Structures

Lecture 14
COP 3014 Spring 2022

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Motivation

- We have plenty of simple types for storing single items like numbers, characters. But is this really enough for storing more complex things, like patient records, address books, tables, etc.?
- It would be easier if we had mechanisms for building up more complex storage items that could be accessed with single variable names
- **Compound Storage** – there are some built-in ways to encapsulate multiple pieces of data under one name
  - **Array** – we already know about this one. Indexed collections, and all items are the same type
  - **Structure** – keyword struct gives us another way to encapsulate multiple data items into one unit. In this case, items do not have to be the same type
- Structures are good for building records – like database records, or records in a file.

What is a Structure?

A structure is a collection of data elements, encapsulated into one unit.

- A structure definition is like a blueprint for the structure. It takes up no storage space itself – it just specifies what variables of this structure type will look like
- An actual structure variable is like a box with multiple data fields inside of it. Consider the idea of a student database. One student record contains multiple items of information (name, address, SSN, GPA, etc)
- Properties of a structure:
  - internal elements may be of various data types
  - order of elements is arbitrary (no indexing, like with arrays)
  - Fixed size, based on the combined sizes of the internal elements

Creating Structure definitions and variables

Structure Definitions The basic format of a structure definition is:

```
struct structureName
{
     // data elements in the structure
};
```

- struct is a keyword
- The data elements inside are declared as normal variables. structureName becomes a new type.
- Note that the two examples below are both just blueprints specifying what will be in corresponding structure variables if and when we create them.
- By themselves, these definitions above are not variables and do not take up storage
- Fraction and Student can now be used as new type names

Example

```
 /* A structure representing the parts of a fraction
(a rational number) */
struct Fraction
{
     int num; // the numerator of the fraction
     int denom; // the denominator of the fraction
};
/* A structure representing a record in a student
database */
struct Student
{
     char fName[20]; // first name
     char lName[20]; // last name
     int socSecNumber; // social security number
     double gpa; // grade point average
};
```

Structure variables

- To create an actual structure variable, use the structure's name as a type, and declare a variable from it. Format: `structureName variableName;`
- Variations on this format include the usual forms for creating arrays and pointers, and the comma-separated list for multiple variables
- Examples

```
Fraction f1; // f1 is now a 'Fraction'
Fraction fList[10]; // an array of 'Fraction'
              //structures
Fraction * fptr; // a pointer to a 'Fraction'
              //structure
Student stu1; // a Student structure variable
Student mathclass[10]; // an array of 10 Students
Student s1, s2, s3; // three Student variables
```

Legal variations in declaration syntax

- The definition of a structure and the creation of variables can be combined into a single declaration, as well.
- Just list the variables after the structure definition block (the blueprint), and before the semi-colon:

```
struct structureName
{
     // data elements in the structure
} variable1, variable2, ...  , variableN;
```

- Example:

```
struct Fraction
{
      int num; // the numerator of the fraction
int denom; // the denominator of the fraction
} f1, fList[10], *fptr; // variable, array, and
pointer created
```

Legal variations in declaration syntax

- In fact, if you only want structure variables, but don't plan to re-use the structure type (i.e. the blueprint), you don't even need a structure name:

  ```
  struct
  // note:  no structure NAME given
  {
       int num;
       int denom;
  } f1, f2, f3;
  // three variables representing fractions
  ```

- Of course, the advantage of giving a structure definition a name is that it is reusable. It can be used to create structure variables at any point later on in a program, separate from the definition block.

Legal variations in declaration syntax

- You can even declare structures as variables inside of other structure defintions (of different types):

```
struct Date // a structure to represent a date
{
     int month;
     int day;
     int year;
};
struct Employee
// a structure to represent an employee of a
company
{
     char firstName[20];
     char lastName[20];
     Date hireDate;
     Date birthDate;
};
```

Using structures

- Once a structure variable is created, how do we use it? How do we access its internal variables (often known as its members)?
- To access the contents of a structure, we use the dot-operator. Format:
  `structVariableName.dataVariableName`
- Example, using the fraction structure:

```
Fraction f1, f2;
f1.num = 4; // set f1's numerator to 4
f1.denom = 5; // set f1's denominator to 5
f2.num = 3; // set f2's numerator to 3
f2.denom = 10; // set f2's denominator to 10
cout << f1.num << '/' << f1.denom; // prints 4/5
cout << f2.num << '/' << f2.denom; // prints 3/10
```

Example, using the student structure:

```
Student sList[10]; // array of 10 students
// set first student's data:  (John Smith, SSN:
          123456789, GPA: 3.75)
strcpy(sList[0].fName, "John");
strcpy(sList[0].lName, "Smith");
sList[0].socSecNumber = 123456789;
sList[0].gpa = 3.75;
// assume there's more code here that initializes
other students
// This loop prints all 10 students -- their names
and their GPA
cout << fixed << setprecision(2);
for (int i = 0; i < 10; i++)
{
     cout << sList[i].fName << ' ' << sList[i].lName
          << ' ' << sList[i].gpa << '\n';
}
```

A shortcut for initializing structs

- While we can certainly initialize each variable in a structure separately, we can use an initializer list on the declaration line, too
- This is similar to what we saw with arrays
- This is only usable on the declaration line (like with arrays)
- The initializer set should contain the struct contents in the same order that they appear in the struct definition
- Example (using the fraction structure):
  ```
  Fraction f1 = 3, 5; //initialize num=3, denom=5
  // This would be the same as doing the following:
  f1.num = 3;
  f1.denom = 5;
  ```
- Example (using the student structure):
  ```
  Student s1 = {"John", "Smith", 123456789, 3.75};
  Student s2 = {"Alice", "Jones", 123123123, 2.66};
  ```

