Linked Lists

For something very important to you, would you rather rely on your own memory or computer memory?

(put your answers in the chat)
Roadmap

Object-Oriented Programming

- vectors + grids
- stacks + queues
- sets + maps

C++ basics

User/client

- diagnostics
- real-world algorithms

Life after CS106B!

Core Tools

- testing
- algorithmic analysis
- recursive problem-solving
Today’s question

How can we use pointers to organize non-contiguous memory on the heap?
Today’s topics

1. Review
2. What is a linked list?
3. How do we manipulate linked lists?
Review
[memory and pointers]
Levels of abstraction
How is computer memory organized?

0xfca0b000
Pointers and Memory

• Every variable you create has an address in memory on your computer (either on the stack or the heap).
Pointers and Memory

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- A pointer is just a type of variable that stores a memory address!
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- A pointer is just a type of variable that stores a memory address!
  - You specify the type of the variable that it points to so that C++ knows how much space the value its pointing to is taking up (e.g. `string*` or `int*` or `Vector*`).
Pointers and Memory

- Every variable you create has an address in memory on your computer (either on the stack or the heap).

- A pointer is just a type of variable that stores a memory address!
  - You specify the type of the variable that it points to so that C++ knows how much space the value its pointing to is taking up (e.g. string* or int* or Vector*).
  - But remember that pointers and what they point to (e.g. string vs. string*) are two completely different data types!
Pointers and Memory

- Every variable you create has an address in memory on your computer (either on the stack or the heap)

- A pointer is just a type of variable that stores a memory address!

- When you **dynamically allocate** variables on the heap, you must use the keyword `new` (or `new[]` for arrays) and must store the address in a pointer to keep track of it.
  - E.g. `int* number = new int;`
Pointers and Memory

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Dynamically allocated variables are the only reason we’ll use pointers in this class!
Pointers and Memory

- Every variable you create has an address in memory on your computer (either on the stack or the heap)

- A pointer is just a type of variable that stores a memory address!

- When you **dynamically allocate** variables on the heap, you must use the keyword `new` (or `new[]` for arrays) and must store the address in a pointer to keep track of it.

- To get the value located at the memory address stored in a pointer, you must **dereference** the pointer using the `*` operator (e.g. `cout << *number << endl;`).
Pointer Fun with Binky: a Stanford CS106 Throwback

- Nick Parlante has been teaching intro CS classes at Stanford for many years.
- In 1999, he created a stop-motion claymation video starring a character named Binky that has been a staple of explaining pointers in intro CS classes at Stanford ever since.
\*y = 13;
Today: Using pointers in practice
Today: Using pointers in practice

How can we use pointers to organize non-contiguous memory on the heap?
Today: Using pointers in practice

How can we use pointers to organize *non-contiguous* memory on the heap? Not arrays!
Levels of abstraction

What is the interface for the user?

How is our data organized?

What stores our data?
(arrays, linked lists)

How is data represented electronically?
(RAM)

Abstract Data Structures

Data Organization Strategies

Fundamental C++ Data Storage

Computer Hardware
Levels of abstraction

What is the interface for the user?

How is our data organized?

What stores our data? (arrays, linked lists)

How is data represented electronically? (RAM)

Pointers move us across this boundary!

Abstract Data Structures

Data Organization Strategies

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Computer Hardware
What is the interface for the user?

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What stores our data? (*arrays*, *linked lists*)

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---

Levels of abstraction

Abstract Data Structures

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Computer Hardware

These are built on top of pointers!
Levels of abstraction

What is the interface for the user?

How is our data organized?

What stores our data? (arrays, linked lists)

How is data represented electronically? (RAM)

Our focus for today!

Abstract Data Structures

Data Organization Strategies

Fundamental C++ Data Storage

Computer Hardware
What is a linked list?
What is a linked list?

- A linked list is a **chain of nodes**.
What is a linked list?

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- Each **node** contains two pieces of information:
  - Some piece of data that is stored in the sequence
  - A link to the next node in the list
What is a linked list?

- A linked list is a **chain of nodes**.

