CS 106X
Lecture 16:
Linked Lists

Wednesday, February 15, 2017

Programming Abstractions (accelerated)
Fall 2016
Stanford University
Computer Science Department

Lecturer: Chris Gregg

reading:
Programming Abstractions in C++, Chapter 11

Today's Topics

- Logistics
  - Midterm information:
    - Thursday February 23rd
    - Midterm Review Session: Monday, 7:30-8:30pm, Location TBA
    - There will be practice midterms on the website Friday.

- Linked Lists
  - Could you architect a Queue?
  - Nodes
  - Linked Lists
  - The Towers of Gondor
  - Do nodes have names?
  - Big O?
  - Stack made from a Linked List
  - Queue made with a Linked List

Your job: Architect a Queue

Easiest Solution...

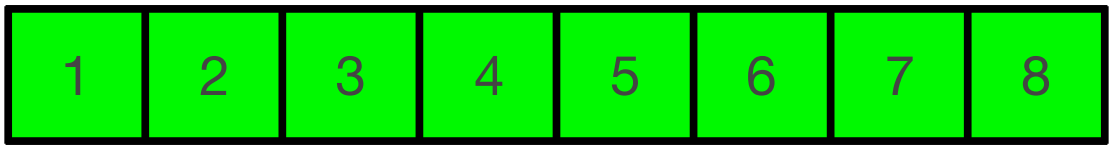
```
class QueueInt {                // in QueueInt.h
public:
    QueueInt ();                // constructor

    void enqueue(int value); // append a value
    int dequeue();              // return the first-in value

private:
    Vector<int> data;       // member variables
};
```

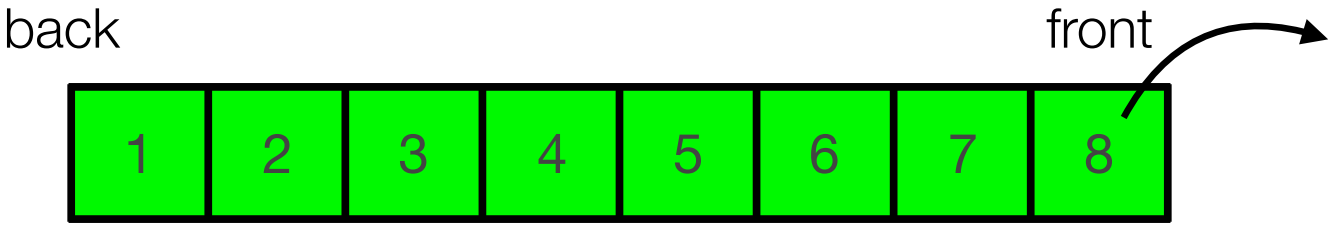
You're next!

back front



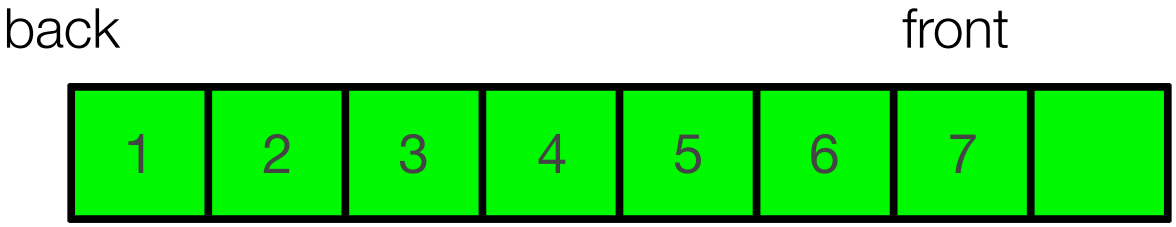
dequeue()

You're next!



dequeue()

Excuse Me, Coming Through



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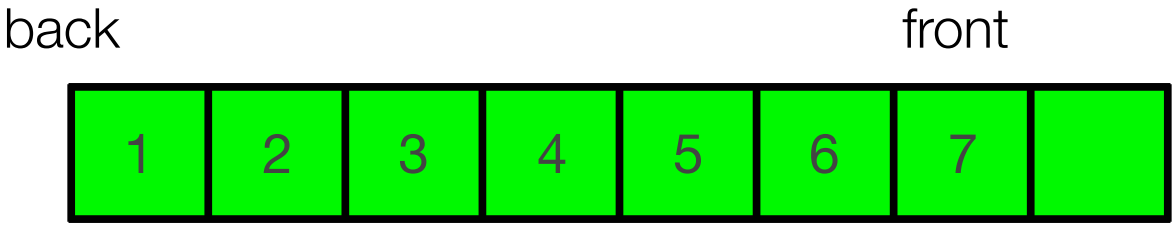

enqueue(42)

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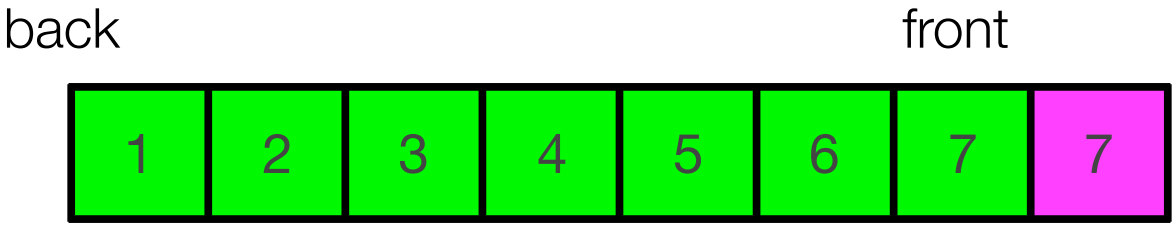

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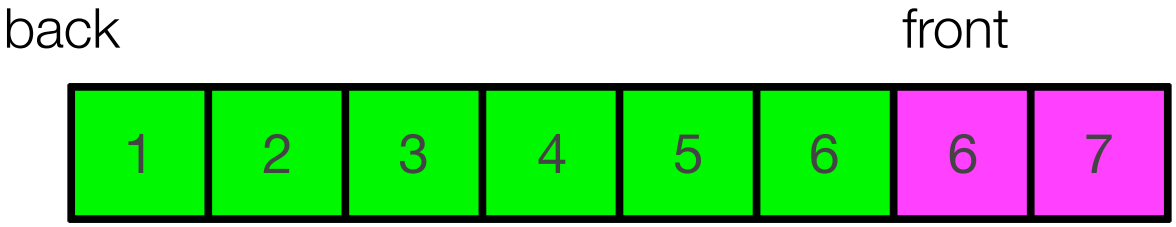

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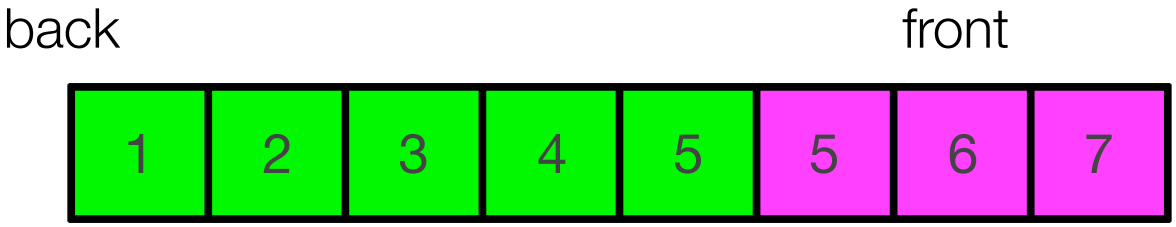

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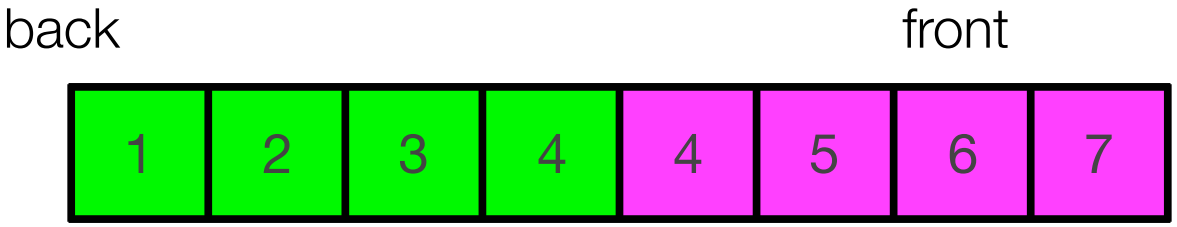

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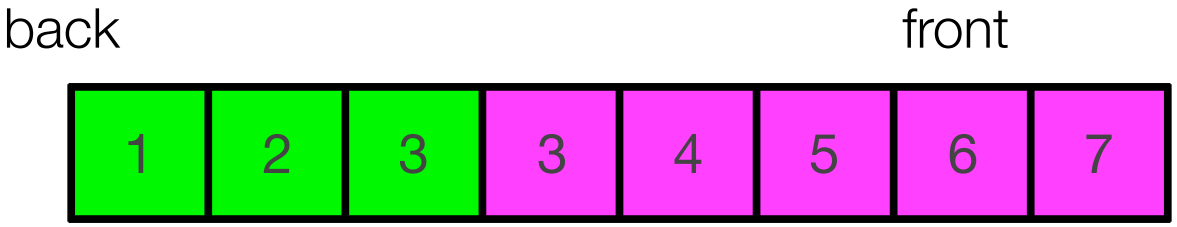

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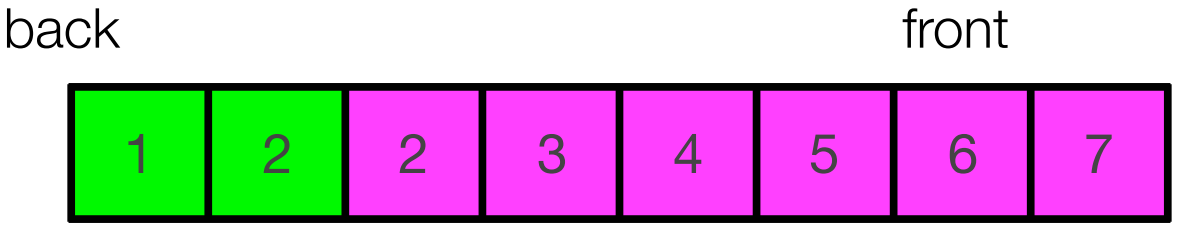

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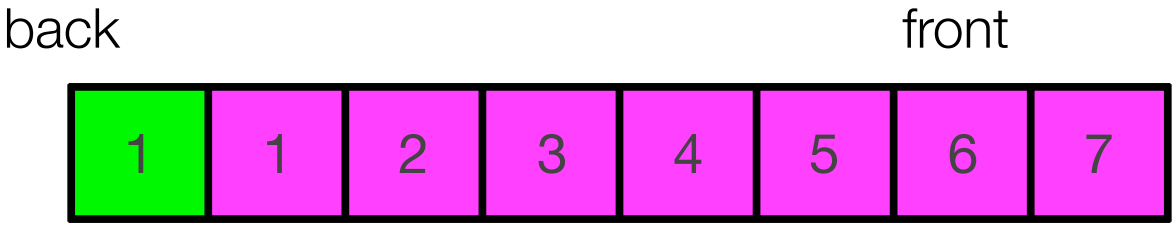

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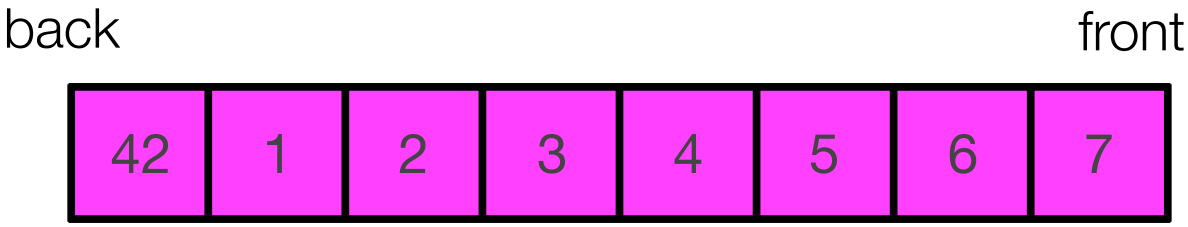


enqueue(42)

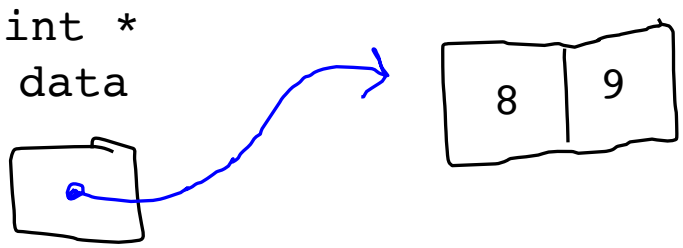
Queue as Vector: Big O

Enqueue: O(n)

Dequeue: O(1)


WE CAN DO
BETTER

And Now for Something Completely Different



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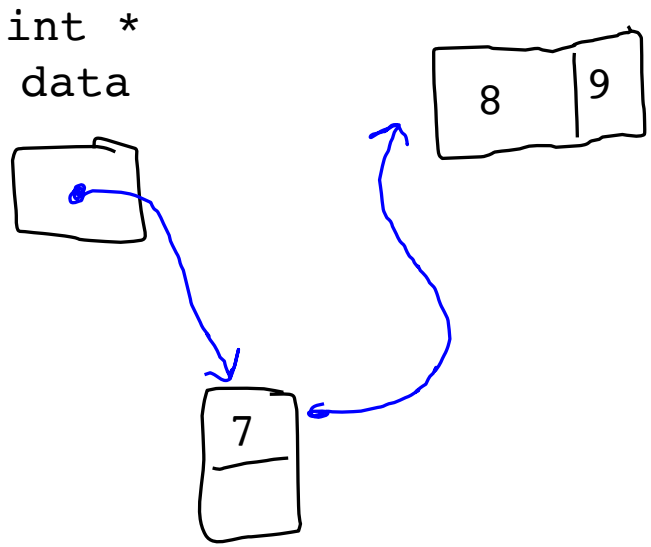

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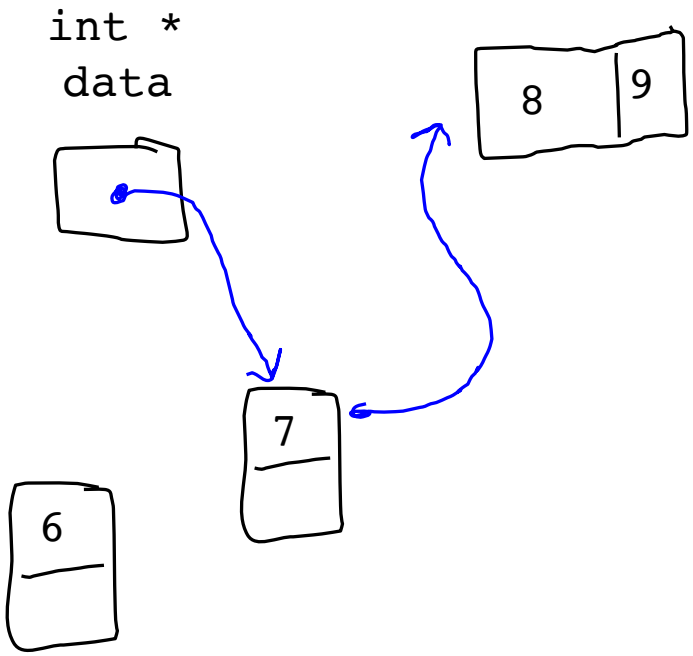

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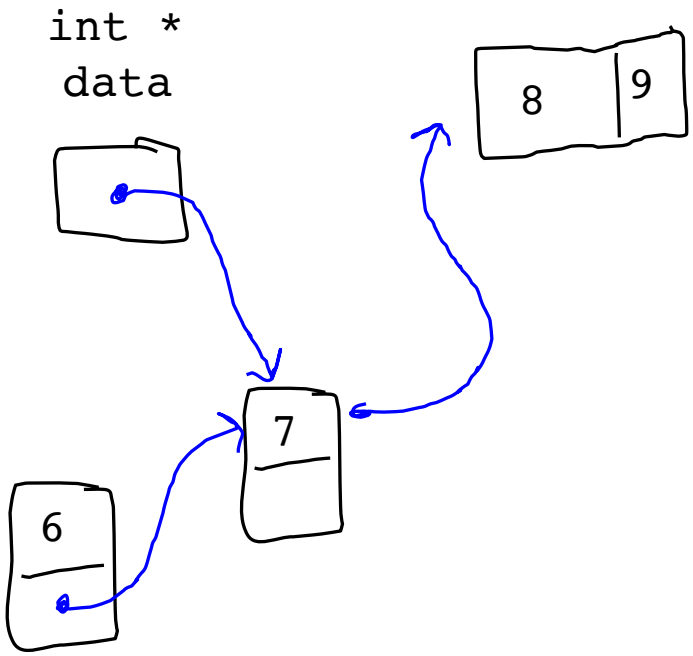

