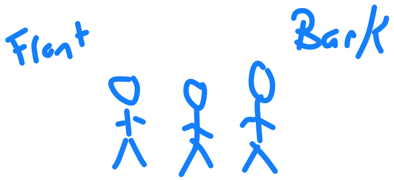
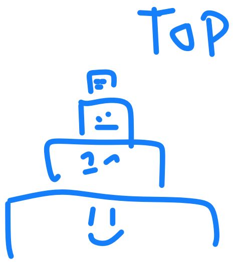
Data Structures

Stacks and Queues

CS 225
Brad Solomon

February 4, 2026





Department of Computer Science

Revamp

Agentic AI Lab

Intelligent by Design. Autonomous by Nature

About Us

Revamp is a new implementation lab at UIUC focused on building at the edge: Agentic AI Architecture and Autonomous Systems. We are a group of builders who architect and ship production-grade multi-agent workflows for real-world clients.

If you want to move past the theory and start engineering AI systems that actually work, this is where you belong.

We are looking for SWE's, Systems Designers, and Marketing wizards ready to build at scale.

Feel free to reach out at revampuiuc@gmail.com if you have any questions

Interest Form

Application Form

Exam 1 (2/09 — 2/11)

Through Monday
↳ stack & queue not on exam

Autograded MC and one coding question

Manually graded short answer prompt

Tradeoffs

Practice exam will be released on PL

Topics covered can be found on website

Register now

https://courses.engr.illinois.edu/cs225/exams/

Preparing for Exams

Make sure you understand the coding assignments

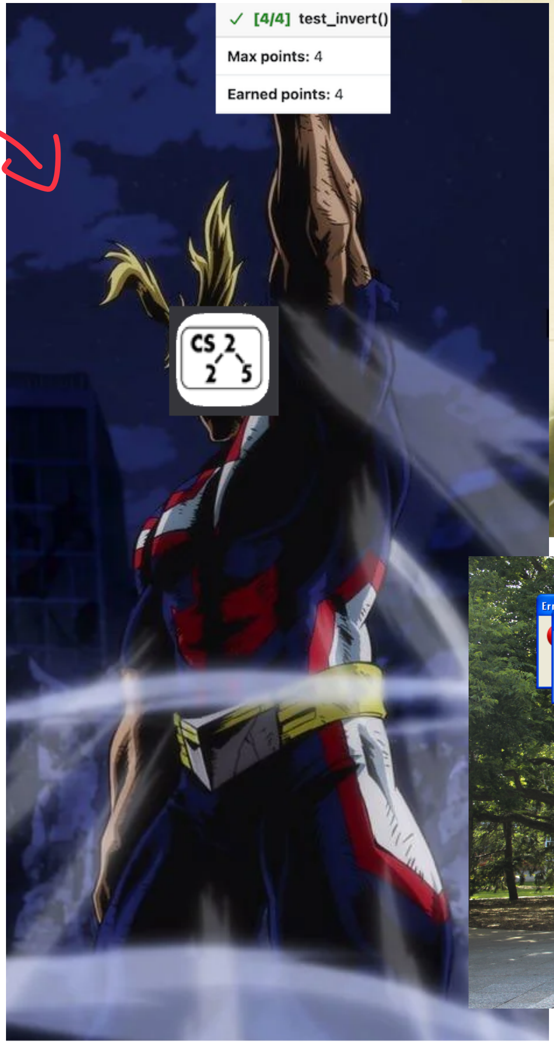
Review lecture slides — especially review slides!

Take a look at 'staff notes' — added to website for past lectures

Do the practice exam before watching practice exam solution video

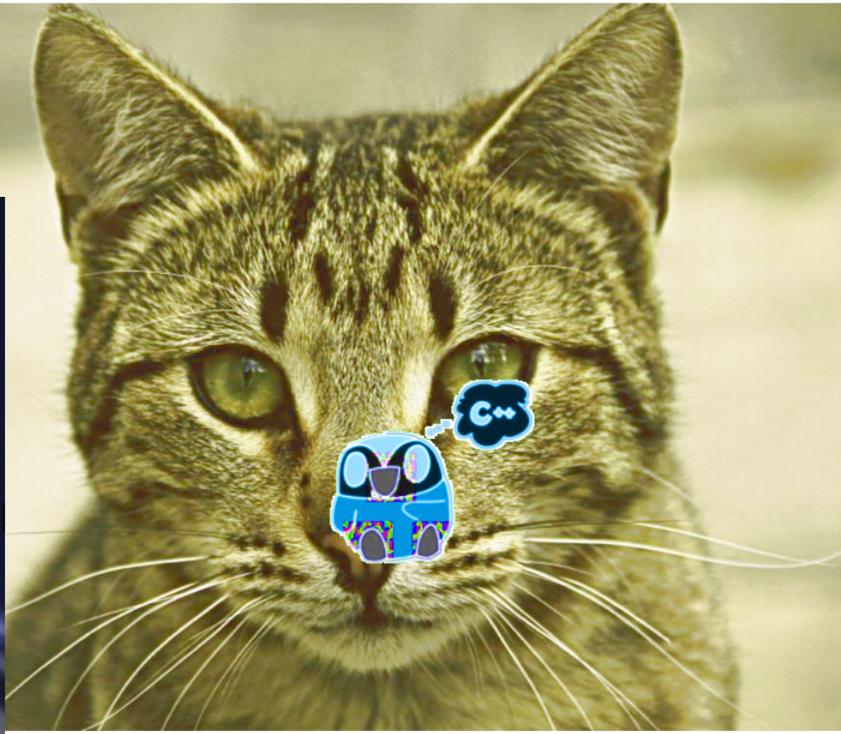
Do this before Friday

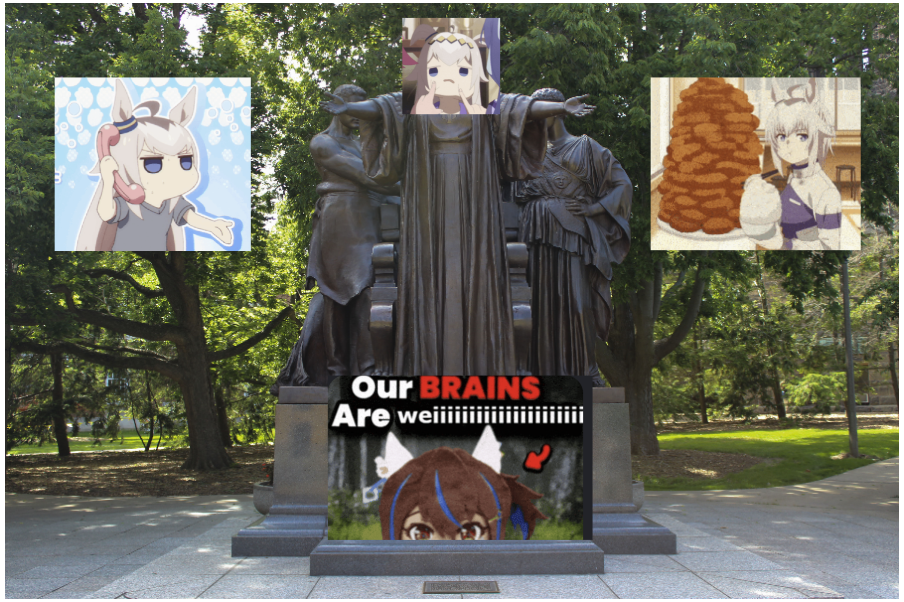
Continue posting your art!

