# Object-Oriented Design and Programming

## C++ Container Classes

## Outline

# Introduction

- Container classes are an important category of ADTs
  - They are used to maintain collections of elements like stacks, queues, linked lists, tables, trees, etc.

- Container classes form the basis for various C++ class libraries
  - Note, making class libraries is a popular way to learn C++...

- C++ container classes can be implemented using several methods:

  (0) *Ad hoc,* rewrite from scratch each time
  (1) Preprocessor Macros
  (2) A `genclass` Facility (*e.g.*, GNU libg++)
  (3) Parameterized Types
  (4) **void** Pointer Method

- Note, methods 1–3 apply to *homogeneous* collections; method 4 allows *heterogeneous* collections

# Container Class Objectives

- *Application Independence*
  - Transparently reuse container class code for various applications

- *Ease of Modification*
  - Relatively easy to extend classes to fit smoothly into a new application

- *Ease of Manipulation*
  - Implementation must hide representation details, *e.g.*, iterators

# Container Class Objectives (cont'd)

- *Type Safety*
  - Insure that the collections remain type safe
    - This is easy for parameterized types, harder for **void** pointers...
- *Run-Time Efficiency and Space Utilization*
  - Different schemes have different tradeoffs
    - *e.g.*, extra indirection vs flexibility

# Object-Oriented Class Library Architecture

- Two general approaches are *tree* vs *forest* (differ in their use of inheritance):

  *Tree*: create a single rooted tree of classes derived from a common base class, *e.g.*, *object*

  - *e.g.*, standard Smalltalk libraries or NIHCL

  *Forest*: a collection of generally independent classes available for individual selection and use

  - *e.g.*, GNU libg++ library, Borland C++ class library, Booch components, Rogue Wave, USL Standard components

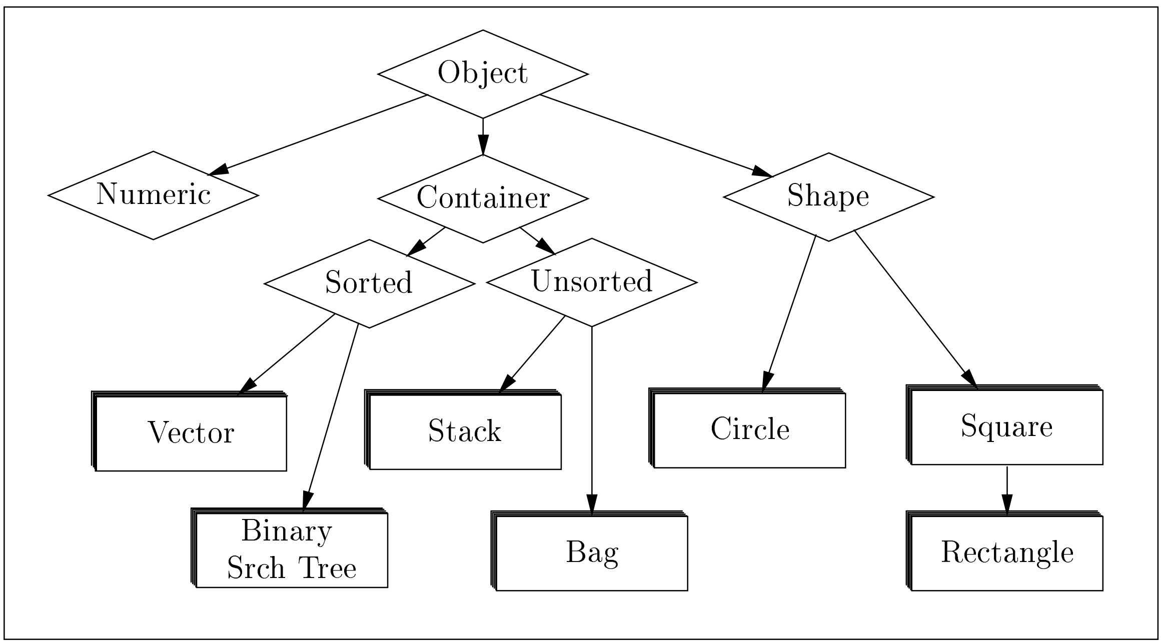
- Tradeoffs:

  1. *Uniformity* (Tree) vs *flexibility* (Forest)

  2. *Sharing* (Tree) vs *efficiency* (Forest)

