# Data Structures

# Stacks and Queues

CS 225

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# Learning Objectives

Introduce the stack and the queue data structure

Introduce and explore iterators

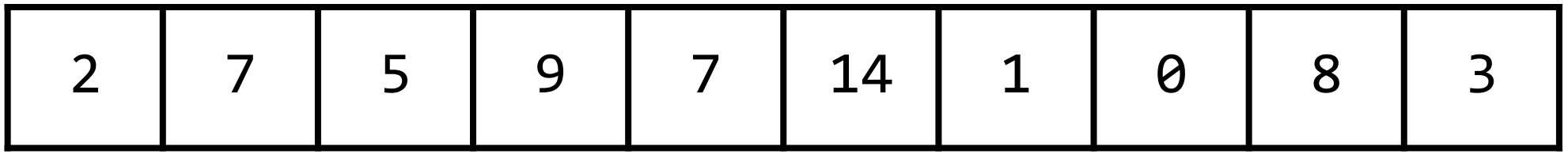
# Array Implementation

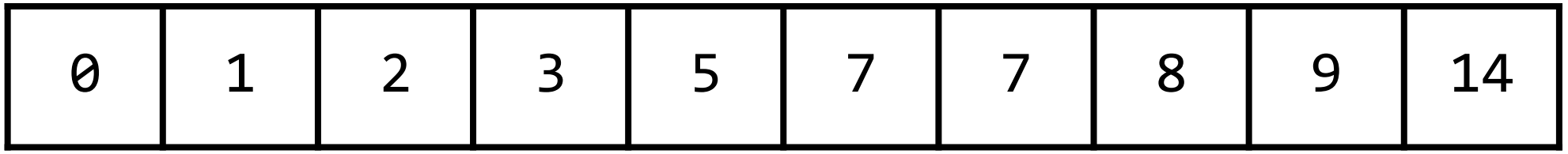
| | Singly Linked List | Array |
|---|---|---|
| Insert/Remove at **front** | | |
| Insert at **given** element | | |
| Remove at **given** element | | |
| Insert at **arbitrary** location | | |
| Remove at **arbitrary** location | | |

# 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:



# Thinking critically about lists: tradeoffs

I want a list that can add and remove in $O(1)$.

I am willing to make random access impossible to do so

# Stack ADT

- [Order]:

- [Implementation]:

- [Runtime]:

# Queue Data Structure

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

However you can only do two operations:

**Enqueue**: Put an item at the back of the queue

**Dequeue**: Remove and 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)

What data structure excels at removing from the front?

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

# Queue Data Structure

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

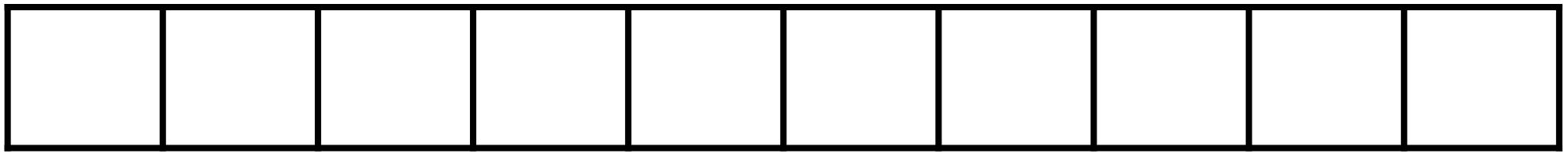
# Engineering vs Theory Efficiency

| | 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. 🎓 |

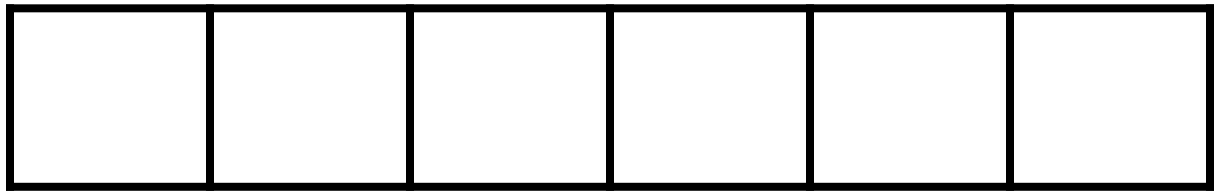
(Care of https://gist.github.com/hellerbarde/2843375)