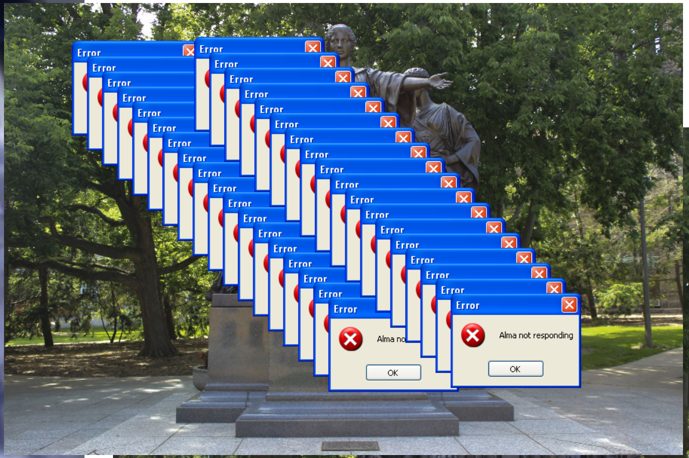


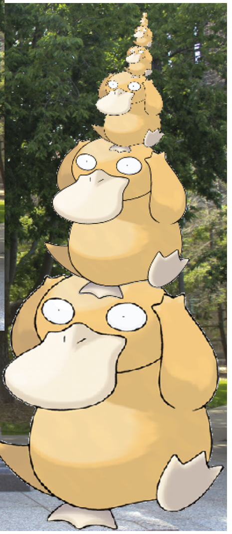
Score: 95/95 (100%)

Test Results









Learning Objectives

Consider extensions to lists (data structure tradeoffs)

Introduce the stack and the queue data structure

Introduce and explore iterators

List Implementation

	Singly Linked List	Array
Look up **arbitrary** location	O(n)	O(1)
Insert after **given** element	O(1)	O(n)
Remove after **given** element	O(1)	O(n)
Insert at **arbitrary** location	O(n)	O(n)
Remove at **arbitrary** location	O(n)	O(n)
Search for an input **value**	O(n)	O(n)

Special Cases: insertFront insertBack (not full)

Thinking critically about lists: tradeoffs

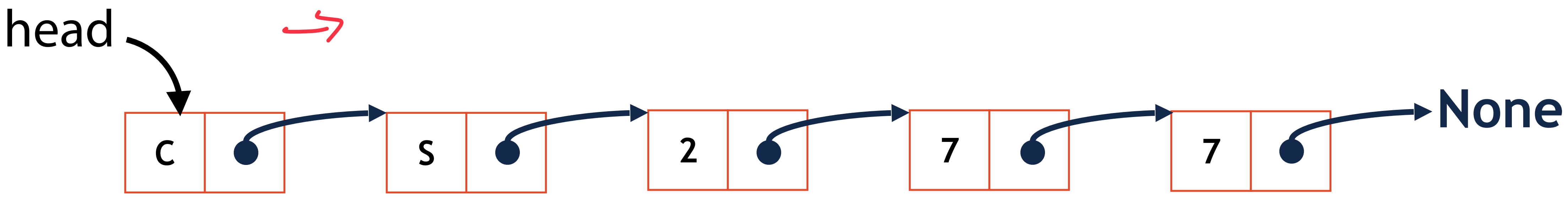
The implementations shown are foundational (simple).

Can we make our lists better at some things? What is the cost?

Thinking critically about lists: tradeoffs

Getting the size of a linked list has a Big O of: $O(n) \rightarrow O(1)$

count++



LinkedList

↳ ListNode * head_;

↳ int/unsigned size;

ListNode

↳ Data

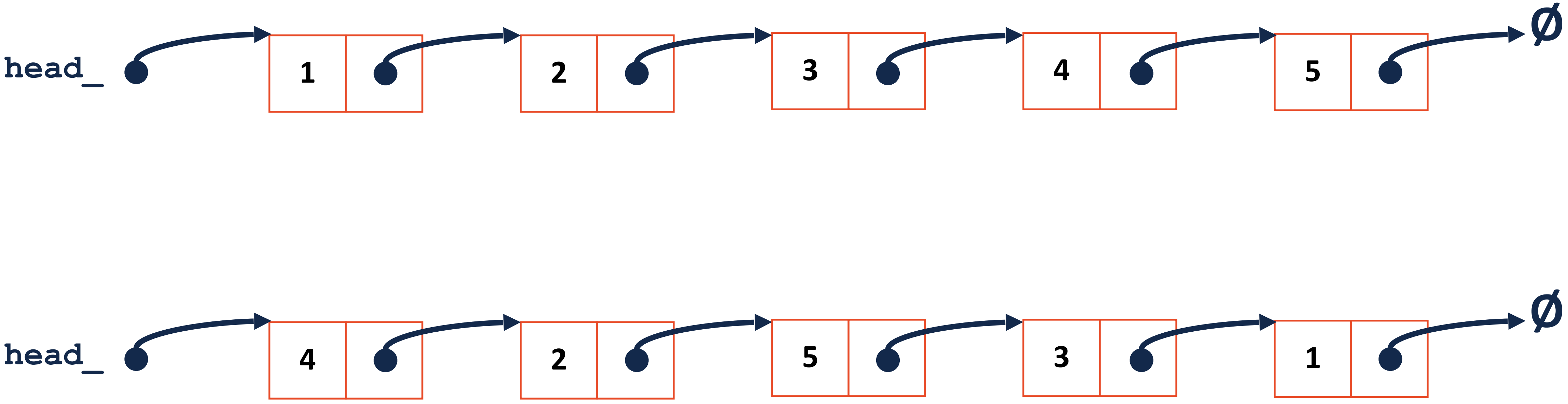
↳ next

cost:

→ 1 int/unsigned memory alloc

O(1) → insert/remove modify size

Thinking critically about lists: tradeoffs



Gain:
↳ minimal (only in instances where we want to traverse entire list in sorted order)

Cost:
↳ No insertFront() [$O(1)$]
↳ Always $O(n)$

Thinking critically about lists: tradeoffs

2	7	5	9	7	14	1	0	8	3

0	1	2	3	5	7	7	8	9	14

$O(n)$

Gain:

Binary search $O(\log n)$

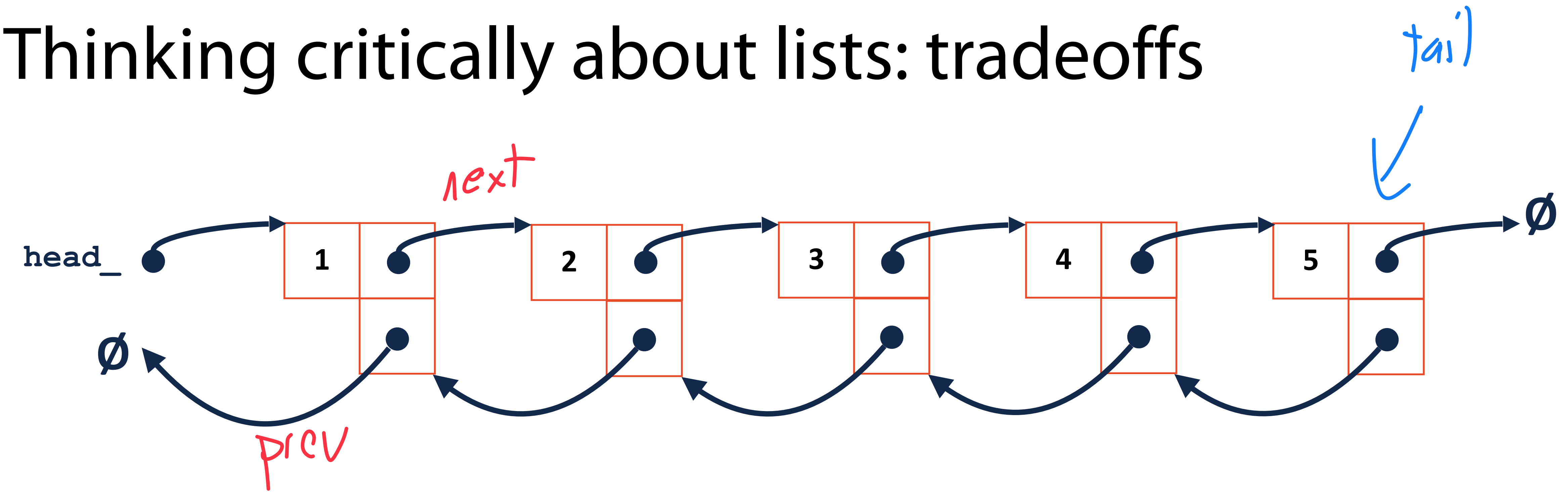
Cost:

↳ insert now $O(n)$

↳ Find using binary search $O(\log n)$

↳ Insert still shuffles

Thinking critically about lists: tradeoffs



Gain:
can move backwards

Cost:
1 pointer per node
(memory)

Thinking critically about lists: tradeoffs

As we progress in the class, we will see that $O(n)$ isn't very good.

Take searching for a specific list value:

2	7	5	9	7	14	1	0	8	3

0	1	2	3	5	7	7	8	9	14

Thinking critically about lists: tradeoffs

Can we make a ‘list’ that is O(1) to insert and remove?

Stack Data Structure

A **stack** stores an ordered collection of objects (like a list)

However you can only do three* operations: (ADT)

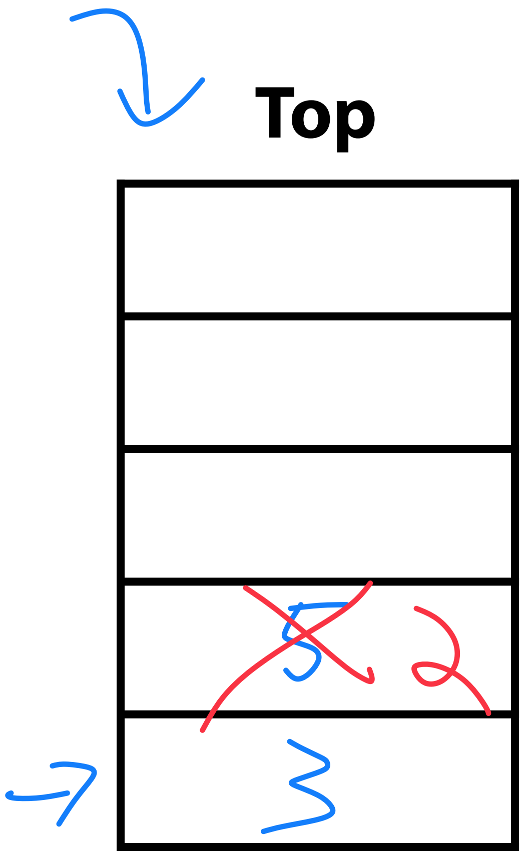
two

Push: Put an item on top of the stack

Pop: Remove the top item of the stack

Top: Return the top item of the stack

```
push(3); push(5); pop(); push(2)
```

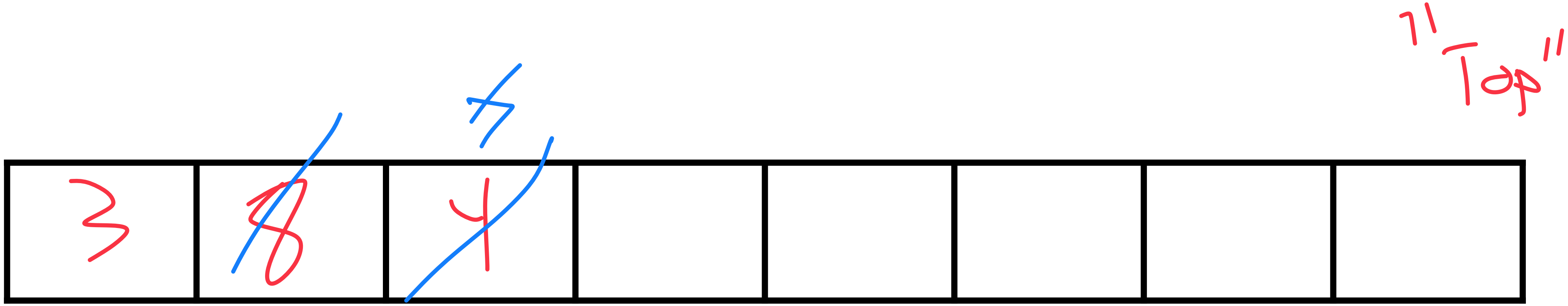


Stack Data Structure

C++ has a built-in stack

Underlying implementation is vector or deque

```
#include <stack>
int main() {
  stack<int> stack;
  stack.push(3);
  stack.push(8);
  stack.push(4);
  stack.pop();
  stack.push(7);
  stack.pop();
  stack.pop();
}
```



