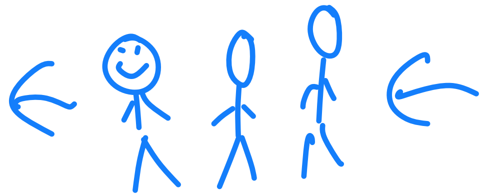
Data Structures

Stacks and Queues

CS 225
Brad Solomon

September 11, 2024

Department of Computer Science



Preparing for Exams

Make sure you understand the coding assignments

Review lecture slides — especially review slides!

↳ or review the next day

Do the practice exam before watching practice exam solution video

Learning Objectives

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: insert front O(1) insert Back O(1)*

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

Binary Search $O(\log n)$

Thinking critically about lists: tradeoffs

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

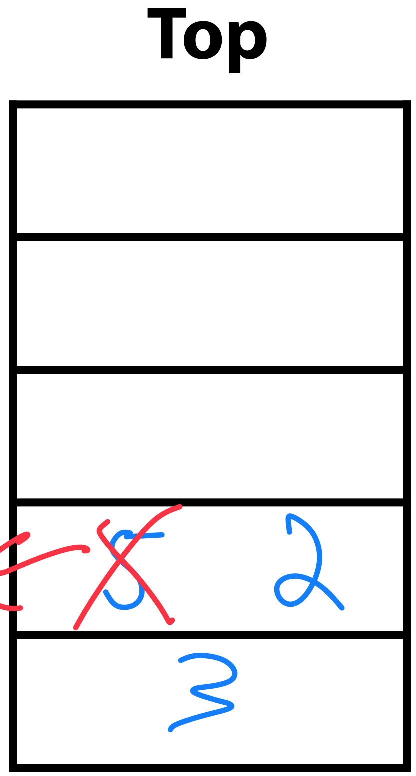
Stack Data Structure

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

However you can only do two* operations:

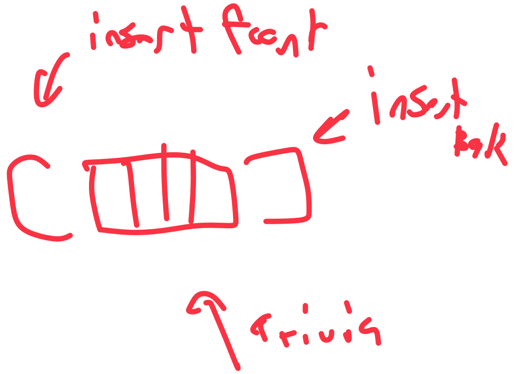
- **Push**: Put an item on top of the stack
- **Pop**: Remove the top item of the stack (and return it)

