Linked Lists 1

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July 31, 2023

Contributions made from previous CS106B Instructors

Stanford University

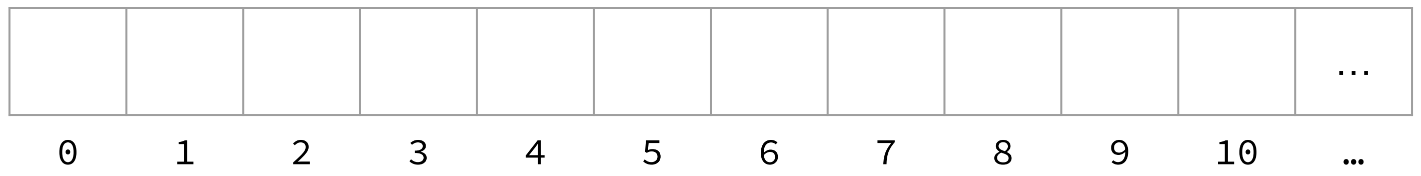
Announcements

- Assignment 3 IGs this week
  - IG attendance is part of section participation grade
- Assignment 4 due this Wednesday at 11:59pm
  - Draws heavily from last week’s lectures
  - Lecture 17 is a conceptual walkthrough of what you’ll be implementing

Recap: Pointers

How is computer memory organized?

- Memory in your computer is just a giant array!
  - Can think of it as a long row of boxes, with each box having a value in it and an associated index



- How can we communicate with the computer to find exactly which box we want to access/store information in?
  - We'll give each box an associated numerical location, called a **memory address**

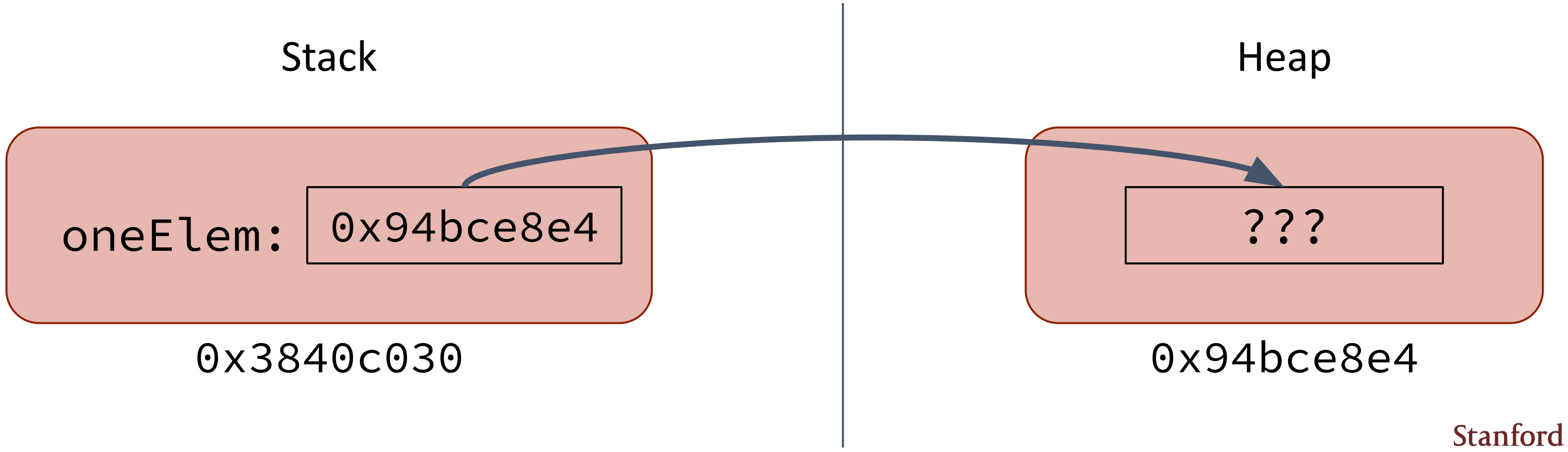
What is a pointer?

A memory address!!

Pointer Syntax

- Pointers are necessary to store the value generated by the new keyword (which is just a memory address on the heap)

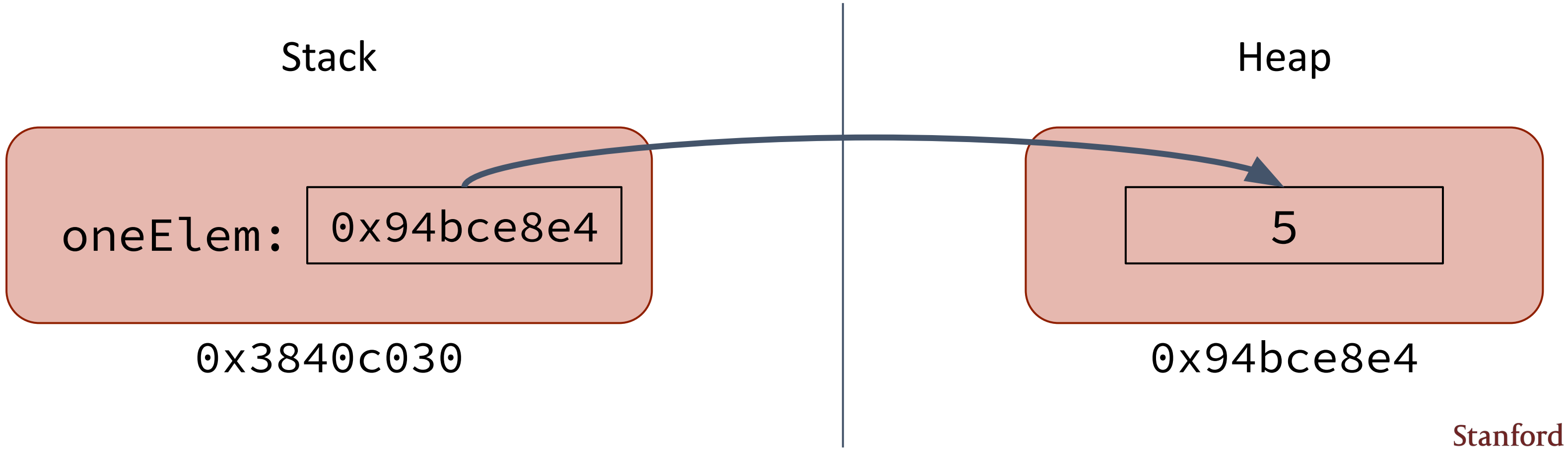
```
int* oneElem = new int;
```



Pointer Syntax

- To read or modify the variable that a pointer points to, we use the `*` (asterisk) operator (in a different way than before!)
- Known as **dereferencing the pointer**
- Follow the arrow to the memory location

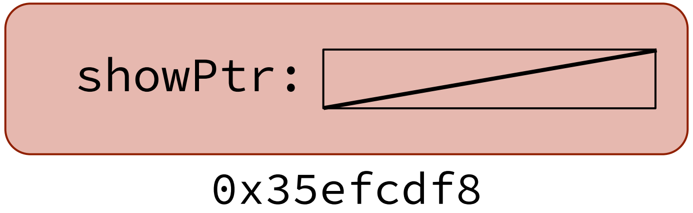
```
*oneElem = 5;
```



`nullptr`

- When we declare/initialize a pointer but don’t have anything to point it at yet, that can be dangerous and unpredictable
- To ensure that we can tell if a pointer has a valid address or not, set your declared pointer to `nullptr`, which means "no valid address"

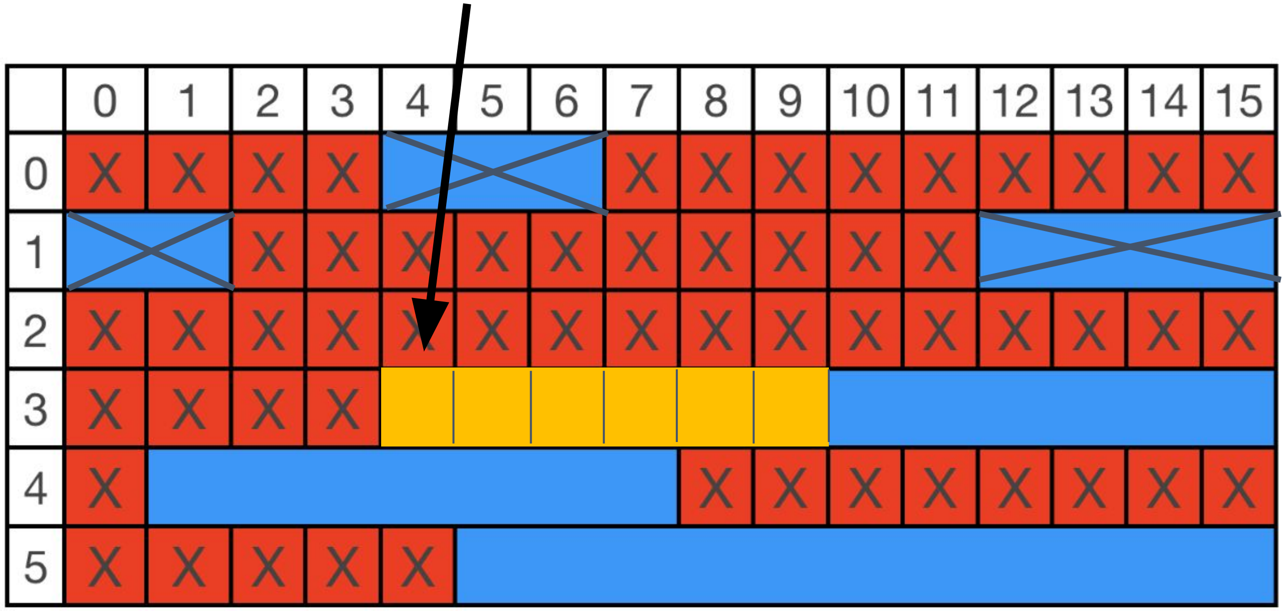
```
string* showPtr = nullptr;
```



Under the Hood

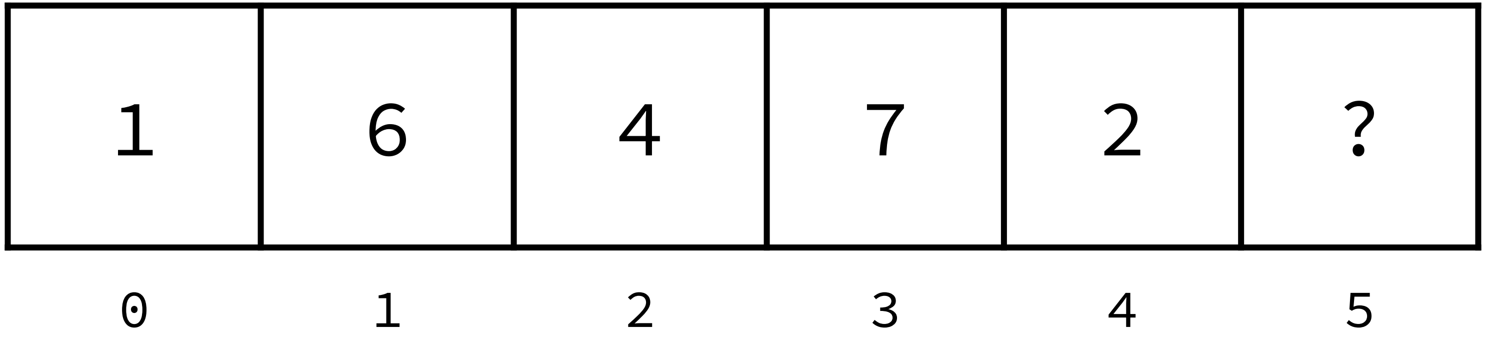
Arrays are ***contiguous*** chunks of space in the computer's memory

```
int* sixInts = new int[6];
```



Frustrations with Arrays

- Not easily resizable
- Not efficient to insert elements at the beginning



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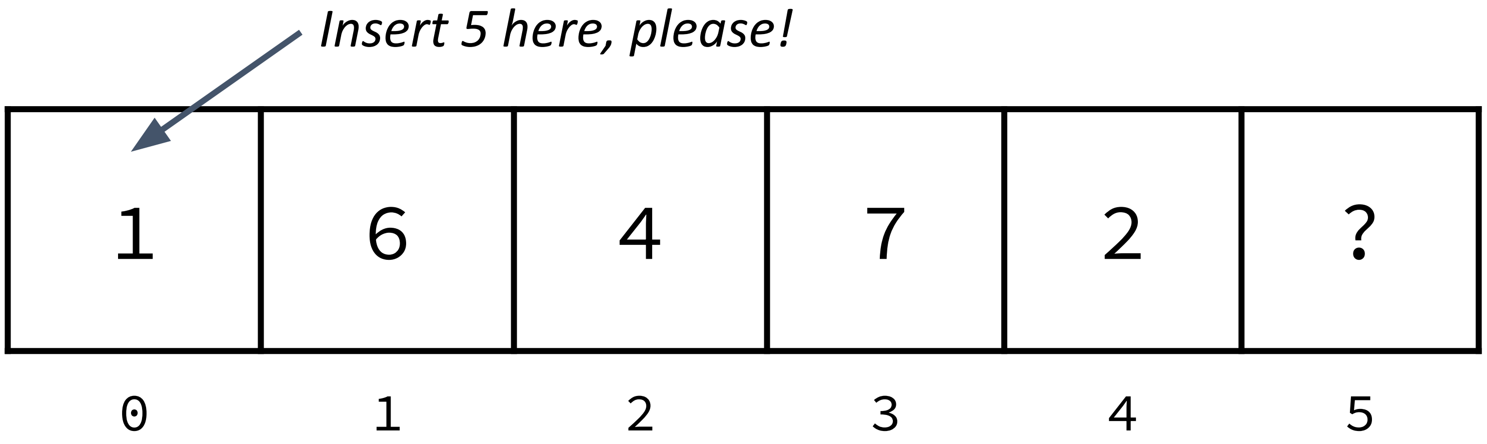

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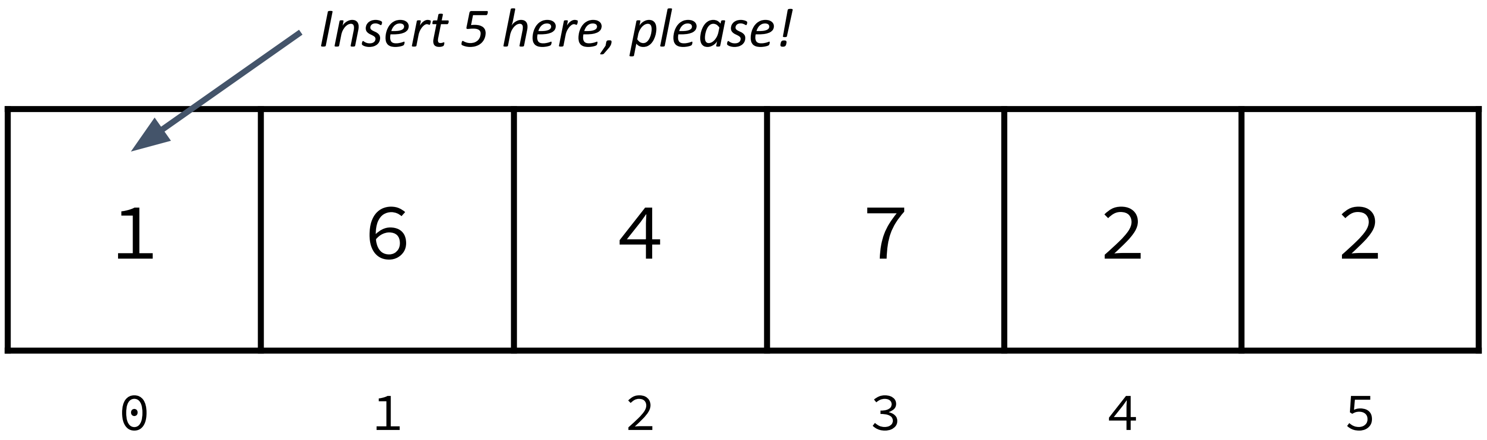

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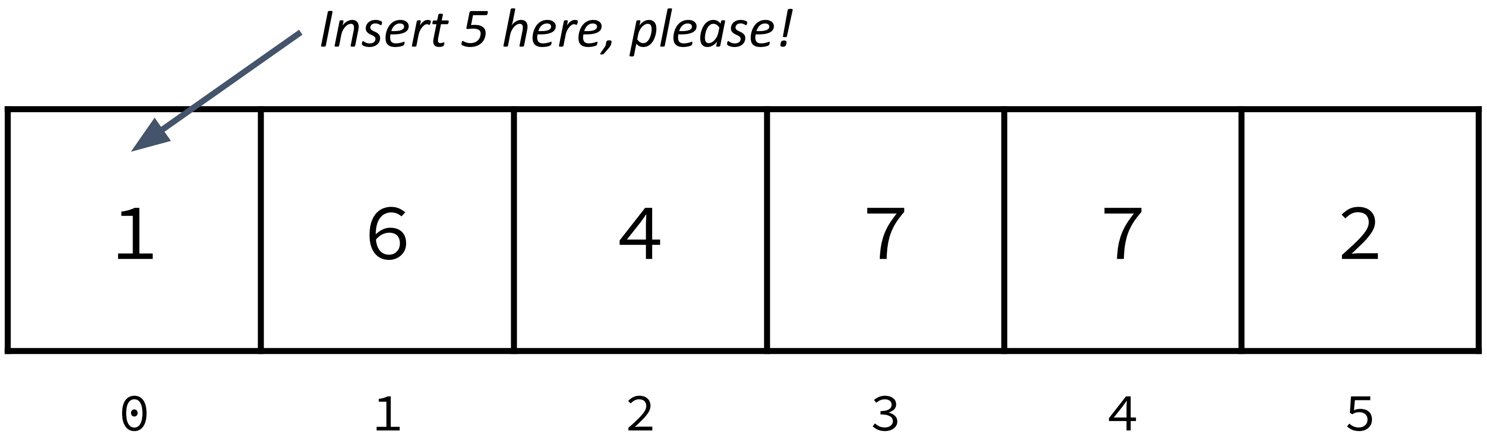