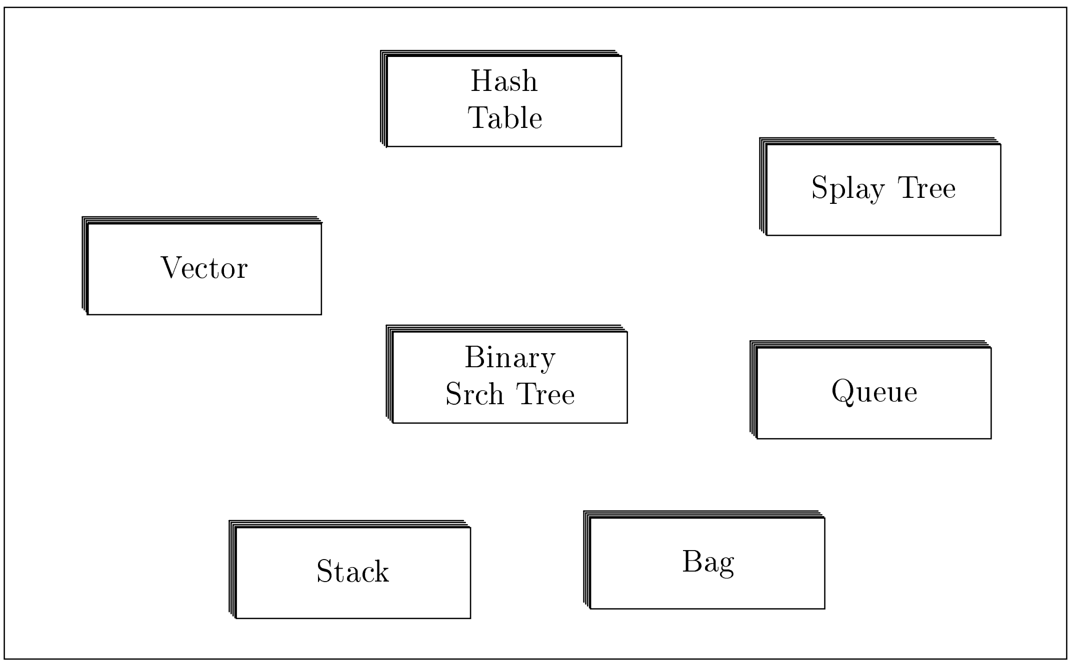
     - Forest classes do not inherit unnecessary functions

# Object-Oriented Class Library Architecture (cont'd)




- Tree-based class library

# Object-Oriented Class Library Architecture (cont'd)




- Forest-based class library

# Parameterized Types

- Parameterized list class

```
template <class T>
class List {
public:
     List (void): head_ (0) {}
     void prepend (T &item) {
          Node<T> *temp =
               new Node<T> (item, this->head_);
          this->head_ = temp;
     }
     /* ...*/
private:
     template <class T>
     class Node {
     private:
          T value_;
          Node<T> *next_;
     public:
          Node (T &v, Node<T> *n)
               : value_ (v), next_ (n) {}
     };
     Node<T> *head_;
};

int main (void) {
     List<int> list;
     list.prepend (20);
     // ...
}
```

# Parameterized Types (cont'd)

- Parameterized Vector class

```
template <class T = int, int SIZE = 100>
class Vector {
public:
    Vector (void): size_ (SIZE) {}
    T &operator[] (size_t i) {
        return this->buf_[i];
    }
private:
    T buf_[SIZE];
    size_t size_;
};
int main (void) {
    Vector<double> d; // 100 doubles
    Vector<int, 1000> d; // 1000 ints
    d[10] = 3.1416;
}
```

# Preprocessor Macros

- Stack example (using GNU g++)

```
#ifndef _stack_h
#define _stack_h

#define name2(a,b) gEnErIc2(a,b)
#define gEnErIc2(a,b) a ## b
#define Stack(TYPE) name2(TYPE,Stack)

#define StackDeclare(TYPE) \
class Stack(TYPE) { \
public: \
    Stack(TYPE) (size_t size): size_ (size) { \
        this->bottom_ = new TYPE[size]; \
        this->top_ = this->bottom_ + size; \
    } \
    TYPE pop (void) { \
        return *this->top_++; \
    } \
    void push (TYPE item) { \
        *--this->top_ = item; \
    } \
    bool is_empty (void) { \
        return this->top_ == this->bottom_ \
                + this->size_; \
    } \
    bool is_full (void) { \
        return this->bottom_ == this->top_; \
    } \
    ~Stack(TYPE) (void) { delete this->bottom_; } \
private: \
    TYPE *bottom_; \
    TYPE *top_; \
    size_t size_; \
}
#endif
```