Top: Preview | get value of top element




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

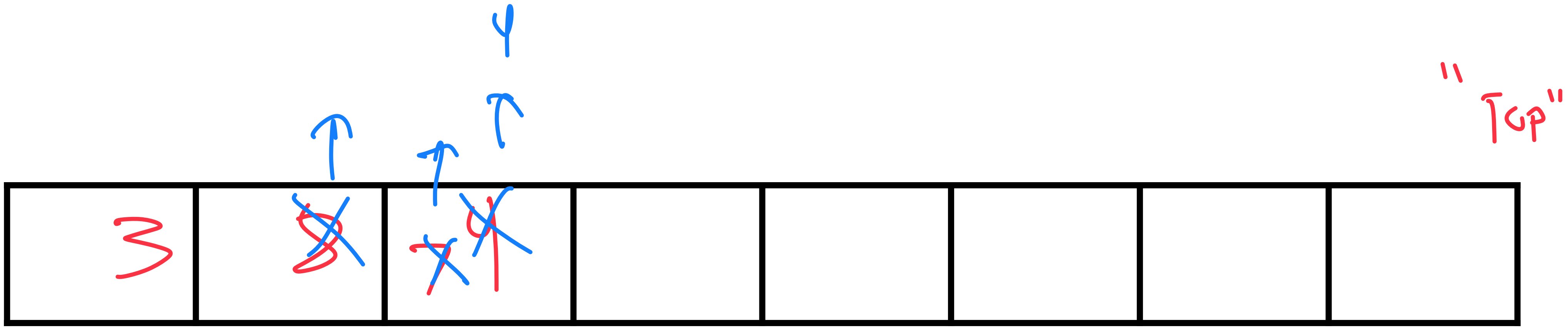
Stack Data Structure



C++ has a built-in stack

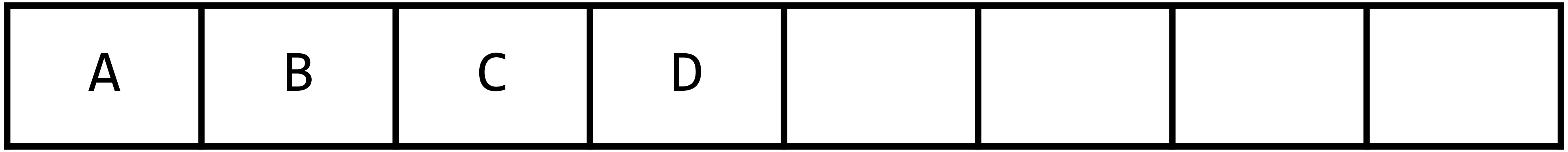
Underlying implementation is vector or deque

```
#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

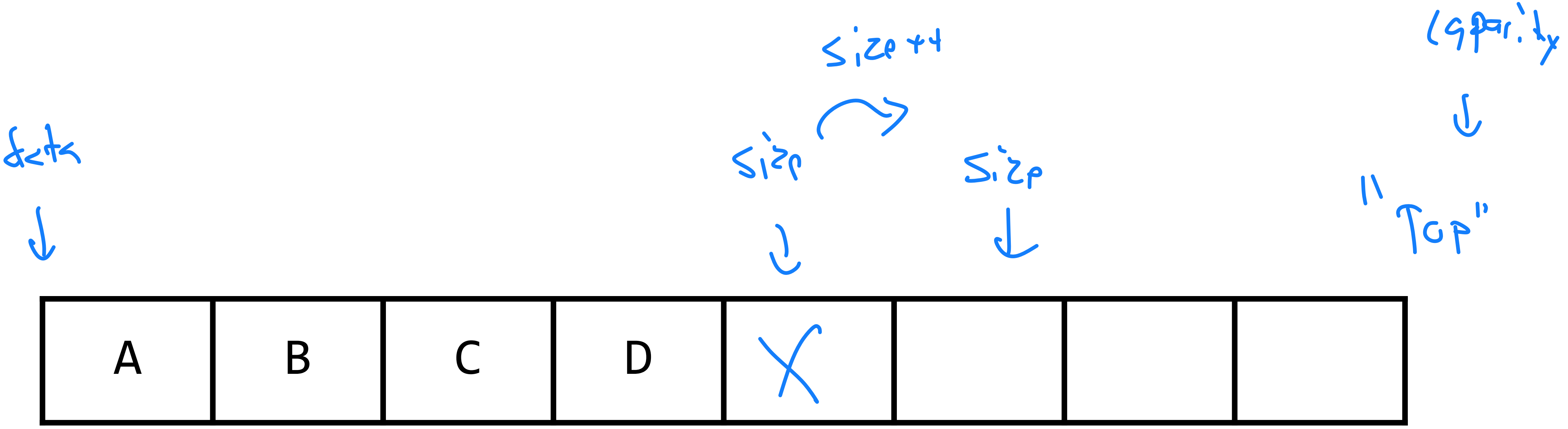
`Push(X)` is equivalent to …



Stack Data Structure

`Push(X)` is equivalent to `insertBack(X)` → O(1)*