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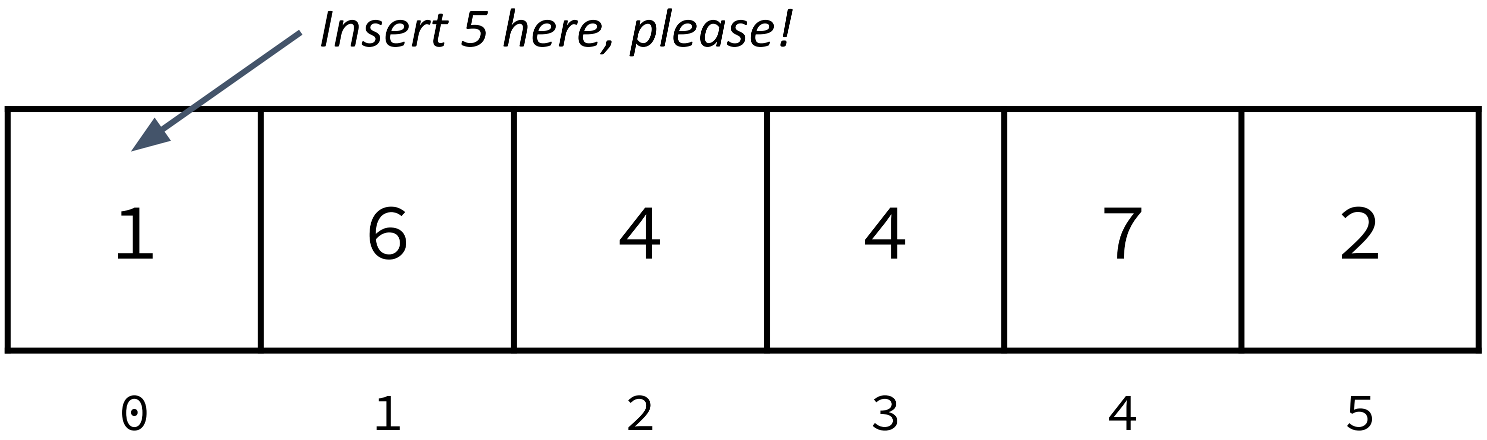

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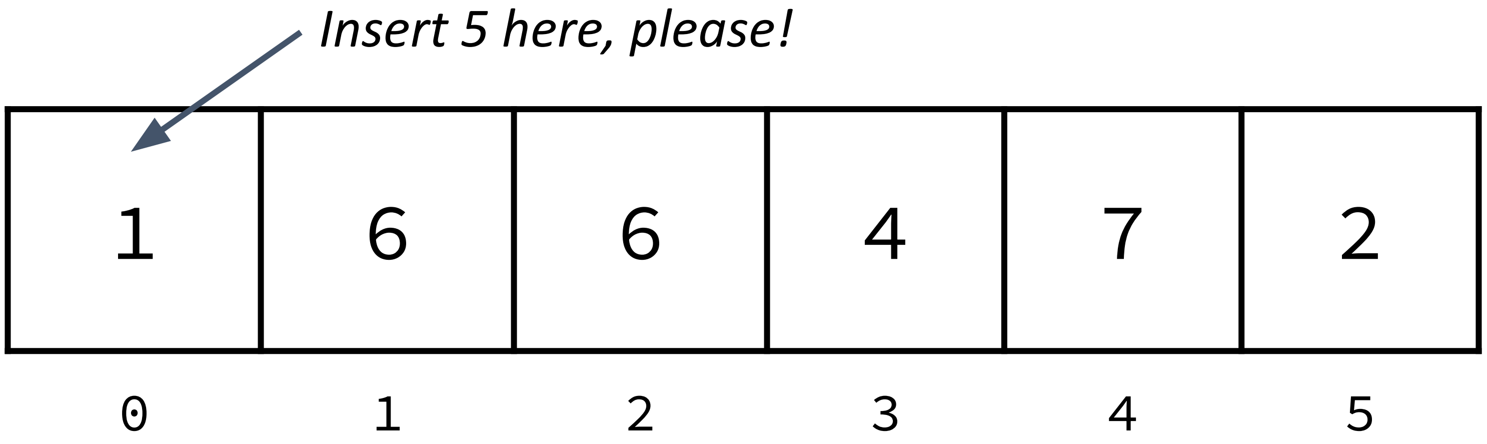

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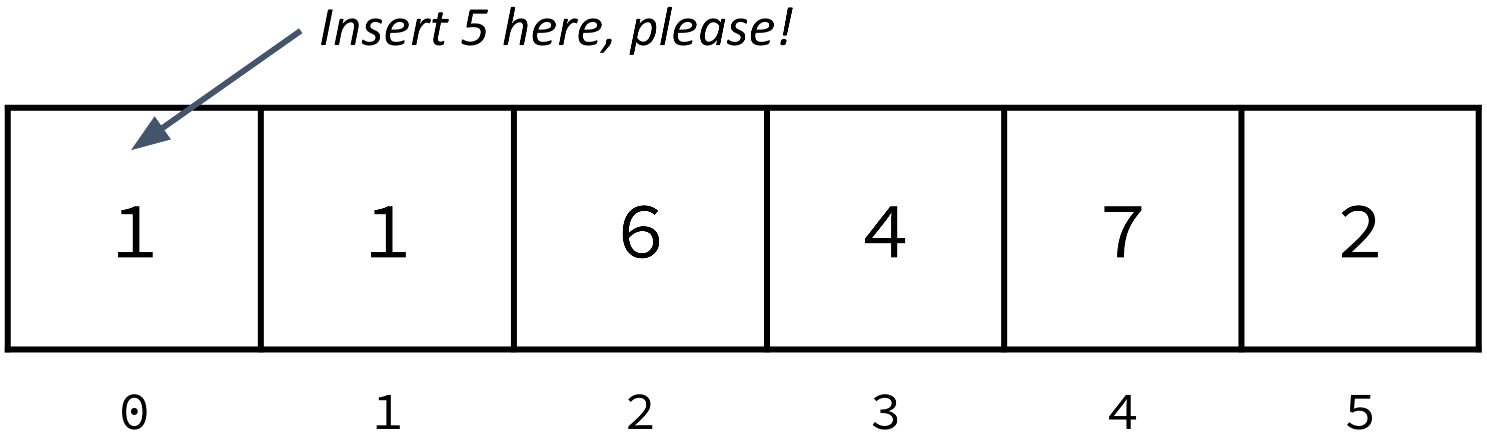

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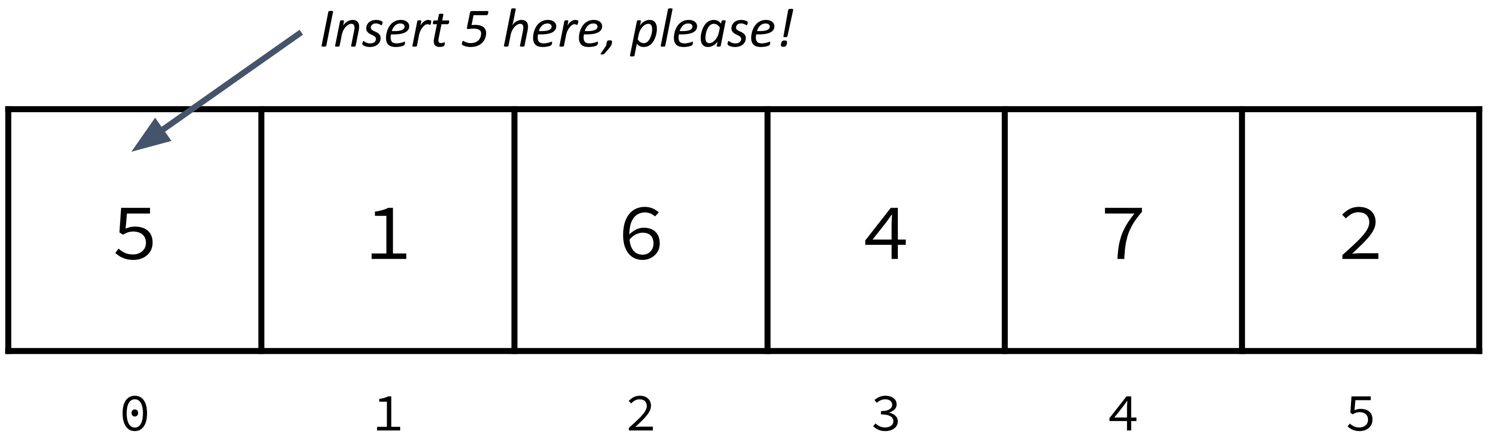

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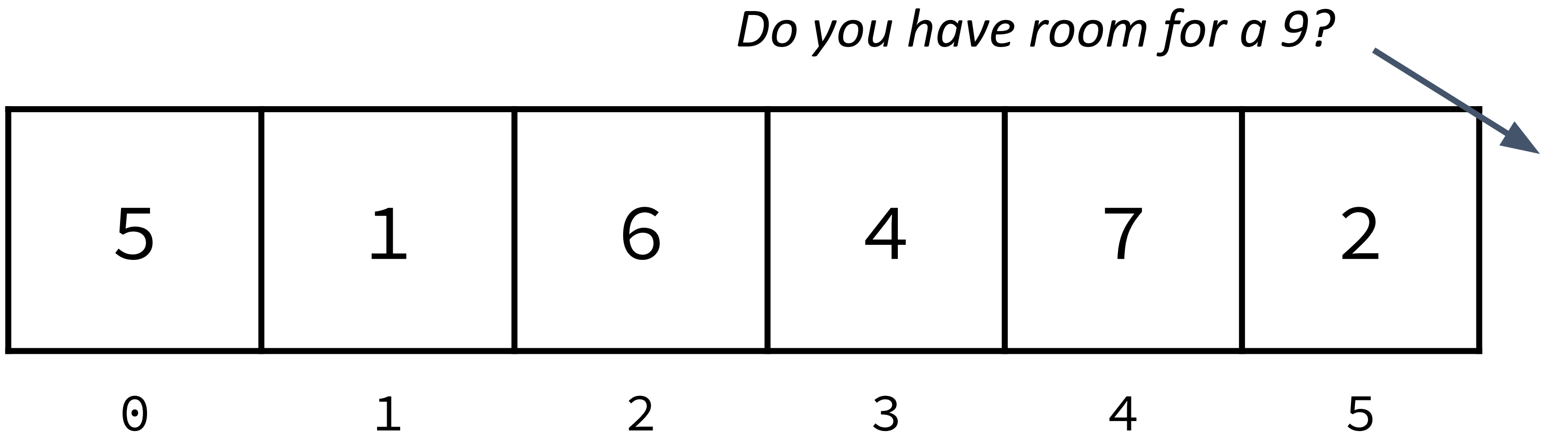

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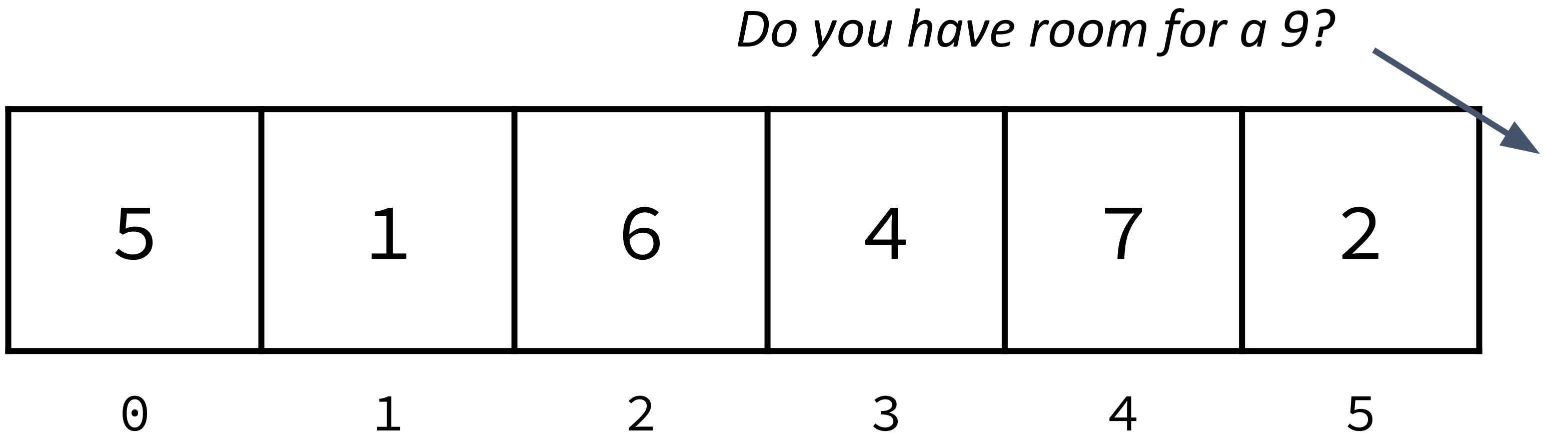

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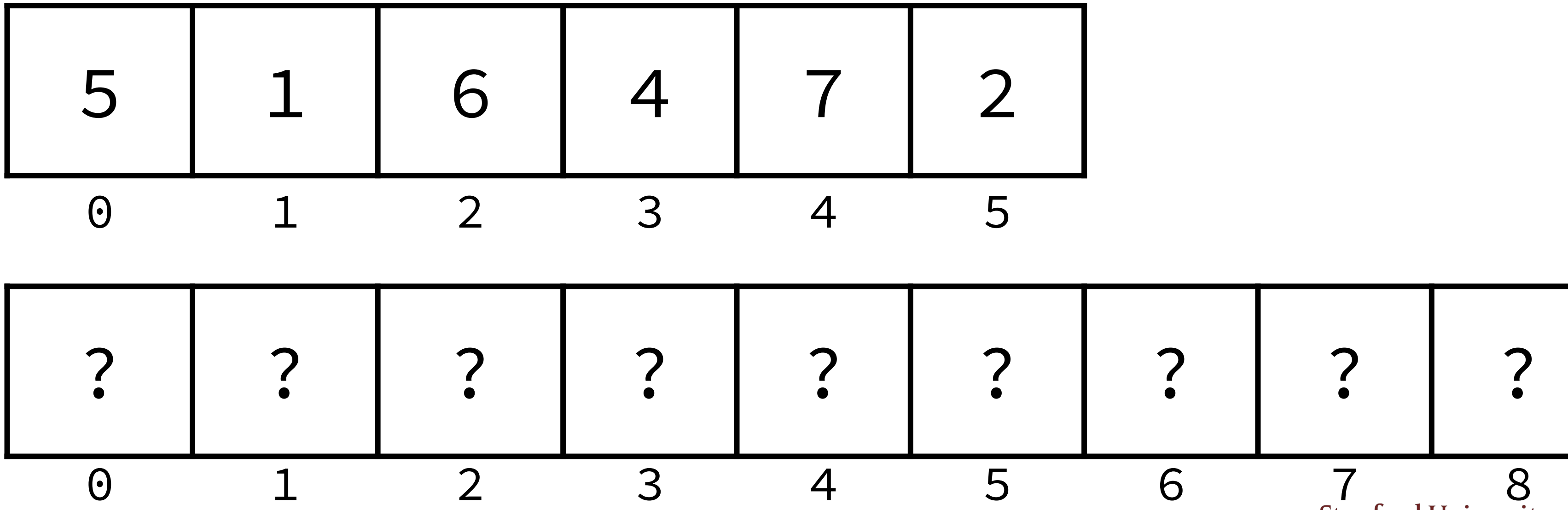

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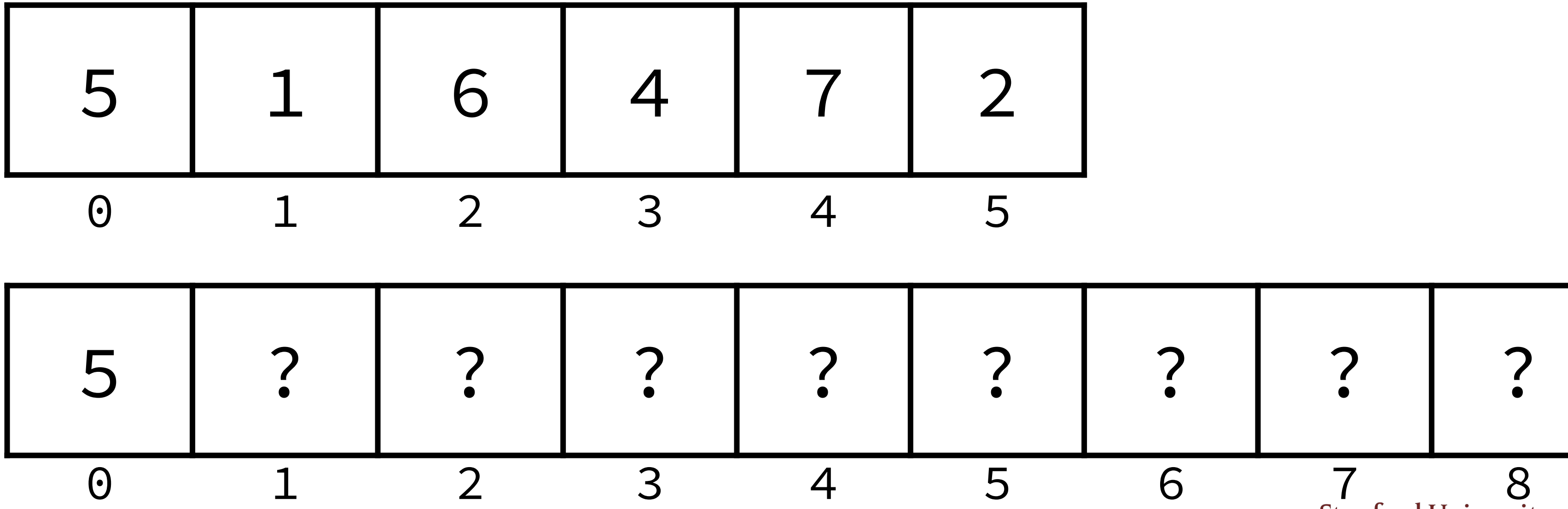

