# Introduction to Linked Lists
# Introduction to Recursion
# Search Algorithms

CS 311 Data Structures and Algorithms

Lecture Slides

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# Unit Overview
# Advanced C++ & Software Engineering Concepts

## Major Topics: Advanced C++

- ✓ The structure of a package
- ✓ Parameter passing
- ✓ Operator overloading
- ✓ Silently written & called functions
- ✓ Pointers & dynamic allocation
- ✓ Managing resources in a class
- ✓ Templates
- ✓ Containers & iterators
- ✓ Error handling
- ✓ Introduction to exceptions
- Introduction to Linked Lists

## Major Topics: S.E. Concepts

- ✓ Abstraction
- ✓ Invariants
- ✓ Testing
- ✓ Some principles

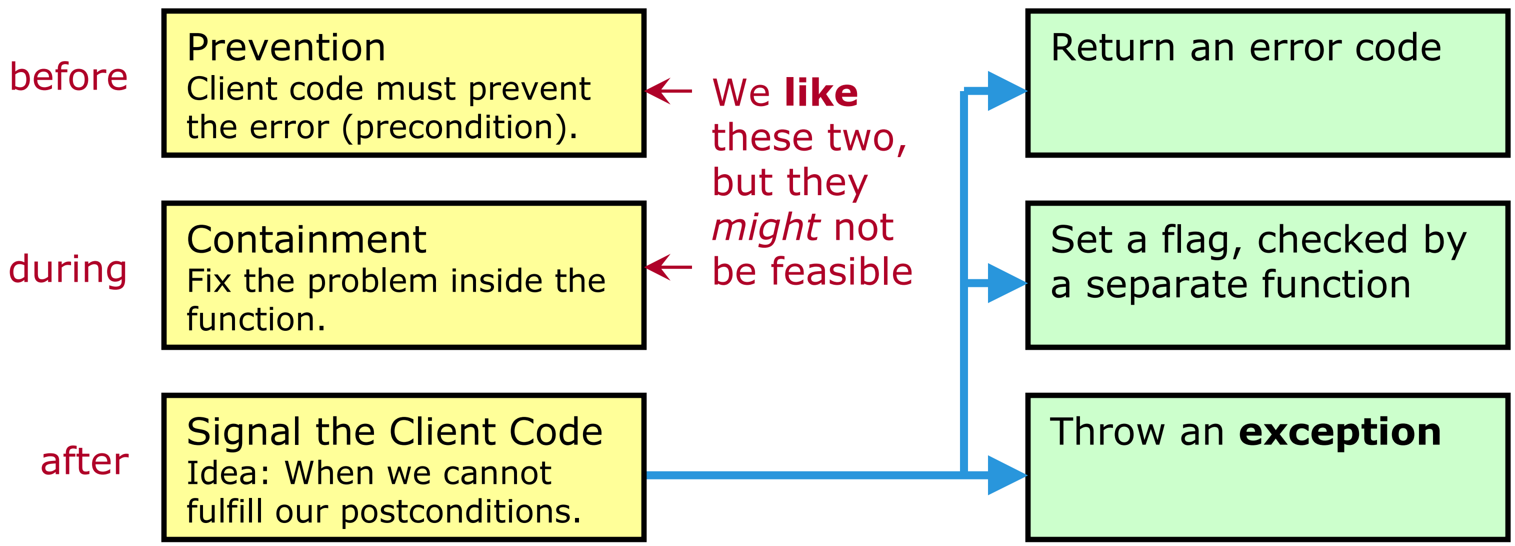
# Review
# Error Handling

An **error condition** (or "error") is a condition occurring during runtime that cannot be handled by the normal flow of execution.

- Not necessarily a bug or a user mistake.
- Example: Could not read file.

Three ways to deal with a *possible* error condition in a function:

Methods for signaling an error condition to the client code:



# Review
# Introduction to Exceptions — Catching

**Exceptions** are objects that are "**thrown**", generally to signal error conditions.

- We **catch** exceptions using a **`try`** … **`catch`** construction.
- "**`throw`**" backs out of blocks & functions, until a matching **`catch`** is found.
- An uncaught exception terminates the program.

```
Foo * makeAFoo() // throw(std::bad_alloc)
{ return new Foo(2, 3); }

void myFunc() // throw()
{
    Foo * p;
    try {
        p = makeAFoo();
    }
    catch (std::bad_alloc & e) {
        allocationSuccessful = false;
        cout << "Oops! Message: " << e.what() << endl;
    }
```

Commented-out **exception specifications**. If uncommented, these are legal C++; I do not recommend using them in release code.