Stack Data Structure

`Push(X)` is equivalent to …

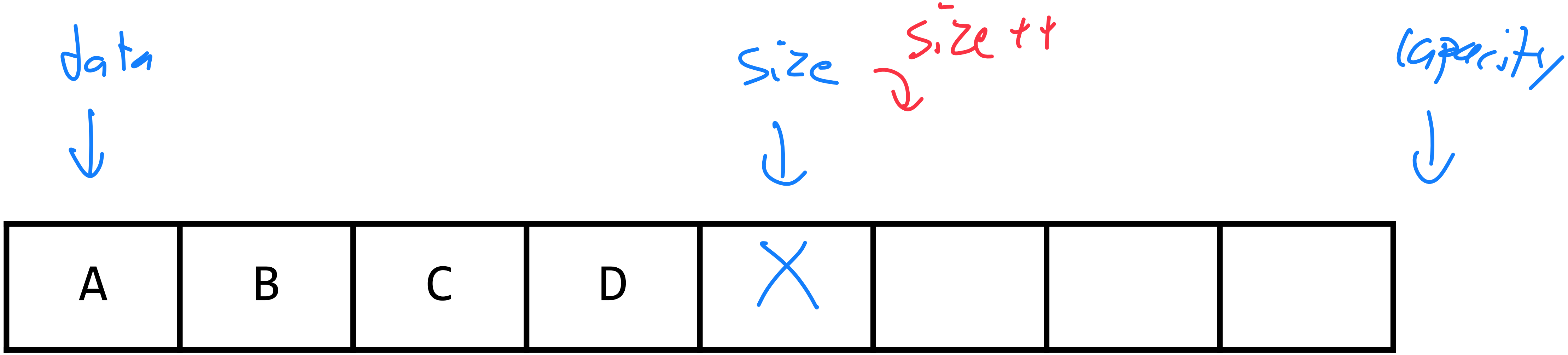
A	B	C	D				

Stack Data Structure

O(1)

`Push(X)` is equivalent to `insertBack(X)`

```
*size = X;

size++;
```



Stack Data Structure

Pop( )   is equivalent to…

A	B	C	D				

Stack Data Structure

Pop() is equivalent to removeBack()

```
size--;
```

$O(1)$

```
remove(size);
```

size

A	B	C	~~D~~				

Stack Data Structure

`Top()` is tricky — remember size points to next available space!

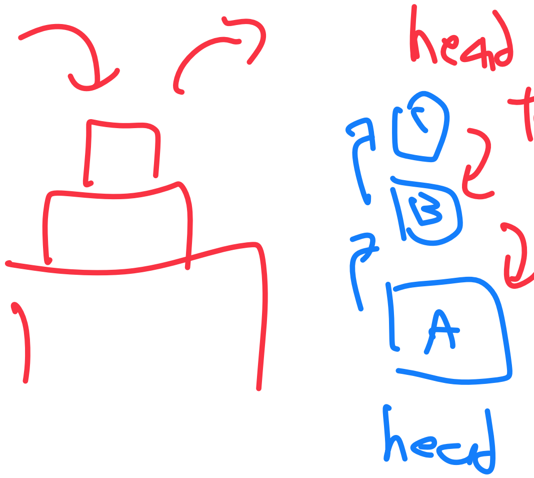
```
return *(size - 1);
```

$O(1)$

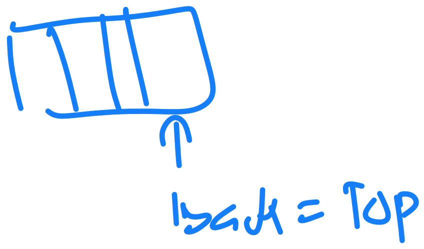
size

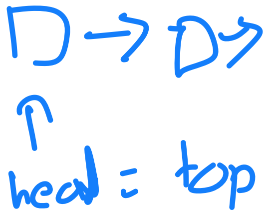
A	B	C	D				

Stack ADT



- [Order]: Last in first out
- [Implementation]: Trivial as array & linked list

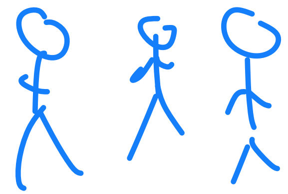




- [Runtime]: O(1)* O(1)

Tradeoff: All access rules are O(1) / cost: no random access allowed

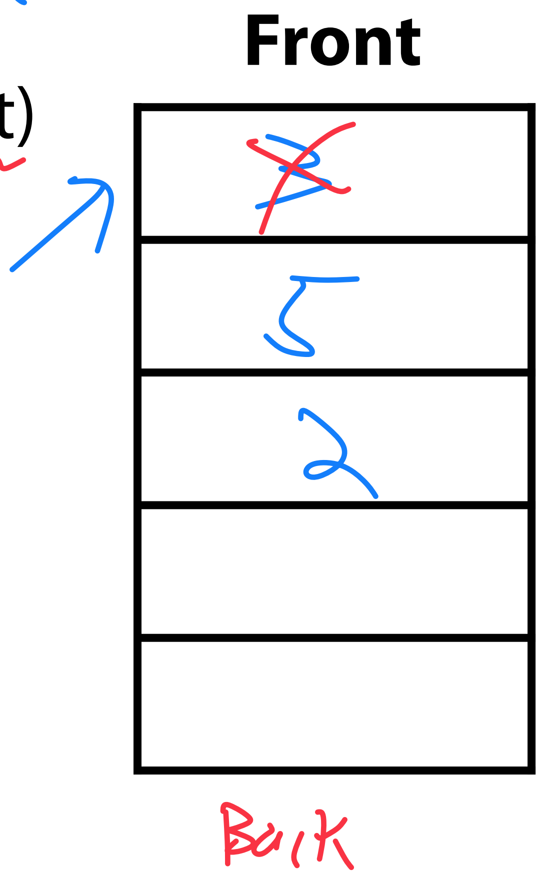
Queue Data Structure



A **queue** stores an ordered collection of objects (like a list)

However you can only do three* operations:

ADT



Enqueue: Put an item at the back of the queue

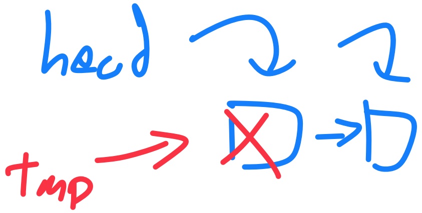
Dequeue: Remove the front item of the queue

Front: Return the front item of the queue

```
enqueue(3); enqueue(5); dequeue(); enqueue(2)
```

Queue Data Structure

The queue is a **first in — first out** data structure (FIFO)



