CSI2110

Data Structures and Algorithms

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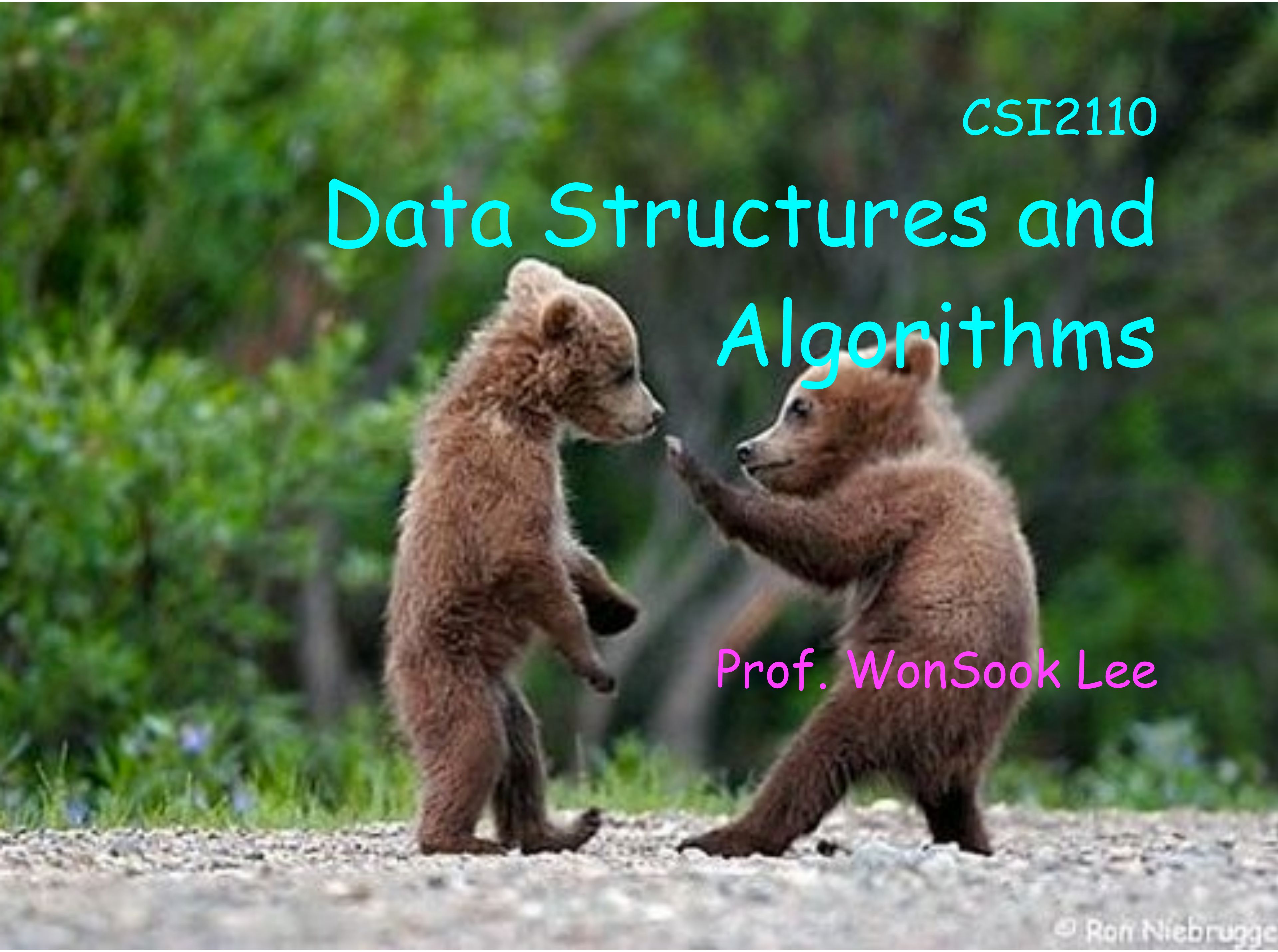
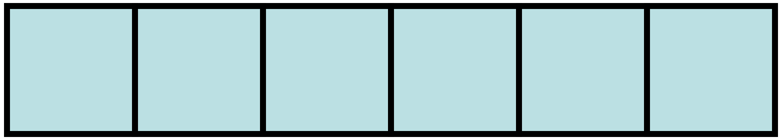


We learned…

Review:

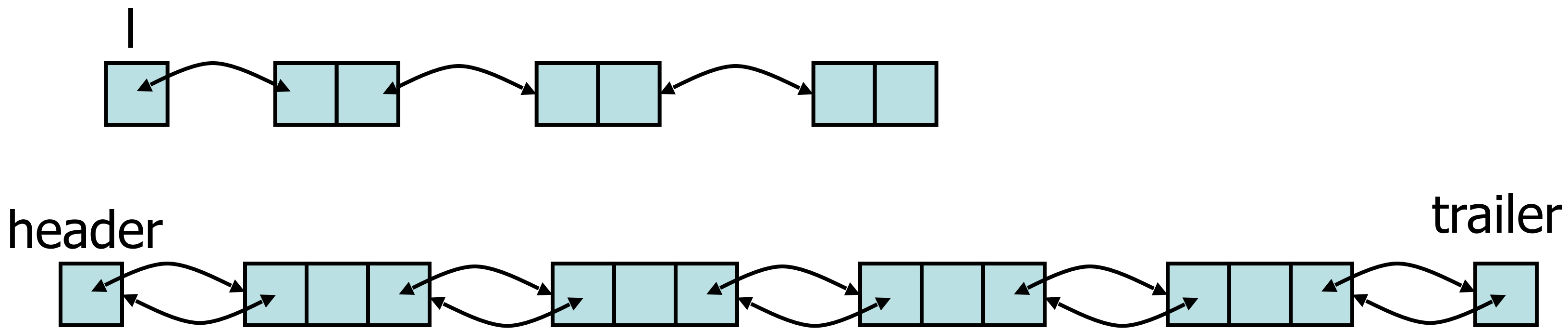
Basic Data Structures ("concrete" data structures)

Array



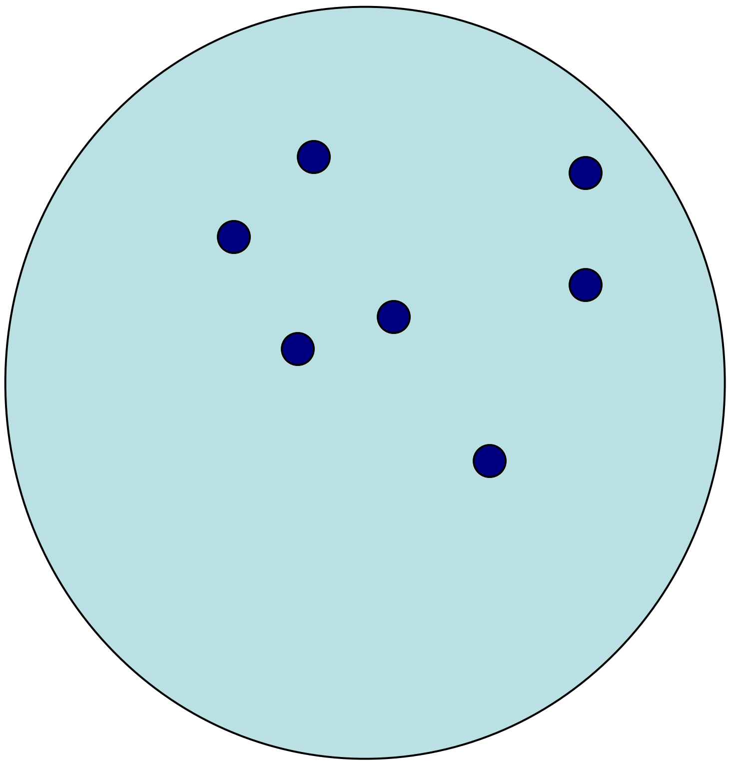
Linked Lists

For example:



Abstract Data Types (ADT)

ADT is an abstraction of a data structure.
ADTs specify what can be stored and what operations can be performed.



