EDAN65: Compilers, Lecture 12

More on code generation

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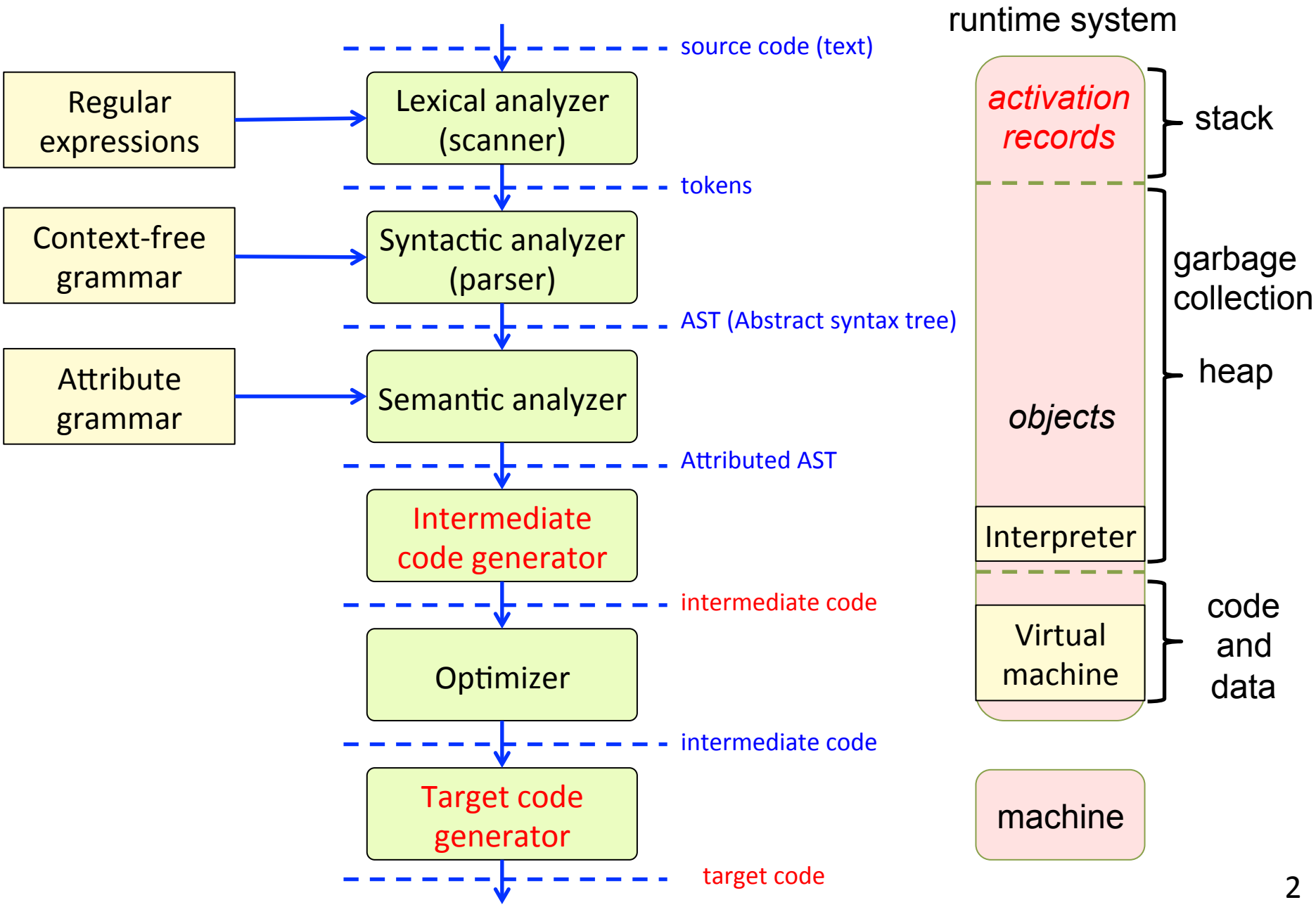
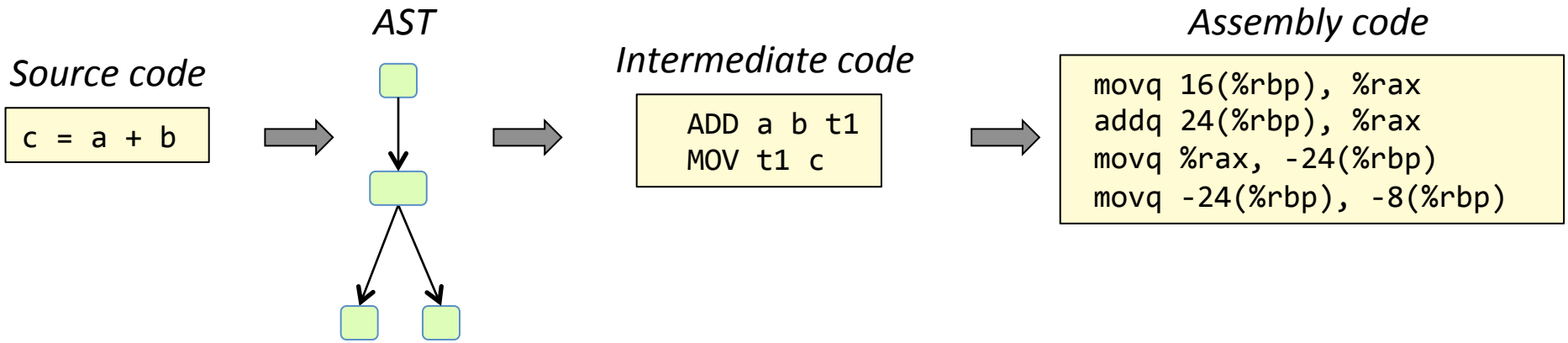
This lecture



