COMP 181

Lecture 12

The procedure abstraction

October 12, 2006

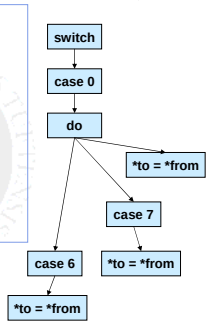
Prelude

- Copying an array

```
do {                          /* count > 0 assumed */
  *to++ = *from++;
} while (--count > 0);
```


Duff's device

```
int n = (count + 7) / 8;
switch (count % 8)
{
  case 0:        do {  *to++ = *from++;
  case 7:              *to++ = *from++;
  case 6:              *to++ = *from++;
  case 5:              *to++ = *from++;
  case 4:              *to++ = *from++;
  case 3:              *to++ = *from++;
  case 2:              *to++ = *from++;
  case 1:              *to++ = *from++;
                     } while (--n > 0);
}
```



- Why is this faster?

Heterogeneous data structures

- Simple example: shapes
  - Abstract type "shape"
  - Concrete subtypes: square, circle, triangle
- C:

```
typedef struct Shape {
  int kind;  /* 0=square, 1=circle, 2=triangle */
  union {
    struct Square { . . . } square;
    struct Circle { . . . } circle;
    struct Triangle { . . . } triangle;
  } info;
} Shape, * ShapePtr;
```


Labeled unions

- Visiting a series of shapes

```
Shape * all_shapes[50];
float area = 0.0;
for (int i = 0; i<50; i++) {
  Shape * cur_shape = all_shapes[i];
  switch (cur_shape->kind) {
    case 0: area += cur_shape->stuff.square.side *
                    cur_shape->stuff.square.side;
            break;
    case 1: . . .
    case 2: . . .
  }
}
```


Labeled unions

- What's good?
  - Code for "area" all in one place
  - Probably fast
- What's bad?
  - Have to make sure to get kinds right
    (Could use enum to help)
  - No control over access to fields
  - New shapes: fix all the switch statements

Objects

- Common superclass
  - Common functionality
  - Required functionality

```
class Shape {
  abstract float area();
}
class Square extends Shape {
  float side;
  float area() { return side * side; }
}
class Circle extends Shape { . . . }
class Triangle extends Shape { . . . }
```


Objects

- What's good
  - Encapsulation – all fields protected
  - No type errors
  - Easy to add new shapes
- What's bad
  - How do we add new functions?
  - May need to modify all subclasses

Visitor

- Method for each kind

```
class Visitor {
  void visitSquare(Square sq) { }
  void visitCircle(Circle ci) { }
  void visitTriangle(Triangle tr) { }
}
```

- Idea:
  - Describe what to do with each kind of object
  - Object calls its visit class

Visitor

- Implement subclass:

```
class areaVisitor extends Visitor {
  float area = 0.0;
  void visitSquare(Square sq) {
          area += sq.side() * sq.side();
  }
  void visitCircle(Circle ci) {
          area += pi * ci.radius() * ci.radius();
  }
  void visitTriangle(Triangle tr) { . . . }
}
```

- Note:
  May need to carry data in the visitor

Supporting visitors

- In the shapes classes

```
class Shape {
  void accept(Visitor vis) {
    vis.visitShape(this);
  }
}
class Square extends Shape {
  float side;
  void accept(Visitor vis) {
    vis.visitSquare(this);
  }
}
```


Using a visitor

- Three parts
  - Create visitor instance
  - Call "accept" method on each shape
  - Read out the result at end

```
Shape[] all_shapes;
Visitor vis = new areaVisitor();
for (int i = 0; i<50; i++) {
  Shape cur_shape = all_shapes[i];
  cur_shape.accept(vis);
}
float result = vis.area;
```

Visitor

- What's good
  - Easy to add new "passes"
  - All code is in one place
- What's bad
  - New shapes: *may* have to modify all visitors

Last time: type checking

- Type system
  - Set of rules for assigning types to parts of the program
  - Inference rules for operators

