Chapter 11: Pointers and Dynamic Objects

- *Mechanisms for developing flexible list representations*

Categorizing Expressions

- *Lvalue expressions*
  - *Represent objects that can be evaluated and modified*
- *Rvalue expressions*
  - *Represent objects that can only be evaluated*
- *Consider*

```
int a;
vector<int> b(3);
int c[3];
a = 1;              // a: lvalue
c[0] = 2*a + b[0];// c[0], a, b[0]: lvalues
```

- *Observation*
  - *Not all lvalues are the names of objects*

Basics

- *Pointer*
  - *Object whose value represents the location of another object*
  - *In C++ there are pointer types for each type of object*
    - *Pointers to int objects*
    - *Pointers to char objects*
    - *Pointers to RectangleShape objects*
  - *Even pointers to pointers*
    - *Pointers to pointers to int objects*

Syntax

- *Examples of uninitialized pointers*

Indicates pointer object

```
int *iPtr;    // iPtr is a pointer to
              // an int
char *s;      // s is a pointer to a
              // char
Rational *rPtr;  // rPtr is a pointer
  //to a Rational
```

- *Examples of initialized pointers*

Indicates to take the address of the object

```
int i = 1;
char c = 'y';
int *ptr = &i;  // ptr is a pointer to
               //int i
char *t = &c;  // t is a pointer to a
              //char c
```

Indirection Operator

- *An asterisk has two uses with regard to pointers*
  - *In a definition, it indicates that the object is a pointer*

```
char *s; // s is of type pointer to char
```

  - *In expressions, when applied to a pointer it evaluates to the object to which the pointer points*

```
int i = 1;
int *ptr = &i;        // ptr points to i
*ptr = 2;
cout << i << endl;    // display a 2
```

* indicates indirection or dereferencing

*ptr is an lvalue

Address Operator

- *& use is not limited to definition initialization*

```
int i = 1;
int j = 2;
int *ptr;
ptr = &i;     // ptr points to
  location of i
*ptr = 3; // contents of i are
            //updated
ptr = &j;     // ptr points to
            //location of j
*ptr = 4;     // contents of j are
                 //updated
cout << i << " " << j << endl;
```

Null Address

- *0 is a pointer constant that represents the empty or null address*
  - *Its value indicates that pointer is not pointing to a valid object*
  - *Cannot dereference a pointer whose value is null*

```
int *ptr = 0;
cout << *ptr << endl; // invalid,
  //ptr does not point to a valid int
```

Member Indirection

- *Consider*

```
Rational r(4,3);
Rational rPtr = &r;
```

- *To select a member of r using rPtr and member selection, operator precedence requires*

```
(*rPtr).Insert(cout);
```

Invokes member Insert() of the object to which rPtr points (r)

- *This syntax is clumsy, so C++ provides the indirect member selector operator ->*

```
rPtr->Insert(cout);
```

Invokes member Insert() of the object to which rPtr points (r)

Traditional Pointer Usage

```
void IndirectSwap(char *Ptr1, char *Ptr2) {
   char c = *Ptr1;
   *Ptr1 = *Ptr2;
   *Ptr2 = c;
}
int main() {
   char a = 'y';
   char b = 'n';
   IndirectSwap(&a, &b);
   cout << a << b << endl;
   return 0;
}
```

In C, there are no reference parameters. Pointers are used to simulate them.

Constants and Pointers

- *A constant pointer is a pointer such that we cannot change the location to which the pointer points*

```
char c = 'c';
const char d = 'd';
char * const ptr1 = &c;
ptr1 = &d; // illegal
```

- *A pointer to a constant value is a pointer object such that the value at the location to which the pointer points is considered constant*

```
const char *ptr2 = &d;
*ptr2 = 'e'; // illegal: cannot change d
             // through indirection with ptr2
```

Differences

- ***Local objects and parameters***
  - Object memory is acquired automatically
  - Object memory is returned automatically when object goes out of scope
- ***Dynamic object***
  - Object memory is acquired by program with an allocation request
    - new operation
  - Dynamic objects can exist beyond the function in which they were allocated
  - Object memory is returned by a deallocation request
    - delete operation

General New Operation Behavior

- ***Memory for dynamic objects***
  - ***Requested from the free store***
    - ***Free store is memory controlled by operating system***
- ***Operation specifies***
  - ***The type and number of objects***
- ***If there is sufficient memory to satisfy the request***
  - ***A pointer to sufficient memory is returned by the operation***
- ***If there is insufficient memory to satisfy the request***
  - ***An exception is generated***
    - ***An exception is an error state/condition which if not handled (corrected) causes the program to terminate***

The Basic New Form

- *Syntax*

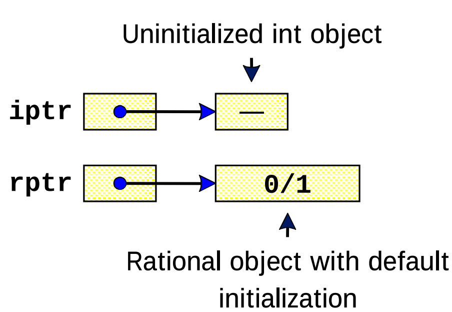
```
Ptr = new SomeType ;
```

  - *Where*
    - *Ptr is a pointer of type SomeType*

- *Beware*
  - *The newly acquired memory is uninitialized unless there is a default SomeType constructor*