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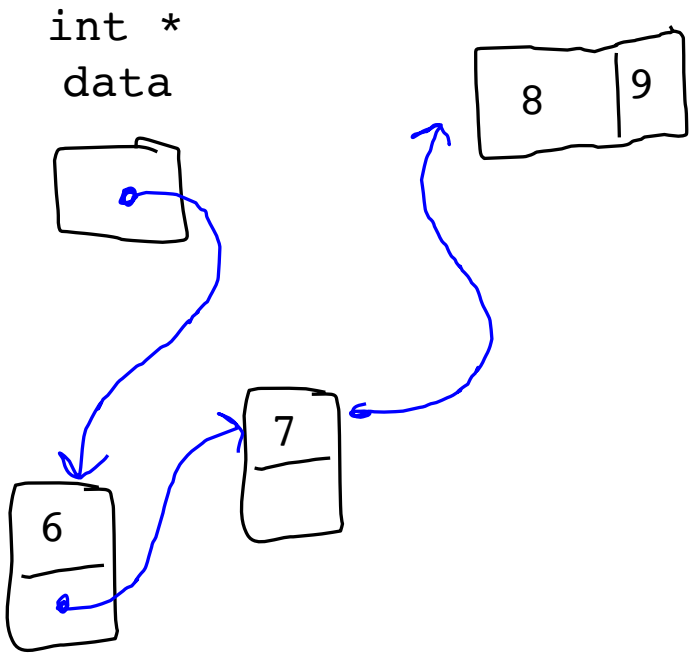

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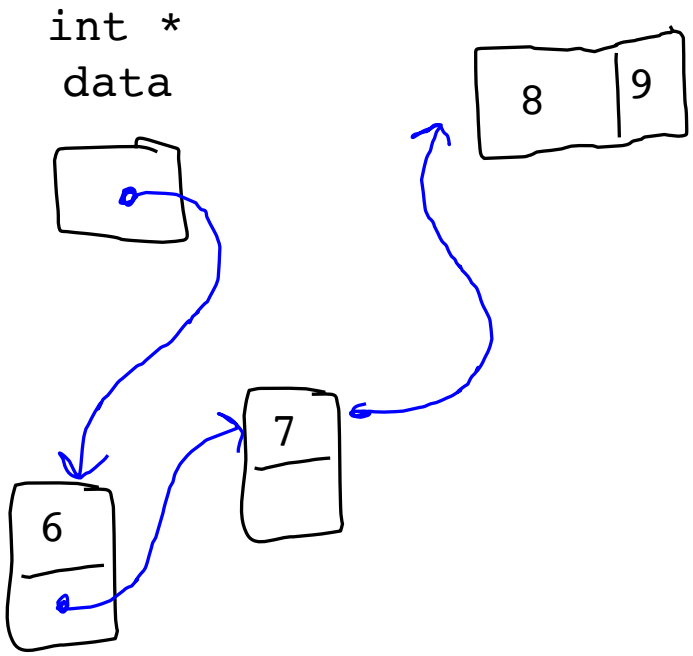
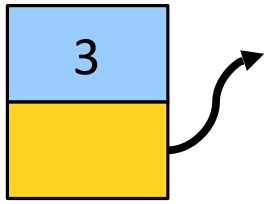
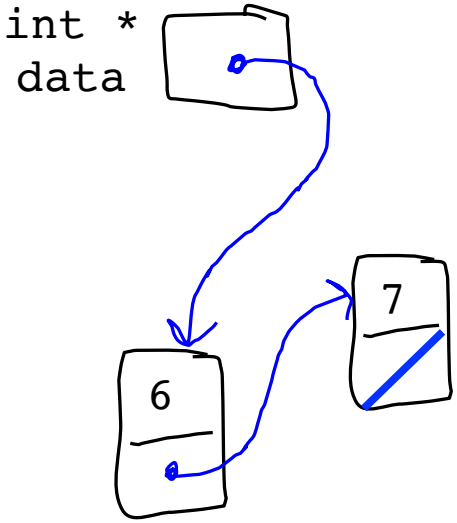


Now we have a way to add to the front in O(1) time!

Linked List

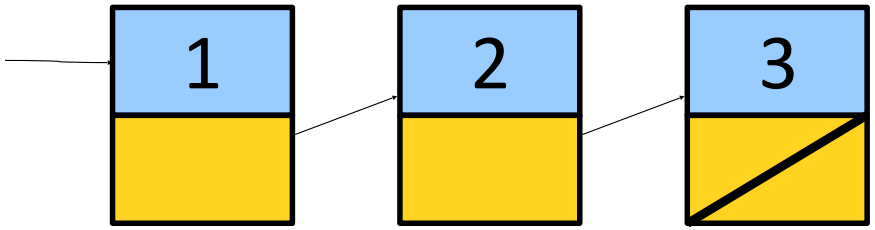
- A linked list is a chain of nodes.
- Each node contains two pieces of information:
  - Some piece of data that is stored in the sequence
  - A link to the next node in the list.
- We can traverse the list by starting at the first cell and repeatedly following its link.





Linked Lists

- 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.



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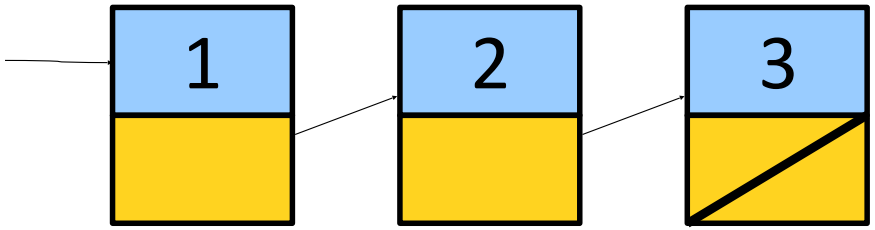

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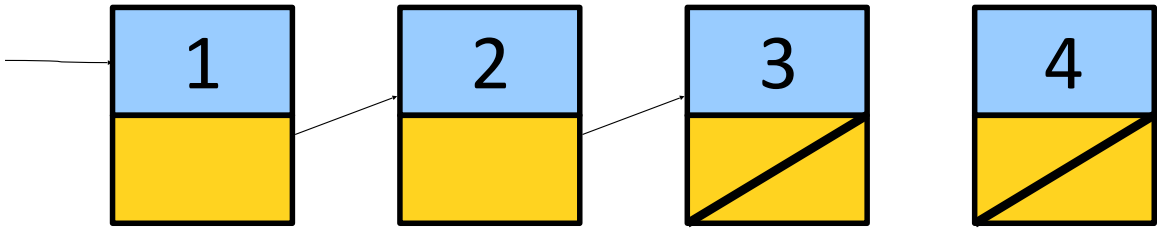

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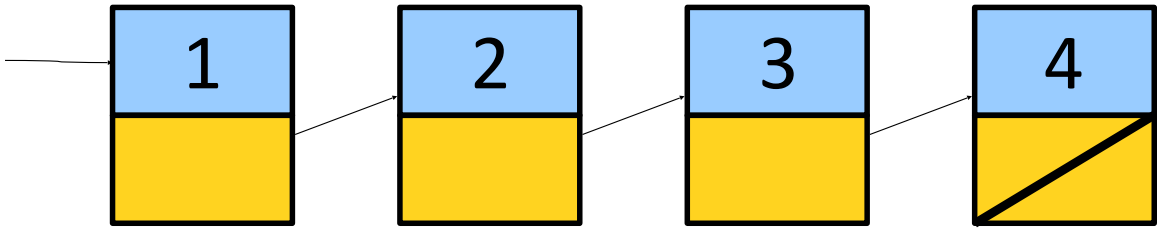

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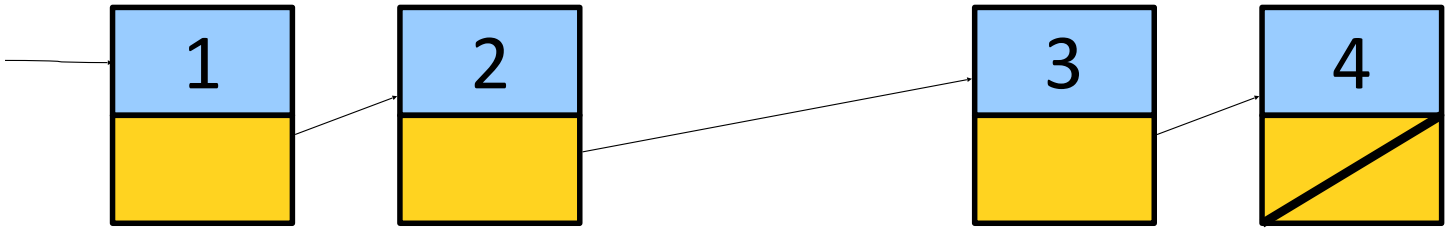

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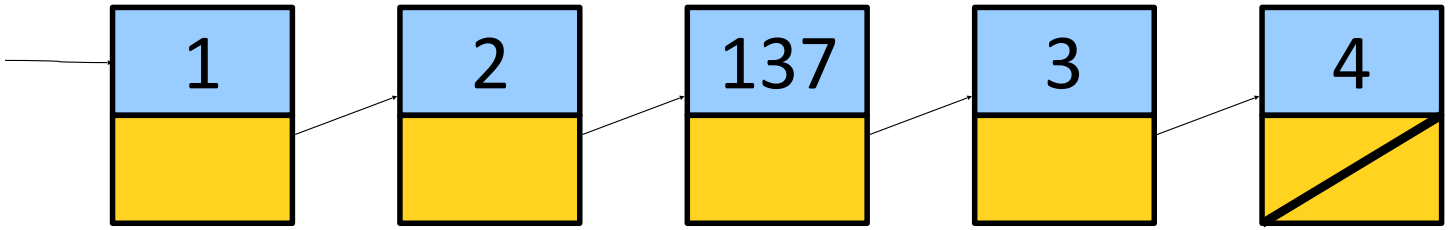

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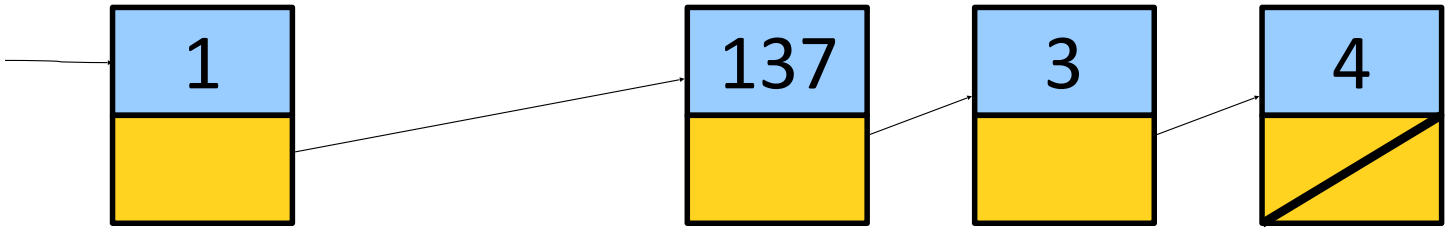

Why Linked Lists?

- Can efficiently splice new elements into the list or remove existing elements anywhere in the list.
- Never have to do a massive copy step;
- Has some tradeoffs; we'll see this later.

Linked List Structure

- For simplicity, let's assume we're building a linked list of strings.
- We can represent a node in the linked list as a structure:

```
struct Node {
    string value;
    /* ? */ next;
};
```

Linked List of Strings

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- We can represent a node in the linked list as a structure:

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struct Node {
    string value;
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};
```

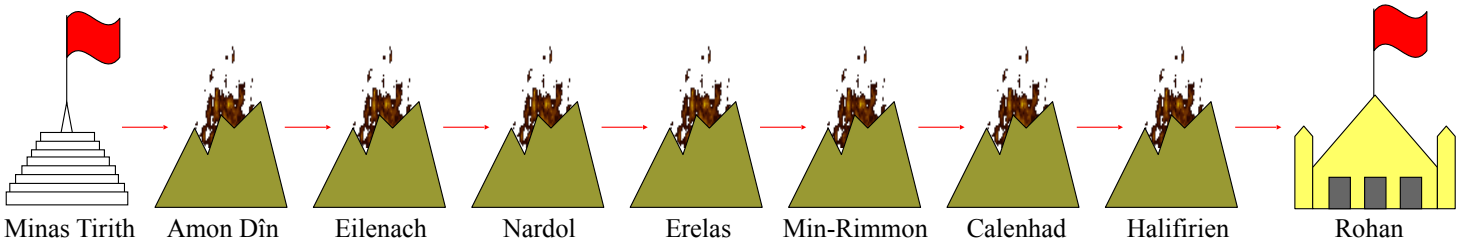
- The structure is defined recursively!

Always!

Draw a picture

Lord of the Linked Lists

In a scene that was brilliantly captured in Peter Jackson's film adaptation of *The Return of the King*, Rohan is alerted to the danger to Gondor by a succession of signal fires moving from mountain top to mountain top. This scene is a perfect illustration of the idea of message passing in a linked list.

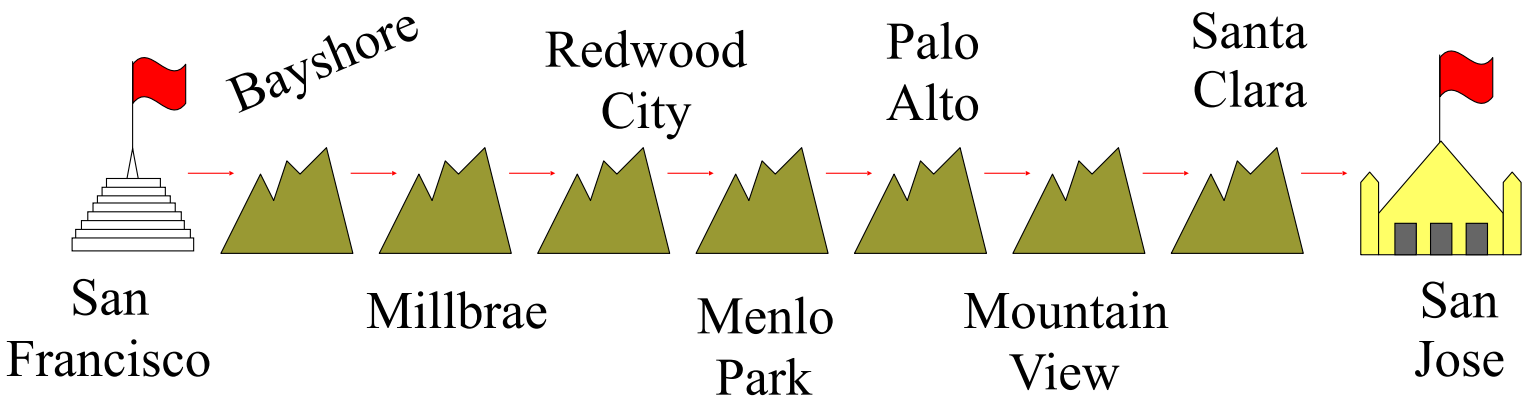



THE LORD OF THE RINGS
THE RETURN OF THE KING
TM

https://www.youtube.com/watch?v=i6LGJ7evrAg

Lord of the Linked Lists

Step 1: Make this linked list



Step 2: Light the fires….