```
*size = X;
size++;
```



Stack Data Structure

Pop( ) is equivalent to…

A	B	C	D				

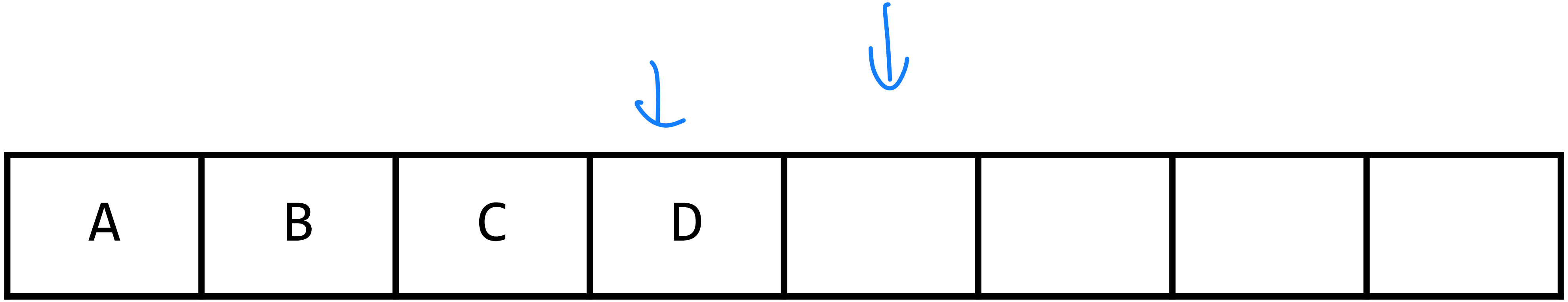
Stack Data Structure

Pop() is equivalent to removeBack() → O(1)

