CSC 533: Organization of Programming Languages

Spring 2005

Procedural and data abstraction

- control structures
  conditionals, loops, branches, …
- subprograms (procedures/functions/subroutines)
  subprogram linkage, parameter passing, implementation, …
- abstract data types (ADTs)
  data + functions, C++ classes, separate compilation, Java classes

We will focus on C++ and Java as example languages

Conditionals & loops

early control structures were tied closely to machine architecture

e.g., FORTRAN arithmetic if: based on IBM 704 instruction

```
     IF (expression) 10, 20, 30
10   code to execute if expression < 0
     GO TO 40
20   code to execute if expression = 0
     GO TO 40
30   code to execute if expression > 0
40   . . .
```

later languages focused more on abstraction and machine independence

some languages provide counter-controlled loops

e.g., in Pascal:

```
for i := 1 to 100 do
begin
    . . .
end;
```

- counter-controlled loops tend to be more efficient than logic-controlled
- C++ and Java don't have counter-controlled loops (for is syntactic sugar for while)

Branching

unconditional branching (i.e., GOTO statement) is very dangerous

- leads to *spaghetti code*, raises tricky questions w.r.t. scope and lifetime
  what happens when you jump out of a function/block?
  what happens when you jump into a function/block?
  what happens when you jump into the middle of a control structure?

most languages that allow GOTO's restrict their use

- in C++, can't jump into another function
  can jump into a block, but not past declarations

```
void foo()
{   . . .
    goto label2;      // illegal: skips declaration of str
    . . .
label1:
    string str;
    . . .
label2:
    goto label1;      // legal: str's lifetime ends before branch
}
```


Branching (cont.)

why provide GOTO's at all? (Java doesn't)

- backward compatibility
- can be argued for in specific cases (e.g., jump out of deeply nested loops)

C++ and Java provide statements for more controlled loop branching

- *break:* causes termination of a loop

```
while (true) {
    cin >> num;
    if (num < 0) break;
    sum += num;
}
```

- *continue:* causes control to pass to the loop test

```
while (inputKey != 'Q') {
    if (keyPressed()) {
        inputKey = GetInput();
        continue;
    }
    . . .
}
```

Procedural control

any implementation method for subprograms is based on the semantics of subprogram linkage (call & return)

in general, a subprogram call involves:

1. save execution status of the calling program unit
2. parameter passing
3. pass return address to subprogram
4. transfer control to subprogram

possibly: allocate local variables, provide access to non-locals

in general, a subprogram return involves:

1. if out-mode parameters or return value, pass back value(s)
2. deallocate parameters, local variables
3. restore non-local variable environment
4. transfer control to the calling program unit

Parameters

in most languages, parameters are *positional*

- Ada also provides *keyword* parameters:

```
AddEntry(dbase -> cds, new_entry -> mine);
```

advantage: don't have to remember parameter order
disadvantage: do have to remember parameter names

C++ & Java allow for optional parameters (specify with …)

- no type checking performed!

```
printf("Hello world\n");

printf("%d, %d", num1, num2);
```

Parameters (cont.)

Ada and C++ allow for default values for parameters

- if value is passed in as argument, that value is assigned to parameter
- if not, default value is assigned

```
void Display(const vector<int> & nums, ostream & ostr = cout)
{
    for (int i = 0; i < nums.size(); i++) {
        ostr << nums[i] << endl;
    }
}


ofstream ofstr("foo.out");
Display(numbers, ofstr);          // displays to file


Display(numbers);                 // displays to cout
```

Note: default parameters must be rightmost in the parameter list WHY?