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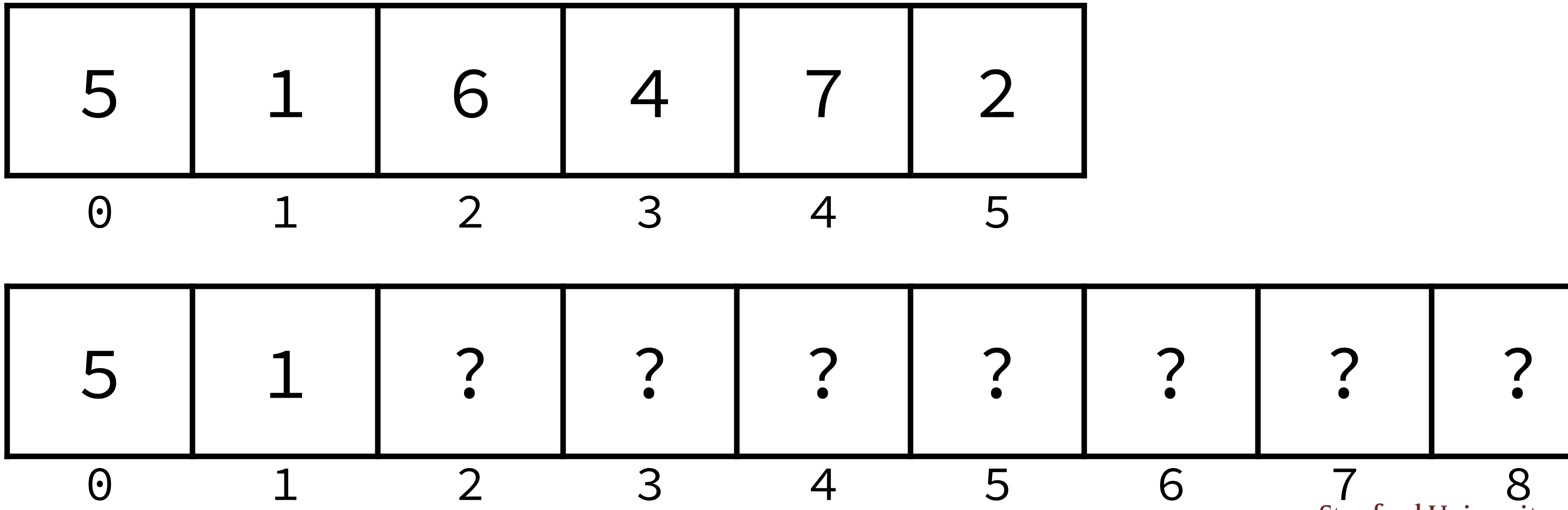

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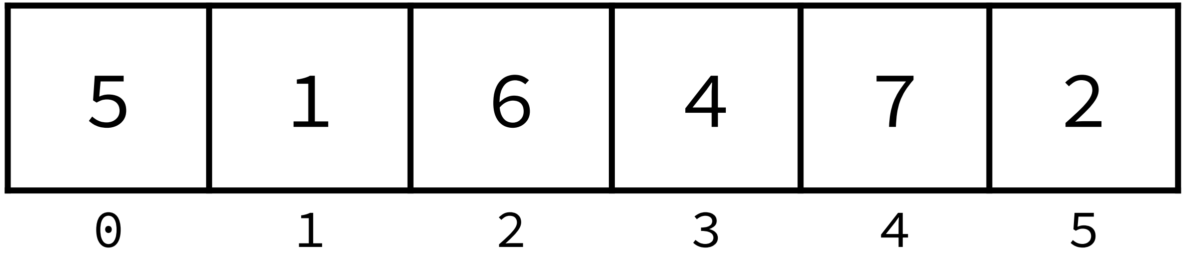

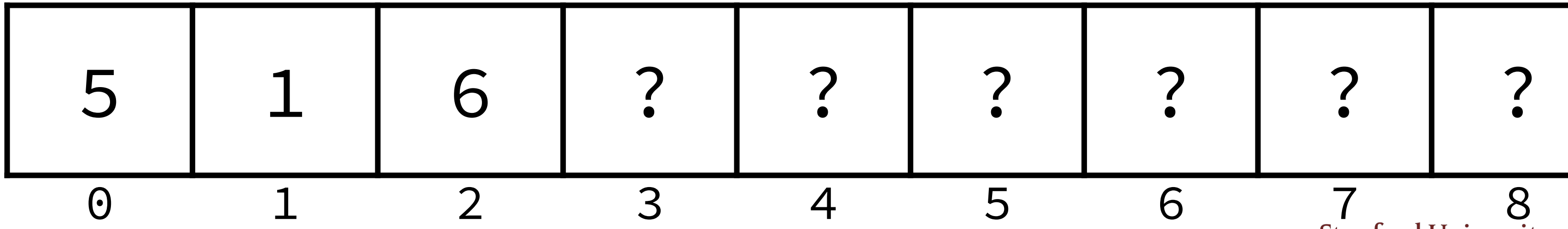

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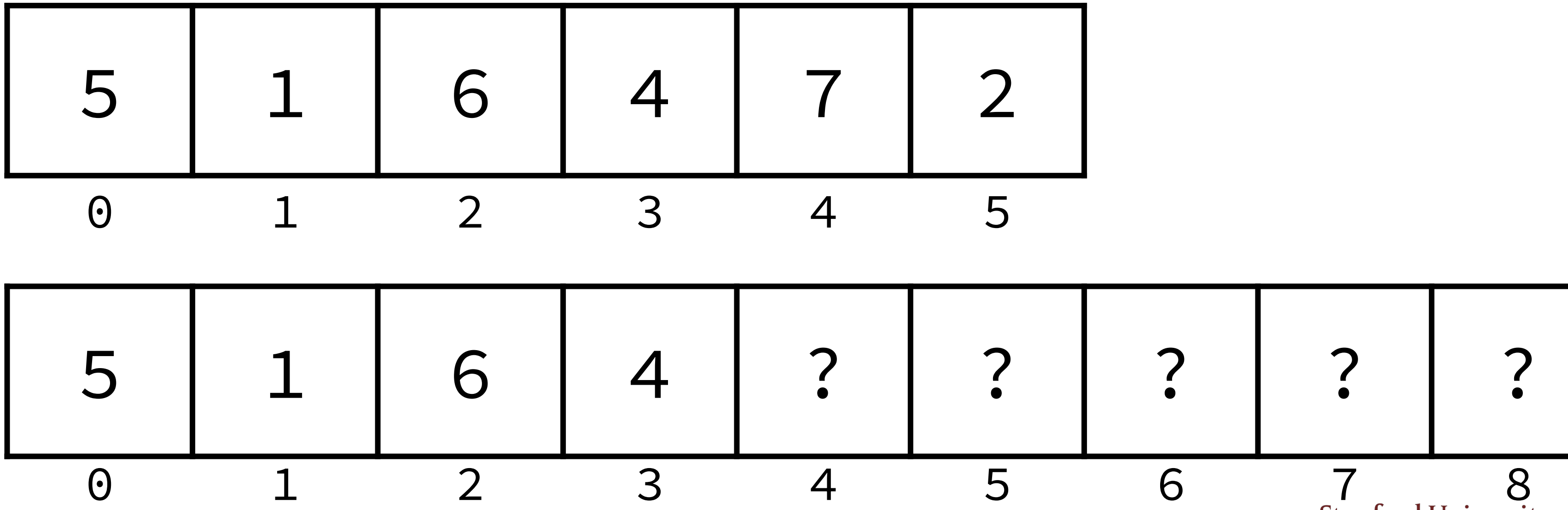

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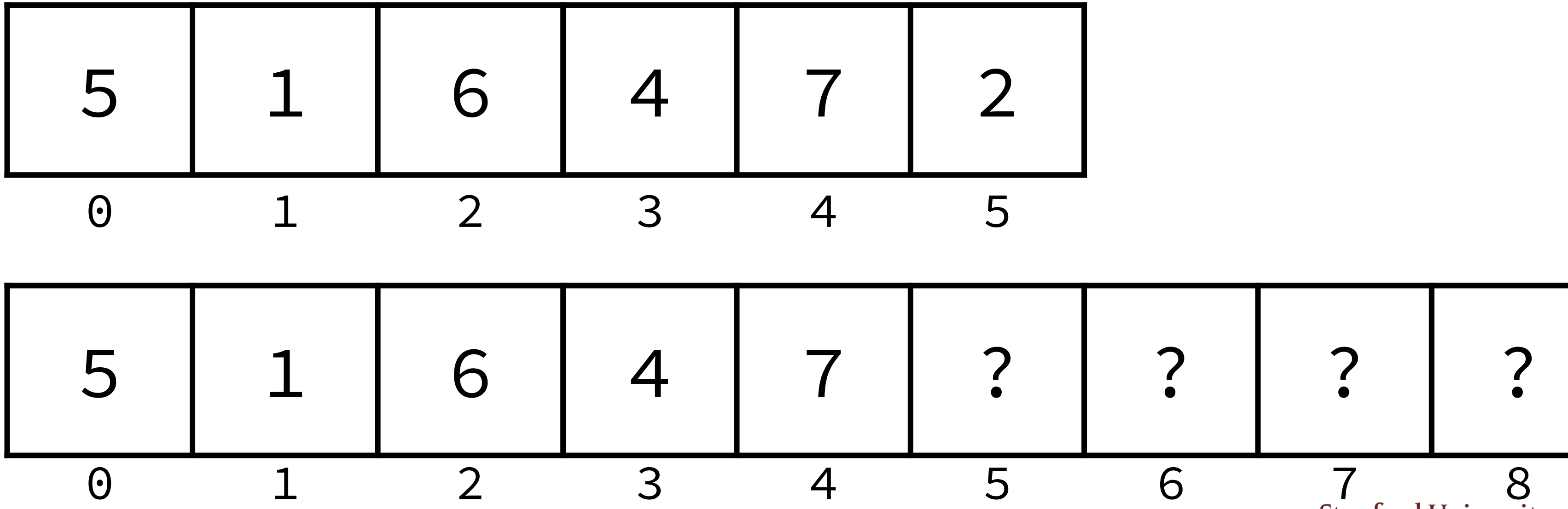

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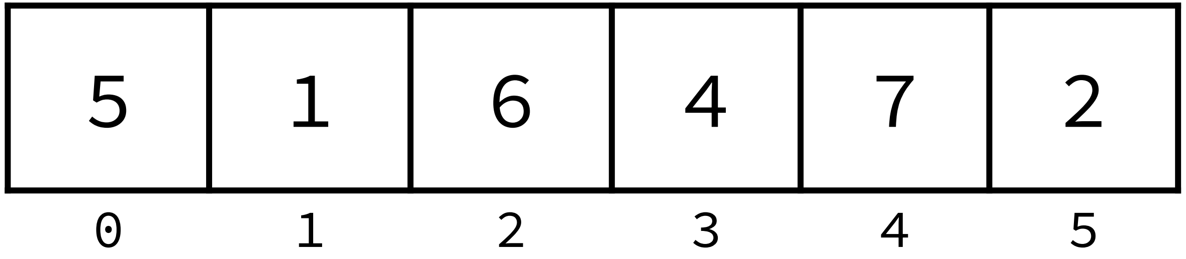

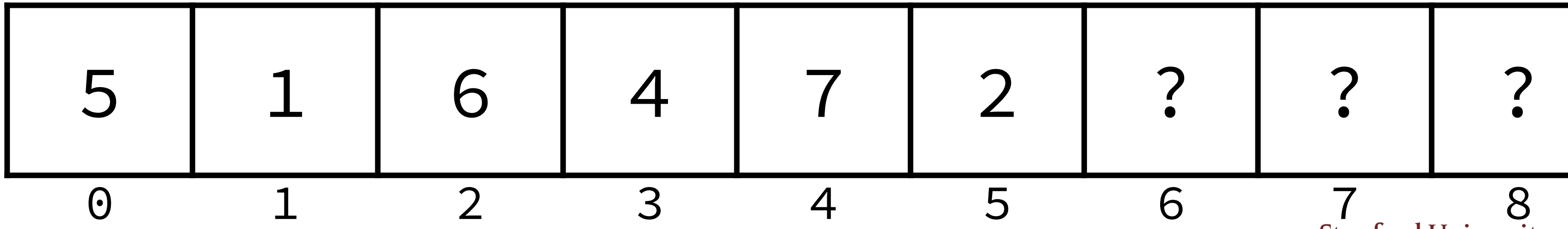

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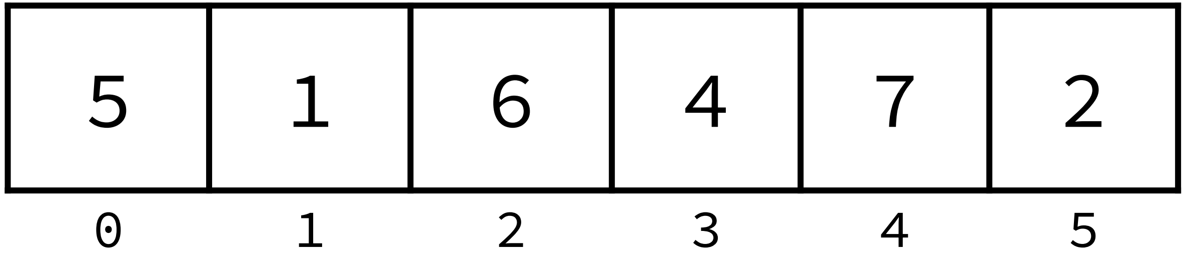

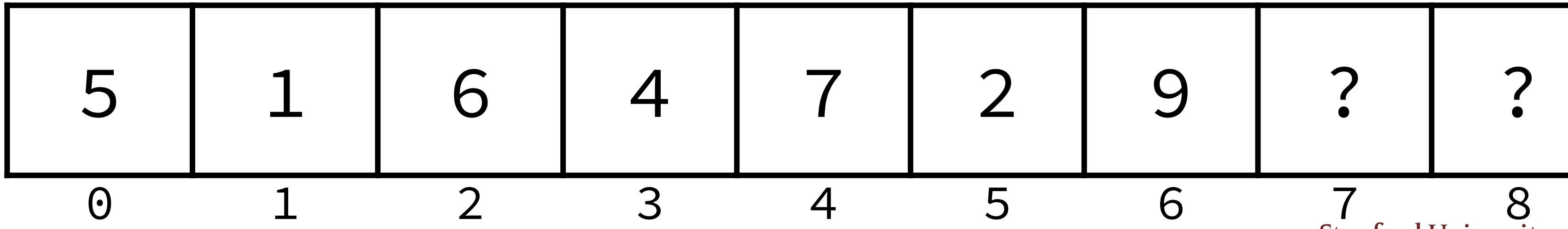

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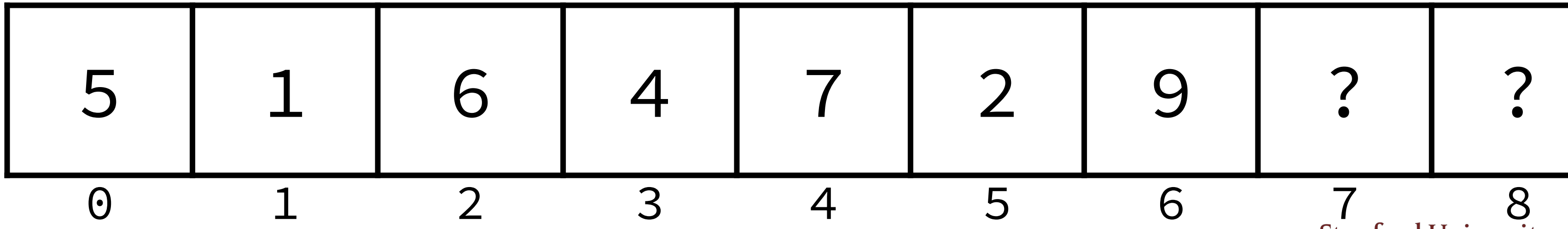

Frustrations with Arrays

Can we do better?

- Not easily resizable
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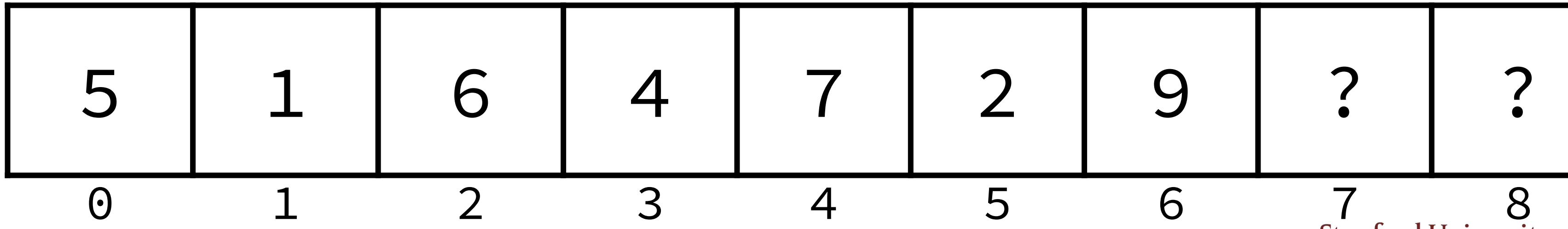

Linked Lists

What are Linked Lists?