```
size--;
T tmp = *size;
return tmp;
```

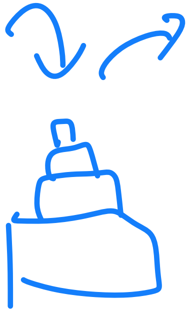
"remove" D

size



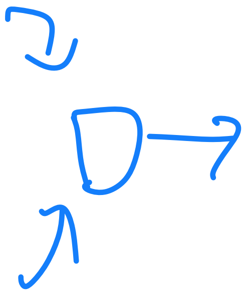
Stack ADT

- [Order]: Last in first out (LIFO)



- [Implementation]: Trivially as vector or LL

Front is top



← student Q

- [Runtime]: O(1)*

* if array is not full
  if array is full, amortized still says O(1)

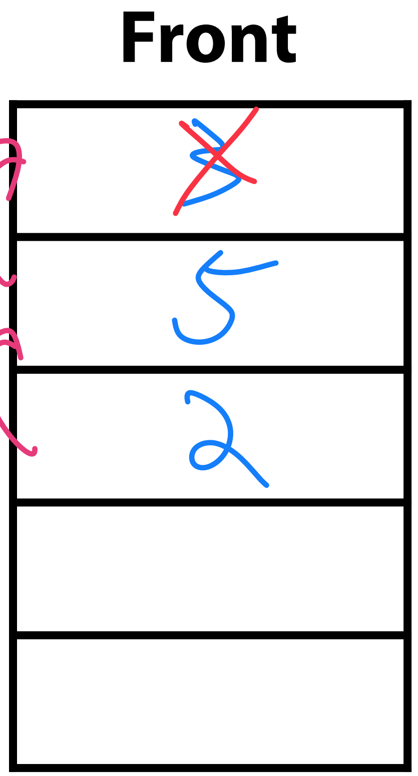
Queue Data Structure

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

However you can only do two* operations:

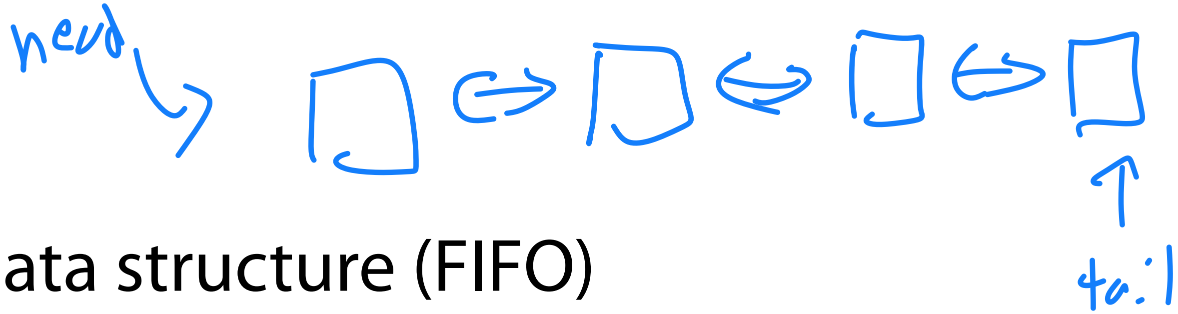
Enqueue: Put an item at the back of the queue

Dequeue: Remove and return the front item of the queue




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

Queue Data Structure



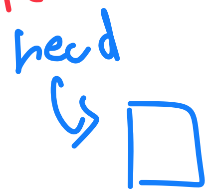
The queue is a **first in — first out** data structure (FIFO)

