Context-sensitive Analysis, II

Ad-hoc syntax-directed translation, Symbol Tables, and Types

Remember the Example from Last Lecture?

Grammar for a basic block *(§ 4.3.3)*

$Block_0$	→	$Block_1$ Assign
	|	Assign
Assign	→	Ident = Expr ;
$Expr_0$	→	$Expr_1$ + Term
	|	$Expr_1$ – Term
	|	Term
$Term_0$	→	$Term_1$ * Factor
	|	$Term_1$ / Factor
	|	Factor
Factor	→	(Expr)
	|	Number
	|	Identifier

Let's estimate cycle counts

- **Each operation has a COST**
- **Add them, bottom up**
- **Assume a load per value**
- **Assume no reuse**

Simple problem for an *AG*

And Its Extensions

Tracking loads

- Introduced *Before* and *After* sets to record loads
- Added ≥ 2 copy rules per production
  - → Serialized evaluation into execution order
- Made the whole attribute grammar large & cumbersome

The Moral of the Story

- Non-local computation needed lots of supporting rules
- Complex local computation was relatively easy

The Problems

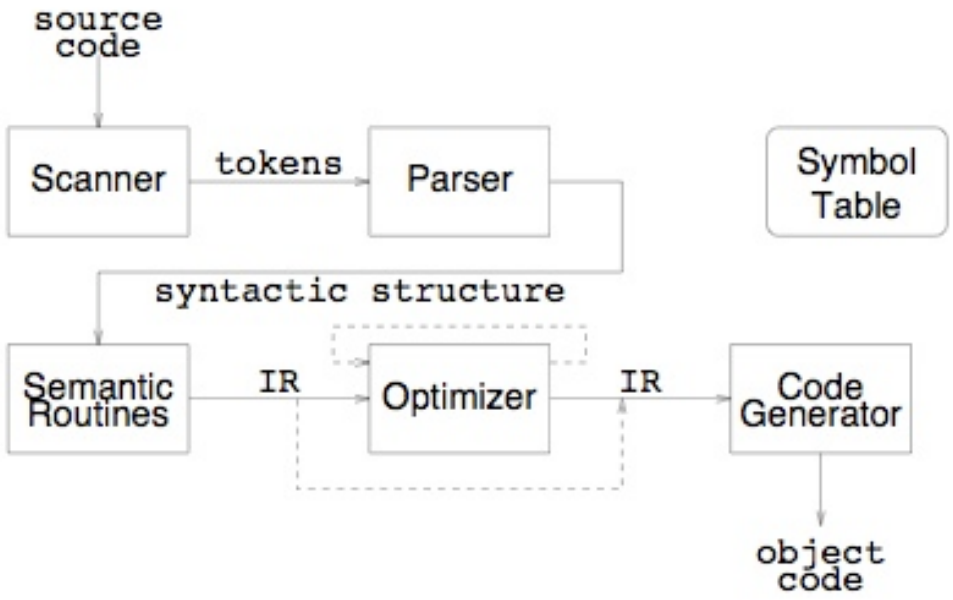
- Copy rules increase complexity
  - → Hard to understand and maintain
- Copy rules increase space requirements
  - → Need copies of attributes
  - → Can use pointers, but harder to understand

Addressing the Problem

If you gave this problem to a programmer at IBM

- Introduce a central repository for facts
- Table of names
  - → Field in table for loaded/not loaded state
- Avoids all the copy rules, allocation & storage headaches
- All inter-assignment attribute flow is through table
  - → Clean, efficient implementation
  - → Good techniques for implementing the table *(hashing, § B.3)*
  - → When its done, information is in the table !
  - → Cures most of the problems
- Unfortunately, this design violates the functional paradigm
  - → Do we care?

Remind ourselves of Compiler Phases



Different Phases of Project

Phase I: Scanner
Phase II: Parser
Phase III: Semantic Routines
Phase IV: Code Generator

The Realist's Alternative

Ad-hoc syntax-directed translation

- Associate a snippet of code with each production
- At each reduction, the corresponding snippet runs
- Allowing arbitrary code provides complete flexibility
  - → Includes ability to do tasteless & bad things

To make this work

- Need names for attributes of each symbol on *lhs* & *rhs*
  - → Typically, one attribute passed through parser + arbitrary code (structures, globals, statics, …)
- Need an evaluation scheme
  - → Fits nicely into **LR(1)** parsing algorithm

Reworking the Example (*with load tracking*)