Expr	*Type rule*
E_1 [E_2]	**if type(E_2) is int and type(E_1) is *array*(T) result type is T else error**

- Type checker
  - Start with declared types
  - Apply typing rules
  - At each step, make sure resulting types obey the rules of the language
- Why type checking?
  - Alert the programmer to errors
  - Help compiler generate a correct translation

Polymorphism

- Ordinary procedures
  - Accept fixed type signature
  - Example: **`search(char c, string s)`**
- Generic procedures
  - Work on arguments of different types
- User-defined generics
  - Define interface with type variables
  - Example: **`search(El c, El [] list)`**

Type checking polymorphism

- Problem:

  How do we check generics statically?

```
int search(El x, El [] list) {
  for (int i = 0; i < list.length; i++)
    if (x.compareTo(list[i])) return i;
  return -1;
}
...
search(5, A);
```

  - What do we need to know?
    - Does El have a method "compareTo"?
    - Is A an array of type int?

Type checking polymorphism

- Checking generic code:
  - C++ templates
    - Checked at instantiation
    - Plug in the type variables
    - Compile and check resulting code
  - Java generics
    - Constrain type variables
    - Declare "type El must implement interface X"
    - Can check generic code independent of use

Type checking polymorphism

- Checking uses of generics
  - Is **`search(5, A)`** correct? *(Let's say int A[20];)*
  - Find a mapping from El, El[] to type(5), type(A)
  - Mapping: (El, El[]) --> (int, int[]) when El is int
  - This process is called ***unification***
- Unification

  Given two type expressions, one with type variables
  - Find a consistent substitution of type variables that turns it into the other type expression
  - Used in many other areas: theorem proving,

Template metaprogramming

- C++ templates are very powerful

```
template<int N>
class Factorial {
public:
    enum { value = N * Factorial<N-1>::value };
};

class Factorial<1> {
public:
    enum { value = 1 };
};

x = Factorial<8>::value;
```


More…

```
template<bool C> class IfThen { };

class IfThen<true> {
public:
    static inline void do() { statement1; } // true case
};

class IfThen<false> {
public:
    static inline void do() { statement2; } // false case
};

// Replacement for 'if/else' statement:
IfThen<condition>::do();
```


Type inference

- Languages without declarations
  - ML, Haskell
  - Still statically typed
  - Types determined by use
- Requires ***type inference*** algorithm
  - Determine constraints from program
  - Results in type expressions with type variables
  - Compute a consistent assignment to variables

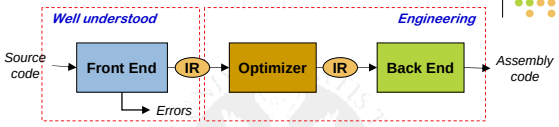
Back to Mars Orbiter

- Language support for units
  - Idea: make units a part of the type
  - Use polymorphism for operators
  - Type-check the computations
- Example:

```
double<kg> weight;
double<s> time;
double<m> distance;
double<m s^-2> gravity = 9.8 * m/(s * s);
double<kg m s^-2> force = weight * gravity;
```

- Issues:
  - Type checker must understand algebra
  - Generics are tricky ***(what is the type of sqrt?)***

Where are we?



The latter half of a compiler contains more open problems, more challenges, and more gray areas than the front half

- Implementing promised behavior

  *What defines the **meaning** of the program?*
- Managing target machine resources
  - Registers, memory, issue slots, locality, power, …
  - These issues determine the ***quality*** of the compiler

Procedure abstraction

- Compile-time versus run-time
  - The compiler takes a ***static*** program and generates code for ***dynamic*** execution
  - Most of the tricky issues arise in "procedures"
- Issues
  - Finding storage, and mapping names to addresses
  - Emit code to compute addresses that the compiler cannot know at compile-time!
  - Interfaces with other programs, other languages, and the OS
  - Efficiency of implementation