```
Lighting the fire of San Francisco!
```

Lord of the Linked Lists

```
struct Tower {
   string name;   /* The name of this tower     */
   Tower *link;   /* Pointer to the next tower */
};
```

Lord of the Linked Lists

```
// add the first tower
Tower * head = new Tower;
head->name = "San Jose";
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Linked List Trace

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struct Tower{
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};
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```

Linked List Trace

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// main
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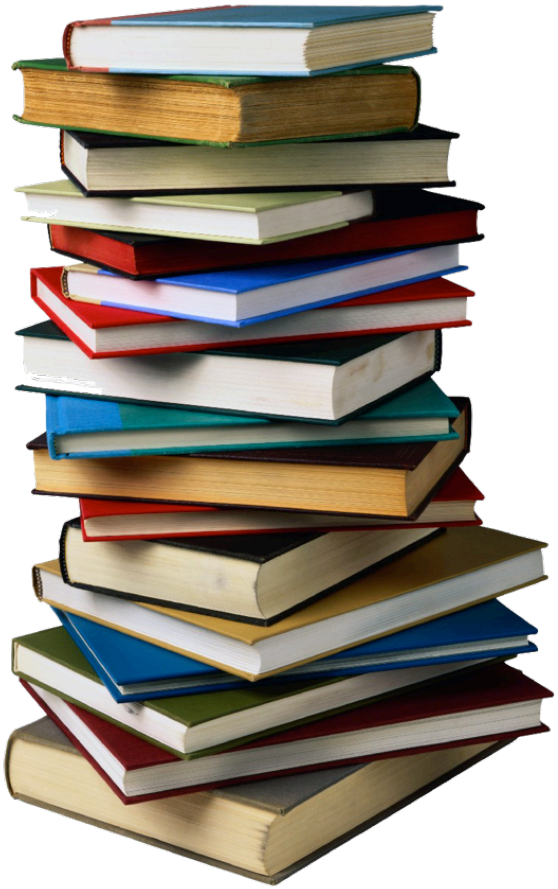
```
Tower *createTower(string name, Tower *link) {
    Tower *tp = new Tower;
    tp->name = name;
    tp->link = link;
    return tp;
}
```

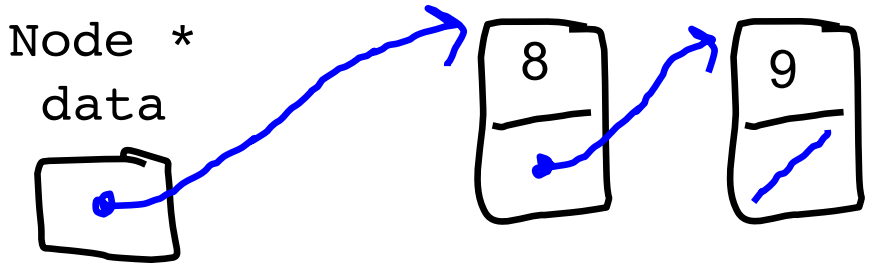
```
void signal(Tower *start) {
    if (start != NULL) {
        cout << "Lighting " << start->name << endl;
        signal(start->link);
    }
}
```

```
signal(head);
```

How is the Stack Implemented?



```
struct Node{
   int value;     /* The value of this elem    */
   Node *link;    /* Pointer to the next node */
};
```


Node *
data
8
9

Stack

```
class StackInt {              // in StackInt.h
public:
    StackInt ();              // constructor

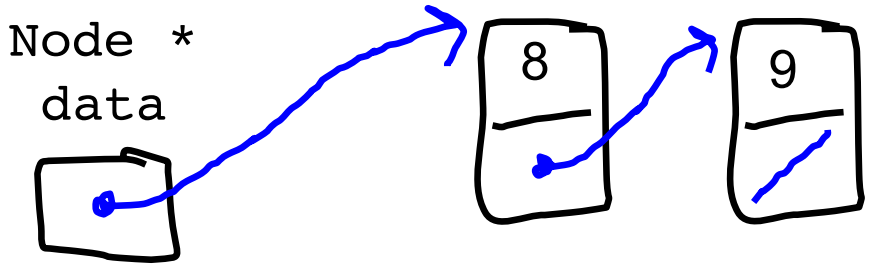
    void push(int value); // append a value
    int pop();                // return the first-in value

private:
    struct Node {
      int value;
      Node * link;
    };
    Node * data;      // member variables
};
```

Stack Implementation

```
void StackInt::push(int v) {
    Node * temp = new Node;
    temp->value = v;
    temp->link = data;
    data = temp;
}

int StackInt::pop() {
    int toReturn = data->value;
    Node * temp = data;
    data = temp->link;
    delete data;
}
```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data
8
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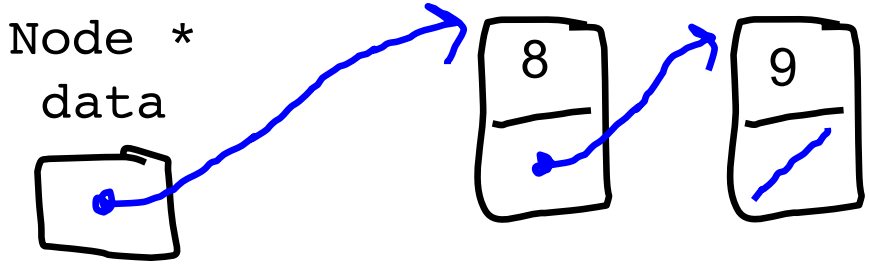
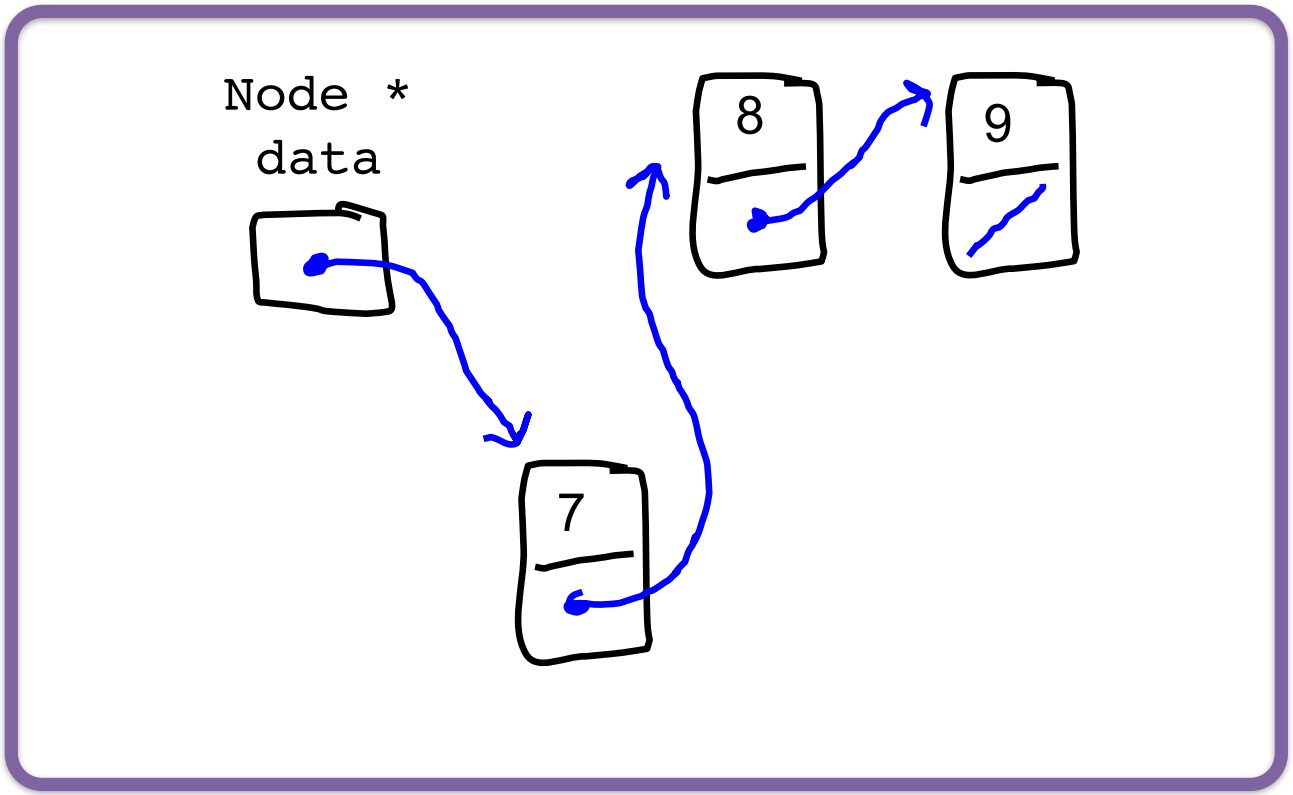
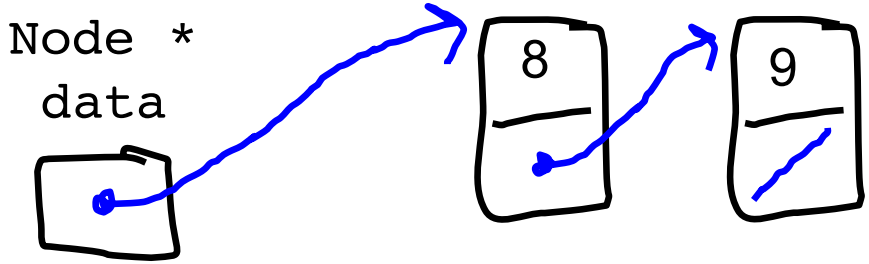



```
push(7);
```

Goal of Push

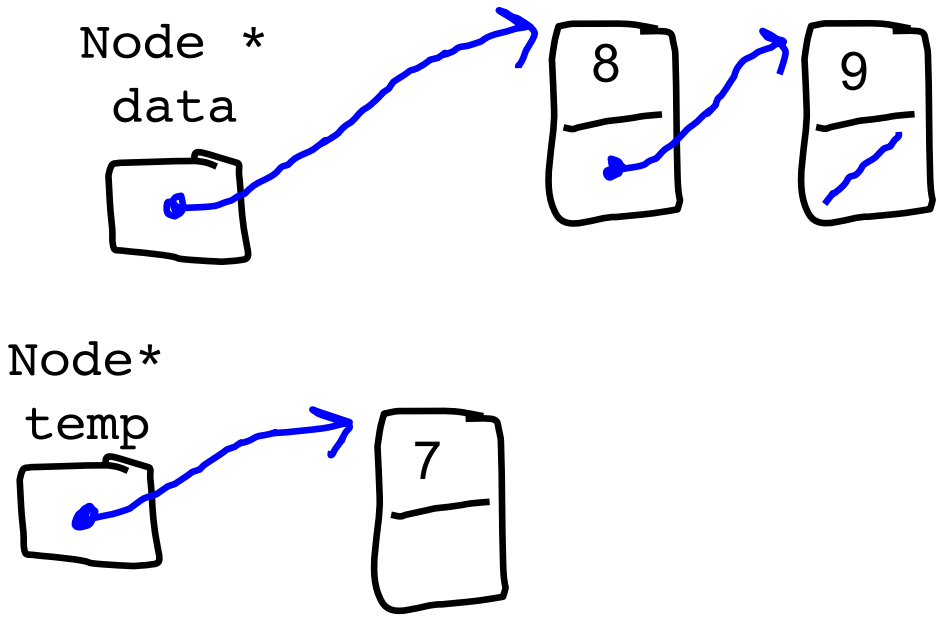





```
push(7);
```

Stack is a Linked List

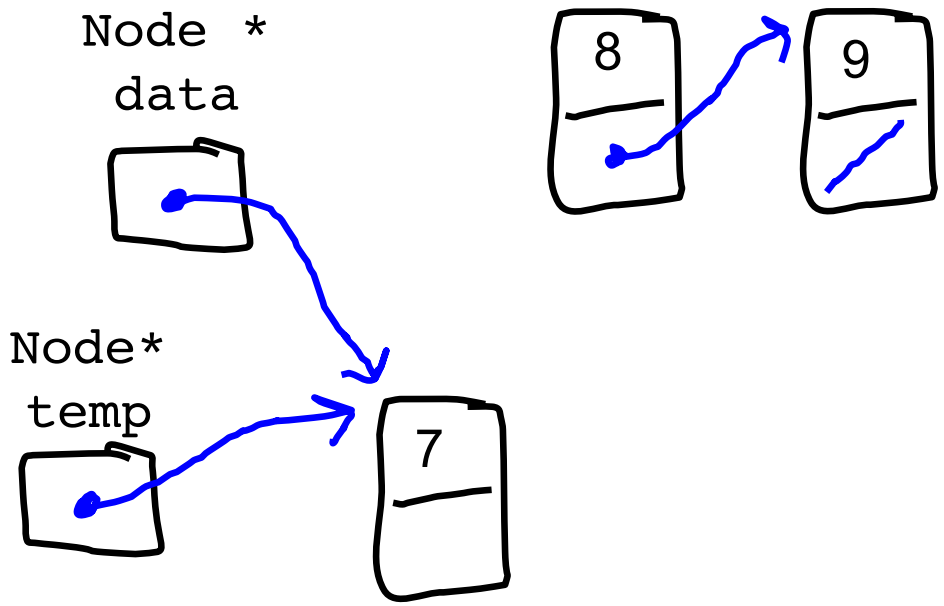
```
push(7);
```



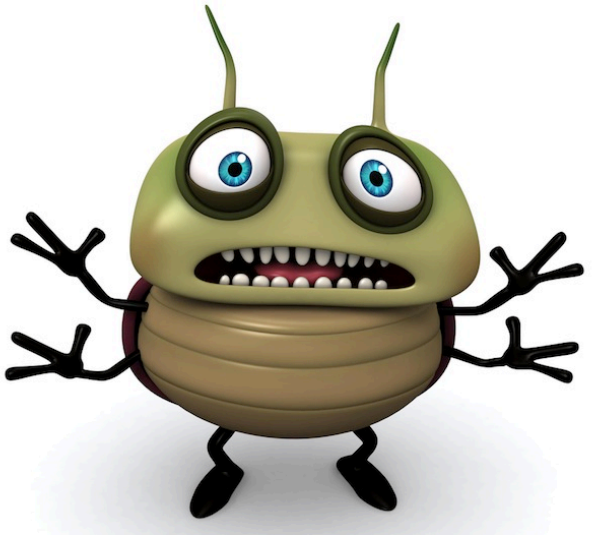

```
Node * temp =  new Node;
temp -> value = 7;
```

Stack is a Linked List

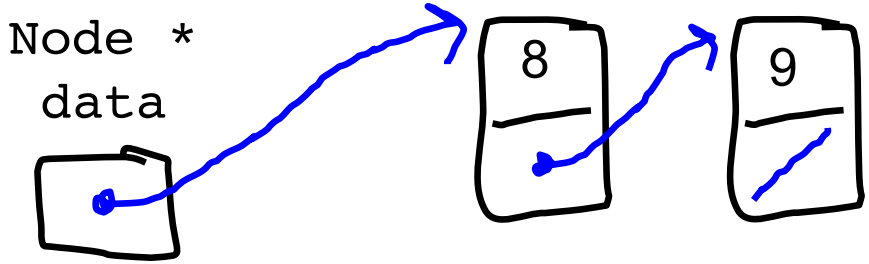
```
push(7);
```




```
data = temp;
```

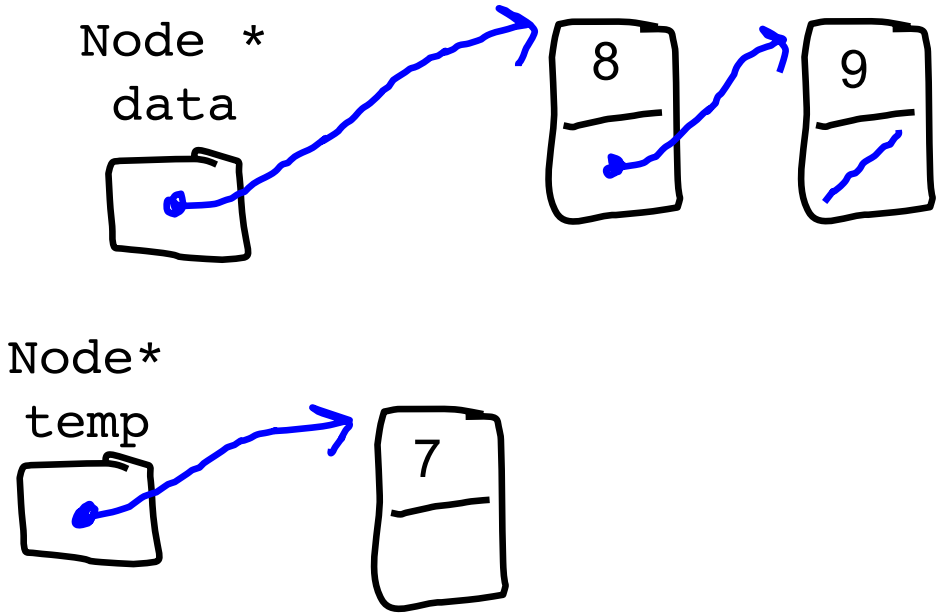


BRAAWWRRRR!