- Each **node** contains two pieces of information:
  - Some piece of data that is stored in the sequence
  - A link to the next node in the list

- We can traverse the list by starting at the first node and repeatedly following its link.
Node

Data

Link
Pointer to a node

ptr

Data

Link

0xfca0b000
Pointer to a node that points to a node
Pointer to a node that points to a node that points to a node
Pointer to a node that points to a node that points to a node
A linked list!

- **ptr**: 0xfca0b000
- **Data**
  - **Link**
- **Data**
  - **Link**
- **Data**
  - **Link**
- **NULL**
A linked list

Data
Link

0xfca0b000
ptr

Data
Link

Data
Link

PT
R

TIL a California man got 'NULL' as a personalized license plate hoping that 'NULL' would confuse the computer system. Instead, when cops left the plate number info empty on a ticket or citation, the fine went to him. He got over $12k fines sent to him his first year.
Why use linked lists?

- More flexible than arrays!
  - Since they’re not contiguous, they’re easier to rearrange.

- We can efficiently splice new elements into the list or remove existing elements anywhere in the list. (We’ll see how shortly!)

- We never have to do a massive copy step.

- Linked lists have many tradeoffs, and are not often the best data structure!
Linked lists in C++
The \textbf{Node} struct

\begin{verbatim}
struct Node {
    string data;
    Node* next;
}
\end{verbatim}
The **Node** struct

```c
struct Node {
    string data;
    Node* next;
};
```

- The structure is defined recursively! (both the Node and the linked list itself)
The **Node** struct

```c
struct Node {
    string data;
    Node* next;
}
```

- The structure is defined recursively! (both the Node and the linked list itself)
- The compiler can handle the fact that in the definition of the **Node** there is a **Node*** because it knows it is simply a pointer.
  - (It would be impossible to recursively define the **Node** with an actual **Node** object inside the struct.)
Node* list = new Node;
Node* list = new Node;

How do we update these values (i.e., the Node itself)?
Node* list = new Node;
(*list).data = "someData";
Node* list = new Node;
(*list).data = "someData";

Use * to dereference the pointer to get the Node struct.
Node* list = new Node;
(*list).data = "someData";

Use dot (.) notation to update the data field of the struct.
Node* list = new Node;
(*list).data = "someData";
(*list).next = nullptr;
```c
Node* list = new Node;
(*list).data = "someData";
(*list).next = nullptr;
```

There's an easier way!
Node* list = new Node;
list->data = "someData";
list->next = nullptr;
Pointer to a node

Node* list = new Node;
list->data = "someData";
list->next = nullptr;

The arrow notation (->) dereferences AND accesses the field for pointers that point to structs specifically.
Node* list = new Node;
(*list).data = "someData";
(*list).next = nullptr;

Node* list = new Node;
list->data = "someData";
list->next = nullptr;
Announcements
Announcements

- Assignment 4 is due tomorrow **Tuesday, July 27 at 11:59pm PDT.**
  - As a reminder, LaIR is happening today from **5-7pm PDT and Tuesday 7-9pm PDT.**
  - If you've encountered any bugs in A4, we encourage you to come to LaIR tonight or tomorrow!
  - When you submit A4, you'll be redirected to our **Mid-Quarter Evaluation.** This is a comprehensive form that will ask for your feedback about CS106B and the course staff.

- Diagnostic regrade requests are due **today at 11:59pm PDT.**
How do we manipulate linked lists?
Common linked lists operations

- **Traversal**
  - How do we walk through all elements in the linked list?

- **Rewiring**
  - How do we rearrange the elements in a linked list?

- **Insertion**
  - How do we add an element to a linked list?

- **Deletion**
  - How do we remove an element from a linked list?
Implementing a Stack

Note: You could do this with an array! This is just for the sake of getting practice with linked lists.
Stack as a linked list

- We’ll keep a pointer `Node* top` that points to the “top” element in our stack.
  - This member var will get initialized to `nullptr` when our stack is empty!
Stack as a linked list

● We’ll keep a pointer `Node* top` that points to the “top” element in our stack.
  ○ This member var will get initialized to `nullptr` when our stack is empty!

● Our linked list nodes will be connected from the top to the bottom of our stack.
Stack as a linked list

- We’ll keep a pointer `Node* top` that points to the “top” element in our stack.
  - This member var will get initialized to `nullptr` when our stack is empty!

