CSE P 501 – Compilers

ASTs, Modularity, and the Visitor Pattern

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Administrivia

- New HW3 (LR constr., LL grammars – today's stuff) out now, due next Tuesday night
  - Will add to gradescope in the next few days
- Parser/AST due in 2 weeks, out now
  - Add parser rules for MiniJava + semantics to build AST
    - Advice: debug grammar rules before adding semantic actions to build the tree
  - Add new visitor to print AST as an indented tree structure
    - Not the same as the AST->source formatter in starter code
    - Needed in any ~~compiler~~ large program: formatted output of key data structure(s)

Agenda

- Representation of ASTs as Java objects
- Parser semantic actions and AST generation
- AST operations: modularity and encapsulation
- Visitor pattern: basic ideas and variations
- Some of the “why” behind the “how”

- For the project, see the MiniJava web site and starter code for more details / ideas

Intermediate Representations

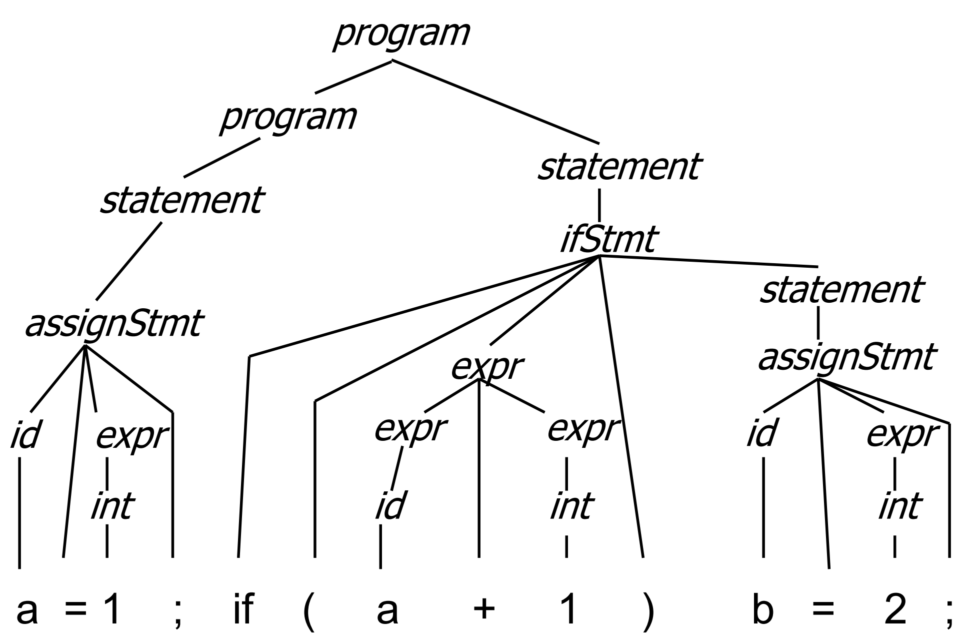
- In most compilers, the parser builds an intermediate representation of the program
  - Typically an AST, as in the MiniJava project
- Rest of the compiler transforms the IR to improve ("optimize") it and eventually translate to final target code
  - Typically will transform initial IR to one or more different IRs along the way
- We'll look at AST's now – other IRs later when we look at optimizations and analysis

Abstract Syntax Trees (ASTs)

