Compilers – The Sequel

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Refresher

- What is a compiler?
  - "A compiler's primary function is to compile, organize the compilation, and go right back to compiling. It compiles basically only those things that require to be compiled, ignoring things that should not be compiled. The main way a compiler compiles, is to compile the things to be compiled until the compilation is complete."

Refresher-in-one-slide

- How does a compiler work?
  - ☑ Lexical analysis – divide program into symbols
  - ☑ Parsing – create tree form of program
  - ☐ Check data types
  - ☐ Determine variables in each section
  - ☐ Transform code to fictitious (IR) machine code
  - ☐ Optimise IR code
  - ☐ Transform IR code to real machine code
  - ☐ Optimise register usage

COMPILERS
Semantic Analysis

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Semantic Analysis

- The compilation process is driven by the syntactic structure of the program as discovered by the parser.
- Semantic routines:
  - interpret meaning of the program based on its syntactic structure
  - it has two functions:
    - finish analysis by deriving context-sensitive information
    - begin synthesis by generating the IR or target code
- Associated with individual productions of a context free grammar or subtrees of a syntax tree.

Context Sensitive Analysis - Why

- What context-sensitive issues can be determined?
  - Is X declared before it is used?
  - Are any names declared but not used?
  - Which declaration of X does this reference?
  - Is an expression type-consistent?
  - Do the dimensions of a reference match the declaration?
  - Where can X be stored? (heap, stack, ,,,)
  - Does *p reference the result of a malloc()?
  - Is X defined before it is used?
  - Is an array reference in bounds?
  - Does function foo(…) produce a constant value?

Context Sensitive Analysis - How

- How to check symbols and their semantics at various points in the program?
  - Process program linearly (roughly, in-order tree traversal).
  - Maintain a list of currently defined symbols and what they mean as the program is processed – this is called a Symbol Table.

Symbol Tables

- Associate lexical names (symbols) with their attributes.
- Can contain:
  - variable names
  - defined constants
  - procedure/function/method names
  - literal constants and strings
  - source text labels
  - compiler-generated temporaries
  - subtables for structure layouts (types) (field offsets and lengths)

Symbol Table Attributes

- The following attributes would be kept in a symbol table:
  - textual name
  - data type
  - dimension information (for aggregates)
  - declaring procedure
  - lexical level of declaration
  - storage class (base address)
  - offset in storage
  - if record, pointer to structure table
  - if parameter, by-reference or by-value?
  - can it be aliased? to what other names?
  - number and type of arguments to functions/methods

Binding

- As the declarations of types, variables, and functions are processed, identifiers are bound to "meanings" in the symbol table.
- A symbol table is a set of bindings.
- … But this binding is not static – it changes over the course of the program.

Scope

- An identifier has scope when it is visible and can be referenced.
- An out-of-scope identifier cannot be referenced.
- Identifiers in open scopes may override older/outer scopes temporarily.
- 2 Types of scope:
  - Static scope is when visibility is due to the lexical nesting of subprograms/blocks.
  - Dynamic scope is when visibility is due to the call sequence of subprograms.

Basic Static Scope

- Usually, a name begins life where it is declared and ends at the end of its block.

```
void foo()  {
        int k;
…….
}
```

Why Scope?

- Scope is not necessary.
  - Languages such as assembly have exactly one scope: the whole program.
- Modern programming languages have more than one scope.
  - Information hiding and modularity.
- Goal of any language is to make the programmer's job simpler.
  - One way: keep things isolated.
  - Make each thing only affect a limited area.
  - Make it hard to break something far away.

Changing Scope

- Identifiers come into scope at the beginning of a subprogram/block and go out of scope at the end.
- Example (in C++):

```
void testfunc ()
{
   int a; // a enters scope;
   for ( int b=1; b<10; b++ ) // b in scope for for
   {
      int c; // c enters scope
      …
   } // b,c leave scope
   …
} // a leaves scope
```

Static Scope

- Consider the Pascal program (which uses static scoping):

```
program test;
var a : integer;

   procedure proc1;
   var b : integer;
   begin
   end;

   procedure proc2;
   var a, c : integer;
   begin
      proc1;
   end;

begin
   proc2;
end.
```

in scope: b (from proc1), a (from test)

in scope: a, c (from proc2)

in scope: a (from test)

Dynamic Scope

- Consider the Pascal-like code (assume dynamic scoping):

```
program test;
var a : integer;

   procedure proc1;
   var b : integer;
   begin
   end;

   procedure proc2;
   var a, c : integer;
   begin
      proc1;
   end;

begin
   proc2;
end.
```

in scope: b (from proc1) a, c (from proc2)

in scope: a, c (from proc2)

in scope: a (from test)

Static vs. Dynamic Scope

- Dynamic scope makes it easier to access variables with lifetime, but it is difficult to understand the semantics of code outside the context of execution.
- Static scope is more restrictive – therefore easier to read – but may force the use of more subprogram parameters or global identifiers to enable visibility when required.