Back

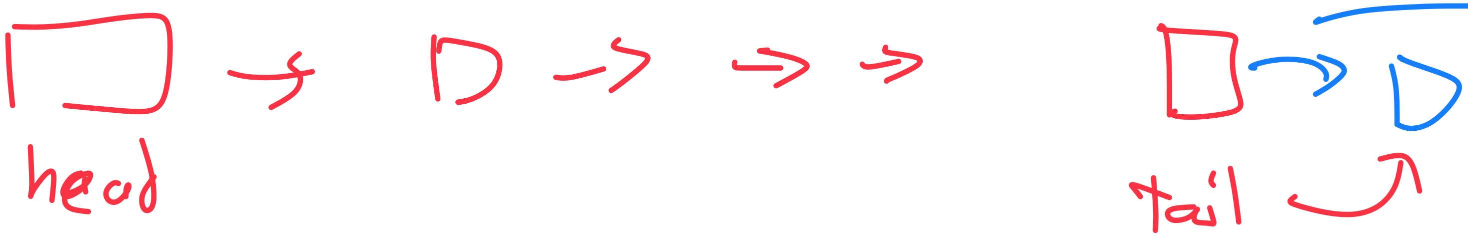
What data structure excels at removing from the front?

↳ the linked list is good at remove front

O(1)

Can we make that same data structure good at inserting at the end?

Insert by ref pointer



O(1)
w/ tail

Queue Data Structure

The C++ implementation of a queue is also a vector or deque — why?

1) Engineering

much faster in array

Store data + pointers (next)

↳ vector takes less memory

↳ pointers aren't always O(1)

↳ Memory allocation

But.... we ignore this

2) We can modify array to be better!

Engineering vs Theory Efficiency

	Time x1 billion	Like
L1 cache reference	0.5 seconds	Heartbeat 💓
Branch mispredict	5 seconds	Yawn 😲
L2 cache reference	7 seconds	Long yawn 😲 😲 😲
Mutex lock/unlock	25 seconds	Make coffee ☕
Main memory reference	100 seconds	Brush teeth
Compress 1K bytes	50 minutes	TV show 📺
Send 2K bytes over 1 Gbps network	5.5 hours	(Brief) Night's sleep 🛌
SSD random read	1.7 days	Weekend
Read 1 MB sequentially from memory	2.9 days	Long weekend
Read 1 MB sequentially from SSD	11.6 days	2 weeks for delivery 📦
Disk seek	16.5 weeks	Semester
Read 1 MB sequentially from disk	7.8 months	Human gestation 🐣
Above two together	1 year	🌍 ☀️
Send packet CA->Netherlands->CA	4.8 years	Ph.D. 🎓

(Care of https://gist.github.com/hellerbarde/2843375)

Engineering vs Theory Efficiency

Small

	Time x1 billion	Like
L1 cache reference	0.5 seconds	Heartbeat 💓
Main memory reference	100 seconds	Brush teeth
SSD random read	1.7 days	Weekend
Disk seek	16.5 weeks	Semester
Send packet CA->Netherlands->CA	4.8 years	Ph.D. 🎓

large

↳ live active memory

↳ RAM

↳

↳

D

D

D → D

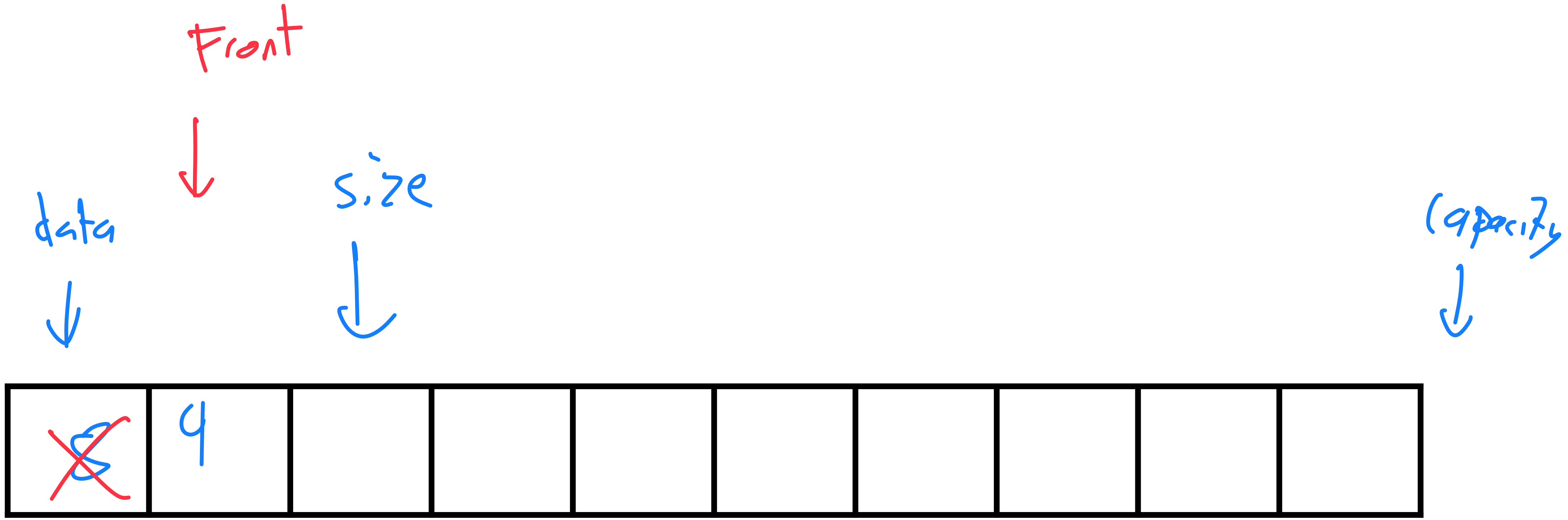
(Care of https://gist.github.com/hellerbarde/2843375)

Queue Data Structure

q.enqueue(8);
q.enqueue(4);
q.dequeue();

What do we need to track to maintain a queue with an array list?

↳ why not add fourth tracking point?

