Unit 08: Stacks and Queues

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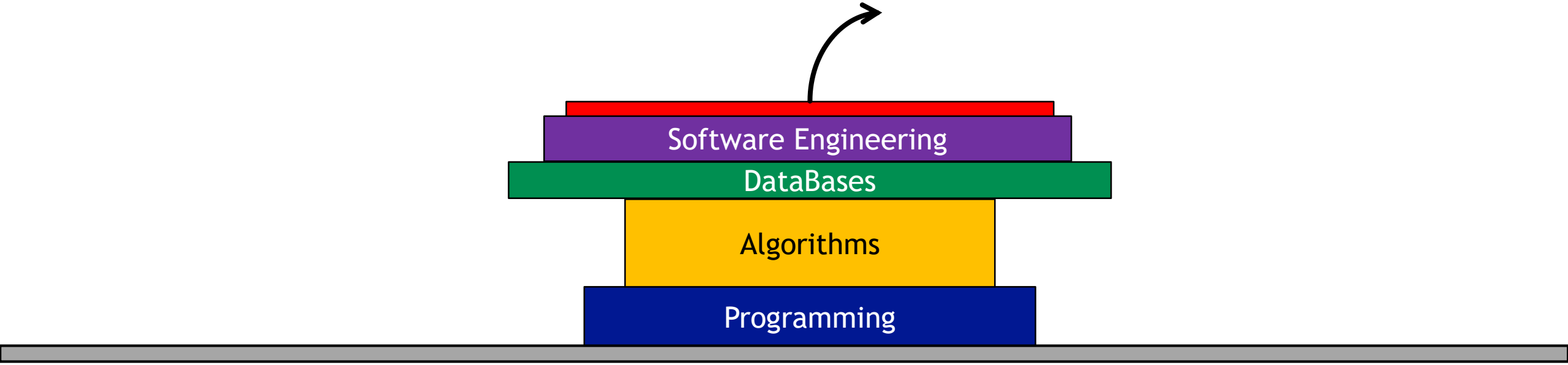
CSC 115: Fundamentals of Programming II

University of Victoria

The Notion of a Stack

- Collection of items
  - Items are returned in the ***reverse*** order they were added
  - This is behavior is often abbreviated LIFO (Last In, First Out)



Stack Examples

- Things we use all the time:
  - “Undo” function found in most applications
  - Back button when browsing the web
- Programming:
  - The runtime environment’s handling of nested method calls
  - Recursion

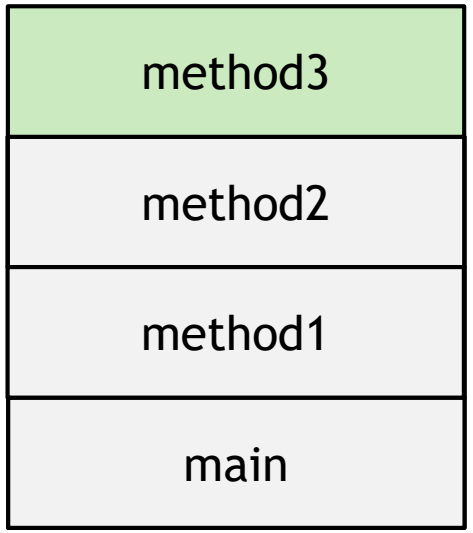
Runtime Environment

```
public static void method3() {}

public static void method2() {
    method3();
}

public static void method1() {
    method2();
    method3();
}

public static void main(String[] args) {
    method1();
}
```



The Stack ADT

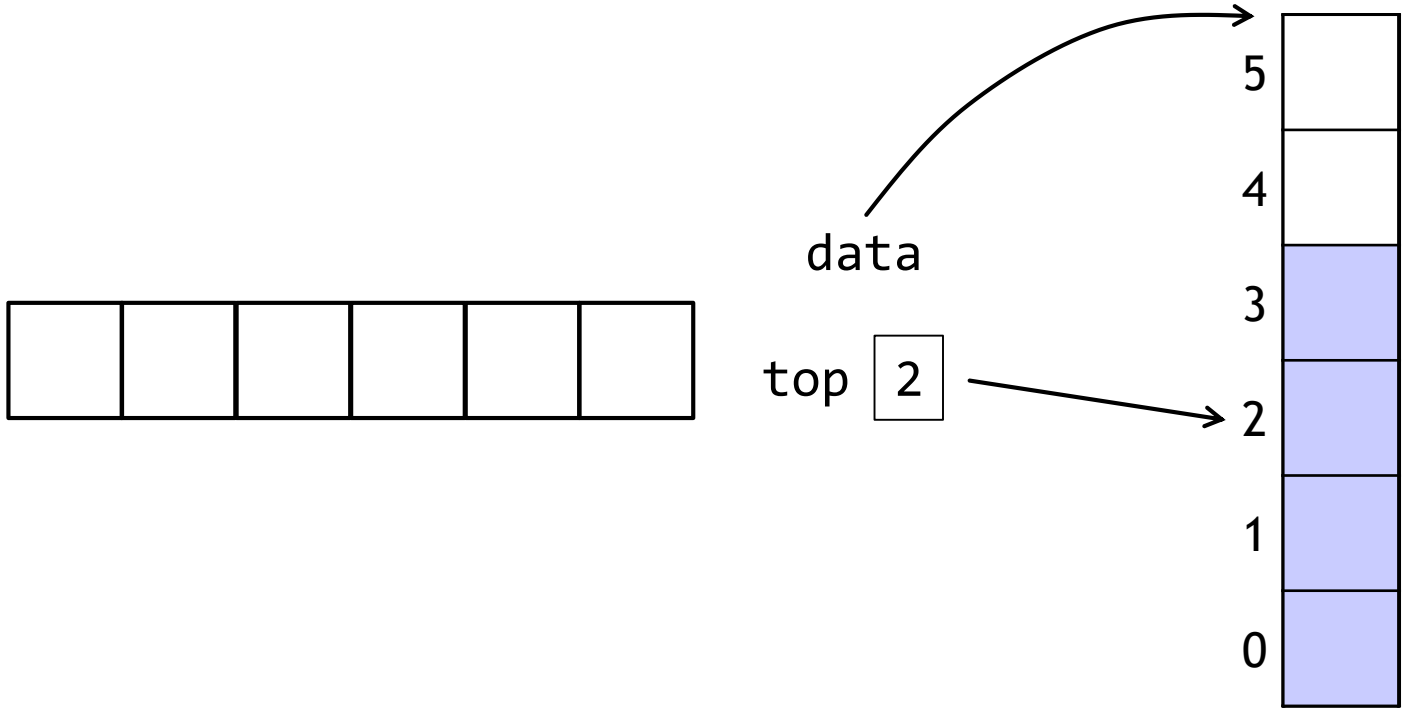
- The Stack ADT specifies the following operations:
  - Create an empty stack
  - Determine whether a stack is empty
  - Insert an object onto the stack
  - Remove the most recently added item from the stack
  - Remove all items from the stack
  - Access the most recently added item from the stack

Stack Interface:

```
isEmpty()
push(o)
pop()
popAll()
top()
```

Stack Implementation (Array)

- A stack can be implemented in multiple ways
- In an array implementation, we typically have the following:
  - **`data`**: an n-element array
  - **`top`**: an integer to keep track of the index to insert the next element
- Example:



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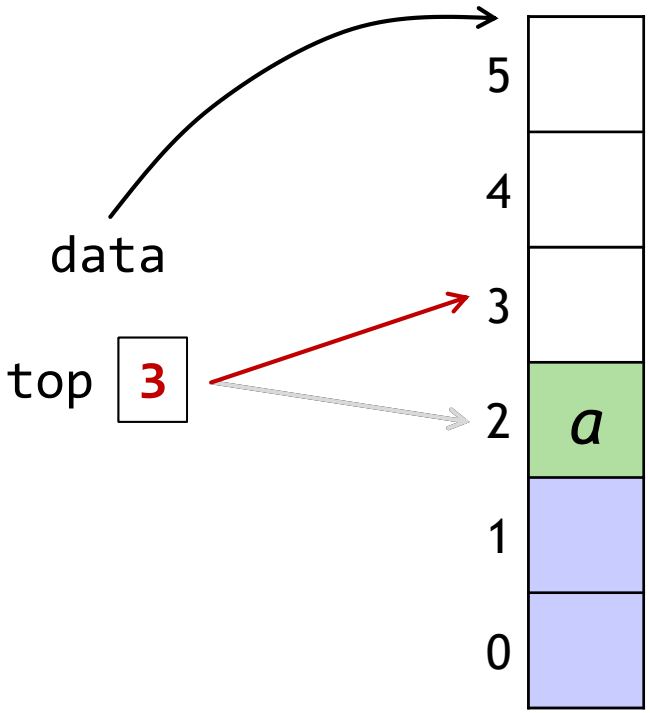
- Example:
  - **push(a)**