Examples

```
int *iptr = new int;
Rational *rptr = new Rational;
```



Another Basic New Form

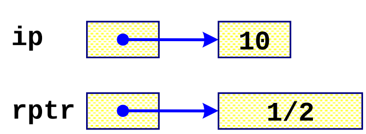
- *Syntax*

```
    SomeType *Ptr = new
SomeType(ParameterList);
```

  - *Where*
    - *Ptr is a pointer of type SomeType*
- *Initialization*
  - *The newly acquired memory is initialized using a SomeType constructor*
  - *ParameterList provides the parameters to the constructor*

Examples

```
int *iptr = new int(10);
Rational *rptr = new
  Rational(1,2);
```



The Primary New Form

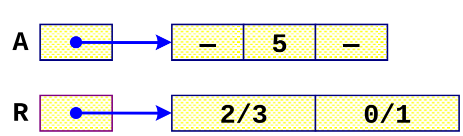
- *Syntax*

```
P = new SomeType [Expression] ;
```

  - *Where*
    - *P is a pointer of type SomeType*
    - *Expression is the number of contiguous objects of type SomeType to be constructed -- we are making a list*
  - *Note*
    - *The newly acquired list is initialized if there is a default SomeType constructor*
- *Because of flexible pointer syntax*
  - *P can be considered to be an array*

Examples

```
int *A = new int [3];
Rational *R = new Rational[2];
A[1] = 5;
Rational r(2/3);
R[0] = r;
```



Right Array For The Job

```
cout << "Enter list size: ";
int n;
cin >> n;
int *A = new int[n];
GetList(A, n);
SelectionSort(A, n);
DisplayList(A, n);
```

- *Note*
  - *Use of the container classes of the STL is preferred from a software engineering viewpoint*
    - *Example vector class*

Delete Operators

- *Forms of request*

```
delete P;    // used if storage came
  from new
delete [] P; // used if storage came
  from new[]
```

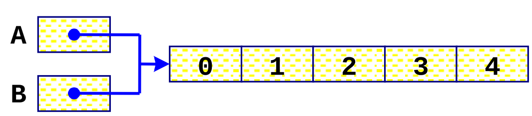
  - *Storage pointed to by P is returned to free store*
    - *P is now undefined*

Cleaning Up

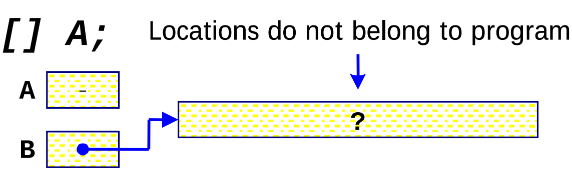
```
int n;
cout << "Enter list size: ";
cin >> n;
int *A = new int[n];
GetList(A, n);
SelectionSort(A, n);
DisplayList(A, n);
delete [] A;
```

Dangling Pointer Pitfall

```
int *A = new int[5];
for (int i = 0; i < 5; ++i)
  A[i] = i;
int *B = A;
```

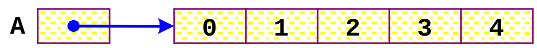



```
delete [] A;
```

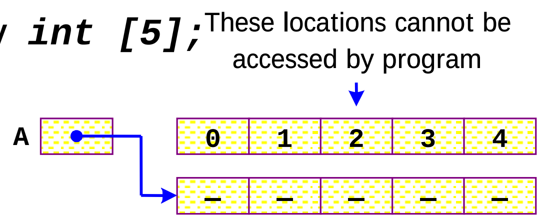


Memory Leak Pitfall

```
int *A = new int [5];
for (int i = 0; i < 5; ++i)
 A[i] = i;
```




```
A = new int [5];
```



A Simple Dynamic List Type

- *What we want*
  - *An integer list data type IntList with the basic features of the vector data type from the Standard Template Library*
- *Features and abilities*
  - *True object*
    - *Can be passed by value and reference*
    - *Can be assigned and copied*
  - *Inspect and mutate individual elements*
  - *Inspect list size*
  - *Resize list*
  - *Insert and extract a list*

Sample IntList Usage

```
IntList A(5, 1);
IntList B(10, 2);
IntList C(5, 4);
for (int i = 0, i < A.size(); ++i) {
  A[i] = C[i];
}
cout << A << endl; // [ 4 4 4 4 4 ]
A = B;
A[1] = 5;
cout << A << endl; // [ 5 2 2 2 2 2 2 2
  2 2 ]
```

IntList Definition

```
class IntList {
  public:
     // constructors
     IntList(int n = 10, int val = 0);
     IntList(const int A[], int n);
     IntList(const IntList &A);
     // destructor
     ~IntList();
     // inspector for size of the list
     int size() const;
     // assignment operator
     IntList & operator=(const IntList &A);
```

