

PG4200: Algorithms And Data Structures

Lesson 02: Generics, Stacks and Queues

Bogdan Marculescu

Generics

Data Types

- In Java (and other statically typed languages) you need to declare the *type* of the variable
 - eg, “*int x*” or “*String y*”
- In collections (arrays, lists, queues, stacks, etc.) you store data, but of which type?

Example

- *StringContainer*. to store strings
- *IntegerContainer*. to store integers
- *WebSocketContainer*. to store web socket objects
- *SongContainer*. to store song objects
- *ShopCartContainer*. to store items in a shop cart
- etc.
- Do you see the problem here?

Polymorphism?

- Issue: would need a different implementation for each container for each possible type class ever
- What about using a *ObjectContainer* to store *java.lang.Object* instances?
- In Java, all objects have *Object* class as ancestor, so could add any type due to polymorphism
 - e.g., can add *String* and *Song* in same *ObjectContainer*
- Problem: yes, we can insert anything, but what would we read back is *Object*, and not *String* or *Song*

//Add: String "foo", Integer 5
container.add("foo");
container.add(5);



ObjectContainer
add(Object x)

[0]	"foo"
[1]	5

Object x = container.get(0);
//we do not know if String or
//something else

Java Generics <T>

- *List<T>*: define a *generic* type, which can be substituted with any type
 - note: “T” is just a label, could be anything
- Eg. *List<String>*, *List<Integer>*, *List<Song>*
- If I am only storing a variable (e.g., in a class field or array), I do need to care of its type, as not going to call any method on it
 - eg, “*T x = input;*” do not need to care of actual type of T, as long as *input* is of that type

<T extends Foo>

- In some cases you need Generics, but still need to call methods on it
- With *<T>* you would only be allowed to call methods from *java.lang.Object*
- *<T extends Foo>* means any type that extends/implements the class/interface *Foo*
- Note: there is also a *<T super Foo>*, but we will not need it

Primitive Types

- Given a generic `List<T>`, then we cannot instantiate with `int`, eg, `List<int>` does not compile
- `int` is a primitive type, and NOT an object extending *java.lang.Object*
 - others: `double`, `float`, `long`, `char`, `boolean`, etc.
- For each primitive type, Java provides an object wrapper, eg `Integer` for `int`
 - so can have `List<Integer>`
- Being an object, it can be null
 - eg, `Integer i = null;`

Autoboxing and Unboxing

- **Integer i = 5;**
 - better than writing: `Integer i = new Integer(5);`
 - Other example: `Character c = 'a';`
- **Autoboxing:** Java compiler can automatically box a primitive into a wrapper object
 - eg, primitive `5` into object of type `Integer`
- **Unboxing:** automatically from wrapper to primitive
 - eg, `int k = i;`
- It is not for free, so usually better to use primitives in your code, unless dealing with collections or nullable values

Stacks and Queues

Stack

- Type of collection
- Add on top of the stack (**push**)
- Remove from top (**pop**)
- Can only read from top (**peek**)
- *LIFO: Last In, First Out*



Why?

- The type of operations are more restricted compared to other collections we saw so far
- But if you are only interested in the operations of a stack, you can have specialized, *high-performant* implementations for it

Example

- You need to work on some data X, so you push X on stack
- While working with X, you need to work on some other Y (**push** Y), but, once done with it (**pop**), need to go back to X (**peek**)
- While working on Y, might need to work on a Z (**push** Z), which itself might need to push more data on stack, etc.

Method Call Stack

- For each method call, there is a frame, eg containing input parameters
- At each call, the JVM needs to push frame, and pop it once method is completed


```
public class StackOverflow {  
  
    public static void main(String[] args) {  
        a(0);  
    }  
  
    public static int a(int x) {  
        x++;  
  
        x = b(x);  
  
        return x;  
    }  
  
    public static int b(int y) {  
        return a(y);  
    }  
}
```

Stack Overflow

Exception in thread "main" **java.lang.StackOverflowError**

```
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow.b(StackOverflow.java:22)
at org.pg4200.datastructure.stack.StackOverflow.a(StackOverflow.java:16)
at org.pg4200.datastructure.stack.StackOverflow
```

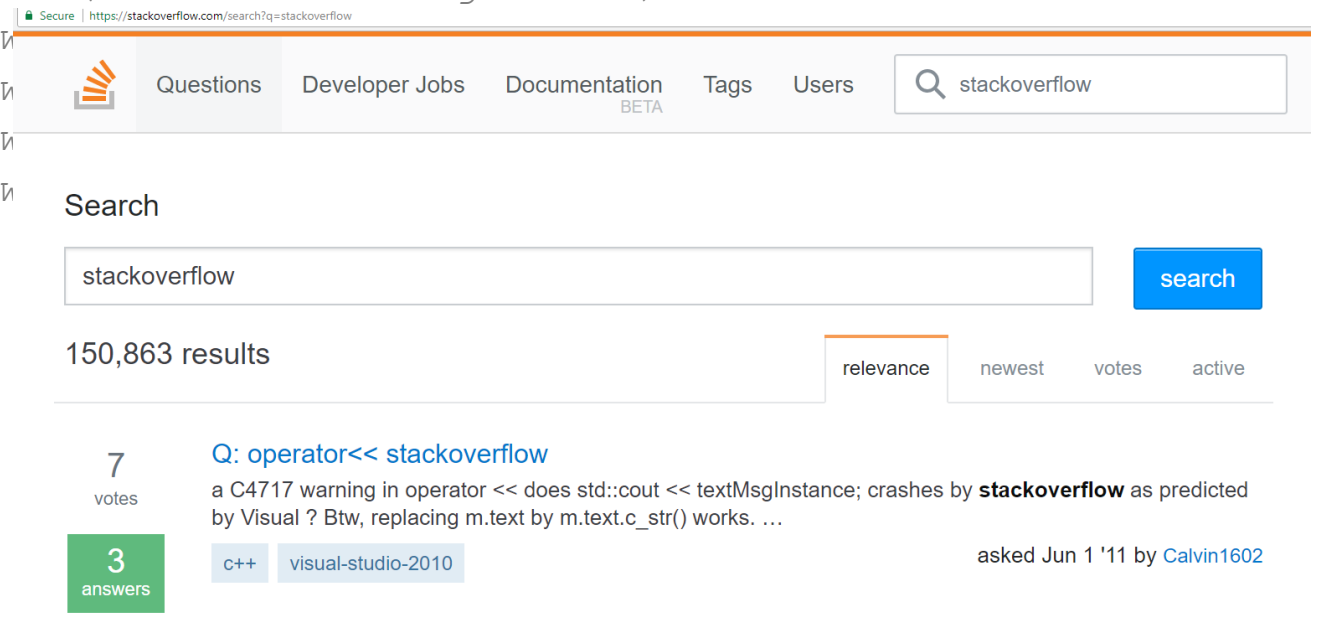
Secure | <https://stackoverflow.com/search?q=stackoverflow>

 Questions Developer Jobs Documentation BETA

Search

```
...

