Data Structures

Lecture 1: Data Types and Data Abstractions

What's Wrong With This Program?

```
void f(int x[], int n){int i, y; unsigned
  ; label10: a = 0; i = 0; label20: if
  (i>n-1)goto label30; if (x[i] <=
  x[i+1])goto label40; a = 1; y = x[i];
  x[i] = x[i+1]; x[i+1]=y;label40:i =
  i+1; goto label20; label30: if(a==1)
  gotolabel10;}
```

- Structured programming is about avoiding GOTOs and other bad programming habits.
- Object-Oriented programming extends this objectives.

Rules Of Structured Programming

- One statement per line
- Meaningful variable names
- Proper documentation, i.e., //Comments
- Indenting `if`, `if..else`, `while`, `for`, etc.
- Match opening and closing braces { }
- Avoiding "*clever code*"
- Extra space for clarity
- Avoid trivial comments
- Code should be as English-like as possible
- Line up statements on the same "level"
- Use functions wherever possible.

sort.cpp

```
// sort() - Classic bubble sort
void sort(int x[], int n)
{
  bool      switched;
  int       i, temp, pass = 0;

  // The outer loop counts passes through the
  //array.  At the end of each pass one more
  //element is in the right place.
```

```
  do  {
      switched = false; // Nothing switched yet
      // The inner loop compared adjacent
      // elements in the array to see whether
      // they should be switched.
      for (i = 0;  i < n-pass-1; i++)
            if (x[i] > x[i+1])      {
                  switched = true;
                  temp = x[i];
                  x[i] = x[i+1];
                  x[i+1] = temp;
            }
  } while (switched && pass < n-1);
}
```

Why Structured Programming?

- Easier to debug
- More readable, better organized; it makes modifications easier
- Makes group effort easier
- Easier to understand by users and programmers

Interpreting Data

- Information is a little difficult to define that exactly.
- Bits (*1*s and *0*s) are organized into groups of 8 bits (known as ***bytes***).
- The same group of bytes can be interpreted as:
  - an integer
  - a real number
  - a computer instruction
  - a string of characters
  - a computer address

Native Data Types

- Every machine has its own native data types, which may or may not correspond to those of the programming language.
- The language's compiler must implement the programming language's data types using the native type available to it.
- Example:

```
int   x, y;
float    a, b;
```

Reserves 4 different locations for 4 different variables

```
x = x + y;
a = a + b;
```

Involve different uses of **+**

Native Data Types - An Example

- Assume we have a native instruction:

  `MOVE (Source, Dest, Length)`

  which moves length bytes from `Source` to `Dest`.

  How do we use it to implement variable length strings?

5	H	E	L	L	O	+	9	E	V	E	R	Y	B	O	D	Y

should produce:

14	H	E	L	L	O	E	V	E	R	Y	B	O	D	Y

Abstract Data Types

- Since a data type is a collection of values and a set of operations over these values, we can define them mathematically even before we implement them.
- Consider the abstract data type rational numbers:

```
//value definition
abstract typedef <int, int> RATIONAL;
condition RATIONAL[1] != 0;

// operator definitions
abstract equal (a, b) // a == b
RATIONAL a, b
postcondition equal == (a[0]*b[1] == a[1]*b[0])
```

Abstract Data Types (continued)

```
abstract RATIONAL makerational(a, b)
//written [a,b]
int   a, b;
precondition      b != 0
postcondition
  makerational[0]*b == a*makerational[1]

abstract RATIONAL add(a, b) //written a+b
RATIONAL a, b;
postcondition
  add = (a[0]*b[1]+b[0]*a[1], a[1]*b[1])
abstract RATIONAL mult(a, b) //written a*b
RATIONAL A, b;
postcondition mult==(a[0]*b[0], a[1]*b[1])
```

ADT for Variable-Length Strings

```
abstract typedef <<char>> STRING;
abstract length(s)
STRING s;
postcondition length = len(s)
abstract STRING concat (s1, s2)
STRINGs1, s2;
postcondition concat == s1+s2
abstract STRING substr(s1, i, j)
STRING s1;
int   i, j;
precondition      0<= i < len(s1);
                  0 <= j < len(S1)-i;
postcondition     substr=sub(s1, i, j);
```