- If we have a pointer to a structure, things are a little trickier:
```
Fraction f1; // a fraction structure
Fraction *fPtr; // pointer to a fraction
fPtr = &f1; // fPtr now points to f1
f1.num = 3; // this is legal, of course
fPtr.num = 10; // how about this?  NO! ILLEGAL
// cannot put a pointer on the left side
// of the dot-operator
```
- Remember that to get to the target of a pointer, we dereference it. The target of fPtr is *fPtr. So how about this?
```
 *fPtr.num = 10; // closer, but still NO (not
quite)
```
- The problem with this is that the dot-operator has higher precedence, so this would be interpreted as:
```
*(fPtr.num) = 10; // cannot put a pointer on the
left of the dot
```

Accessing internal data using a pointer to a structure

- But if we use parentheses to force the dereference to happen first, then it works:
  ```
  (*fPtr).num = 10; // YES!
  ```
- Alternative operator for pointers: While the above example works, it's a little cumbersome to have to use the parentheses and the dereference operator all the time.
- So there is a special operator for use with pointers to structures. It is the arrow operator:
  ```
  pointerToStruct -> dataVariable
  ```
- Example:
  ```
  Fraction * fPtr; // pointer to a fraction
  // assume this has been pointed at a valid target
  fPtr->num = 10; // set fraction's numerator to 10
  fPtr->denom = 11; // denominator set to 11
  cout << fPtr->num << '/' << fPtr->denom; //
  prints:  10/11
  ```

Accessing members of nested structures

- Earlier, we saw an example of a structure variable used within another structure definition

```
struct Date // Date is now a type name
{
     int month;
     int day;
     int year;
}; // so that "Date" is the type name
struct Employee
{
     char firstName[20];
     char lastName[20];
     Date hireDate;
     Date birthDate;
};
```

Accessing members of nested structures

Here's an example of initializing all the data elements for one employee variable: `Employee emp; // emp is an employee variable`

```
// Set the name to "Alice Jones"
strcpy(emp.firstName, "Alice");
strcpy(emp.lastName, "Jones");

// set the hire date to March 14, 2001
emp.hireDate.month = 3;
emp.hireDate.day = 14;
emp.hireDate.year = 2001;

// sets the birth date to Sept 15, 1972
emp.birthDate.month = 9;
emp.birthDate.day = 15;
emp.birthDate.year = 1972;
```

Accessing members of nested structures

- Here's an example of an employee initialization using our shortcut initializer form:

```
Employee emp2 = { "John", "Smith", {6, 10, 2003},
{2, 19, 1981} };

// John Smith, whose birthday is Feb 19, 1981,
was hired on June 10, 2003
```

Structures and the assignment operator

- With regular primitive types we have a wide variety of operations available, including assignment, comparisons, arithmetic, etc.
- Most of these operations would NOT make sense on structures. Arithmetic and comparisons, for example:

```
Student s1, s2;
s1 = s1 + s2; // ILLEGAL!
// How would we add two students, anyway?
if (s1 < s2) // ILLEGAL. What would this mean?
// yadda yadda
```

- Using the assignment operator on structures IS legal, as long as they are the same type. Example (using previous struct definitions):

```
Student s1, s2;
Fraction f1, f2;
s1 = s2; // LEGAL. Copies contents of s2 into s1
f1 = f2; // LEGAL. Copies f2 into f1
```

Structures and the assignment operator

- Note that in the above example, the two assignment statements are equivalent to doing the following:

  ```
  // these 4 lines are equivalent to s1 = s2;
  strcpy(s1.fName, s2.fName);
  strcpy(s1.lName, s2.lName);
  s1.socSecNumber = s2.socSecNumber;
  s1.gpa = s2.gpa;
  //these 2 lines are equivalent to f1 = f2;
  f1.num = f2.num;
  f1.denom = f2.denom;
  ```

- Clearly, direct assignment between entire structures is easier, if a full copy of the whole thing is the desired result!

Passing structures into and out of functions

- Just like a variable of a basic type, a structure can be passed into functions, and a structure can be returned from a function.
- To use structures in functions, use structname as the parameter type, or as a return type, on a function declaration
- Examples (assuming struct definition examples from previous page):

```
// function that passes a structure variable as a
//parameter
void PrintStudent(Student s);
// function that passes in structure variables
// and returns a struct
Fraction Add(Fraction f1, Fraction f2);
```

Pass by value, reference, address

- Just like with regular varaibles, structures can be passed by value or by reference, or a pointer to a structure can be passed (i.e. pass by address)
- If just a plain structure variable is passed, as in the above examples, it's pass by value. A copy of the structure is made
- To pass by reference, use the & on the structure type, just as with regular data types
- To pass by address, use pointers to structures as the parameters and/or return
- As with pointers to the built-in types, you can use const to ensure a function cannot change the target of a pointer
- It's often a GOOD idea to pass structures to and from functions by address or by reference
  - structures are compound data, usually larger than plain atomic variables
  - Pass-by-value means copying a structure. NOT copying is desirable for efficiency, especially if the structure is very large

Example

```
// function that passes a pointer to student
//structure as a parameter
void GetStudentData(Student* s);

// function that passes in structures by const
// reference, and returns a struct by value
Fraction Add(const Fraction& f1, const Fraction& f2);

//function that uses const on a structure pointer
// parameter.  This function could take in an array
// of Students, or the address of one student.
void PrintStudents(const Student* s);

// or, this prototype is equivalent to the one above
void PrintStudents(const Student s[]);
```