Containers

Contains objects

I can INSERT

I can REMOVE

I can .....

Abstract Data Types seen so far

Insert = PUSH

Remove = POP

STACK

"last in first out"

Insert = ENQUEUE

Remove = DEQUEUE

QUEUE

"first in first out"

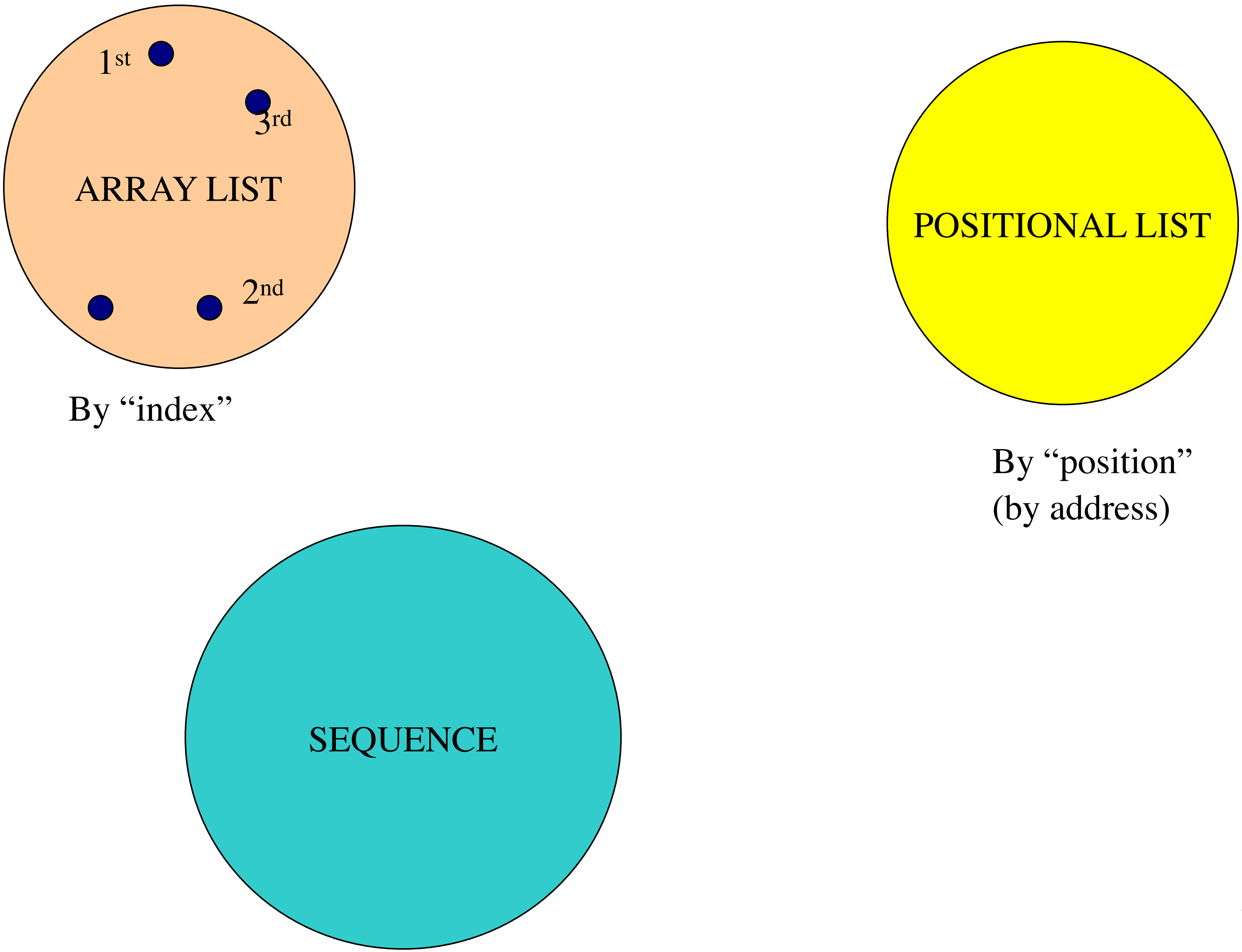
DEQUE

Insert: InsertFirst, InsertLast

Remove: RemoveFirst RemoveLast

What are we going to see next ...

Generalization…

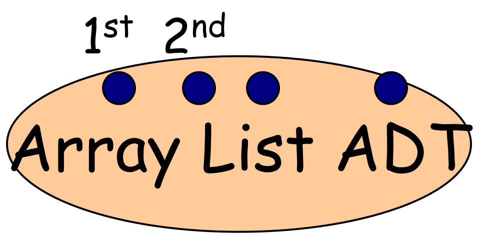

1st
3rd
ARRAY LIST
2nd
By “index”
POSITIONAL LIST
By “position”
(by address)
SEQUENCE

Lists

- Array-List ADT
- Positional-List ADT
- Sequence ADT

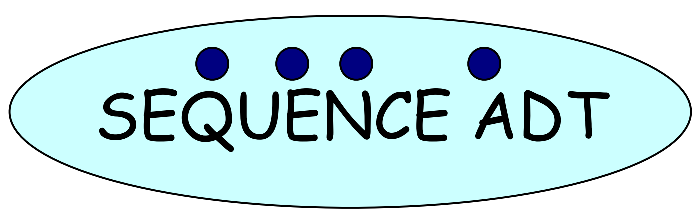
Lists or Sequences

LISTS or SEQUENCES= collection of elements in linear order



To be implemented by arrays. Access by "index"

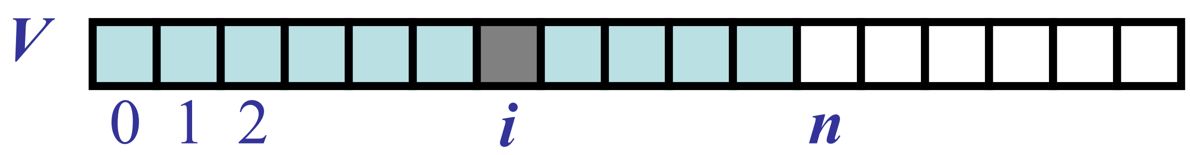
To be implemented by linked lists Access by "position" (or address)