Catch by reference

## Review
## Introduction to Exceptions — Throwing

We can throw our own exceptions, using "**throw**".

```
class Foo {
public:
    int & operator[](int index)  // May throw std::range_error
    {
        if (index < 0 || index >= arraySize)
            throw std::range_error("Foo: index out of range");
        return theArray[index];
    }
private:
    int * theArray;
    std::size_t arraySize;
};
```

**We do not do this very much.** And we only do it when we must signal the client code that an error condition has occurred.

## Review
## Introduction to Exceptions — Catch All & Re-Throw

We can catch **all** exceptions, using "`...`".

- In this case, we do not get to look at the exception, since we do not know what type it is.

```
try {
    myFunc4(17);
}
catch (...) {
    fixThingsUp();
    throw;
}
```

- Inside any **`catch`** block, we can **re-throw the same exception** using **`throw`** with no parameters.

## Review
## Introduction to Exceptions — Dctors

**Destructors generally should not throw.**

- Why? Destructors are called when an automatic object goes out of scope due to an exception. If such a destructor throws, then the program terminates.
- Another reason for this is that a throwing destructor says, “This object cannot be destroyed (now).” Thus, the function that created the object cannot exit, the program cannot end, etc.

## Review
## Introduction to Exceptions — Example 2

Last time, we did this:

- Write a function **`allocate1`** that:
  - Takes a **`size_t`**, indicating the size of an array to be allocated.
  - Attempts to allocate an array of **`int`**s, of the given size.
  - Returns a pointer to this array, using a reference parameter.
  - If the allocation fails, throws **`std::bad_alloc`**.
  - … and has no memory leaks.
- Write a function **`allocate2`** that:
  - Takes a **`size_t`**, the size of **two arrays** to be allocated.
  - Attempts to allocate **two arrays** of **`int`**s, both of the given size.
  - Returns pointer to these arrays, using reference parameters.
  - If the allocation fails, throws **`std::bad_alloc`**.
  - … and has no memory leaks.

*See* **`allocate2.cpp`***,*
*on the web page.*

## Review
## Introduction to Exceptions — Final Thoughts

When to Do Things:

- **Throw** when a function you are writing is unable to fulfill its postconditions.
- **Catch** when you can handle an error condition that may be signaled by some function you call.
  - Or simply to prevent a program from crashing.
- **Catch all and re-throw** when you call a function that may throw, you cannot handle the error, but you do need to do some clean-up before your function exits.

**Typically we do not do more than one of the above.**

- For example, someone else throws, and we catch.

Some people do not like exceptions.

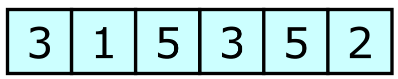
- A *bad reason* not to like exceptions is that they require lots of work.
  - Dealing with **error conditions** is a lot of work. Exceptions are one method of dealing with them. Handling exceptions properly is hard work simply because **writing correct, robust code is hard work**.
- A *good reason* might be that they add hidden execution paths.

# Introduction to Linked Lists
## Basics

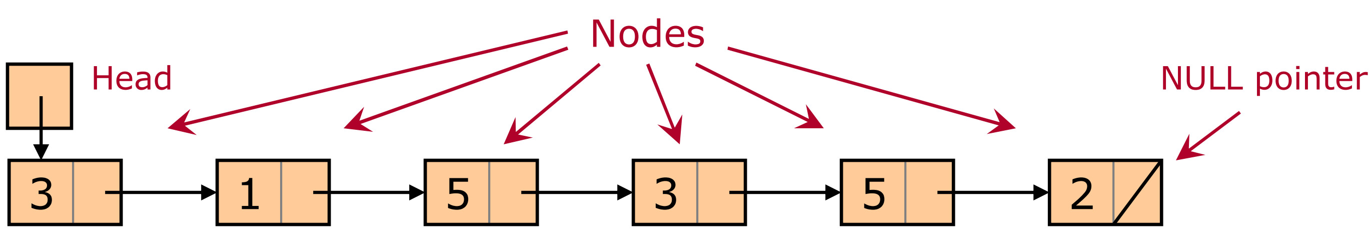
We now take a brief look at **Linked Lists**.

We discuss Linked Lists in detail later in the semester. For now:

- Like an array, a Linked List is a structure for storing a sequence of items.

Array 


- A Linked List is composed of **nodes**. Each has a single data item and a pointer to the next node.

Linked List 


- These pointers are the **only** way to find the next data item. Thus, unlike an array, we cannot quickly skip to (say) the 100th item in a Linked List. Nor can we quickly find the previous item.
- A Linked List is a one-way sequential-access data structure. Thus, its natural iterator is a **forward iterator**, which has only the **++** operator.