- A way we can use pointers to organize non-contiguous memory on the heap

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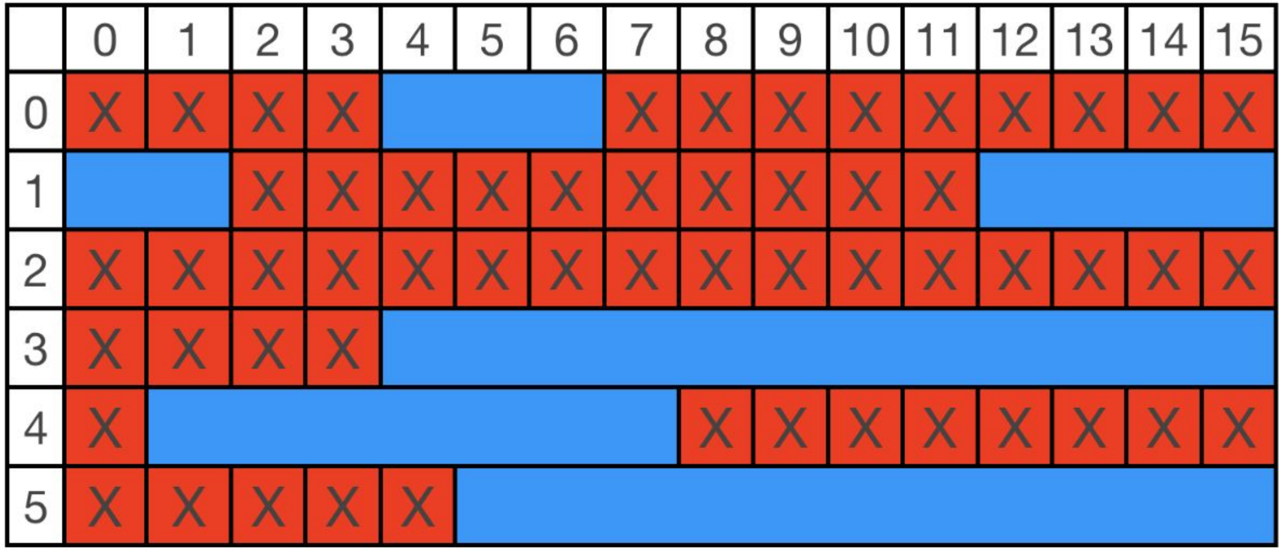

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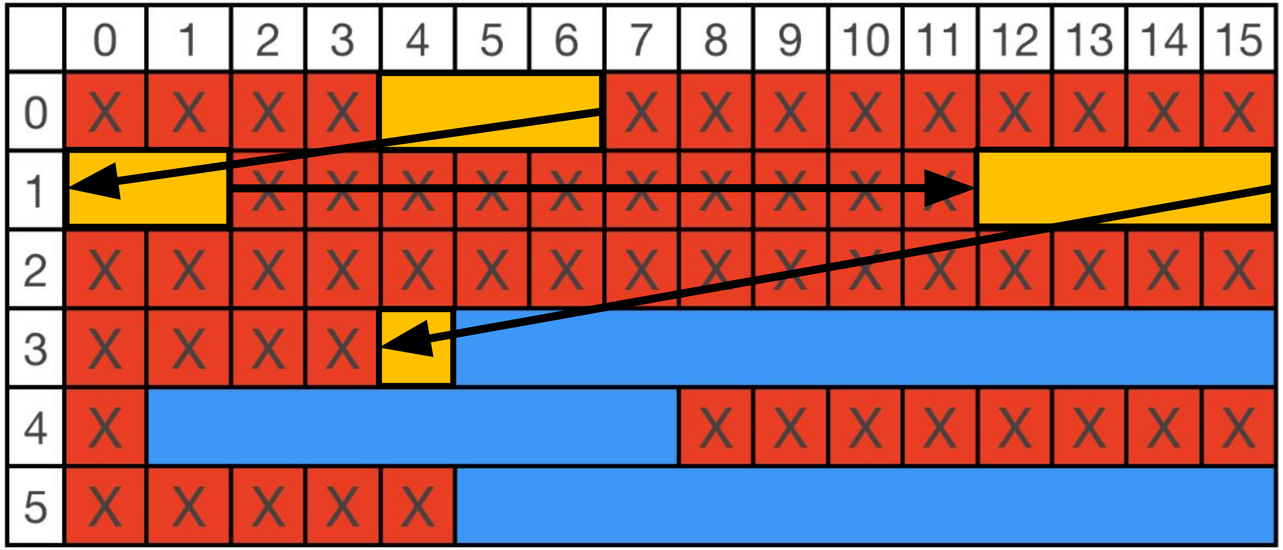
- A way we can use pointers to organize non-contiguous memory on the heap

Could we store 10 integers like this?



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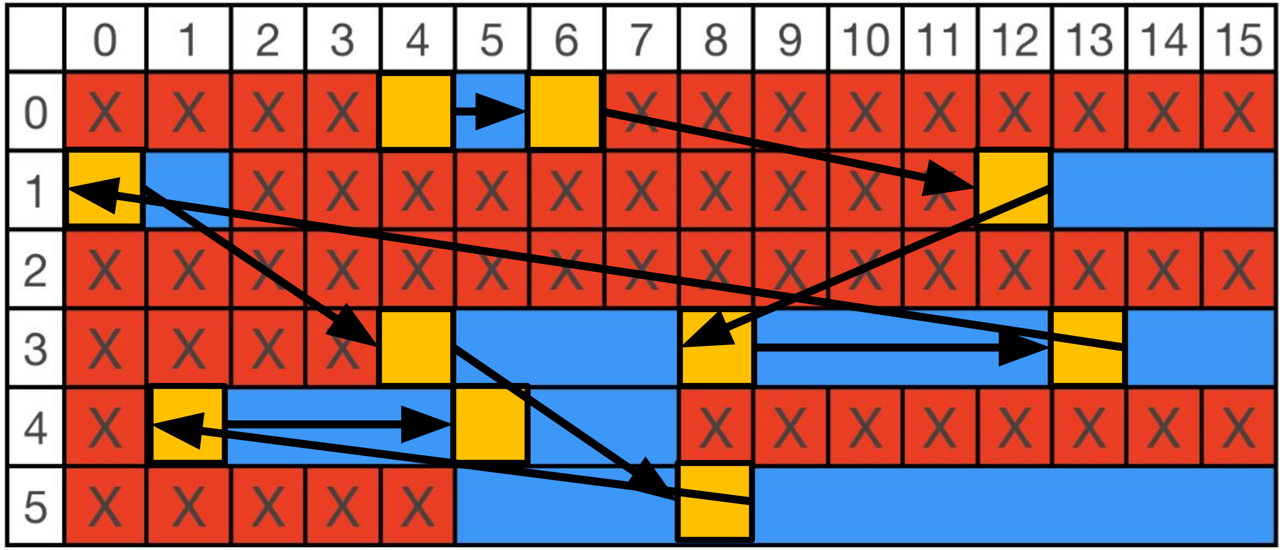
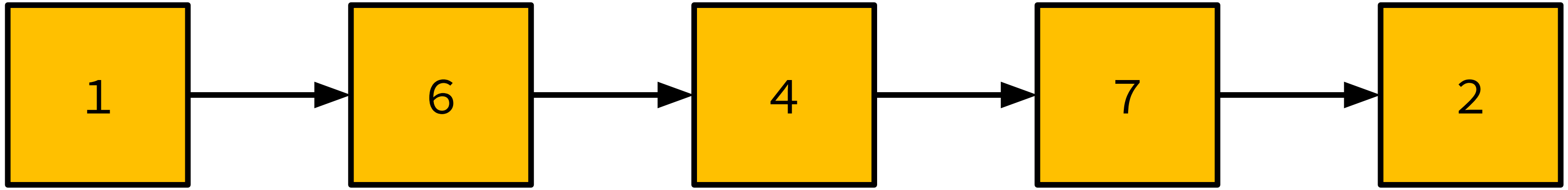
- A way we can use pointers to organize non-contiguous memory on the heap

Or this?



Benefits of Linked Lists



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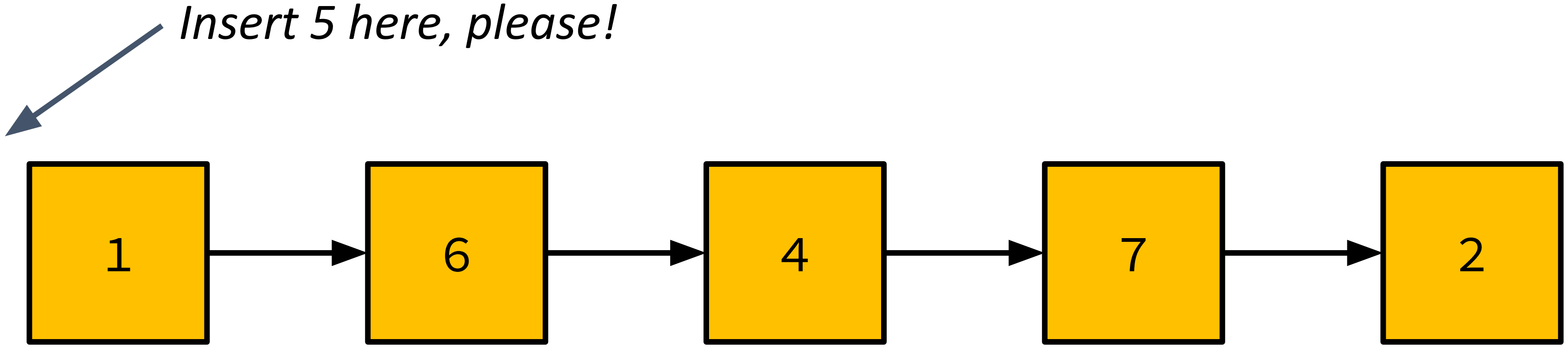

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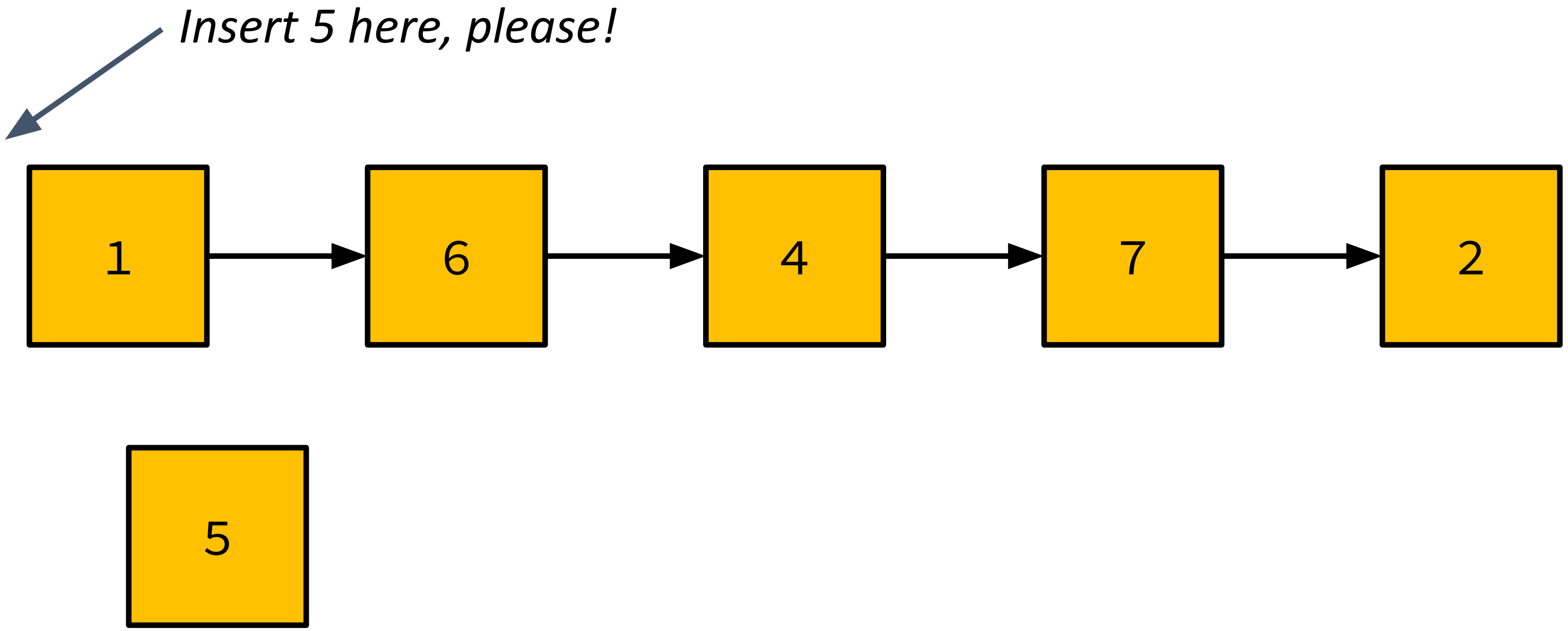

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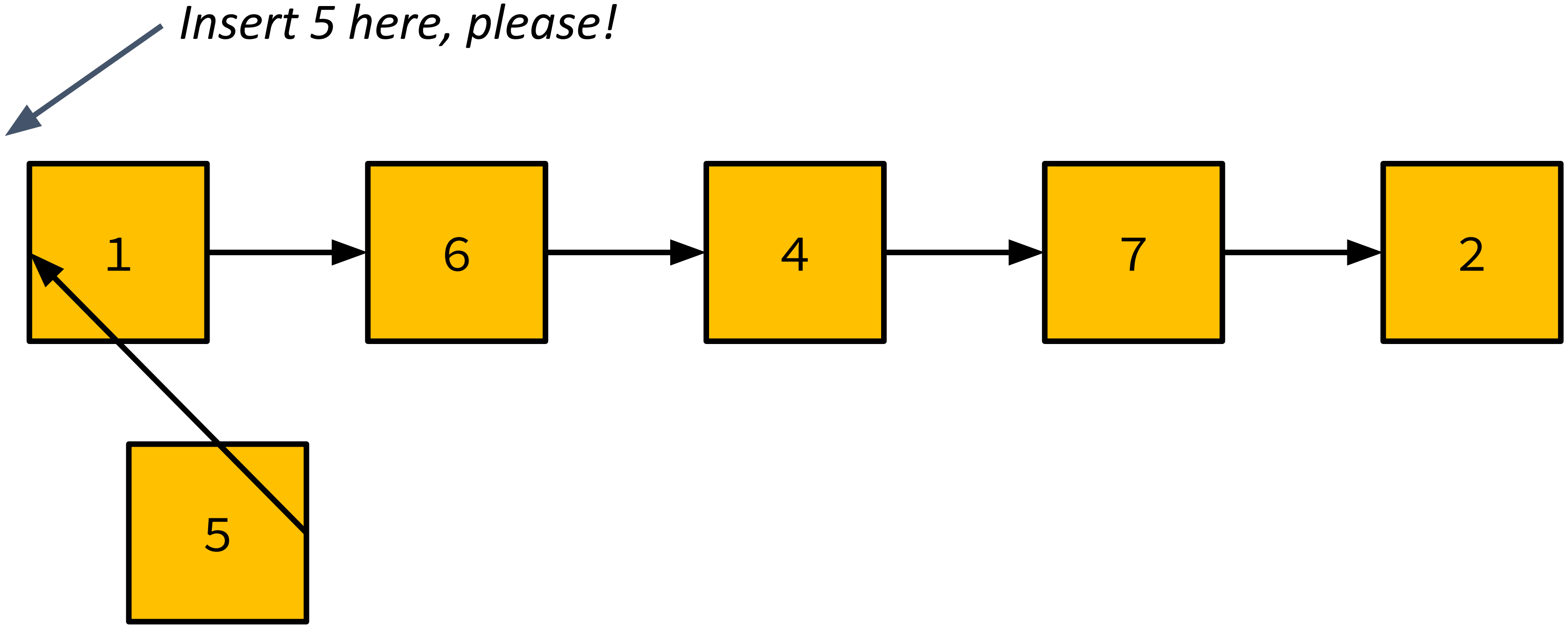

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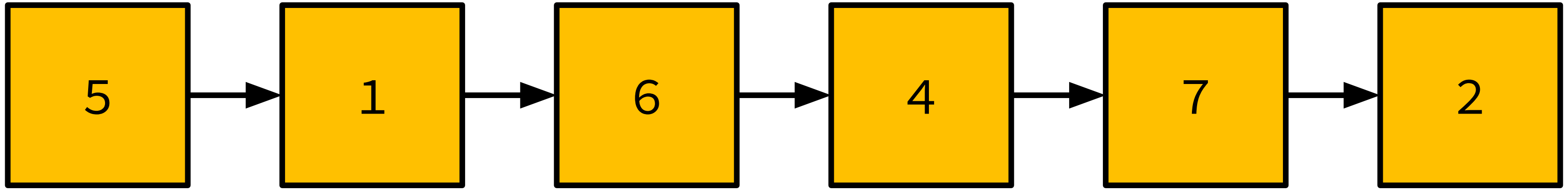
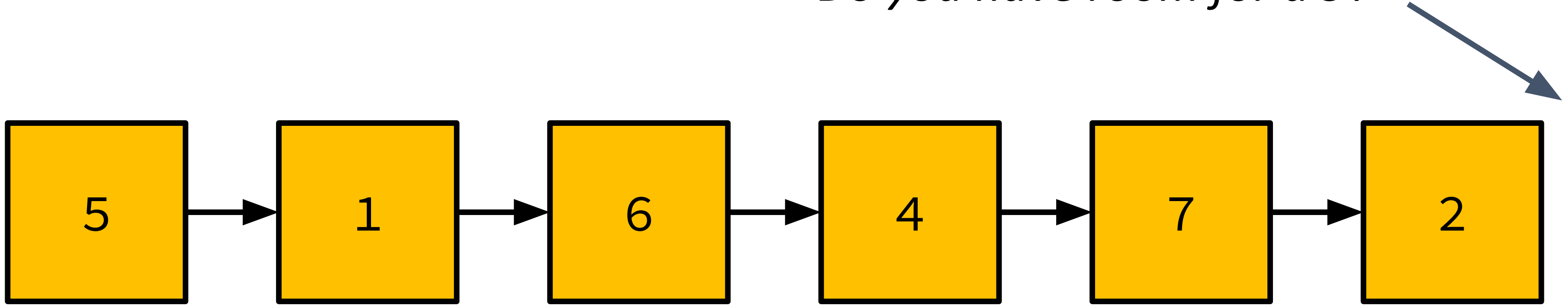


Benefits of Linked Lists

Do you have room for a 9?



