

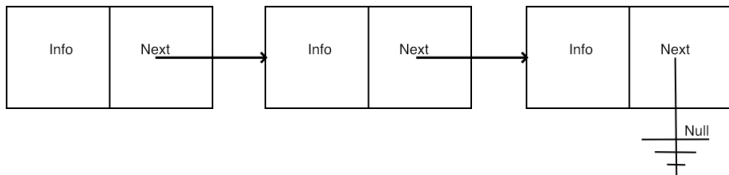
Smart Pointers

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Fall 2025

last formatted: October 29, 2025

1. Motivating application: linked list



- Used inside operating systems
- Model for complicated structures: trees, DAGs.

2. Recursive data structures

Naive code:

```
1 class Node {  
2 private:  
3     int value;  
4     Node tail; // This does not work!  
5     /* ... */  
6 };
```

This does not work: would take infinite memory.

Indirect inclusion: only 'point' to the tail:

```
1 class Node {  
2 private:  
3     int value;  
4     PointToNode tail;  
5     /* ... */  
6 };
```

3. Pointer types

- Smart pointers. You will see ‘shared pointers’.
- There are ‘unique pointers’. Those are tricky.
- Please don’t use old-style C pointers, unless you become very advanced.

4. Example: step 3: headers to include

Using smart pointers requires at the top of your file:

```
1 #include <memory>
2 using std::shared_ptr;
3 using std::make_shared;
4
5 using std::unique_ptr;
6 using std::make_unique;
```

(unique pointers will not be discussed further here)

5. Example: step 1, we need a class

Simple class that stores one number:

Definition:

```
1 // pointer/pointx.cpp
2 class HasX {
3 private:
4     double x;
5 public:
6     HasX( double x) : x(x) {};
7     auto value() { return x; };
8     void set(double xx) {
9         x = xx; };
10 };
```

Example usage

```
1 // pointer/pointx.cpp
2 HasX xobj(5);
3 println("{} ", xobj.value());
4 xobj.set(6);
5 println("{} ", xobj.value());
```

6. Example: step 2, creating the pointer

Allocation of object and pointer to it in one:

```
1 auto X = make_shared<HasX>( /* args */ );  
2  
3 // or explicitly:  
4  
5 shared_ptr<HasX> X =  
6     make_shared<HasX>( /* constructor args */ );
```

7. Use of a shared pointer

Object vs pointed-object:

Code:

```
1 // pointer/pointx.cpp
2 #include <memory>
3 using std::make_shared;
4
5     /* ... */
6     HasX xobj(5);
7     println("{} ", xobj.value());
8     xobj.set(6);
9     println("{} ", xobj.value());
10
11     auto xptr = make_shared<HasX>(5);
12     println("{} ", xptr->value());
13     xptr->set(6);
14     println("{} ", xptr->value());
```

Output:

```
1 5
2 6
3 5
4 6
```


8. Pointer dereferencing

Example: function

```
1 float distance_to_origin( Point p );
```

How do you apply that to a `shared_ptr<Point>`?

Use 'dereference' operator `*`:

```
1 shared_ptr<Point> p;  
2 distance_to_origin( *p );
```

Exercise 1

Make a *DynRectangle* class, which is constructed from two shared-pointers-to-*Point* objects:

```
1 // pointer/dynrectangle.cpp
2 auto
3   origin = make_shared<Point>(0,0),
4   fivetwo = make_shared<Point>(5,2);
5 DynRectangle lielow( origin,fivetwo );
```

Exercise 2

Test this design: Calculate the area, scale the top-right point, and recalculate the area:

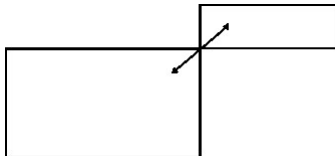
Code:

```
1 // pointer/dynrectangle.cpp
2 println( "Area: {}",lielow.area() );
3 /* ... */
4 println( "Area: {}",lielow.area() );
```

Output:

```
1 Area: 10
2 Area: 40
```

9. Illustration



Exercise 3

Make two *DynRectangle* objects so that the top-right corner of the first is the bottom-left corner of the other.