Combination of both

Array-lists

- Can access any element directly, not just first or last.
- Elements are accessed by index (or rank), the number of elements which precede them (if starting from index 0).
- Typically implemented by an array



The Array-List ADT

- A sequence S (with n elements) that supports the following methods:

  -get(i): Return the element of S with index i; an error occurs if i < 0 or i > n -1

  -set(i,e): Replace the element at index i with e and return the old element; an error condition occurs if i < 0 or i > n - 1

  -add(i,e): Insert a new element into S which will have index i; an error occurs if i< 0 or i > n

  -remove(i): Remove from S the element at index i; an error occurs if i < 0 or i > n - 1

Adapter Pattern

- Two data structures A and B are often similar
- Adapt data structure B to be used as A
- Create a "wrapper class" A holding B

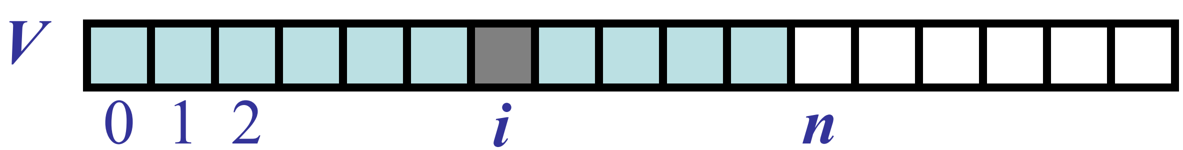
Examples:

- Regular array as an ArrayList, or
- ArrayList can be adapted as a Deque

Deque	ArrayList
getFirst(), getLast()	get(0), get(size()-1)
addFirst(e), addLast(e)	add(0,e), add(size(),e)
removeFirst(), removeLast()	remove(0), remove(size()-1)

Natural Implementation of Array-List: with an Array

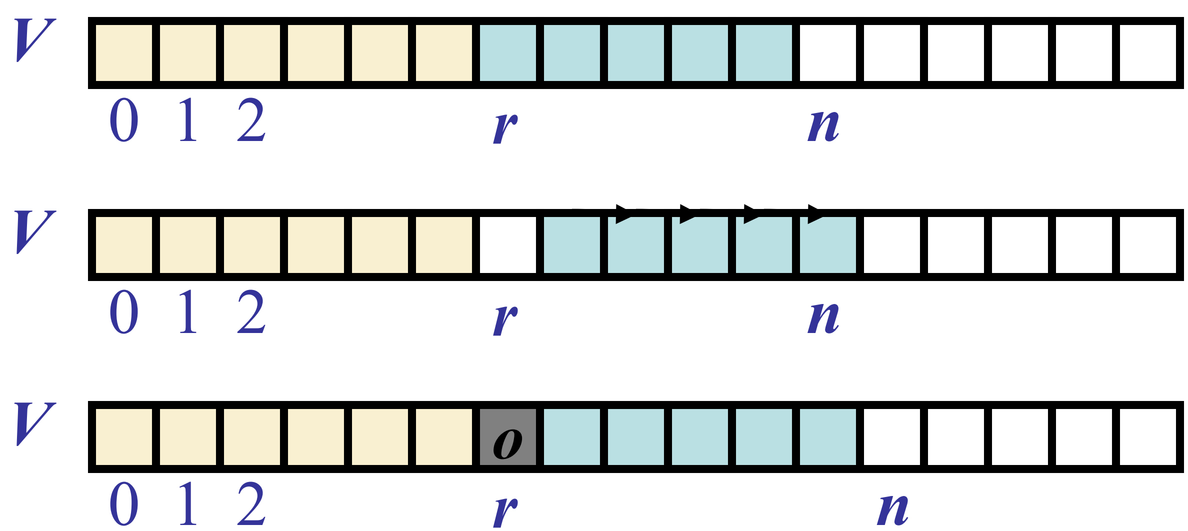
- Array **V** of size **N**
- A variable **n** keeps track of the size of the array-list (number of elements stored)
- Operation **get**(**i**) is implemented in **O**(1) time by returning **V**[**i**]



Insertion

- In operation **add(r, o)**, we need to make room for the new element by shifting forward the **n - r** elements **V[r]**, …, **V**[n - 1]
- In the worst case (**r** = 0), this takes **O**(**n**) time

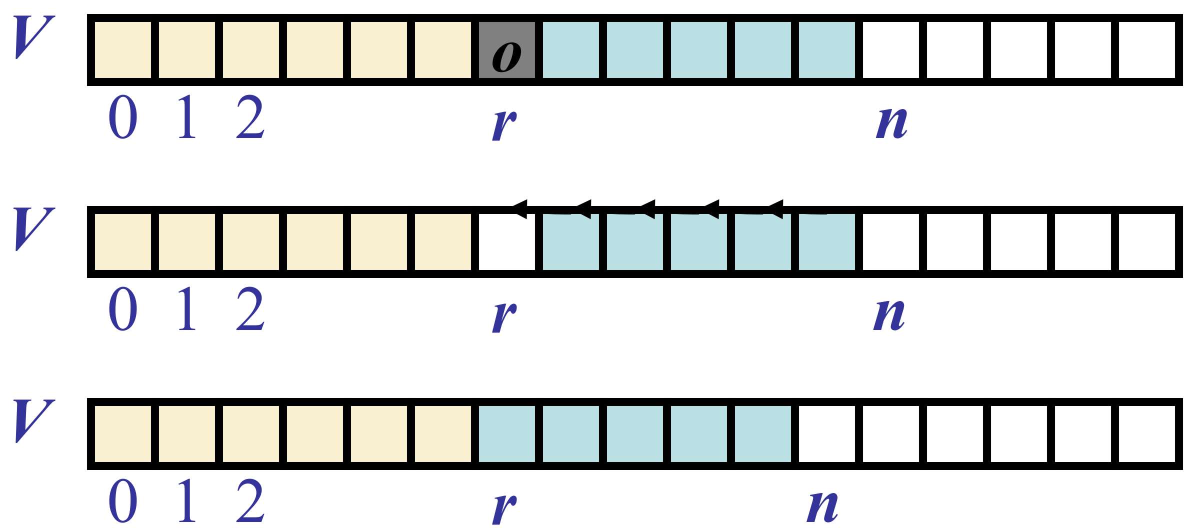
```
add(r,o):
    for i = n - 1, n - 2, ... , r do
            S[i+1] ← s[i]
    S[r] ← o
    n ← n + 1
```



Deletion

- In operation **remove**(**r**), we need to fill the hole left by the removed element by shifting backward the **n** - **r** - 1 elements **V**[**r** + 1], …, **V**[**n** - 1]
- In the worst case (**r** = 0), this takes **O**(**n**) time

```
remove(r):
    e ← S[r]
    for i = r, r + 1, … , n - 2 do
        S[i] ← S[i + 1]
    n ← n - 1
 return
```



Performance

- In the array based implementation of an array-list
  - The space used by the data structure is **O**(**n**)
  - **size**, **isEmpty**, **get** and **replace** run in **O**(1) time
  - **insert** and **remove** run in **O**(**n**) time
- In an **insert** operation, when the array is full, instead of having an ERROR, we can replace the array with a larger one: extendable arrays seen earlier

Performance (contd.)