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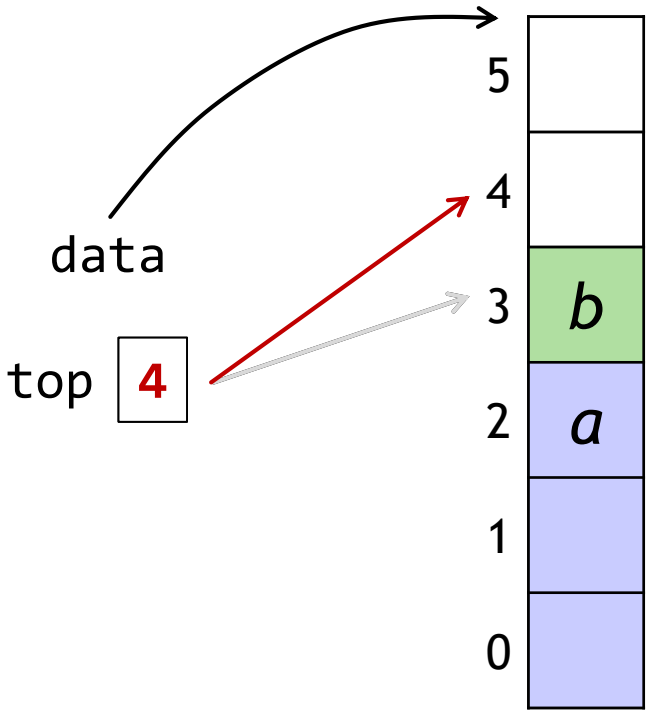
  - **push(b)**



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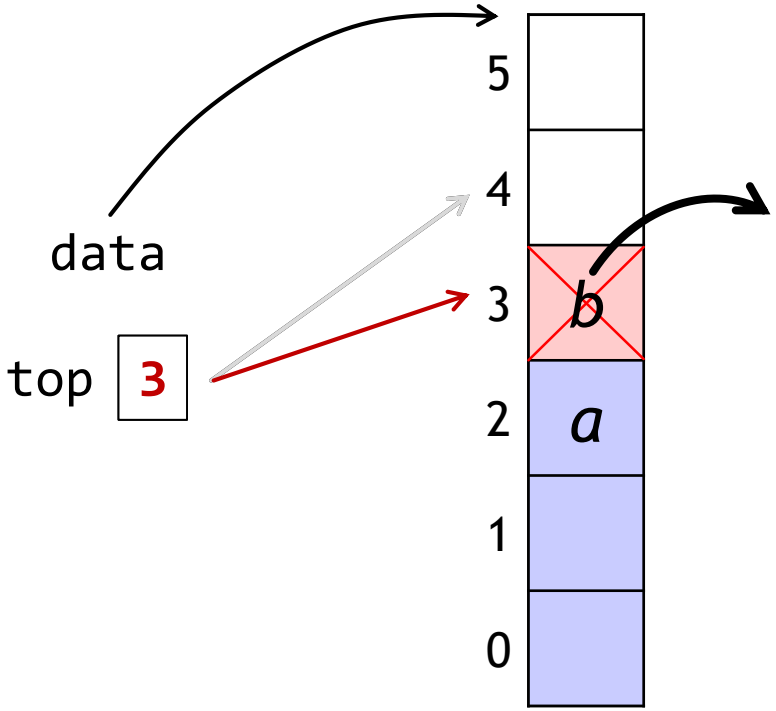
  - push(a)
  - push(b)
  - **pop()**



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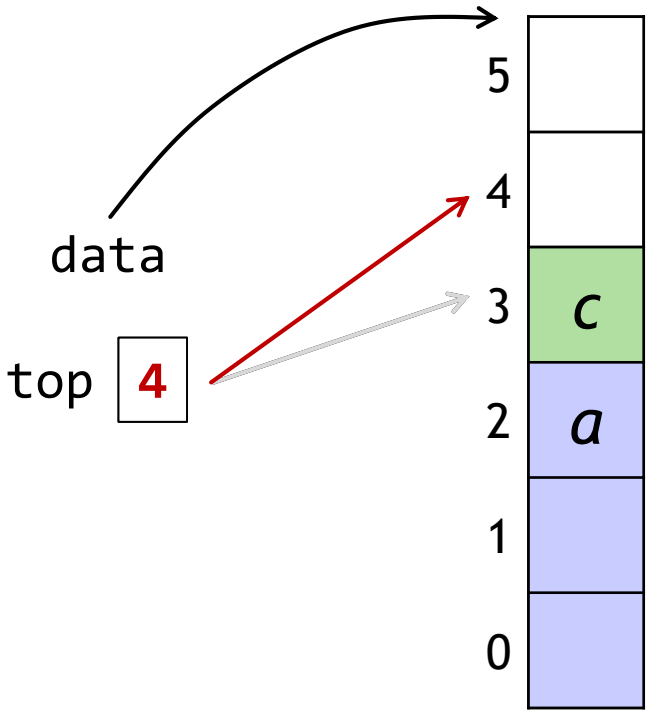
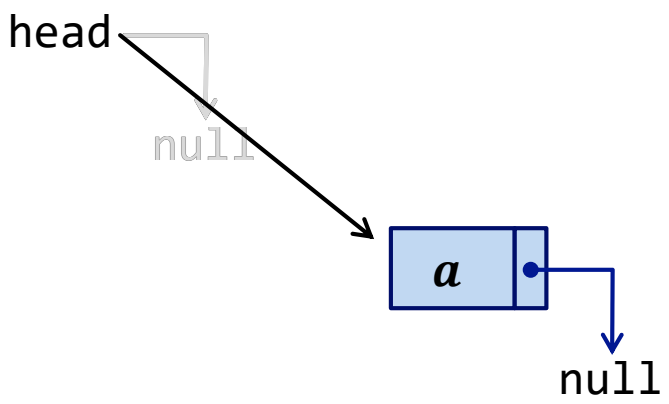
- Example:
  - push(a)
  - push(b)
  - pop()
  - **push(c)**

Key observation: We've done this before (**`addBack`** and **`removeBack`**)



Stack Implementation (Linked List)

- A stack can be implemented in multiple ways
- In a linked list implementation, a stack can easily be implemented using singly-linked nodes and a **head** reference (**tail** isn't necessary!)
- Example:
  - **push(*a*)**



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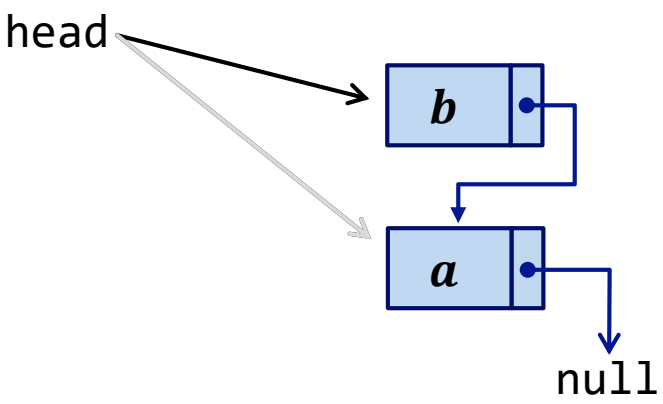