Procedure: three abstractions

- ***Control*** abstraction
  - Well defined entries & exits
  - Mechanism to return control to caller
  - Some notion of parameterization (usually)
- Clean ***name space***
  - Clean slate for writing locally visible names
  - Local names may obscure identical, non-local names
  - Local names cannot be seen outside
- External ***interface***
  - Access is by procedure name & parameters
  - Clear protection for both caller & callee
  - Invoked procedure can ignore calling context

The Procedure
(Realist's View)

Procedures are the key to building large systems

- Requires ***system-wide contract***
  - Conventions on memory layout, protection, resource allocation calling sequences, & error handling
  - Must involve architecture (**ISA**), **OS**, & compiler
- Provides shared ***access to system-wide facilities***
  - Storage management, flow of control, interrupts
  - Interface to input/output devices, protection facilities, timers, synchronization flags, counters, …
- Establishes a ***private context***
  - Create private storage for each procedure invocation
  - Encapsulate information about control flow & data abstractions

Run Time versus Compile Time

These concepts are often confusing to the newcomer

- ***Linkage*** is the code that implements the procedure interface
- Code for the linkage is emitted at ***compile time***
- Linkages execute at ***run time***
- The linkage is designed long before either of these

- More confusion:
  - Dynamic linking and shared libraries
  - Just-in-time compilers

The Procedure
(Realist's View)

Procedures allow us to use ***separate compilation***

- Keeps compile times reasonable
- Lets multiple programmers collaborate
- Allows procedures to be independent

➡ Without it, we *would not* build large systems

The ***linkage convention*** ensures that

- Procedures inherit a valid run-time environment
- Callers environment is saved/restored
- The compiler generates code to make this happen

The Procedure
(More Abstract View)

- A procedure is an abstract structure constructed via software
- Underlying hardware does explicitly not support:
  - Entries and exits
  - Interfaces and parameter passing
  - Call and return mechanism ***(may be special instructions)***
  - Name spaces and nested scopes
- Abstraction created by cooperation between:
  - Compiler
  - Run-time system
  - Linkage editor and loader
  - Operating system

ABI
Application Binary Interface

The Procedure as a Control Abstraction

Procedures have well-defined control-flow

The Algol-60 procedure call

- Invoked at a call site, with some set of *actual parameters*
- Control returns to call site, immediately after invocation

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```
…
s = p(10,t,u);
…

int p(a,b,c)
  int a, b, c;
{
  int  d;
  d = q(c,b);
  …
}
```


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  return x + y;
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}

int q(x,y)
  int x,y;
{
  return x + y;
}
```

- Most languages allow recursion

The Procedure as a Control Abstraction

Implementing procedures with this behavior

- Requires code to save and restore a "return address"
- Must map actual parameters to formal parameters ($c \rightarrow x$, $b \rightarrow y$)
- Must create storage for local variables (and, maybe, parameters)
  - *p* needs space for *d* (and, maybe, a, b, & c)
  - Where does this space go in recursive invocations?

```
…
s = p(10,t,u);
…

int p(a,b,c)
  int a, b, c;
{
  int  d;
  d = q(c,b);
  …
}
```

The Procedure as a Name Space

Each procedure creates its own name space

- Any name (almost) can be declared locally
- Local names hide identical non-local names (***shadowing)***
- Local names cannot be seen outside the procedure
- We call this set of rules & conventions ***lexical scoping***

Examples

- C has global, static, local, and block scopes
  Blocks can be nested, procedures cannot
- Scheme has global, procedure-wide, and nested scopes
  Procedure scope (typically) contains formal parameters

The Procedure as a Name Space

- Why introduce lexical scoping?
  - Flexibility for programmer
  - Simplifies rules for naming & resolves conflicts
- Implementation:
  The compiler responsibilities:
  - At point *p*, which "x" is the programmer talking about?
  - At run-time, where is the value of *x* found in memory?
- Solution:
  Lexically scoped symbol tables

Examples

- In C++ and Java

```
{
  for (int i=0; i < 100; i++) {
   ...
  }

  for (Iterator i=list.iterator(); i.hasNext();) {
   ...
  }
}
```

- This is actually useful!