# Queue Data Structure

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



# Queue Data Structure



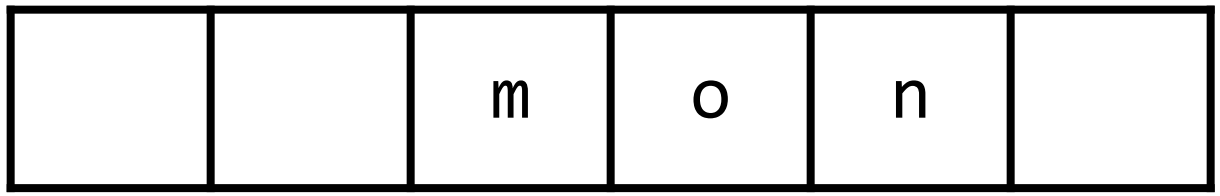
```
Queue<int> q;
q.enqueue(3);
q.enqueue(8);
q.enqueue(4);
q.dequeue();
q.enqueue(7);
q.dequeue();
q.dequeue();
q.enqueue(2);
q.enqueue(1);
q.enqueue(3);
q.enqueue(5);
q.dequeue();
q.enqueue(9);
```

Size:

Front:

Capacity:

# Queue Data Structure: Resizing

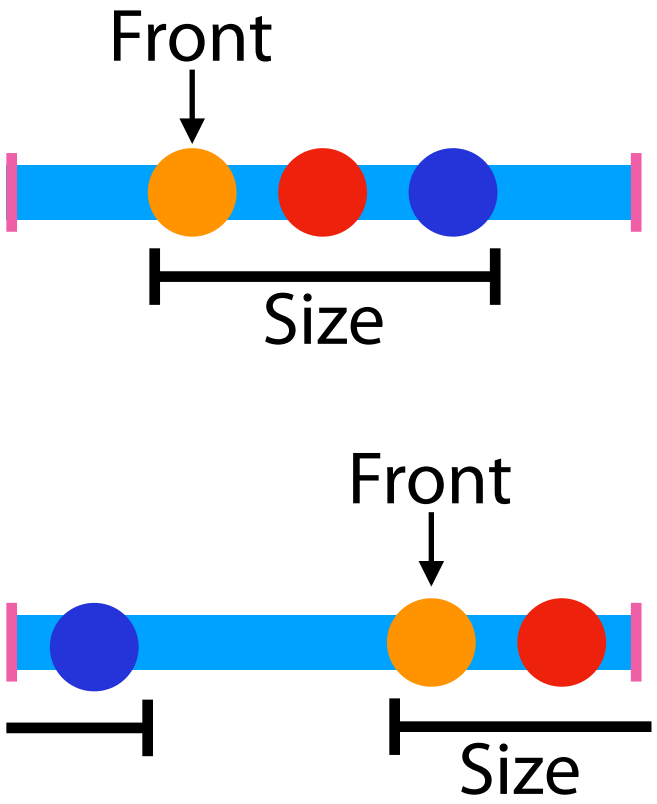



```
Queue<char> q;
…
q.enqueue(m);
q.enqueue(o);
q.enqueue(n);
…
q.enqueue(d);
q.enqueue(a);
q.enqueue(y);
q.enqueue(i);
q.enqueue(s);
q.dequeue();
q.enqueue(h);
q.enqueue(a);
```

# (Circular) Queue Data Structure

**Queue.h**

```
 1  #pragma once
 2
 3  template <typename T>
 4  class Queue {
 5    public:
 6      void enqueue(T e);
 7      T dequeue();
 8      bool isEmpty();
 9
10    private:
11      T *items_;
12      unsigned capacity_;
13      unsigned size_;
14      unsigned front_;
15  };
```

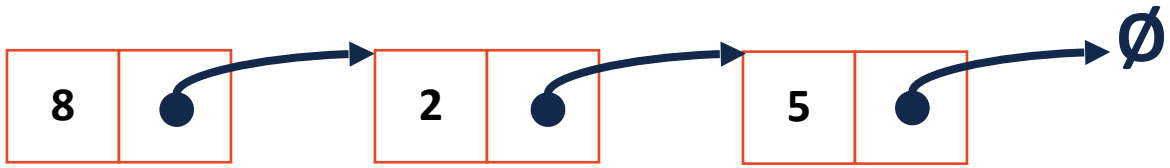


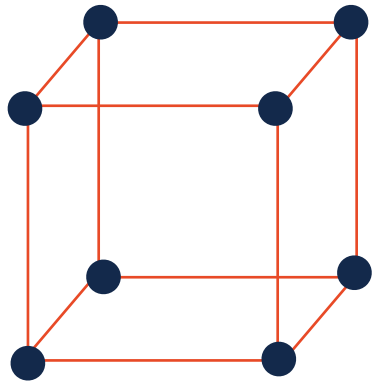
# Queue ADT

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

# Iterators

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



# Iterators

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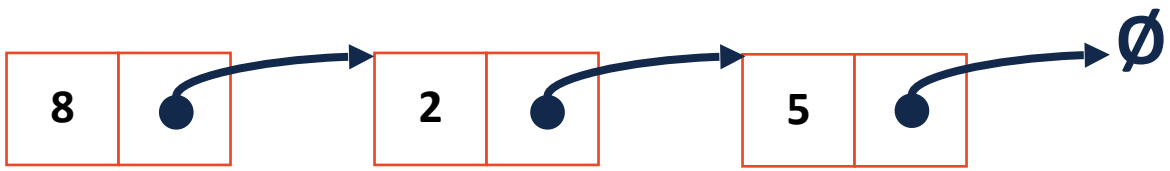
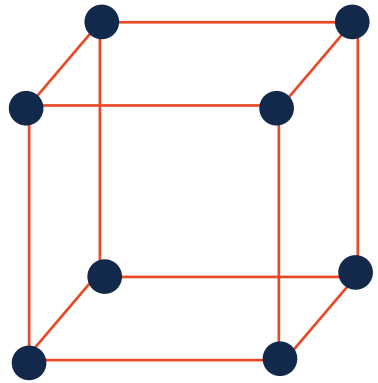