Generating code



Intermediate code:

- Where most optimizations are done

Assembly code:

- For given machine, operating system, assembler, and calling conventions

In assignment 6

- Generate AT&T assembly code for x86-64, using simple calling conventions
- No intermediate code – we generate the assembly code directly from the AST.

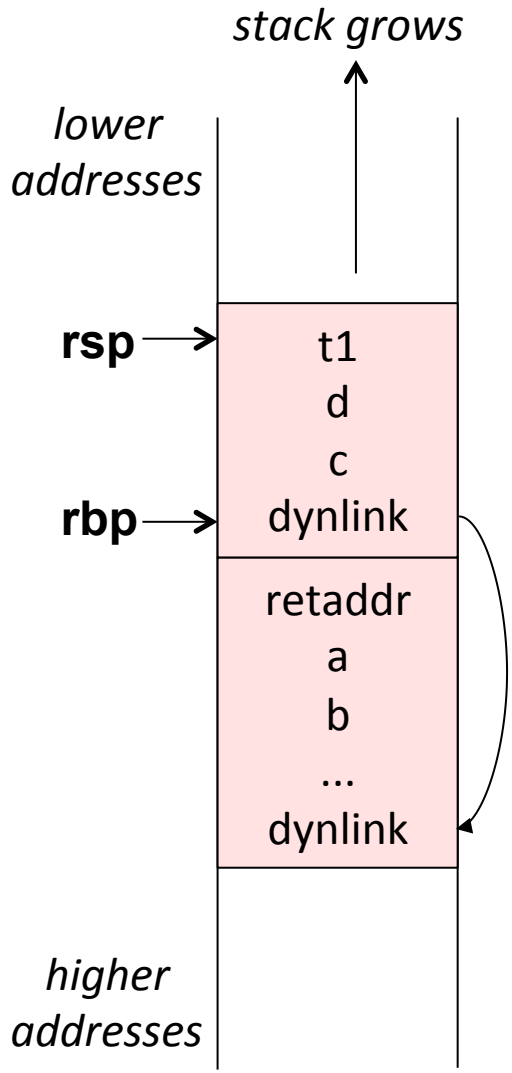
AT&T x86-64 assembly code

Source code

```
void m(int a, int b) {
  int c, d;
  ...
  c = a + b
  ...
}
```

Assembly code

```
m:                      # Label for the method
  pushq %rbp            # Push the dynamic link
  movq %rsp, %rbp       # Set the new frame pointer
  subq $24, %rsp        # Make room on stack for c, d, t1
  ...
  movq 16(%rbp), %rax         # a -> rax
  addq 24(%rbp), %rax         # b + rax -> rax
  movq %rax, -24(%rbp)        # rax -> t1
  movq -24(%rbp), -8(%rbp)    # t1 -> c
  ...

  movq %rbp, %rsp       # Move back the stack pointer
  popq %rbp             # Restore the frame pointer
  ret                   # Return to the calling method
```



Generating code for different constructs

Expression evaluation, using temporaries, local variables, formal arguments

Method call, passing arguments and return values

Method activation and return, setting up a new frame, restoring it

Control structures, labels and branching

Explicit temps

(like in previous lecture)