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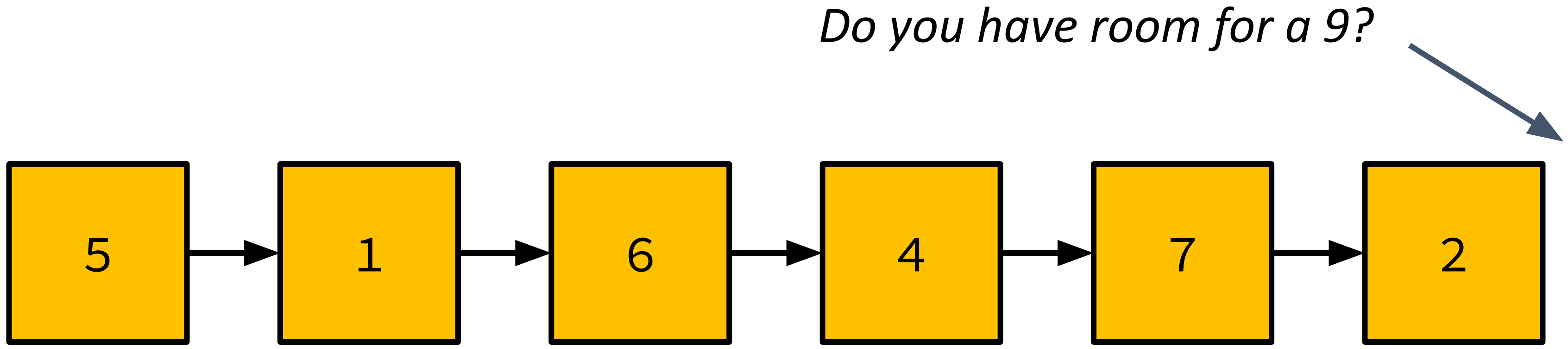

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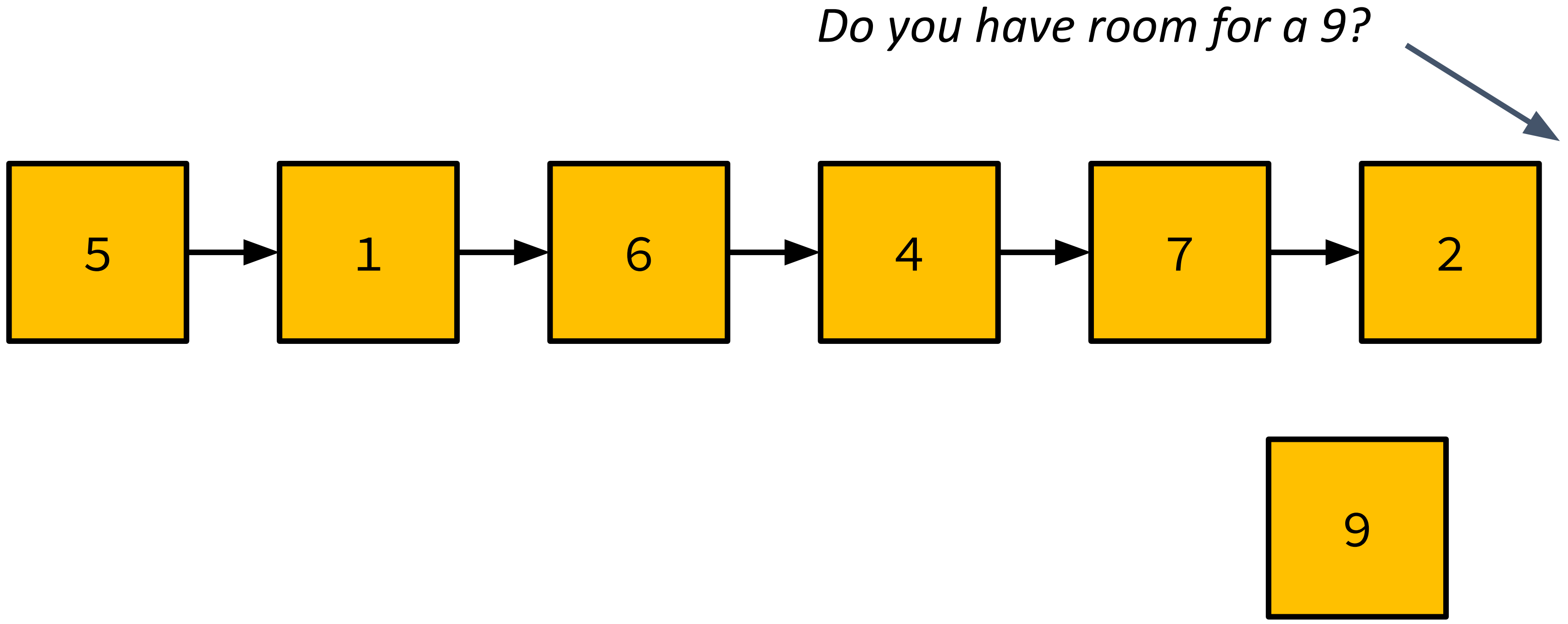

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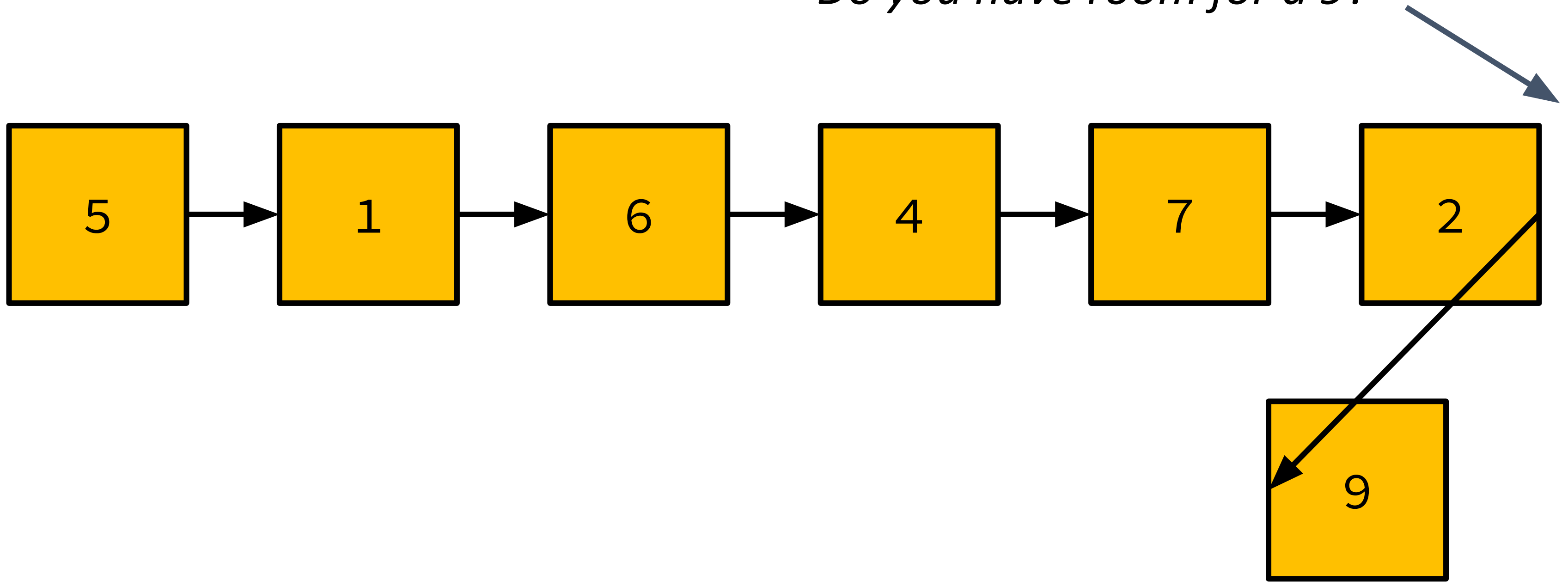
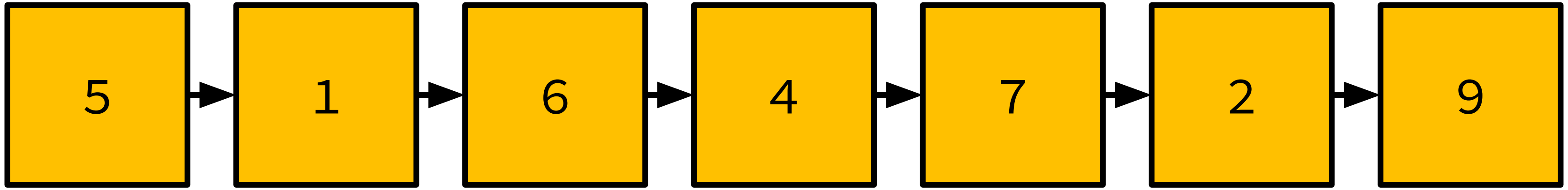


Benefits of Linked Lists

- Easily resizable
- Efficient to insert elements at the beginning



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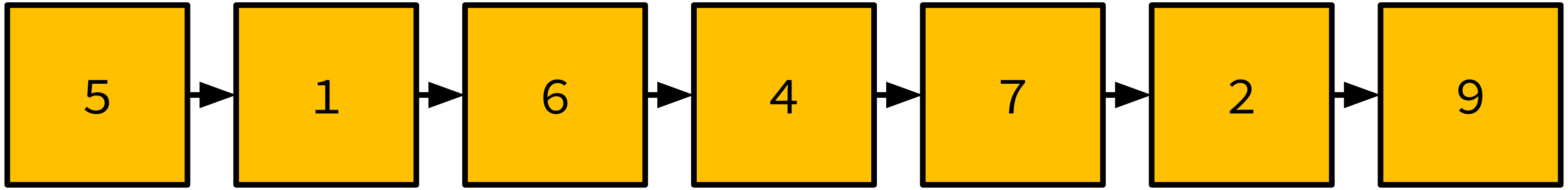

Okay, but what are these little boxes?

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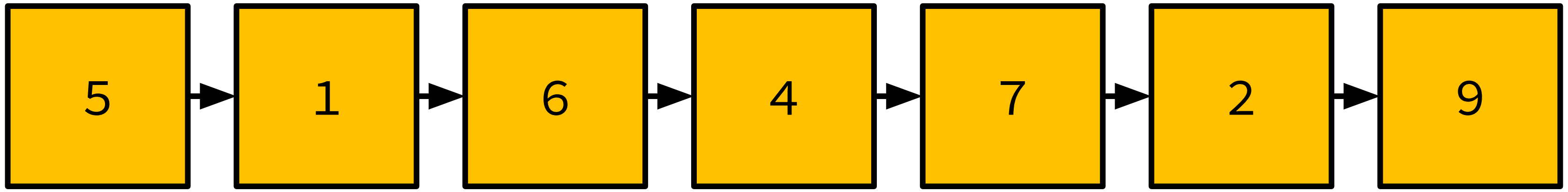

Ints?

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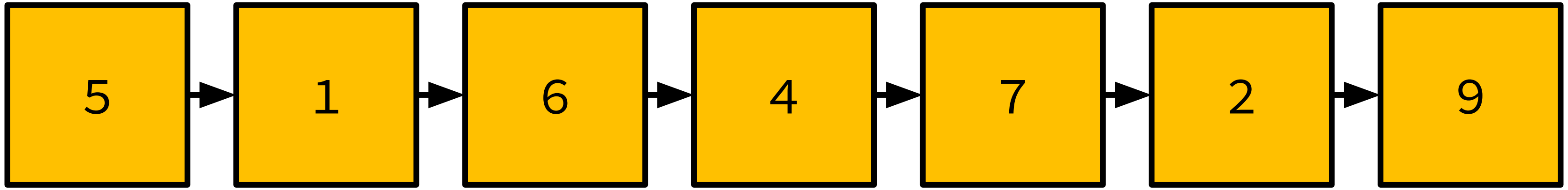
Length 1 arrays?



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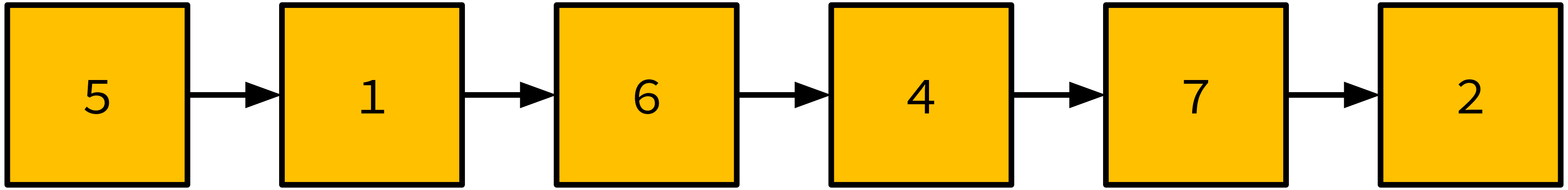
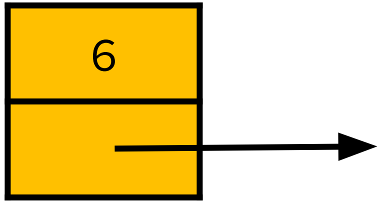
Linked Lists, Structurally

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


$$\begin{tikzcd} \boxed{5} \arrow[r] & \boxed{1} \arrow[r] & \boxed{6} \arrow[r] & \boxed{4} \arrow[r] & \boxed{7} \arrow[r] & \boxed{2} \end{tikzcd}$$

Linked Lists, Structurally

- A linked list is a chain of **nodes**
- Each node contains:
  - A piece of data (like an int, or string)
  - A link to the next node



Linked Lists, Structurally

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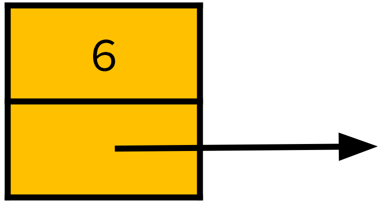
What are pointers again?



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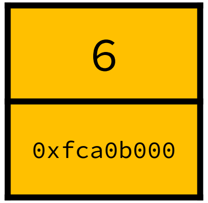

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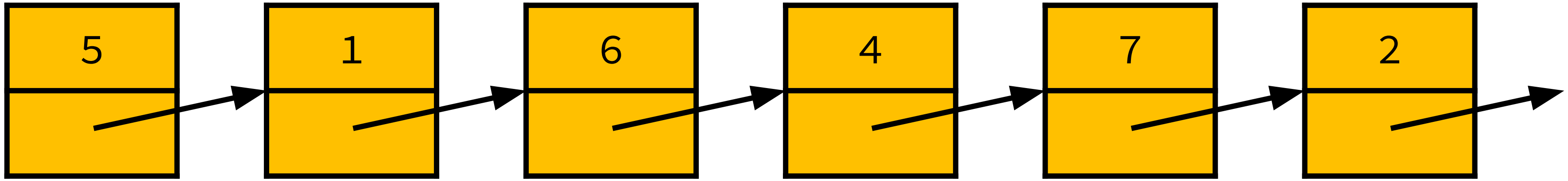

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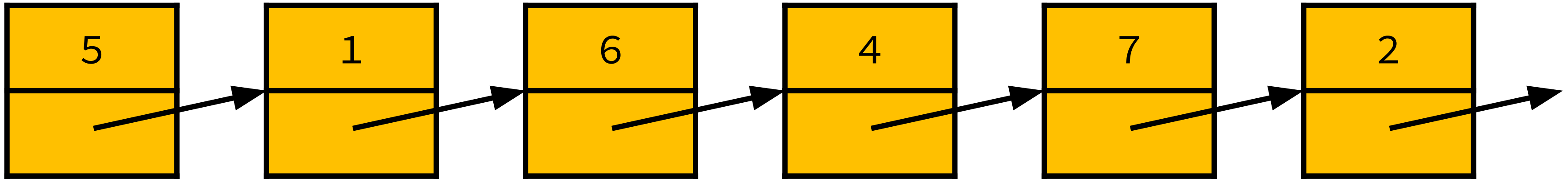
👥 *What should the last node point to?*



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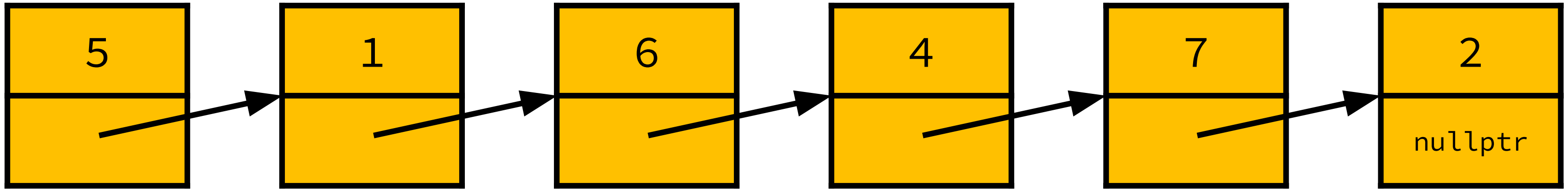

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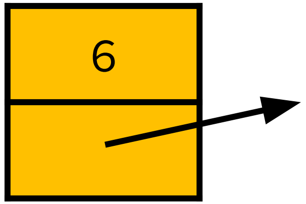

👥 *How can we implement a node in C++? How do we store two or more pieces of data together?*

Linked Lists, Structurally

- A linked list is a chain of nodes
- Each node **is a struct** that contains:
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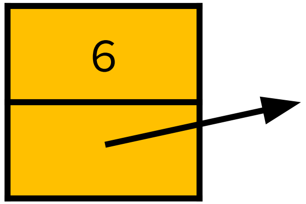
  - A pointer to the next node



```
struct Node {
   // data
   // pointer
};
```

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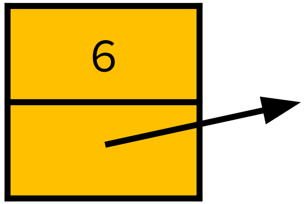

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struct Node {
    int data;
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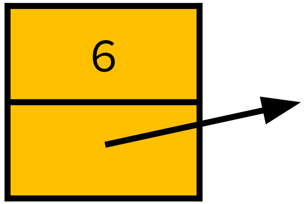
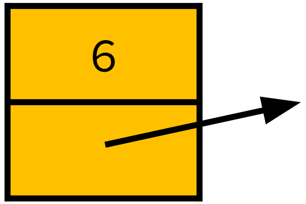


```
struct Node {
   int data;
   Node* next;
};
```

Yes, this recursive definition is allowed!