```



4

Q: log4j stackoverflow [closed]

Queue

- Type of collection
- Add at the back, *tail* of the queue/line (enqueue)
- Remove from the head of the line (dequeue)
- *FIFO: First In, First Out*



Example: Task Scheduler

- Process/thread add *tasks to do* on a queue
- Other process/thread workers read from queue and execute the task
- The *oldest* tasks need to be completed *first*
- While workers are executing tasks, new tasks could be added to the queue

Stack/Queue as List

- Stack
 - `push(value)` -> `add(size(), value)`
 - `pop()` -> `delete(size()-1)`
 - `peek()` -> `get(size()-1)`
- Queue
 - `enqueue(value)` -> `add(size(), value)`
 - `dequeue()` -> `delete(0)`
- It could be fine to use a list implementation for stacks/queues, but there are cases in which it is *very inefficient*

Memory Model

Questions

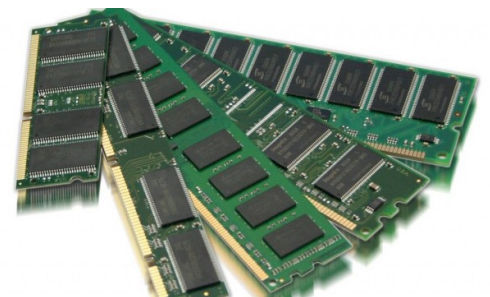
- `Node bar = new Node();`
 - what is the variable “*bar*” concretely?
 - what does “*new*” actually do?
 - what is the difference between “*bar*” variable and the object created by “*new Node()*”?
- `bar.next = bar.next.next;`
 - what is happening here?
 - are objects created or deleted?

Overview

- Before we go into details of how to implement a Stack or a Queue, we need to have clear understanding of how memory is handled in Java
- *Pointers* and *memory* are usually hard to understand... but critical, otherwise it will be nearly impossible to understand the data structures in this course
- Should had been covered in the 1st year
 - so this is just a high level revision...

Very Simplified Model

- A process will get allocated a certain amount of space on your RAM by the Operating System (OS)
 - eg, you have 16G on your laptop and process needs 1G
- The process will use such memory to allocate variables and objects
 - How the process handles this memory should be independent from the other processes
- *Think of the memory like a big array*, where process is allowed to write/read within a $[i] - [j]$ range
 - Eg, if process got 1GB, it could use RAM from position 12G till 13G



Task Manager

File Options View

Processes	Performance	App history	Startup	Users	Details	Services	

Java Memory



- At a very, very high level, the JVM divides its allocated memory in 3 main parts
- **Static:** containing for example the bytecode to run
- **FCS:** one stack per thread for the function calls
- **Heap:** where objects are stored

Function Call Stack

```
public void foo(){
    int x = 0;
    int k = bar(x);
    print(k);
}

private void bar(int y){
    int z = y * y;
    return z;
}
```

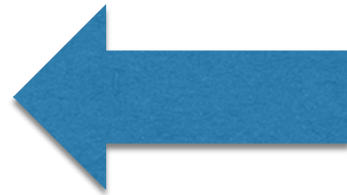
- When *foo()* is called, we need to store *x* and *k* somewhere in memory
- When *bar()* is called, we need to store *y* and *z*, plus we should not lose *x* from *foo()*
- Once *bar()* is terminated, we do not need *y* and *z* any more

Function Call Frame

- Create a *frame* for each function call
- A frame stores all the input and all the local variables, eg., x , k , y and z
- When we start a function call, we *push* its frame to the stack
- Once function call ends, we *pop* its frame

Before *bar()* Is Called

```
public void foo(){  
    int x = 2;  
    int k = bar(x);  
    print(k);  
}
```



```
private void bar(int y){  
    int z = y * y;  
    return z;  
}
```

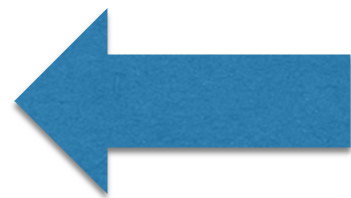
x = 2
k = ?

One frame on stack for the *foo()* call

Inside *bar()*

```
public void foo(){  
    int x = 2;  
    int k = bar(x);  
    print(k);  
}
```

```
private void bar(int y){  
    int z = y * y;  
    return z;  
}
```



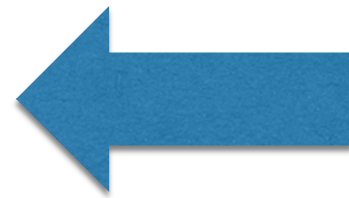
y = 2
z = 4
x = 2
k = ?

Push new frame for *bar(y)*

Note that *y* is initialized with same value of *x*. Changing *y* does not affect *x*, as in different frames

Once *bar()* Is Completed

```
public void foo(){  
    int x = 2;  
    int k = bar(x);  
    print(k);  
}
```



```
private void bar(int y){  
    int z = y * y;  
    return z;  
}
```

x = 2
k = 4

Pop stack of bar(y), as no
needed any more.