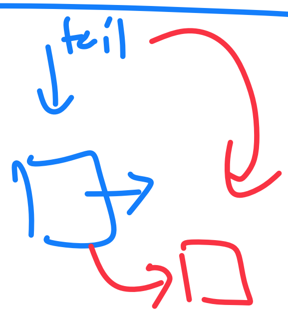
What data structure excels at removing from the front?

↳ Linked List

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

↳ tail pointer lets me insertBack O(1)





Queue Data Structure

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

↳ LL too much memory ; More overhead

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

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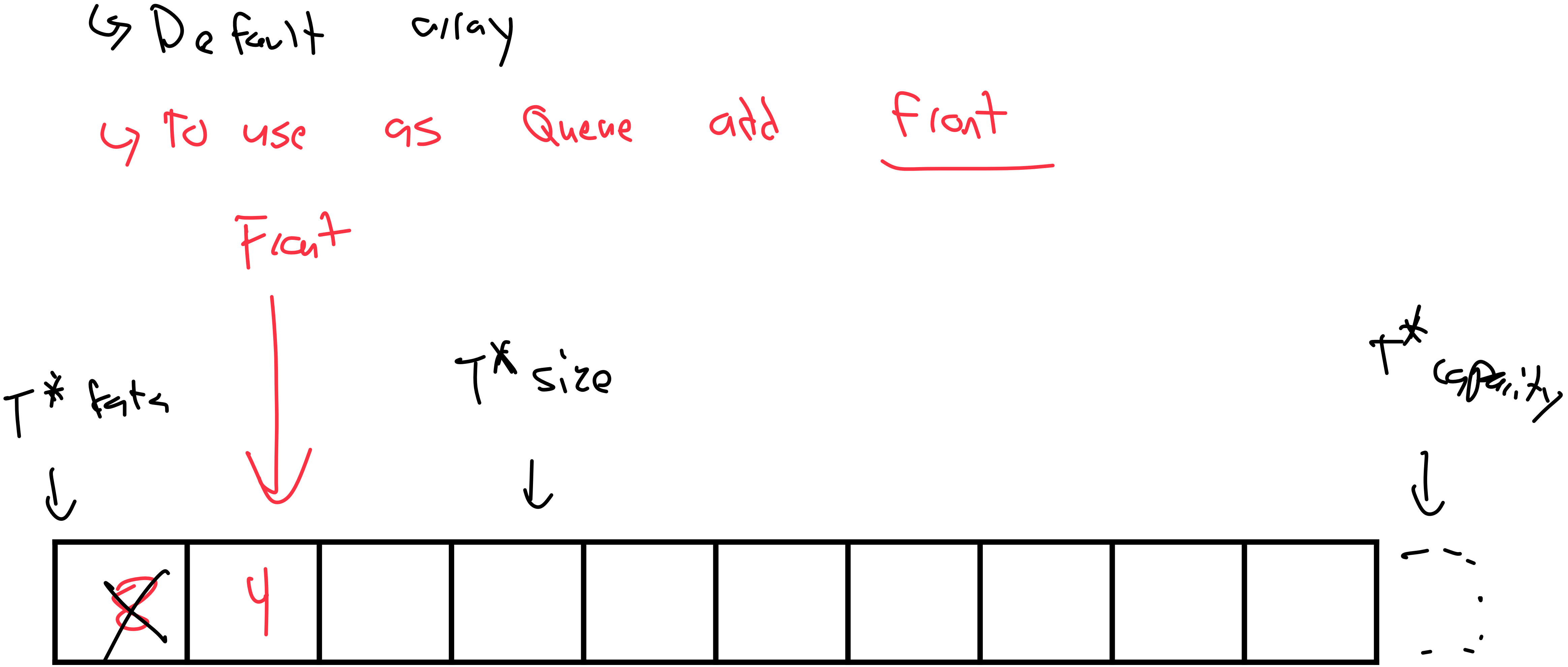
(Care of https://gist.github.com/hellerbarde/2843375)

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?



Queue Data Structure

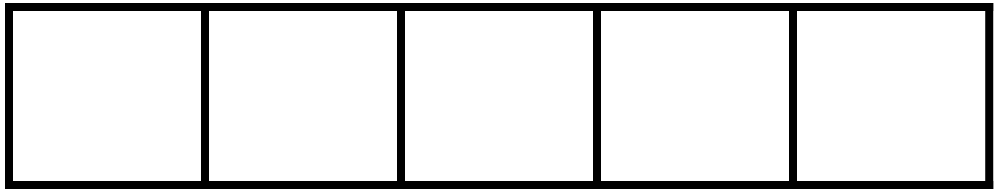
Unlike the array list, it is easier to implement a Queue using unsigned ints

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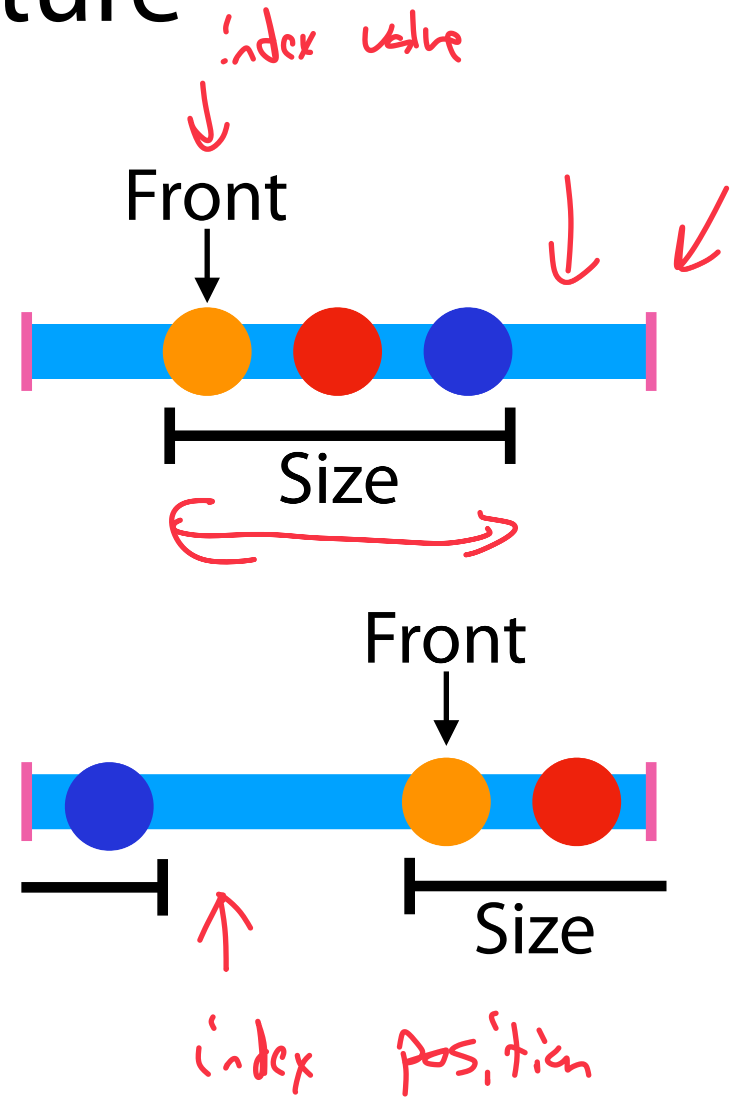
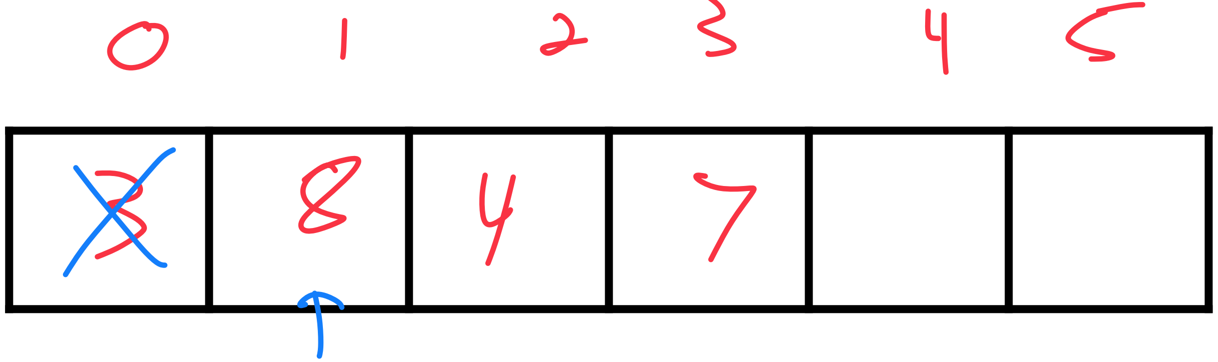






