Arrays and Linked Lists

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What is an array?

Definition

An array is a **contiguous** sequence of memory locations each of which can hold items of a fixed data type

A	$A[0]$	$A[1]$	$A[2]$	$\cdots$	$A[n-1]$
	M	$M+k$	$M+2k$		$M+(n-1)k$

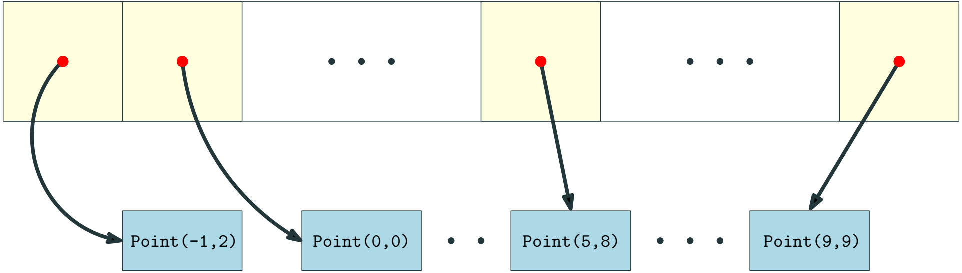
Your first data structure!

☞ ***Things work a bit differently when we work with non-primitives! In this case, the cells store references as opposed to storing the objects.***

An array of primitives

10	-13	$\cdots$	5	$\cdots$	11

An array of objects



How to create an array of objects?

- ***Approach 1.*** declaring and defining the array at the same time.

```
Point[] anArrayOfPoints = {new Point(1.1,2.1), new Point(3.1, 4.1), new Point(5.1,6.1)};
```

- ***Approach 2.*** allocate the array and then create the objects.

```
Point[] anArrayOfPoints = new Point[n]; // point objects are not created yet!
// double x = anArrayOfPoints[5].getX(); <-- cannot use this; objects are not created yet; will throw a NullPointerException
for(int i = 0; i < anArrayOfPoints.length; i++)
   anArrayOfPoints[i] = new Point(Math.random() * 10, Math.random() * 10);
```

Deep copy vs shallow copy

Shallow copy: source and destination point to the same entities

```
int[] sourceArrayA = {10,20,30,40,50};
int[] destinationArrayA = sourceArrayA; // shallow-copy; just copying references; both point to the same array in the memory
```

Deep copy: source and destination point to different entities

```
int[] sourceArrayB = {50,60,70,80,90,100};
int[] destinationArrayB = new int[sourceArrayB.length];

for(int index = 0; index < sourceArrayB.length; index++) //deep-copy; copying stuff to the destination array
    destinationArrayB[index] = sourceArrayB[index];

// Another way to deep copy in Java
int[] sourceArrayC = {11,21,31,41,51};
int[] destinationArrayC = sourceArrayC.clone(); // deep-copy; beware! shallow-copy for non-primitives
```

Let us look at a demo

Class name. `CopyingDemo`

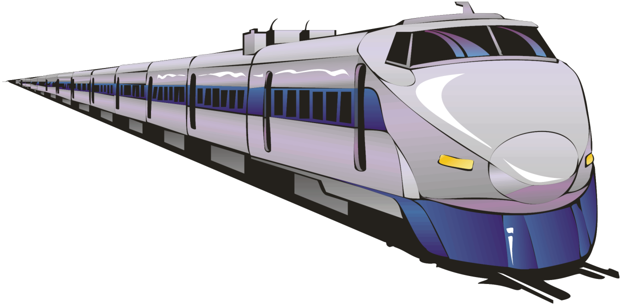
A few things about arrays

Good things

- Fast accesses for reading and writing since every location is indexed; every access takes $O(1)$ time (constant time)
- Once allocated no more memory allocation worries!
- Super-simple coding (`arr[i] = 10; a[i] = b[j] + c[k]; x = t[i]; etc.`)

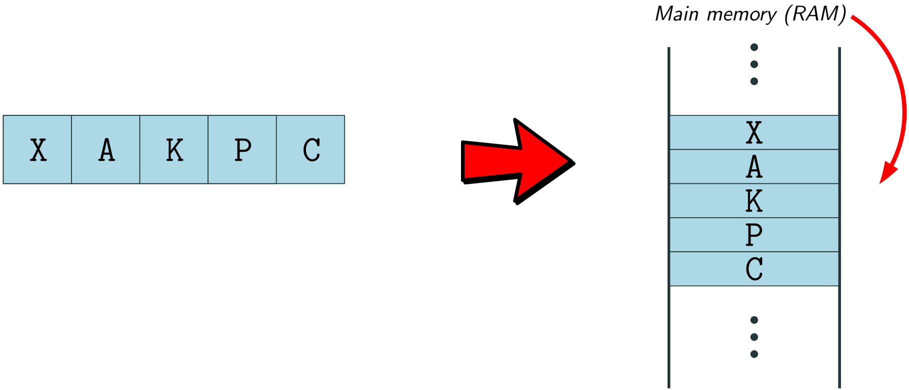
Bad things

- Need to know size in advance otherwise it may run out of space for holding the incoming items; if more space is allocated in advance, space may remain unused!
- Cannot grow (arrays are static)
- Insertion/deletion can be expensive since right/left shifts are required which take $O(n)$ time in the worst case