- Time time complexity of the various methods:

size	$O(1)$
isEmpty	$O(1)$
get	$O(1)$
replace	$O(1)$
insert	$O(n)$
remove	$O(n)$

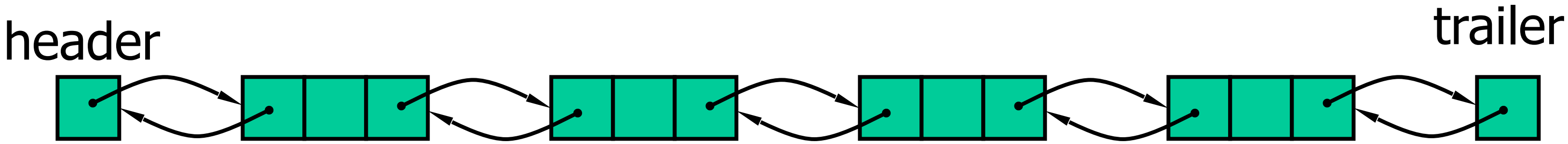
Class java.util.ArrayList<E>

- Inherits from
  - java.util.AbstractCollection<E>
  - java.util.AbstractList<E>
- Implements
  - Iterable<E>
  - Collection<E>
  - List<E>
  - RandomAccess

Implementation with extendable arrays

- The methods
  - size(), isEmpty(), get(int) and set(int,E) in time O(1)
  - add(int,E) and remove(int) in time O(n)

If we were to implement an array-list with a doubly linked list it would be quite inefficient !



get(rank) ?

Finding an element at a certain rank

```
Algorithm get(rank)
        if (rank <= size()/2) { //scan forward from head
                node ← header.next
                for (int i=0; i < rank; i++)
                node ← node.next
    }else { // scan backward from the tail
                node ← trailer.prev
                for (int i=0; i < size()-rank-1 ; i++)
                node ← node.prev
    }
    return node;
```

Performance with linked list ...

size	$O(1)$
isEmpty	$O(1)$
get	$O(n)$
replace	$O(n)$
insert	$O(n)$
remove	$O(n)$

Positional Lists

Container of elements that store each element at a position and that keeps these positions arranged in a linear order

- Cannot access any element directly, can access just first or last.

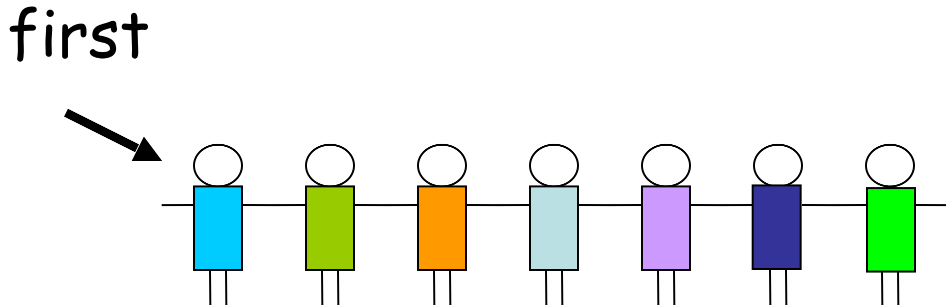
(node) (address)

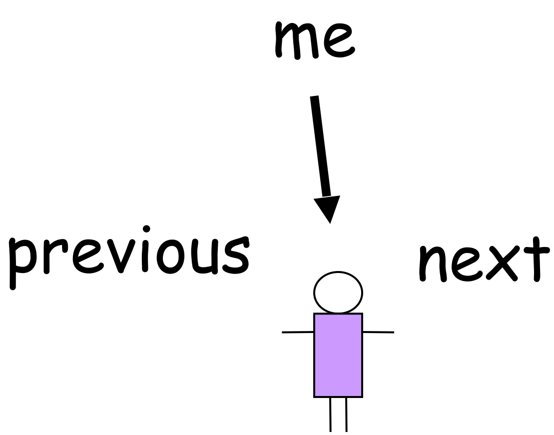
(place)

- Elements are accessed by position.

Positions are defined relatively to other positions

(before/after relation)





There is no notion of rank - I don't know my rank.
I only know who is next and who is before

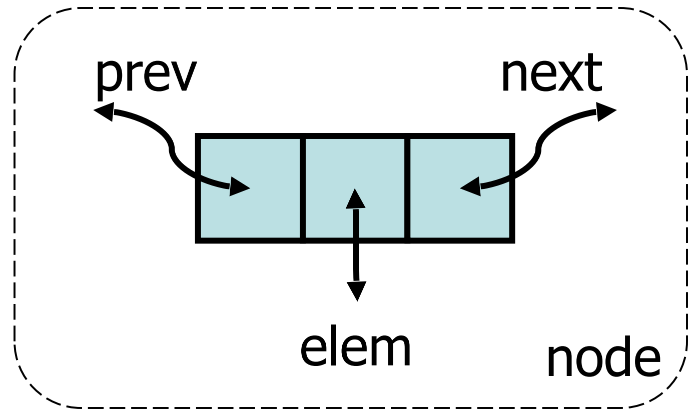
The Positional-List ADT

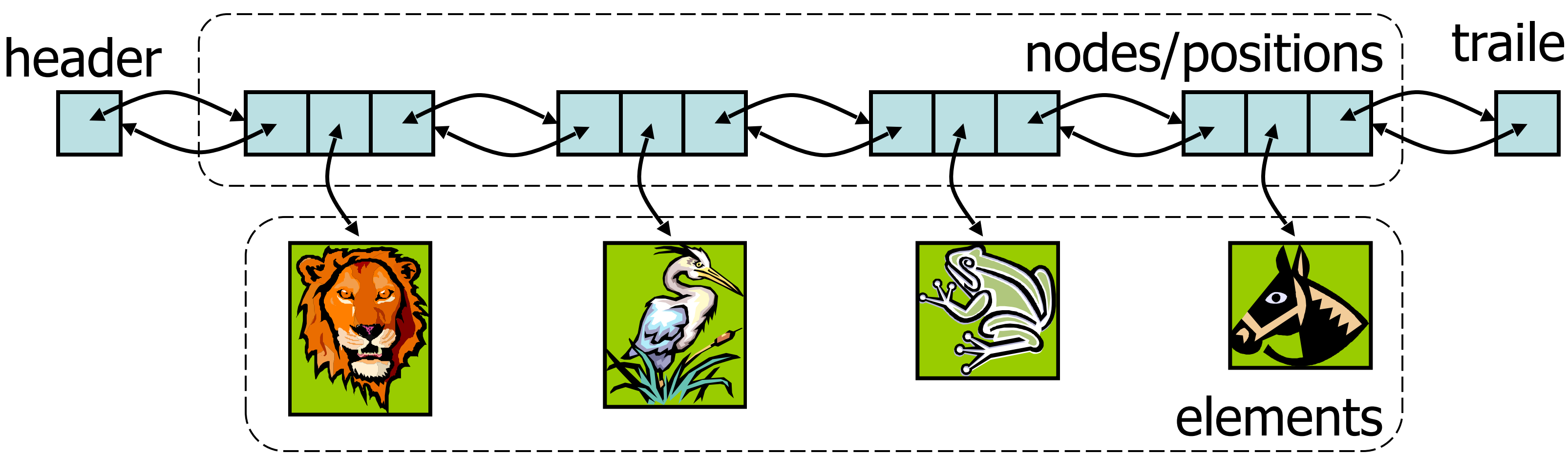
ADT with position-based methods

- generic methods — size(), isEmpty()
- accessor methods — first(), last()
  before(p), after(p)
- update methods
  addFirst(e), addLast(e)
  addBefore(p,e), addAfter(p,e)
  set(p,e), remove(p)