ADT for Variable-Length Strings (continued)

```
abtract pos(s1, s2)
STRINGV s1, s2;
postcondition // lastpos = len(s1) - len(s2)
((pos=-1) && for (i = 0;  i < lastpos; i++)
(s2 <> sub(sub(s1, i, len(s2)))))
  //s2 is not within s1
  || ((pos) > 0) && pos <= lastpos)
            && (s2 == sub(str1, pos, len(s2))
            && (for (i = 1; i < pos ; i++)
                  (s2 <> sub (s1, i, len(s2)))));
                  // s2 is within s1
```

Data Types in C and C++

- The 4 native data types in C are:
  - `int`, `float`, `char` and `double`
- `int` can be qualified with:
  - `long`, `short`, or `unsigned`
- A C variable declaration specifies 2 things:
  - How much storage is allocated
  - How is data represented in memory

Pointers

- Pointers allow us to reference a data object ***location*** as well as its ***value***:

```
int     *pi;       int   i;   pi = &i;
float   *pf;       float f;   pf = &f;
char    *pc;       char c;    pc = &c;
```

- We can convert between pointer types:

```
pi = (int *) pf;
```

- <u>Question</u> – What do these mean?

```
*pi + 2    *(pi+2)      pi[2]
```

Arrays

- An array is a one-dimensional (or more) structure of similar data types.
  - A one-dimensional array is a ***list*** or a ***vector***.
  - e.g., `int  a[100];`
- Strings (in C) are arrays of characters with a null byte at the end.

```
char   s[100];
```

with support functions in string.h like `strcat`, `strcpy`, `strlen`.

Multidimensional Arrays

2-dimensional arrays

```
int   t[3][5];
```

3 lists of 5 elements

	0	1	2	3	4
0					
1					
2					

A two-dimensional array like this is called a ***matrix***

3-dimensional arrays

int class[3][4][25]

colleges in university
depts in college
class in dept

Implementation of Arrays in Pascal

-3	3
a[-3]	
a[-2]	
a[-1]	
a[0]	
a[1]	
a[2]	
a[3]	

One-dimensional

position of x[i]
= base + (i-lbound)*esize

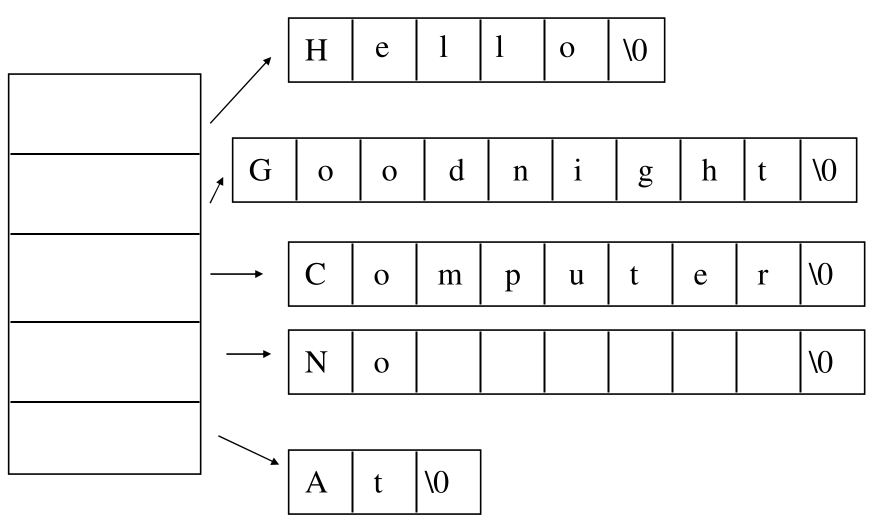
Implementation of Arrays in Pascal (continued)