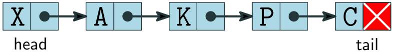
Linked Lists (Singly/Doubly/Circular)
Our first dynamic data structure

Layouts of arrays

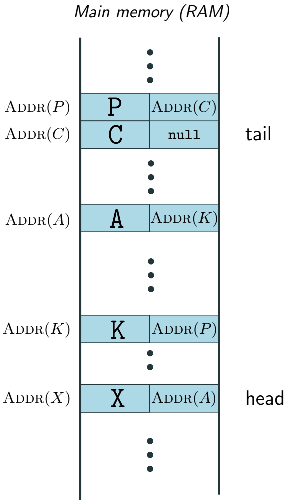


Layout of arrays in the main memory (RAM)

Linked lists: what are they?



This linked list has five nodes in it



Layout of **singly** linked lists in the main memory (RAM)

Coding the example (a very naive way of course!)

```java
public class ToySinglyLinkedList {

   public static class Node { // a nested node
      Character element;
      Node next;

      public Node(Character element, Node next) {
         this.element = element;
         this.next = next;
      }

      public void setNext(Node next) {
         this.next = next;
      }

      public Character getElement() {
         return element;
      }
   }
   // contd. on the next slide
```

Coding the example (a very naive way of course!)

```java
public class ToySinglyLinkedList {
  // contd. from the previous slide
  public static void main(String[] args) {
    Node nodeX = new Node('X',null);
    Node nodeA = new Node('A',null);   nodeX.setNext(nodeA);
    Node nodeK = new Node('K',null);   nodeA.setNext(nodeK);
    Node nodeP = new Node('P',null);   nodeK.setNext(nodeP);
    Node nodeC = new Node('C',null);   nodeP.setNext(nodeC);

    Node current = nodeX;
    while( current != null ) {
      System.out.print(current.getElement());

      if(current.next != null)
        System.out.print(" -> ");

      current = current.next;
    }
  }
}
```

Output

```
X -> A -> K -> P -> C
```

- No need to worry about length in advance
- Can be grown/shrunk by manipulating the links and adding/deleting nodes (linked lists are **dynamic**)

☞ You ***cannot*** jump to a node directly like arrays! We need to traverse the list starting at the head using a `for` loop or a while loop and reach that node

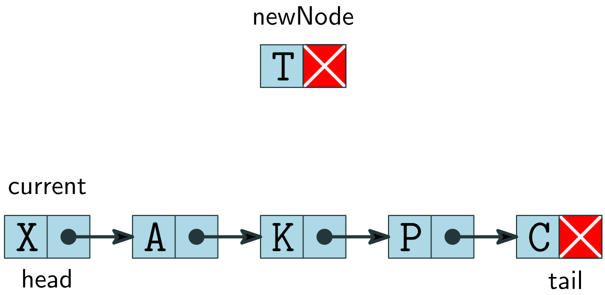
☞ Coding can get a bit challenging at times.
`NullPointerException` is a common thing

It is time to go for generics!

public class SinglyLinkedList<E> implements Iterable<E>

```java
int size() {...}
boolean isEmpty() {...}
E first() {...}
E last() {...}
void addFirst(E e) {...}
void addLast(E e) {...}
E removeFirst() {...}
boolean addAfter(E predecessor, E incomingItem) {...}
String toString() {...}
Iterator<E> iterator() {...}
```

Adding a new node after a node: `addAfter('K','T')`



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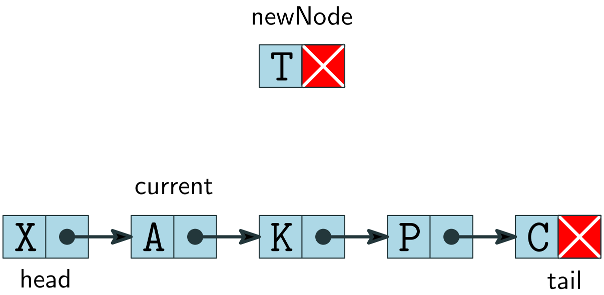