Actual Bytes In Memory

0
0
0
0
0
0
0
0
0
0
0
x = 2
k = 0

Consider each cell as
contiguous 32 bits

0
0
0
0
0
0
0
0
0
y = 2
z = 4
x = 2
k = 0

0
0
0
0
0
0
0
0
2
4
x = 2
k = 4

When we pop frame,
data is still actually there.
Will be overwritten at next
frame push

Performance Issue

```
public void foo(){  
    int x = 2;  
    int k = bar(x);  
    print(k);  
}
```

```
private void bar(int y){  
    int z = y * y;  
    return z;  
}
```

- When we call *bar(x)*, the 32 bits of *x* are copied from current frame to the frame of *bar()* in the *y* variable
- 32 bits are OK, but what if we have large objects???
- *Passing by value* is inefficient

Pointers/References

- Java does not allow you (yet) to have objects on the FCS
 - Only allowed primitive values (eg, int, double, boolean) and pointers
 - Note: other languages allows you objects on FCS, eg C++
- To have objects, those will be allocated on the **heap**
- The FCS will have **pointers** to the **heap**

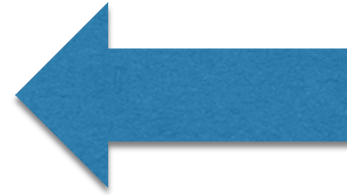
Allocation on Heap

```
public void foo(  
    int a, boolean b,  
    char c, double d){  
    X x = new X(a,b,c,d);  
    int k = bar(x);  
    print(k);  
}
```

```
private void bar(X y){  
    int z = y.compute();  
    return z;  
}
```

- The *x* variable is not going to contain the 4 inputs
- These are stored in the *heap*
- *x* is just a **pointer** to the location on the heap
- Assume *X* has 4 private fields, initialized in constructor

```
public void foo(  
    int a, boolean b,  
    char c, double d){  
    X x = new X(a,b,c,d);  
    int k = bar(x);  
    print(k);  
}
```

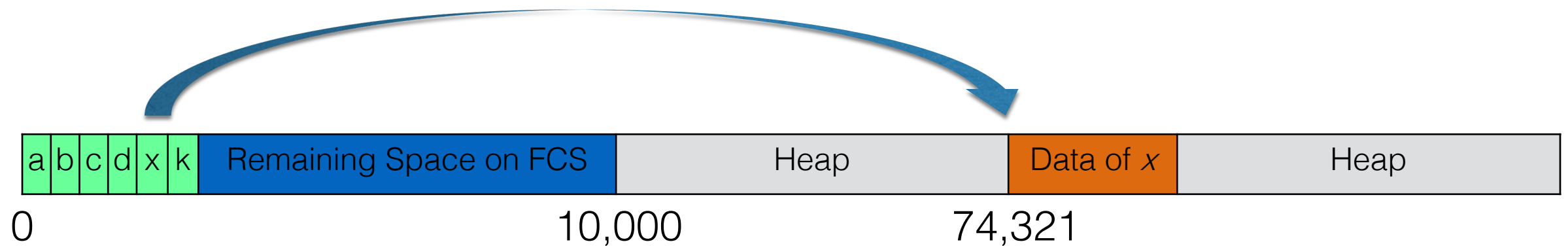
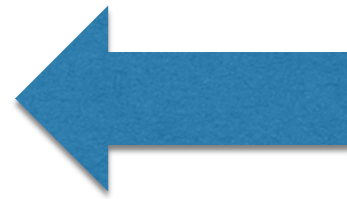


- FCS growing from left to right
- Frame contains data for 4 inputs and 2 local variables
- *X* is a 64 bit address in the memory, ie it is a number, like an index in an array

```

public void foo(
    int a, boolean b,
    char c, double d){
    X x = new X(a,b,c,d);
    int k = bar(x);
    print(k);
}

```



- The *new* keyword allocates memory in the heap for storing all the data of *x*
- Can't control where in heap data of *x* is allocated, but will be at some known position, eg 74321
- When JVM calls *new*, it will choose a *free* area in the heap
- The variable *x* in the FCS will contain the numeric address, eg 74321

```

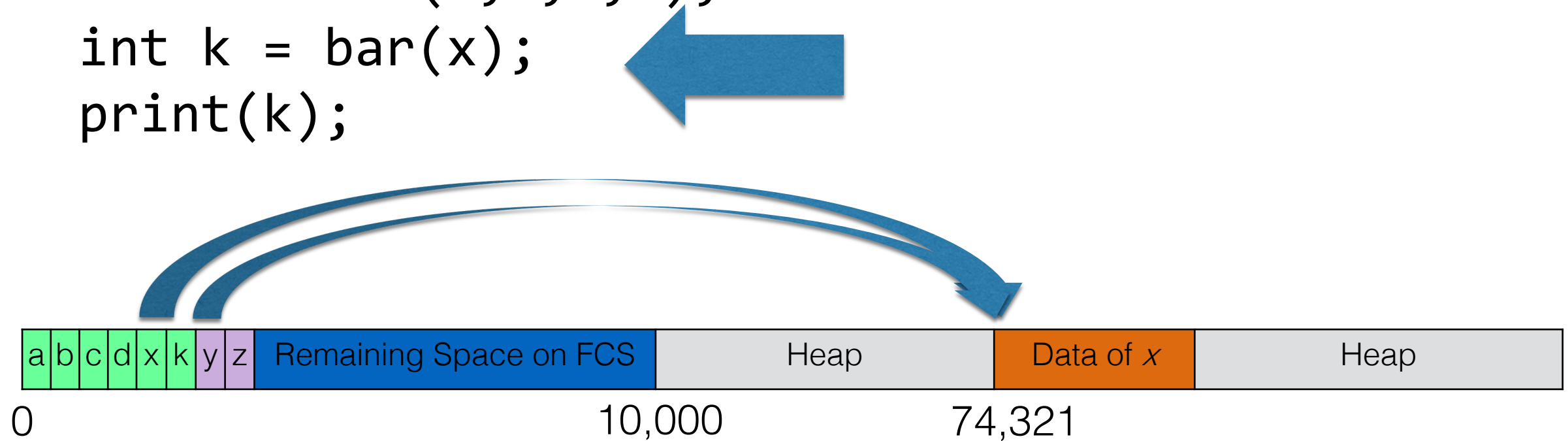
public void foo(
    int a, boolean b,
    char c, double d){
    X x = new X(a,b,c,d);
    int k = bar(x);
    print(k);
}

```

```

private void bar(X y){
    int z = y.compute();
    return z;
}

```



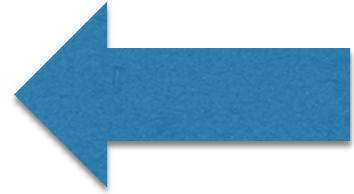
- The frame pushed for *bar(x)* contains data for *y* and *z*
- *x* in the frame of *foo()* has same value of *y* in frame of *bar()*, ie 74321
- The “Data of *x*” has not be copied when calling *bar(x)*, we just copied the *reference*, ie the address 74321