Parameter passing

can be characterized by the direction of information flow

in mode: pass by-value
out mode: pass by-result
inout mode: pass by-value-result, by-reference, by-name

by-value (in mode)

- parameter is treated as local variable, initialized to argument value

advantage: safe (function manipulates a copy of the argument)
disadvantage: time & space required for copying

used in ALGOL 60, ALGOL 68
default method in C++, Pascal, Modula-2
only method in C (and, technically, in Java)

Parameter passing (cont.)

by-result (out mode)

- parameter is treated as local variable, no initialization
- when function terminates, value of parameter is passed back to argument

potential problems:

```
ReadValues(x, x);

Update(list[GLOBAL]);
```

by-value-result (inout mode)

- combination of by-value and by-result methods
- treated as local variable, initialized to argument, passed back when done

same potential problems as by-result

used in ALGOL-W, later versions of FORTRAN

Parameter passing (cont.)

by-reference (inout mode)

- instead of passing a value, pass an access path (i.e., reference to argument)

advantage: time and space efficient
disadvantage: slower access to values (must dereference), alias confusion

```
void IncrementBoth(int & x, int & y)
{
    x++;
    y++;
}
```

```
int a = 5;
IncrementBoth(a, a);
```

requires care in implementation: arguments must be l-values (i.e., variables)

used in early FORTRAN
can specify in C++, Pascal, Modula-2
Java objects look like by-reference

Parameter passing (cont.)

by-name (inout mode)

- argument is textually substituted for parameter
- form of the argument dictates behavior

  if argument is a: variable → by-reference
  constant → by-value
  array element or expression → ???

```
real procedure SUM(real ADDER, int INDEX, int LENGTH);
begin
    real TEMPSUM := 0;
    for INDEX := 1 step 1 until LENGTH do
        TEMPSUM := TEMPSUM + ADDER;
    SUM := TEMPSUM;
end;
```

```
SUM(X, I, 100)            →    100 * X
SUM(A[I], I, 100)         →    A[1] + . . . + A[100]
SUM[A[I]*A[I], I, 100)    →    A[1]² + . . . + A[100]²
```

- flexible but tricky – used in ALGOL 60, replaced with by-reference in ALGOL 68

Parameters in Ada

in Ada, programmer specifies parameter mode

- implementation method is determined by the compiler

in → by-value
out → by-result
inout → by-value-result (for non-structured types)
→ by-value-result *or* by-reference (for structured types)

- choice of inout method for structured types is implementation dependent

  DANGER: `IncrementBoth(a, a)` yields different results for each method!

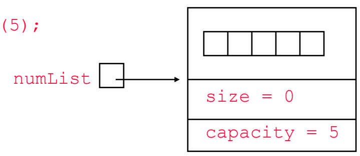
Parameters in Java

parameter passing is by-value, but looks like by-reference for objects

- recall, Java objects are implemented as pointers to dynamic data

```
public static void Foo(ArrayList lst)
{
    lst.set(0, "okay");
    . . .
    lst = new ArrayList();
}
```

```
ArrayList numList = new ArrayList(5);
Foo(numList);
```



when pass an object, by-value makes a copy (here, copies the pointer)

pointer copy provides access to data fields, can change

but, can't move the original

Polymorphism

in C++ & Java, can have different functions with the same name

- overloaded functions must have different parameters to distinguish

```
void Display(string X)
{
    cout << X << endl;
}
```

```
void Display(string X, ostream & ostr)
{
    ostr << X << endl;
}
```

in C++, could get same effect with default parameter

common use in OOP: different classes with same member function names

in C++, can overload operators for new classes

```
bool Date::operator==(const Date & d1, const Date & d2)
// postcondition: returns true if d1 and d2 are same date, else false
{
    return (d1.day == d2.day &&
            d1.month == d2.month &&
            d1.year == d2.year);
}
```

Generic types

in C++ can parameterize classes/functions using templates

```
template <class Type>
class MyList {
  public:
    . . .
  private:
    <Type> items[];
};
```

must specify `Type` when declare an object

```
MyList<int> nums(20);
```

```
template <class Item>
void Display(Item x)
{
    cout << x << endl;
}
```

when called, `Item` is automatically instantiated (must support <<)

```
Date day(9, 27, 2000);
Display(day);
```

can similarly write generic classes & methods in Java

```
public class MyList<T> { private T[] items; . . . }

public <T> void Display(T x) { System.out.println(x) }
```


Implementing subprograms

- some info about a subprogram is independent of invocation

  e.g., constants, instructions

  ➔ can store in static code segment

- some info is dependent upon the particular invocation

  e.g., return value, parameters, local variables (?)