Natural Implementation: with a Linked List

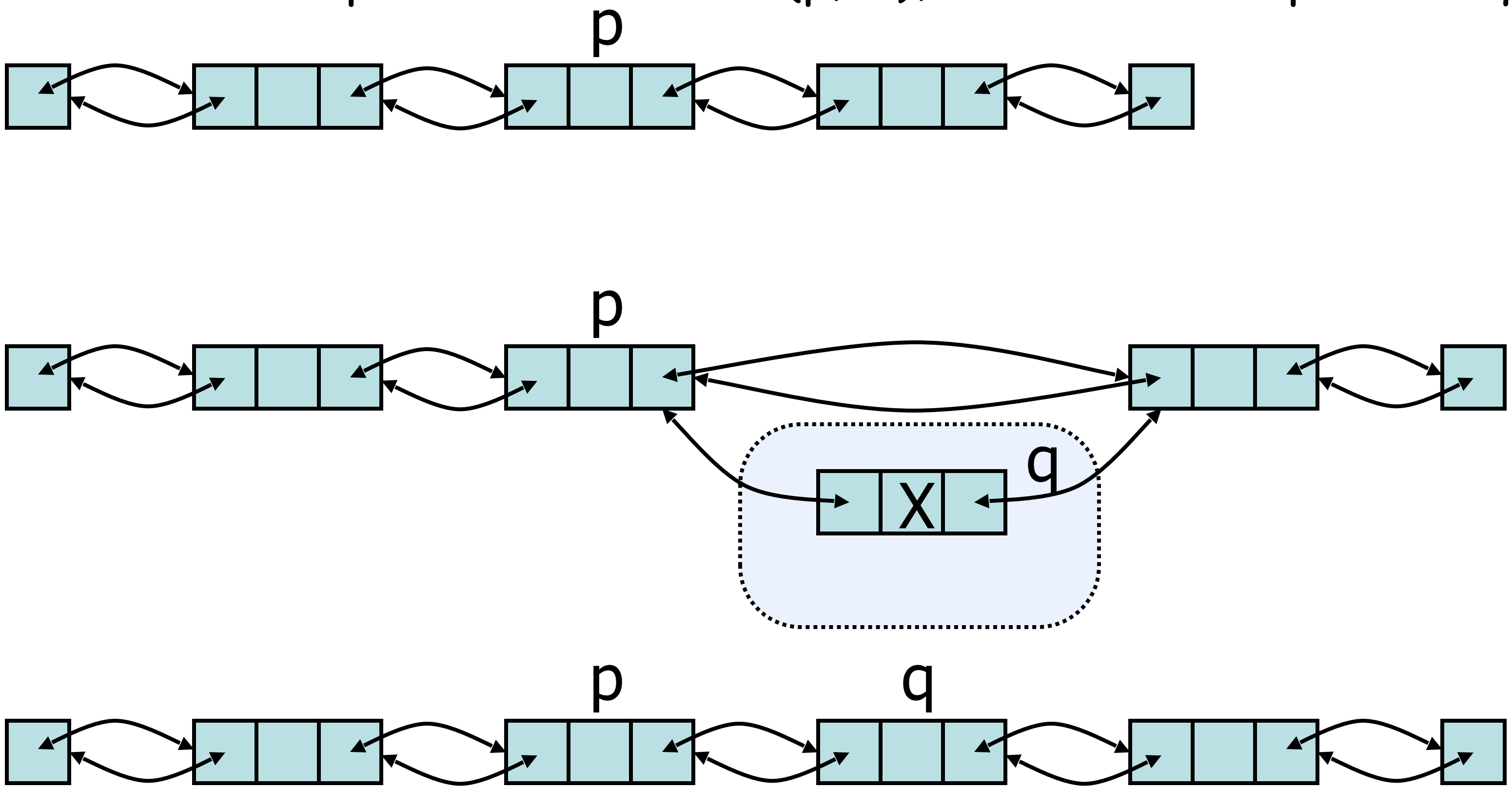
- A doubly linked list provides a natural implementation of the Positional-List ADT
- Nodes implement Position and store:
  - element
  - link to the previous node
  - link to the next node
- Special trailer and header nodes





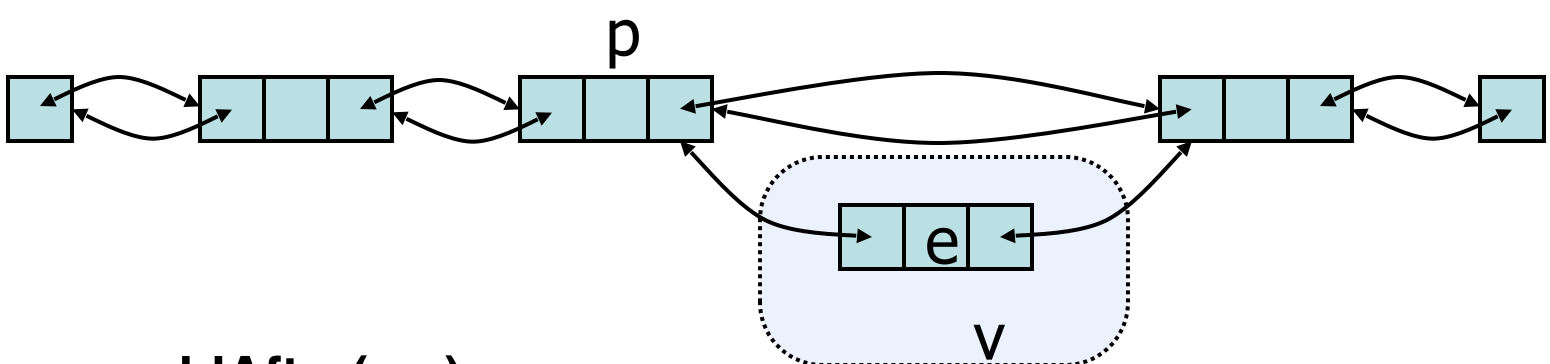
Insertion

- We visualize operation addAfter(p, X), which returns position q



Insertion

- We visualize operation addAfter(p, e), which returns position v



addAfter(p,e)

Create a new node v

Correct order??

v.setNext(p.getNext())

v.setElement(e)