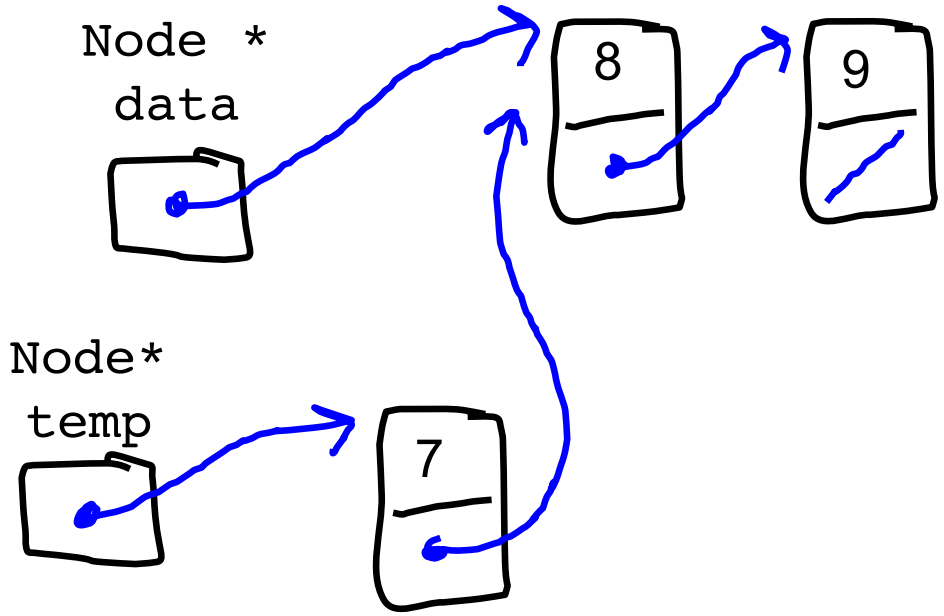

```
push(7);
```

```
push(7);
```



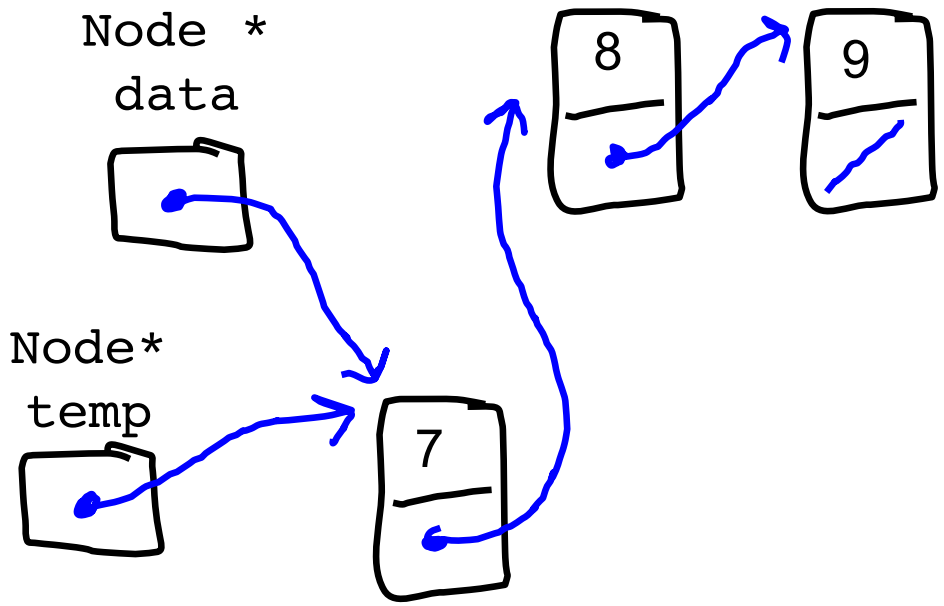

```
Node * temp =  new Node;
temp -> value = 7;
```

```
push(7);
```



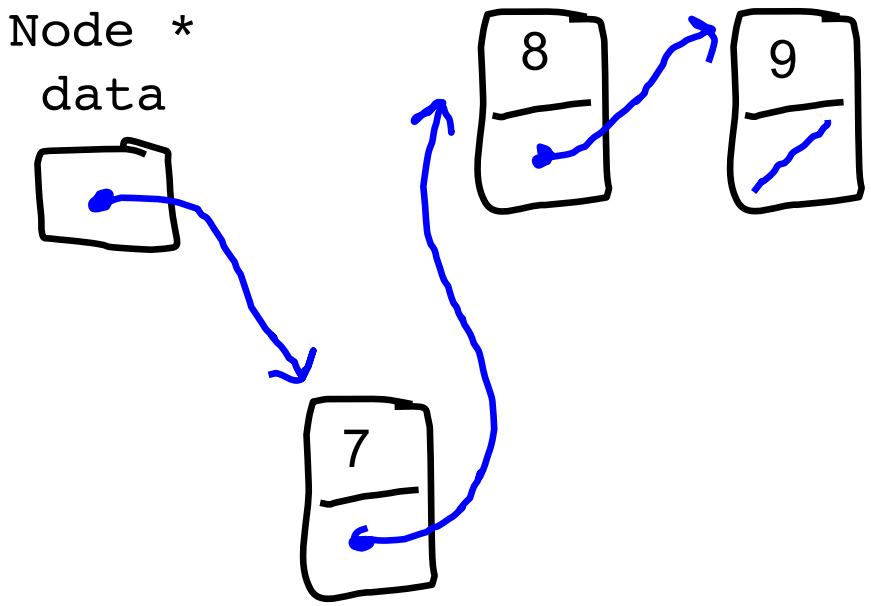

```
temp -> link = data;
```

```
push(7);
```




```
data = temp;
```

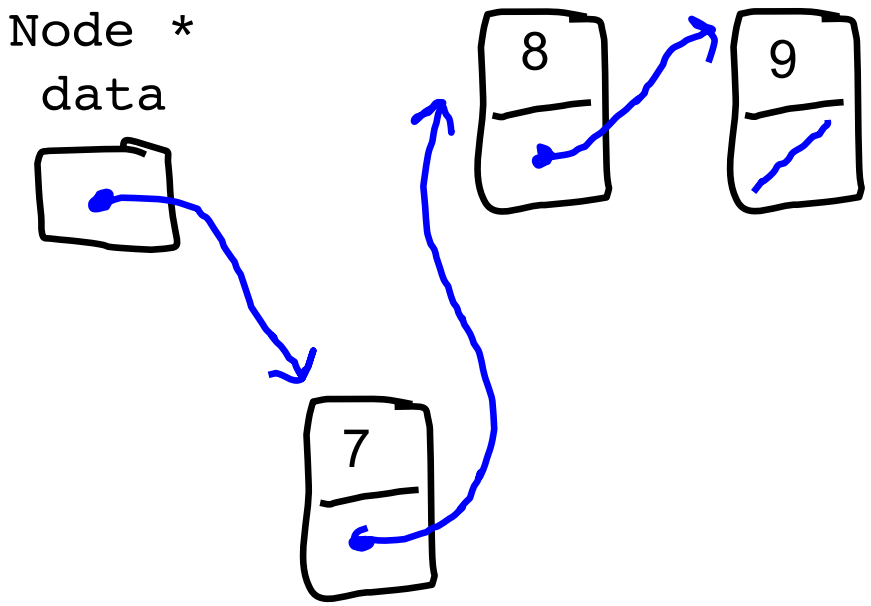
```
push(7);
```



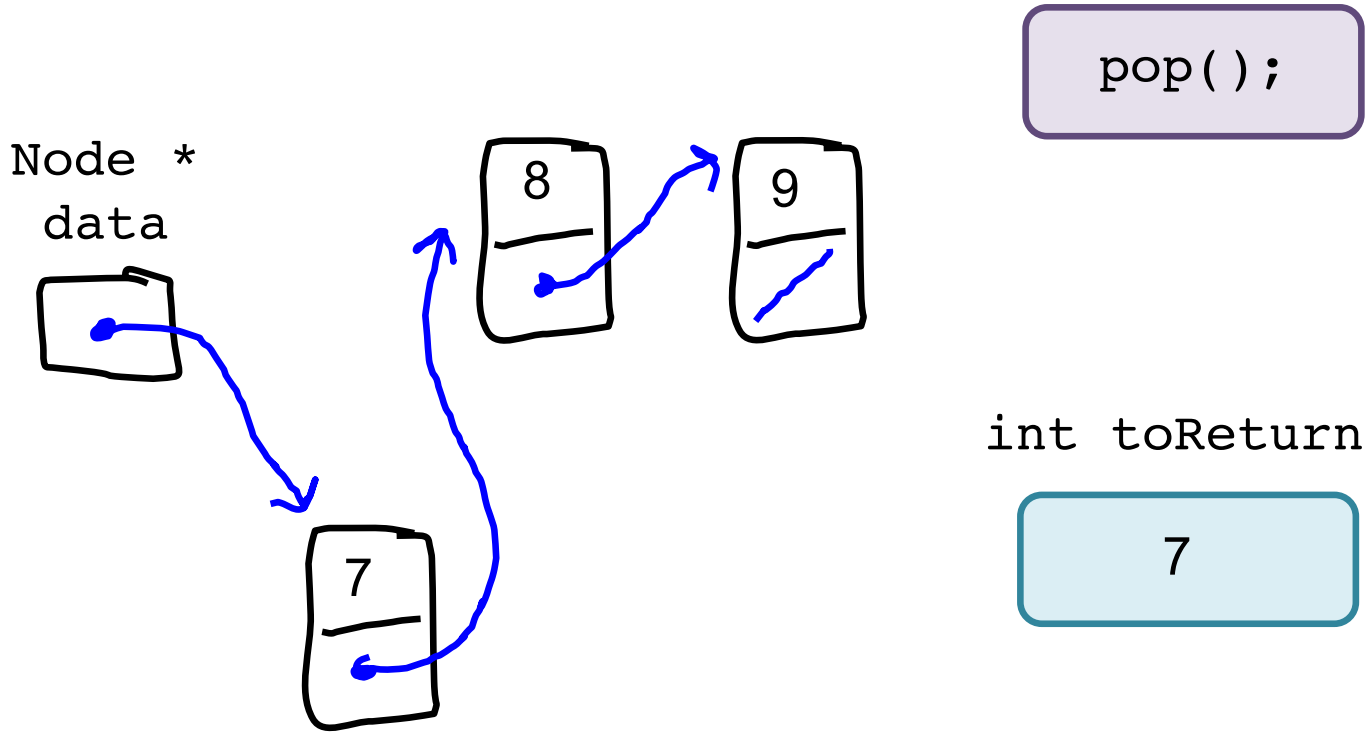
exit function

Stack is a Linked List

```
pop();
```

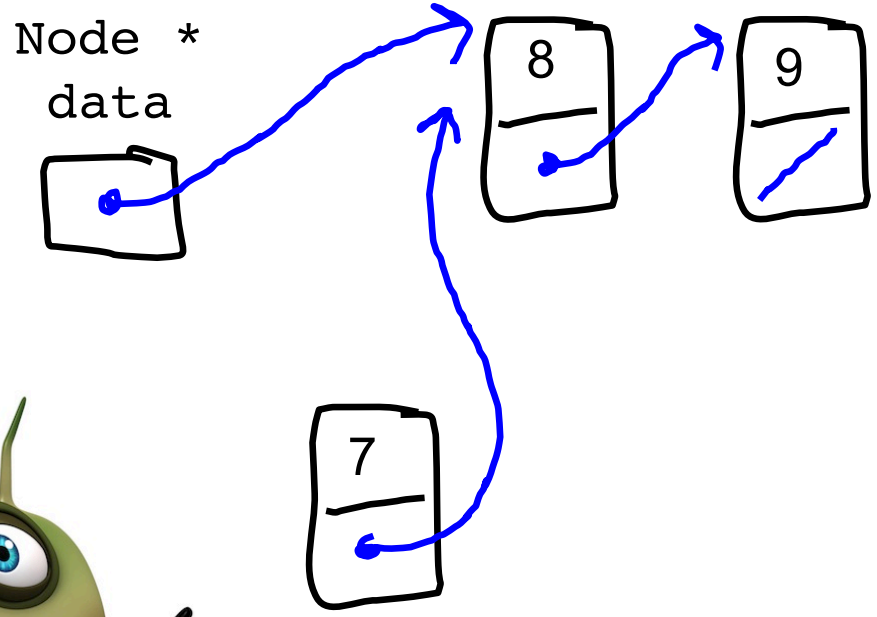


Stack is a Linked List




```
int toReturn = data->value;
```

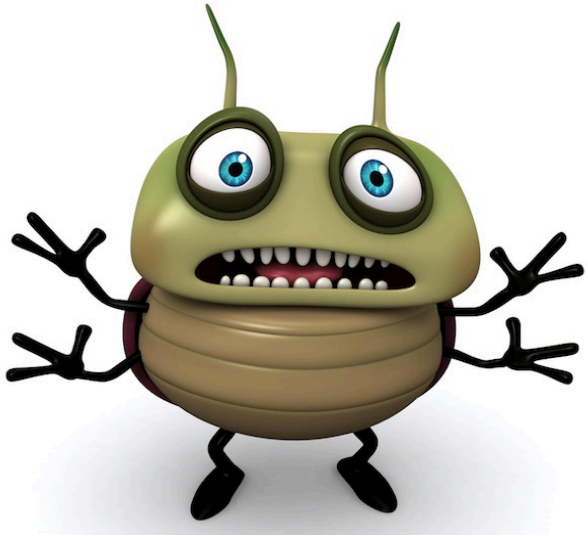
Stack is a Linked List




```
pop();
```

```
int toReturn
```

```
7
```

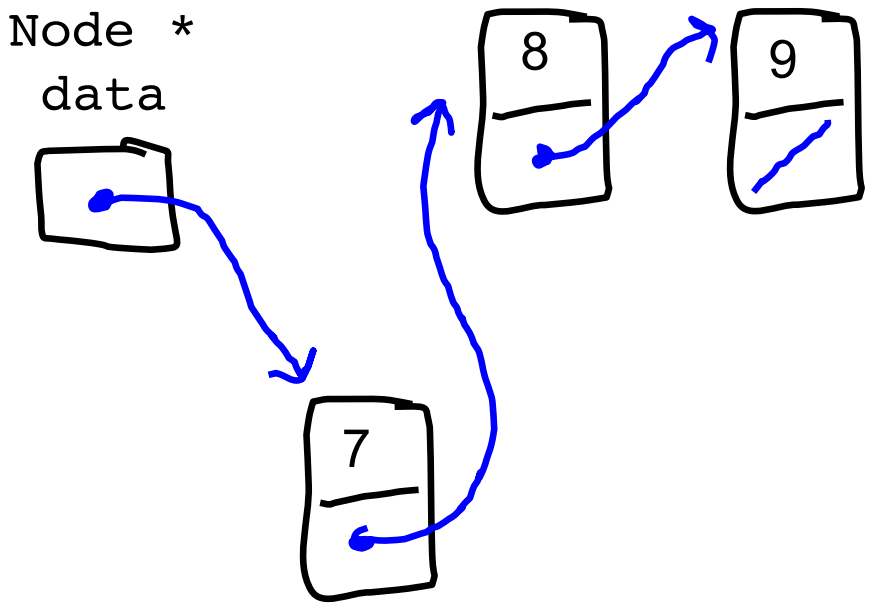


```
data = data->link;
```

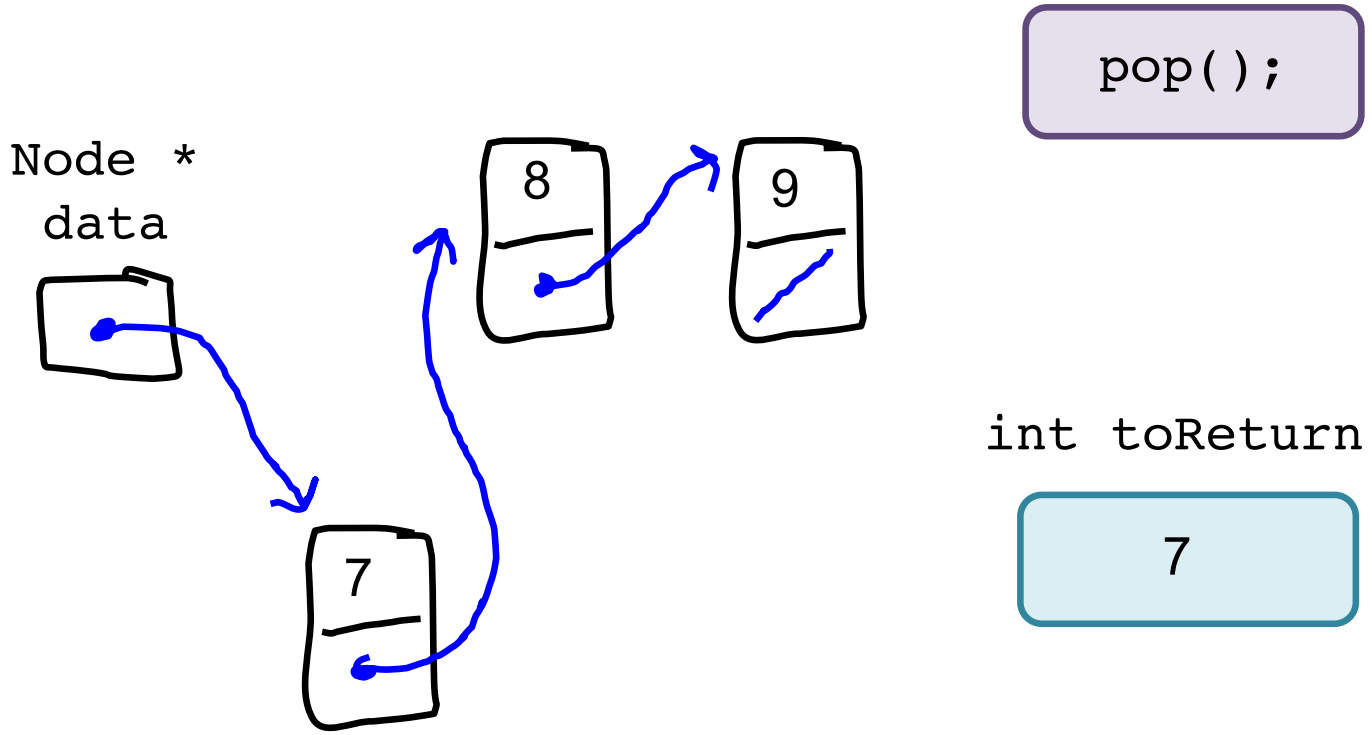
That didn’t work. Let’s try again…

Stack is a Linked List

```
pop();
```



Stack is a Linked List

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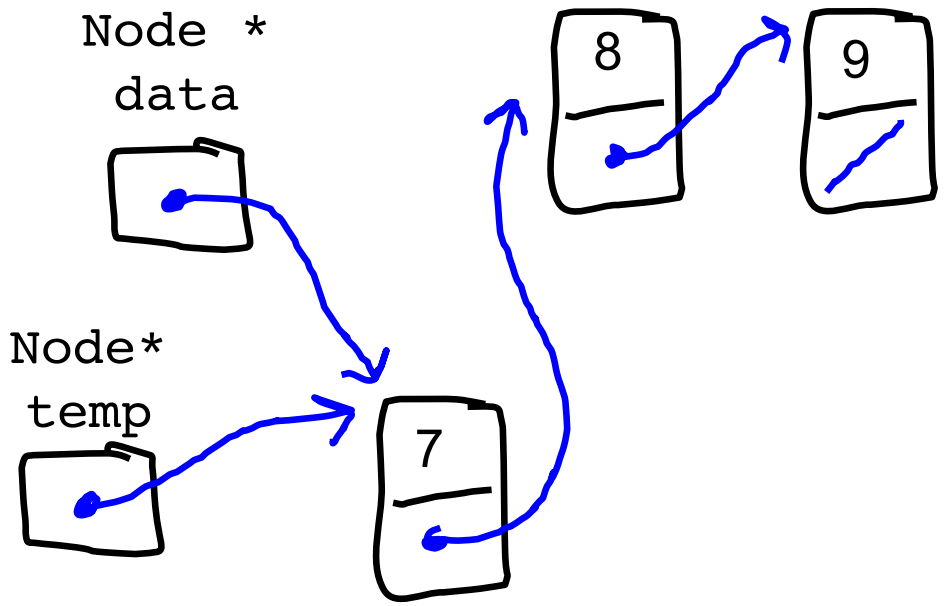
Stack is a Linked List



