CSE 401 – Compilers

Intermediate Representations

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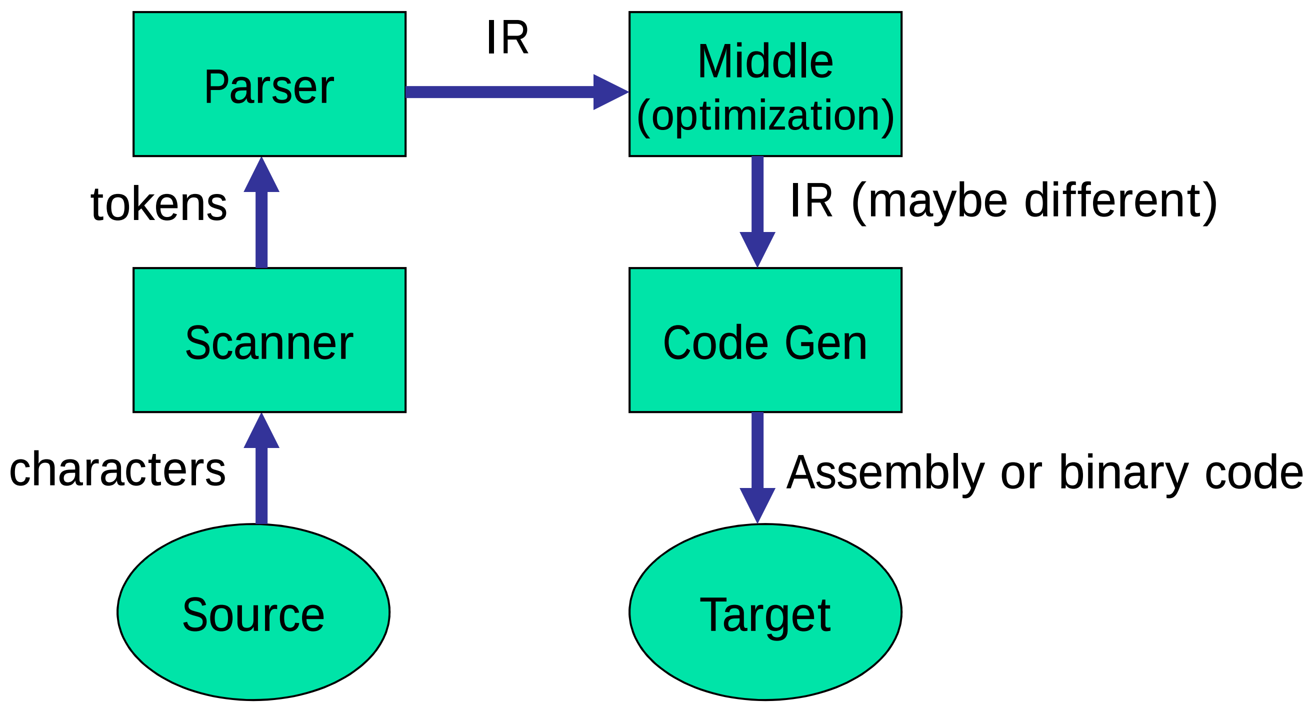
Agenda

- Parser Semantic Actions
- Intermediate Representations
  - Abstract Syntax Trees (ASTs)
  - Linear Representations
  - & more

- We're going to skip past LL parsing for the moment to keep the project on track.

Compiler Structure (review)



What's a Parser to Do?

- Idea: at significant points in the parse perform a *semantic action*
  - Typically when a production is reduced (LR) or at a convenient point in the parse (LL)
- Typical semantic actions
  - Build (and return) a representation of the parsed chunk of the input (compiler)
  - Perform some sort of computation and return result (interpreter)

Intermediate Representations

- In most compilers, the parser builds an intermediate representation of the program
- Rest of the compiler transforms the IR to “improve” (optimize) it and eventually translates it to final code
  - Often will transform initial IR to one or more different IRs along the way
- Some general examples now; specific examples as we cover later topics

IR Design

- Decisions affect speed and efficiency of the rest of the compiler
- Desirable properties
  - Easy to generate
  - Easy to manipulate
  - Expressive
  - Appropriate level of abstraction
- Different tradeoffs depending on compiler goals
- Different tradeoffs in different parts of the same compiler

IR Design Taxonomy

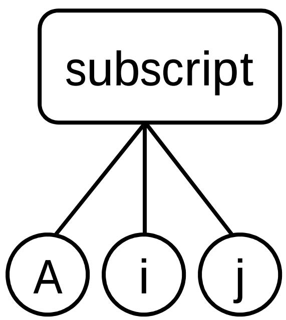
- Structure
  - Graphical (trees, DAGs, etc.)
  - Linear (code for some abstract machine)
  - Hybrids are common (e.g., control-flow graphs)
- Abstraction Level
  - High-level, near to source language
  - Low-level, closer to machine