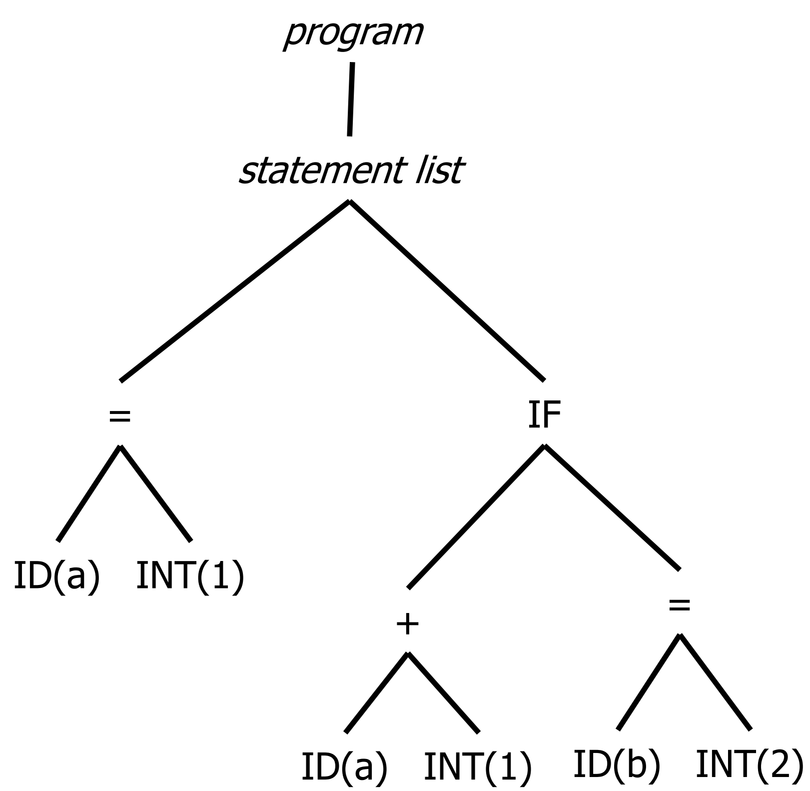
- Idea: capture the essential structure of a program; omit extraneous details
  - i.e, include only what the rest of the compiler needs; omit concrete syntax used only to guide the parse (punctuation, chain productions, etc.)
- Full grammar and derivation needed as part of parsing (it's the control flow for the parser), but a full derivation contains many details that are only needed for parsing, and not after

Parse Tree / AST example (1)

Full parse tree

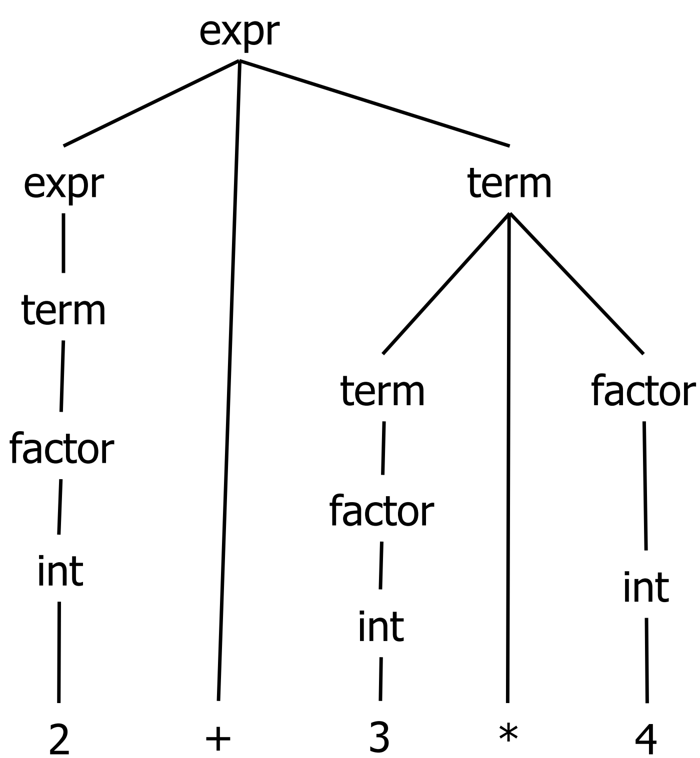


Abstract syntax (AST)

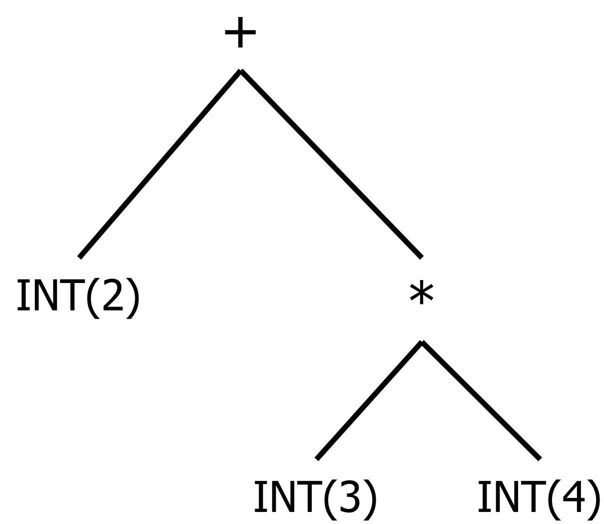


Parse Tree / AST example (2)

Full parse tree



Abstract syntax (AST)