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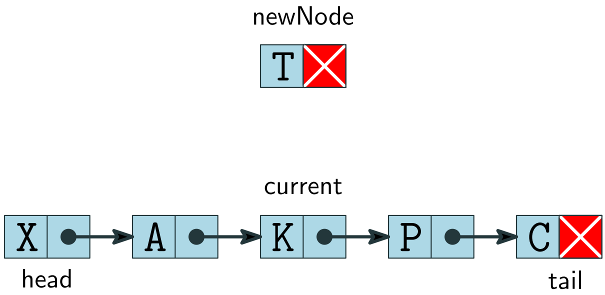

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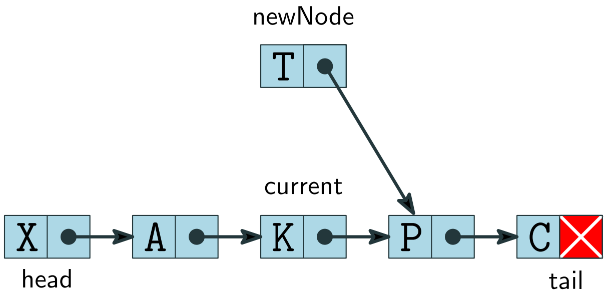

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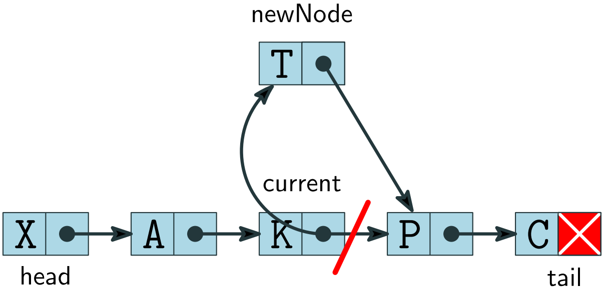

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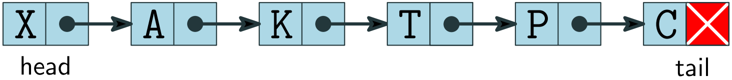


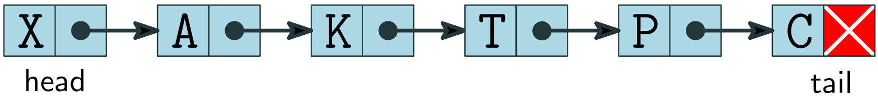
Complexity stuff

☞ Linked list traversals take $O(n)$ time

SinglyLinkedList<E>

1. `int size() {...}`, **Time complexity**: $O(1)$
2. `boolean isEmpty() {...}`, **Time complexity**: $O(1)$
3. `E first() {...}`, **Time complexity**: $O(1)$
4. `E last() {...}`, **Time complexity**: $O(1)$
5. `void addFirst(E e) {...}`, **Time complexity**: $O(1)$
6. `void addLast(E e) {...}`, **Time complexity**: $O(1)$
7. `E removeFirst() {...}`, **Time complexity**: $O(1)$
8. `boolean addAfter(E predecessor, E incomingItem) {...}`, **Time complexity**: $O(n)$ where n is the number of nodes in the list currently
9. `String toString() {...}`, **Time complexity**: $O(n)$ where n is the number of nodes in the list currently

Limitations of singly linked lists



- Given just a reference to a node, we **cannot** efficiently delete it or add a node before it
- **Cannot** traverse from right to left just by following the links, if needed

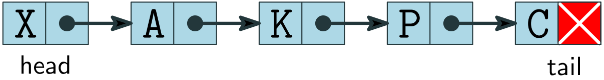
Solution

Store two links at every node: **prev** and **next**

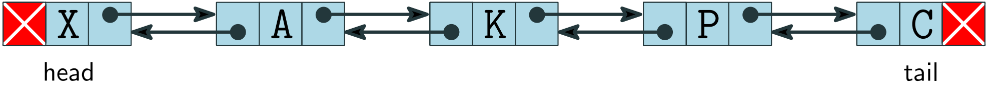
Downside?

Use of extra space at every node and possibly more complicated code

Doubly linked lists



A **singly** linked list



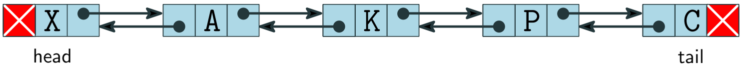
A **doubly** linked list

Methods

`public class DoublyLinkedList<E> implements Iterable<E>`

1. `int size() {...}`
2. `boolean isEmpty() {...}`
3. `E first() {...}`
4. `E last() {...}`
5. `void addBetween(E e, Node<E> predecessor, Node<E> successor) {...}`
6. `E remove(Node<E> node) {...}`
7. `void addFirst(E e) {...}`
8. `void addLast(E e) {...}`
9. `E removeFirst() {...}`
10. `E removeLast() {...}`
11. `String toString() {...}`
12. `Iterator<E> iterator() {...}`