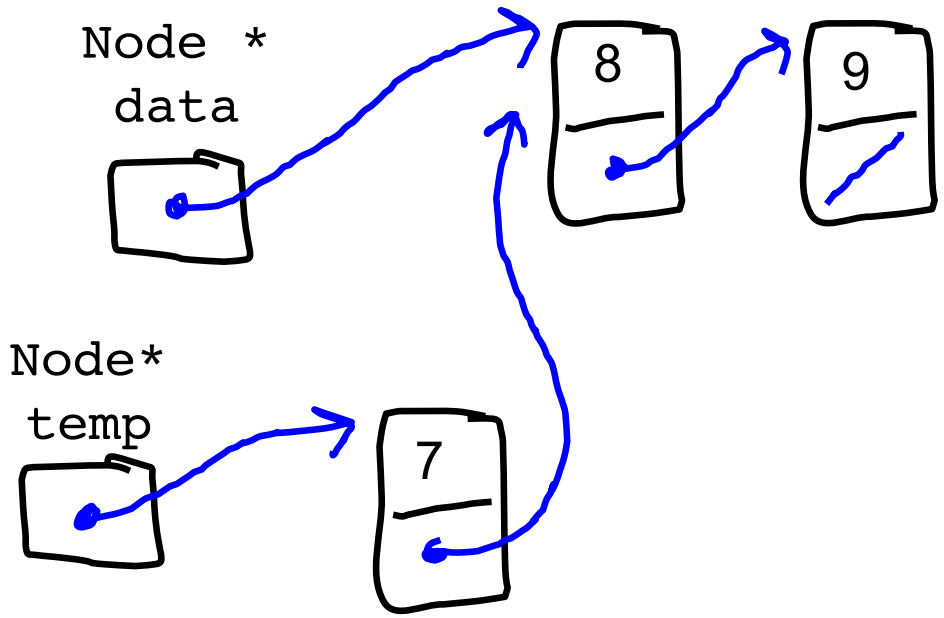

```
pop();
```

```
int toReturn
```

```
7
```

```
Node * temp = data;
```

Stack is a Linked List




```
pop();
```

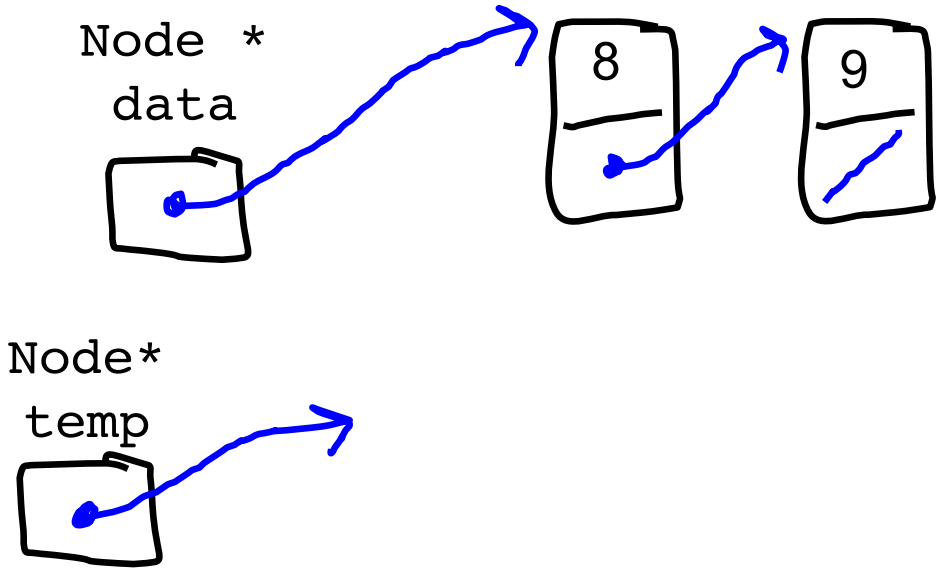
```
int toReturn
```

```
7
```

```
data = temp->link;
```

Stack is a Linked List

```
pop();
```

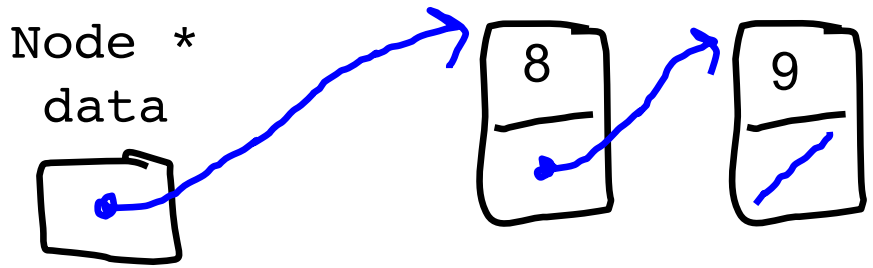



```
int toReturn
```

```
7
```

```
delete temp;
```

Stack is a Linked List




```
pop();
```

```
int toReturn
```

7

```
return toReturn;
```

Stack

```
class StackInt {              // in StackInt.h
public:
    StackInt ();              // constructor

    void push(value);          // append a value
    int pop();                // return the first-in value

private:
    struct Node {
      int value;
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    Node * data;      // member variables
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```

Stack Implementation