- Our linked list nodes will be connected from the top to the bottom of our stack.

- Our stack will specifically hold integers, so our `Node` struct will hold an `int` type for our `data` field:

```c
struct Node {
    int data;
    Node* next;
}
```
Three Stack operations

- push()
- pop()
- Destructor
Three Stack operations

- push()
- pop()
- Destructor
Common linked lists operations

- **Traversal**
  - How do we walk through all elements in the linked list?

- **Rewiring**
  - How do we rearrange the elements in a linked list?

- **Insertion (at the front)**
  - How do we add an element to a linked list?

- **Deletion**
  - How do we remove an element from a linked list?
push()

- Suppose we have the following Stack we want to push to:

```java
Stack myStack = {9, 8}; // 8 is at the "top" of the stack
myStack.push(7); // we want the result to be {9, 8, 7}
```
push()

- Suppose we have the following Stack we want to push to:

```java
Stack myStack = {9, 8}; // 8 is at the "top" of the stack
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How our linked list starts:
push()

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```java
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```

Goal:
push()

How our linked list starts:

Goal:
Let’s code push()!
Initial State (beginning of \textbf{push()} function)
Node*  

```plaintext
top  
```
Node *temp = new Node;
temp->data = 7;
Node *temp = new Node;
temp->data = 7;
top = temp; // INCORRECT
Node *temp = new Node;
temp->data = 7;
temp->next = top;
Node *temp = new Node;
temp->data = 7;
temp->next = top;
top = temp;
Three Stack operations

- push()
- pop()
- Destructor
Common linked lists operations

- **Traversal**
  - How do we walk through all elements in the linked list?

- **Rewiring**
  - How do we rearrange the elements in a linked list?

- **Insertion**
  - How do we add an element to a linked list?

- **Deletion**
  - How do we remove an element from a linked list?
Now we want to remove the top value:

```java
myStack.pop(); // we want the result to be {9, 8}
```
pop()

- Now we want to remove the top value:

  ```java
  ...  
  myStack.pop(); // we want the result to be {9, 8}
  ```

Goal:
Let’s code `pop()`!
Initial State (beginning of \texttt{pop()} function)
top = top->next;  // INCORRECT
Node* temp = top;
Node* temp = top;
top = top->next;
delete temp;
Three Stack operations

- `push()`
- `pop()`
- `Destructor`
Common linked lists operations

- **Traversal**
  - How do we walk through all elements in the linked list?

- **Rewiring**
  - How do we rearrange the elements in a linked list?

- **Insertion**
  - How do we add an element to a linked list?

- **Deletion**
  - How do we remove an element from a linked list?
Destructor

- We have to make sure we delete all of the Node.
- The top pointer should be nullptr when we’re done.
Let’s code the destructor!
Summary
Linked lists summary

- Linked lists are chains of Node structs, which are connected by pointers.
  - Since the memory is not contiguous, they allow for fast rewiring between nodes (without moving all the other Nodes like an array might).
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- Common traversal strategy
  - While loop with a pointer that starts at the front of your list
  - Inside the while loop, reassign the pointer to the next node
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- Common traversal strategy
  - While loop with a pointer that starts at the front of your list
  - Inside the while loop, reassign the pointer to the next node

- Common bugs
  - Be careful about the order in which you delete and rewire pointers!
  - It’s easy to end up with dangling pointers or memory leaks (memory that hasn’t been deallocated but that you not longer have a pointer to)
What’s next?
Roadmap

Object-Oriented Programming

- C++ basics
- User/client
  - vectors + grids
  - stacks + queues
  - sets + maps

Core Tools
- testing
- algorithmic analysis
- recursive problem-solving

Implementation
- arrays
- dynamic memory management
- linked data structures
- real-world algorithms

Life after CS106B!

More on linked lists!

Okay, Human.

Huh?

Before you hit 'compile', listen up.

You know when you're falling asleep, and you imagine yourself walking or something.

And suddenly you misstep, stumble, and jolt awake?

Yeah!

Well, that's what a segfault feels like.

Double-check your darn pointers, okay?