IntList Definition (continued)

```
public:
   // inspector for element of constant
list
   const int& operator[](int i) const;
   // inspector/mutator for element of
   // nonconstant list
   int& operator[](int i);
   // resize list
   void resize(int n = 0, int val = 0);
   // convenience for adding new last
element
   void push_back(int val);
```

IntList Definition (continued)

```
  private:
     // data members
     int *Values;      // pointer to elements
     int NumberValues; // size of list
};

// IntList auxiliary operators -- nonmembers

ostream& operator<<(ostream &sout, const IntList &A);

istream& operator>>(istream &sin, IntList &A);
```

Default Constructor

```
IntList::IntList(int n, int val)
  {
  assert(n > 0);
  NumberValues = n;
  Values = new int [n];
  assert(Values);
  for (int i = 0; i < n; ++i) {
     Values[i] = val;
  }
}
```

Gang of Three Rule

- *If a class has a data member that points to dynamic memory then that class* **normally** *needs a class-defined*
  - *Copy constructor*
    - *Constructor that builds an object out of an object of the same type*
  - *Member assignment operator*
    - *Resets an object using another object of the same type as a basis*
  - *Destructor*
    - *Anti-constructor that typically uses delete the operator on the data members that point to dynamic memory*

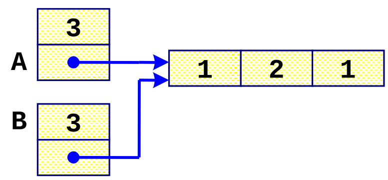
Why A Tailored Copy Constructor

- *Suppose we use the default copy constructor*

```
IntList A(3, 1);
IntList B(A);
```

- *And then*

```
A[2] = 2;
```



- *Then*
  - `B[2]` *is changed!*
  - *Not what a client would expect*
- *Implication*
  - *Must use tailored copy constructor*

Tailored Copy Constructor

```
IntList::IntList(const IntList
  &A) {
  NumberValues = A.size();
  Values = new int [size()];
  assert(Values);
  for (int i = 0; i < size(); ++i)
     Values[i] = A[i];
}
```

What kind of subscripting is being performed?

Gang Of Three

- *What happens when an IntList goes out of scope?*
  - *If there is nothing planned, then we would have a memory leak*
- *Need to have the dynamic memory automatically deleted*
  - *Define a destructor*
    - *A class object going out of scope automatically has its destructor invoked*

Notice the tilde

```
IntList::~IntList() {
   delete [] Values;
}
```

First Assignment Attempt

- *Algorithm*
  - *Return existing dynamic memory*
  - *Acquire sufficient new dynamic memory*
  - *Copy the size and the elements of the source object to the target element*

Initial Implementation (Wrong)

```
IntList& operator=(const IntList &A) {
  NumberValues = A.size();
  delete [] Values;
  Values = new int [NumberValues ];
  assert(Values);
  for (int i = 0; i < A.size(); ++i)
      Values[i] = A[i];
  return A;
}
```

- *Consider what happens with the code segment*

```
IntList C(5,1);
C = C;
```

This Pointer

- *Consider*
  - `this`
- *Inside a member function or member operator this is a pointer to the invoking object*

```
IntList::size() {
    return NumberValues;
}
```

or equivalently

```
IntList::size() {
    return this->NumberValues;
}
```

Member Assignment Operator

```
IntList& IntList::operator=(const
  IntList &A) {
  if (this != &A) {
     delete [] Values;
     NumberValues = A.size();
     Values = new int [A.size()];
     assert(Values);
     for (int i = 0; i < A.size(); ++i)
  {
        Values[i] = A[i];
     }
  }
  return *this;
}
```

Notice the different uses of the subscript operator

Why the asterisk?

Accessing List Elements

```
// Compute an rvalue (access
  constant element)
const int& IntList::operator[](int
  i) const {
  assert((i >= 0) && (i < size()));
  return Values[i];
}

// Compute an lvalue
int& IntList::operator[](int i) {
  assert((i >= 0) && (i < size()));
  return Values[i];
}
```

Stream Operators

- *Should they be members?*

```
class IntList {
  // ...
  ostream& operator<<(ostream &sout);
  // ...
};
```

- *Answer is based on the form we want the operation to take*

```
IntList A(5,1);
A << cout;  // member form (unnatural)
cout << A;  // nonmember form (natural)
```

Beware of Friends

- *If a class needs to*
  - *Can provide complete access rights to a nonmember function, operator, or even another class*
    - *Called a friend*
- *Declaration example*

```
class IntList {
  // ...
  friend ostream& operator<< (
     ostream &sout, const IntList &A);
  // ...
};
```

Implementing Friend <<

```
ostream& operator<<(ostream &sout,
 const IntList &A){
   sout << "[ ";
   for (int i = 0; i <
  A.NumberValues; ++i) {
       sout << A.Values[i] << " ";
   }
   sout << "]";
   return sout;
}
```

Is there any need for this friendship?

Proper << Implementation

```
ostream& operator<<(ostream
  &sout,
 const IntList &A){
   sout << "[ ";
   for (int i = 0; i < A.size();
  ++i) {
       sout << A[i] << " ";
   }
   sout << "]";
   return sout;
}
```