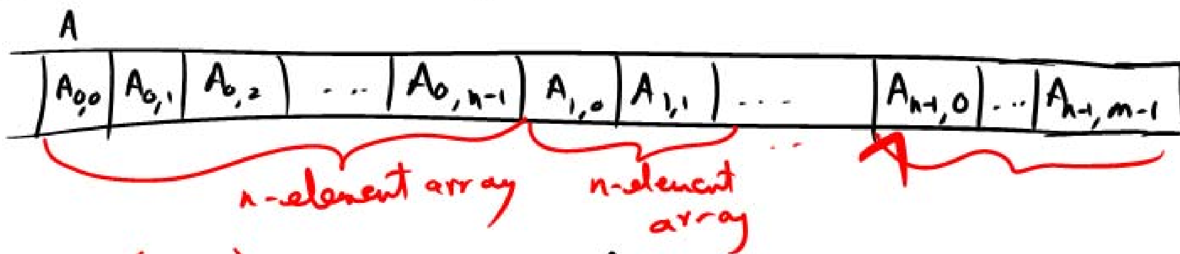
Compiling array references

- Simple rule: If A has elements of type T, and if elements of type T occupy n bytes, then address of A[i] is address of A + i*n.
-
```
[A[e]]  =  let (l, t) = [e]
           in   (l
                 t1 = &A
                 t2 = t*w   (w size of A's elements)
                 t3 = t1+t2
                 t4 = LOADIND t3,        t4)
```

Compiling array references

- Idea extends to multi-dimensional arrays.

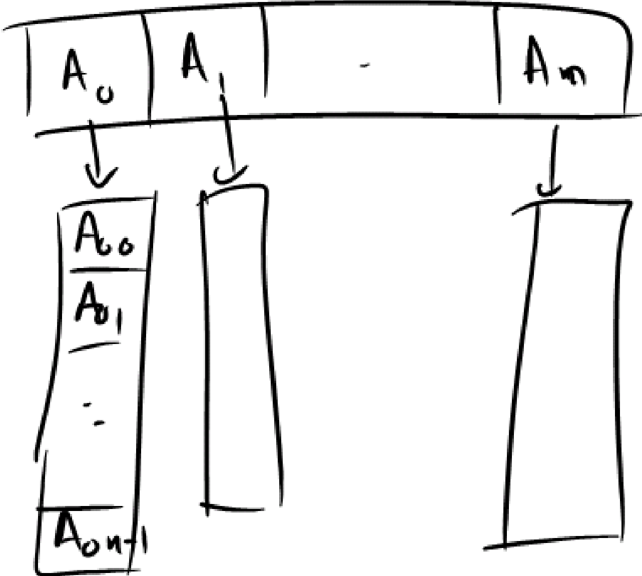
Traditional 2-d arrays (C, FORTRAN)



[(A[i])[j]] = t1 = &A
t2 = i * (4 * n) ~ width of elements of A
t3 = t1+t2
t4 = j * 4
t5 = t3 + t4
t6 = LOADIND t5

For Java, LOADIND t3 for location of array — also, use 4 instead of 4*n

Java 2-d arrays



Machine-independent optimizations

- Machine-independent optimization = optimizations that can be done at the level of IR – i.e. does not depend upon features of target machine such as registers, pipeline, special instructions
- E.g. "loop-invariant code motion":

```
int A[100][100]

while (j<n) {
   x = x + A[i][j]
   j++;
}
```

```
t1 = &A
t2 = i*100
t3 = t2+j
t4 = t3*4
t5 = t1+t4
t6 = LOADIND t5
x = x+t6
j = j+1
```

move to before loop

Machine-dependent optimizations

- Machine-dependent optimization = optimizations that exploit features of target machine such as registers, pipeline, special instructions
  - Register allocation
  - Instruction selection
  - Instruction scheduling