Source code

```
a = b * (c + d)
```

Variable addresses

```
a      -8(%rbp)
b     -16(%rbp)
c     -24(%rbp)
d     -32(%rbp)
t1    -40(%rbp)
t2    -48(%rbp)
```

x86 assembly code, explicit temps

```
  movq  -24(%rbp), %rax        # c -> rax
  addq  -32(%rbp), %rax        # d + rax -> rax
  movq  %rax,      -40(%rbp)   # rax -> t1
  movq  -16(%rbp), %rax        # b -> rax
  imulq -40(%rbp), %rax        # t1 * rax -> rax
  movq  %rax,      -48(%rbp)   # rax -> t2
  movq  -48(%rbp), -8(%rbp)    # t2 -> a
```

Main idea:

- Each operation puts its result in a new temp

Code generation for binary operation:

- generate code for left op (result at some address)
- generate code for right op (result at some address)
- move left op to %rax
- perform operation on right op and %rax
- move %rax into new temp

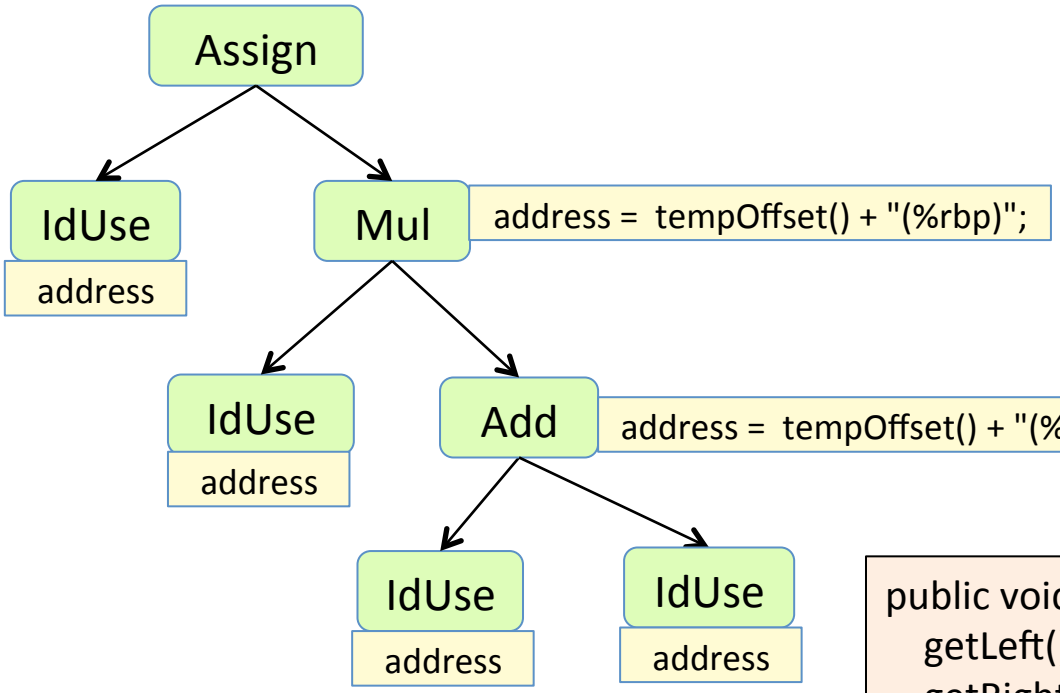
Code generation for assignment:

- generate code for right-hand side (result at some address)
- move result to left var

Code generation for IdUse:

- No code needed.

Example code generation with explicit temps




```
public void Mul.genCode(PrintStream s) {
   getLeft(). genCode(s);
   getRight(). genCode(s);
   s.println("movq " + getLeft().address() + ", %rax");
   s.println("imulq " + getRight().address() + ", %rax");
   s.println("movq %rax, " address());
}

public void IdUse. genCode(PrintStream s) { }
```

Stack of temps

an alternative to explicit temps

Source code

```
a = b * (c + d)
```

Variable addresses

```
a       -8(%rbp)
b      -16(%rbp)
c      -24(%rbp)
d      -32(%rbp)
```

Main idea:

- each expression puts its result in rax

Code generation for binary operation

- generate code for left op (result in rax)
- push rax
- generate code for right op (result in rax)
- pop left op into rbx
- op rbx rax (result in rax)

x86 assembly code, temps on stack

```
  movq  -16(%rbp), %rax     # b -> rax
  pushq %rax                # push rax
  movq  -24(%rbp), %rax     # c -> rax
  pushq %rax                # push rax
  movq  -32(%rbp), %rax     # d -> rax
  popq  %rbx                # pop -> rbx
  addq  %rbx,      %rax     # rbx + rax -> rax
  popq  %rbx                # pop -> rbx
  imulq %rbx,      %rax     # rbx * rax -> rax
  movq %rax,       -8(%rbp) # rax -> a
```