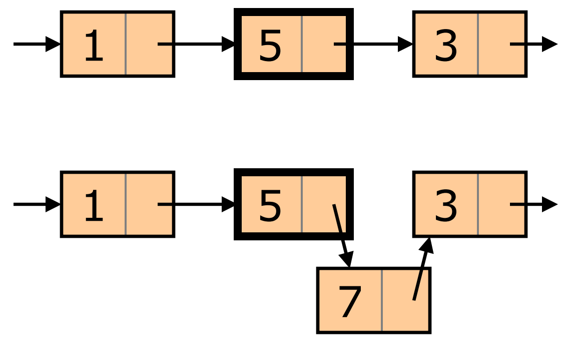
# Introduction to Linked Lists
## Advantages

Why not always use (smart) arrays?

- One important reason: we can often insert and remove much faster with a Linked List.

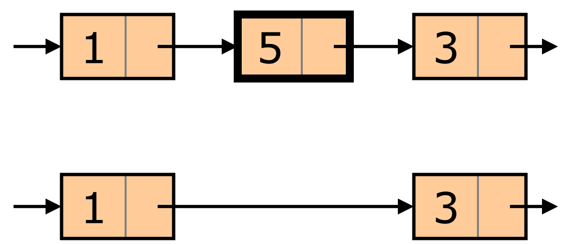
Inserting

- Inserting an item at a given position in an array is slow-ish.
- Inserting an item at a given position (think "iterator") in a Linked List is very fast.
- Example: insert a "7" after the bold node.




Removing

- Removing the item at a given position from an array *is also slow-ish.*
- Removing the item at a given position from a Linked List is very fast.
  - We need an iterator to the *previous* item.
- Example: Remove the item in the bold node.



## Introduction to Linked Lists
## Implementation

A Linked List node might be implemented like this.

```
template <typename ValueType>
struct LLNode {
    ValueType data_;  // Data for this node
    LLNode * next_;   // Ptr to next node, or NULL if none

    // The following simplify creation & destruction
    LLNode(const ValueType & theData, LLNode * theNext = 0)
        :data_(theData), next_(theNext)
    {}
    ~LLNode()
    { delete next_; }
};
```

Then the head of our list would keep an **(LLNode<…> *)**.

## Introduction to Linked Lists
## Write Something

TO DO

- Write a function to find the size (number of nodes) of a Linked List, given an **`(LLNode<…> *)`**.

*Done. See **`list_size.cpp`**, on the web page.*

# Unit Overview
# Recursion & Searching

We now begin a unit on recursion & searching.

Major Topics

- Introduction to Recursion
- Search Algorithms
- Recursion vs. Iteration
- Eliminating Recursion
- Recursive Search with Backtracking

We will follow the text a little more closely than we have been.

- Recursion & Searching material is in chapters 2 & 5.

After this, we will look at Algorithmic Efficiency & Sorting, covered in chapter 9.

## Introduction to Recursion
## Basics — Definition

A **recursive** algorithm is one that makes use of itself.

- An algorithm solves a problem. If we can write the solution of a problem in terms of the solutions to **simpler** problems of the same kind, then recursion may be called for.
- At some point, there needs to be a simplest problem, which we solve directly. This is the **base case**.

# Introduction to Recursion
## Basics — Four Questions

When designing a recursive algorithm or function, consider the following questions (text, page 68):

- How can you define the problem in terms of a smaller problem of the same type?
- How does each recursive call diminish the size of the problem?
- What instance of the problem can serve as the base case?
- As the problem size diminishes, will you reach this base case?

This is critical!

## Introduction to Recursion
## Sum Example — The Goal

We start with a (somewhat silly) example: Write a recursive function to find the sum of the first *n* integers, given *n*.

- So, given 3, we return 1 + 2 + 3 = 6.
- We look at this as practice in thinking about recursion. Then we will try a more serious example.

## Introduction to Recursion
## Sum Example — Four Questions

How can you define the problem in terms of a <u>smaller problem</u> of the same type?

- $1 + 2 + \ldots + n = [1 + 2 + \ldots + (n-1)] + n$.
- Say $f(n) = 1 + 2 + \ldots + n$. Then, $\boxed{\text{for n} > 0, \mathrm{f}(n) = \mathrm{f}(n-1) + n.}$
  - This is called a **recurrence relation**.

How does each recursive call diminish the size of the problem?

- It reduces by 1 the number of numbers to be summed.

What instance of the problem can serve as the base case?

- $n = 0$.
  - $n = 1$ would also have worked.

As the problem size diminishes, will you reach this base case?

- Yes, as long as $n$ is nonnegative.
- Therefore the statement "$n >= 0$" needs to be a **precondition**.

# Introduction to Recursion
## Sum Example — Specifications & Algorithm

Next we write **specifications**.