| Cur. Location | Cur. Data | Next |
|---|---|---|
| `ListNode *` | | |
| `index` | | |
| `(x, y, z)` | | |

# 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

Future assignments will have you write custom iterators:

```
 1 template <class T>
 2 class List {
 3
 4     class ListIterator : public
   std::iterator<std::bidirectional_iterator_tag, T> {
 5       public:
 6
 7         ListIterator& operator++();
 8
 9         ListIterator& operator--()
10
11         bool operator!=(const ListIterator& rhs);
12
13         const T& operator*();
14     };
15
16     ListIterator begin() const;
17
18     ListIterator end() const;
19 };
```

# stlList.cpp

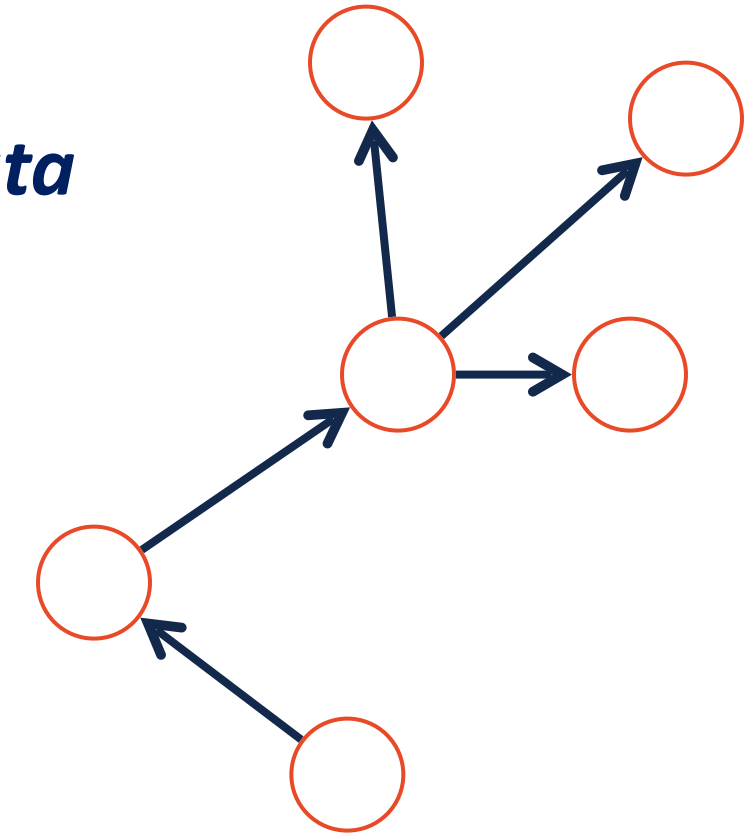
```
1  #include <list>
2  #include <string>
3  #include <iostream>
4
5  struct Animal {
6    std::string name, food;
7    bool big;
8    Animal(std::string name = "blob", std::string food = "you", bool big = true) :
9      name(name), food(food), big(big) { /* nothing */ }
10 };
11
12 int main() {
13   Animal g("giraffe", "leaves", true), p("penguin", "fish", false), b("bear");
14   std::vector<Animal> zoo;
15
16   zoo.push_back(g);
17   zoo.push_back(p);   // std::vector's insertAtEnd
18   zoo.push_back(b);
19
20   for ( std::vector<Animal>::iterator it = zoo.begin(); it != zoo.end(); ++it ) {
21     std::cout << (*it).name << " " << (*it).food << std::endl;
22   }
23
24   return 0;
25 }
```

```
1
2  std::vector<Animal> zoo;
3
4
5  /* Full text snippet */
6
7    for ( std::vector<Animal>::iterator it = zoo.begin(); it != zoo.end(); ++it ) {
8      std::cout << (*it).name << " " << (*it).food << std::endl;
9    }
10
11
12 /* Auto Snippet */
13
14   for ( auto it = zoo.begin(); it != zoo.end; ++it ) {
15     std::cout << animal.name << " " << animal.food << std::endl;
16   }
17
18 /* For Each Snippet */
19
20   for ( const Animal & animal : zoo ) {
21     std::cout << animal.name << " " << animal.food << std::endl;
22   }
23
24
25
```

# Trees

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

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



**A tree is:**

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