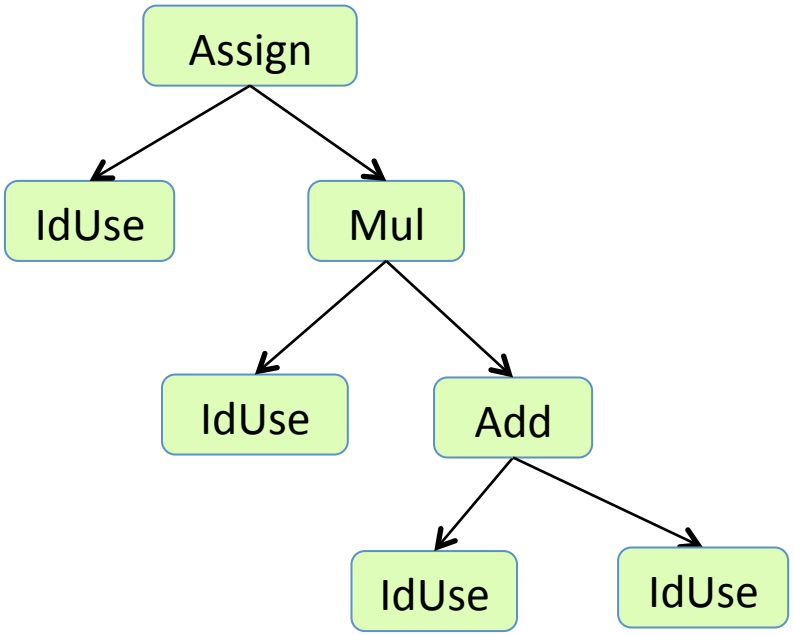
Code generation for assignment:

- generate code for right-hand side (result in rax)
- move rax to left var

Code generation for IdUse:

- move value into rax

Example code generation with stack of temps




```
public void Mul.genCode(PrintStream s) {
   getLeft().genCode(s);
   s.println("pushq %rax");
   getRight().genCode(s);
   s.println("popq %rbx");
   s.println("imulq %rbx, %rax");
}

public void IdUse.genCode(PrintStream s) {
   s.println(”movq " + decl().address() + ”, %rax”);
}
```

Explicit or stacked temps?

Code generation is simpler for stacked temps – we don't need to compute addresses for temps.

But: to generate code for method calls, we need to evaluate the arguments from right to left, to push them in the appropriate order on the stack. Not all languages allow this.

If evaluating the arguments have side effects, the evaluation order can make a difference.

Some languages, like Java, define the evaluation order on arguments from left to right.

In assignment 6, we will use stacked temps. (For SimpliC it is ok to evaluate the arguments from right to left.)

Generating code from the AST

Define suitable node properties, using attributes, to make the code generation easy.

Then write the code generation as a recursive method, printing the code to a file.

What properties do we need?