$Block_0$	→	$Block_1$ Assign	
	|	Assign	
Assign	→	Ident = Expr ;	cost← cost + COST(store);
$Expr_0$	→	$Expr_1$ + Term	cost← cost + COST(add);
	|	$Expr_1$ - Term	cost← cost + COST(sub);
	|	Term	
$Term_0$	→	$Term_1$ * Factor	cost← cost + COST(mult);
	|	$Term_1$ / Factor	cost← cost + COST(div);
	|	Factor	
Factor	→	(Expr)	
	|	Number	cost← cost + COST(loadi);
	|	Identifier	{ i← hash(Identifier);
			if (Table[i].loaded = false)
			then {
			cost ← cost + COST(load);
			Table[i].loaded ← true;
			}
			}

This looks simpler than the Attribute Grammar solution!

Example — Building an Abstract Syntax Tree

- Assume constructors for each node
- Assume stack holds pointers to nodes

Goal	→	*Expr*	Goal.node = E.node;
Expr	→	*Expr + Term*	E_0.node= MakeAddNode(E_1.node,T.node);
	|	*Expr - Term*	E_0.node= MakeSubNode(E_1.node,T.node);
	|	*Term*	E.node = T.node;
Term	→	*Term * Factor*	T_0.node= MakeMulNode(T_1.node,F.node);
	|	*Term / Factor*	T_0.node= MakeDivNode(T_1.node,F.node);
	|	*Factor*	T.node = F.node;
Factor	→	(*Expr*)	F.node = Expr.node;
	|	number	F.node= MakeNumNode(token);
	|	id	F.node = MakeIdNode(token);

Reality

Most parsers are based on this *ad-hoc* style of context-sensitive analysis

Advantages

- Addresses shortcomings of Attribute Grammar paradigm
- Efficient, flexible

Disadvantages

- Must write the code with little assistance
- Programmer deals directly with the details

Most parser generators support a yacc/bison-like notation

Typical Uses

- Building a symbol table
  - → Enter declaration information as processed
  - → At end of declaration syntax, do some post processing
  - → Use table to check errors as parsing progresses

assumes table is global

- Simple error checking/type checking
  - → Define before use → lookup on reference
  - → Dimension, type, ... → check as encountered
  - → Type conformability of expression → bottom-up walk
  - → Procedure interfaces are harder
    - ♦ Build a representation for parameter list & types
    - ♦ Create list of sites to check
    - ♦ Check offline, or handle the cases for arbitrary orderings

Symbol Tables

- For compile-time efficiency, compilers use symbol tables
  - → Associates lexical names (symbols) with their attributes

- What items go in symbol tables?

  - → Variable names
  - → Defined constants
  - → Procedure/function/method names
  - → Literal constants and strings

  - → Separate layout for structure layouts
    - ♦ Field offsets and lengths

- A symbol table is a compile-time structure
- More after mid-term!

Attribute Information

- Attributes are internal representation of declarations
- Symbol table associates names with attributes
- Names may have different attributes depending on their meaning:
  - → Variables: type, procedure level
  - → Types: type descriptor, data size/alignment
  - → Constants: type, value
  - → Procedures: Signature (arguments/types) , result type, etc.

Is This Really "Ad-hoc" ?

Relationship between practice and attribute grammars

Similarities

- Both rules & actions associated with productions
- Application order determined by tools, not author
- (Somewhat) abstract names for symbols

Differences

- Actions applied as a unit; not true for AG rules
- Anything goes in *ad-hoc* actions; AG rules are functional
- AG rules are higher level than *ad-hoc* actions

Type Systems

- Types
  - → Values that share a set of common properties
  - → Defined by language (built-ins) and/or programmer (user-defined)
- Type System
  - → Set of types in a programming language
  - → Rules that use types to specify program behavior
- Example type rules
  - → If operands of addition are of type integer, then result is of type integer
  - → The result of the unary "&" operator is a pointer to the object referred to by the operand
- Advantages
  - → Ensures run-time safety
  - → Provides information for code generation

Type Checker

- Enforces rules of the type system
- May be strong/weak, static/dynamic

- Static type checking
  - → Performed at compile time
  - → Early detection, no run-time overhead
  - → Not always possible (e.g., A[I], where I comes from input)

- Dynamic type checking
  - → Performed at run time
  - → More flexible, rapid prototyping
  - → Overhead to check run-time type tags

Type expressions

- Used to represent the type of a language construct
- Describes both language and programmer types

- Examples
  - → Basic types (built-ins) : integer, float, character
  - → Constructed types : arrays, structs, functions