Lecture 17

Templates, Part I

What is a Template?

- In short, it's a way to define generic functionality on parameters without needing to declare their types.
- Consider the following example…
- Suppose you are in need of sorting arrays of various types.
- You may initially know that you only need to to sort integers, but what if you need to sort other types down the road?
- No matter what type(s) are involved, all sorting algorithms have a common need to swap (exchange) data elements in an array.
- We could abstractly represent this with the following pseudo-code:

```
void swap(<sometype> *a, int i, int j)
{
  <sometype> temp = a[i];
  a[i] = a[j];
  a[j] = temp;
}
```

What is a Template?

- This pseudo-code gives us a "blueprint" for implementing the swap function for any given type.
- So, if I needed to sort arrays of integers, floating points and strings, I could provide three overloaded definitions of `swap()`.

```
void swap(int *a, int i, int j)
{
  int temp = a[i];
  a[i] = a[j];
  a[j] = temp;
}
void swap(float *a, int i, int j)
{
  float temp = a[i];
  a[i] = a[j];
  a[j] = temp;
}
```

What is a Template?

```
void swap(string *a, int i, int j)
{
  string temp = a[i];
  a[i] = a[j];
  a[j] = temp;
}
```

- With these three definitions of swap, I can happily write three sorting functions each dealing with one of the three types.
- Their prototypes might look like this:

```
// Sorting function prototypes...
void sort(int *intArray, int size);
void sort(float *floatArray, int size);
void sort(string *stringArray, int size);
```

What is a Template?

- But wait… being big believers in choice and our natural tendencies to like to compare things…
- We want to have sorting routines for multiple sorting methods!
- We need more prototypes (well, and function definitions too!)

```
// Insertion Sort function prototypes...
void insertionSort(int *intArray, int size);
void insertionSort(float *floatArray, int size);
void insertionSort(string *stringArray, int size);
// Bubble Sort function prototypes...
void bubbleSort(int *intArray, int size);
void bubbleSort(float *floatArray, int size);
void bubbleSort(string *stringArray, int size);
// Selection Sort function prototypes...
void selectionSort(int *intArray, int size);
void selectionSort(float *floatArray, int size);
void selectionSort(string *stringArray, int size);
```

What is a Template?

- Uh oh, I just remembered.
- We can get a better range of numbers if we use `doubles` instead of `floats`, and in past semesters I've liked using `MyString` better than `string`. So...

```
// swap function prototypes…
void swap(int *a, int i, int j);
void swap(float *a, int i, int j);
void swap(string *a, int i, int j);
void swap(double *a, int i, int j);
void swap(MyString *a, int i, int j);
// Insertion Sort function prototypes...
void insertionSort(int *intArray, int size);
void insertionSort(float *floatArray, int size);
void insertionSort(string *stringArray, int size);
void insertionSort(double *doubleArray, int size);
void insertionSort(MyString *coolArray, int size);
```

What is a Template?

```
// Bubble Sort function prototypes...
void bubbleSort(int *intArray, int size);
void bubbleSort(float *floatArray, int size);
void bubbleSort(string *stringArray, int size);
void bubbleSort(double *doubleArray, int size);
void bubbleSort(MyString *coolArray, int size);
// Selection Sort function prototypes...
void selectionSort(int *intArray, int size);
void selectionSort(float *floatArray, int size);
void selectionSort(string *stringArray, int size);
void selectionSort(double *doubleArray, int size);
void selectionSort(MyString *coolArray, int size);
```

- Had enough yet?
- Let's go back to our "blueprints"

Templates Defined

```
void swap(<sometype> *a, int i, int j)  // pseudo code
{
  <sometype> temp = a[i];
  a[i] = a[j];
  a[j] = temp;
}
```

- I could also use the same abstraction to pseudo code to provide definitions for each of the sorting functions.
- In doing so I have (abstractly) defined the 20 functions I need for all of this sorting!

```
// Sorting function prototypes...
void bubbleSort(<sometype> *someArray, int size);
void insertionSort(<sometype> *someArray, int size);
void selectionSort(<sometype> *someArray, int size);
```

Templates Defined

- So how does all of this relate to templates?
- Well, the notion of abstracting out a function definition into pseudo code such that *any type* could be substituted is exactly what the concept of (function) templates is all about.
- If only the syntax were a little easier to look at! *sigh*
- Consider the following C++ function template definitions of `swap()` and `sort()`:

```
template <class someType> void swap(someType *a,int i,int j)
{
  someType temp = a[i];
  a[i] = a[j];
  a[j] = temp;
}
template <class aType> void insertionSort(aType *a,int size);
template <class aType> void bubbleSort(aType *a,int size);
template <class aType> void selectionSort(aType *a,int size);
```