```
void StackInt::push(int v) {
    Node * temp = new Node;
    temp->value = v;
    temp->link = data;
    data = temp;
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int StackInt::pop() {
    int toReturn = data->value;
    Node * temp = data;
    data = temp->link;
    delete temp;
    return toReturn;
}
```

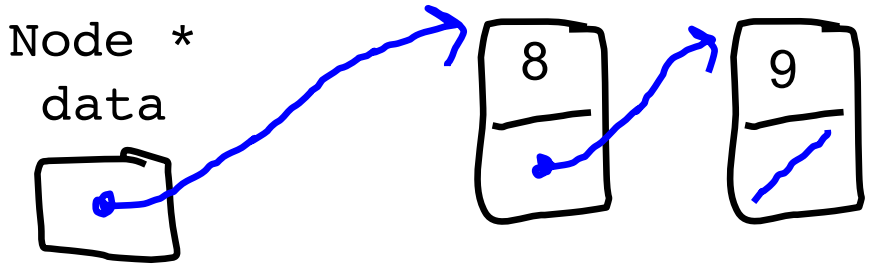
Stack Implementation: Big O?

Big O of `push()`? O(1)

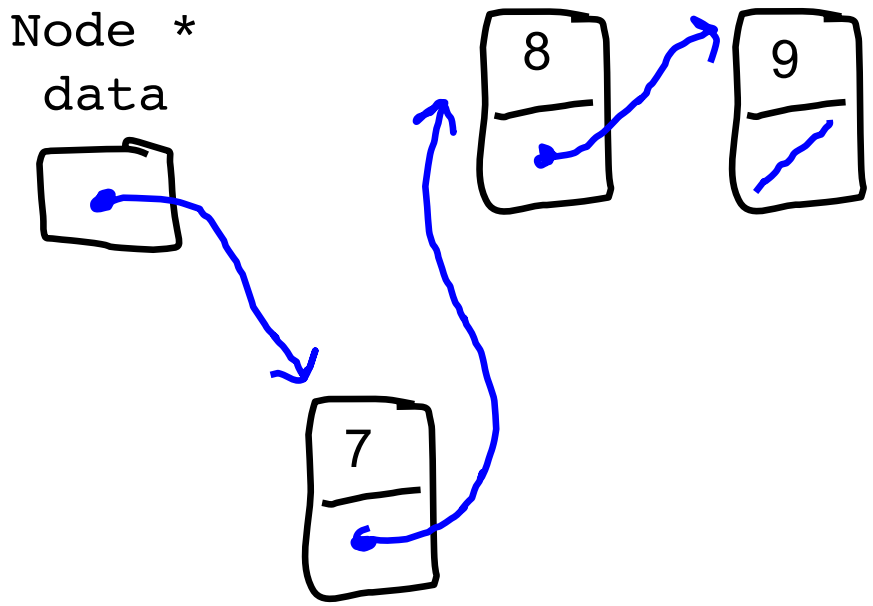
Big O of `pop()`? O(1)

Yay!

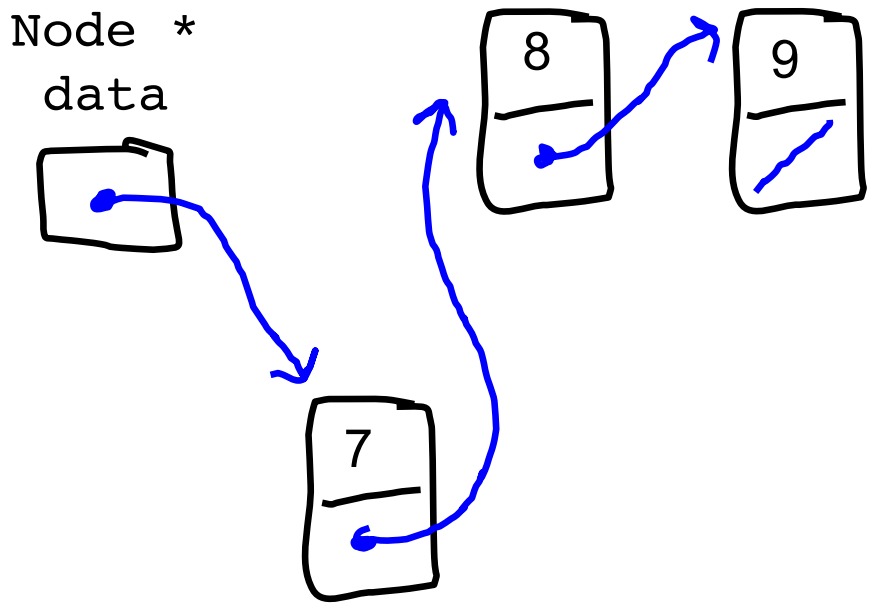
Queue?



Queue Enqueue?

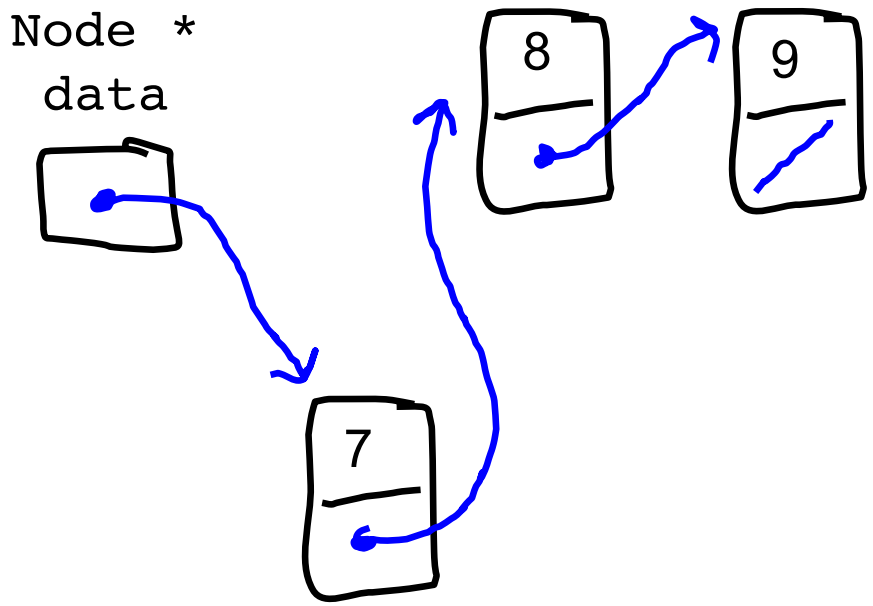


Queue Enqueue?

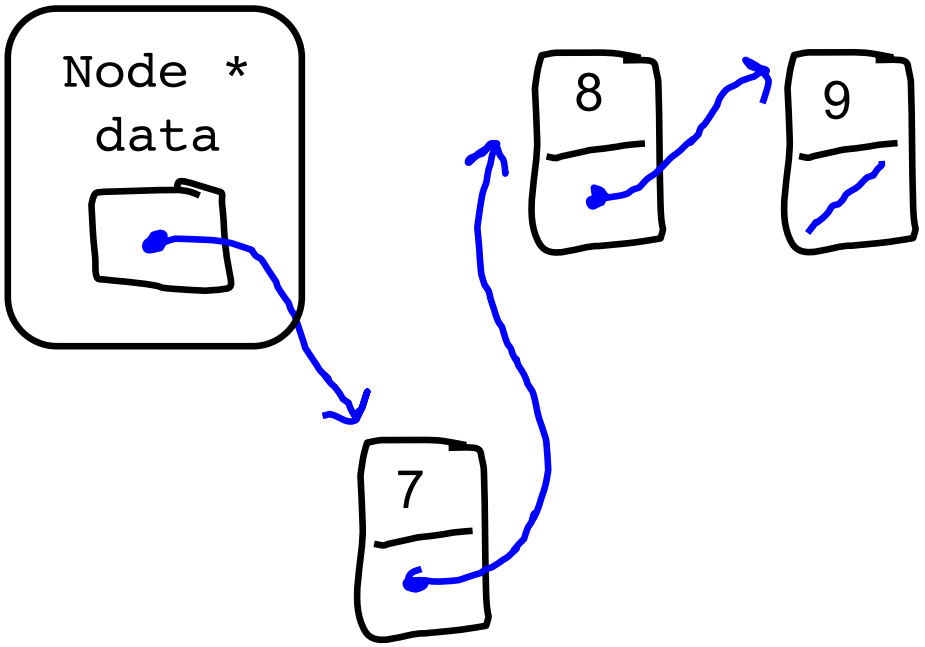


O(1)

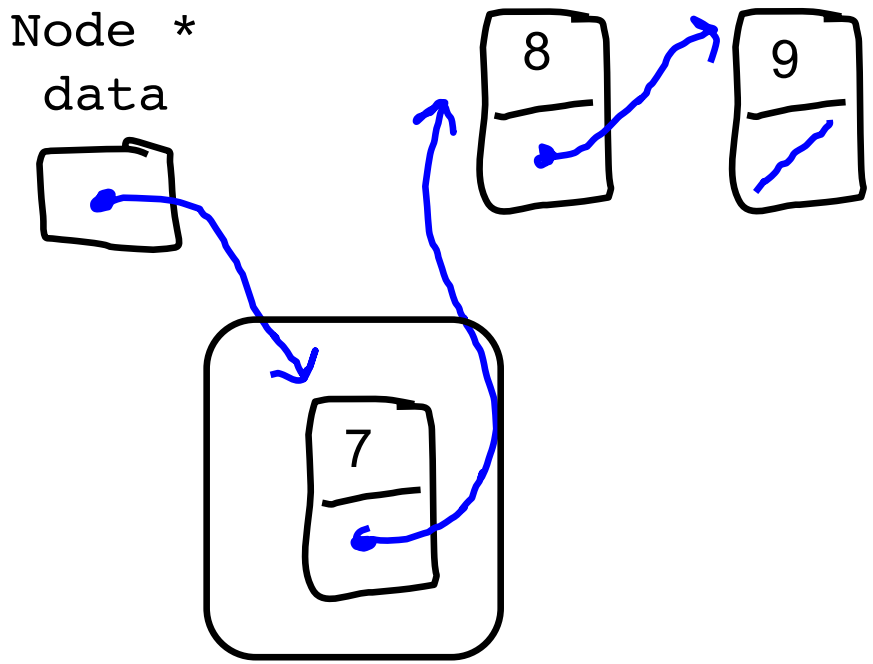
Queue Dequeue?



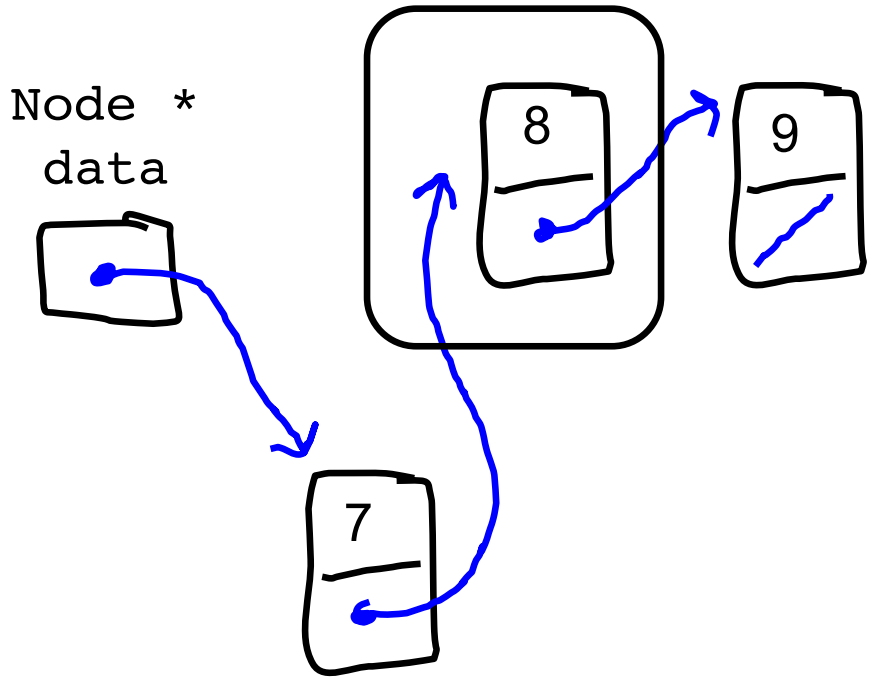
Queue Dequeue?



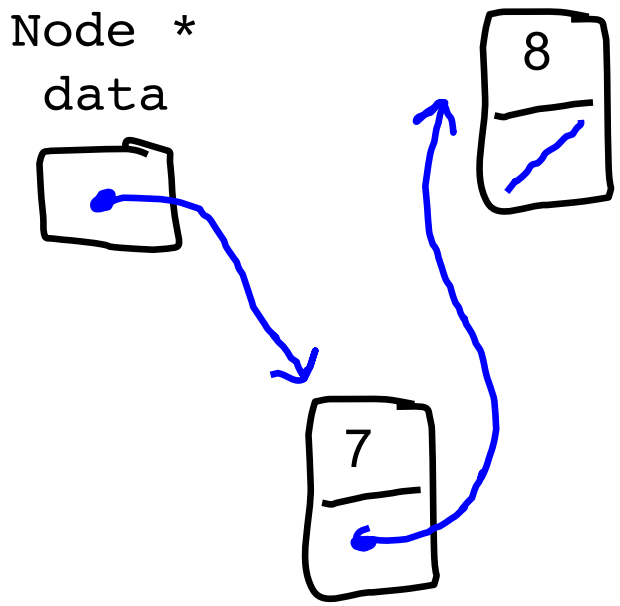
Queue Dequeue?



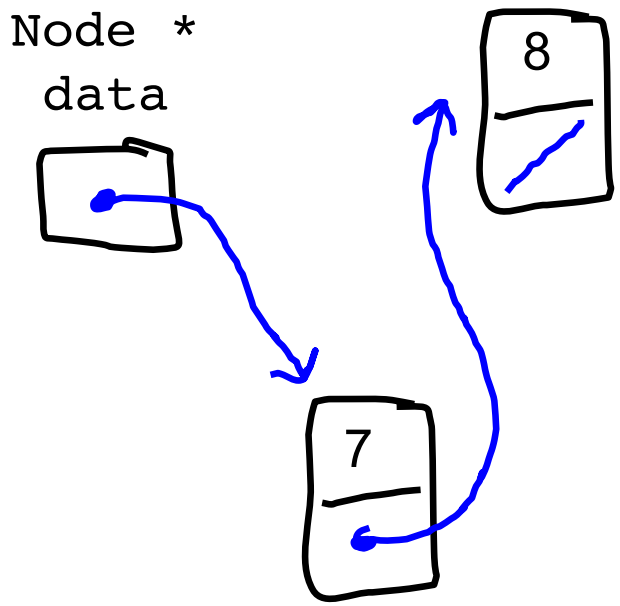
Queue Dequeue?



Queue Dequeue?



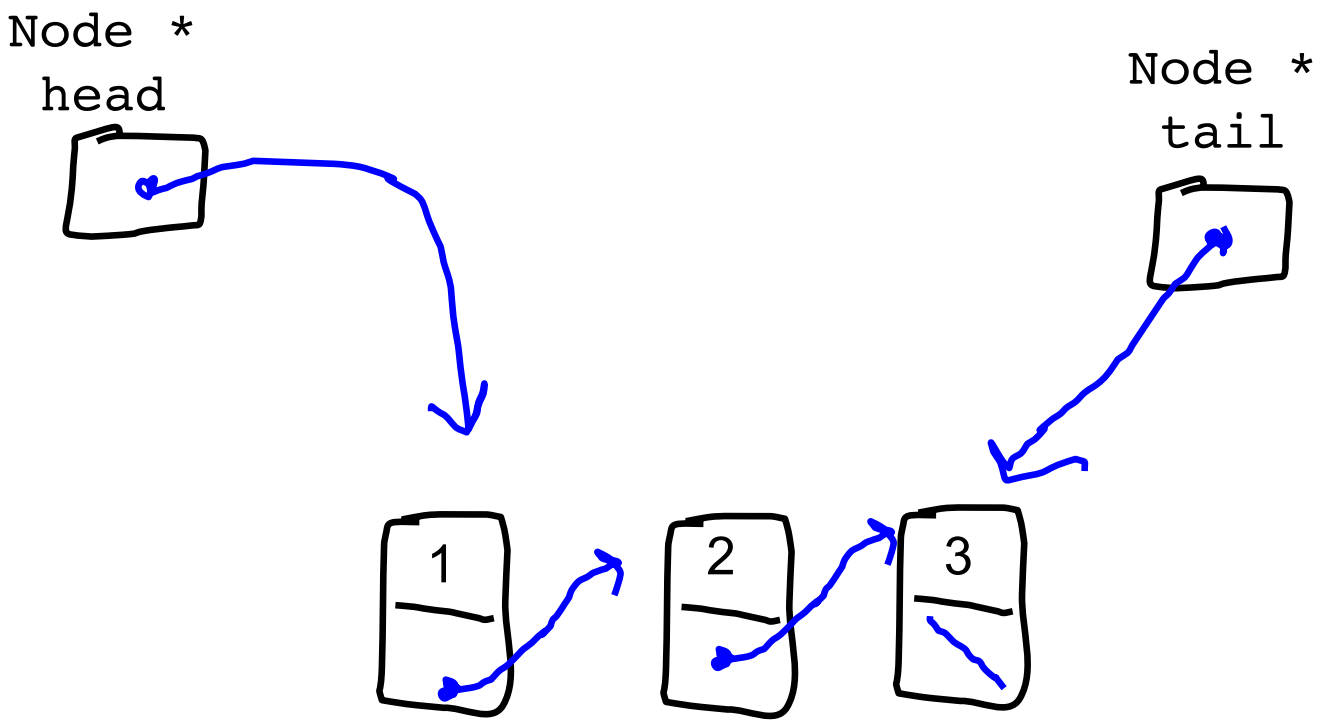
Queue Dequeue?



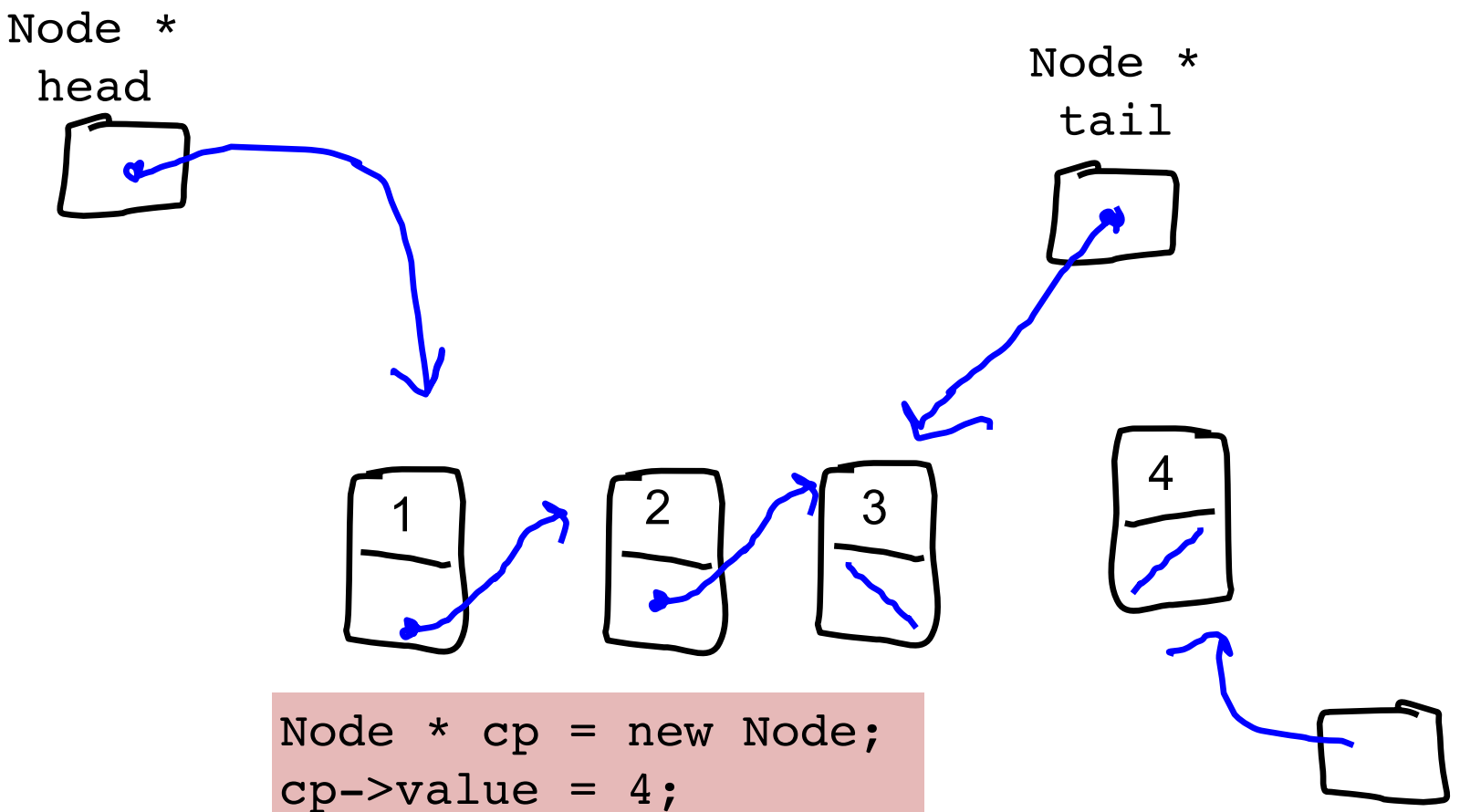
$$\mathcal{O}(n)$$

Always a Better Way

Actual Queue: Enqueue

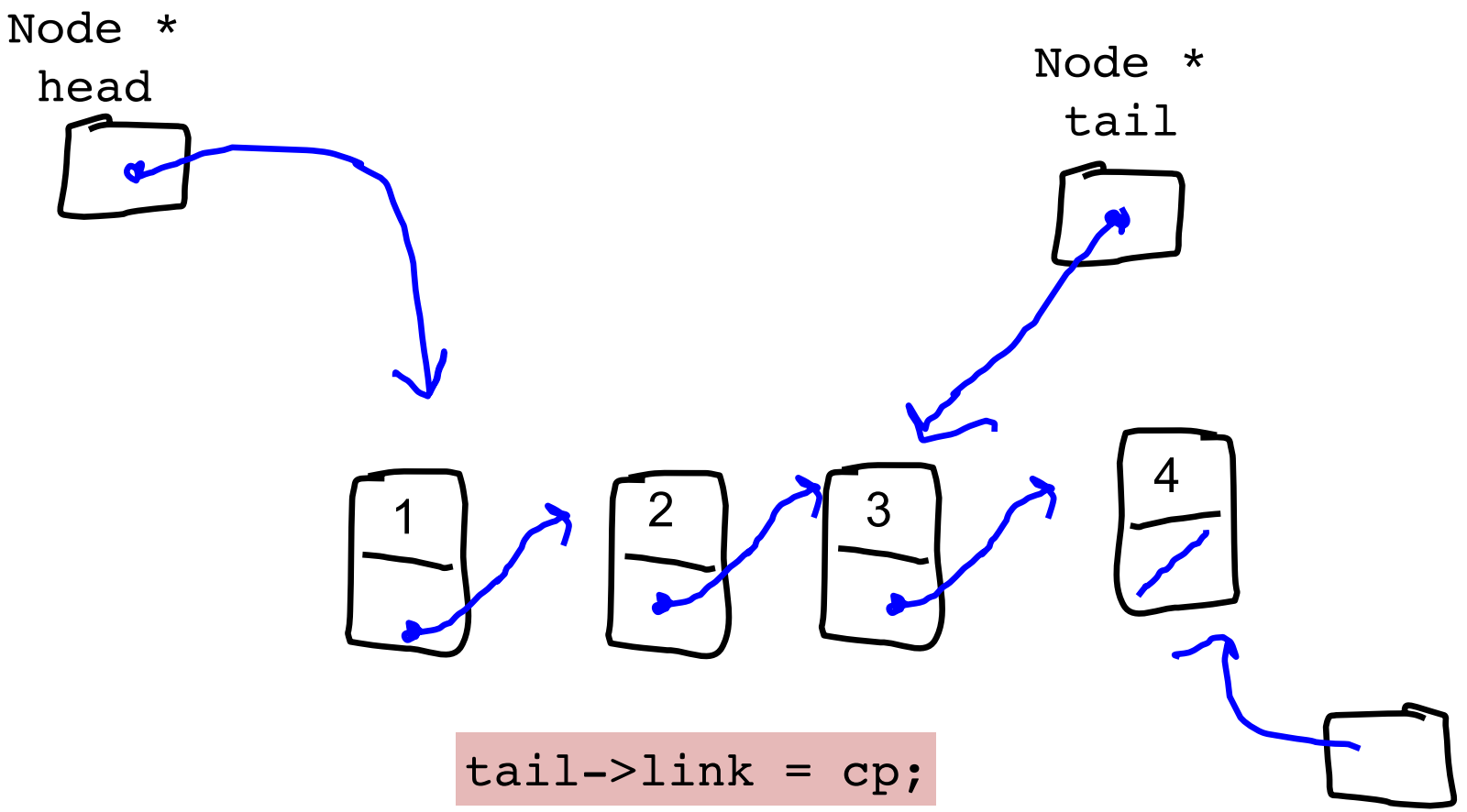


Actual Queue: Enqueue



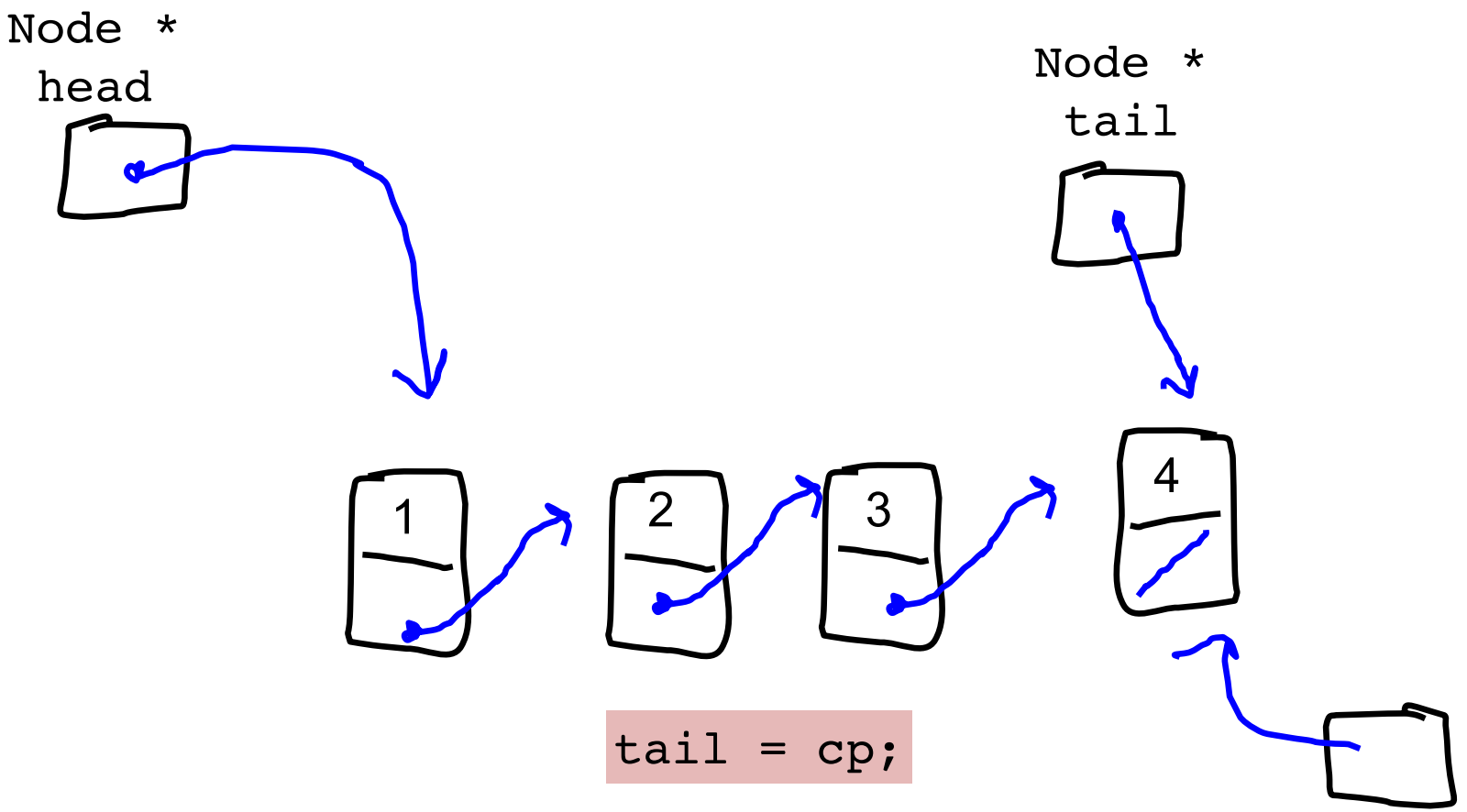