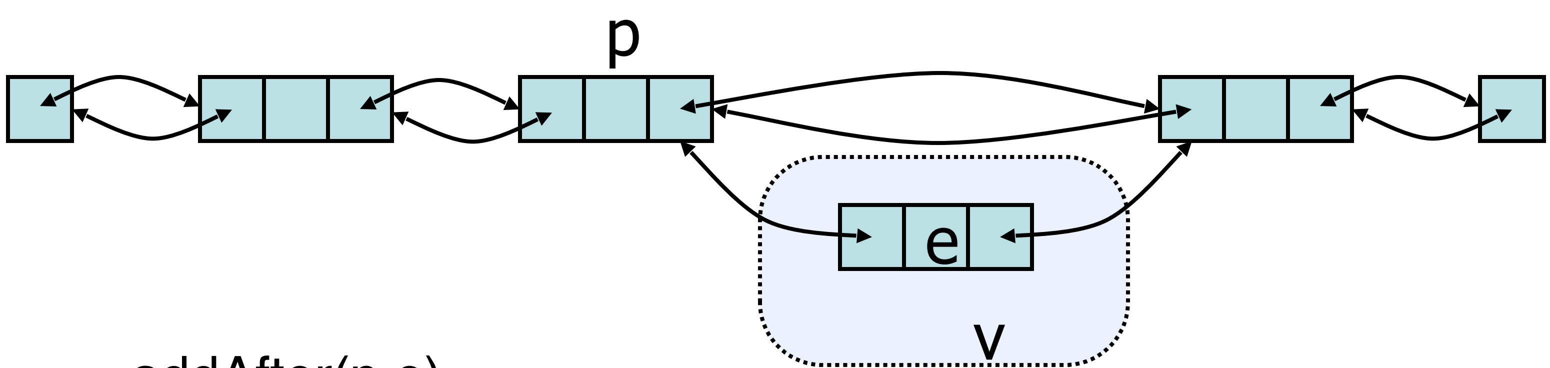
(p.getNext()).setPrev(v)

v.setPrev(p)

p.setNext(v)

Insertion

- We visualize operation addAfter(p, e), which returns position v

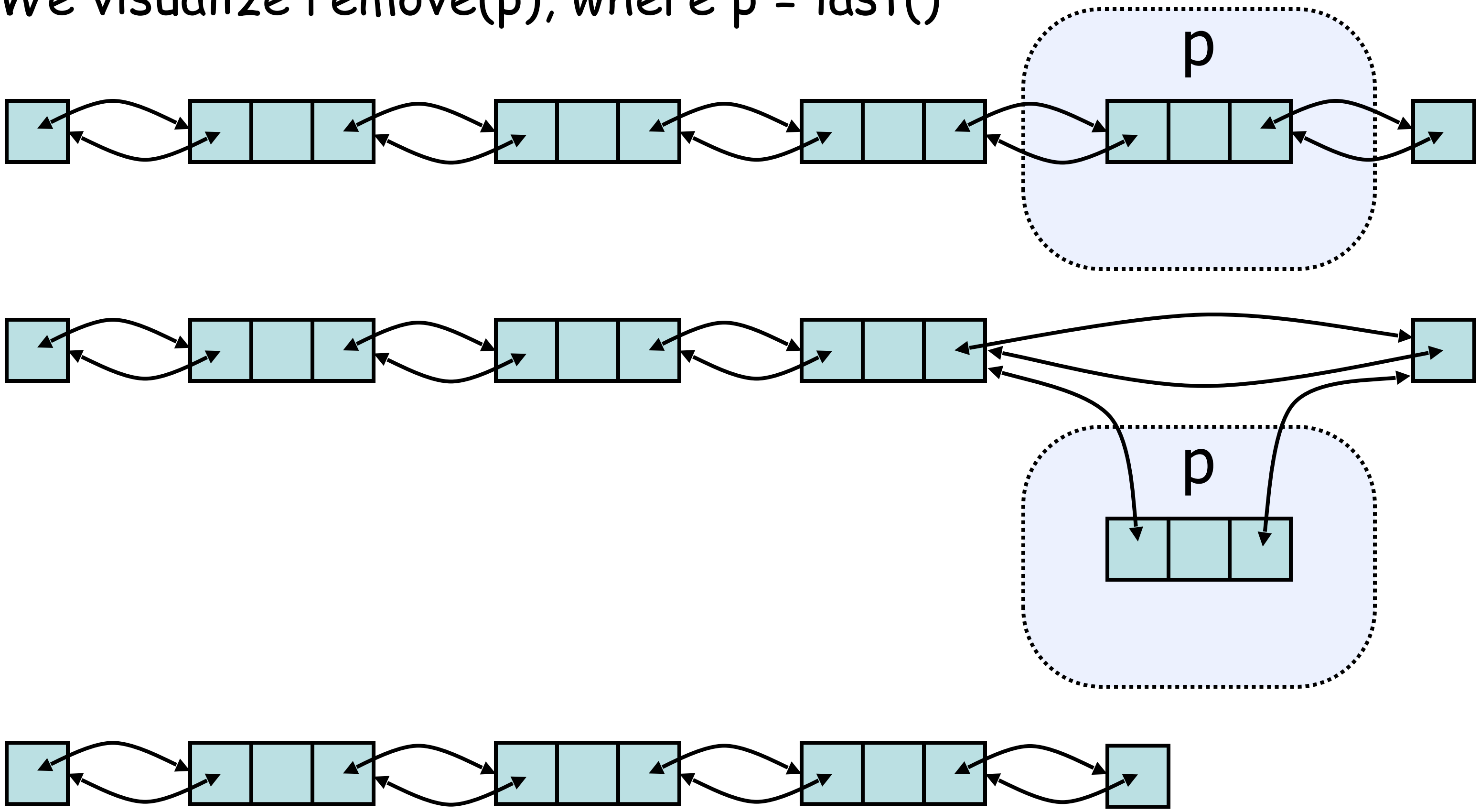


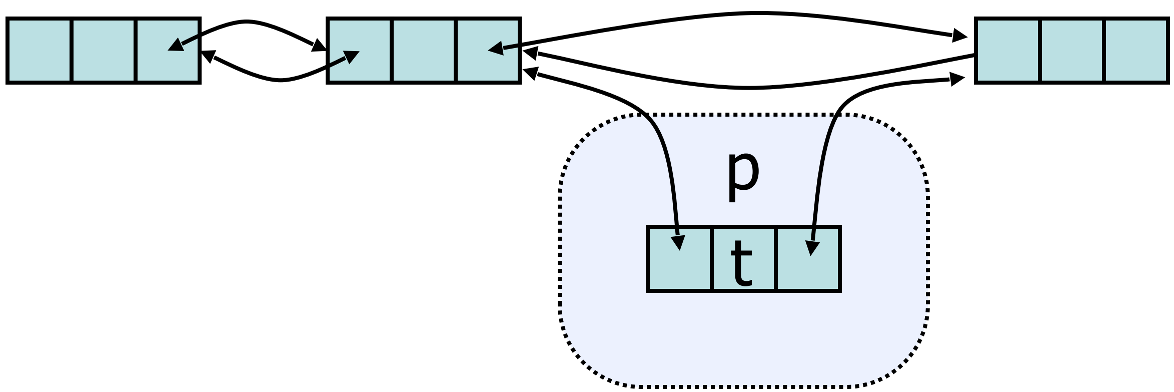
addAfter(p,e)