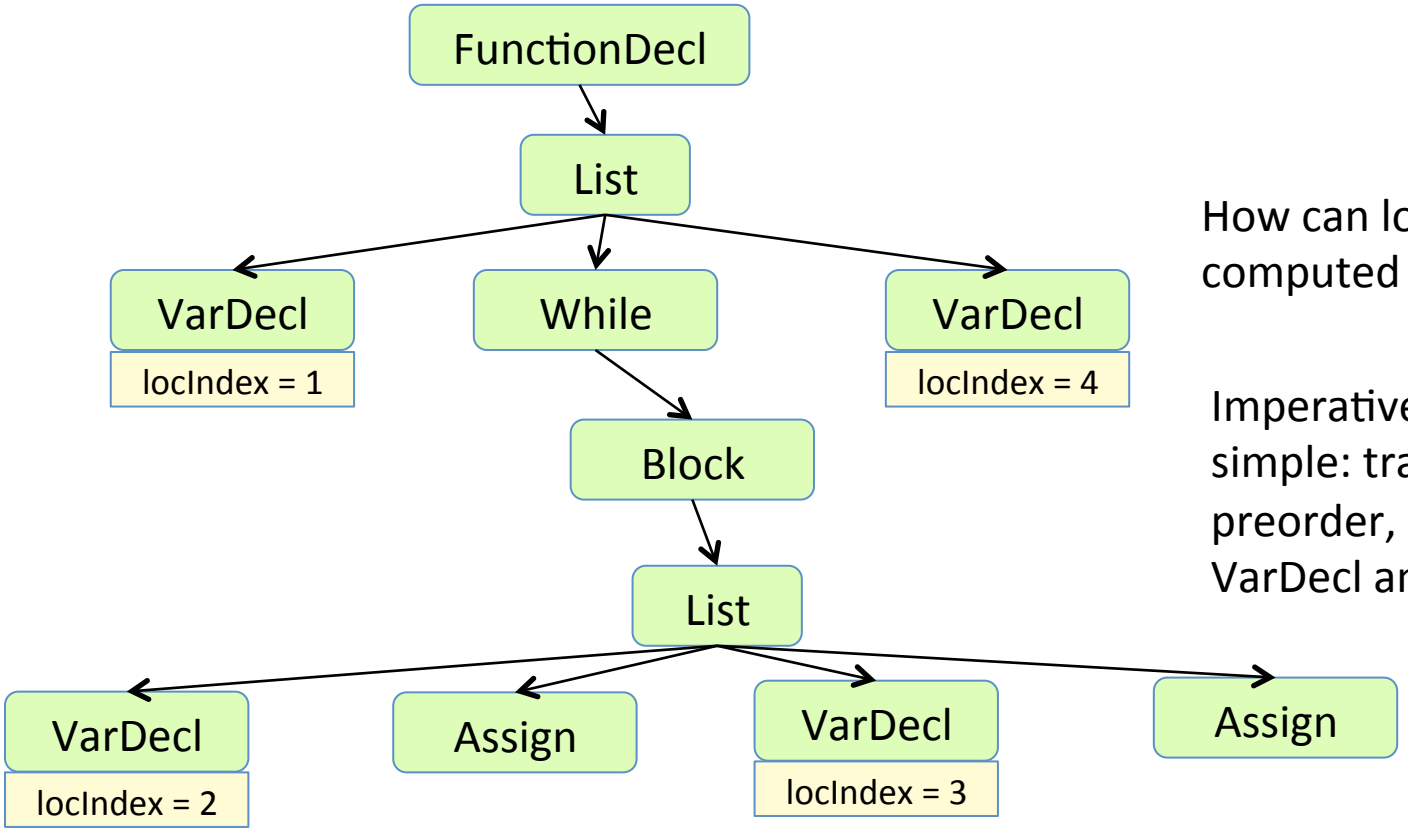
- The address of each variable declaration, for example "-8(%rbp)".
- The number of local variables of a method (to reserve space on the stack).
- The address of each formal argument, for example, "16(%rbp)".
- Unique labels for each control structure.

Computing addresses of declarations

using attributes

Main idea:

- Enumerate the variable declarations inside each function, giving them local indexes: 1, 2, ...
- Translating to the address is then simple: "-8(%rbp)", "-16(%rbp)", ...



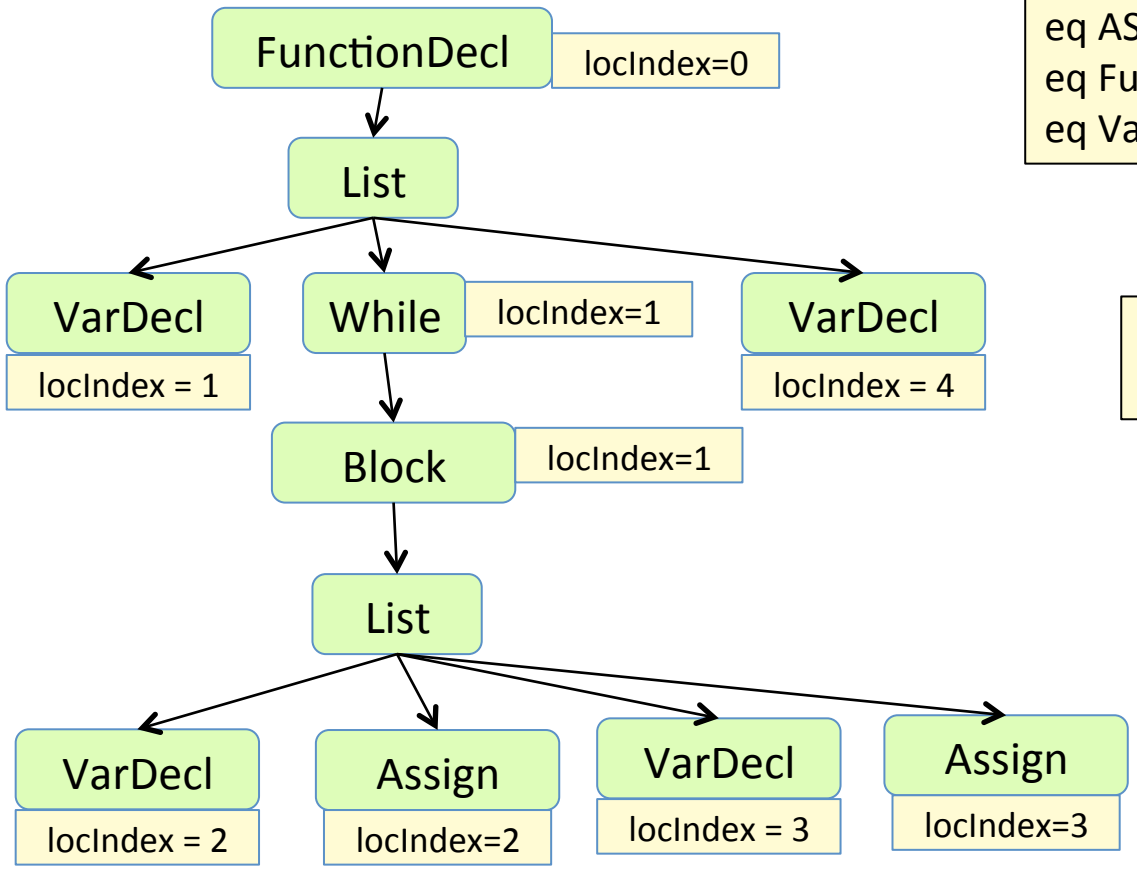
How can locIndex be computed using attributes?

