Linked Lists
Part Two
Recap from Last Time
Linked Lists at a Glance

- A **linked list** is a data structure for storing a sequence of elements.
- Each element is stored separately from the rest.
- The elements are then chained together into a sequence.
Representing a Cell

• For simplicity, let's assume we're building a linked list of strings.

• We can represent a cell in the linked list as a structure:

```cpp
struct Cell {
    string value;
    Cell* next;
};
```

• The structure is defined recursively!
A Linked List is Either...

...an empty list, represented by `nullptr`, or...

...at another linked list.

A single linked list cell that points...
Traversing a Linked List

• Once we have a linked list, we can traverse it by following the links one at a time.

```c
for (Cell* ptr = list; ptr != nullptr; ptr = ptr->next) {
    /* … use ptr … */
}
```
Traversing a Linked List

- Once we have a linked list, we can traverse it by following the links one at a time.

```c
for (Cell* ptr = list; ptr != nullptr; ptr = ptr->next) {
    /* … use ptr … */
}
```

[Diagram of a linked list with nodes labeled 1, 2, 3, 4, and an arrow pointing to the last node with a forbidden symbol.]
Traversing a Linked List

- Once we have a linked list, we can traverse it by following the links one at a time.

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for (Cell* ptr = list; ptr != nullptr; ptr = ptr->next) {
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for (Cell* ptr = list; ptr != nullptr; ptr = ptr->next) {
    /* ... use ptr ... */
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```
A Linked List is Either...

...an empty list, represented by `nullptr`, or...

...a single linked list cell that points...

...at another linked list.
New Stuff!
Cleaning Up Our Messes
Freeing a Linked List

• All good things must come to an end, and we eventually need to reclaim the memory for a linked list.

• The following code triggers *undefined behavior*. *Don’t do this!*

```cpp
for (Cell* ptr = list; ptr != nullptr; ptr = ptr->next) {
    delete ptr;
}
```
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• The following code triggers *undefined behavior*. **Don’t do this!**

```cpp
for (Cell* ptr = list; ptr != nullptr; ptr = ptr->next) {
    delete ptr;
}
```

```plaintext
 ptr ➔ ???
```
Freeing a Linked List Properly

• To properly free a linked list, we have to be able to
  • Destroy a cell, and
  • Advance to the cell after it.
• How might we accomplish this?
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
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    list = next;
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    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}

quokka!  dikdik!
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
```c++
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
```
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
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    delete list;
    list = next;
}
while (list != nullptr) {
    Cell* next = list->next;
    delete list;
    list = next;
}

list
A Linked List is Either...

...an empty list, represented by `nullptr`, or...

A single linked list cell that points... ...at another linked list.
Linked Lists: The Tricky Parts

• Suppose that we want to write a function that will add an element to the front of a linked list.

• What might this function look like?
What went wrong?
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");

    return 0;
}
```c
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");

    return 0;
}
```
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}

list
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");

    return 0;
}

list
```c
int main() {
    void listInsert(Cell* list, const string& value) {
        Cell* newCell = new Cell;
        newCell->value = value;
        newCell->next = list;
        list = newCell;
    }
    list = NULL;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}
```
int main() {
    listInsert(Cell* list, const string& value) {
        Cell* newCell = new Cell;
        newCell->value = value;
        newCell->next = list;
        list = newCell;
    }
}

list value "A"
```cpp
void listInsert(Cell* list, const string& value) {
    Cell* newCell = new Cell;
    newCell->value = value;
    newCell->next = list;
    list = newCell;
}
```
```c
int main() {
    void listInsert(Cell* list, const string& value) {
        Cell* newCell = new Cell;
        newCell->value = value;
        newCell->next = list;
        list = newCell;
    }
```
```c
int main() {
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}
```
```c
int main() {
    Cell* list = NULL;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}

void listInsert(Cell* list, const string& value) {
    Cell* newCell = new Cell;
    newCell->value = value;
    newCell->next = list;
    list = newCell;
}
```
int main() {
    void listInsert(Cell* list, const string& value) {
        Cell* newCell = new Cell;
        newCell->value = value;
        newCell->next = list;
        list = newCell;
    }

    list = NULL;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}
int main() {
    Cell* list = NULL;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
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void listInsert(Cell* list, const string& value) {
    Cell* newCell = new Cell;
    newCell->value = value;
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}
```c
int main() {
    void listInsert(Cell* list, const string& value) {
        Cell* newCell = new Cell;
        newCell->value = value;
        newCell->next = list;
        list = newCell;
    }
    Cell* list = NULL;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}
```
```cpp
int main() {
    void listInsert(Cell* list, const string& value) {
        Cell* newCell = new Cell;
        newCell->value = value;
        newCell->next = list;
        list = newCell;
    }

    Cell* list = NULL;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");
    return 0;
}
```
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");

    return 0;
}

list

"A"
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");

    return 0;
}

Why does nobody love me?
Pointers by Reference

• To resolve this problem, we can pass the linked list pointer by reference.