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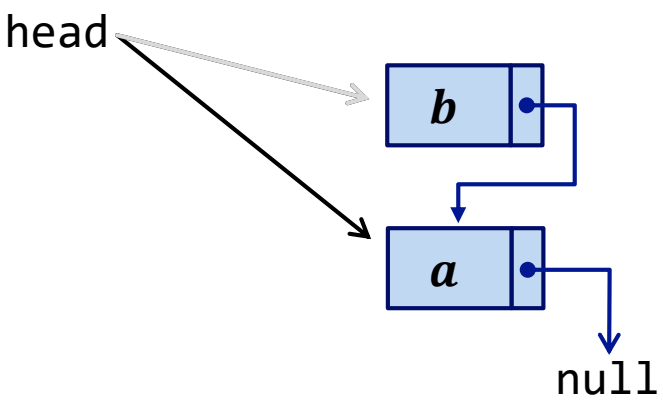
  - **pop()**



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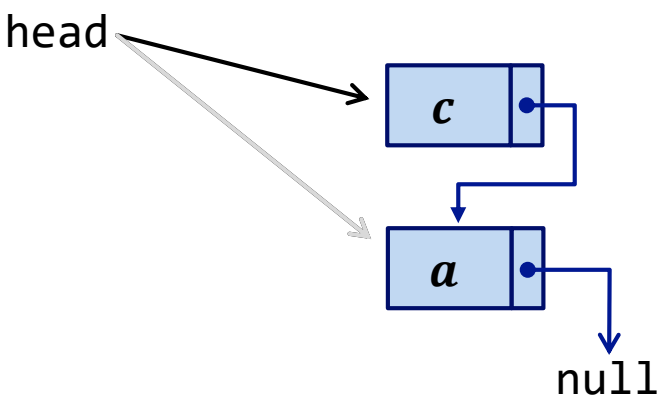
  - pop()
  - **push(c)**



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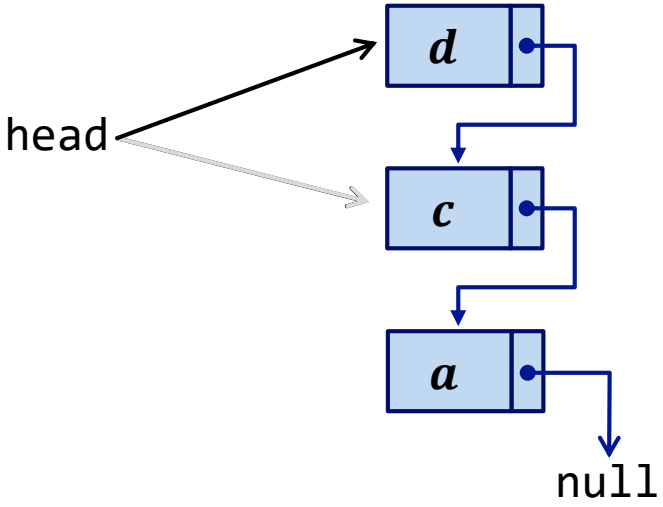
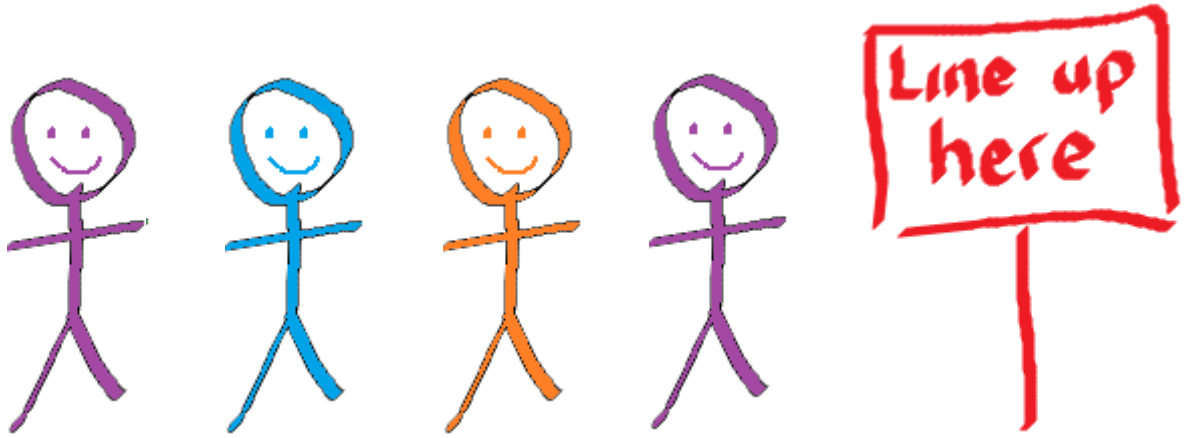
- Example:
  - push(a)
  - push(b)
  - pop()
  - push(c)
  - **push(d)**

Key observation: We've done this before (**`addFront`** and **`removeFront`**)



The Notion of a Queue

- Collection of items
  - Items are returned in the ***same*** order they were added
  - This is behavior is often abbreviated FIFO (First In, First Out)



Queue Examples

- Any time people wait in line for something
  - the bank, the cafeteria, etc.

- Waitlists for classes here at Uvic!

The Queue ADT

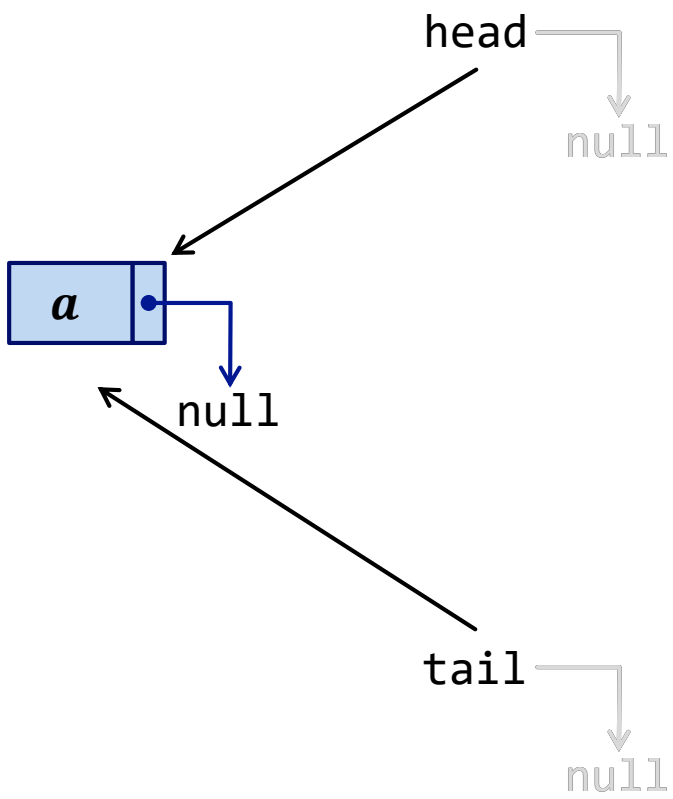
- The Queue ADT specifies the following operations:
  - Create an empty queue
  - Determine whether a queue is empty
  - Add an object to the back of the queue
  - Remove the object from the from of the queue
  - Remove all objects from the queue
  - Access the object at the front of the queue

Queue Interface:

```
isEmpty()
enqueue(o)
dequeue()
dequeueAll()
front()
```

Queue Implementation (Linked List)

- A queue can be implemented in multiple ways
- In a linked list implementation, a queue can easily be implemented using singly-linked nodes with **head** and **tail** references
- Example:
  - **enqueue(*a*)**



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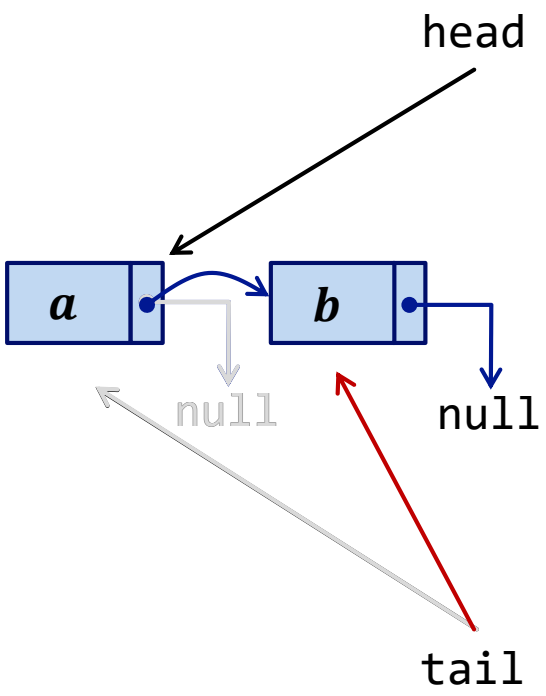