Now shift that point. Print out the two areas before and after to check correct behavior.

Automatic memory management

10. Memory leaks

C has a 'memory leak' problem

```
1 // the variable `array' doesn't exist
2 {
3     // attach memory to `array':
4     double *array = new double[N];
5     // do something with array;
6     // forget to free
7 }
8 // the variable `array' does not exist anymore
9 // but the memory is still reserved.
```

The application 'is leaking memory'.

(even worse if you do this in a loop!)

Java/Python have 'garbage collection': runtime impact

C++ has the best solution: smart pointers with reference counting.

11. Illustration

We need a class with constructor and destructor tracing:

```
1 // pointer/ptr1.cpp
2 class thing {
3 public:
4     thing() { cout << ".. calling constructor\n"; };
5     ~thing() { cout << ".. calling destructor\n"; };
6 };
```


12. Constructor / destructor in action

Code:

```
1 // pointer/ptr0.cpp
2 cout << "Outside\n";
3 {
4     thing x;
5     cout << "create done\n";
6 }
7 cout << "back outside\n";
```

Output:

```
1 Outside
2 .. calling
   ↪ constructor
3 create done
4 .. calling destructor
5 back outside
```

13. Illustration 1: pointer overwrite

Let's create a pointer and overwrite it:

Code:

```
1 // pointer/ptr1.cpp
2 cout << "set pointer1"
3     << '\n';
4 auto thing_ptr1 =
5     make_shared<thing>();
6 cout << "overwrite pointer"
7     << '\n';
8 thing_ptr1 = nullptr;
```

Output:

```
1 set pointer1
2 .. calling
   ↪ constructor
3 overwrite pointer
4 .. calling destructor
```

14. Illustration 2: pointer copy

Code:

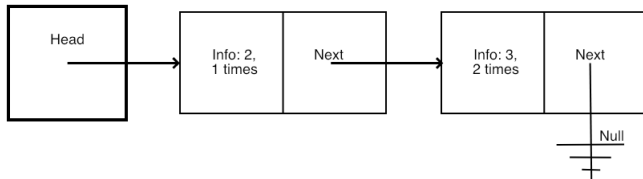
```
1 // pointer/ptr2.cpp
2 cout << "set pointer2" << '\n';
3 auto thing_ptr2 =
4     make_shared<thing>();
5 cout << "set pointer3 by copy"
6     << '\n';
7 auto thing_ptr3 = thing_ptr2;
8 cout << "overwrite pointer2"
9     << '\n';
10 thing_ptr2 = nullptr;
11 cout << "overwrite pointer3"
12     << '\n';
13 thing_ptr3 = nullptr;
```

Output:

```
1 set pointer2
2 .. calling
   ↪ constructor
3 set pointer3 by copy
4 overwrite pointer2
5 overwrite pointer3
6 .. calling destructor
```

Example: linked lists

15. Linked list



16. Definition of List class

A linked list has as its only member a pointer to a node:

```
1 // tree/linkshared.cpp
2 class List {
3 private:
4     shared_ptr<Node> head{nullptr};
5 public:
6     List() {};
```

Initially null for empty list.

17. Definition of Node class

A node has information fields, and a link to another node:

```
1 // tree/linkshared.cpp
2 class Node {
3 private:
4     int datavalue{0},datacount{0};
5     shared_ptr<Node> next{nullptr};
6 public:
7     Node() {};
```

8 Node(int value,shared_ptr<Node> next=nullptr)

9 : datavalue(value),datacount(1),next(next) {};

A Null pointer indicates the tail of the list.