```
Queue<int> q;
q.enqueue(3);
q.enqueue(8);
q.enqueue(4);
q.dequeue();
q.enqueue(7);
q.dequeue();
q.dequeue();
q.enqueue(2);
q.enqueue(1);
q.enqueue(3);
q.enqueue(5);
q.dequeue();
q.enqueue(9);
```

Enqueue(D): insert at front + size

size ++

Dequeue(): remove item at front index

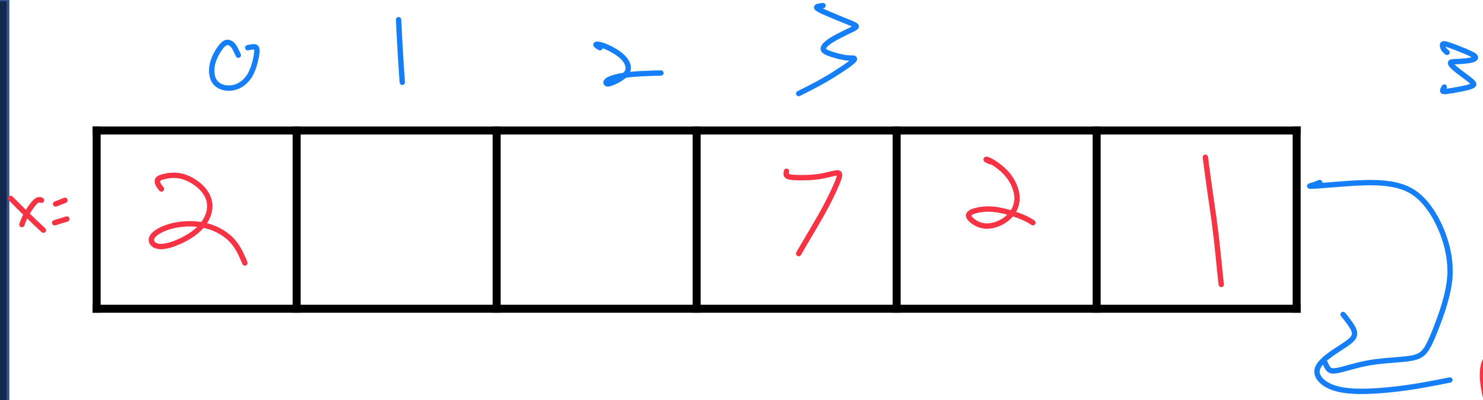
front ++;

size --;

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

Front: ~~0~~ 1

Capacity: 6



Enqueue(D): Insert @ (size+front) % capacity

size++ until size == capacity

Dequeue(): Remove @front

front = (front+1) % capacity

size--

Size:

Front:

```
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);
```

Capacity:

Queue Data Structure: Resizing

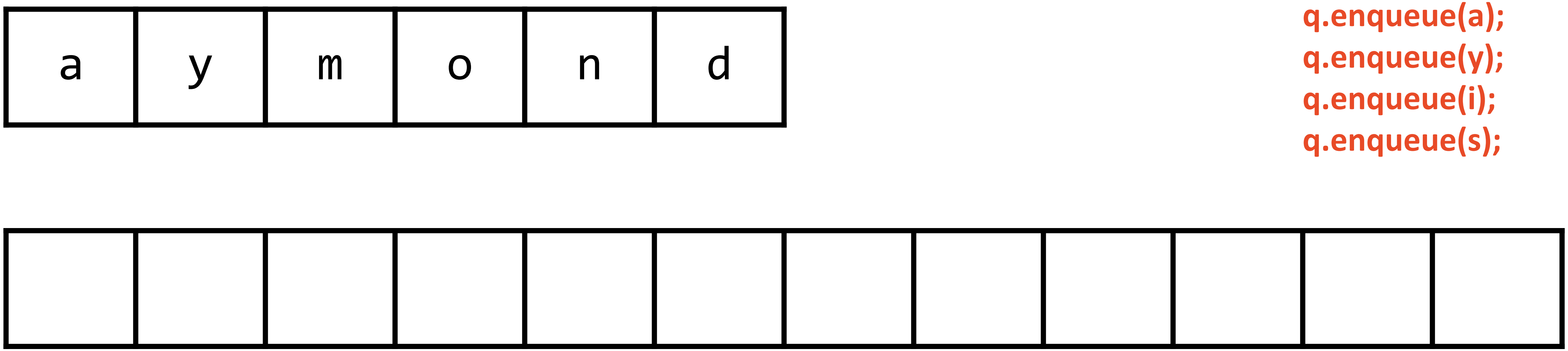
		m	o	n	

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

We do this on Friday

Queue Data Structure: Resizing

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

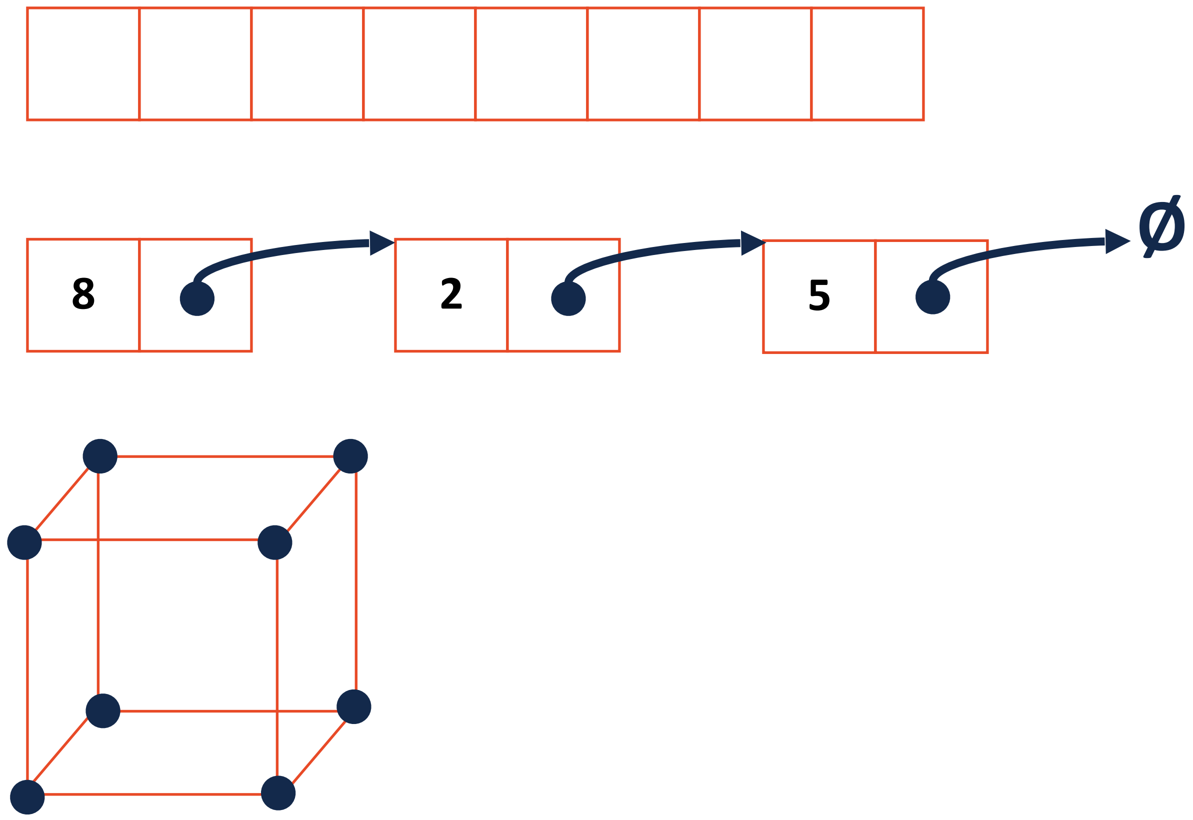


Queue ADT

- [Order]: First in First out (FIFO)
- [Implementation]: vector / dequeue → LL is possible easily
- [Runtime]: O(1)*

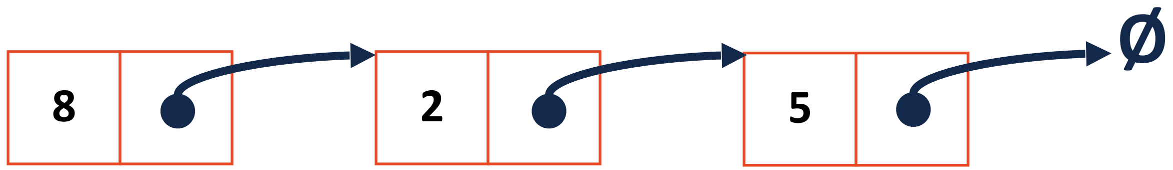
Iterators

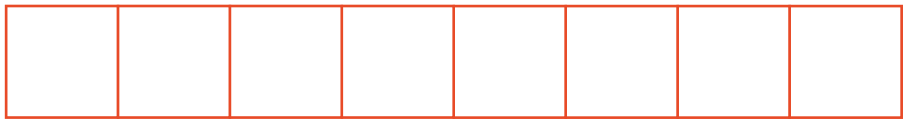