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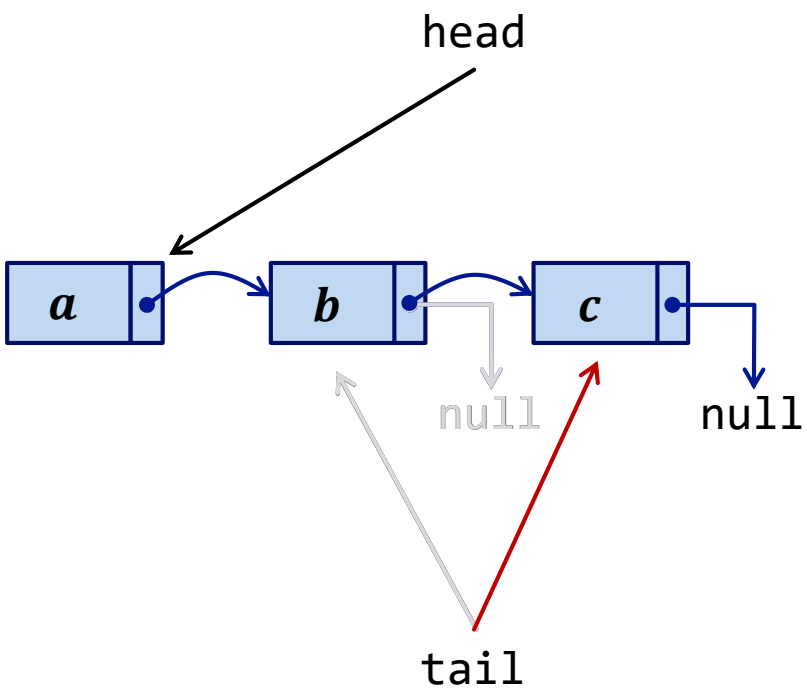

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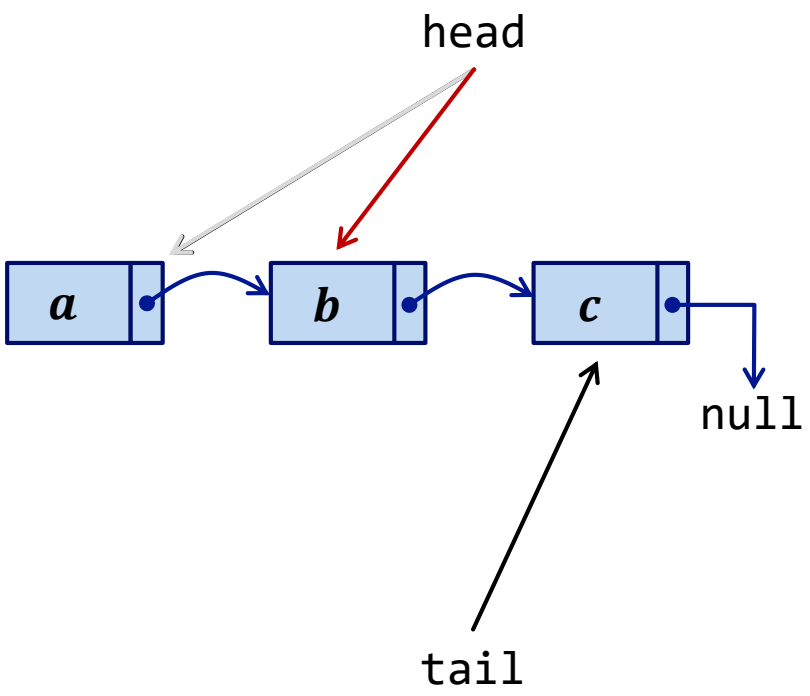

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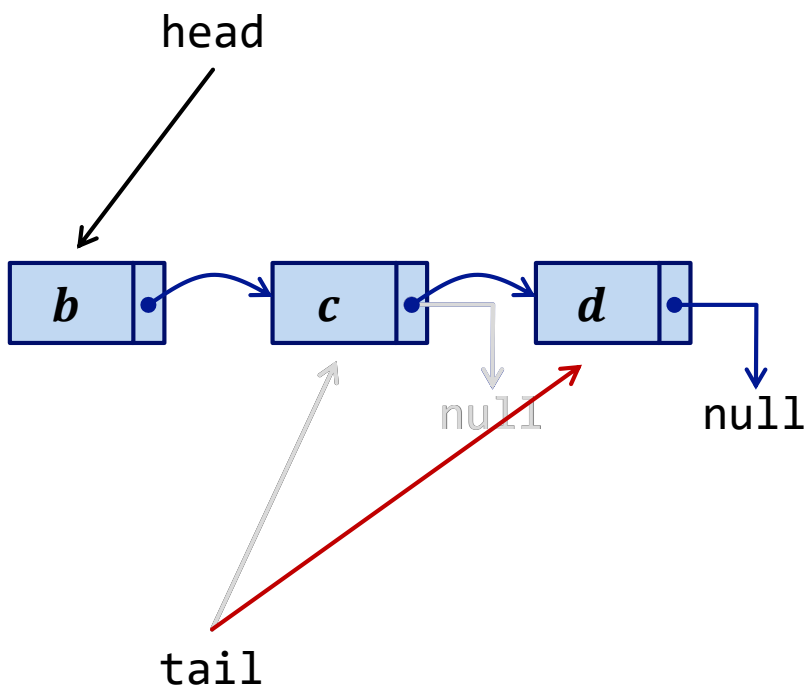
  - enqueue(c)
  - dequeue()
  - **enqueue(d)**

Key observation: We've done this before (**`addBack`** and **`removeFront`**)



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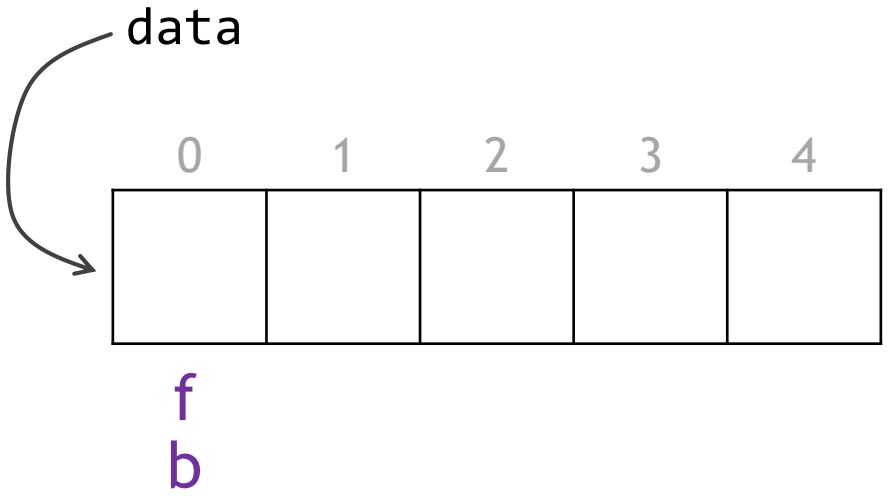