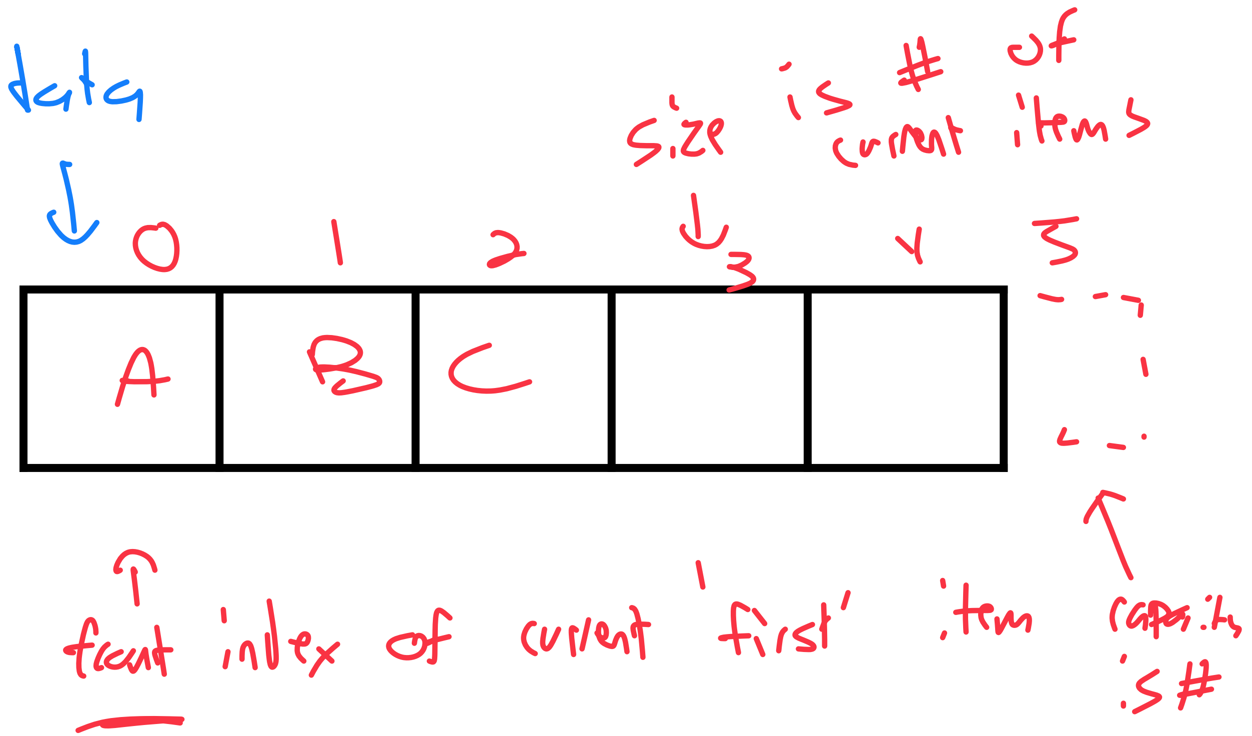


Queue Data Structure

Unlike the array list, it is easier to implement a Queue using unsigned ints

Queue.h

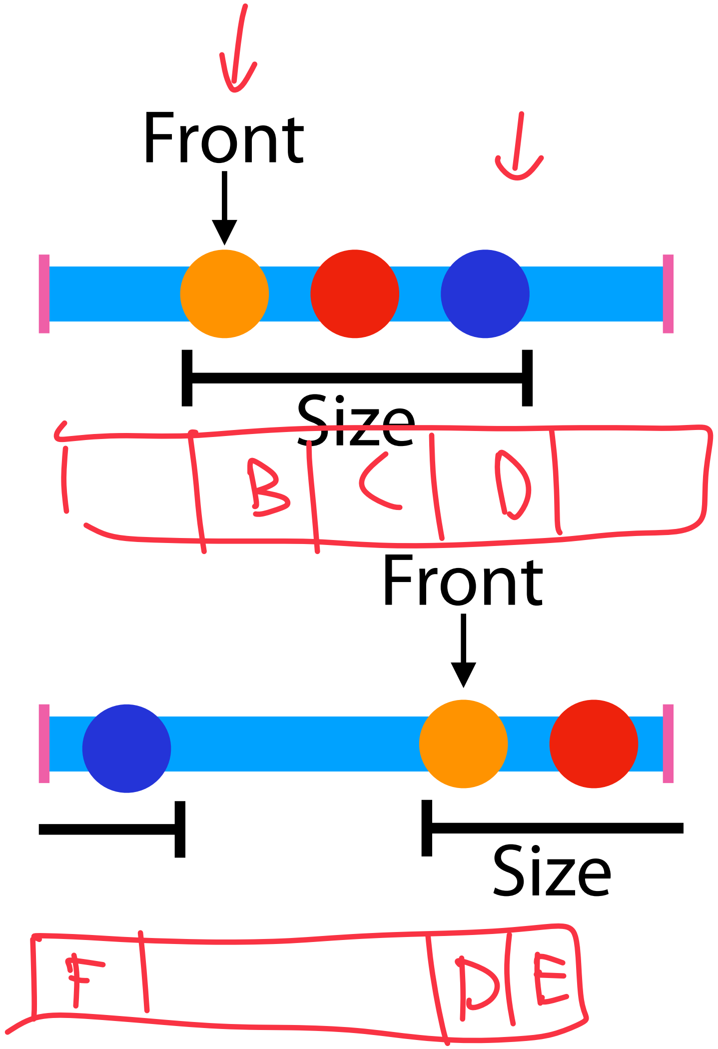
```
#pragma once

template <typename T>
class Queue {
  public:
    void enqueue(T e);
    T dequeue();
    bool isEmpty();

  private:
    T *data_;
    unsigned size_;
    unsigned capacity_;
    unsigned front_;
};
```



(Circular) Queue Data Structure

Queue.h

```
#pragma once

template <typename T>
class Queue {
  public:
    void enqueue(T e);
    T dequeue();
    bool isEmpty();

  private:
    T *data_;
    unsigned capacity_;
    unsigned size_;
    unsigned front_;
};
```



Front   front ↓   +   size ↓

~~3~~	8	4			

Enqueue(D): Add 'D' to index (front + size)

size++;

Dequeue(): Remove value @ index front

size--;

front++;

We will return on Friday here!

Size: ~~0~~ ~~1~~ ~~2~~ ~~3~~ 2

Front: ~~0~~ 1

Capacity: 6

```
Queue<int> q;
q.enqueue(3);
q.enqueue(8);
q.enqueue(4);
q.dequeue();
q.enqueue(7);
q.dequeue();
q.dequeue();
q.enqueue(2);
q.enqueue(1);
q.enqueue(3);
q.enqueue(5);
q.dequeue();
q.enqueue(9);
```

			A	B	C

```
Queue<int> q;
…
q.enqueue(D);
q.dequeue();
q.dequeue();
q.dequeue();
q.dequeue();
q.enqueue(E);
```

Enqueue(D): Add data to ‘back’ of queue

Insert D at index (size+front) % capacity

size++ (as long as size != capacity)

Dequeue(): Remove data at index front

front = (front+1) % capacity

size-- (as long as size != 0)