18. List methods

List testing and modification.

```
1  List mylist;
2  cout << "Empty list has length: "
3      << mylist.length() << '\n';
4
5  mylist.insert(3);
6  cout << "After one insertion the length is: "
7      << mylist.length() << '\n';
8  if (mylist.contains_value(3))
9      cout << "Indeed: contains 3" << '\n';
```


19. Print a list

Auxiliary function so that we can trace what we are doing:
Print the list head. Print a node and its tail:

```
1 // tree/linkshared.cpp
2 void List::print() {
3     cout << "List:";
4     if (head!=nullptr)
5         cout << " => "; head->print();
6     cout << '\n';
7 };
```

```
1 // tree/linkshared.cpp
2 void Node::print() {
3     cout << datavalue << ":" <<
4         datacount;
5     if (has_next()) {
6         cout << ", "; next->print();
7     }
8 };
```

20. Recursive length computation

For the list:

```
1 // tree/linkshared.cpp
2 int List::length() {
3     if (head==nullptr)
4         return 0;
5     else
6         return head->length();
7 };
```

For a node:

```
1 // tree/linkshared.cpp
2 int Node::length() {
3     if (!has_next())
4         return 1;
5     else
6         return 1+next->length();
7 };
```

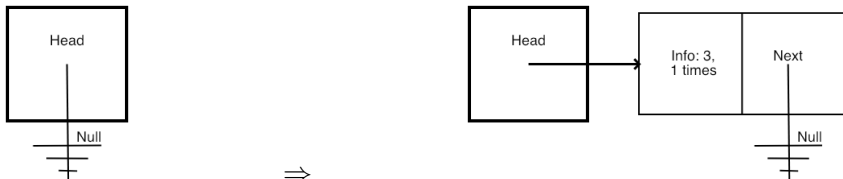
21. Iterative computation of the list length

Use a shared pointer to go down the list:

```
1 // tree/linkshared.cpp
2 int List::length_iterative() {
3     int count = 0;
4     if (head!=nullptr) {
5         auto current_node = head;
6         while (current_node->has_next()) {
7             current_node = current_node->nextnode(); count += 1;
8         }
9     }
10    return count;
11 };
```

(Fun exercise: can do an iterative de-allocate of the list?)

22. Creating the first list element

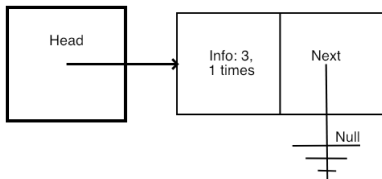


Exercise 4

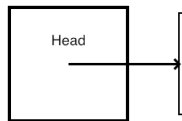
Next write the case of `Node::insert` that handles the empty list. You also need a method `List::contains` that tests if an item is in the list.

```
1 // tree/linkshared.cpp
2 mylist.insert(3);
3 cout << "After inserting 3 the length is: "
4     << mylist.length() << '\n';
5 if (mylist.contains_value(3))
6     cout << "Indeed: contains 3" << '\n';
7 else
8     cout << "Hm. Should contain 3" << '\n';
9 if (mylist.contains_value(4))
10    cout << "Hm. Should not contain 4" << '\n';
11 else
12    cout << "Indeed: does not contain 4" << '\n';
13 cout << '\n';
```

23. Elements that are already in the list



\Rightarrow

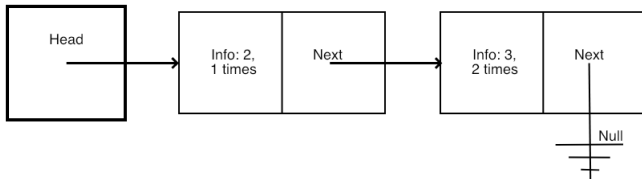


Exercise 5

Inserting a value that is already in the list means that the `count` value of a node needs to be increased. Update your `insert` method to make this code work:

```
1 // tree/linkshared.cpp
2 mylist.insert(3);
3 cout << "Inserting the same item gives length: "
4     << mylist.length() << '\n';
5 if (mylist.contains_value(3)) {
6     cout << "Indeed: contains 3" << '\n';
7     auto headnode = mylist.headnode();
8     cout << "head node has value " << headnode->value()
9         << " and count " << headnode->count() << '\n';
10 } else
11     cout << "Hm. Should contain 3" << '\n';
12 cout << '\n';
```