LinkedList Example

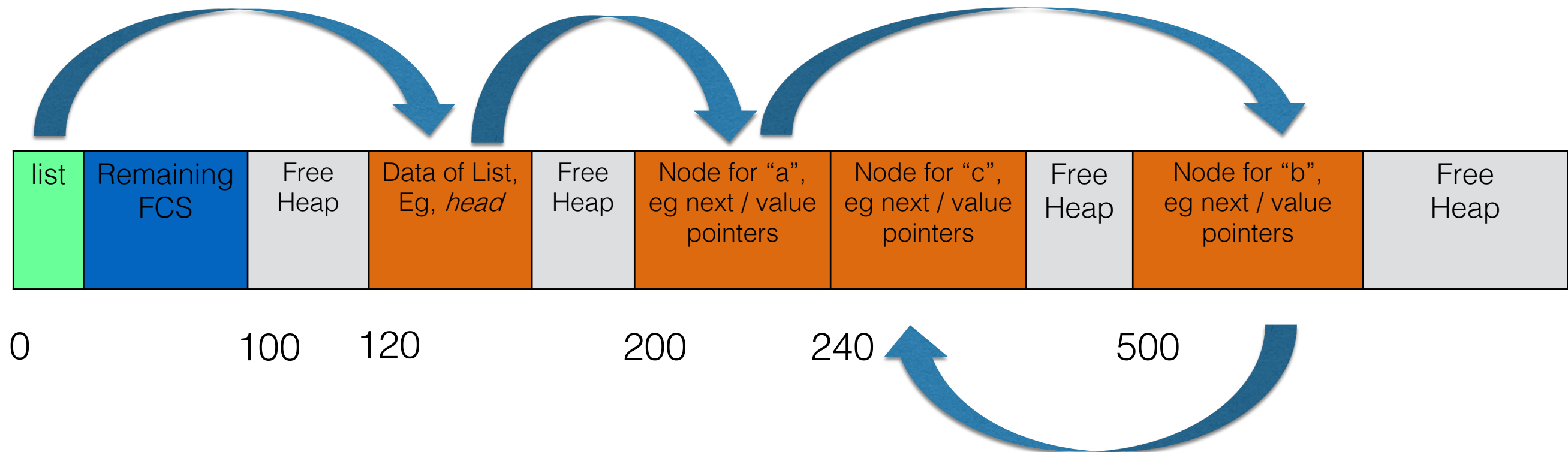
```
public void foo(){  
    List list =  
        new LinkedList();  
    list.add("a");  
    list.add("b");  
    list.add("c");  
}
```

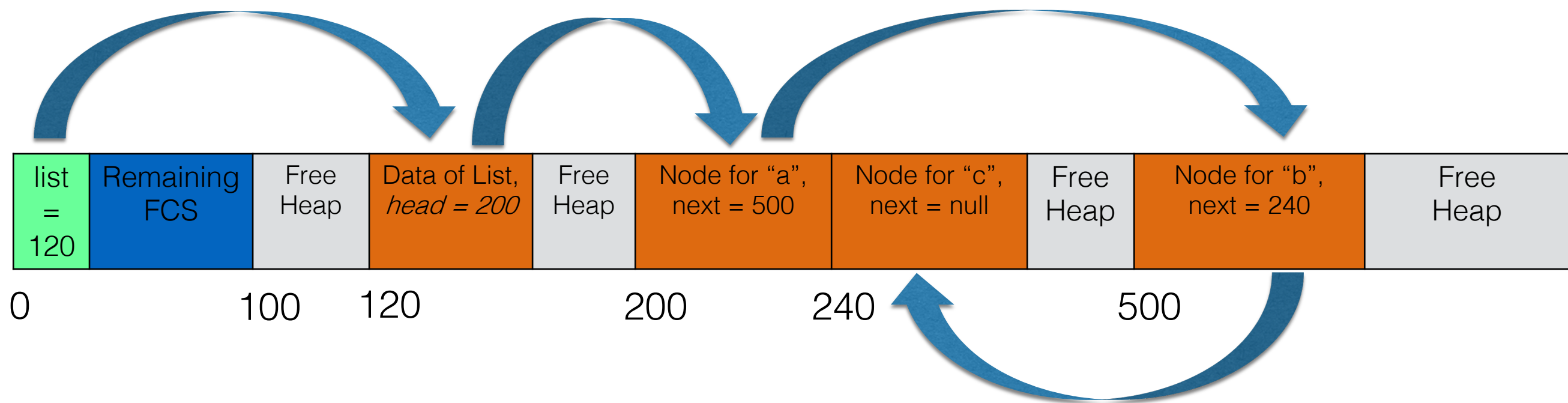
- Assume LinkedList based on nodes
- List has an *head*
- Each node has a *next* reference

```
public void foo(){
    List list =
        new LinkedList();
    list.add("a");
    list.add("b");
    list.add("c");
}
```