• Our new function:

```cpp
void listInsert(Cell*& list, const string& value) {
    Cell* newCell = new Cell;
    newCell->value = value;
    newCell->next = list;
    list = newCell;
}
```
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```cpp
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    Cell* newCell = new Cell;
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Pointers by Reference

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• Our new function:

```c
void listInsert(Cell*& list, const string& value) {
    Cell* newCell = new Cell;
    newCell->value = value;
    newCell->next = list;
    list = newCell;
}
```

This is a reference to a pointer to a Cell. If we change where list points in this function, the changes will stick!
```c
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
    listInsert(list, "B");
    listInsert(list, "C");

    return 0;
}
```
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
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}
```

### listInsert

```c
void listInsert(Cell*& list, const string& value) {
    Cell* newCell = new Cell;
    newCell->value = value;
    newCell->next = list;
    list = newCell;
}
```
```c
int main() {
    Cell* list = nullptr;
    listInsert(list, "A");
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}
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int main() {
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    listInsert(list, "C");

    return 0;
}
```
Pointers by Reference

- If you pass a pointer into a function by value, you can change the contents at the object you point at, but not which object you point at.

- If you pass a pointer into a function by reference, you can also change which object is pointed at.
Time-Out for Announcements!
Assignment 5

- Assignment 5 (*Priority Queue*) goes out today. It’s due next Friday at the start of class.
- It’s a four-parter, and we’ve included a timetable on the front of the assignment.
  - *Start this assignment as soon as you get it!* You’ll have plenty of time to finish everything, but not if you put it off to the last minute.
- Working in pairs is permitted – and encouraged! – on this assignment.
- Anton will be holding YEAH hours tomorrow evening. We’ll announce the time and location on Piazza and over email.
Stanford Women in Computer Science

CASUAL CS DINNER

Monday, February 27 from 6-7 PM at the WCC
RSVP link here!

Come have dinner with CS students and faculty. Everyone is welcome, especially students just starting out in CS!
Midterm Timetable

• You’re done with the midterm exam! Woohoo!
• We’ll be grading it over the weekend and returning graded exams on Monday along with stats and solutions.
• Have any questions in the meantime? Just ask!
Back to Linked Lists!
Tail Pointers

• A tail pointer is a pointer to the last element of a linked list.

• Tail pointers make it easy and efficient to add new elements to the back of a linked list.

• We can use tail pointers to implement an efficient Queue using a linked list.
Tail Pointers

- A **tail pointer** is a pointer to the last element of a linked list.
- Tail pointers make it easy and efficient to add new elements to the back of a linked list.
- We can use tail pointers to implement an efficient `Queue` using a linked list.
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- Tail pointers make it easy and efficient to add new elements to the back of a linked list.
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- We can use tail pointers to implement an efficient Queue using a linked list.
Enqueueing Things

- **Case 1:** The queue is empty.
Enqueuing Things

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- **Case 1:** The queue is empty.
Enqueuing Things

- **Case 1:** The queue is empty.

- **Case 2:** The queue is not empty.
Enqueuing Things

- **Case 1:** The queue is empty.

- **Case 2:** The queue is not empty.
Enqueuing Things

- **Case 1:** The queue is empty.

- **Case 2:** The queue is not empty.
Enqueuing Things

- **Case 1:** The queue is empty.

- **Case 2:** The queue is not empty.
Dequeuing Things

- **Case 1:** Dequeuing when there are 2+ elements.
Dequeuing Things

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**Dequeuing Things**

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Dequeuing Things

- **Case 1:** Dequeuing when there are 2+ elements.

- **Case 2:** Dequeuing the last element.
Dequeuing Things

- **Case 1:** Dequeuing when there are 2+ elements.

- **Case 2:** Dequeuing the last element.
Analyzing Efficiency

- What is the big-O complexity of a dequeue?
  - Answer: $O(1)$.

- What is the big-O complexity of an enqueue?
  - Answer: $O(1)$. 