Imperatively, it would be simple: traverse the tree in preorder, and give each VarDecl an increasing index.

Computing locIndex declaratively

Main idea:

- Give *all* nodes a **locIndex**, the locIndex of the latest VarDecl in a preorder traversal.
- Normally the same as for the previous node in the traversal.
- But 0 for the root, and one more for each VarDecl.




```
syn int ASTNode.locIndex();
eq ASTNode.locIndex() = prev().locIndex();
eq FunctionDecl.locIndex() = 0;
eq VarDecl.locIndex() = prev().locIndex() + 1;
```

computing the number of locals

```
syn int FunctionDecl.numLocals() =
  last().locIndex();
```

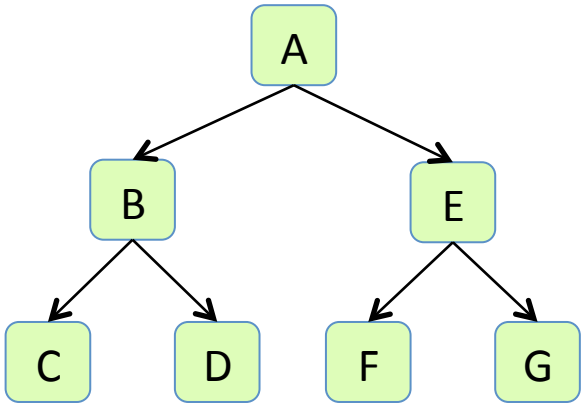
But how are prev() and last() defined?

Computing prev declaratively

Preorder traversal: Visit the nodes in the order A, B, C, D, E, F, G

Each node ***n*** has

- a **prev** attribute, the previous node in a preorder traversal.
- a **prev(i)** attribute, the previous node before traversing the i'th child of ***n***.
- a **last** attribute, the last attribute in a preorder traversal of the ***n*** subtree.