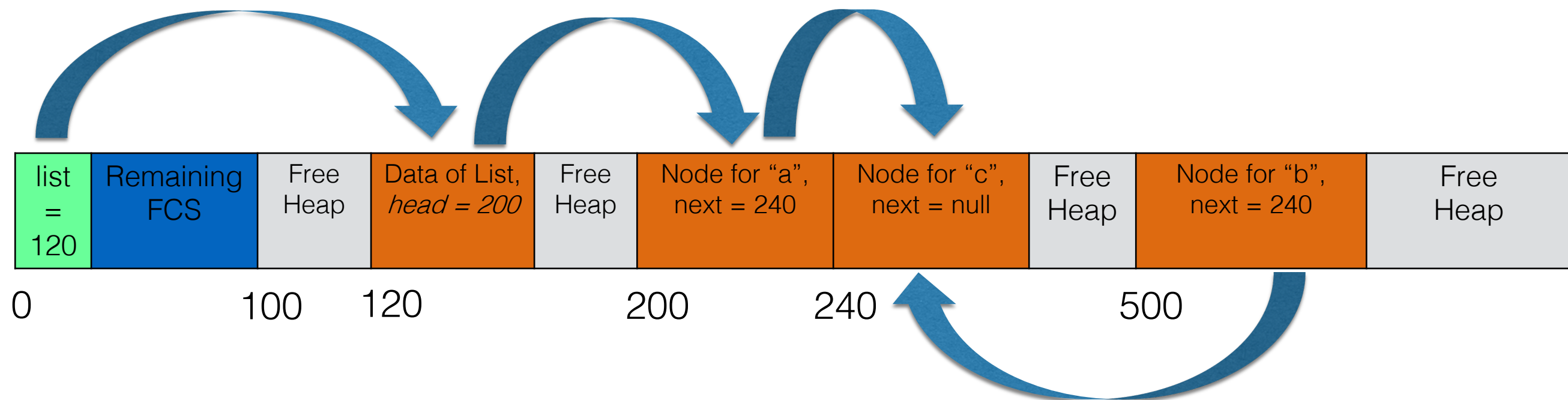


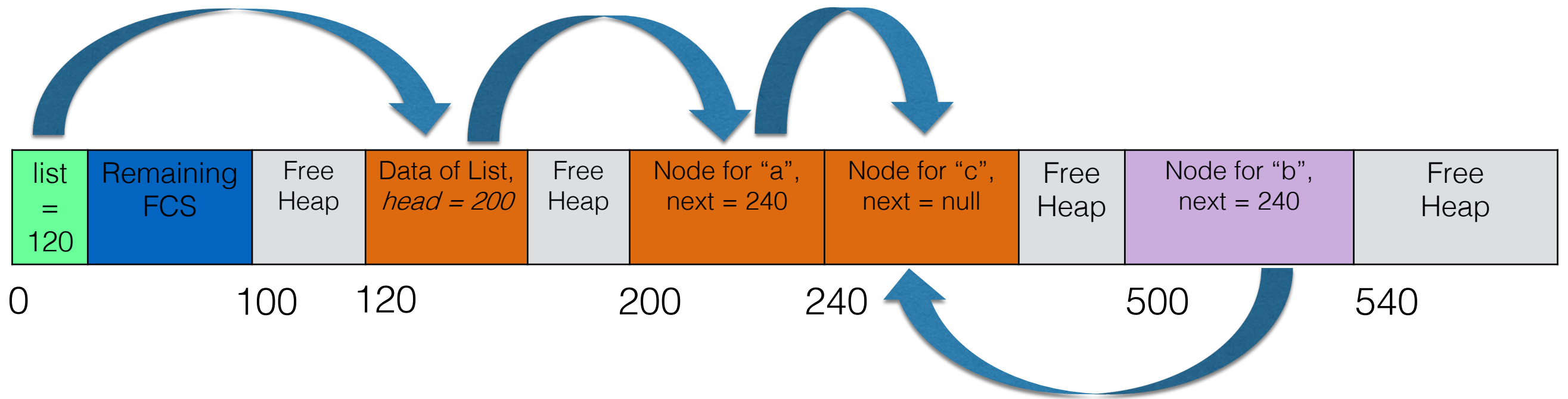
- The *list* reference on FCS will point to position where list object is, ie 120
- The *head* in such data will contain the value 200, ie address of first element
- The *next* fields contains address of next elements





- Delete node for "b" with: `current.next = current.next.next`
- Where `current` is the node for "a"





- Deleting "b" means it is not accessible any more starting from *list* pointer in the FCS
 - but it is still there in memory!!!
- When calling *new* many times, might *run out of free space*
- At that point, somehow we need to be able to reuse the space occupied by the "b" node, ie location 500-540

Garbage Collector (GC)

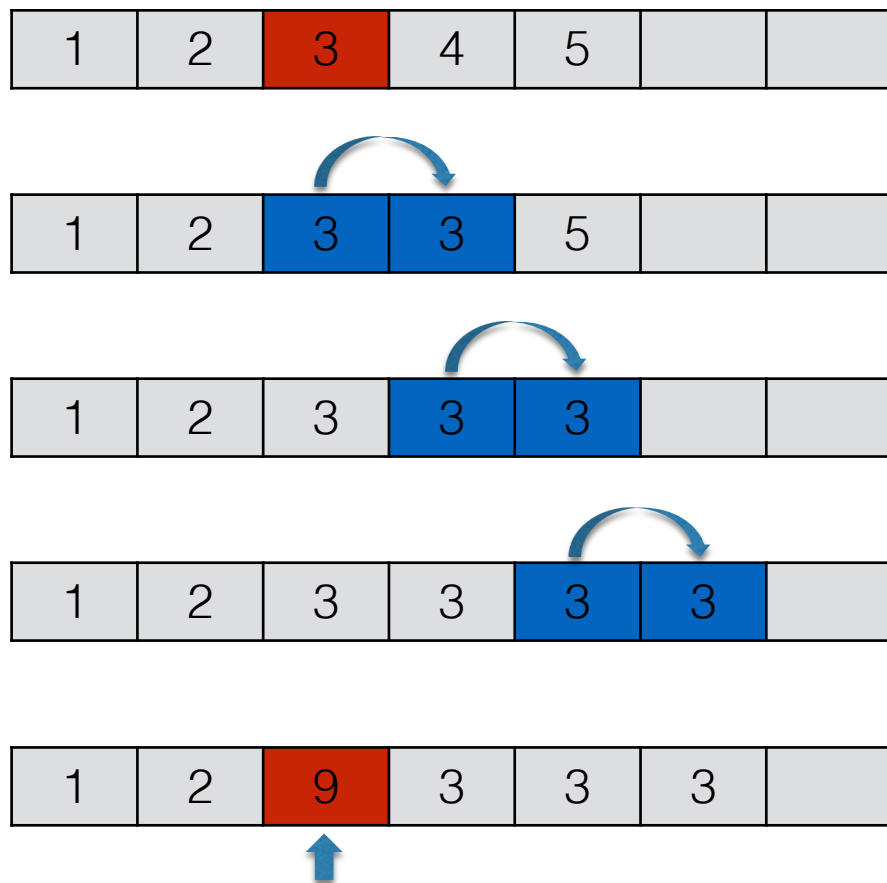
- Called by JVM when run out of space on heap
- Starting from the pointers on FCS, recursively find all reachable objects
- Non-reachable objects (eg “*b*” node) will be marked as “Free Heap”, and their space can be reused by **new** operator when new instances are created
- GC are quite complex, as need to be very efficient, because they **block** the entire code execution