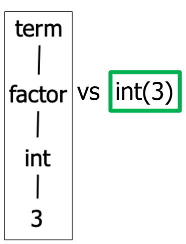


Implementing ASTs in Java

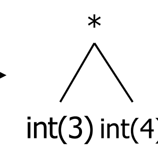
- Multiple ways to do this, but typically (and in our our project)
  - Simple tree node objects (basically structs/records)
    - Subtree pointers plus (usually) other useful information like source program locations (e.g., line numbers), links to semantic (symbol table, types) information (later), …
    - But not much more!
    - Basically dumb data structures with public fields, not “smart objects”
  - Use type system and inheritance to factor common information and allow polymorphic treatment of related kinds of nodes

Building ASTs

- Idea is that each time the parser reduces, the result of that reduction is an AST tree node or subtree representing that production / handle / nonterminal
  - Based on nodes of constituent RHS symbols
  - Maybe just echo node from RHS (e.g. T::=F)



  - Maybe new node links RHS constituents (T::=T*F)



- Attach the code to do this to the grammar rules in our CUP (parser generator) input.
  - More in sections and in the Parser+AST project assignment

MiniJava Starter Code

- AST type hierarchy: root is ASTNode. Some subclasses:
  - Exp (subclasses: And, Plus, Times, True, Call, …)
  - Statement (subclasses: While, Assign, If, Print, …)
  - Type (abstract rep. of types, *not* source code type declarations – more about that when we get to semantics)
  - Declarations, Classes, others parts of abstract grammar, …
- Additional information in all AST nodes
  - Source code position info (hooks in starter JFlex and CUP rules to capture this, use in error messages, AST printout)
  - accept methods for visitors (more later this lecture)
- Not required to use this code, but it is *strongly* advised

Example: AST generation for a Recursive-Descent Parser

```
// parse while (exp) stmt
WhileNode whileStmt() {
    // skip "while ("
    skipToken(WHILE);
    skipToken(LPAREN);

    // parse exp
    ExpNode cond = exp();

(continued next col.)
```

```
    // skip ")"
    skipToken(RPAREN);

    // parse stmt
    StmtNode body = stmt();

    // return AST node for while
    return  new WhileNode (cond, body);
}
```

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

YACC/CUP Parser Specification

- CUP code

```
non terminal StmtNode stmt, whileStmt;
non terminal ExpNode exp;
…
stmt ::= …
      | WHILE LPAREN exp:e RPAREN stmt:s
        {:  RESULT = new WhileNode(e,s);  :}
      ;
```

  – See the starter code for examples showing how to capture additional things in the AST like line numbers

Operations on ASTs

- Once we have the AST, we may want to:
  - Print a readable dump of the tree
  - Print a parseable (source-code) version of the tree (so-called pretty-printing)
  - Do static semantic analysis:
    - Type checking
    - Verify that things are declared and initialized properly
    - Etc. etc. etc. etc.
  - Perform optimizing transformations on the tree
  - Generate code from the tree, or
  - Generate another IR from the tree for further processing

Modularity

- Classic slogans:
  - Do one thing well
  - Minimize coupling, maximize cohesion
  - Isolate operations/abstractions in modules
  - Hide implementation details

- Okay, so where in the MiniJava compiler does the typechecker module belong?

Where do the Operations Go?

- Pure “object-oriented” style
  - Really, really, really smart AST nodes
  - Each node knows how to perform every operation on itself

```
public class WhileNode extends StmtNode {
  public WhileNode(…);
  public typeCheck(…);
  public StrengthReductionOptimize(…);
  public DeadCodeEliminationOptimize(…);
  public generateCode(…);
  public prettyPrint(…);
  …
}
```

Critique

- This is nicely encapsulated – all details about a WhileNode are hidden in that class
- But it is poor modularity
- What happens if we want to add a new optimization (or any other) operation?
  - Have to modify every node class ☹
- Worse: the details of any particular operation (optimization, type checking) are scattered across the node classes

Modularity Issues

- Smart nodes make sense if the set of operations is relatively fixed, but we expect to need flexibility to add new kinds of nodes
- Example: graphics system
  - Operations: draw, move, iconify, highlight
  - Objects: textbox, scrollbar, canvas, menu, dialog box, window, plus new objects defined as the system evolves
- Another example: objects in a game or simulation

Modularity in a Compiler

- Abstract syntax does not change frequently over time – language changes are usually incremental
  - ∴ Kinds of nodes are relatively fixed
- As a compiler evolves, it is common to modify or add operations on the AST nodes
  - Want to modularize each operation (type check, optimize, code gen) so its parts are together in the source code
  - Want to avoid having to change node classes when we modify or add an operation on the tree