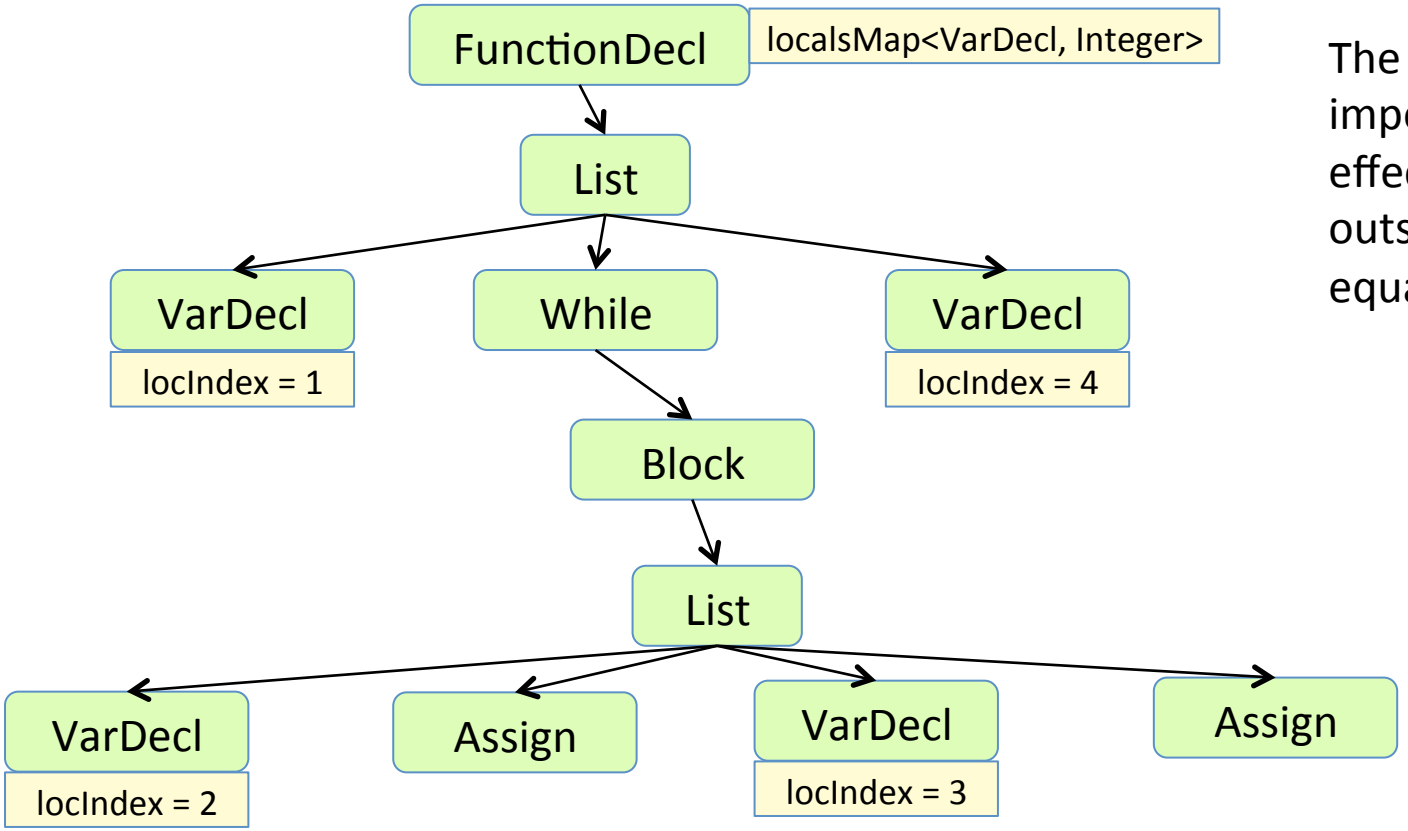



```
inh ASTNode ASTNode.prev();

eq ASTNode.getChild(int i).prev() =
  prev(i);

syn ASTNode ASTNode.prev(int i) =
  i=0 ? this : getChild(i-1).last();

syn ASTNode ASTNode.last() =
  prev(getNumChild());
```

E.prev() == A.prev(1) == B.last() == B.prev(2) == D.last() == D.prev(0) == D

Alternative solution using a map attribute

- Define an attribute
  ```
  syn HashMap<VarDecl, Integer> FunctionDecl.localsMap();
  ```
- Compute it by traversing the function with a method
  ```
  void addLocals(HashMap<VarDecl, Integer> map, Counter c) ...
  ```
- Use the Root Attribute pattern to give each VarDecl access to the map, and let them look up their index.



The **addLocals** method is imperative, but the side effects do not escape outside the **localsMap** equation, so that is ok.

Computing unique labels

Main idea:

- Give each statement a "pathname" relative to the function.
- E.g., 3_2 means the 2nd statement in the 3rd statement in the function.
- Generate labels like m_3_2_whilestart and m_3_2_whileend

```
void m(int a) {
  int x = 1;
  int y;
  while (a > x) {
    y = a*2;
    if (y > 3) {
      ...
    }
  }
}
```

```
m:
  ...
m_3_whilestart:
  ...
m_3_2_ifend:
  ...
m_3_whileend:
  ...
```

Compute the "pathnames" in a similar way as the unique variable names were implemented in assignment 5.