ArrayList

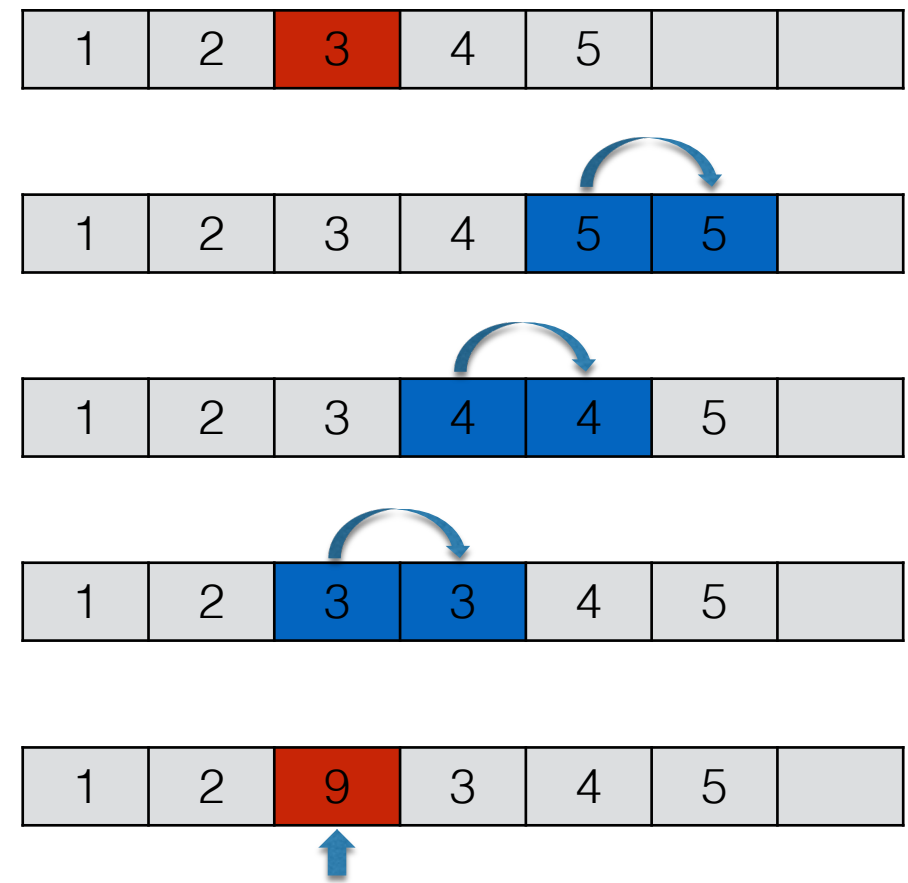
Insertion

- Need to right-shift all values from *index* before inserting new value
- On an array, we set 1 value at a time, ie $a[i+1] = a[i]$, possibly in a loop
- Loop must start from end to avoid overwrite
- Assume adding a 9 at position 2 (currently occupied by value 3)
- *But what if array is full???*

WRONG

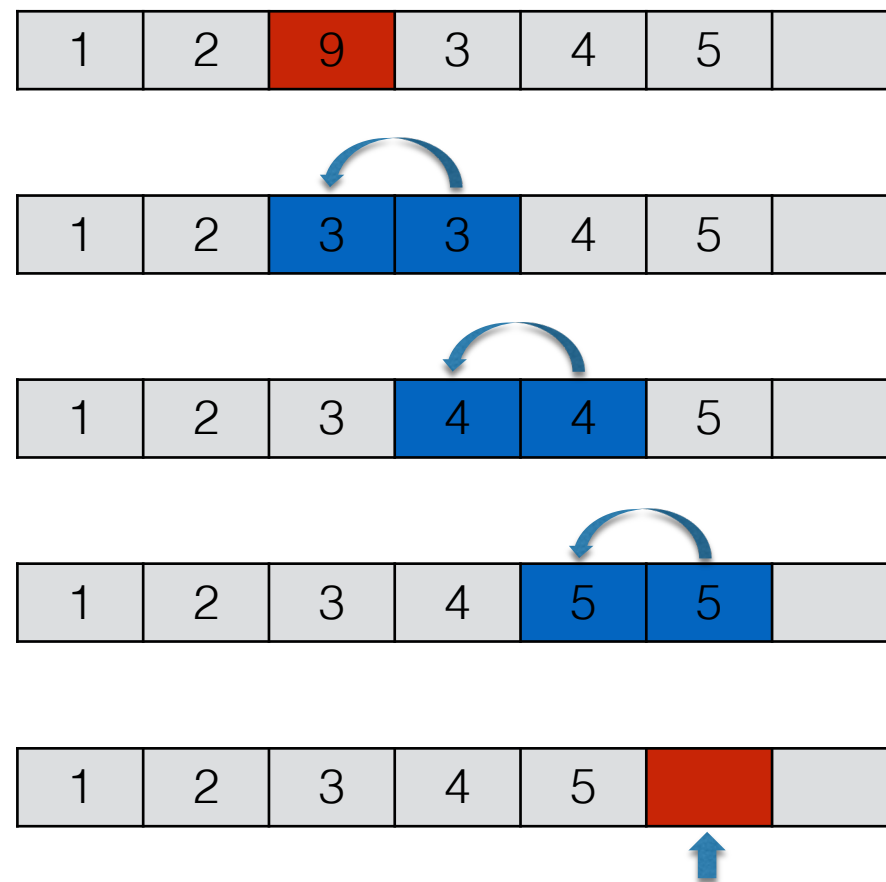


CORRECT



Deletion

- Similar to addition, here we need to shift left, and then remove last element
- $a[i] = a[i+1]$, in a loop
- Assume *delete(2)*, ie remove the value 9 at index position 2