<u>Two-dimensional</u>

x[0][0]	x[0][1]	x[0][2]	x[0][3]
x[1][0]	x[1][1]	x[1][2]	x[1][3]
x[2][0]	x[2][1]	x[2][2]	x[2][3]
x[3][0]	x[3][1]	x[3][2]	x[3][3]
x[4][0]	x[4][1]	x[4][2]	x[4][3]
x[5][0]	x[5][1]	x[5][2]	x[5][3]

position of a[i][j]
= base +
$[(i_1-l_1)r_2+i_2-l_2)]$
* esize

Implementation of Arrays in C/C++



Arrays As Parameters

```
float avg(float a[], int size)
//no size specified
{
  int     i;
  float   sum;
  sum = 0;

  for (i = 0;  i < size;  i++)
     sum += a[i];
  return(sum/size);
}
```

String Operations

```
const int StrSize = 80;
char string[StrSize];

int  strlength(char string[])
{
  int     i;
  for (i = 0;  string[i]!= '\0'; i++)
     ;
  return(i);
}
```

String Operations (continued)

```
int   strpos(char s1[], char s2[])
{
  int i, j, k;

  for(i = 0; s1[i] != '\0'; i++) {
      for(j = i, k = 0; s2[k] != '\0'
             && s1[j] == s2[k]; j++, k++)
             ;
      if(k > 0 && s2[k] == '\0')
             return i;
  }
  return -1;
}
```

String Operations (continued)

```
void strconcat(char s1[], char s2[])
{
  int     i, j;
  for (i = 0;  s1[i] != '\0'; i++)
          ;
  for (j = 0;  s2[j] != '\0';
               s1[i++] = s2[j++])
          ;
  s1[i] = '\0';
}
```

String Operations (continued)

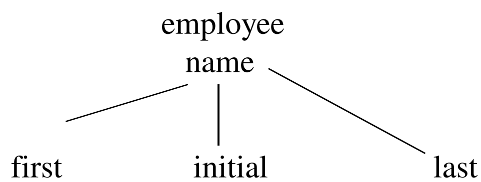
```
void strcopy(char s1[], char s2[])
{
  int     i;
  for (i = 0;  s1[i] != '\0'; i++)
          s1[i] = s2[i];
  s1[i] = '\0';
}
```

String Operations (continued)

```
void substring(char s1[], int i, int j,
          char s2[])
{
  int     k, m;
  for (k = i, m = 0;  m < j;
               s2[m++] = s1[k++])
     ;
  s2[m] = '\0';
}
```

Structures

- While an array is a *homogeneous* collection of data, a ***structure*** is a *heterogeneous* collection of data, i.e., a collection of fields that may be quite different.




```
struct          {
     char first[10];
     char midinitial;
     char last[20];
}    sname, ename;
```

declares the structures `sname` and `ename`

Structures (continued)

- If we wish to define such a type:

```
struct nametype   {
  char  first[10];
  char  midinitial;
  char  last[20];
};
struct nametype   sname, ename;
```

Structures (continued)

- We could define such a type using a **`typedef`** :

```
typedef struct nametype     {
  char  first[10];
  char  midinitial;
  char  last[20];
} NameType;
NameType     sname, ename;
```

Unions

- Unions allow a variable to be interpreted in several different ways:

```
union utype           {
  int    i;
  float  x;
  char   c;
};
```

- If we say:

```
u.c = 'a';
putchar(u.c);
u.x = 0.5;
```

we have changed **`u.c`**'s value as well – they share the same memory

Unions (continued)

- We can use unions to create variant records:

```
typedef enum insuretype {Life, Auto, Home};
typedef struct {
  char   street[50];
  char   city[10];
  char   state[2];
  char   zip[5];
}  addr;

typedef  struct      {
  int    month;
  int    date;
  int    year;
} date;
```

```
typedef struct {
  int    polnumber;
  char   name[30];
  addr   address;
  int    amount;
  float  premium;
  int    kind; //Life, Home or Auto
```

```
union   {
 struct {
        char   beneficiary[30];
        date   birthday;
 } Life;
 struct {
        int    autodeduct;
        char   license[10];
        char   state[2];
        char   model[15];
        int    year;
 } Auto;
 struct {
        int    homededuct;
        int    yearbuilt;
 } Home;
} policyinfo;
} policy;
```