Scope in a symbol table

- Most modern programming languages have nested static scope.
  - The symbol table must reflect this.
- What additional information can reflect nested scope?
  - A name query must access the most recent declaration, from the current scope or some enclosing scope.
  - Innermost scope overrides declarations from outer scopes.

Scope and Symbol Table Operations

- What symbol table operations do we need?
  - void put (Symbol key, Object value)
    - binds key to value
  - Object get(Symbol key)
    - returns value bound to key
  - void beginScope()
    - remembers current state of table
  - void endScope()
    - restores table to state at most recent scope that has not been ended

Attribute Information

- Attributes are internal representations of declarations.
- Symbol table associates names with attributes.
- Names may have different attributes depending on their meaning:
  - variables: type, procedure level, frame offset
  - types: type descriptor, data size/alignment
  - constants: type, value
  - methods: formals (names/types), result type, block information (local decls.), frame size

Symbol Table Implementation

- Implemented as a collection of dictionaries in which each symbol is placed.
- Two operations:
  - insert adds a binding to a table and
  - lookup locates the binding for a name.
- Many different possible data structures:
  - linked list
  - hash table
  - binary tree

Symbol Table Lookup

- Basic operation is to find the entry for a given symbol.
- Each symbol table may have a pointer to its parent scope.
- Lookup: if symbol in current table, return it, otherwise look in parent.
- Hash tables and binary trees can be used more efficiently.

Types of Implementation

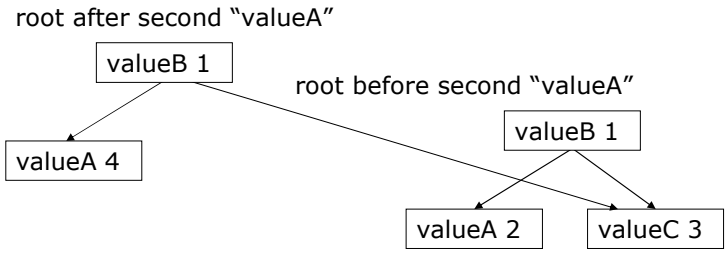
- Imperative
  - Auxiliary data structures are modified as the analysis progresses, always reflecting only the current state.
- Functional
  - Auxiliary data structures are maintained intact as the analysis progresses, with new versions created when needed – thus previous and current states are all available at any time.

Hash Table

- beginScope/put
  - Imperative - Chain new entries to beginning of table, thus overriding older entries.
  - Functional - Create copy of hash table array.
- endScope
  - Imperative – Remove entries from head of each linked list.
    - Each entry can point to the next one that should be removed.
  - Functional – Dispose of array.

Binary Tree

- put
  - Functional – Insert new entries into a new subtree, duplicating nodes up to the root.
- endScope
  - Functional – Delete all nodes in new subtree.



Symbols vs. Names

- Names are the textual entities found in the source code.
- Symbols are entities assigned to each name for more efficient processing during compilation.
- Example:
  - Name: valueA
    - Symbol: V001
  - Name: valueB
    - Symbol: V002
- Remember perfect hash functions?

Type Checking

- Static semantics should be checked after/as the symbol table is populated.
  - Is every name defined before it is used?
  - Does the type of each subexpression conform to what is expected?
  - Are the types on either side of an assignment compatible?
- The tree can be walked/visited to perform these checks.
  - May need multiple passes – so retain symbol table across passes.

Type Equivalence

- Two approaches:
  - Name equivalence: each type name is a distinct type.
  - Structural equivalence: two types are equivalent iff. they have the same structure (after substituting type expressions for type names).
- Example (structural):

```
typedef int bignumber;
int c;
bignumber b =c;
```

Error Handling

- If errors are detected, correct program representation and continue analysis to detect other errors.
- Example:

```
int a, b;
String c;
c = a;
b = a;
```