LinkedList

Implementation

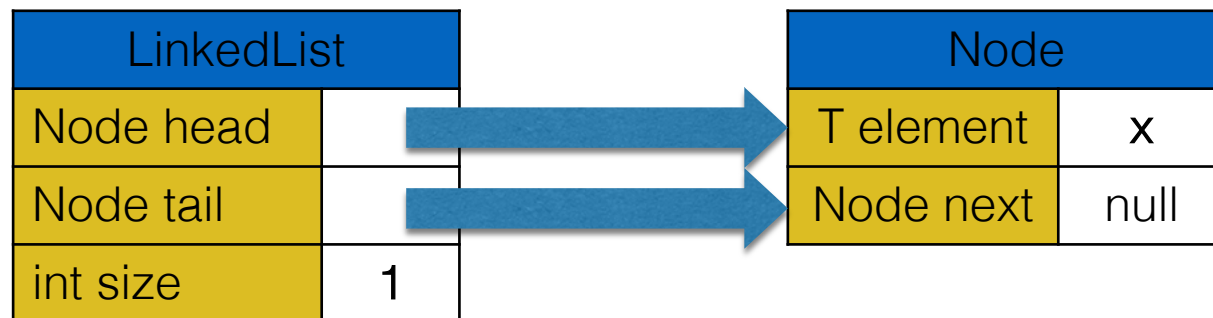
- Each element T contained in a *node* instance
- Each node contains a value, and a **next** field to the following node in the sequence
- *LinkedList* object has pointers to the **head** and **tail nodes** of the list
 - could also keep track of the **size** in a variable, to avoid compute it when queried (which would be expensive)

LinkedList	
Node head	null
Node tail	null
int size	0

Node	
T element	null
Node next	null

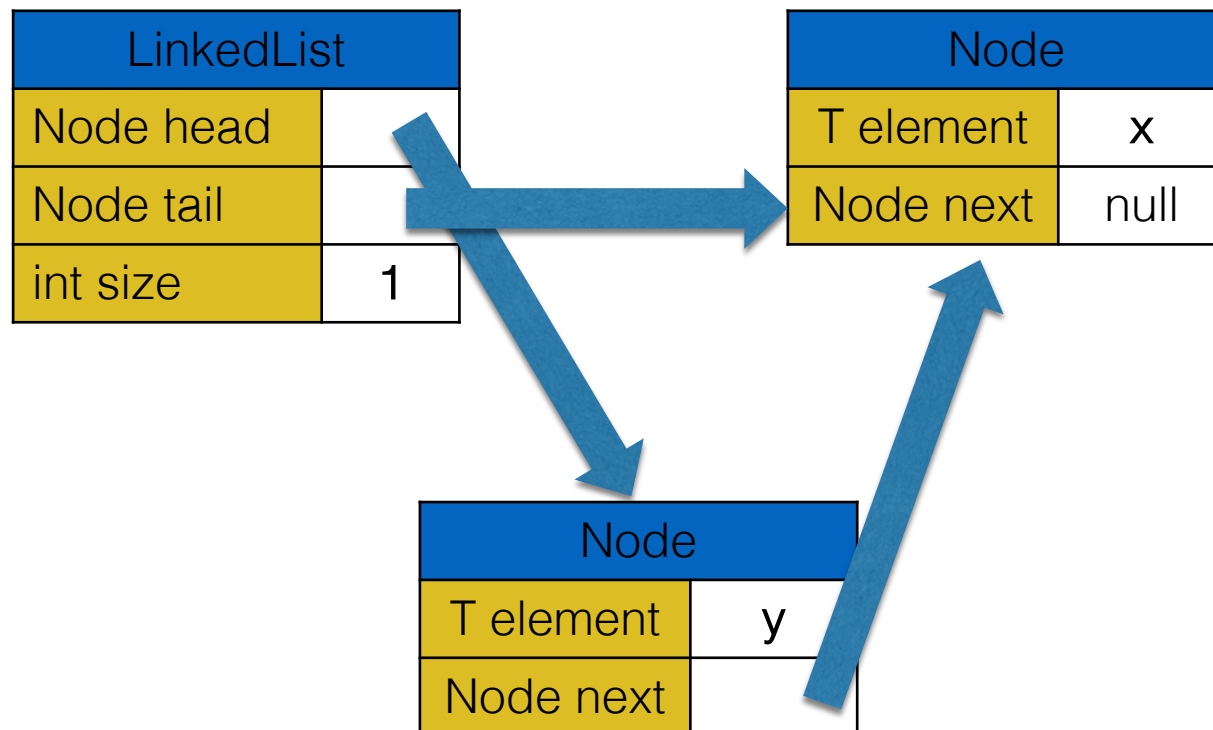
Insertion When Empty

- Create new node for the element x
- Update both **head** and **tail** to point to such node



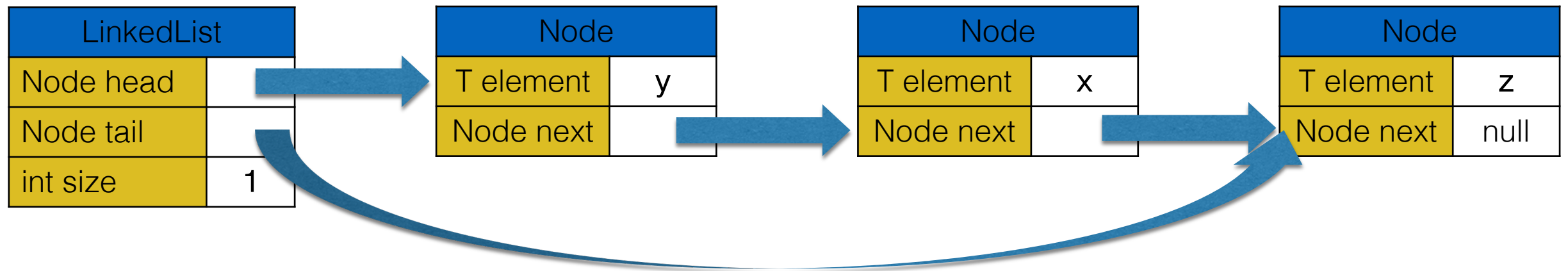
Insertion at 0

- Insert y in a non-empty LinkedList
- Besides creating new node, need to update the **head**
- New node will have to point to the previous head