What is a Template?

```
template <class a,class b,…> fn (formal args)
```

- This is the "official" specification for a template.
- It says that to define a template you must:
  - start with the keyword `template`
  - specify, in angle brackets, a placeholder name for each type you are using (these aren't necessarily classes, that's just the name chosen for this task)
  - follow the angle brackets with your function name
  - follow the function name with your parameter list (using any combination of real types and placeholder names)
- Again, the fact that you are using the keyword `class` for each placeholder you are defining has nothing to do with a C++ class.
- At compilation time the compiler will look at your code and generate a separate function for each type used throughout your code when calling template functions.

Calling Function Templates

- A function template is called just like any other function.
- There is an optional syntax for allowing the default "type resolution" to be overridden.
- Consider the following code:

```
class Person {
public:
  void whoAmI() { cout << "I am a Person!" << endl; }
};
class Student : public Person {
public:
  void whoAmI() { cout << "I am a student!" << endl; }
};
template <class someone> whoAmI(someone *x,Person *y)
{
  x->whoAmI();
  y->whoAmI();
}
```

Calling Function Templates

```
template <class someone> whoAmI(someone *x,Person *y)
{
  x->whoAmI();
  y->whoAmI();
}
```

- In addition to calling whoAmI() like a normal function, I can also override the type of the argument being passed as the first parameter, like this:

```
int main()
{
  Student alex;
  whoAmI(&alex,& alex);
  // Even though "alex" is a "Student", treat like a "Person"
  whoAmI<Person>(&alex,&alex);
}
```

Demonstration #1

Calling Function Templates

Overloading Operators with Templates

- We can take advantage of some existing global templates in the Standard Template Library to simplify INT.
- You see, operators can be overloaded with templates as well.
- The following templates exist in the Standard Template Library:

```
template <class T>
inline bool operator!=(const T& x,const T& y)
{
  return !(x == y);
}
template <class T>
inline bool operator>(const T& x,const T& y)
{
  return (y < x);
}
```

Overloading Operators with Templates

```
template <class T>
inline bool operator<=(const T& x,const T& y)
{
  return !(y < x);
}
template <class T>
inline bool operator>=(const T& x,const T& y)
{
  return !(x < y);
}
```

- If you'll notice, this provides a definition for the operators `!=`, >, >= and <= in terms of == and <.
- This means that for any class you create that can be ordered, all you need to do is overload == and < and you'll get all the comparison operators thanks to these templates.

Demonstration #2

Simplifying INT

Specialization

- Sometimes having a generic solution applied across all types doesn't work the way you want it to.
- Consider the example of a template function used to do generic comparisons:
- It works fine for most types, but when we start using C style strings, it breaks down:

```
// A generic template to compare two parameters of same type
template <class aType>
bool isLessThan(aType arg1,aType arg2)
{
  return arg1 < arg2;
}
```

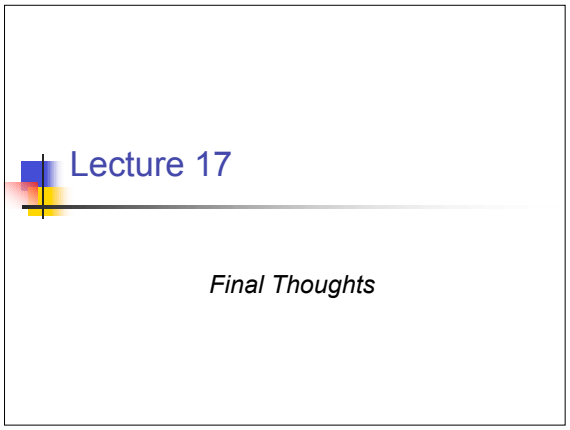
Specialization

```
int main() {
  int x = 7, y = 2;
  char *str1="oregano", *str2="basil";
  if (isLessThan(x,y))          // This is OK
    cout << "x less than y" << endl;
  if (isLessThan(str1,str2))    // Is this what we want?
    cout << "str1 less than str2" << endl;
}
```

- The problem is that our generic comparison routine will be comparing the pointer values for str1 and str2, not the strings they point at.
- If only we could make a special case… (can we?)

```
bool isLessThan(char *str1,char *str2)
{
  return (strcmp(str1,str2) < 0);
}
```


Demonstration #3
Specialization


Lecture 17
Final Thoughts