# Preprocessor Macros (cont'd)

- Stack driver

```
#include <stream.h>
#include "stack.h"
StackDeclare (char);
typedef Stack(char) CHARSTACK;
int main (void) {
     const int STACK_SIZE = 100;
     CHARSTACK s (STACK_SIZE);
     char c;
     cout << "please enter your name..: ";

     while (!s.is_full () && cin.get (c) && c != '\n')
          s.push (c);

     cout << "Your name backwards is..: ";
     while (!s.is_empty ())
          cout << s.pop ();
     cout << "\n";
}
```

- Main problems:

(1) Ugly ;-)
(2) Code bloat
(3) Not integrated with compiler

# genclass

- Technique used by GNU libg++
  - Uses **sed** to perform text substitution

```
sed -e "s/<T>/$T1/g" -e "s/<T&>/$T1$T1ACC/g"
```

- Single Linked List class

```
class <T>SLList {
public:
     <T>SLList (void);
     <T>SLList (<T>SLList &a);
     ~<T>SLList (void);
     <T>SLList &operator = (<T>SLList &a);
     int empty (void);
     int length (void);
     void clear (void);
     Pix prepend (<T&> item);
     Pix append (<T&> item);
     /* ...*/
protected:
     <T>SLListNode* last_;
};
```

# void Pointer Method

- General approach:
  - **void** * pointers are the actual container elements
  - Subclasses are constructed by coercing **void** * elements into pointers to elements of interest

- *Advantages*:
  1. Code sharing, less code redundancy
  2. Builds on existing C++ features (*e.g.*, inheritance)

- *Disadvantages*:
  1. Somewhat awkward to design correctly
  2. Inefficient in terms of time and space (requires dynamic allocation)
  3. Reclamation of released container storage is difficult (need some form of garbage collection)

# void Pointer Example

- One example application is a generic ADT *List* container class. It contains four basic operations:

  1. *Insertion*
     - add item to either front or back
  2. *Membership*
     - determine if an item is in the list
  3. *Removal*
     - remove an item from the list
  4. *Iteration*
     - allow examination of each item in the list (without revealing implementation details)

- The generic list stores pointers to elements, along with pointers to links
  - This allows it to hold arbitrary objects (but watch out for type-safety!!)

# void Pointer Example (cont'd)

- Generic_List.h

```
#ifndef Generic_List
#define Generic_List
class List {
public:
      List (void);
      ~List (void);
      void remove_current (void);
      // Used as iterators...
      void reset (void);
      void next (void);
protected:
      class Node {
      friend List;
      public:
            Node (void *, Node *n = 0);
            ~Node (void);
            void add_to_front (void *);
            void add_to_end (void *);
            Node *remove (void *);
      private:
            void *element_; // Pointer to actual data
            Node *next_;
      };
```

- Generic_List.h (cont'd)

```
protected:
    // used by subclasses for implementation
    void add_to_end (void *);
    void add_to_front (void *);
    Node *current_value (void);
    void *current (void);
    bool includes (void *);
    void *remove (void *);

    // important to make match virtual!
    virtual bool match (void *, void *);
private:
    Node *head_;
    Node *iter_; // used to iterate over lists
};
```

- Generic_List.h (cont'd)

```
// Iterator functions
inline List::Node *List::current_value (void) {
     return this->iter_;
}

inline void List::reset (void) {
     this->iter_ = this->head_;
}

inline void *List::current (void) {
     if (this->iter_)
          return this->iter_->element_;
     else
          return 0;
}

inline void List::next (void) {
     this->iter_ = this->iter->next_;
}
```

- Generic_List.C

```
// Node methods
inline List::Node::Node (void *v, List::Node *n)
    : element_ (v), next_ (n) {}

inline List::Node::~Node (void) {
    if (this->next_) // recursively delete the list!
        delete this->next_;
}

inline void List::Node::add_to_front (void *v) {
    this->next_ = new List::Node (v, this->next_);
}
void List::Node::add_to_end (void *v) {
    if (this->next_) // recursive!
        this->next_->add_to_end (v);
    else
        this->next_ = new List::Node (v);
}
List::Node *List::Node::remove (void * v) {
    if (this == v)
        return this->next_;
    else if (this->next_) // recursive
        this->next_ = this->next_->remove (v);
    return this;
}
```