Size: 3

Front: 3

Capacity: 6

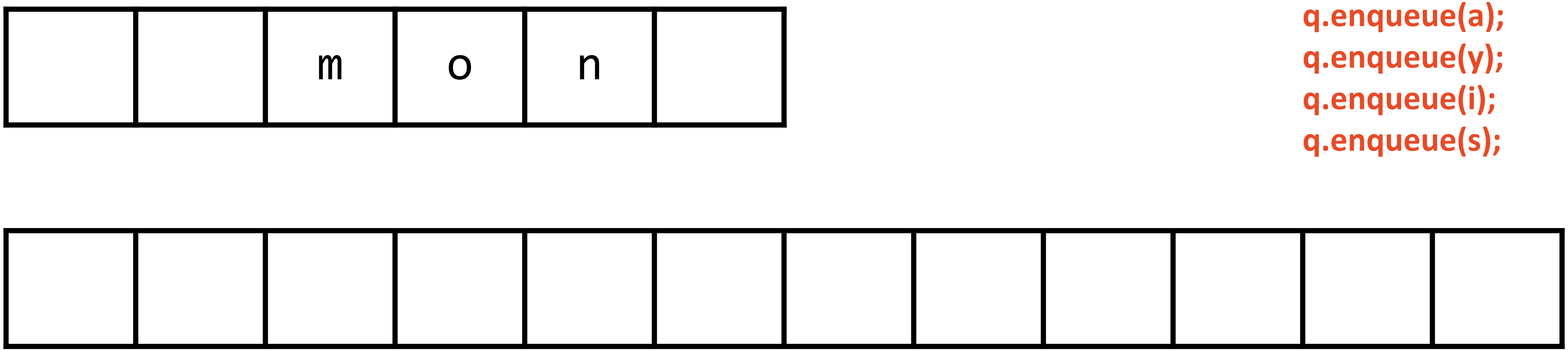
Queue Data Structure: Resizing

		m	o	n	

```
Queue<char> q;
...
q.enqueue(d);
q.enqueue(a);
q.enqueue(y);
q.enqueue(i);
q.enqueue(s);
```

Queue Data Structure: Resizing

```
Queue<char> q;
...
q.enqueue(d);
q.enqueue(a);
q.enqueue(y);
q.enqueue(i);
q.enqueue(s);
```

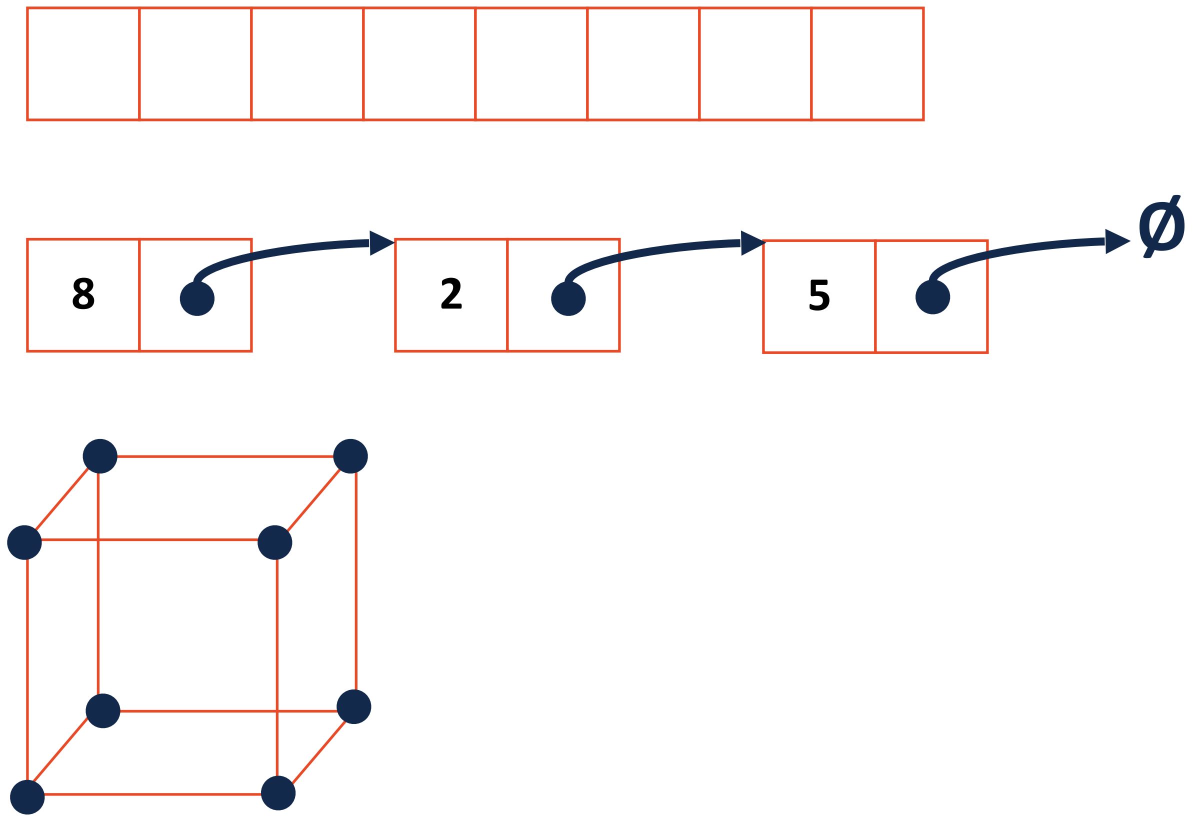


Queue ADT

- [Order]:
- [Implementation]:
- [Runtime]:

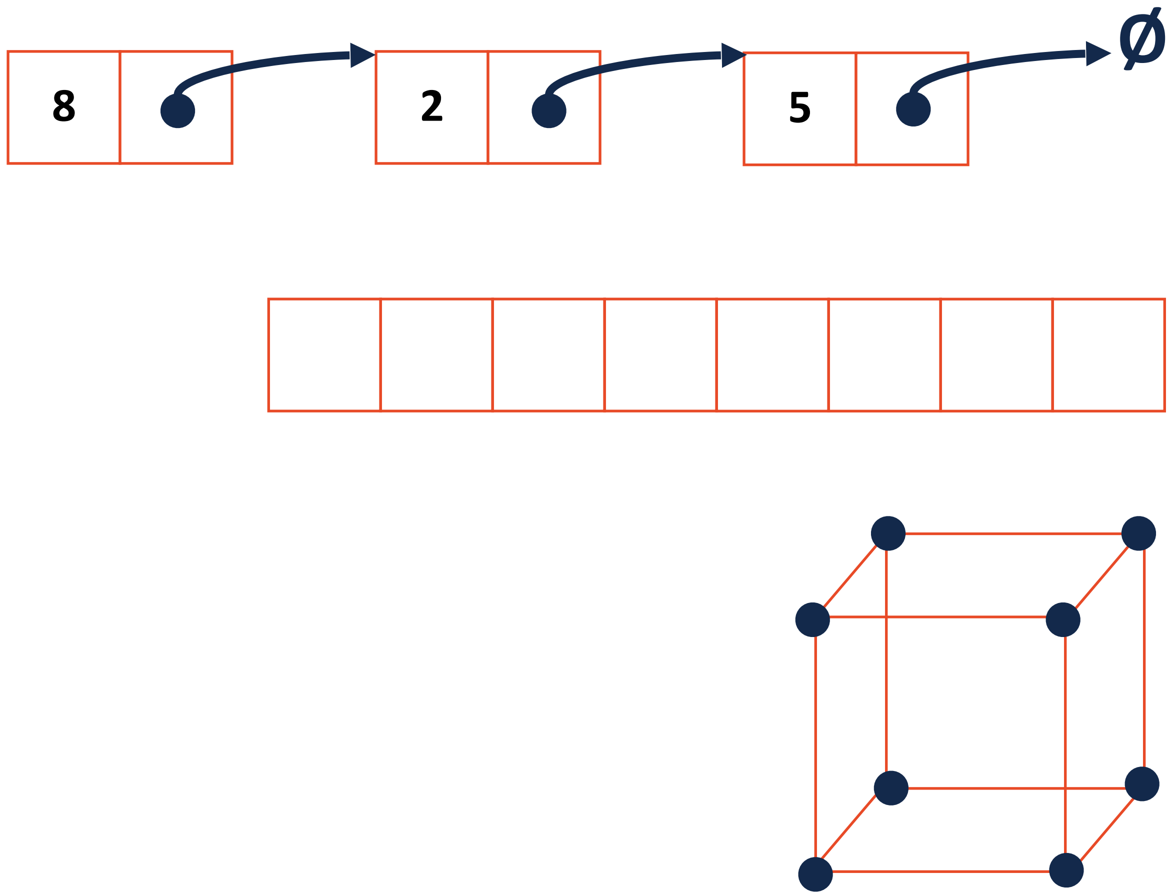
Iterators

We want to be able to loop through all elements for any underlying implementation in a systematic way



Iterators

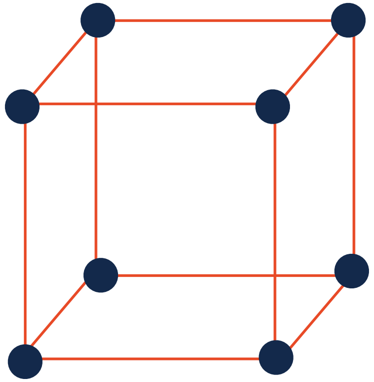
We want to be able to loop through all elements for any underlying implementation in a systematic way



Cur. Location	Cur. Data	Next
`ListNode * curr`		
`unsigned index`		
`Some form of (x, y, z)`		

Iterators

Iterators provide a way to access items in a container without exposing the underlying structure of the container



```
Cube::Iterator start = myCube.begin();

while (it != myCube.end()) {
    std::cout << *it << " ";
    it++;
}

```

Iterators

For a class to implement an iterator, it needs two functions:

```
Iterator begin()
```

```
Iterator end()
```

Iterators

The actual iterator is defined as a class **inside** the outer class:

1. It must be of base class **std::iterator**

2. It must implement at least the following operations:

```
Iterator& operator ++()

const T & operator *()

bool operator !=(const Iterator &)
```

Iterators

Here is a (truncated) example of an iterator:

```
template <class T>
class List {

    class ListIterator : public std::iterator<std::bidirectional_iterator_tag, T> {
      public:

        ListIterator& operator++();

        ListIterator& operator--()

        bool operator!=(const ListIterator& rhs);

        const T& operator*();
    };

    ListIterator begin() const;

    ListIterator end() const;
};
```

stlList.cpp

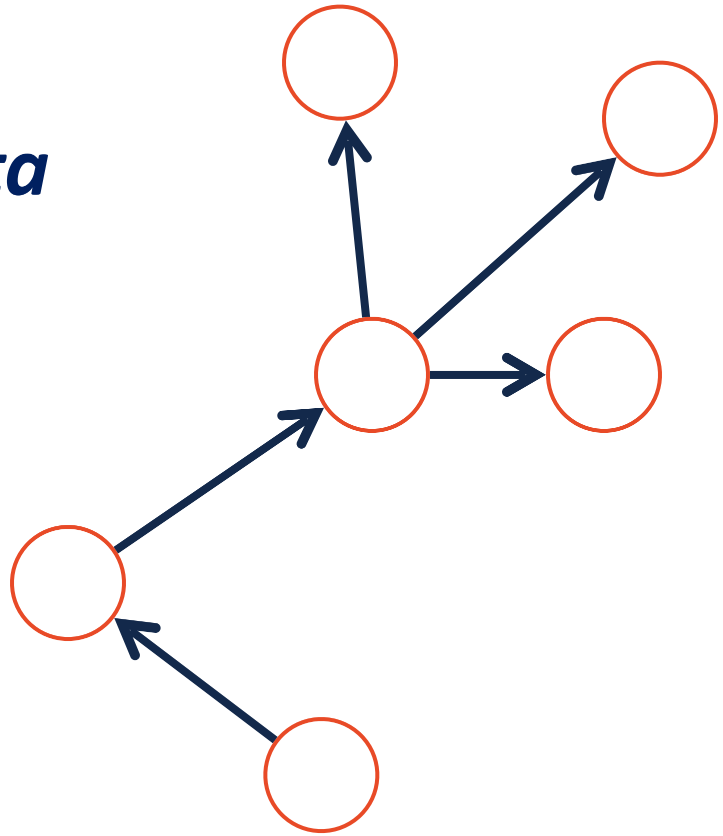
```
#include <list>
#include <string>
#include <iostream>

struct Animal {
  std::string name, food;
  bool big;
  Animal(std::string name = "blob", std::string food = "you", bool big = true) :
    name(name), food(food), big(big) { /* nothing */ }
};

int main() {
  Animal g("giraffe", "leaves", true), p("penguin", "fish", false), b("bear");
  std::vector<Animal> zoo;

  zoo.push_back(g);
  zoo.push_back(p);   // std::vector's insertAtEnd
  zoo.push_back(b);

  for ( std::vector<Animal>::iterator it = zoo.begin(); it != zoo.end(); ++it ) {
    std::cout << (*it).name << " " << (*it).food << std::endl;
  }

  return 0;
}
```

```

std::vector<Animal> zoo;


/* Full text snippet */

  for ( std::vector<Animal>::iterator it = zoo.begin(); it != zoo.end(); ++it ) {
    std::cout << (*it).name << " " << (*it).food << std::endl;
  }


/* Auto Snippet */

  for ( auto it = zoo.begin(); it != zoo.end; ++it ) {
    std::cout << animal.name << " " << animal.food << std::endl;
  }

/* For Each Snippet */

  for ( const Animal & animal : zoo ) {
    std::cout << animal.name << " " << animal.food << std::endl;
  }
```

Trees

"The most important non-linear data structure in computer science."

- David Knuth, The Art of Programming, Vol. 1



A tree is:

-
-