Create a new node v
v.setElement(e)
v.setPrev(p)
v.setNext(p.getNext())
(p.getNext()).setPrev(v)
p.setNext(v)

Deletion

- We visualize remove(p), where p = last()





remove(p)

t ← p.element

(p.getPrev()).setNext(p.getNext())

(p.getNext()).setPrev(p.getPrev())

p.setPrev(null)

p.setNext(null)

return t

Performance

- In the implementation of the Positional-List ADT by means of a doubly linked list
    - The space used by a list with **n** elements is **O**(**n**)
  - The space used by each position of the list is **O**(1)
  - All the operations of the Positional-List ADT run in **O**(1) time

A more general ADT: Sequence ADT

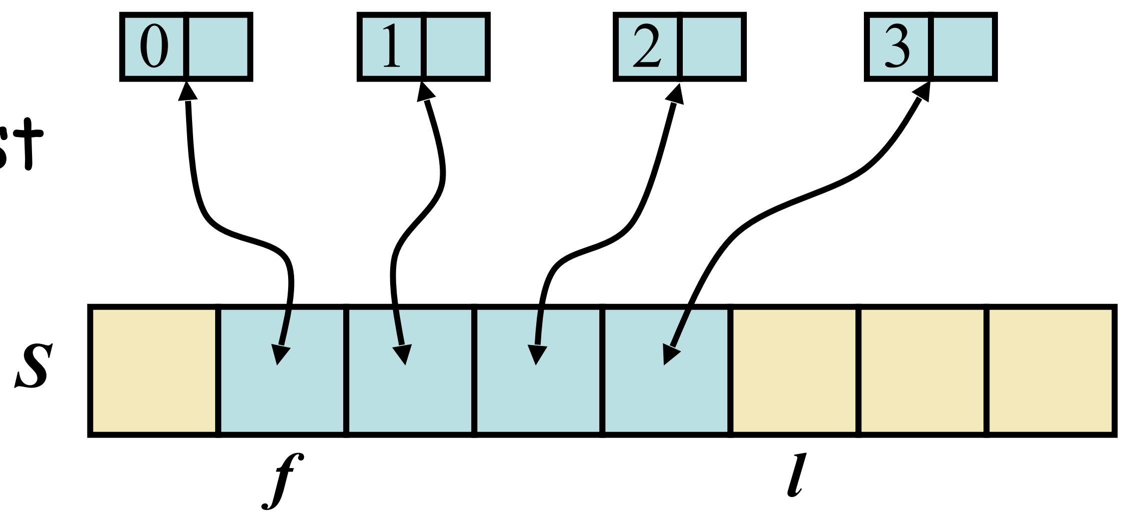
- Combines the Array-List and Positional-List ADT
- Adds methods that bridge between index and positions