- Generic_List.C

```
// List methods
void List::add_to_front (void *v) {
     this->head_ = new List::Node (v, this->head_);
}
void List::add_to_end (void *v) {
     if (this->head_) // recursive!
          this->head_->add_to_end (v);
     else
          this->head_ = new List::Node (v);
}
bool List::includes (void *v) {
     // Iterate through list
     for (this->reset (); this->current (); this->next ())
          // virtual method dispatch!
          if (this->match (this->current (), v))
               return true;
     return false;
}
bool List::match (void *x, void *y) {
     return x == y;
}
```

- Generic_List.C (cont'd)

```
void List::remove_current (void) {
    if (this->head_ == this->iter_)
        this->head_ = this->iter_->next_;
    else
        this->head_ = this->head_->remove (this->iter_);
    this->iter_->next_ = 0;
    delete this->iter_; // Deallocate memory
    this->iter_ = 0;
}

void *List::remove (void *v) {
    for (this->reset (); this->current (); this->next ())
        if (this->match (this->current (), v)) {
            void *fv = this->current ();
            this->remove_current();
            return fv;
        }
    return 0;
}

inline List::List (void): head_ (0), iter_ (0) {}

List::~List (void) {
    if (this->head_) delete this->head_; // recursive!
}
```

# void Pointer Example (cont'd)

- Card.h

```
#include "Generic_List.h"
class Card {
     friend class Card_List;
public:
     enum Suit {
          SPADE = 1, HEART = 2, CLUB = 3, DIAMOND = 4
     };
     enum Color { BLACK = 0, RED = 1 };
     Card (int r, int s);
     int rank (void);
     Suit suit (void);
     Color color (void);
     bool operator == (Card &y);
     void print (ostream &);
private:
     int rank_;
     Suit suit_;
};
```

- Card.h

```
inline int Card::rank (int) { return this->rank_; }
inline Card::Suit Card::suit (void) { return this->suit_; }

inline bool Card::operator == (Card &y) {
     return this->rank () == y.rank ()
          && this->suit () == y.suit();
}

inline void Card::print (ostream &str) {
     str << "suit " << this->suit ()
          << "rank " << this->rank () << endl;
}

inline Card::Card (int r, Card::Suit s)
          : rank_ (r), suit_ (s) {}

inline Card::Color Card::color (void) {
     return Card::Color (int (this->suit ()) % 2);
}
```

- Card_List.h

```
#include "Card.h"

class Card_List : public List {
public:
     void add (Card *a_card) {
          List::add_to_end (a_card);
     }

     Card *current (void) {
          return (Card *) List::current ();
     }

     int includes (Card *a_card) {
          return List::includes (a_card);
     }

     void remove (Card *a_card) {
          List::remove (a_card);
     }

     void print (ostream &);

protected:
     // Actual match function used by List!
     virtual bool match (void *, void *);
};
```

- Card_List.C

```
// Virtual method
bool Card_List::match (void *x, void *y) {
     Card &xr = *(Card *) x;
     Card &yr = *(Card *) y;
     // Calls Card::operator ==
     return xp == yp;
}

void Card_List::print (ostream &str) {
     for (this->reset (); this->current (); this->next ())
          this->current ()->print (str);
}
```

- main.C

```
#include "Card.h"
int main (void) {
    Card_List cl;

    Card *a = new Card (Card::HEART, 2);
    Card *b = new Card (Card::DIAMOND, 4);
    Card *c = new Card (Card::CLUB, 3);

    cl.add (a); cl.add (b); cl.add (c); cl.add (b);

    cl.print (cout);

    if (cl.includes (new Card (Card::DIAMOND, 4)))
        cout << "list includes 4 of diamonds\n";
    else
        cout << "something's wrong!\n";

    cl.remove (new Card (Card::CLUB, 3));
    cl.print (cout);
    return 0;
}
```

- Main problem:
  - Must dynamically allocate objects to store into generic list!
    - Handling memory deallocation is difficult without garbage collection or other tricks...