CS 4120
Introduction to Compilers

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Lecture 13: Intermediate Code

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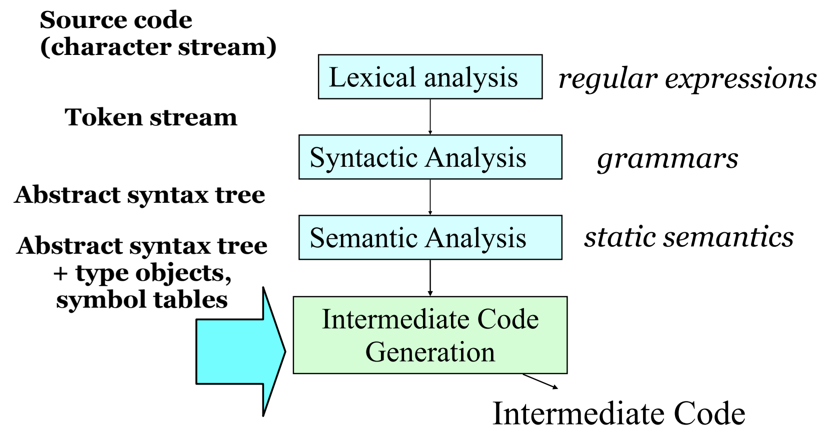
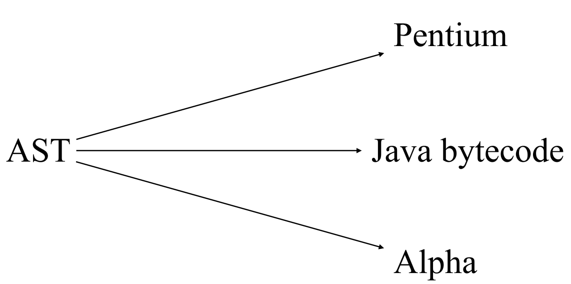
Where we are



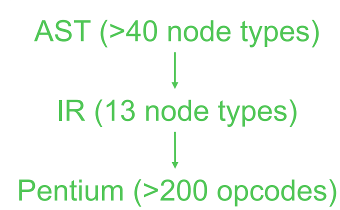
Intermediate Code

- Abstract machine code - simpler
- Allows machine-independent code generation, optimization



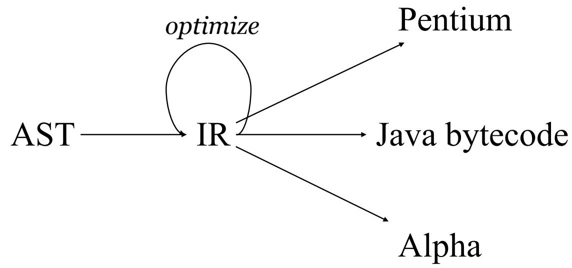
What makes a good IR?

- Easy to translate from AST
- Easy to translate to assembly
- Narrow interface: small number of node types (instructions)
  - Easy to optimize
  - Easy to retarget



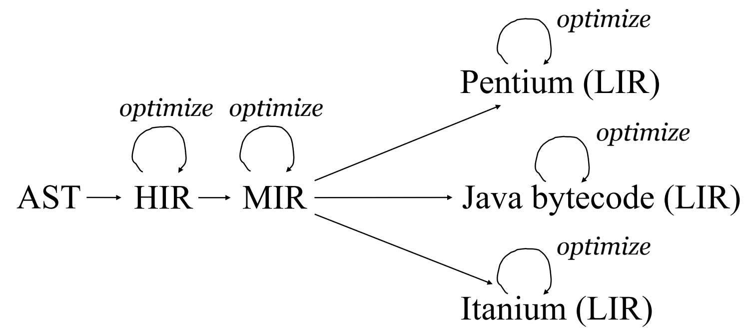
Intermediate Code

- Abstract machine code (**I**ntermediate **R**epresentation)
- Allows machine-independent code generation, optimization



Optimizing compilers

- Goal: get program closer to machine code without losing information needed to do useful optimizations
- Need multiple IR stages



High-level IR (HIR)

- AST + new node types not generated by parser
- Preserves high-level language constructs
  - structured flow, variables, methods
- Allows high-level optimizations based on properties of source language (*e.g.* inlining, reuse of constant variables)
- More passes: ideal for visitors

Medium-level IR (MIR)

- Intermediate between AST and assembly
- Appel's IR: tree structured IR (triples)
- Unstructured jumps, registers, memory loc'ns
- Convenient for translation to high-quality machine code
- Other MIRs:
  - quadruples: $a = b$ OP c ("a" is explicit, not arc)
  - UCODE: stack machine based (like Java bytecode)
  - advantage of tree IR: easier instruction selection
  - advantage of quadruples: easier dataflow analysis, optimization
  - advantage of UCODE: slightly easier to generate

Low-level IR (LIR)

- Assembly code + extra pseudo-instructions
- Machine-dependent
- Translation to assembly code is trivial
- Allows optimization of code for low-level considerations: scheduling, memory layout

MIR tree

- **I**ntermediate **R**epresentation is a tree of nodes representing abstract machine instructions: can be interpreted
- IR almost the same as Appel's (except CJUMP)
- Statement nodes return no value, are executed in a particular order
  - *e.g.* MOVE, SEQ, CJUMP
  - Iota statement ≠ IR statement!
- Expression nodes return a value, children are executed in no particular order
  - *e.g.* ADD, SUB
  - non-determinism gives flexibility for optimization