  ➔ must store an *activation record* for each invocation

  - local variables may be allocated when subprogram is called, or wait until declarations are reached (stack-dynamic)

Activation Record

local variables
parameters
static link
dynamic link
return address

Run-time stack

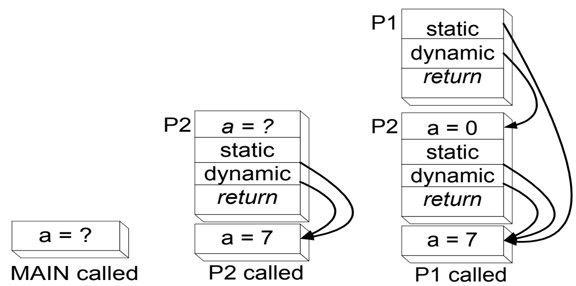
when a subroutine is called, an instance of its activation record is pushed

```
program MAIN;
  var a : integer;

  procedure P1;
  begin
    print a;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1;
  end; {of P2}

  begin
      a := 7;
      P2;
  end. {of MAIN}
```



when accessing a non-local variable

- follow static links for static scoping
- follow dynamic links for dynamic scoping

Run-time stack (cont.)

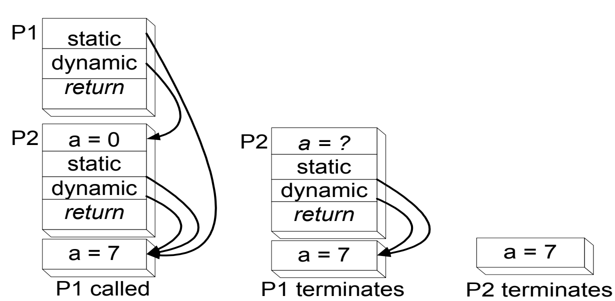
when a subroutine terminates, its activation record is popped (note LIFO behavior)

```
program MAIN;
  var a : integer;

  procedure P1;
  begin
    print a;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1;
  end; {of P2}

  begin
      a := 7;
      P2;
  end. {of MAIN}
```



when the last activation record is popped, control returns to the operating system

Run-time stack (cont.)

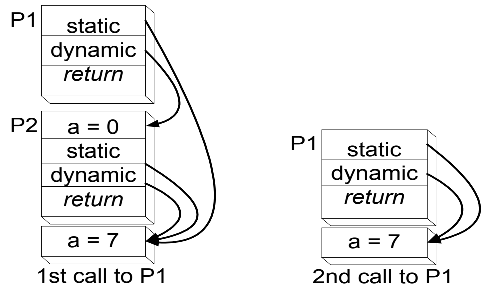
Note: the same subroutine may be called from different points in the program

```
program MAIN;
  var a : integer;

  procedure P1;
  begin
    print a;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1;
  end; {of P2}

  begin
      a := 7;
      P2;
      P1;
  end. {of MAIN}
```



➔ using dynamic scoping, the same variable in a subroutine may refer to a different addresses at different times

In-class exercise

run-time stack?

output using static scoping?

output using dynamic scoping?

```
program MAIN;
  var a : integer;

  procedure P1(x : integer);
    procedure P3;
    begin
      print x, a;
    end; {of P3}
  begin
    P3;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1(a+1);
  end; {of P2}

  begin
      a := 7;
      P1(10);
      P2;
  end. {of MAIN}
```

Optimizing scoping

naïve implementation:

- if variable is not local, follow chain of static/dynamic links until found

in reality, can implement static scoping more efficiently (displays)

- block nesting is known at compile-time, so can determine number of links that must be traversed to reach desired variable
- can also determine the offset within the activation record for that variable

➔ can build separate data structure that provides immediate access

can't predetermine # links or offset for dynamic scoping

- subroutine may be called from different points in the same program

can't even perform type checking statically why not?