Printing Variant Records

- We can print the policy information:

```
policy p;
… …
if (p.kind == Life)
 printf("\n%s  %2d//%2d//%4d",
 p.policyinfo.Life.beneficiary,
 p.policyinfo.Life.birthday.month,
 p.policyinfo.Life.birthday.date,
 p.policyinfo.Life.birthday.year);
else if (p.kind == Auto)
 printf("\n%d  %s  %s  %s  %d",
 p.policyinfo.Auto.autodeduct,
 p.policyinfo.Auto.license,
 p.policyinfo.Auto.state,
 p.policyinfo.Auto.model,
 p.policyinfo.Auto.year);
```

```
else if (p.kind == Home)
 printf("\n%d %d",
 p.policyinfo.Home.homededuct,
 p.policyinfo.Home.yearbuilt);
else
 printf("\nbad type %d in kind", p.kind);
```

- We could declare an array of structures by writing:

```
policy   a[100];
```

Structures As Parameters

- Traditionally in C, we pass the structure's address (not the whole structure) to save memory. A function using a structure might look like this:
- ```
  //Prints name in a neat format
  int       writename(struct nametype *name)
  {
    int     count, i;
    printf("\n");
    count = 0;
    for (i = 0;  (i<10)
            && name-> first[i] != '\0'; i++){
     putchar(name->first[i];
     count++;
    }
  ```
  ```

```
  putchar(' ');
  count++;
  if (name -> midinitial != ' ') {
   printf("%c%s", name -> midinitial, ". ");
   count += 3;
  }
  for (i = 0;  (i<20)
         && (name->last[i] !='\0'); i++)     {
   putchar(name->last[i];
   count++;
  }
}
```

Four features of Object-Oriented Programming

- Data abstraction – using data in a program as we conceive it in the real world.
- Encapsulation – manipulate private data only within the class itself or within “friend" classes.
- Polymorphism – Overloading functions and operators, allowing them to be used in multiple ways differing only in parameter (or operand) types.
- Inheritance – designing new classes based on previously defined classes.

An Example in C++ - A *Rational* Class

```
class Rational    {
public:
  Rational operator +(Rational);
  Rational operator +(long);
  Rational operator *(Rational);
  Rational operator /(Rational);
  int operator ==(Rational);
  void      print(void);
  void      setrational(long, long);
private:
  long      numerator;
  long      denominator;
        void      reduce(void);
};
```

```
Rational Rational::operator +(Rational r)
{
  int       k, denom, num;
  Rational  rnl;

  //First reduce both rationals to lowest terms
  reduce();
  r.reduce();

  //implement the line k=rden(b, d)
  rnl.setrational(denominator,r.denominator);
  rnl.reduce();
  k = rnl.denominator;

  //Compute the result's denominator
  denom = denominator*k;
```

```
    //Compute the result's numerator
    num = numerator*k +
         rnl.numerator*(denom/rnl.denominator);

    //Form a Rational from the result and reduce
    rnl.setrational(num, denom);
    rnl.reduce();
    return(rnl);
}
```

```
void  Rational::print(void)
{
    cout << numerator << "/" << denominator
        << endl;
}

void  Rational::setrational(long n, long d)
{
    if (d == 0)     {
        cerr << "Error: denominator may not "
              "be zero" << endl;
        exit(1);
    }
    numerator = n;
    denominator = d;
    reduce();
}
```

```
Rational    Rational:: operator *(Rational r)
{
  Rational rnl, rnl1, rnl2;
  int num, denom;

  //reduce both inputs to lowest terms
  reduce();
  rnl.reduce();

  //switch numerators and denominators and
  //reduce
  rnl1.setrational(numerator, r.denominator);
  rnl.reduce();
  rnl2.setrational(r.numerator, denominator);
  rnl2.reduce();
```