```
Node * cp = new Node;
cp->value = 4;
```

Actual Queue: Enqueue

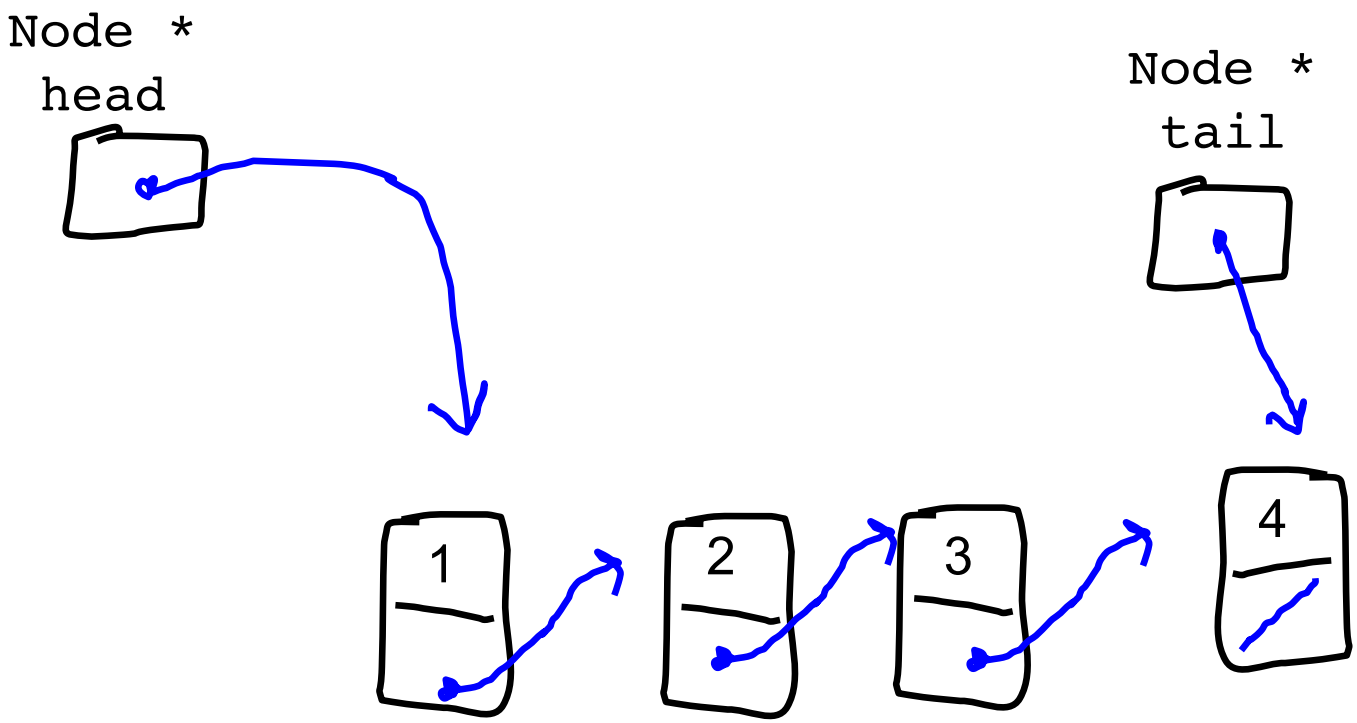



```
tail->link = cp;
```

Actual Queue: Enqueue

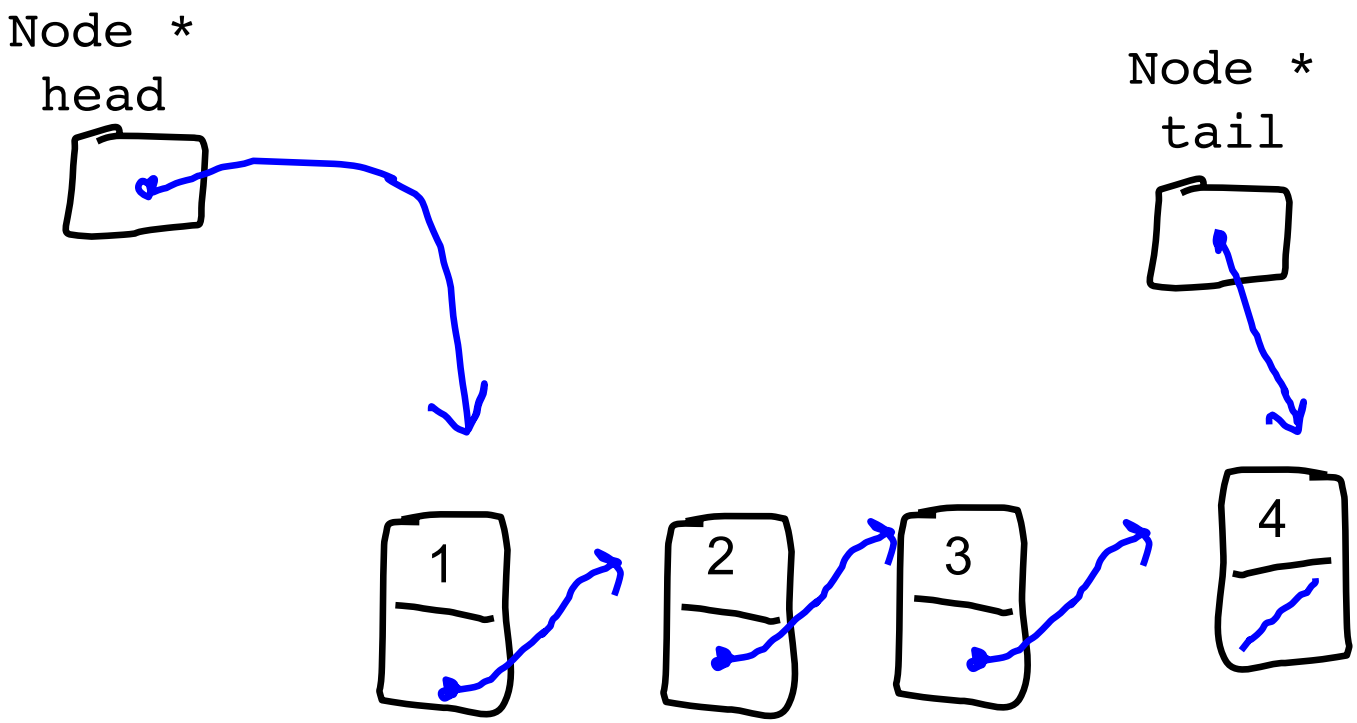


Actual Queue: Enqueue




```
return;
```

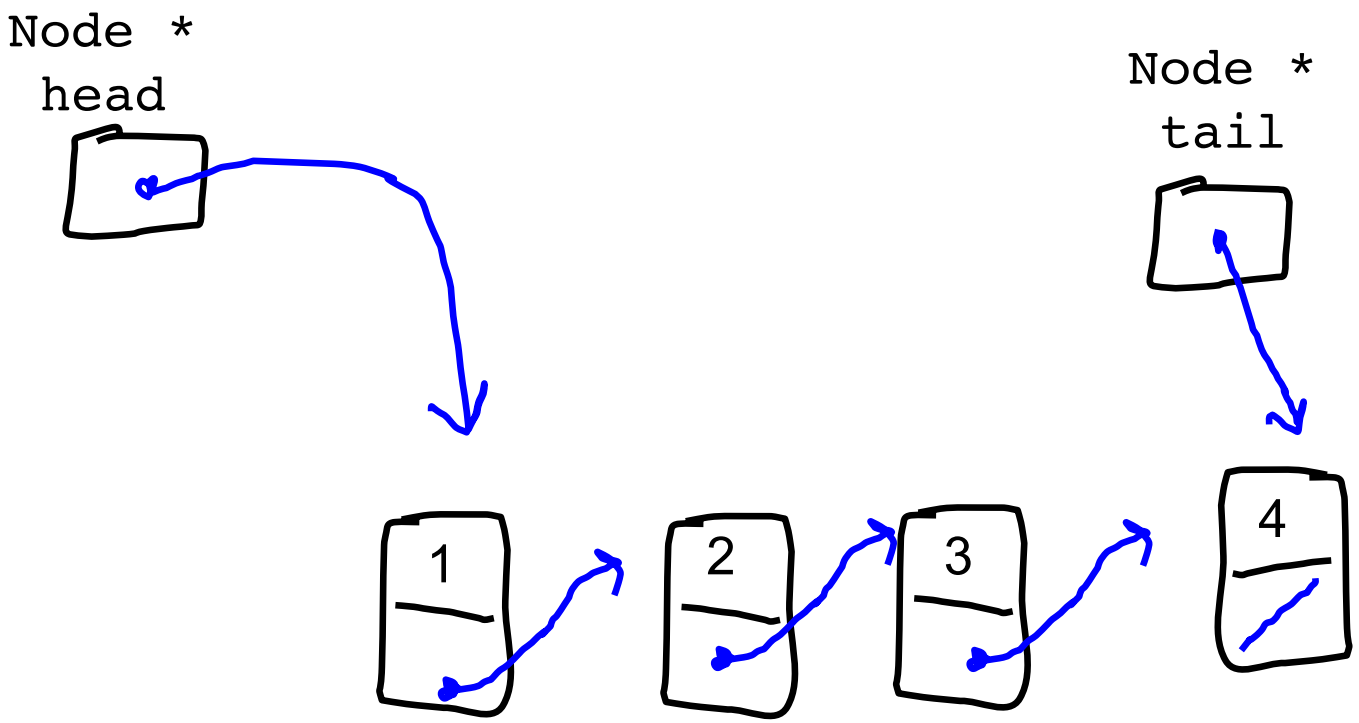
Actual Queue: Enqueue



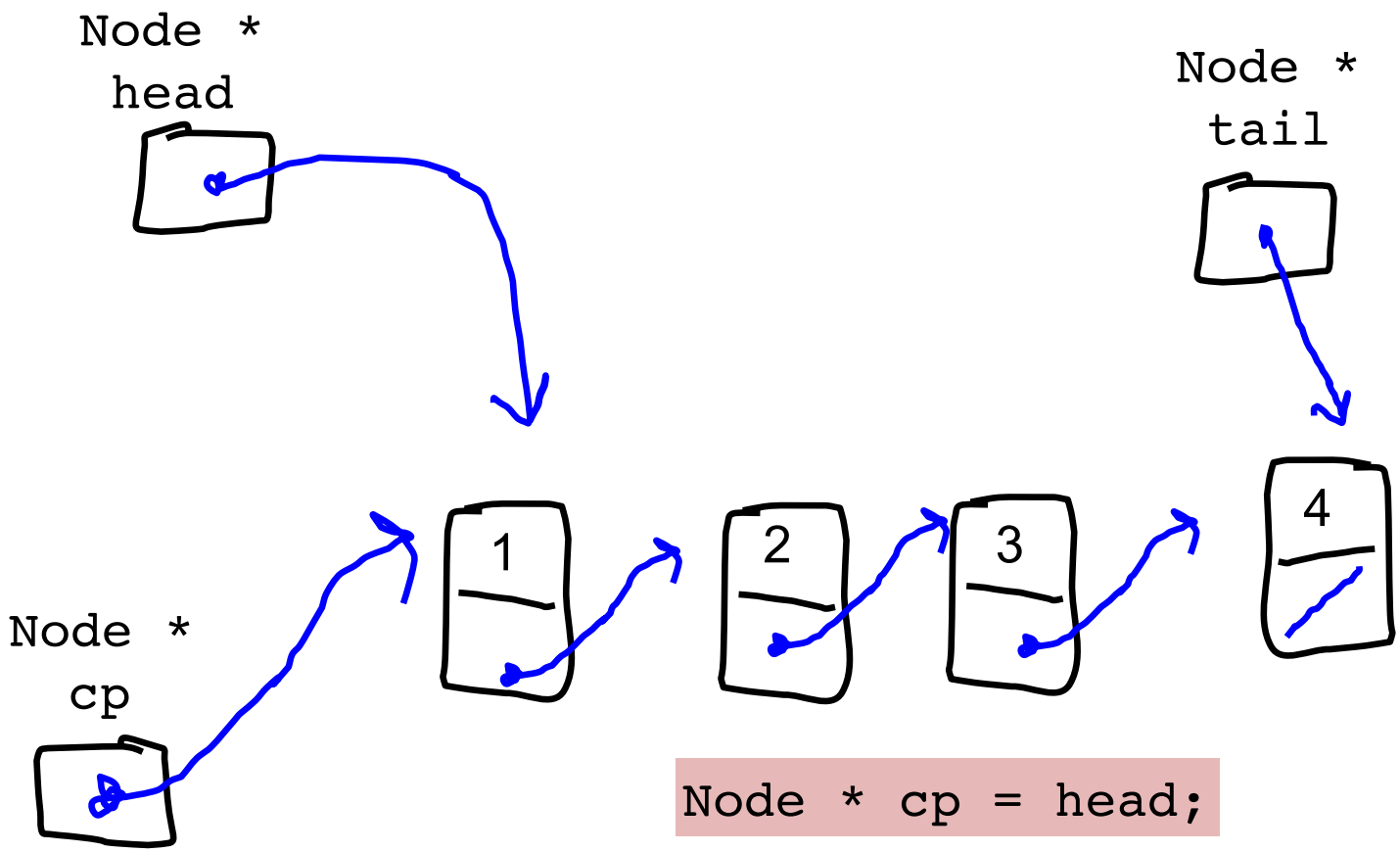
O(1)

Dequeue

Actual Queue: Dequeue

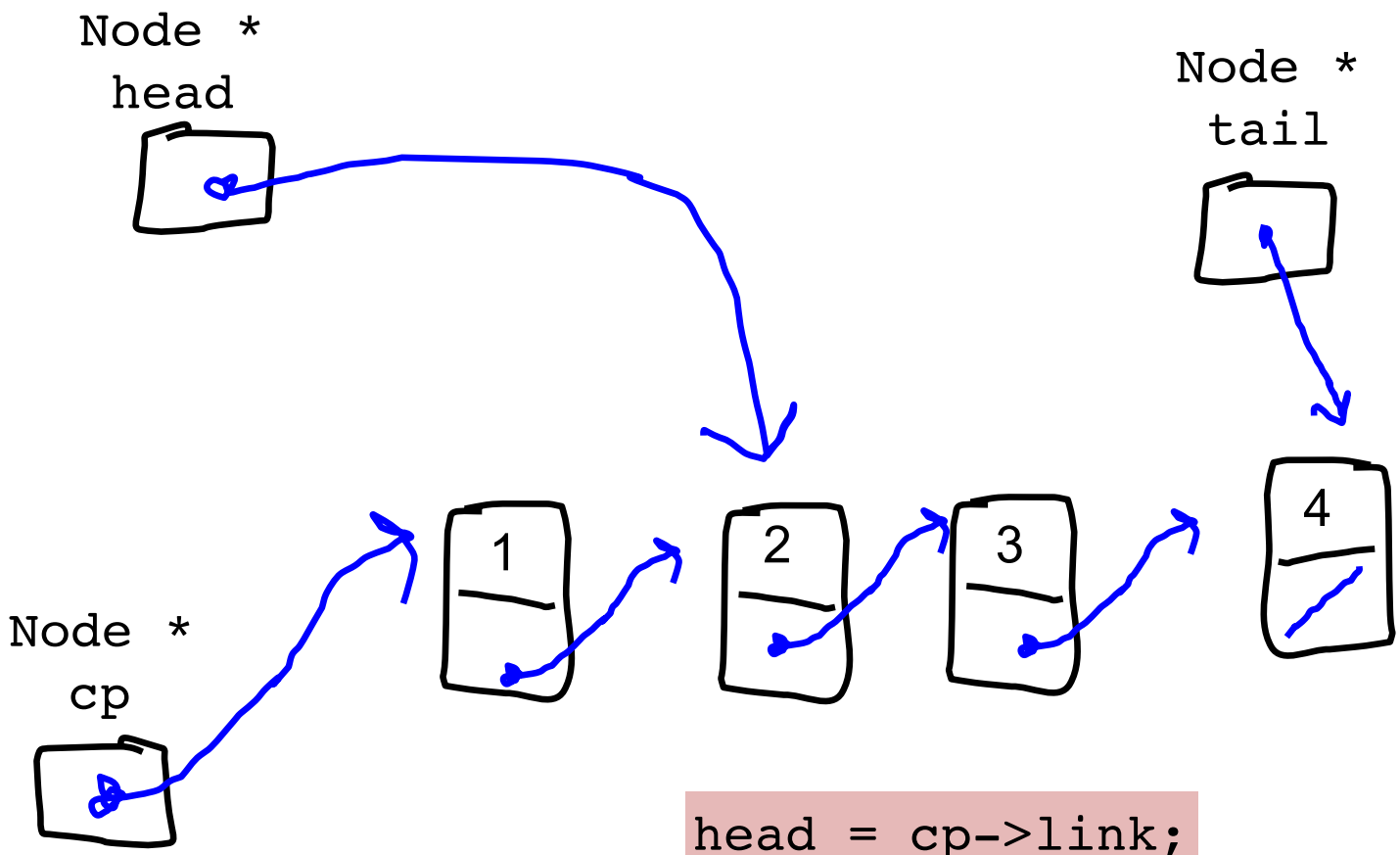


Actual Queue: Dequeue



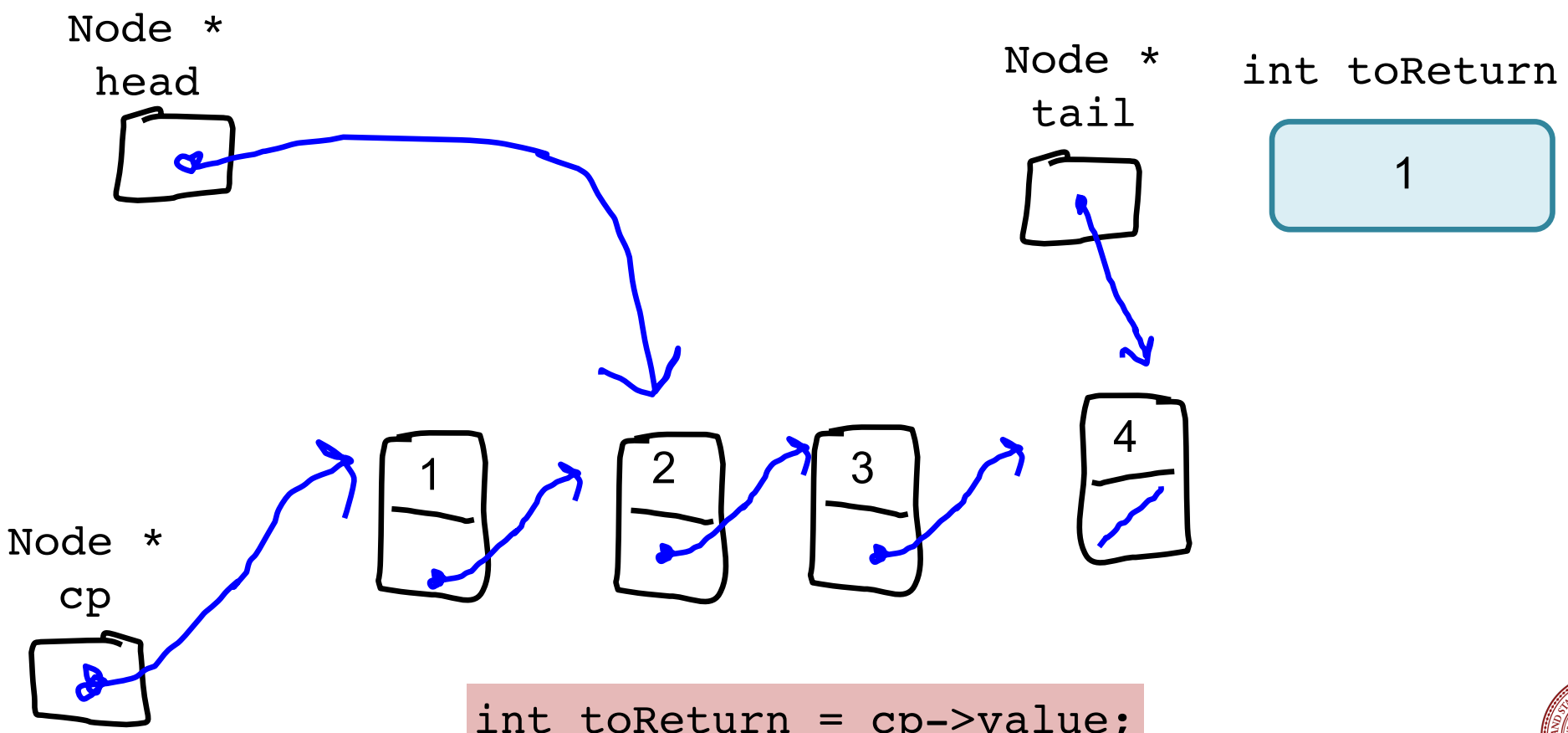