Levels of Abstraction

- Key design decision: how much detail to expose
  - Affects possibility and profitability of various optimizations
  - Structural IRs are typically fairly high-level
  - Linear IRs are typically low-level
  - But these generalizations don't necessarily hold

Examples: Array Reference

A[i,j]



or

t1 ← A[i,j]

```
loadI   1    => r1
sub  rj,r1   => r2
loadI  10    => r3
mult r2,r3   => r4
sub  ri,r1   => r5
add  r4,r5   => r6
loadI @A     => r7
add  r7,r6   => r8
load r8      => r9
```


Structural IRs

- Typically reflect source (or other higher-level) language structure
- Tend to be large
- Examples: syntax trees, DAGs
- Generally used in early phases of compilers

Concrete Syntax Trees

- The full grammar is needed to guide the parser, but contains many extraneous details
  - Chain productions
  - Rules that control precedence and associativity
- Typically the full syntax tree does not need to be used explicitly

Abstract Syntax Trees

- Want only essential structural information
  - Omit extraneous junk
- Can be represented explicitly as a tree or in a linear form
  - Example: LISP/Scheme S-expressions are essentially ASTs
- Common output from parser; used for static semantics (type checking, etc.) and high-level optimizations
  - Usually lowered for later compiler phases

ASTs in Java

- Basic idea is simple: use small classes as records (or structs) for nodes in the AST
  - Simple data structures, not too smart
- But also use a bit of inheritance so we can treat related nodes polymorphically
  - E.g., abstract AST class; extend to get generic classes for statements and expressions; extend those to get node types for specific kinds of statements and expressions
- Project details and survey of MiniJava AST classes in sections

Position Information in Nodes

- To produce useful error messages, it's helpful to record the source program location corresponding to a node in that node
  - Most scanner/parser generators have a hook for this, usually storing source position information in tokens
  - Included in the MiniJava starter code we distributed – take advantage of it in your code

AST Generation

- Idea: each time the parser recognizes a complete production, it produces as its result an AST node (with links to the subtrees that are the components of the production in its instance variables)
- When we finish parsing, the result of the goal symbol is the complete AST for the program

AST Generation in YACC/CUP

- A result type can be specified for each item in the grammar specification
- Each parser rule can be annotated with a semantic action, which is just a piece of Java code that returns a value of the result type
- The semantic action is executed when the rule is reduced

ANTLR/JavaCC/others

- Integrated tools like these can generate syntax trees automatically
  - Advantage: saves work, don't need to define AST classes and write semantic actions
  - Disadvantage: generated trees might not have the right level of abstraction for what you want to do
- For our project, do-it-yourself with CUP
  - The starter code contains the AST classes from the minijava web site

Linear IRs

- Pseudo-code for some abstract machine
- Level of abstraction varies
- Simple, compact data structures
- Examples: three-address code, stack machine code

Abstraction Levels in Linear IR

- Linear IRs can also be close to the source language, very low-level, or somewhere in between.
- Example: Linear IRs for C array reference a[i][j+2]

  - High-level: $t1 \leftarrow a[i,j+1]$

IRs for a[i,j+2], cont.

- Medium-level

  t1 ← j + 2

  t2 ← i * 20

  t3 ← t1 + t2

  t4 ← 4 * t3

  t5 ← addr a

  t6 ← t5 + t4

  t7 ← *t6

- Low-level

  r1 ← [fp-4]

  r2 ← r1 + 2

  r3 ← [fp-8]

  r4 ← r3 * 20

  r5 ← r4 + r2

  r6 ← 4 * r5

  r7 ← fp – 216

  f1 ← [r7+r6]

Abstraction Level Tradeoffs

- High-level: good for source optimizations, semantic checking
- Low-level: need for good code generation and resource utilization in back end; many optimizing compilers work at this level for middle/back ends
- Medium-level: fine for optimization and most other middle/back-end purposes

Hybrid IRs

- Combination of structural and linear
- Level of abstraction varies
- Most common example: control-flow graph
  - Nodes: basic blocks – uninterrupted linear sequences of instructions
  - Edge from B1 to B2 if execution can flow from B1 to B2
  - More later when we survey optimization

What IR to Use?

- Common choice: all(!)
  - AST or other structural representation built by parser and used in early stages of the compiler
    - Closer to source code
    - Good for semantic analysis
    - Facilitates some higher-level optimizations
  - Lower to linear IR for later stages of compiler
    - Closer to machine code
    - Exposes machine-related optimizations
    - Use to build control-flow graph

Coming Attractions

- Working with ASTs
  - Where do the algorithms go?
  - Is it really object-oriented? (Does it matter?)
  - Visitor pattern
- Then: Go back and look at LL (top-down) parsing
- After that: semantic analysis, type checking, and symbol tables