```
  //compute result
  num = rnl1.numerator * rnl2.numerator;
  denom = rnl1.denominator * rnl2.denominator;
  rnl.setrational(num, denom);
        rnl.print();
        return(rnl);
}
```

```
Rational    Rational::operator /(Rational r)
{
  Rational rnl1, rnl2, rnl3;

  //compute the reciprocal of r
  rnl1.setrational (numerator, denominator);
  rnl2.setrational(r.denominator, r.numerator);


  //Multiply by the reciprocal
  return(rnl1*rnl2);
}
```

```
int   Rational::operator ==(Rational r)
{
  reduce();
  r.reduce();
  if (numerator == r.numerator
      && denominator == r.denominator)
      return (1);
  else
      return(0);
}
```

```
void  Rational::reduce(void)
{
  int a, b, rem, sign;

  if (numerator == 0)
      denominator = 1;
  sign = 1; //assume positive
  //check if any negatives
  if (numerator < 0 && denominator < 0)   {
      numerator = -numerator;
      denominator = -denominator;
  }
```

```
  if (numerator < 0)    {
      numerator = -numerator;
      sign = -1;
  }

  if (denominator < 0)  {
      denominator = -denominator;
      sign =-1;
  }
  if (numerator > denominator)      {
      a = numerator;
      b = denominator;
  }
```

```
    else      {
        a = denominator;
        b = numerator;
    }

    while (b != 0)  {
        rem = a % b;
        a = b;
        b = rem;
    }
    numerator = sign * numerator/a;
    denominator = denominator / a;
  }
```

Function Overloading – An Example

```
Rational Rational::operator +(long i)
{
      Rational    r, r2;

      r.setrational(i, 1);
      r2.setrational(numerator, denominator);
      return(r + r2);
}
```

Using the *Rational* Class

```
#include    "rational.h"
#include    <string.h>

void  main(void)
{
      int   readtoken(char **);
      void  error(char *);

      char  *optr, *token1, *token2, *token3;
      int         int1, int2;
      Rational    opnd1, opnd2, result;
```

```
      while (readtoken(&optr) != EOF)     {
            // read the operator
            readtoken(&token1);
            // read the first integer's
            // character string
            int1 = atol(token1);
            // convert the first token to an
            //    integer
            readtoken(&token2);
```

```
if (strcmp(token2, "/") != 0)
      //convert the integer operand
      // to a Rational
      opnd1.setrational(int1, 1);
else  {
      //get the denominator of the
      readtoken(&token3);
      int2 = atol(token3);
      //convert the numerator and
      // denominator to a Rational
      opnd1.setrational(int1, int2);
      readtoken(&token2);
}
```

```
//get the second operand
int1 = atol(token2);
readtoken(&token2);
if (strcmp(token2, "/") != 0)
// convert the operand to Rational
      opnd2.setrational(int1, 1);
else  {
      //get the operand's denominator
      readtoken(&token3);
      int2 = atol(token3);
      // convert the numerator and
      // denominator to a Rational
      opnd2.setrational(int1, int2);
      readtoken(&token2);
}
```

```
            if (strcmp(token2, ";") != 0) {
              cout << "ERROR! ; expected, not"
                  << " found" << endl;
                        exit(1);
            }
            // apply the operator to the operands
            if (*optr == '+')
                  result = opnd1 + opnd2;
            else if (*optr == '*')
                  result = opnd1 * opnd2;
            else    {
              cout << "ERROR: illegal operator;"
                  << " must be * or +"    << endl;
              exit(1);
            }
            result.print();
      }
}
```

Constructors

- A constructor performs necessary initialization work when an object of this class is first defined.
- Constructors can be used for:
  - initializing private data
  - converting input values into the object's class
  - allocating necessary storage

Rational Constructors

```
Rational::Rational(void)
{
      //assume that the rational is 0
      numerator = 0;
      denominator = 1;
}

Rational::Rational(long i)
{
      numerator = i;
      denominator = 1;
}
```

Rational Constructors (continued)

```
Rational::Rational(long num, long denom)
{
      numerator = num;
      denominator = denom;
}
```