Node*

- Each Node contains a pointer to another Node, or nullptr
- A pointer to a Node is of type Node*



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Creating a Linked List

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
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    Node* list = new Node;
```
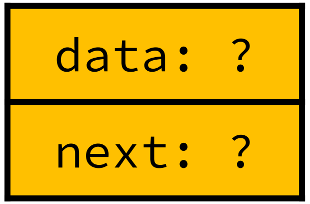



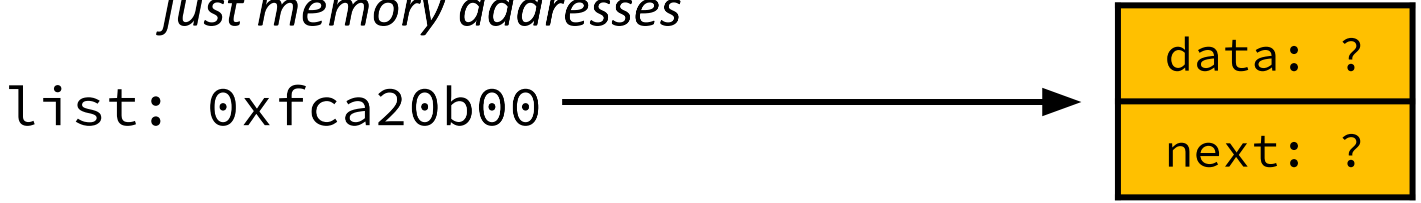
Lives at `0xfca20b00` on the heap

Creating a Linked List

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
```

Remember, pointers are just memory addresses



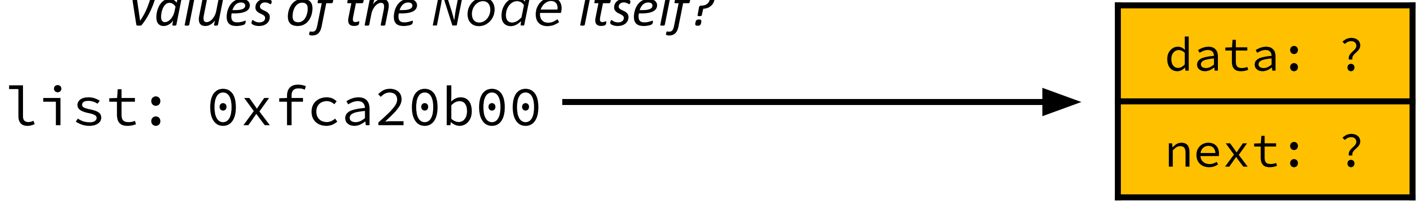
Lives at 0xfca20b00 on the heap

Creating a Linked List

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
```

How do we update the values of the Node itself?

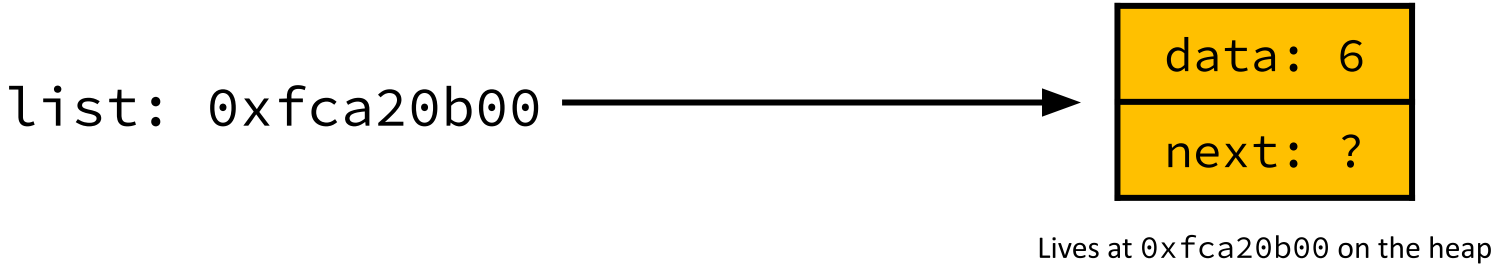


Lives at `0xfca20b00` on the heap

Creating a Linked List

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
(*list).data = 6;
```

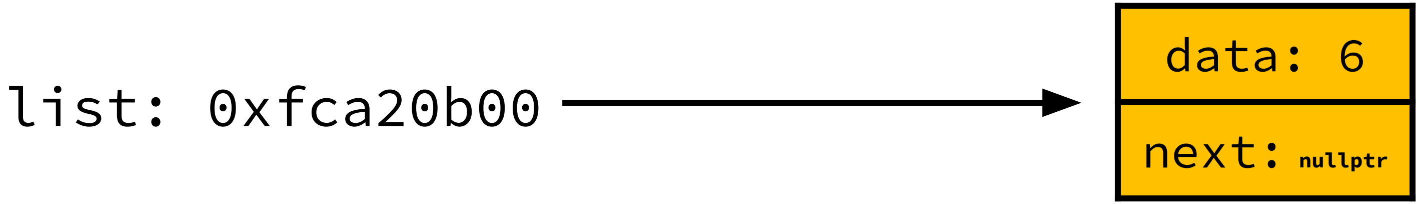


Creating a Linked List

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
(*list).data = 6;
(*list).next = nullptr;
```

*Dereference with *, access field with .*



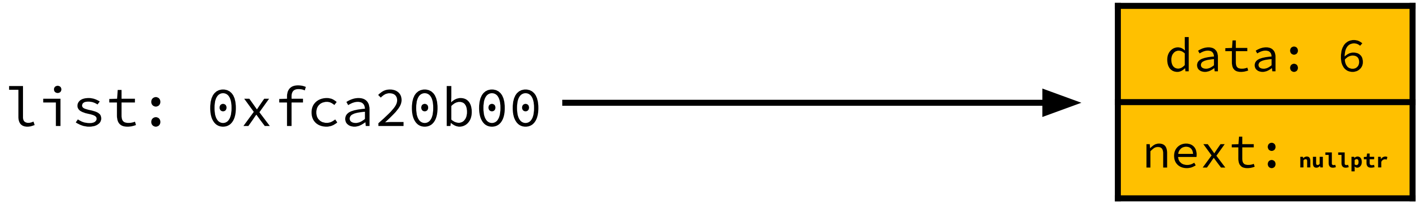
Lives at `0xfca20b00` on the heap

Creating a Linked List

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
```

Dereference AND access the field for struct pointers using ->



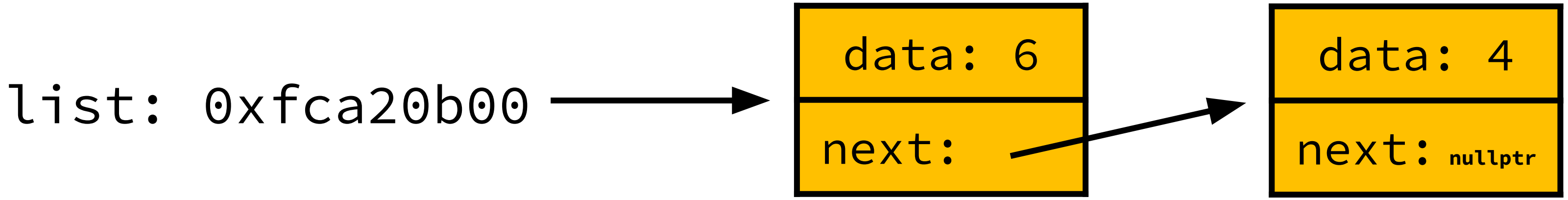
Lives at `0xfca20b00` on the heap

Appending Nodes

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
```

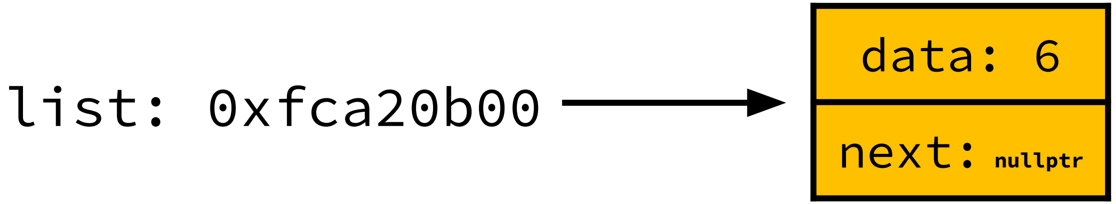
👥 *How could we build a list that looks like this?*



Appending Nodes

- Create a new Node on the heap and store a pointer to it

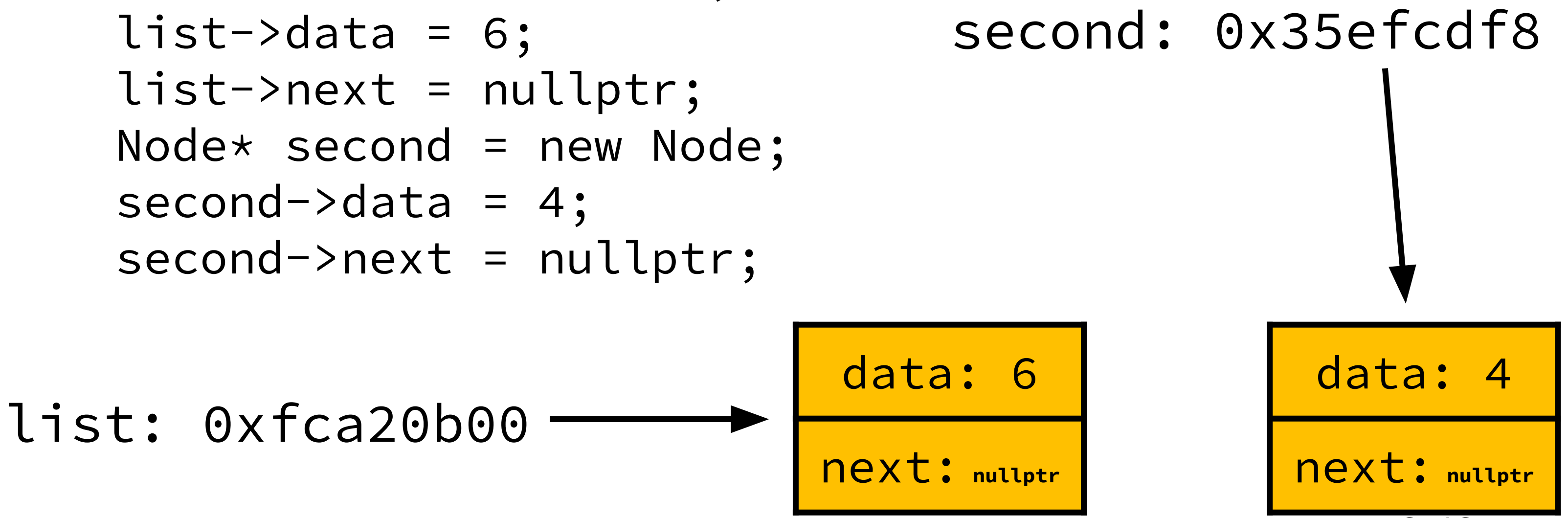
```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
```



Appending Nodes

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
Node* second = new Node;
second->data = 4;
second->next = nullptr;
```

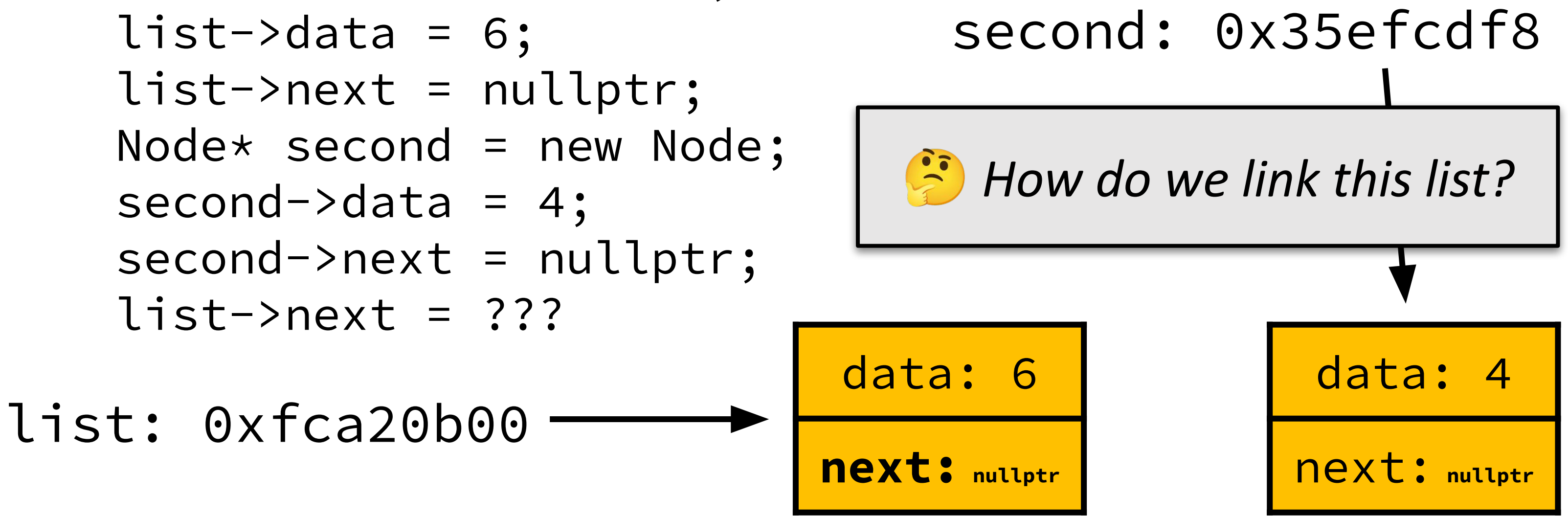


Lives at `0x35efcdf8` on the heap

Appending Nodes

- Create a new Node on the heap and store a pointer to it

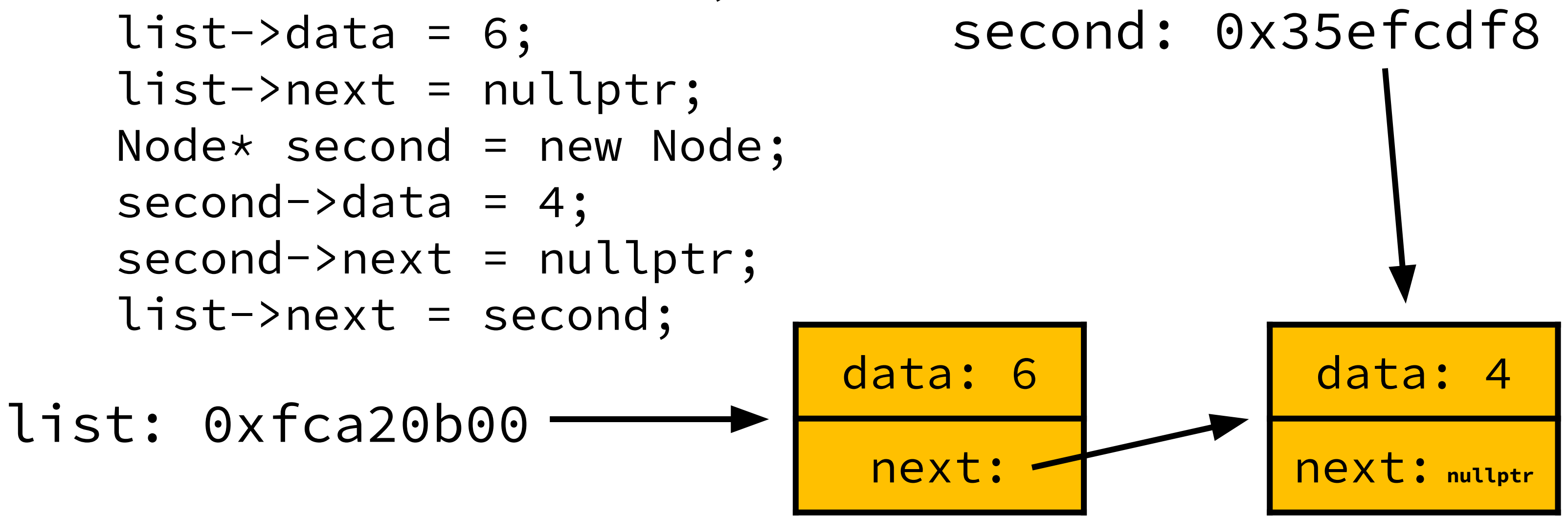
```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
Node* second = new Node;
second->data = 4;
second->next = nullptr;
list->next = ???
```



Appending Nodes

- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
Node* second = new Node;
second->data = 4;
second->next = nullptr;
list->next = second;
```

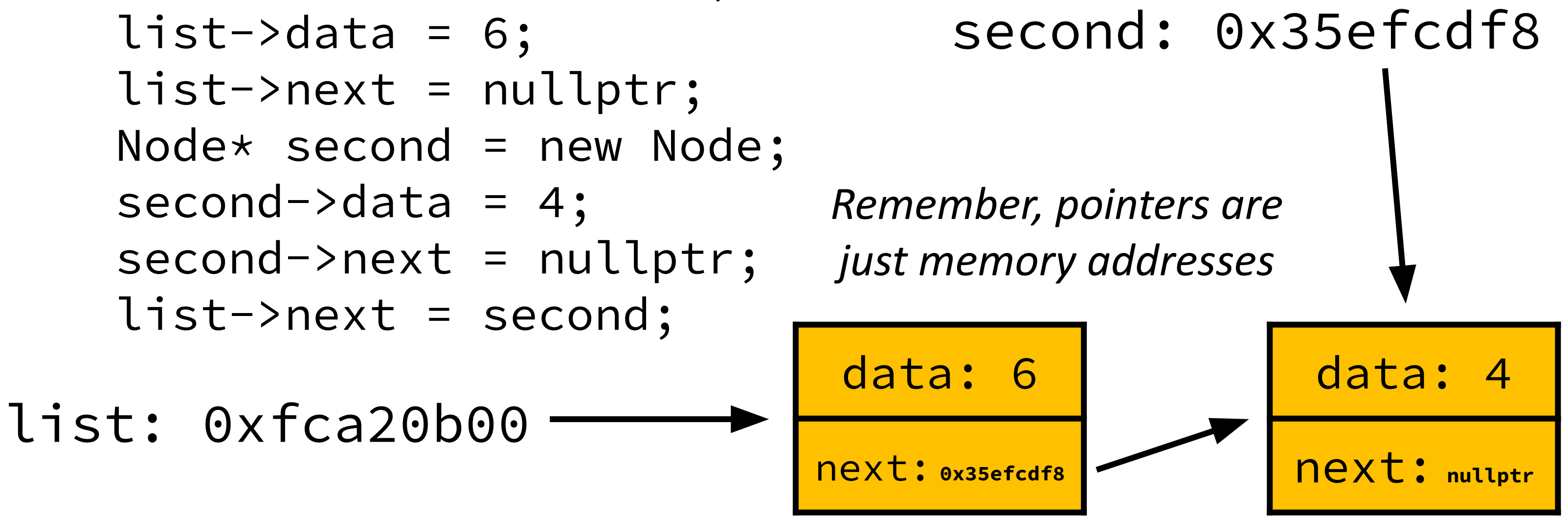


Appending Nodes

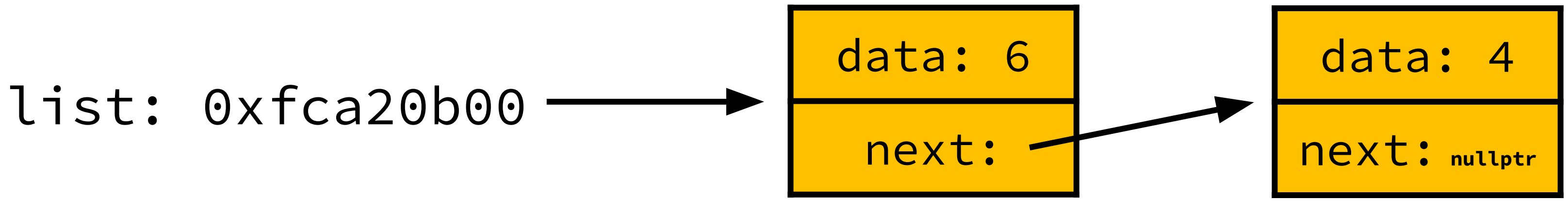
- Create a new Node on the heap and store a pointer to it

