Lecture 7

Templates
Learning Objectives

• Function Templates
  – Syntax, defining
  – Compiler complications

• Class Templates
  – Syntax
  – Example: array template class

• Templates and Inheritance
  – Example: partially-filled array template class
Introduction

• C++ templates
  – Allow very "general" definitions for functions and classes
  – Type names are "parameters" instead of actual types
  – Precise definition determined at run-time
Function Templates

• Recall function swapValues:
  void swapValues(int& var1, int& var2)
  {
    int temp;
    temp = var1;
    var1 = var2;
    var2 = temp;
  }

• Applies only to variables of type int
• But code would work for any types!
Function Templates vs. Overloading

• Could overload function for chars:
  ```cpp
  void swapValues(char& var1, char& var2)
  {
    char temp;
    temp = var1;
    var1 = var2;
    var2 = temp;
  }
  ```

• But notice: code is nearly identical!
  – Only difference is type used in 3 places
Function Template Syntax

• Allow "swap values" of any type variables:
  
  template<class T>
  void swapValues(T& var1, T& var2)
  {
    T temp;
    temp = var1;
    var1 = var2;
    var2 = temp;
  }

• First line called "template prefix"
  – Tells compiler what’s coming is "template"
  – And that T is a type parameter
Template Prefix

• Recall:
  template<class T>

• In this usage, "class" means "type", or "classification"

• Can be confused with other "known" use of word "class"!
  – C++ allows keyword "typename" in place of keyword "class" here
  – But most use "class" anyway
Template Prefix 2

• Again:
  template<class T>

• T can be replaced by any type
  – Predefined or user-defined (like a C++ class type)

• In function definition body:
  – T used like any other type

• Note: can use other than "T", but T is "traditional" usage
Function Template Definition

• \texttt{swapValues()} function template is actually large "collection" of definitions!
  – A definition for each possible type!

• Compiler only generates definitions when required
  – But it’s "as if" you’d defined for all types

• Write one definition \( \rightarrow \) works for all types that might be needed
Calling a Function Template

• Consider following call:
  
  swapValues(int1, int2);
  
  – C++ compiler "generates" function definition for two int parameters using template

• Likewise for all other types

• Needn’t do anything "special" in call
  
  – Required definition automatically generated
Another Function Template

• Declaration/prototype:
  Template<class T>
  void showStuff(int stuff1, T stuff2, T stuff3);

• Definition:
  template<class T>
  void showStuff(int stuff1, T stuff2, T stuff3)
  {
    cout << stuff1 << endl
    << stuff2 << endl
    << stuff3 << endl;
  }
showStuff Call

• Consider function call:
  showStuff(2, 3.3, 4.4);

• Compiler generates function definition
  – Replaces T with double
    • Since second parameter is type double

• Displays:
  2
  3.3
  4.4
Compiler Complications

• Function declarations and definitions
  – Typically we have them separate
  – For templates → not supported on most compilers!

• Safest to place template function definition in file where invoked
  – Many compilers require it appear 1st
  – Often we #include all template definitions
More Compiler Complications

• Check your compiler’s specific requirements
  – Some need to set special options
  – Some require special order of arrangement of template definitions vs. other file items

• Most usable template program layout:
  – Template definition in same file it’s used
  – Ensure template definition precedes all uses
    • Can #include it
Multiple Type Parameters

• Can have:
  template<class T1, class T2>

• Not typical
  – Usually only need one "replaceable" type
  – Cannot have "unused" template parameters
    • Each must be "used" in definition
    • Error otherwise!
Algorithm Abstraction

• Refers to implementing templates
• Express algorithms in "general" way:
  – Algorithm applies to variables of any type
  – Ignore incidental detail
  – Concentrate on substantive parts of algorithm
• Function templates are one way C++ supports algorithm abstraction
Defining Templates Strategies

• Develop function normally
  – Using actual data types
• Completely debug "ordinary" function
• Then convert to template
  – Replace type names with type parameter as needed
• Advantages:
  – Easier to solve "concrete" case
  – Deal with algorithm, not template syntax
Inappropriate Types in Templates