We want to be able to loop through all elements for any underlying implementation in a systematic way

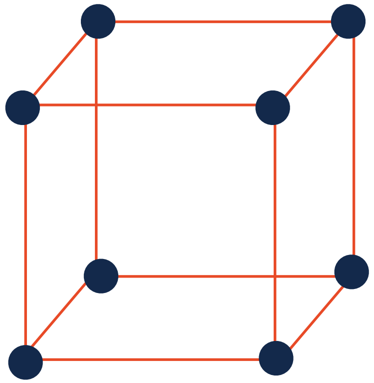


Iterators

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



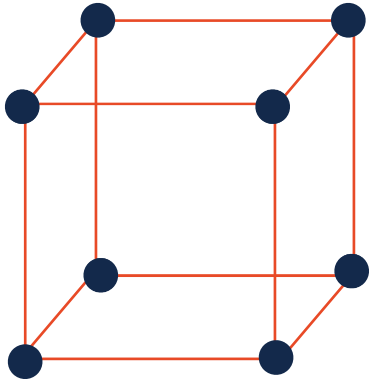




Cur. Location	Cur. Data	Next
`ListNode * curr`		
`unsigned index`		
`Some form of (x, y, z)`		

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

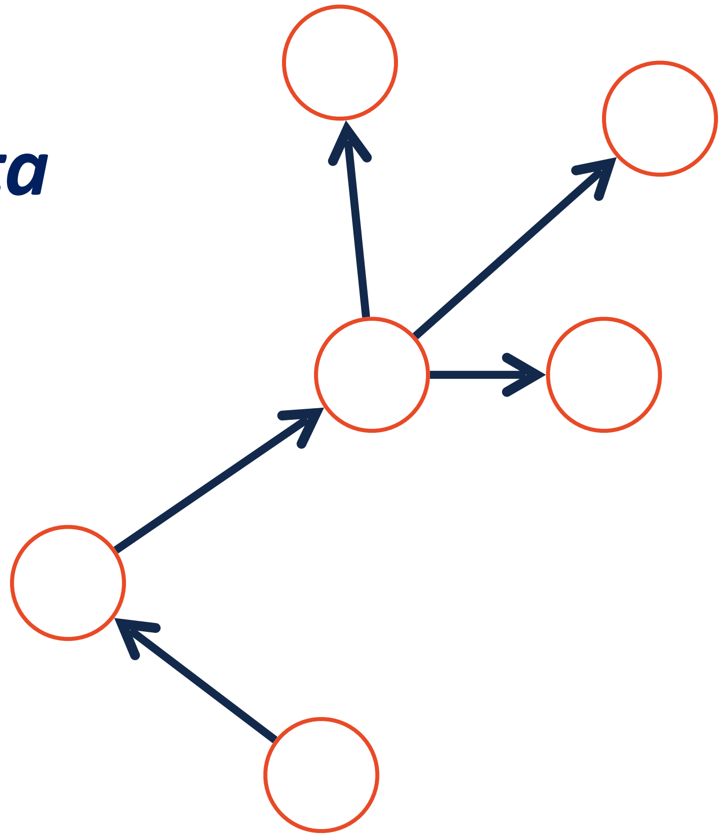
```
#include <list>
#include <string>
#include <iostream>

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:

-
-