Two Views of Modularity

	draw	move	iconify	highlight	transmogrify
circle	X	X	X	X	X
text	X	X	X	X	X
canvas	X	X	X	X	X
scroll	X	X	X	X	X
dialog	X	X	X	X	X
…					

	Type check	Optimize	Generate x86	Flatten	Print
IDENT	X	X	X	X	X
exp	X	X	X	X	X
while	X	X	X	X	X
if	X	X	X	X	X
Binop	X	X	X	X	X
…					

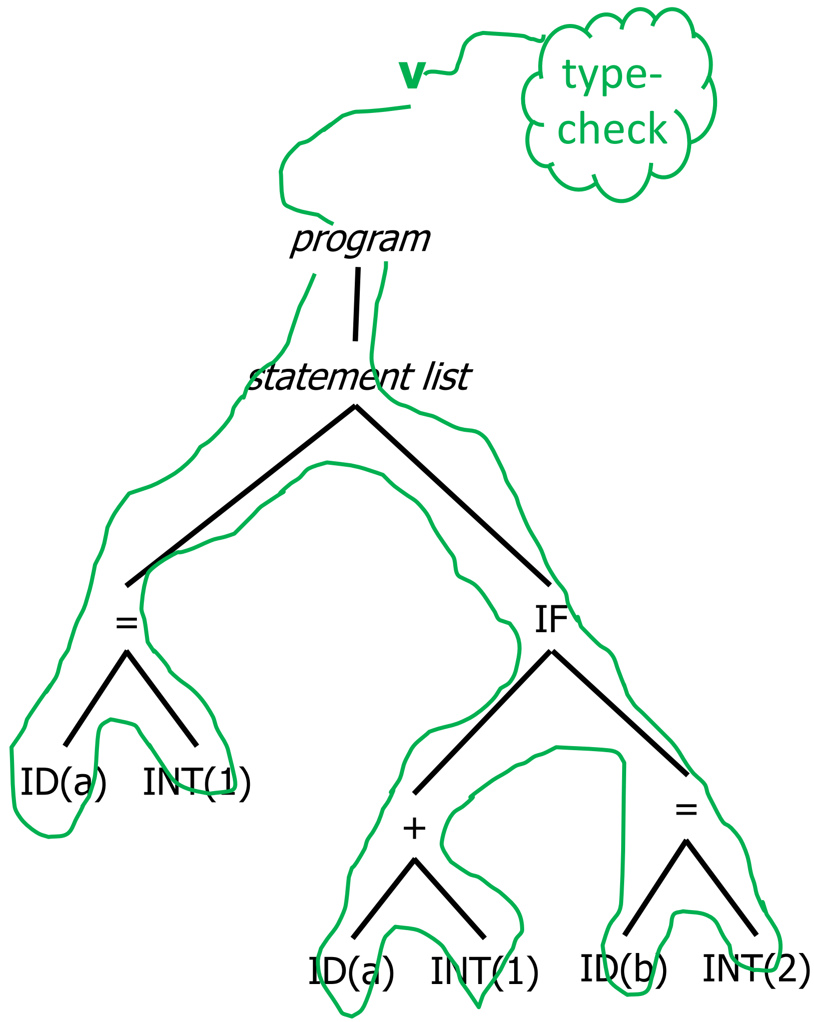
Visitor Pattern

- Idea: Package each operation (optimization, print, code gen, …) in a separate visitor class (module)
- Create exactly one instance of each visitor class (a singleton!)
  – Sometimes called a "function object"
  – Contains all of the methods for that particular operation, one for each kind of AST node
- Include a generic "accept visitor" method in every node class
- To perform an operation, pass the appropriate "visitor object" around the AST during a traversal

Here's the idea

To type-check this AST:

1. Create an object (instance) v of the Type-Check visitor class
2. Pass the type-check object to the root note accept(visitor) method
3. Each node passes the visitor object around the tree by calling accept(v) in subtrees to type-check the subtree, and then combine results (a tree traversal)
4. When each node "accepts" the visitor, it arranges to call the visitor method that knows how to type-check *that* particular kind of node



Visitor issue: avoiding instanceof

- We'd like to avoid huge if-elseif nests in the visitor to discover what node type it is processing as it is passed around the tree

```
void checkTypes(ASTNode p) {
    if (p instanceof WhileNode) { … }
    else if (p instanceof IfNode) { … }
    else if (p instanceof BinExp) { … }
…
}
```

Visitor “Double Dispatch”