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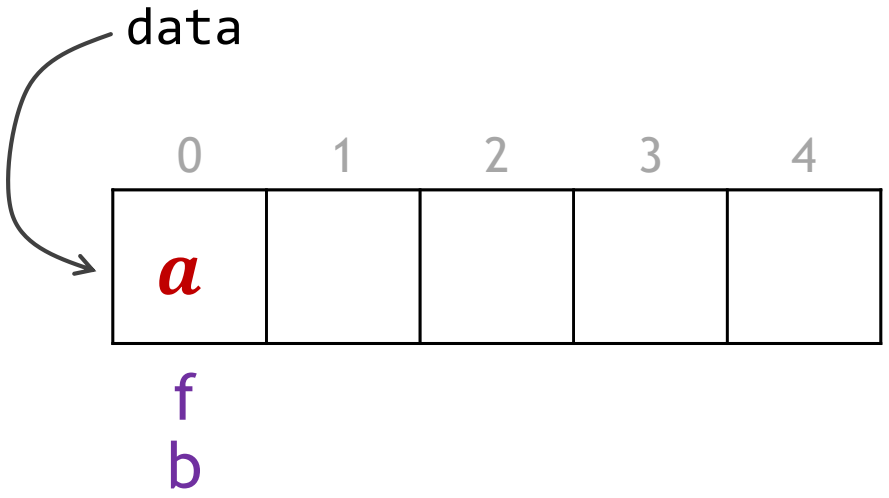

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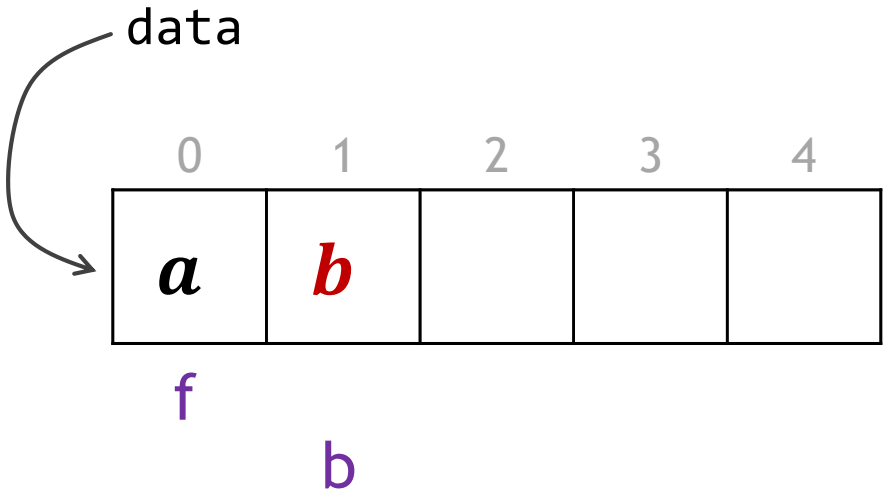
  - **enqueue(b)**



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- Example:
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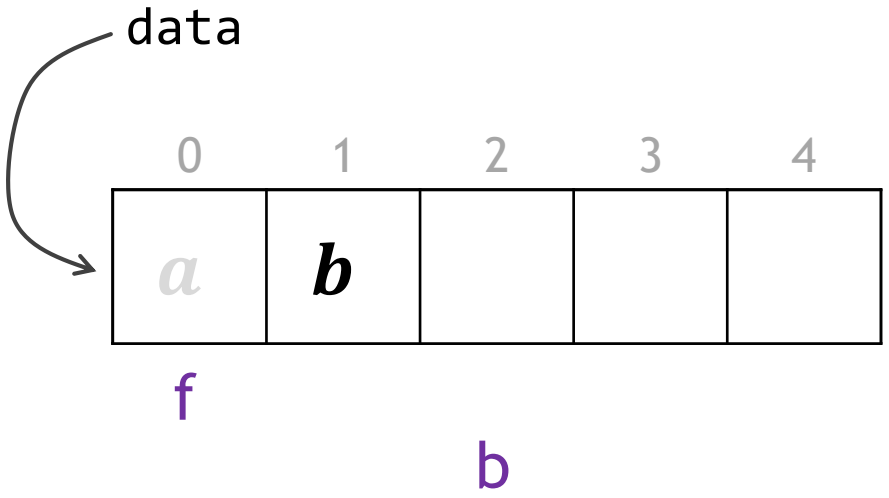
  - enqueue(b)
  - **dequeue()**



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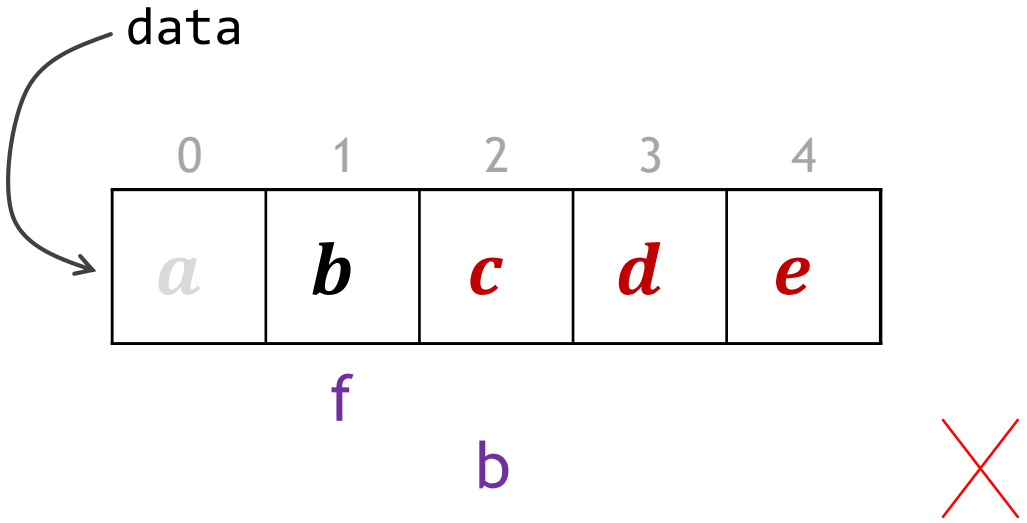
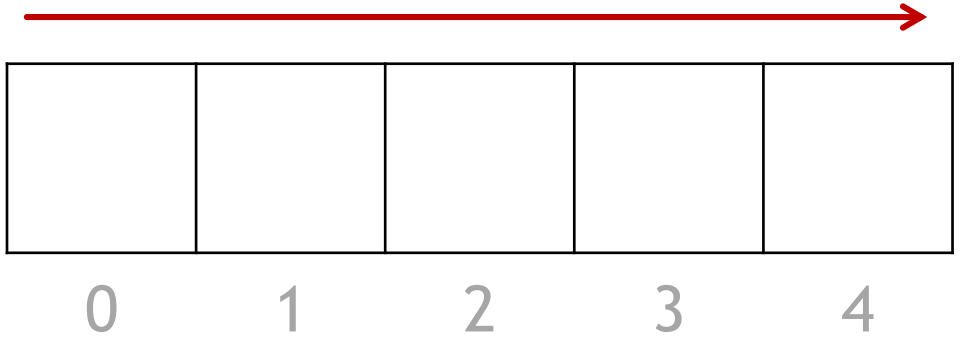
- Example:
  - enqueue(a)
  - enqueue(b)
  - dequeue()
  - **3*enqueue**

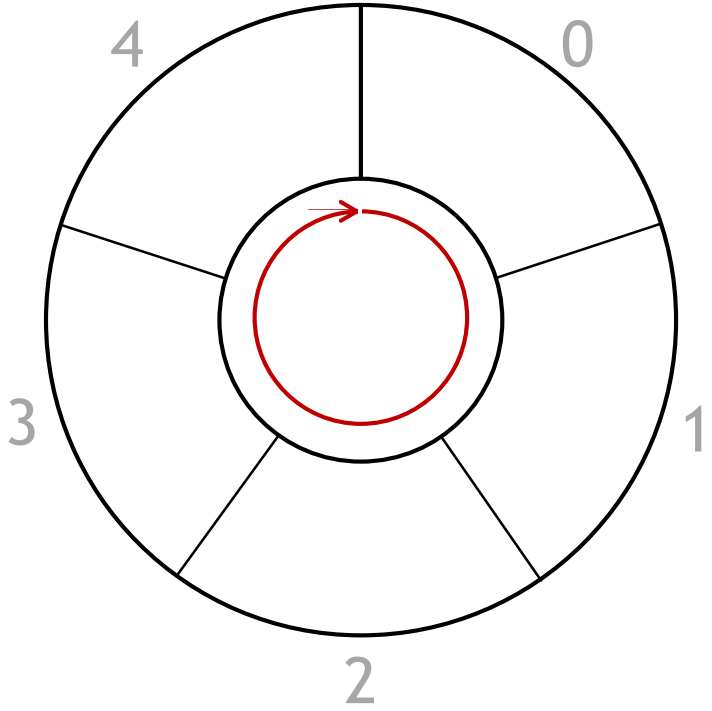


`ArrayIndexOutOfBoundsException`

Idea: Circular Arrays

- Problem: ArrayIndexOutOfBoundsException
- Solution: Have the **b** variable go back around to the first index