IR expressions

- CONST(i) : the integer constant i
- TEMP(t) : a temporary register t. The abstract machine has an infinite number of registers
- OP(e_1, e_2) : one of the following operations
  - arithmetic: ADD, SUB, MUL, DIV, MOD
  - bit logic: AND, OR, XOR, LSHIFT, RSHIFT, ARSHIFT
  - comparisons: EQ, NEQ, LT, GT, LEQ, GEQ
- MEM(e) : contents of memory locn w/ address e
- CALL(f, a_0, a_1, ...) : result of fcn f applied to arguments a_i
- NAME(n) : address of the statement or global data location labeled n (TBD)
- ESEQ(s, e) : result of e after stmt s is executed

CONST

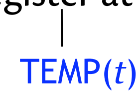
- CONST node represents an integer constant i

CONST(i)

- Value of node is i

TEMP

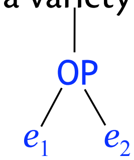
- TEMP node is one of the infinite number of registers (temporaries)
- For brevity, FP = TEMP(FP)
- Used for local variables and temporaries
- Value of node is the current content of the named register at the time of evaluation



OP

- Abstract machine supports a variety of different operations

OP(e_1, e_2)

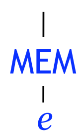


- Evaluates e_1 and e_2 and then applies operation to their results
- e_1 and e_2 must be expression nodes
- Any order of evaluation of e_1 and e_2 is allowed

MEM

- MEM node is a memory location

MEM(e)



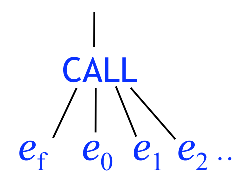
- Computes value of e and looks up contents of memory at that address

CALL

- CALL node represents a function call

CALL(e_f, e_0, e_1, e_2, ...)

function code address (e_f); arguments (e_0, e_1, e_2, ...)



- No explicit representation of argument passing, stack frame setup, etc.
- Value of node is result of call

NAME

- Address of memory location named n
- Two kinds of named locations
  - labeled statements in program (from LABEL statement)
  - global data definitions (not represented in IR)

NAME(n)

ESEQ

- Evaluates an expression e **after** completion of a statement s that might affect result of e
- Result of node is result of e

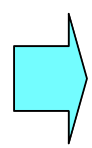
ESEQ(s, e)

IR statements

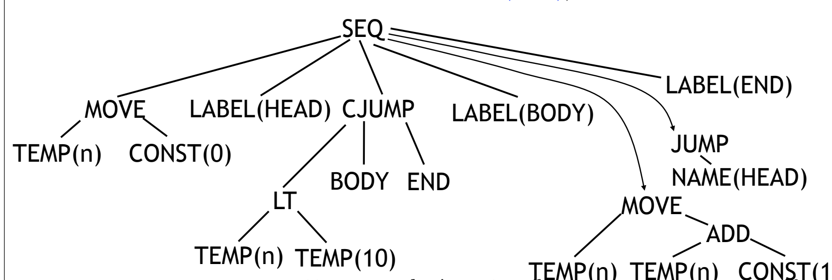
- MOVE($dest$, e) : move result of e into $dest$
  - $dest$ = TEMP(t) : assign to temporary t
  - $dest$ = MEM(e) : assign to memory locn e
- EXP(e) : evaluate e for side-effects, discard result
- SEQ(s_1, …, s_n) : execute each stmt s_i in order
- JUMP(e) : jump to address e
- CJUMP(e, l_1, l_2) : jump to statement named l_1 or l_2 depending on whether e is true or false
- LABEL(n) : labels a statement (for use in NAME)

Example

```
n = 0;
while (n < 10) (
   n = n + 1
)
```

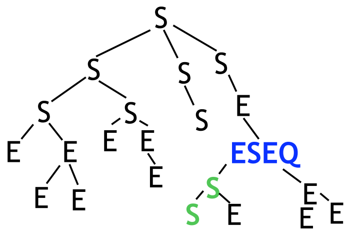


```
SEQ(MOVE(TEMP(n), CONST(0)),
    LABEL(HEAD),
    CJUMP(LT(TEMP(n), CONST(10)),
          BODY, END),
    LABEL(BODY),
    MOVE(TEMP(n), ADD(TEMP(n),
                      CONST(1))),
    JUMP(NAME(HEAD)),
    LABEL(END))
```



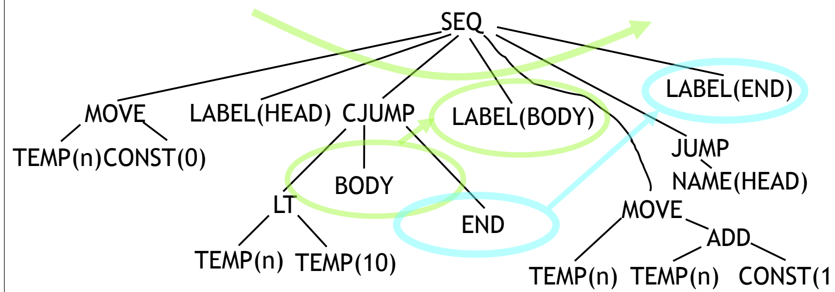
Structure of IR tree

- Top of tree is a statement
- Expressions are under some statements
- Statements under expressions only if there is an ESEQ node



Executing the IR

- IR tree is a program representation; can be executed directly by an interpreter
- Execution is tree traversal (exc. jumps)



How to translate?

- How do we translate an AST/High-level IR into this IR representation?
- Next: syntax-directed translation