```
Node* list = new Node;
list->data = 6;
list->next = nullptr;
Node* second = new Node;
second->data = 4;
second->next = nullptr;
list->next = second;
```

Remember, pointers are just memory addresses

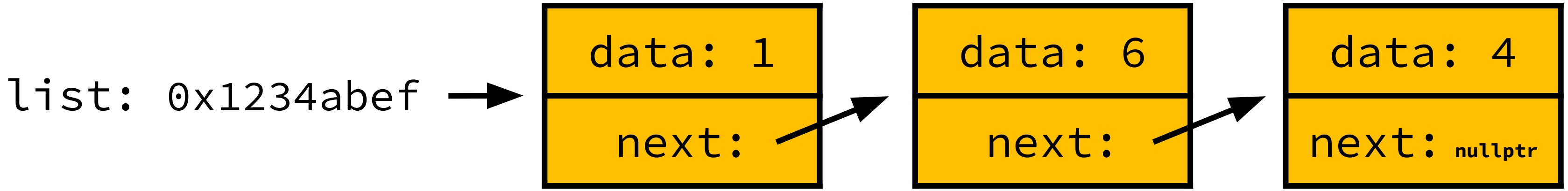


Prepending Nodes



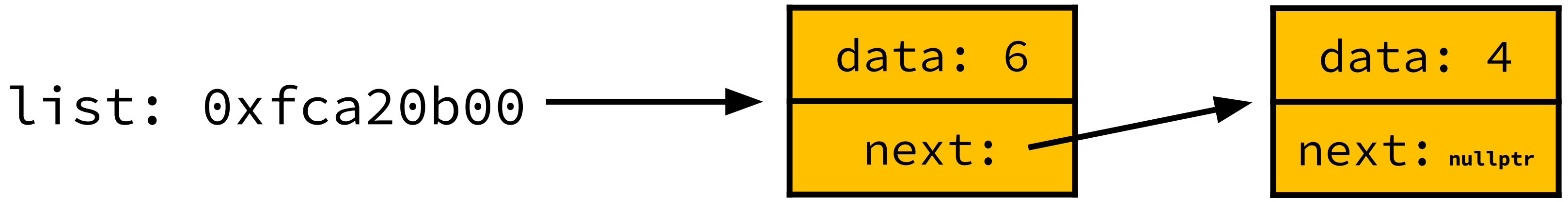
How would we go from this…

Prepending Nodes

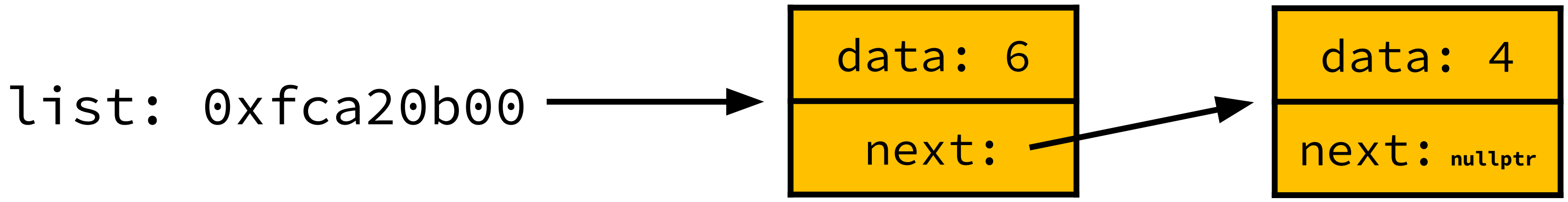


… to this?

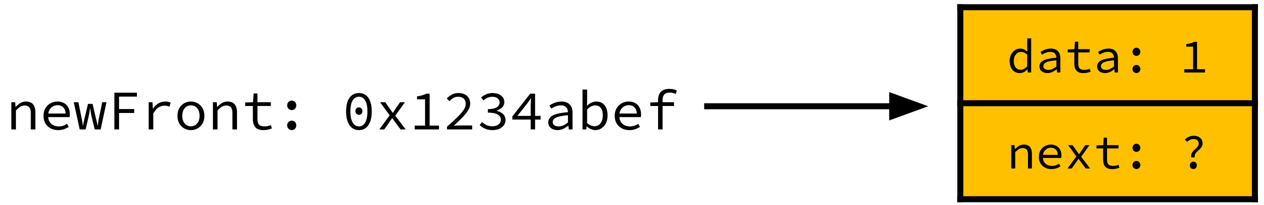
Prepending Nodes



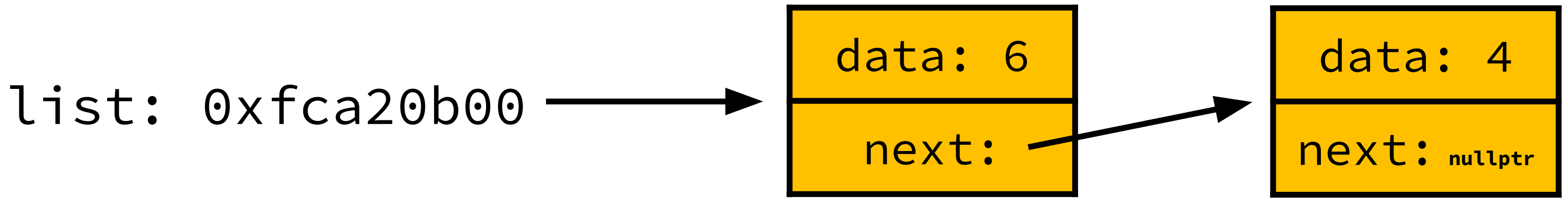
Prepending Nodes



```
Node* newFront = new Node;
newFront->data = 1;
```

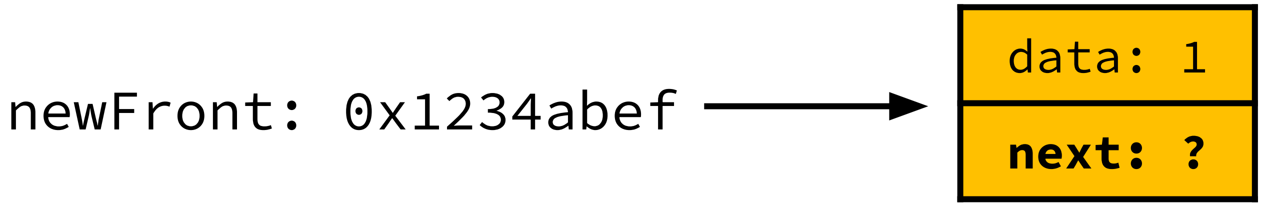


Prepending Nodes

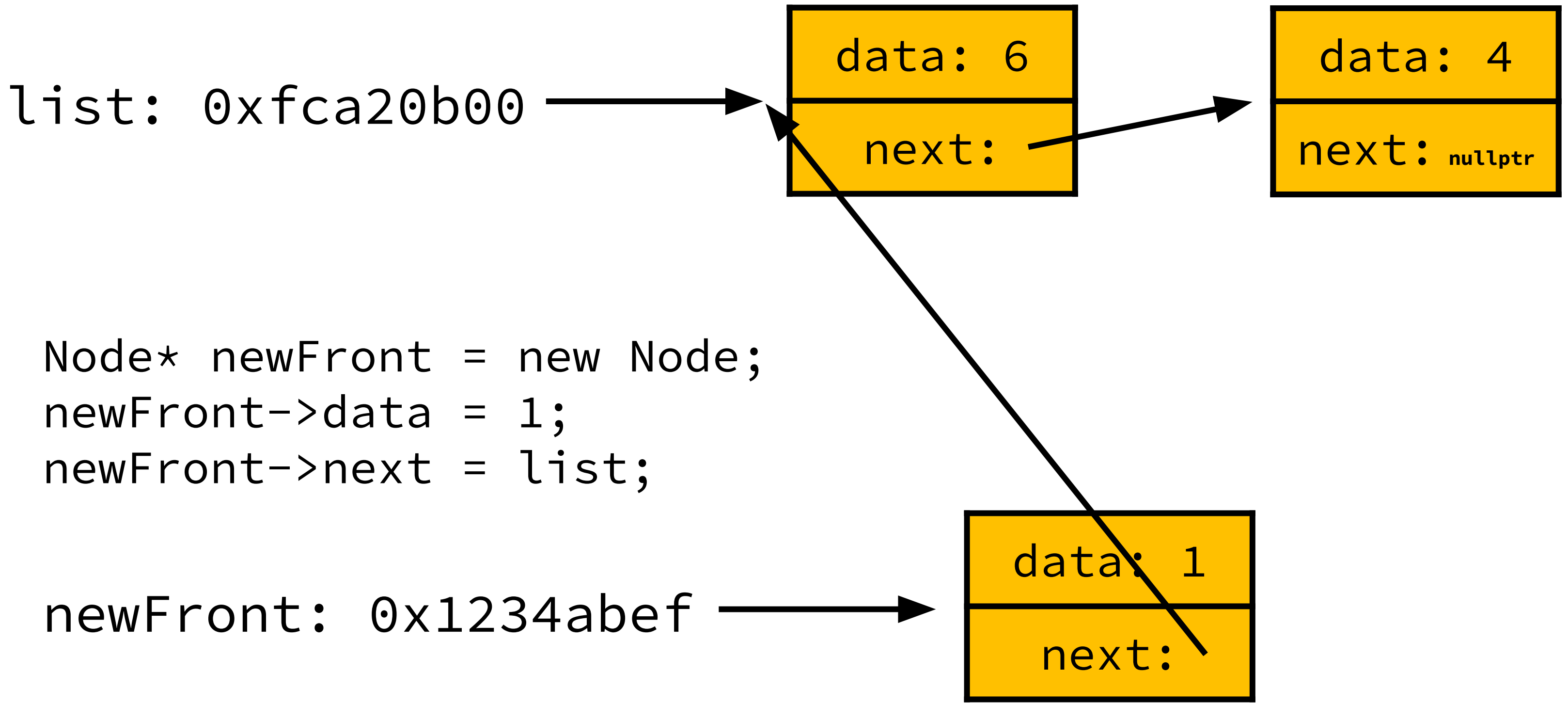


```
Node* newFront = new Node;
newFront->data = 1;
newFront->next = ???
```

🤔 *Help me out here…*

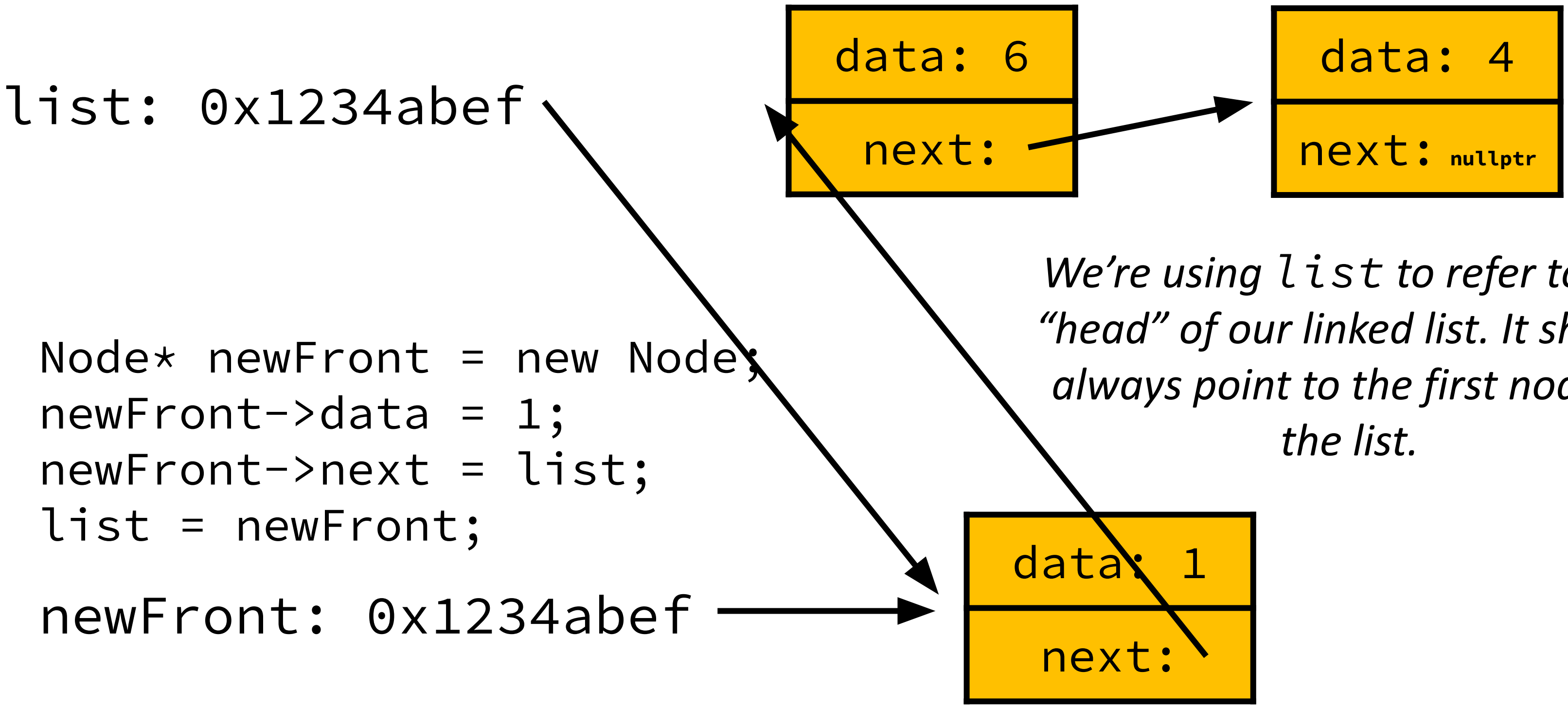


Prepending Nodes



```
Node* newFront = new Node;
newFront->data = 1;
newFront->next = list;
```

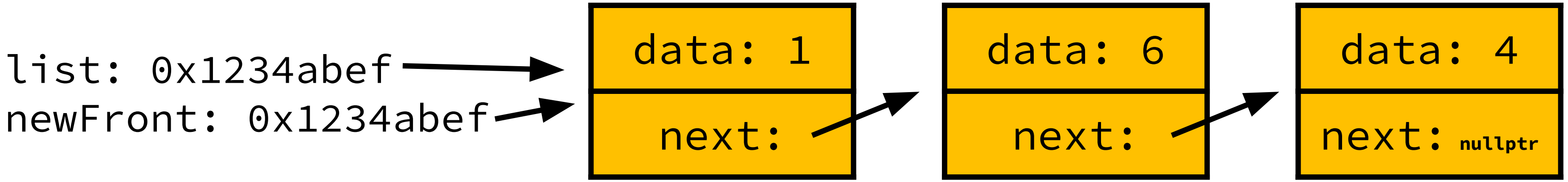
Prepending Nodes



```
Node* newFront = new Node;
newFront->data = 1;
newFront->next = list;
list = newFront;
```

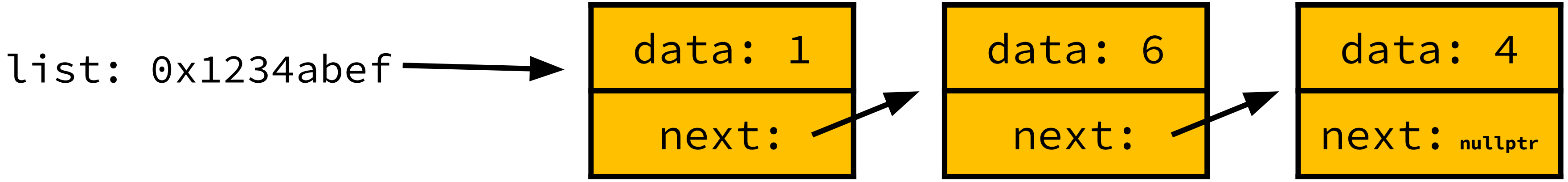
We're using `list` to refer to the "head" of our linked list. It should always point to the first node in the list.

Prepending Nodes



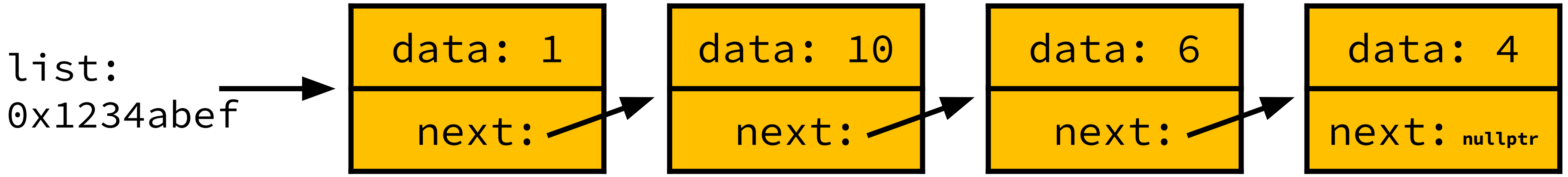
```
Node* newFront = new Node;
newFront->data = 1;
newFront->next = list;
list = newFront;
```

Let’s Trace Some Code



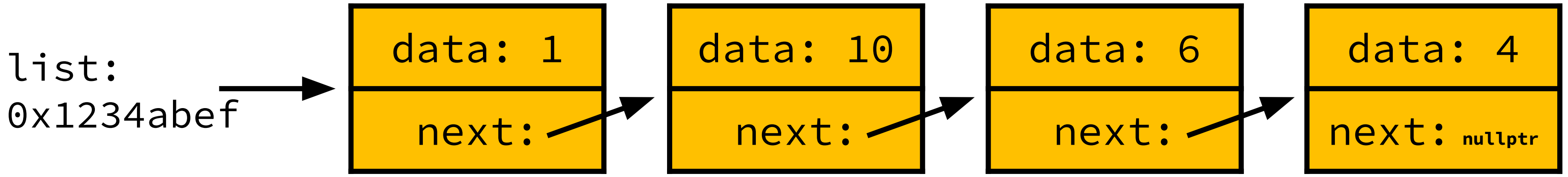
```
Node* mystery = new Node;
mystery->data = 10;
mystery->next = list->next;
list->next = mystery;
```

Let’s Trace Some Code



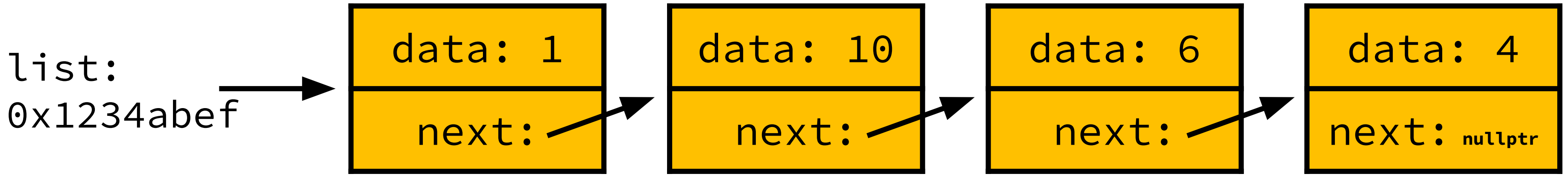
```
Node* mystery = new Node;
mystery->data = 10;
mystery->next = list->next;
list->next = mystery;
```

Let’s Trace Some Code (Inserting Nodes)

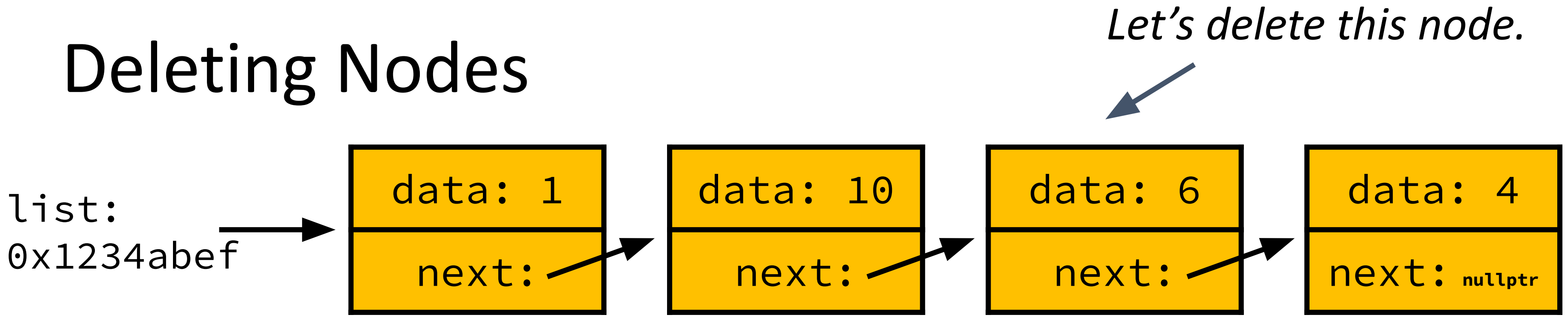