- Include an overloaded “visit” method for every AST node type in each Visitor (singleton) object
  - These are the operation methods for the different nodes

    void visit(WhileNode);

    void visit(ExpNode);

    etc.
- Include an accept(Visitor v) method in each AST node class
- When Visitor v is passed to an AST node, the node’s accept method calls v.visit(this)
  - Calls correct Visitor method for this node type
  - Often called “double dispatch”, but really single dispatch combined with method overloading

Visitor Interface

```
interface Visitor {
    // overload visit for each AST node type
    public void visit(WhileNode s);
    public void visit(IfNode s);
    public void visit(BinExp e);
    …
}
```

- Every separate Visitor class implements this interface
- Aside: Method result type can be whatever is convenient, doesn't have to be void, although that is common
- Note: could also give methods unique names e.g., visitWhile, visitIf, visitBinExp, etc. instead of overloading visit(…). Best to follow existing code if either convention already adopted, otherwise individual preference.

Accept Method in Each AST Node Class

- Every AST class overrides accept(Visitor)
- Example

```
public class WhileNode extends StmtNode {
    …
    // accept a visit from a Visitor object v
    @Override
    public void accept(Visitor v) {
        v.visit(this);   // call using type of “this” (WhileNode) to
    }                    // select proper overloaded method in the
    …                    // visitor object
}
```

- Key points
  - Visitor object passed as a parameter to WhileNode
  - WhileNode calls visit, which calls visit(WhileNode) automatically because of overloading – i.e., the correct method for this kind of node
- Note: if visitor methods have unique names instead of overloading visit(…) then WhileNode would call something like v.visitWhile(this).

Composite Objects (1)

- How do we handle composite objects? (e.g., loops containing condition and statement body)
- One possibility: the accept method passes the visitor down to subtrees before (or after) visiting itself

```
public class WhileNode extends StmtNode {
  Expr exp; Stmt stmt;   // children
  …
  // accept a visit from visitor v
  public void accept (Visitor v) {
    this.exp.accept(v);
    this.stmt.accept(v);
    v.visit(this);
  }
```

Composite Objects (2)

- Another possibility: the visitor can control the traversal inside the visit method for that particular kind of node

```
public void visit(WhileNode w) {
    w.expr.accept(this);
    w.stmt.accept(this);
}
```

So which to choose?

- Possibilities:
  - Node objects drive the traversal and pass the visitors around the tree in standard ways
  - Visitor object drives the traversal (the visitor has access to the node, including references to child subtrees)
- In a compiler:
  - First choice handles many common cases
  - Big compilers often have multiple visitor schemes (e.g., several different traversals defined in Node interface – postorder, inorder, … – plus custom traversals in some visitors)
  - For MiniJava: keep it simple and start with supplied examples, but if you really need to do something different, you can
    - (i.e., keep an open mind, but not so open that you create needless complexity)

Encapsulation

- A visitor object often needs to be able to access state in the AST nodes
  - ∴ May need to expose more node state than we might have done otherwise
    - i.e., lots of public fields in AST node objects
  - – Overall a good tradeoff – better modularity

    (plus, the nodes should be relatively simple data objects anyway – not hiding much of anything)

Visitor Actions and State

- A visitor function has a reference to the node it is visiting (the parameter)
  - ∴ can access and manipulate subtrees directly
- Visitor object can also include local data (state) shared by methods in the visitor
  - – This data is effectively "global" to the methods in the visitor object, and can be used to store and pass around information accumulated by the visit methods

```
public class TypeCheckVisitor extends NodeVisitor {
    public void visit(WhileNode s) { … }
    public void visit(IfNode s) { … }
    …
    private <local state>;        // all typecheck visitor methods can read/write this
}
```

Why is it so complicated?

- What we're really trying to do: 2-argument dynamic dispatch
  - Pick correct method to execute based on dynamic types of both the node and the visitor
- But Java and most O-O languages only support single dispatch
  - So we use single dispatch plus overloading to get the effect we want

References

- For Visitor pattern (and many others)
  - *Design Patterns: Elements of Reusable Object-Oriented Software*, Gamma, Helm, Johnson, and Vlissides, Addison-Wesley, 1995 (the classic; examples are in old C++ and Smalltalk)
  - *Object-Oriented Design & Patterns*, Horstmann, A-W, 2nd ed, 2006 (uses Java)
- Specific information for MiniJava AST and visitors in our project starter code + Appel textbook & online

Coming Attractions

- Static Analysis
  - Type checking & representation of types
  - Non-context-free rules (variables and types must be declared, etc.)
- Symbol Tables
- & more

- Later, more about compiler IRs when we get to optimizations