Templates
- Mechanism in C++ for generic programming
- Allows programs to be parameterized on types as well as values
- Captures repeated patterns where types involved may change
- Examples:
  - Data structures – lists, vectors, arrays of different types are likely to be identical except for the element type
  - A mapping between two type values is a generic programming concept, e.g., a map between int and string, between string and string, etc
  - Even a string is a generic concept – could have other types of “character”
- Templates are recipes for code generation
- Avoids manual duplication of code and type substitution, which is very error prone and nearly impossible to maintain
- Early approaches used preprocessor macros to do systematic code duplication
  - No compiler knowledge of what was going on
  - Difficult to debug
- Functions can be parameterized on types
  - E.g., sorting algorithm is same regardless of type being sorted
- Classes can be parameterized on types
  - E.g., Data containers like vector, set, array, etc.
- Very useful for library code
  - Promotes reuse
  - Library templates should be carefully designed
  - Can force pre-instantiations for common types
- Java generics introduced in Java 1.5 are similar – based on the C++ model
  - But implemented differently by the compiler

Syntax of C++ Templates
- Keyword `template` is followed by one or more type names in angle brackets
  - Type names are only placeholders for concrete type names
  - May also parameterize on constant values
    - E.g., constant int sizes
- Used for parameterizing a block of code by a type name placeholder
  - Parameterization applies for the block that follows immediately
  - Block is at high level
    - class definition
    - function definition
  - Code is only partially compiled
    - Syntax is checked
    - Type checking up to the parameterized type
    - The parameterized type can only be treated as syntactically a type about which nothing is known
  - No actual executable code is generated
    - Compiler “remembers” this template for use in instantiating code for a particular type when needed
- Instantiation of code occurs when concrete types are supplied for the parameterized block
  o E.g., for a parameterized function definition, when the function is called with concrete values, their types are used to generate a definition of the function for those types
  o E.g., for a parameterized class definition, the class name followed by concrete type names in angle brackets is an explicit reference to the concrete type of that class for those types

Examples of Template function definitions
- A template swap function that interchanges two values
  
  ```
  // Swap two objects of the same type
  template <class T>
  void _swap(T & x, T & y) {
      T tmp = x; x = y; y = tmp;
  }
  ```
  
  - Note that swap only requires that the parameterized type T support assignment
- Template function _sort is recursive implementation of K&Rs quick sort
  ```
  template <class T>
  void _sort(T & vlist, int left, int right) {
      int last;
      if (left >= right) return;  // Nothing to do for fewer than two elements
      _swap(vlist[left], vlist[(left + right)/2]);
      last = left;
      for (int i = left + 1; i <= right; ++i)
          if (vlist[i] < vlist[left])
              _swap(vlist[++last], vlist[i]);
      _sort(vlist, left, last - 1);
      _sort(vlist, last + 1, right);
  }
  ```
  ```
  template <class T>
  void sort(T & vlist, int length) {
      _sort(vlist, 0, length - 1);
  }
  ```
  - Note that only requirement is that the type T support an array operator, and the elements support assignment and comparison with the operator ‘<’

Function Instantiation
- Template function is not instantiated until there is a need for it
  o A call to the function requires instantiation with types corresponding to the argument types of the call
  - E.g.,
    ```
    int ivals[] = { -9, 8, 10, 39, -13, 22, 8, 18, 44, 100, 0 };
    const int ilen = sizeof(ivals)/sizeof(int);
    sort(ivals, ilen);
    ```
    o Causes instantiation of sort with type T of array of int
    o In turn causes instantiation of _sort for array of int
    o And instantiation of _swap for type int
  - We get separate array of string versions from:
    ```
    string svals[] = . . .
    ```
sort(svals, slen);
- And vector<int> versions from
  vector<int> v(ilen);
  . . .
  sort(v, v.size());

Class Template Example
- Class Set is a generic container for objects of the same type
- Checks for duplicates
  o Requires comparison (overloaded ==) for objects
- Requires output method for objects
- Note that copy constructor and assignment must give the class name as
  parameterized – only the constructor and destructor names themselves do not
  need to be parameterized

  template <class TYPE>
  class Set {
    public:
      // Constructor and destructor
      Set() : head(NULL) { }
      ~Set() { release(); }

      // Copy constructor
      Set(const Set<TYPE> & s) { copy(s); }

      // Assignment of sets
      Set<TYPE> & operator = (const Set<TYPE> & s) {
        if (this != & s) { release(); copy(s); }
        return *this;
      }

      // Check if a value is in the set
      bool contains(const TYPE & v) {
        for (Item * cur = head; cur != NULL; cur = cur->next)
          if (cur->value == v) return true;
        return false;
      }

      // Add the value to set if not already there
      void add(const TYPE & v) {
        if (contains(v)) return;
        Item * newitem = new Item(v);
        if (head != NULL) newitem->next = head;
        head = newitem;
      }

      // Remove the value if it's there
      void remove(const TYPE & v) {
        for (Item *prev = NULL, *cur = head; cur != NULL;
            prev = cur, cur = cur->next) {
          if (cur->value == v) {
            Item * tmp = cur->next;
            delete cur;
            if (prev == NULL) head = tmp;
            else prev->next = tmp;
            return;
          }
        }
    }
// Display the set
ostream & print(ostream & o) const {
    for (Item * cur = head; cur != NULL; cur = cur->next) {
        if (cur != head) o << ' ';
        o << cur->value;
    }
    return o;
}

private:
// Private structure for value and linkage
struct Item {
    TYPE value;
    Item * next;
    Item(const TYPE & v, Item * n = NULL) : value(v), next(n) { }
};

Item * head;

// Delete all items in set - used by destructor and assignment
void release() {
    Item * cur = head;
    while (cur != NULL) {
        Item * tmp = cur;
        cur = cur->next;
        delete tmp;
    }
}

// Copy the set - used by copy constructor and assignment
void copy(const Set<TYPE> & s) {
    Item * cur = NULL;
    for (Item * exist = s.head; exist != NULL; exist = exist->next) {
        Item * newitem = new Item(exist->value);
        if (cur == NULL) head = cur = newitem;
        else {
            cur->next = newitem;
            cur = cur->next;
        }
    }
    }
    }

// Copy the set - used by copy constructor and assignment
inline ostream & operator << (ostream & o, const Set<TYPE> & s) {
    return s.print(o);
}