Templates and generic programming

Improving on the first week's assignment

- Quiz: How did you calculate the machine precision?

1. Did you just have a main() function
2. Did you have three functions with different names?
   1. `epsilon_float()`
   2. `epsilon_double()`
   3. `epsilon_long_double()`
3. Did you have three functions with the same name?
   1. `epsilon(float x)`
   2. `epsilon(double x)`
   3. `epsilon(long double x)`
4. Or did you have just one function that could be used for any type?
   1. `epsilon()`

Generic algorithms versus concrete implementations

- Algorithms are usually very generic:
  for min() all that is required is an order relation "< "

$$\min(x,y) = \begin{cases} x & \text{if } x < y \\ y & \text{otherwise} \end{cases}$$

- Most programming languages require concrete types for the function definition
  - C:

```
int min_int(int a, int b) { return a<b ? a : b;}
float min_float (float a, float b) { return a<b ? a : b;}
double min_double (double a, double b) { return a<b ? a : b;}
…
```

  - Fortran:

```
MIN(), AMIN(), DMIN(), …
```

Function overloading in C++

- solves one problem immediately: we can use the same name

```
int min(int a, int b) { return a<b ? a : b;}
float min (float a, float b) { return a<b ? a : b;}
double min (double a, double b) { return a<b ? a : b;}
```

- Compiler chooses which one to use

```
min(1,3); // calls min(int, int)
min(1.,3.); // calls min(double, double)
```

- However be careful:

```
min(1,3.1415927); // Problem! which one?
min(1.,3.1415927); // OK
min(1,int(3.1415927)); // OK but does not make sense
```

  or define new function `double min(int,double);`

How can several functions have the same name?

1. Why should it be a problem?
2. I don't know
3. The compiler uses magic
4. It is a problem, but I know how it can be solved

C++ versus C linkage

- How can three different functions have the same name?
  - Look at what the compiler does
    ```
    c++ -c -save-temps -O3 min.cpp
    ```
  - Look at the assembly language file min.s and also at min.o
    ```
    nm min.o
    ```
- The functions actually have different names!
  - Types of arguments appended to function name
- C and Fortran functions just use the function name
  - Can declare a function to have C-style name by using `extern "C"`
    ```
    extern "C" { short min(short x, short y);}
    ```

Using macros (is dangerous)

- We still need many functions (albeit with the same name)
- In C we could use preprocessor macros:
  - `#define min(A,B) (A < B ? A : B)`
- However there are serious problems:
  - No type safety
  - Clumsy for longer functions
  - Unexpected side effects:

```
min(x++,y++);  // will increment the smaller number twice!!!
               // since this is: (x++ < y++ ? x++ : y++)
```

- Look at it:
  - `c++ -E minmacro.cpp`

Generic algorithms using templates in C++

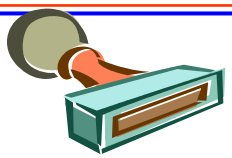
- C++ templates allow a generic implementation:

```
template <class T>
inline T min (T x, T y)
{
  return (x < y ? x : y);
}
```

$$\min(x,y) \text{ is } \begin{cases} x & \text{if } x < y \\ y & \text{otherwise} \end{cases}$$

- Using templates we get functions that
  - work for many types `T`
  - are optimal and efficient since they can be inlined
  - are as generic and abstract as the formal definition
  - are one-to-one translations of the abstract algorithm

Usage Causes Instantiation



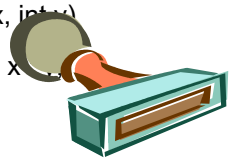
```
template <class T>
T min(T x, T y)
{
    return x < y ? x : y;
}

int x = min(3, 5);
int y = min(x, 100);

float z = min(3.14159f, 2.7182f);
```

```
// T is int
int min<int>(int x, int y)
{
    return x < y ? x : y;
}

// T is float
float min<float>(float x, float y)
{
    return x < y ? x : y;
}
```



Polymorphism

- **Definition**: Using many different types through the same interface
- What are the advantages?

Generic programming process

- Identify useful and efficient algorithms
- Find their generic representation
  - Categorize functionality of some of these algorithms
  - What do they need to have in order to work **in principle**
- Derive a set of (minimal) requirements that allow these algorithms to run (efficiently)
  - Now categorize these algorithms and their requirements
  - Are there overlaps, similarities?
- Construct a framework based on classifications and requirements
- Now realize this as a software library

Generic Programming Process: Example

- (Simple) Family of Algorithms: min, max
- Generic Representation

$$\min(x,y) = \begin{cases} x & \text{if } x < y \\ y & \text{otherwise} \end{cases}$$

$$\max(x,y) = \begin{cases} x & \text{if } x > y \\ y & \text{otherwise} \end{cases}$$

- Minimal Requirements?
- Find Framework: Overlaps, Similarities?

Generic Programming Process: Example

- (Simple) Family of Algorithms: min, max
- Generic Representation

$$\min(x,y) = \begin{cases} x & \text{if } x < y \\ y & \text{otherwise} \end{cases}$$

$$\max(x,y) = \begin{cases} x & \text{if } y < x \\ y & \text{otherwise} \end{cases}$$

- Minimal Requirements yet?
- Find Framework: Overlaps, Similarities?

Generic Programming Process: Example

- Possible Implementation

```
template <class T>
T min(T x, T y)
{
  return x < y ? x : y;
}
```

- What are the Requirements on **T**?
  - operator < , result convertible to bool

Generic Programming Process: Example

- Possible Implementation

```
template <class T>
T min(T x, T y)
{
  return x < y ? x : y;
}
```

- What are the Requirements on **T**?
  - operator < , result convertible to bool
  - Copy construction: need to copy the result!

Generic Programming Process: Example

- Possible Implementation

```
template <class T>
T const& min(T const& x, T const& y)
{
  return x < y ? x : y;
}
```

- What are the Requirements on **T**?
  - operator < , result convertible to bool
  - that’s all!

The problem of different types: manual solution

- What if we want to call min(1,3.141)?

```
template <class R, class U, class T>
R const& min(U const& x, T const& y)
{
  return (x < y ? static_cast<R>(x) : static_cast<R>(y));
}
```

- Now we need to specify the first argument since it cannot be deduced.

```
min<double>(1,3.141);
min<int>(3,4);
```