• Can use any type in template for which code makes "sense"
  – Code must behave in appropriate way
• e.g., swapValues() template function
  – Cannot use type for which assignment operator isn’t defined
  – Example: an array:
    int a[10], b[10];
    swapValues(a, b);
    • Arrays cannot be "assigned"!
Class Templates

• Can also "generalize" classes
  
  \[
  \text{template<class } T \rangle
  \]
  – Can also apply to class definition
  – All instances of "T" in class definition replaced by type parameter
  – Just like for function templates!

• Once template defined, can declare objects of the class
Class Template Definition

- template<class T>
  class Pair
  {
  public:
    Pair();
    Pair(T firstVal, T secondVal);
    void setFirst(T newVal);
    void setSecond(T newVal);
    T getFirst() const;
    T getSecond() const;
  private:
    T first; T second;
  }
Template Class Pair Members

- template<class T>
  Pair<T>::Pair(T firstVal, T secondVal)
  {
    first = firstVal;
    second = secondVal;
  }
  template<class T>
  void Pair<T>::setFirst(T newVal)
  {
    first = newVal;
  }
Template Class Pair

• Objects of class have "pair" of values of type T
• Can then declare objects:
  Pair<int> score;
  Pair<char> seats;
  – Objects then used like any other objects
• Example uses:
  score.setFirst(3);
  score.setSecond(0);
Pair Member Function Definitions

• Notice in member function definitions:
  – Each definition is itself a "template"
  – Requires template prefix before each definition
  – Class name before :: is "Pair<T>"
    • Not just "Pair"
  – But constructor name is just "Pair"
  – Destructor name is also just "~Pair"
Class Templates as Parameters

• Consider:
  int addUP(const Pair<int>& the Pair);
  – The type (int) is supplied to be used for T in defining this class type parameter
  – It "happens" to be call-by-reference here

• Again: template types can be used anywhere standard types can
Class Templates
Within Function Templates

• Rather than defining new overload:
  template<class T>
  T addUp(const Pair<T>& the Pair);
  //Precondition: Operator + is defined for values
  of type T
  //Returns sum of two values in thePair

• Function now applies to all kinds
  of numbers
Restrictions on Type Parameter

• Only "reasonable" types can be substituted for T

• Consider:
  – Assignment operator must be "well-behaved"
  – Copy constructor must also work
  – If T involves pointers, then destructor must be suitable!

• Similar issues as function templates
Type Definitions

• Can define new "class type name"
  – To represent specialized class template name

• Example:
  `typedef Pair<int> PairOfInt;`

• Name "PairOfInt" now used to declare objects of type `Pair<int>`:
  `PairOfInt pair1, pair2;`

• Name can also be used as parameter, or anywhere else type name allowed
Friends and Templates

• Friend functions can be used with template classes
  – Same as with ordinary classes
  – Simply requires type parameter where appropriate

• Very common to have friends of template classes
  – Especially for operator overloads (as we’ve seen)
Predefined Template Classes

• Recall vector class
  – It’s a template class!

• Another: basic_string template class
  – Deals with strings of "any-type" elements
  – e.g.,
  
  basic_string<char>       works for char’s
  basic_string<double>     works for doubles
  basic_string<YourClass>  works for YourClass objects
basic_string Template Class

• Already used it!
• Recall "string"
  – It’s an alternate name for basic_string<char>
  – All member functions behave similarly for basic_string<T>
• basic_string defined in library <string>
  – Definition is in std namespace
Templates and Inheritance

• Nothing new here
• Derived template classes
  – Can derive from template or nontemplate class
  – Derived class is then naturally a template class
• Syntax same as ordinary class derived from ordinary class
Summary

• Function templates
  – Define functions with parameter for a type
• Class templates
  – Define class with parameter for subparts of class
• Predefined vector and basic_string classes are template classes
• Can define template class derived from a template base class