Data abstraction

pre 80's: focus on process abstraction

recently: data abstraction increasingly important

Object-Oriented Programming (OOP) is an outgrowth of data abstraction in software development

an abstract data type (ADT) requires

1. encapsulation of data and operations
   cleanly localizes modifications
2. information hiding (hide internal representation, access through operations)
   makes programs independent of implementation, increases reliability

Simula 67: first to provide direct support for data abstraction

- class definition encapsulated data and operations
- no information hiding

ADT's in Modula-2

Modula-2 provides encapsulation via modules

definition module: partial specification of types, plus subprogram headers
implementation module: completed definitions of types, subprograms

can be defined in separate files, compiled separately

Modula-2 provides information hiding via opaque types

transparent type: complete definition of type in definition module
➔ underlying data is visible and accessible
opaque type: no implementation details in definition module
➔ underlying data is hidden

client program imports definition module (implementation is linked later):
PROBLEM: compiler must know size of an object when declared
SOLUTION: opaque types must be implemented as pointers to structures

Modula-2 example

```
DEFINITION MODULE stackmod;
  TYPE stacktype;
  PROCEDURE create(VAR stk:stacktype);
  PROCEDURE push(VAR stk:stacktype; ele:INTEGER);
  PROCEDURE pop(VAR stk:stacktype);
  PROCEDURE top(stk:stacktype):INTEGER;
  PROCEDURE empty(stk:stacktype):BOOLEAN;
END stackmod.
```

here, stacktype is opaque

- no details in definition module
- defined as a pointer to a record in the implementation module
- memory must be dynamically allocated
- lots of pointer dereferencing

```
IMPLEMENTATION MODULE stackmod;
  FROM InOut IMPORT WriteString, WriteLn;
  FROM Storage IMPORT ALLOCATE;
  const max = 100;

  TYPE stacktype = POINTER TO
    RECORD
      list : ARRAY[1..max] OF INTEGER;
      topsub : [0..max]
    END;

  PROCEDURE create(VAR stk:stacktype);
  BEGIN
    NEW(stk);
    stk^.topsub := 0
  END create;

  PROCEDURE push(VAR stk:stacktype; ele:INTEGER);
  BEGIN
    IF stk^.topsub = max THEN
      WriteString("ERROR – Stack overflow");
      WriteLn
    ELSE
      INC(stk^.topsub);
      stk^.list[stk^.topsub] := ele
    END
  END push;
  . . .

END stackmod;
```

ADT's in C++

C++ classes are based on Simula 67 classes, extend C struct types

- in Modula-2, modules export type definitions and applicable functions
- in C++, classes export an ADT that contains its own member functions

all instances of a C++ class share a single set of member functions
each instance gets its own set of data fields (unless declared `static`)

data fields/member functions can be:

- *public* visible to all
- *private* invisible (except to class instances)
- *protected* invisible (except to class instances & derived class instances)

can override protections by declaring a class/function to be a `friend`

C++ example

`#ifndef`, `#define`, `#endif` are used to ensure that the file is not included more than once

a templated class must be defined in one file (cannot be compiled separately)

- member functions are *inlined*

here, default constructor for vector suffices, so Stack constructor does not need to do anything

```
#ifndef _STACK_H
#define _STACK_H

#include <vector>
using namespace std;

template <class Item>
class Stack {
  public:
    Stack() {
      // nothing more needed
    }

    void push(Item x) {
      vec.push_back(x);
    }

    void pop() {
      vec.pop_back();
    }

    Item top() const {
      return vec.back();
    }

    bool isEmpty() const {
       return (vec.size() == 0);
    }

  private:
    vector<Item> vec;
};

#endif
```

C++ example (cont.)

the client program must:

- include the .h file

once included, the user-defined class is indistinguishable from primitives

- can declare objects of that type
- can access/modify using member functions

```
object.memberFunc(params)
```

```
#include <iostream>
#include <string>
#include "Stack.h"
using namespace std;

int main()
{
  Stack<string> wordStack;

  string str;
  while (cin >> str) {
    wordStack.push(str);
  }

  while (!wordStack.isEmpty()) {
    cout << wordStack.top() << endl;
    wordStack.pop();
  }

  return 0;
}
```


C++ example (cont.)

the Standard Template Library (STL) contains many useful class definitions:

- stack
- queue
- priority_queue
- set
- map

```
#include <iostream>
#include <stack>
using namespace std;

int main()
{
  stack<string> wordStack;

  string str;
  while (cin >> str) {
    wordStack.push(str);
  }

  while (!wordStack.empty()) {
    cout << wordStack.top() << endl;
    wordStack.pop();
  }

  return 0;
}
```

Separate compilation

as in Modula-2, can split non-templated class definitions into:

- interface (.h) file
- implementation (.cpp) file

```
#ifndef _DIE_H
#define _DIE_H

class Die
{
  public:
    Die(int sides = 6);
    int Roll();
    int NumSides();
    int NumRolls();
  private:
    int myRollCount;
    int mySides;
    static bool ourInitialized;
};

#endif
```

```
#include <cstdlib>
#include <ctime>
#include "Die.h"

bool Die::ourInitialized = false;

Die::Die(int sides) {
    mySides = sides;
    myRollCount = 0;

    if (ourInitialized == false) {
        srand((unsigned)time(NULL));
        ourInitialized = true;
    }
}

int Die::Roll() {
    myRollCount++;
    return (rand() % mySides) + 1;
}

int Die::NumSides() {
    return mySides;
}

int Die::NumRolls() {
    return myRollCount;
}
```


Separate compilation (cont.)

the client program must:

- include the .h file
- add the .cpp file to the project (Visual C++)

advantages:

- compiler only compiles files that have been changed
- .h file is a readable reference
- can distribute compiled .obj file, hide .cpp source code from user

```
#include <iostream>
#include "Die.h"
using namespace std;

int main()
{
    Die sixSided(6), eightSided(8);

    int roll6 = -1, roll8 = -2;
    while (roll6 != roll8) {
      roll6 = sixSided.Roll();
      roll8 = eightSided.Roll();

      cout << sixSided.numRolls() << ": "
           << roll6 << " " << roll8 << endl;
    }
    cout << "DOUBLES!" << endl;

    return 0;
}
```

ADTs in Java

Java classes look very similar to C++ classes

- each field/method has its own visibility specifier
- must be defined in one file, can't split into header/implementation
- javadoc facility allows automatic generation of documentation
- extensive library of data structures and algorithms
  ```
  List: ArrayList, LinkedList
  Set: HashSet, TreeSet
  Map: HashMap, TreeMap
  Queue, Stack, …
  ```
- load libraries using `import`

```
public class Die
{
  private int numSides;
  private int numRolls;

  public Die()
  {
   numSides = 6;
   numRolls = 0;
  }

  public Die(int sides)
  {
   numSides = sides;
   numRolls = 0;
  }

  public int getNumberOfSides()
  {
   return numSides;
  }

  public int getNumberOfRolls()
  {
   return numRolls;
  }

  public int roll()
  {
    numRolls = numRolls + 1;
    return (int)(Math.random()*getNumberOfSides() + 1);
  }
}
```


Tuesday: TEST 1

types of questions:

- factual knowledge: TRUE/FALSE
- conceptual understanding: short answer, discussion
- synthesis and application: parse trees, heap trace, scoping rules, …

the test will include extra points (Mistakes Happen!)

- e.g., 52 or 53 points, but graded on a scale of 50

study advice:

- review online lecture notes (if not mentioned in class, won't be on test)
- review text
- reference other sources for examples, different perspectives
- look over quizzes