Dynamic vs static

- Static scoping
  - Most compiled languages – C, C++, Java, Fortran
  - Scopes only exist at compile-time
  - We'll see the corresponding run-time structures that are used to establish addressability later.
- Dynamic scoping
  - Interpreted languages – Perl, Common Lisp

```
int x = 0;
int f() { return x; }
int g() { int x = 1; return f(); }
```


Lexically-scoped Symbol Tables

- The problem
  - Compiler needs a distinct entry for each declaration
  - Nested lexical scopes admit duplicate declarations
- The interface
  - **enter()** – enter a new scope level
  - **insert(*name*)** – creates entry for *name* in current scope
  - **lookup(*name*)** – lookup a name, return an entry
  - **exit()** – leave scope, remove all names declared there

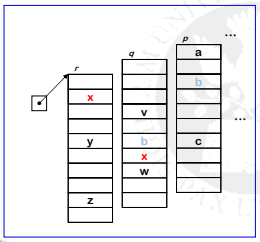
Example

```
procedure p {
   int a, b, c
   procedure q {
      int v, b, x, w
      procedure  r {
         int x, y, z
         ….
      }
      procedure s {
         int x, a, v
         …
      }
      … r … s
   }
  … q …
}
```

```
L0:{
      int a, b, c
L1:   {
        int v, b, x, w
L2a:    {
          int x, y, z
           ...
        }
L2b:    {
          int x, a, v
          ...
        }
      }
    }
```

Chained implementation

- Create a new table for each scope, chain them together for lookup

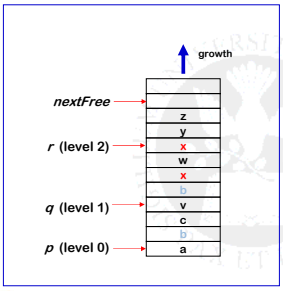


"***Sheaf of tables***" implementation

- ***enter()*** creates a new table
- ***insert()*** adds at current level
- ***lookup()*** walks chain of tables & returns first occurrence of name
- ***exit()*** throws away table for level *p*, if it is top table in the chain

Individual tables can be hash tables.

Stack implementation



Implementation

- **enter()** puts a marker in stack
- **insert ()** inserts at nextFree
- **lookup ()** searches linearly from nextFree–1 forward
- **exit ()** sets nextFree back to the previous marker.

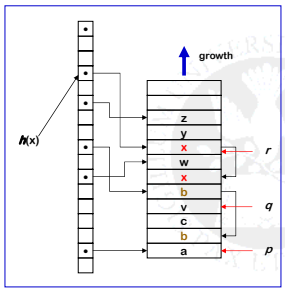
Advantage

- Uses less space

Disadvantage

- Lookups can be expensive

Threaded stack implementation



Implementation

- ***insert ()*** puts new entry at the head of the list for the name
- ***lookup ()*** goes direct to location
- ***exit ()*** processes each element in level being deleted to remove from head of list

Advantage

- lookup is fast

Disadvantage

- exit takes time proportional to number of declared variables in level

Symbol tables in C

- Identifiers
  - Mapping from names to declarations
  - Fully nested – each '{' opens new scope
- Labels
  - Mapping from names to labels (for goto)
  - Flat table – one set of labels for each procedure
- Tags
  - Mapping from names to struct definitions
  - Fully nested
- Externals
  - Record of extern declarations
  - Flat table – redundant extern declarations must be identical

In general, rules can be very subtle

Examples

- Example of typedef use:

```
typedef int T;
struct S { T T; }; /* redefinition of T as member name */
```

- Example of proper declaration binding:

```
int;       /* syntax error: vacuous declaration      */
struct S;  /* no error: tag is defined or elaborated */
```

- Example of declaration name spaces
  - Declare "a" in the name space before parsing initializer

```
int a = sizeof(a);
```

  - Declare "b" with a type before parsing "c"

```
int b, c[sizeof(b)];
```


Next time…

- Midterm review
- More on language abstractions
  - Methods (vs procedures)
  - Object-oriented programs