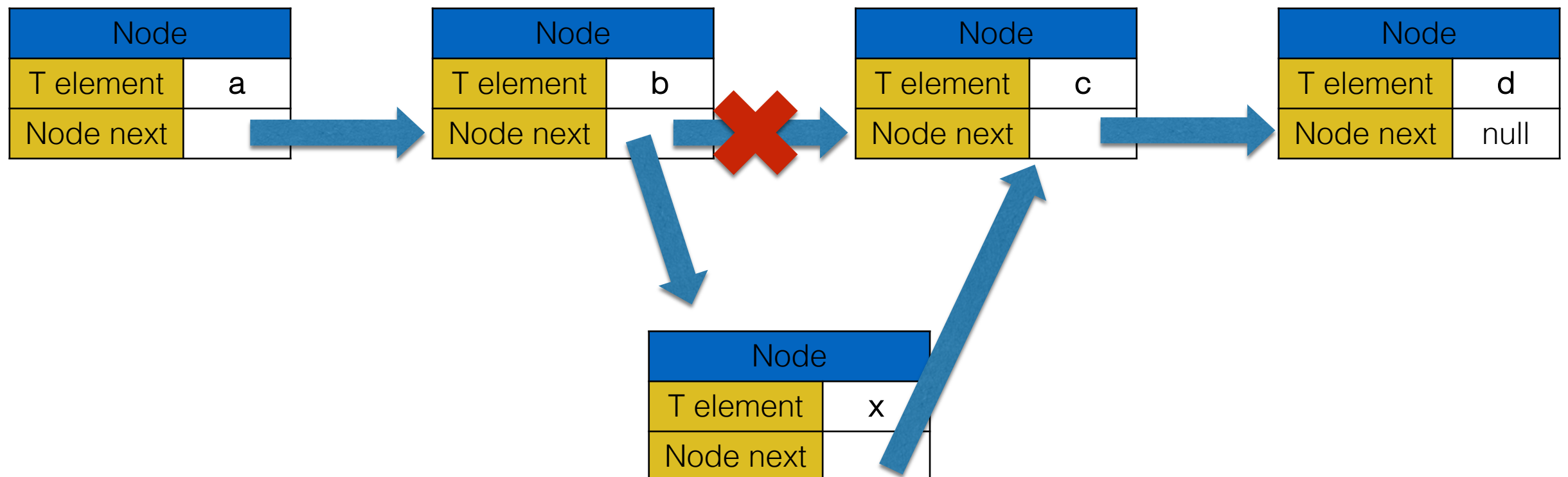
Insertion At The End

- Create new node for z
- The **next** of current **tail** should point to this new node
- The **tail** should then be updated to point to it



Insertion In The Middle

- Bit more complex, as no direct access to position **index** from the *LinkedList*
 - we only have **head** and **tail**
- We need to navigate from **head**, following the nexts of **next**
 - eg, `head.next.next.next.next...`
 - usually in a loop `current = current.next`, starting from `current = head`



ArrayList or LinkedList?

- For most cases, *ArrayLists* are better
- Creating node objects for each element in a *LinkedList* is expensive, plus overhead for GC
- *ArrayLists* have the issue of *resize*
 - although it can be automated, it is still expensive when it happens
 - but, if you have an idea of how many elements at most you will store, you can create a buffer array larger than that
- Still very important to understand *LinkedList*, as foundation for *Tree* data-structures

Stack as List

- Fine for both *ArrayList* and *LinkedList* implementations
 - operations at the end of the list are efficient in both implementations
- In the case of *LinkedList*, code can be simplified
 - No need for **head**, as only working at the end of the list with **tail**
 - In the nodes, instead of pointer to **next** node, have pointer to **previous** node
 - ★ otherwise could not delete

Queue

Queue As List

- Fine for *LinkedList*
 - in a queue, we only operate on **head** and **tail**, no need to navigate whole list with **head.next.next...** (which would be inefficient)
- VERY INEFFICIENT for *ArrayList*
 - each *dequeue()* call would force a left-shift of the whole list
- If want to use an array as internal data-structure, we need a better implementation than an *ArrayList*

Implementation

- Besides an internal array, need to have 2 indices, representing position of the **head** and **tail** of the queue on such array
- When empty, **head** = **tail** = -1 (ie an invalid index)
- We do not care what the array contains in the positions outside the head-tail range

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
?	?	1	4	5	3	?	?	?	?

head = 2
tail = 5

Deque

- Get the value at position **head**
- Then increase **head** by 1
- We could ignore the value that was stored at the head, but better to put it to **null** for GC

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
?	?	1	4	5	3	?	?	?	?

head = 3
tail = 5

Enqueue

- Increase **tail** by 1
- Add at position given by the **tail** index
- Assuming adding a 4

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
?	?	1	4	5	3	4	?	?	?

head = 2
tail = 6

End of the Array

- What happens when **tail** reaches the end of the array?
- Several options
 - Left-shift
 - Resize into longer array
 - Ring access (we will see this one in the exercises)

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
?	?	?	?	?	?	?	3	1	5

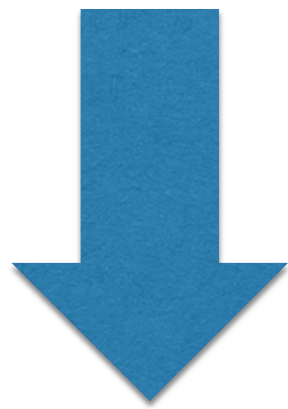
head = 7
tail = 9

Left-Shift

- Only possible if $\text{head} > 0$, otherwise no space
- Good if only few elements

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
?	?	?	?	?	?	?	3	1	5

head = 7
tail = 9



[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
3	1	5	?	?	?	?	?	?	?

head = 0
tail = 2

Resize

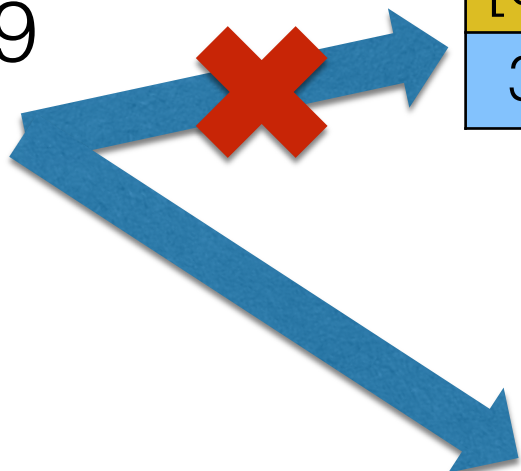
- Create new, larger array
- Copy over all elements
- Use new array as current internal buffer
- Only real option when **head=0**, but can also do it for **head>0** and **size()>k** to avoid too many left-shifts

head = 0

tail = 9

array =

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
3	1	5	7	1	1	9	9	8	2



[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
3	1	5	7	1	1	9	9	8	2	?	?	?	?	?	?	?

Homework

- Study Book Chapter 1.3
- Study code in the *org.pg4200.les02* package
- Do exercises in *exercises/ex02*
- Extra: do exercises in the book