- Let's write a recursive function **`sumUpTo`** that takes a single **`int`** parameter and returns an **`int`**.
  - The parameter will be "*n*", and the return value will be the sum.
- Preconditions
  - $n >= 0$.
- Postconditions
  - Return == $1 + \ldots + n$.

The $\boxed{\text{recurrence relation}}$ turns into an **algorithm**.

- Are we in the base case? If so handle it.
  - If $n$ is 0, then return 0.
- Otherwise, recurse.
  - Recursive call, parameter: $n - 1$.
  - Add $n$ to the result.
  - Return this.

For $n > 0$,
$f(n) = f(n-1) + n$.

## Introduction to Recursion
## Sum Example — Coding

Now we write the actual code:

```
// sumUpTo
// Given n, return sum of integers 1 to n.
// Recursive.
// Pre: n >= 0.
// Post: Return == 1 + ... + n.
int sumUpTo(int n)
{
    if (n == 0)
        return 0;
    else
        return sumUpTo(n-1) + n;
}
```

How do we know we can make the recursive call?

- Hint: When we call a function, we must satisfy its preconditions.

# Introduction to Recursion
## Sum Example — Invariants

We know we can make the recursive call because we have an **invariant** that makes the preconditions for the call true:

```
// sumUpTo
// Given n, return sum of integers 1 to n.
// Recursive.
// Pre: n >= 0.
// Post: Return == 1 + ... + n.
int sumUpTo(int n)
{
    if (n == 0)
        return 0;
    else  // Invariant: n >= 1. (Therefore n-1 >= 0.)
        return sumUpTo(n-1) + n;
}
```

**Here** we have an invariant that says *n* ≥ 0 (the precondition).

**Here** we leave if *n* is exactly 0.
**Result**: If we stay, then *n* ≥ 1.

**This** is the precondition for **this** function call.

## Introduction to Recursion
## Sum Example — Iterative Version

Often we do not really need recursion:

```
// sumUpTo
// Given n, return sum of integers 1 to n.
// Pre: n >= 0.
// Post: Return == 1 + ... + n.
int sumUpTo(int n)
{
    int sum = 0;
    for (int i = 1; i <= n; ++i)
        sum += i;
    return sum;
}
```

This uses **iteration** (a loop) instead.

## Sum Example — Formula Version

And sometimes there is a not-so-obvious way to do things *much* faster:

```
// sumUpTo
// Given n, return sum of integers 1 to n.
// Pre: n >= 0.
// Post: Return == 1 + ... + n.
int sumUpTo(int n)
{
    return n * (n+1) / 2;
}
```

# Search Algorithms
# Binary Search Example — What is It?

The sum example from “Introduction to Recursion” was a little silly. Here is one that is not.

Binary Search

- How does it work?
- How would you implement it recursively?

# Binary Search Example — Method

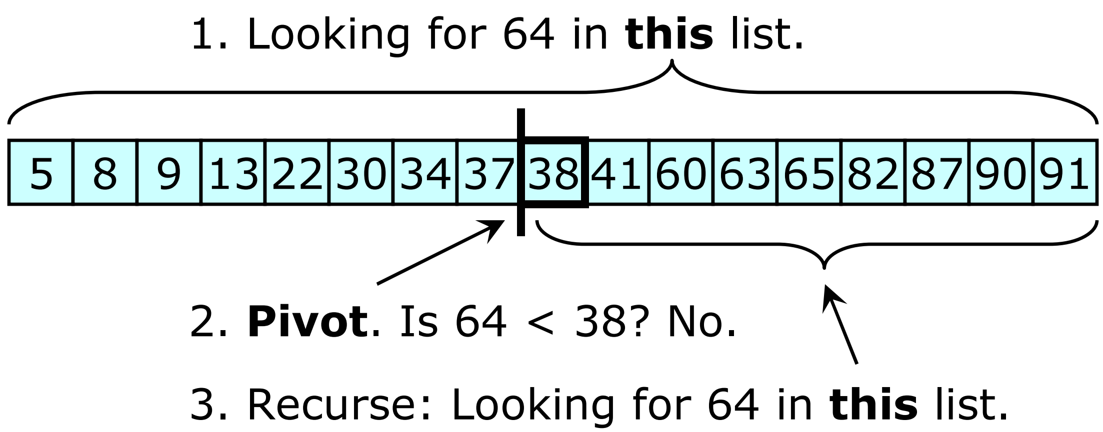
Binary Search is an algorithm to find a given **key** in a **sorted list**.

- Here, *key* = thing to search for. Often there is associated data.
- In computing, *sorted* = in (some) order.

Procedure

- Pick an item in the middle: the **pivot**.
- Use this to narrow search to top or bottom half of list. Recurse.

Example: Binary Search for 64 in the following list.



## Search Algorithms
## TO BE CONTINUED …

*Search Algorithms* will be continued next time.