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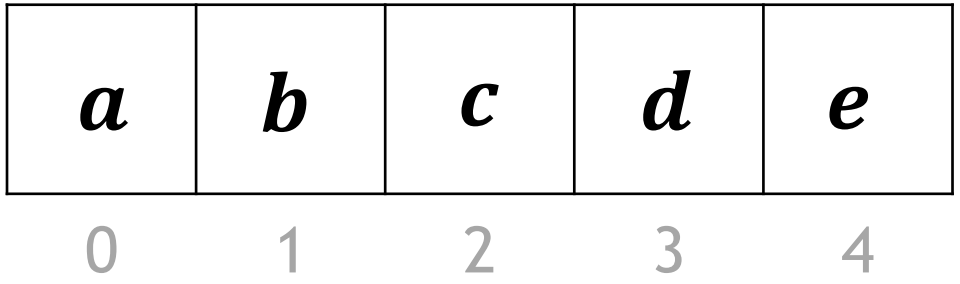

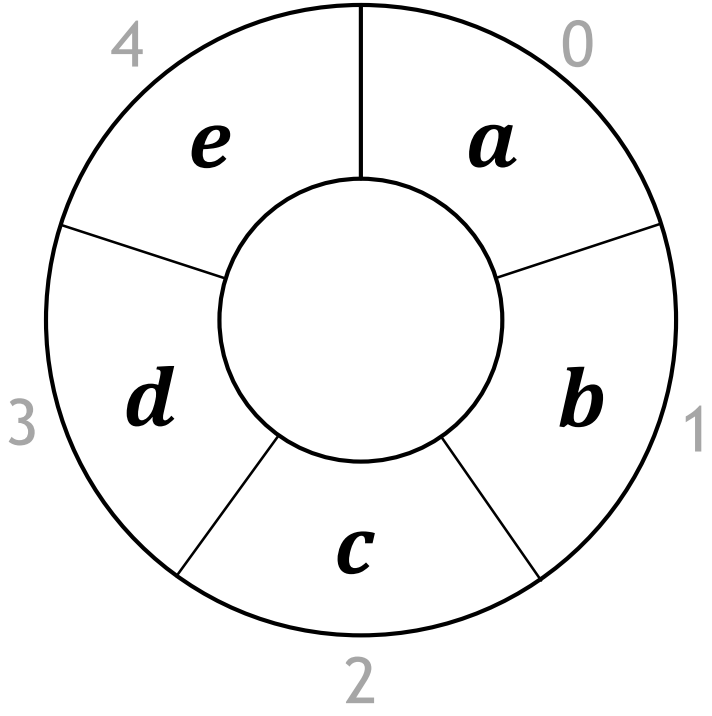

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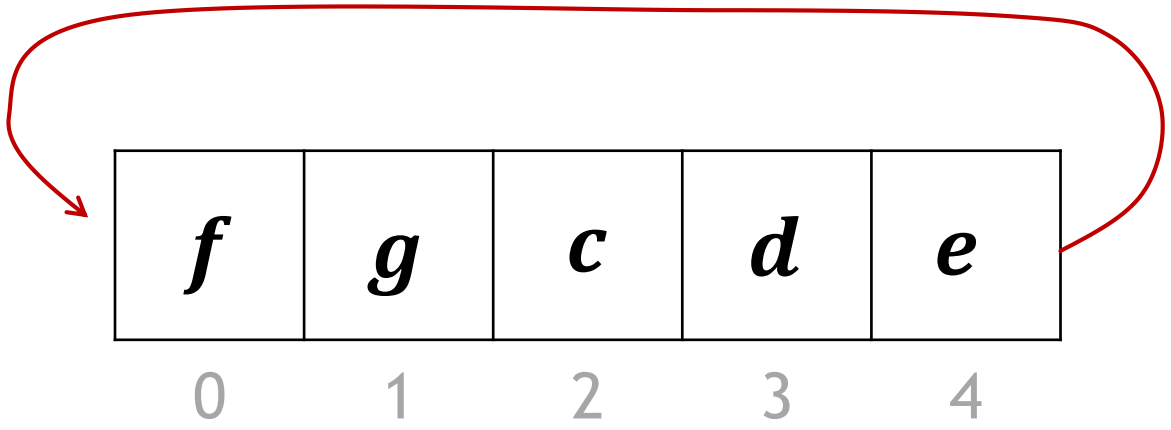

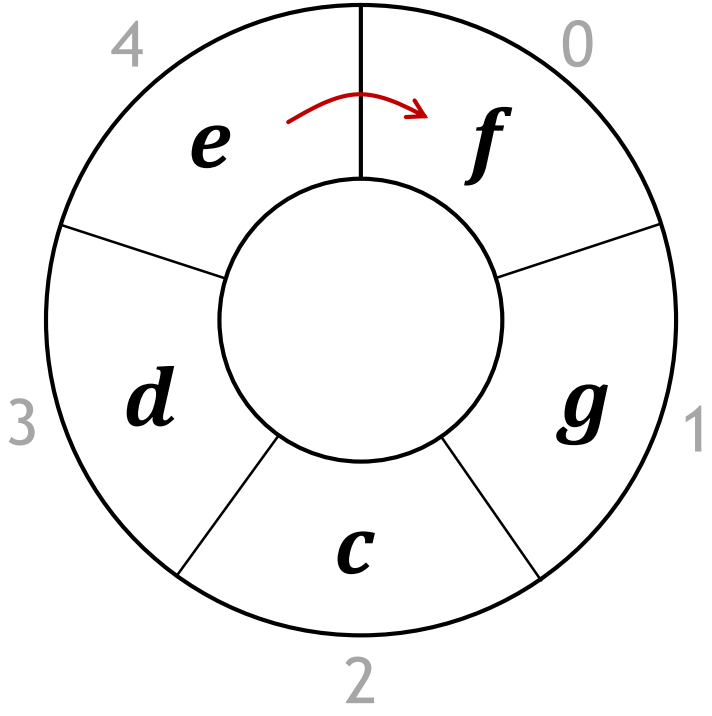

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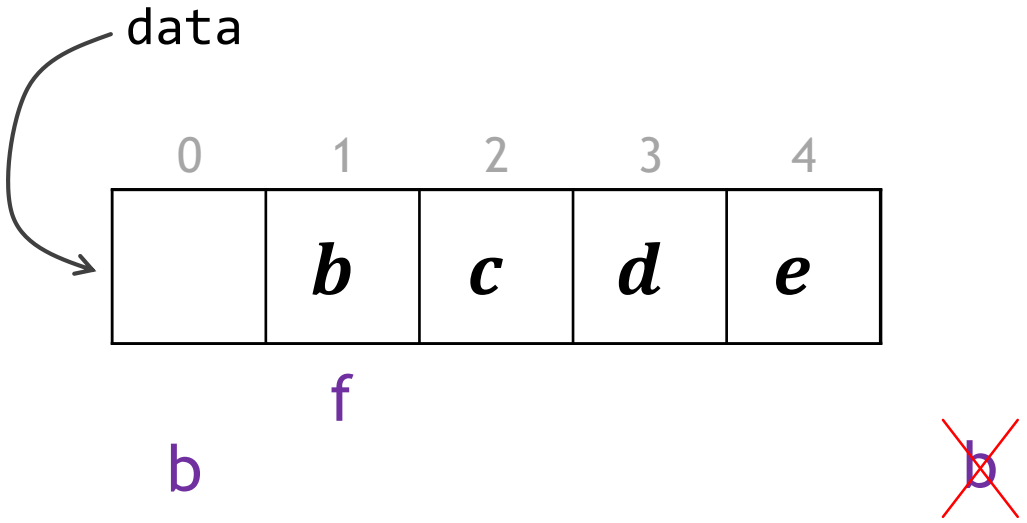