24. Element at the head

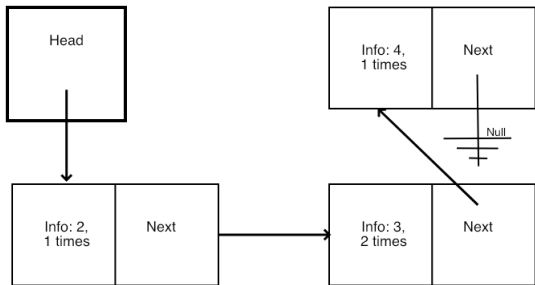


Exercise 6

One of the cases for inserting concerns an element that goes at the head. Update your `insert` method to get this to work:

```
1 // tree/linkshared.cpp
2 mylist.insert(2);
3 cout << "Inserting 2 goes at the head;\nnow the length is: "
4     << mylist.length() << '\n';
5 if (mylist.contains_value(2))
6     cout << "Indeed: contains 2" << '\n';
7 else
8     cout << "Hm. Should contain 2" << '\n';
9 if (mylist.contains_value(3))
10    cout << "Indeed: contains 3" << '\n';
11 else
12    cout << "Hm. Should contain 3" << '\n';
13 cout << '\n';
```

25. Element at the tail

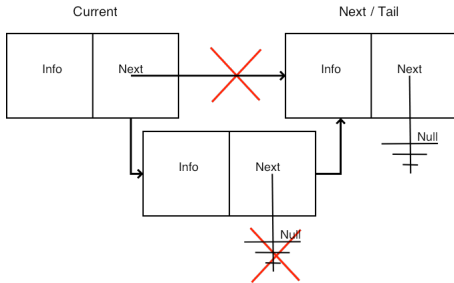
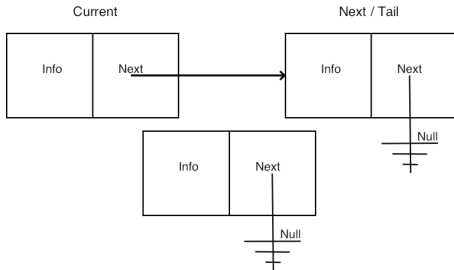


Exercise 7

If an item goes at the end of the list:

```
1 // tree/linkshared.cpp
2 mylist.insert(6);
3 cout << "Inserting 6 goes at the tail;\nnow the length is: "
4     << mylist.length()
5     << '\n';
6 if (mylist.contains_value(6))
7     cout << "Indeed: contains 6" << '\n';
8 else
9     cout << "Hm. Should contain 6" << '\n';
10 if (mylist.contains_value(3))
11     cout << "Indeed: contains 3" << '\n';
12 else
13     cout << "Hm. Should contain 3" << '\n';
14 cout << '\n';
```

26. Insertion



Exercise 8

Update your insert routine to deal with elements that need to go somewhere in the middle.

```
1 // tree/linkshared.cpp
2 mylist.insert(4);
3 cout << "Inserting 4 goes in the middle;\nnow the length is: "
4     << mylist.length()
5     << '\n';
6 if (mylist.contains_value(4))
7     cout << "Indeed: contains 4" << '\n';
8 else
9     cout << "Hm. Should contain 4" << '\n';
10 if (mylist.contains_value(3))
11     cout << "Indeed: contains 3" << '\n';
12 else
13     cout << "Hm. Should contain 3" << '\n';
14 cout << '\n';
```

27. Linked list exercise

Write a program that constructs a linked list where the elements are sorted in increasing numerical order.

Your program should accept a sequence of numbers from interactive input, and after each number print the list for as far as it has been constructed. Print the list on a single line, with elements separated by commas.

An input value of zero signals the end of input; this number is not added to the list.

Turn it in!

- If you have compiled your program, do:

```
coe_link yourprogram.cxx
```

where 'yourprogram.cxx' stands for the name of your source file.

- Is it reporting that your program is correct? If so, do:

```
coe_link -s yourprogram.cc
```

where the -s flag stands for 'submit'.

- If you don't manage to get your code working correctly, you can submit as incomplete with

```
coe_link -i yourprogram.cc
```