```
Node* mystery = new Node;
mystery->data = 10;
mystery->next = list->next;
list->next = mystery;
```

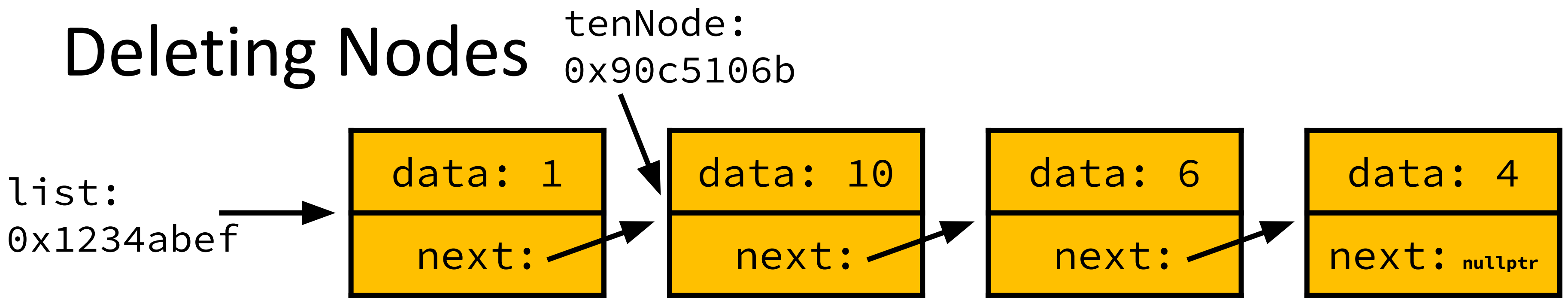
Deleting Nodes



Deleting Nodes

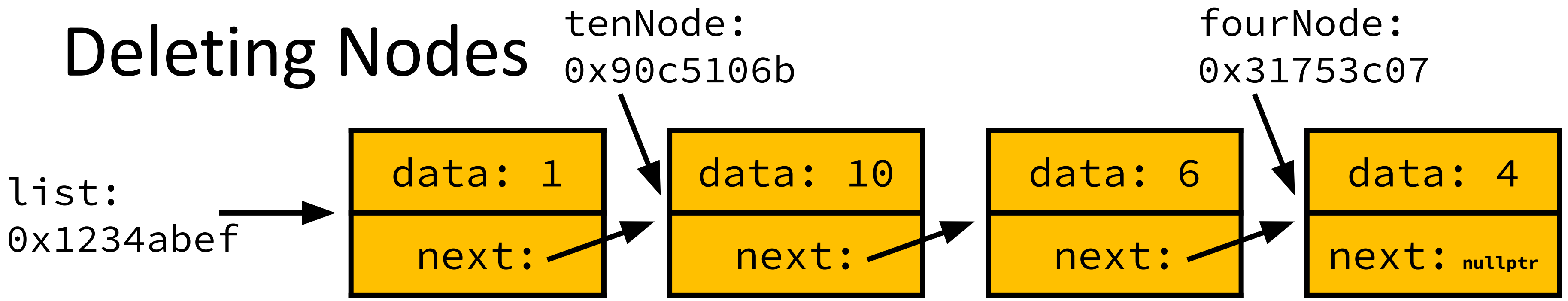


Deleting Nodes



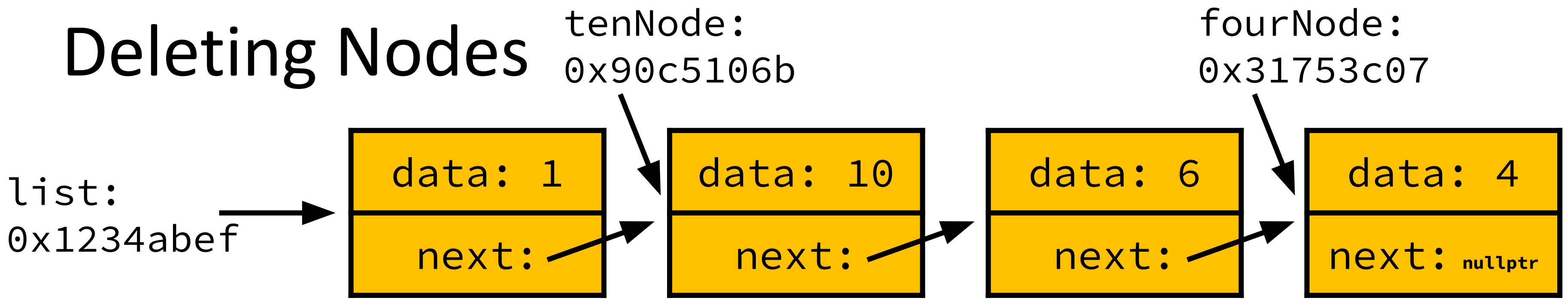
```
Node* tenNode = list->next;
```

Deleting Nodes



```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;
```

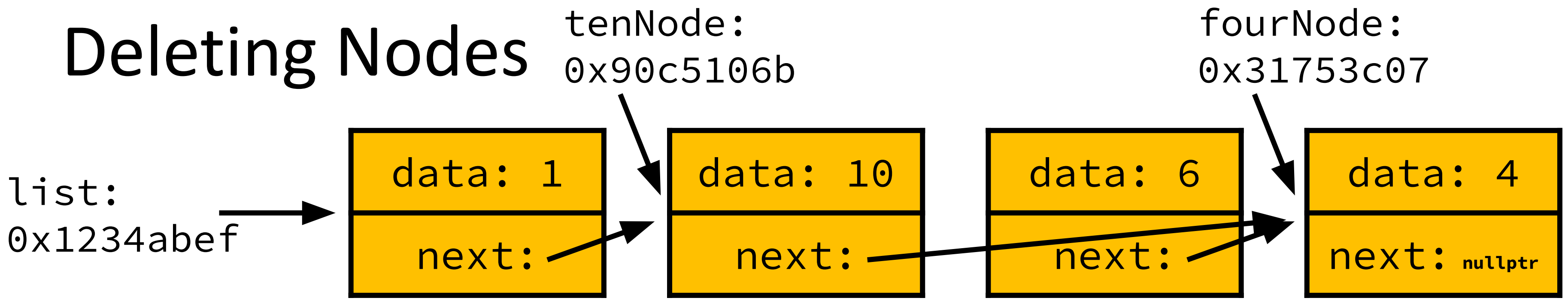
Deleting Nodes



```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;
```

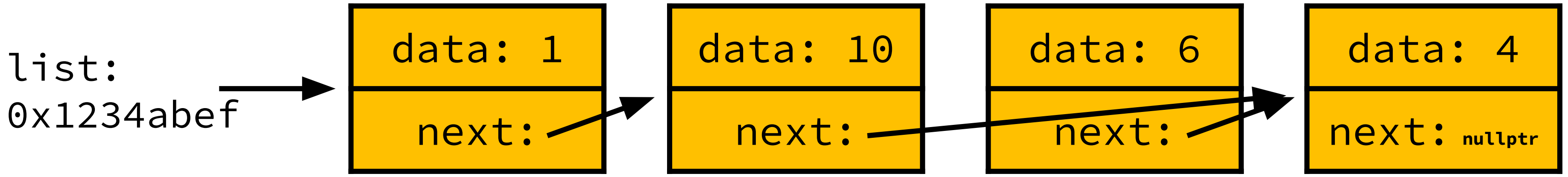
In practice, we wouldn't hard-code the number of `->next`*s like this…*
We'll see linked list traversal shortly!

Deleting Nodes



```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;

tenNode->next = fourNode;
```

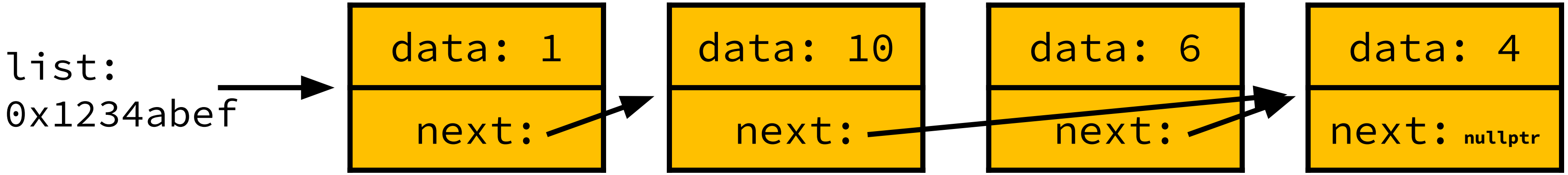
Deleting Nodes *BUGGY



```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;

tenNode->next = fourNode;
```

👥 *What's wrong with this approach?*

Deleting Nodes *BUGGY

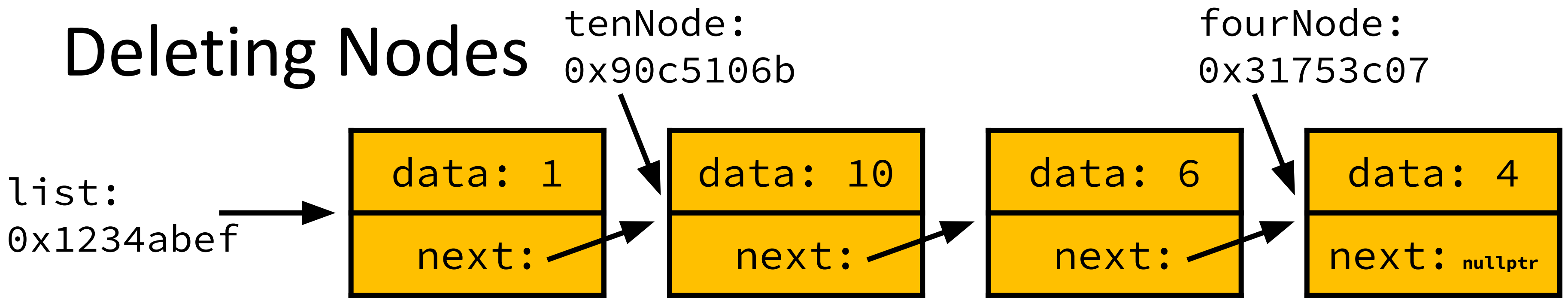


```
Node* tenNode = list->next;
Node* fourNode = list->next->next->next;
tenNode->next = fourNode;
```

MEMORY LEAK 👎

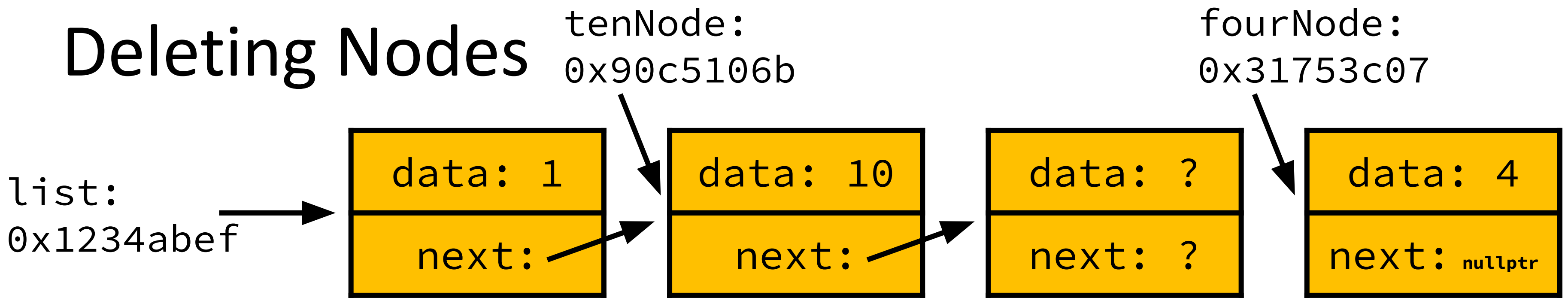
Now, we have no way of referring to the node that contains 6!
We'd like to `delete` it, but we don't have a pointer to it.

Deleting Nodes



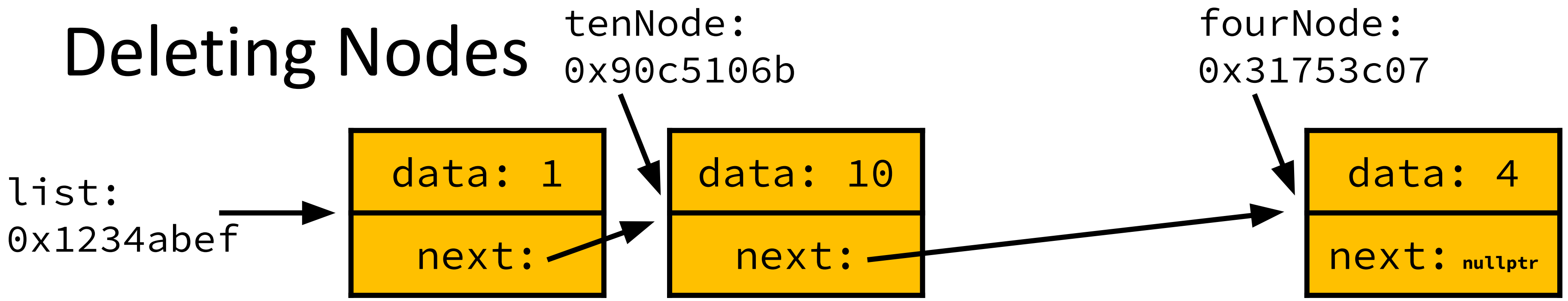
```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;
```

Deleting Nodes



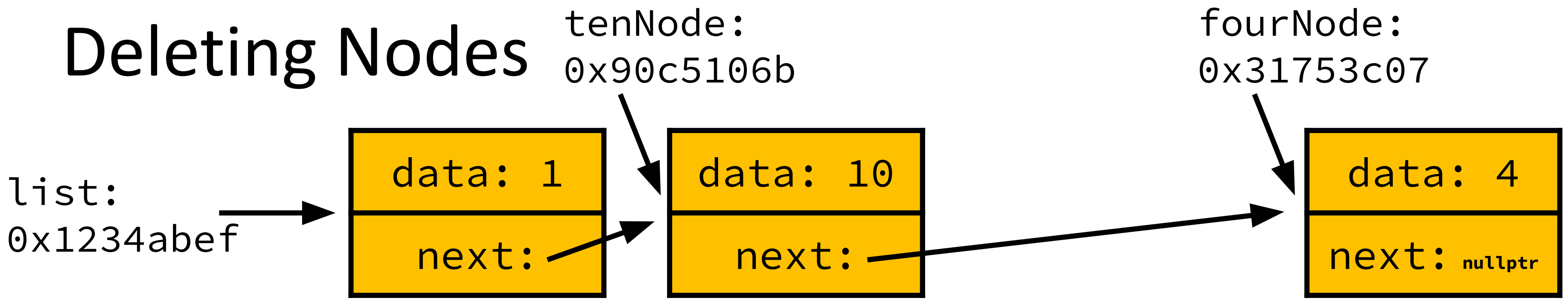
```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;

delete tenNode->next;
```

Deleting Nodes



```
Node* tenNode = list->next;
Node* fourNode = list->next->next->next;
delete tenNode->next;
tenNode->next = fourNode;
```

Deleting Nodes



```
Node* tenNode = list->next;

Node* fourNode = list->next->next->next;

delete tenNode->next;

tenNode->next = fourNode;
```

When deleting a node, we need to free its memory AND rewire the other nodes.

Demo: Traversing a Linked List

🎟️ *Attendance ticket: applications of linked list traversal*

Solution: Traversing a Linked List

```
void printList(Node* list) {
    while (list != nullptr) {
        cout << list->data << endl;
        list = list->next;
    }
}

int measureList(Node* list) {
    int count = 0;
    while (list != nullptr) {
        count++;
        list = list->next;
    }
    return count;
}
```

```
void freeList(Node* list) {
    while (list != nullptr) {
        Node* temp = list->next;
        delete list;
        list = temp;
    }
}
```

Recap

- Downsides of arrays
- Benefits of linked lists
- Basic linked list operations
    - Initializing nodes
    - Adding nodes: Append / Prepend / Insert
    - Deleting nodes
- Traversing a linked list

Thank you!