An example assembly program

Generated by:

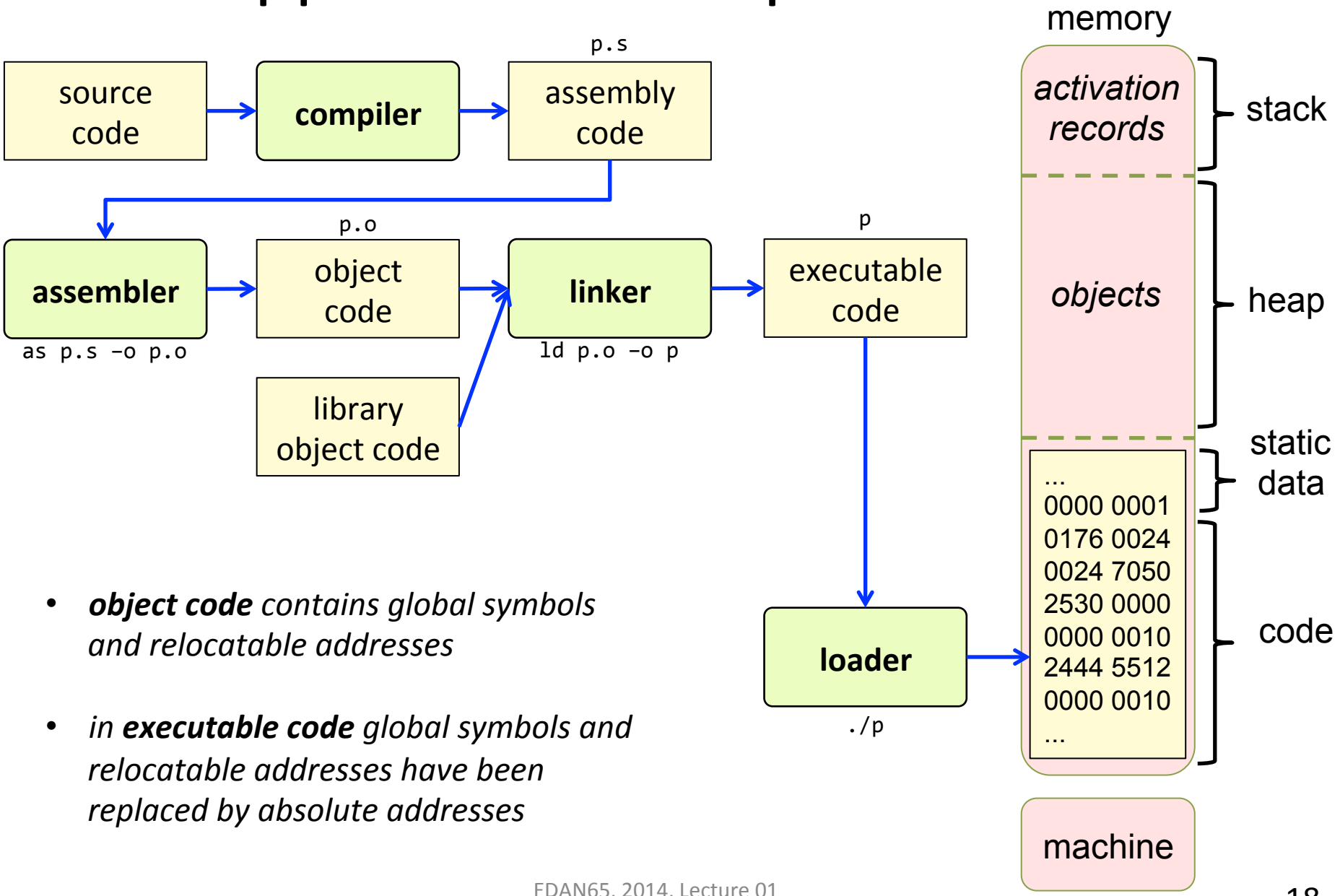
```
.global _start              # global segment
.data                       # data segment (for global data)
...
.text                       # text segment (for code, write protected)
_start:                     # execution starts here
        call fstart_main    # call the main program
        movq %rax, %rdi     # use the result as the exit code
        movq $60, %rax
        syscall             # call system exit

fstart_main:                # pushing the frame for the main function
        pushq %rbp
        movq %rsp, %rbp
        subq $0, %rsp
        ...                 # the code of the main function
fend_main:                  # popping the frame for the main function
        movq %rbp, %rsp
        popq %rbp
        ret

fstart_p:
        ...
fend_p:

...
```

Program node

FunctionDecl node

FunctionDecl node

What happens after compilation?



- ***object code*** *contains global symbols and relocatable addresses*
- *in* ***executable code*** *global symbols and relocatable addresses have been replaced by absolute addresses*

Summary questions

- What information needs to be computed before generating code?
- How do explicit temporaries work? How do stacked temporaries work? What are the advantages and disadvantages of these implementation techniques?
- How can local variable numbers be computed using attributes?
- How can unique labels be computed?
- What is the difference between a text and a data segment in an assembly program?
- What needs to be done to run a program in assembly code?