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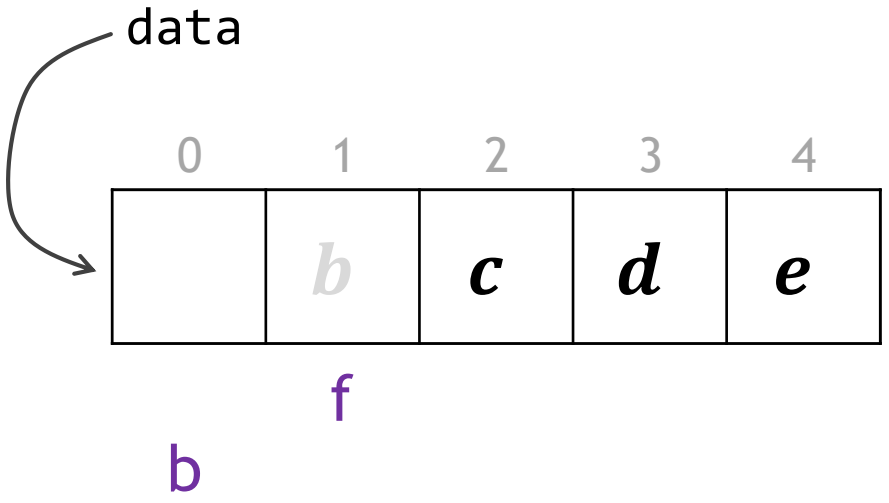
- Example:
  - **dequeue()**



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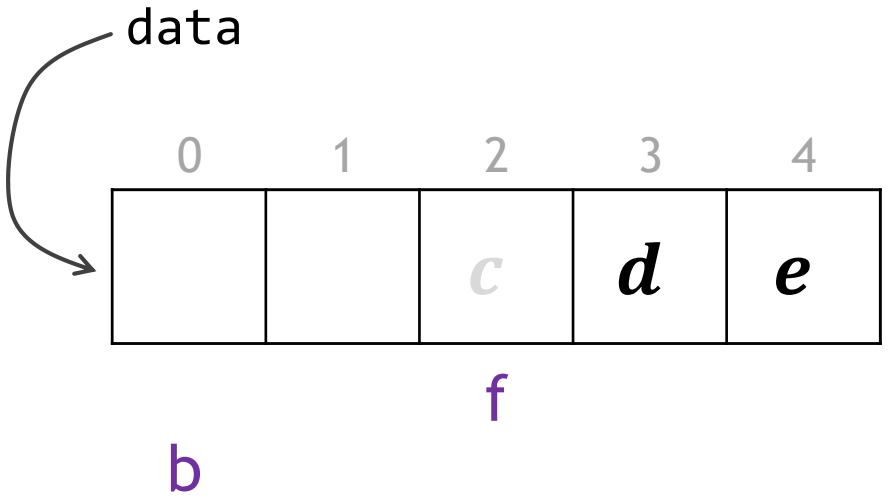

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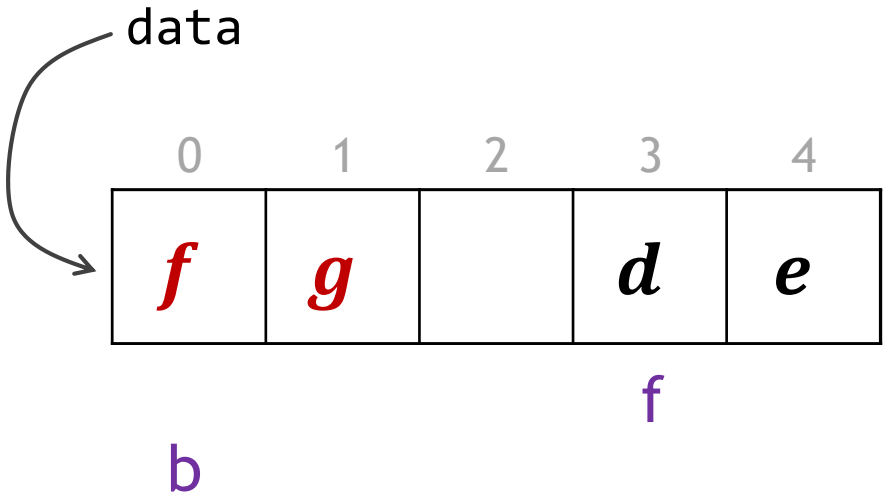
- Example:
  - dequeue()
  - dequeue()
  - **enqueue(f)**
  - **enqueue(g)**

Key observation: We've done this before (**`addBack`** and **`removeFront`**)



Analysis

Method	Array		Singly Linked		Doubly Linked	
	average	worst	no tail	tail	no tail	tail
Object get(int pos)						
int size()						
int find(Object o)						
String toString()						
void addAt(Object o, int pos)						
void addFront(Object o)						
void addBack(Object o)						
void removeAt(int pos)						
void removeFront()						
void removeBack()						
void swapElements(int pos1, int pos2)						

Analysis

Method	Array		Singly Linked		Doubly Linked	
	average	worst	no tail	tail	no tail	tail
Object get(int pos)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
int size()	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
int find(Object o)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
String toString()	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addAt(Object o, int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addFront(Object o)	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void addBack(Object o)	$O(1)$	$O(n)$	$O(n)$	$O(1)$	$O(n)$	$O(1)$
void removeAt(int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void removeFront()	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void removeBack()	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(1)$
void swapElements(int pos1, int pos2)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$

Analysis - Stacks

Method	Array		Singly Linked		Doubly Linked	
	average	worst	no tail	tail	no tail	tail
Object get(int pos)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
int size()	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
int find(Object o)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
String toString()	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addAt(Object o, int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addFront(Object o)	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void addBack(Object o)	$O(1)$	$O(n)$	$O(n)$	$O(1)$	$O(n)$	$O(1)$
void removeAt(int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void removeFront()	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void removeBack()	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(1)$
void swapElements(int pos1, int pos2)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$

Array

`push: addBack`

`pop: removeBack`

$O(1)$ runtime!

Analysis - Stacks

Method	Array		Singly Linked		Doubly Linked	
	average	worst	no tail	tail	no tail	tail
Object get(int pos)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
int size()	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
int find(Object o)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
String toString()	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addAt(Object o, int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addFront(Object o)	$O(n)$	$O(n)$	$\boxed{O(1)}$	$O(1)$	$O(1)$	$O(1)$
void addBack(Object o)	$O(1)$	$O(n)$	$O(n)$	$O(1)$	$O(n)$	$O(1)$
void removeAt(int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void removeFront()	$O(n)$	$O(n)$	$\boxed{O(1)}$	$O(1)$	$O(1)$	$O(1)$
void removeBack()	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(1)$
void swapElements(int pos1, int pos2)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$

Linked List

`push: addFront`

`pop: removeFront`

$O(1)$ runtime!

Analysis - Queues

Method	Array		Singly Linked		Doubly Linked	
	average	worst	no tail	tail	no tail	tail
Object get(int pos)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
int size()	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
int find(Object o)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
String toString()	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addAt(Object o, int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addFront(Object o)	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void addBack(Object o)	$O(1)$	$O(n)$	$O(n)$	$\boxed{O(1)}$	$O(n)$	$O(1)$
void removeAt(int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void removeFront()	$O(n)$	$O(n)$	$O(1)$	$\boxed{O(1)}$	$O(1)$	$O(1)$
void removeBack()	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(1)$
void swapElements(int pos1, int pos2)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$

Linked List

`push: addFront`

`pop: removeFront`

$O(1)$ runtime!

Analysis - Queues

Method	Array		Singly Linked		Doubly Linked	
	average	worst	no tail	tail	no tail	tail
Object get(int pos)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
int size()	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
int find(Object o)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
String toString()	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addAt(Object o, int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void addFront(Object o)	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void addBack(Object o)	$O(1)$	$O(n)$	$O(n)$	$O(1)$	$O(n)$	$O(1)$
void removeAt(int pos)	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$
void removeFront()	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$	$O(1)$
void removeBack()	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(1)$
void swapElements(int pos1, int pos2)	$O(1)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$

Array

`push: addBack`

`pop: removeBack`

`circular array`

$O(1)$ runtime!