Illustrating `addBetween(E e, Node<E> predecessor, Node<E> successor)`



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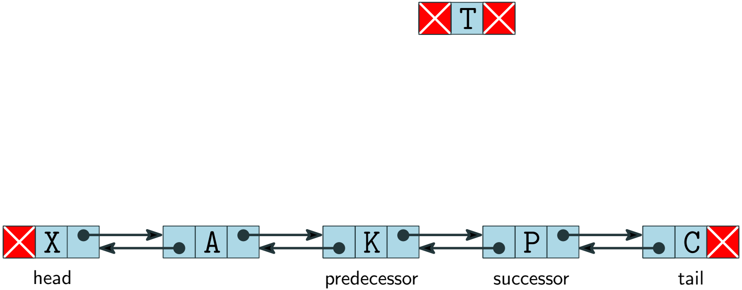

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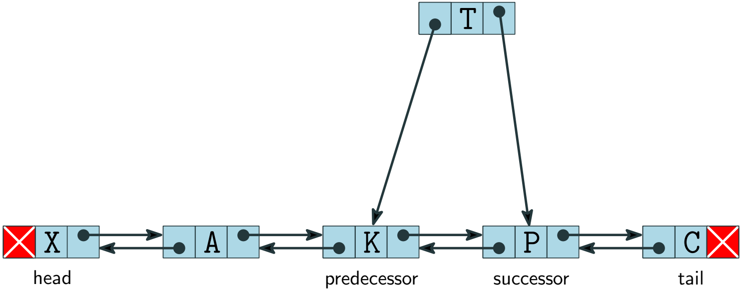

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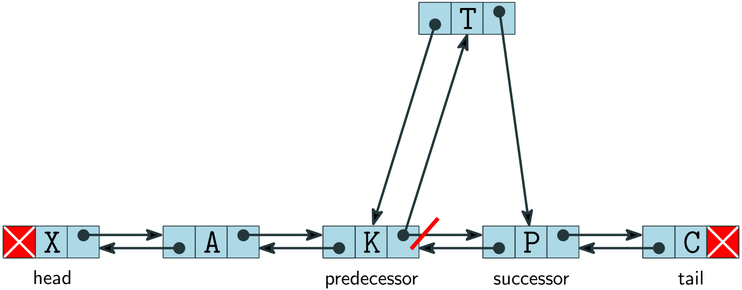

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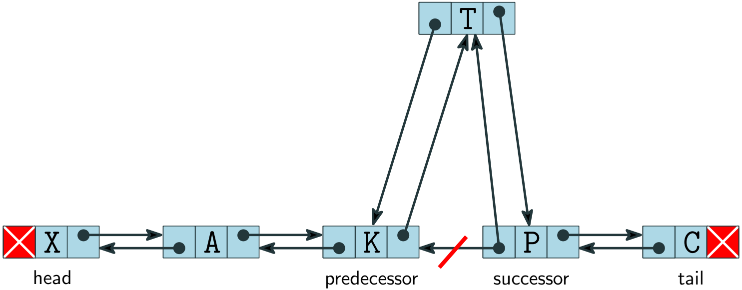

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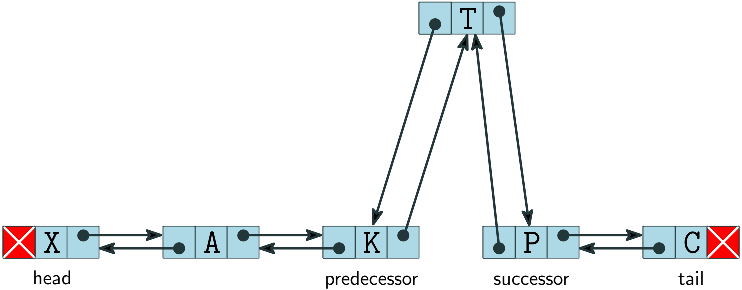

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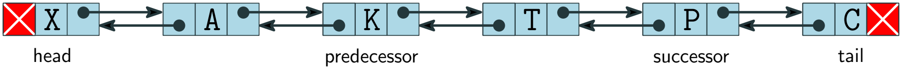

Complexity stuff

DoublyLinkedList<E>

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For most linked list methods, traversing is required Two popular approaches for traversing a linked list

Option A: `while` loop

```
Node<E> current = head;
while( current != null ) {
   // do something
   current = current.next;
}
```

Option B: `for` loop

```
Node<E> current = head;
for(int pos = 0; pos < size; pos++) {
   // do something
   current = current.next;
}
```

Words of caution

- In some cases, linked lists can be slow especially when you are trying to do many insertions since every time a memory allocation request has to be made
- In Java, for a large number of insertions, `ArrayLists` can beat singly linked lists in terms of speed
- Linked lists can take substantially more space per data element compared to arrays and `ArrayLists` since every node is storing at least one link (reference to another node in the same list)