```
Node * cp = head;
```

Actual Queue: Dequeue



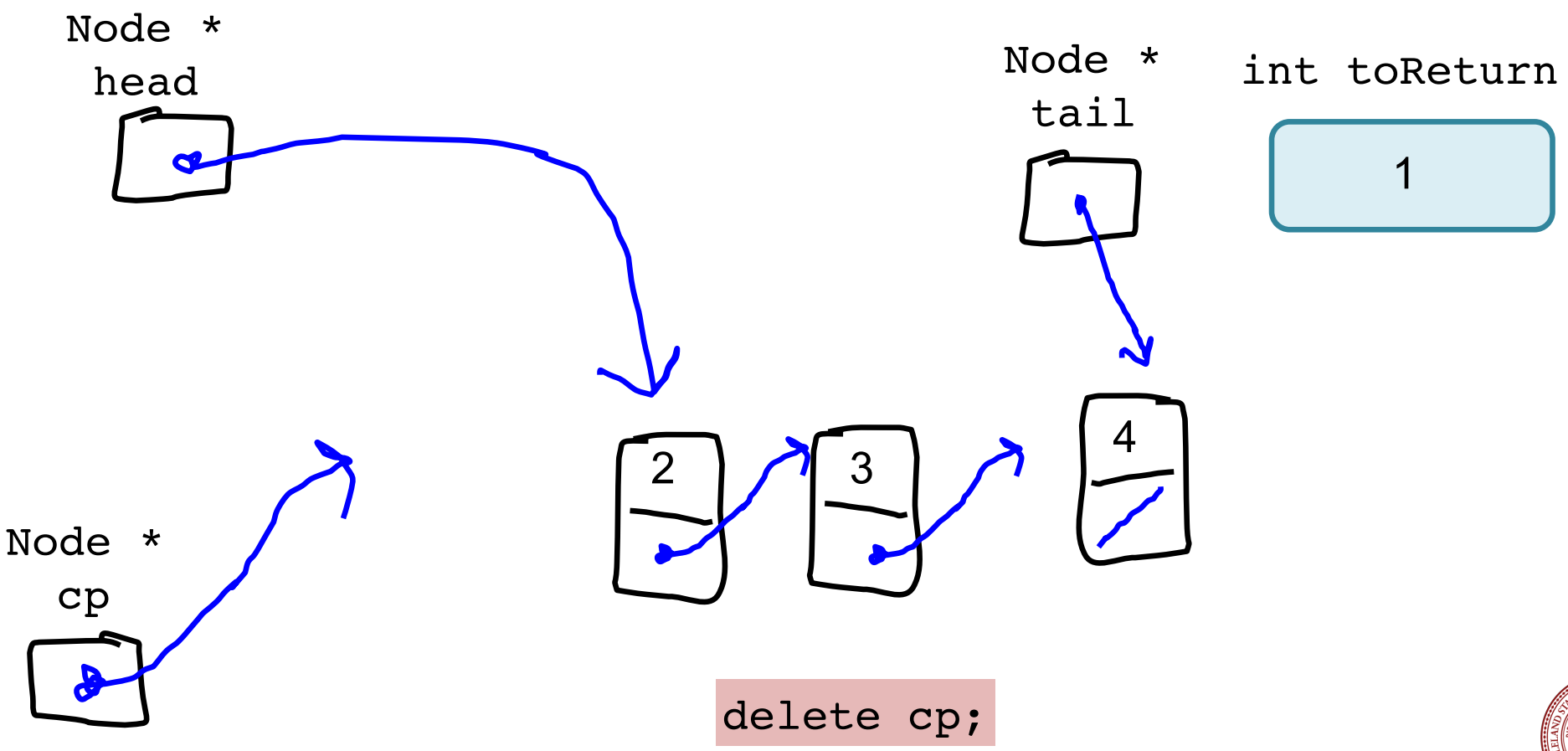

```
head = cp->link;
```

Actual Queue: Dequeue

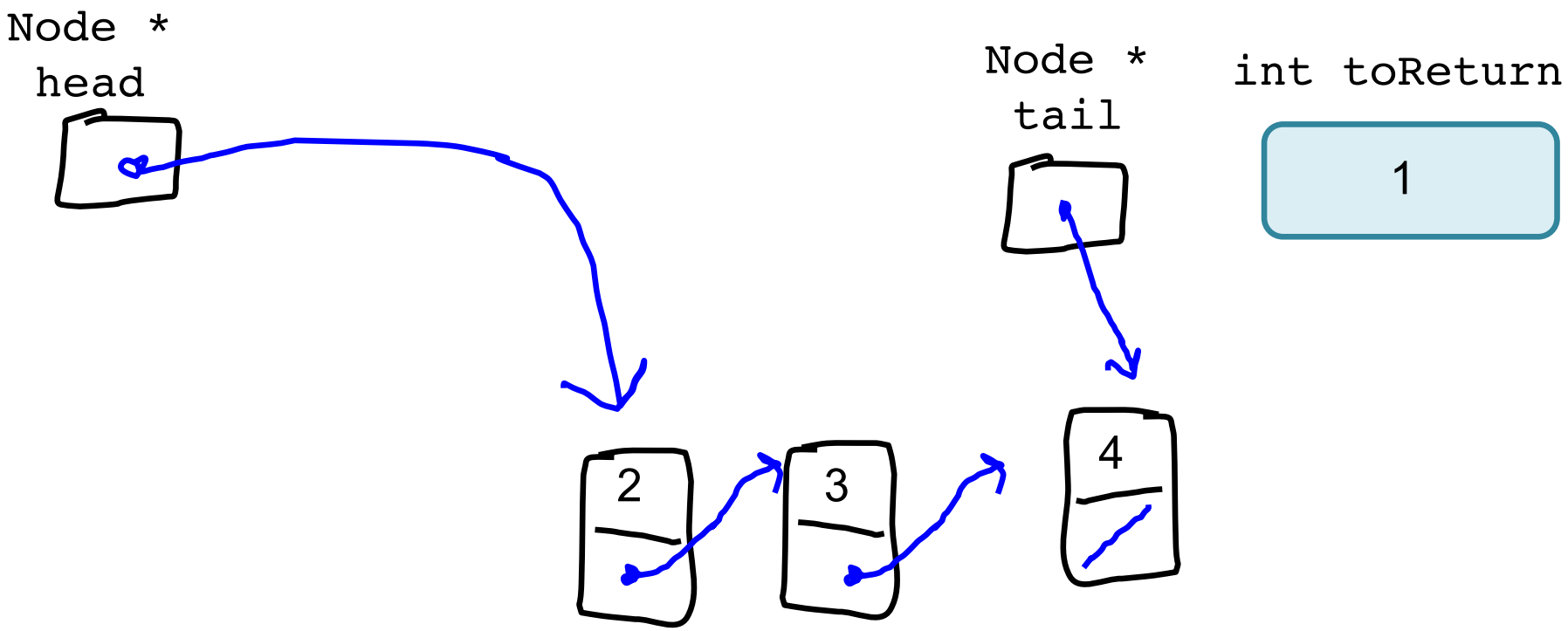



```
int toReturn = cp->value;
```

Actual Queue: Dequeue

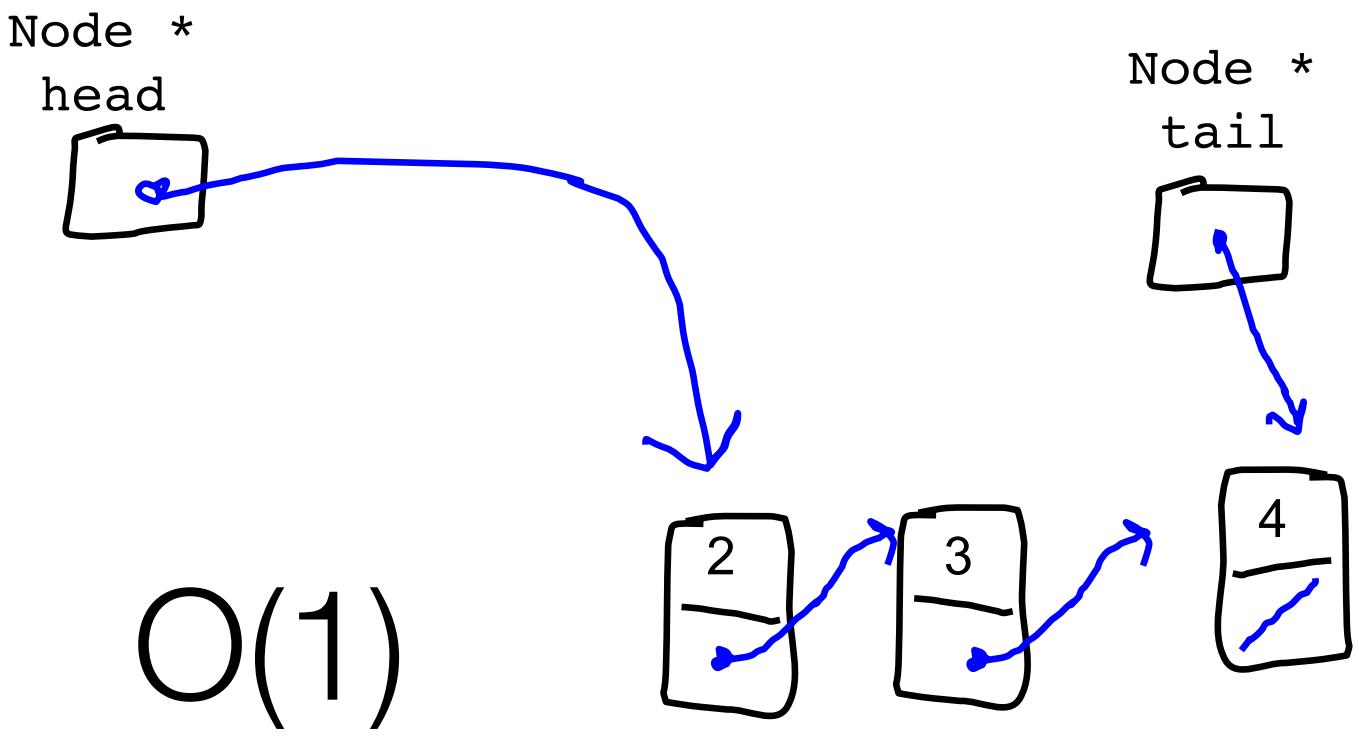


Actual Queue: Dequeue




```
return toReturn;
```

Actual Queue: Dequeue



Queue

```
class QueueInt {                // in QueueInt.h
public:
    QueueInt ();                // constructor

    void enqueue(int value); // append a value
    int dequeue();              // return the first-in value

private:
    struct Node {
      int value;
      Node * link;
    };
    Node * head;      // has a pointer to the first node
    Node * tail;      // and a pointer to the last node
};
```

Queue Implementation

```
void QueueInt::enqueue(int v) {
    Node * temp = new Node;
    temp->value = v;
    tail->link = temp;
    tail = temp;
}

int QueueInt::dequeue() {
    int toReturn = head->value;
    Node * temp = head;
    head = temp->link;
    delete temp;
    return toReturn;
}
```

Linked Lists are Excellent

	Worst
Stack Push	$\mathcal{O}(1)$
Stack Pop	$\mathcal{O}(1)$
Queue Enqueue	$\mathcal{O}(1)$
Queue Dequeue	$\mathcal{O}(1)$