Using ADTs

- So far we have focused on the implementation of ADTs
  - We have seen both array-based and reference-based (linked list) implementations of both stacks and queues
- Assume we now have a working implementation of a Stack or Queue
- What are the benefits of using an ADT like a stack to solve a problem?
  - the operations are clearly defined and easy to understand
  - it can be reused to solve many different problems
  - the implementation can be changed without changing the behaviour of the program that uses the ADT

Using a stack to solve problems

- One error you may have encountered programming in Java is when your open and close curly braces ({ and }) don't line up
- For example:

```
public static int countOdd(int[] arr) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] % 2 == 0) {
            count++;
        }
    }
    return count;
}
```

if

loop

method

Using a stack to solve problems

- Sometimes, we forget a closing curly brace:

```
public static int countOdd(int[] arr) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] % 2 == 0) {
            count++;
        }
    }
    return count;
}
```

if

loop

method

Uh oh – no closing if-statement curly brace!

Now the return statement is inside the loop, and there is no closing brace for the method

Using a stack to solve problems

- Or, for some reason, there is an extra closing brace:

```
public static int countOdd(int[] arr) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] % 2 == 0) {
            count++;
        }

    }
}
return count;
}
```

if

loop

method

Now the return statement is outside the method!

Using a stack to solve problems

- How could a compiler determine when there is an error with opening and closing braces in a program?

- There are a few things that must be true:
  - There must be the same total number of {'s and }'s
  - There should never be a point where we have seen more }'s than {'s

- We can determine if either of the two violations above occur using a stack!

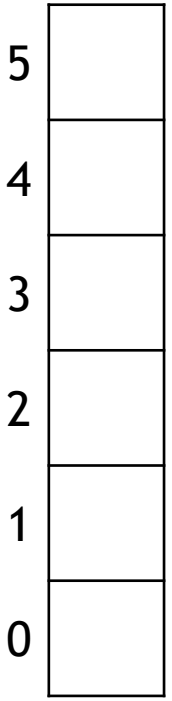
Brace matching

- Idea:
  - Read though the contents of the .java file
  - Every time we see an open brace ({), push it to the stack
  - Every time we see a closing brace (}), pop from the stack
- At the end of the code, the stack should be empty
- But how do we determine if at some point there were more close braces than open braces?
  - If we try and pop from an empty stack!

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

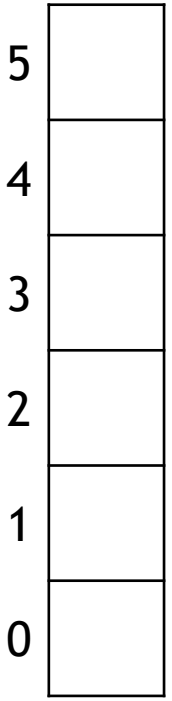


Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

push

stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

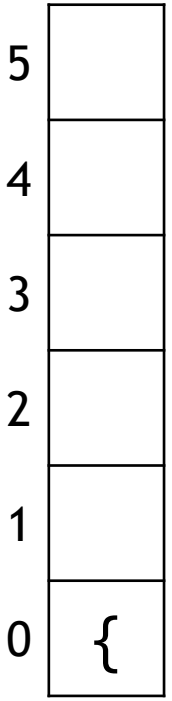
stack:

5	
4	
3	
2	
1	
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

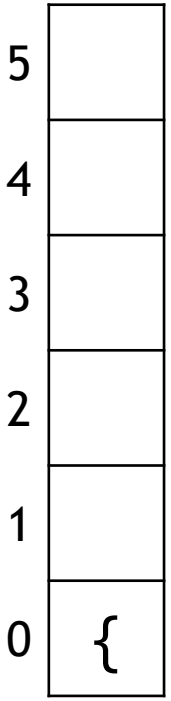
stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

push

stack:

5	
4	
3	
2	
1	
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

5	
4	
3	
2	
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

5	
4	
3	
2	
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

push

stack:

5	
4	
3	
2	
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

5	
4	
3	
2	{
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

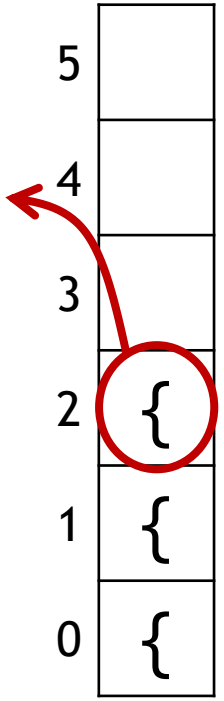
5	
4	
3	
2	{
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

pop

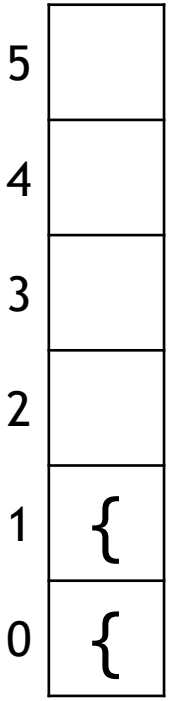
stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

push

stack:

5	
4	
3	
2	
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

5	
4	
3	
2	{
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

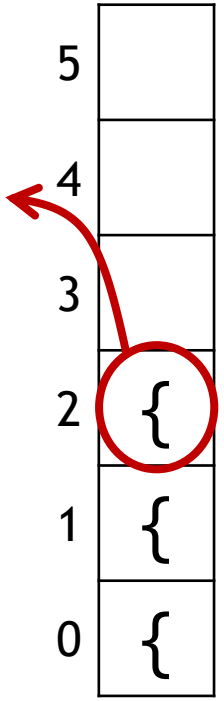
5	
4	
3	
2	{
1	{
0	{

Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

pop

stack:

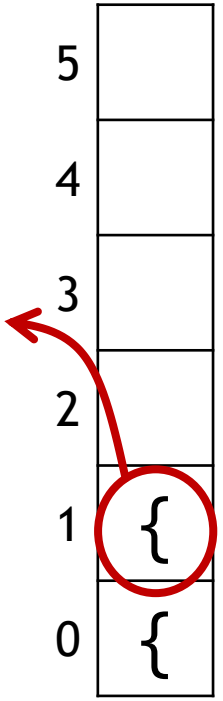


Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

pop

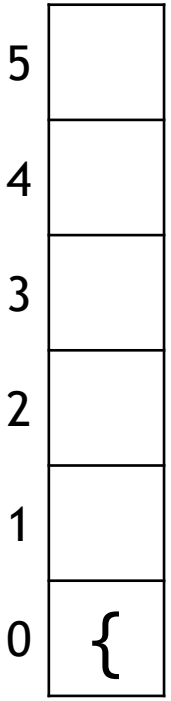
stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:

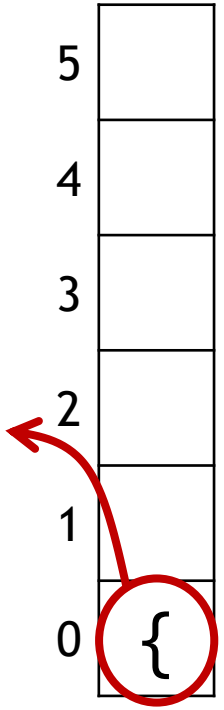


Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

pop

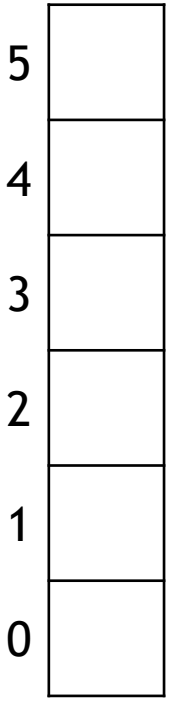
stack:



Brace matching

```
public static int countXY(int[] arr, int x, int y) {
    int count = 0;
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == x) {
            count++;
        } else if (arr[i] == y) {
            count++;
        }
    }
    return count;
}
```

stack:



stack is empty → braces match!