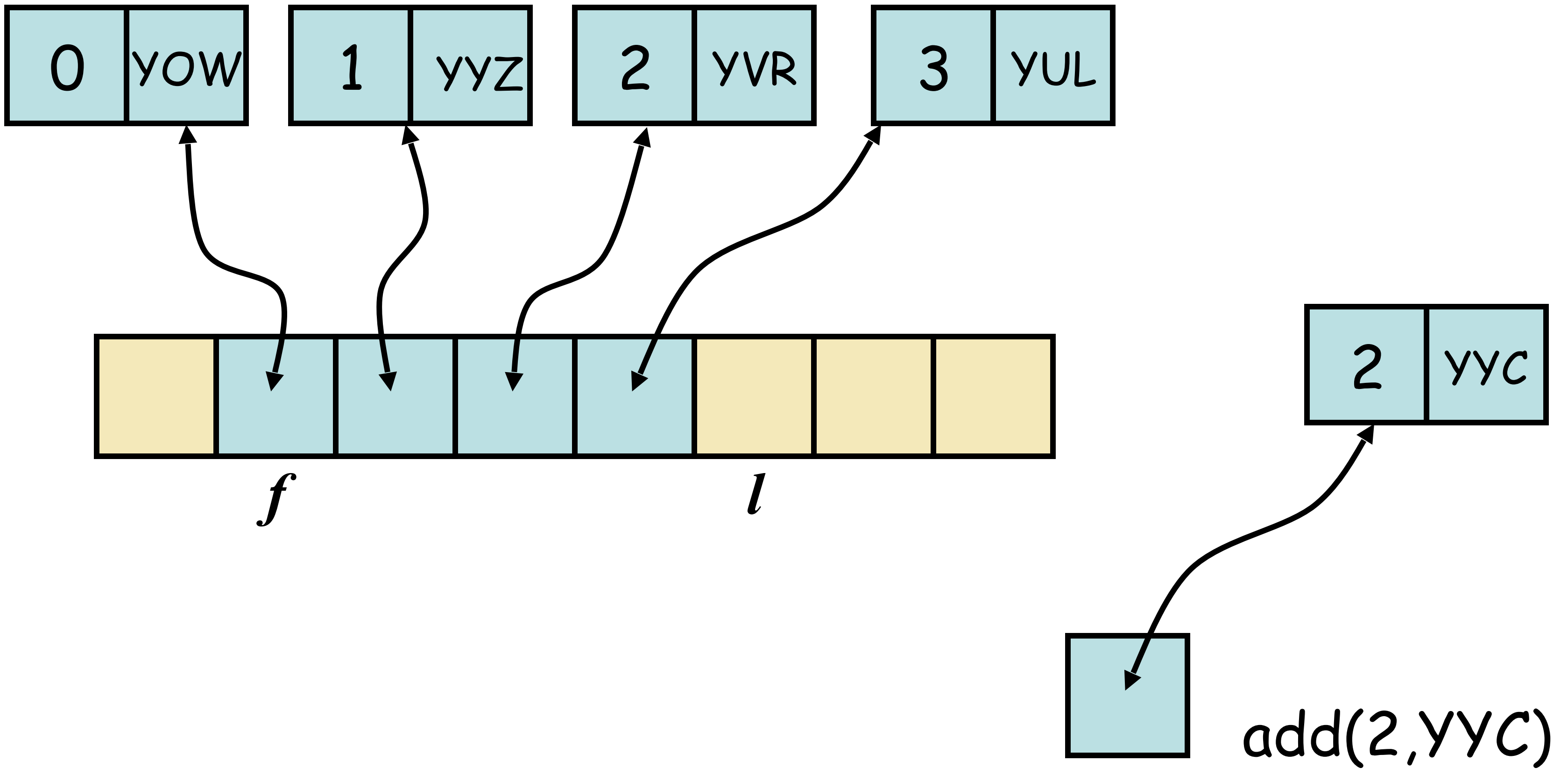
  -atIndex(i) returns a position

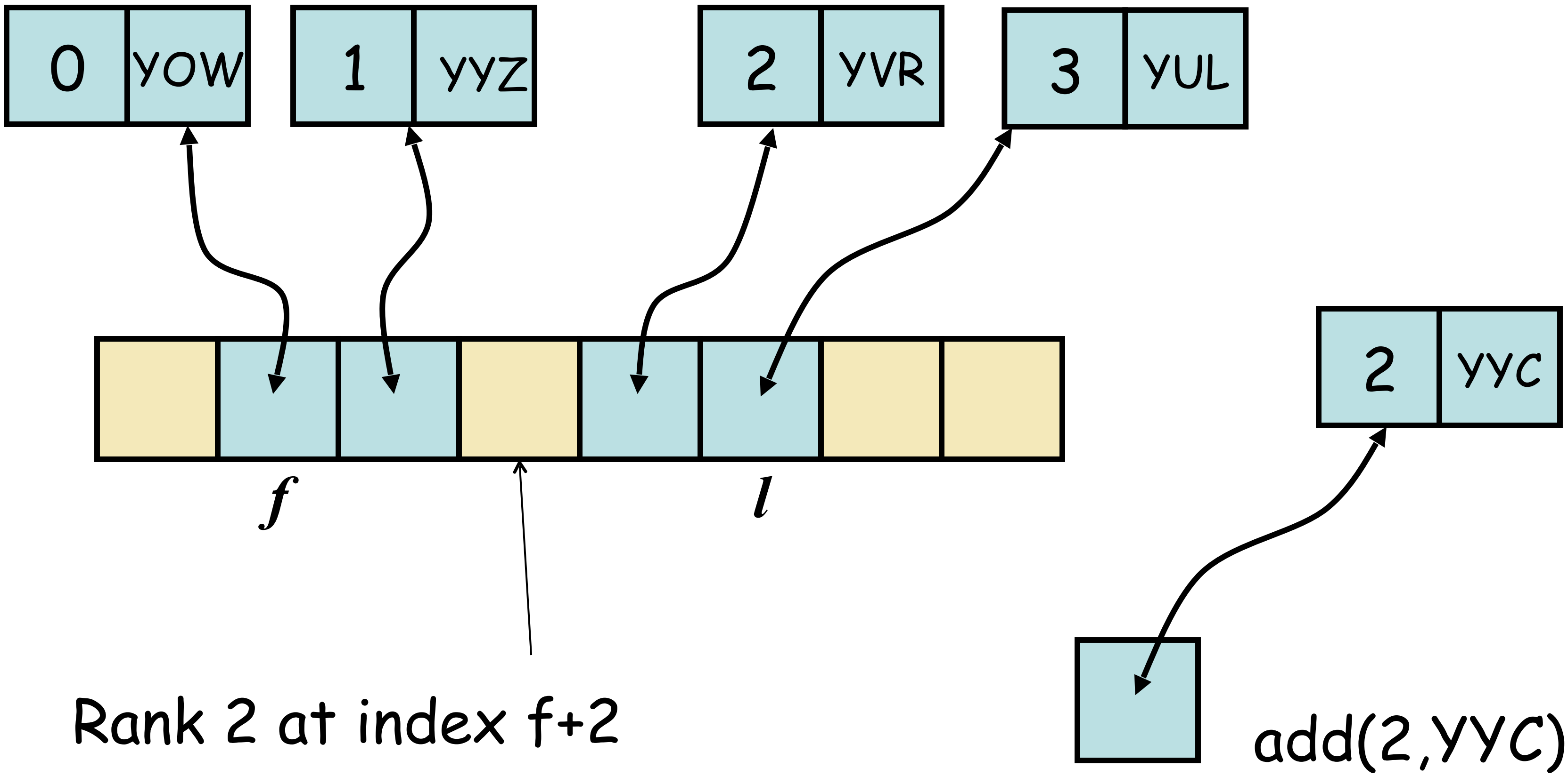
  -indexOf(p) returns an integer index

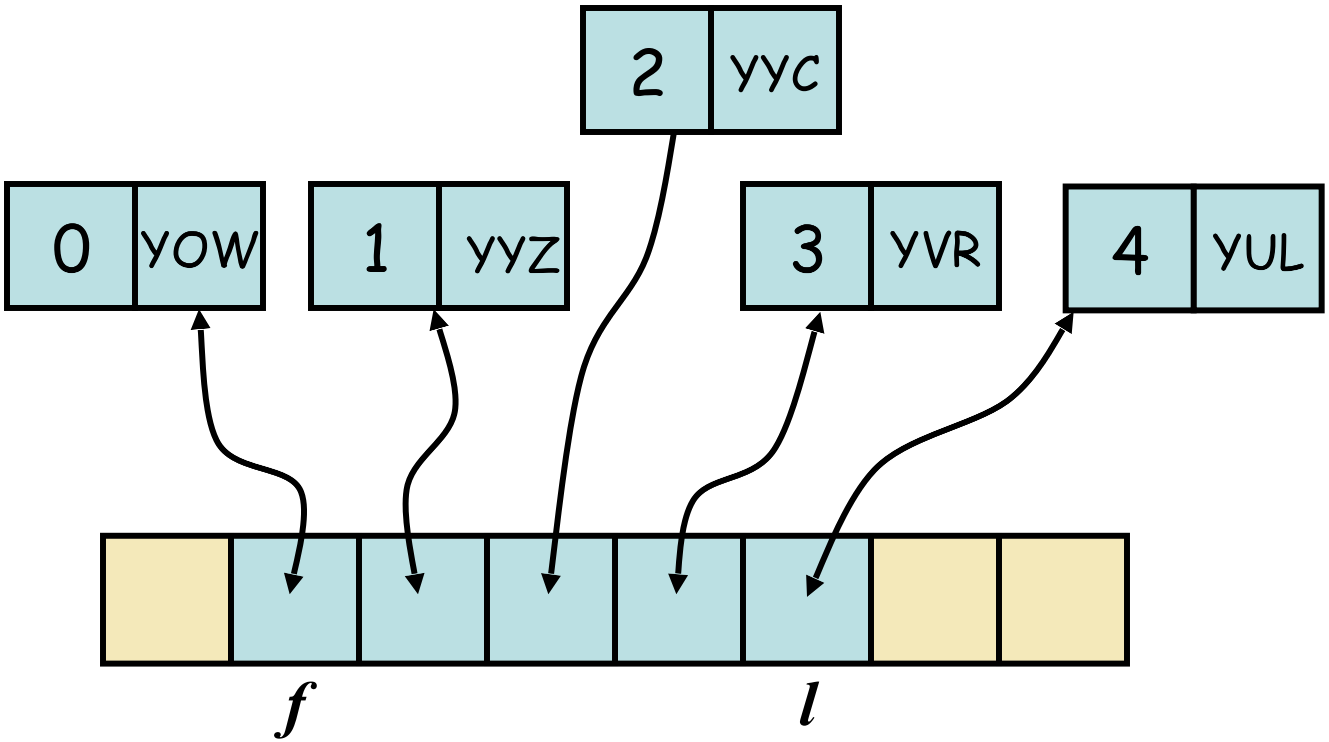
An array-based Implementation

- Circular array storing positions
- A position object stores:
  - Element
  - index
- **f** and **l** keep track of first and last positions

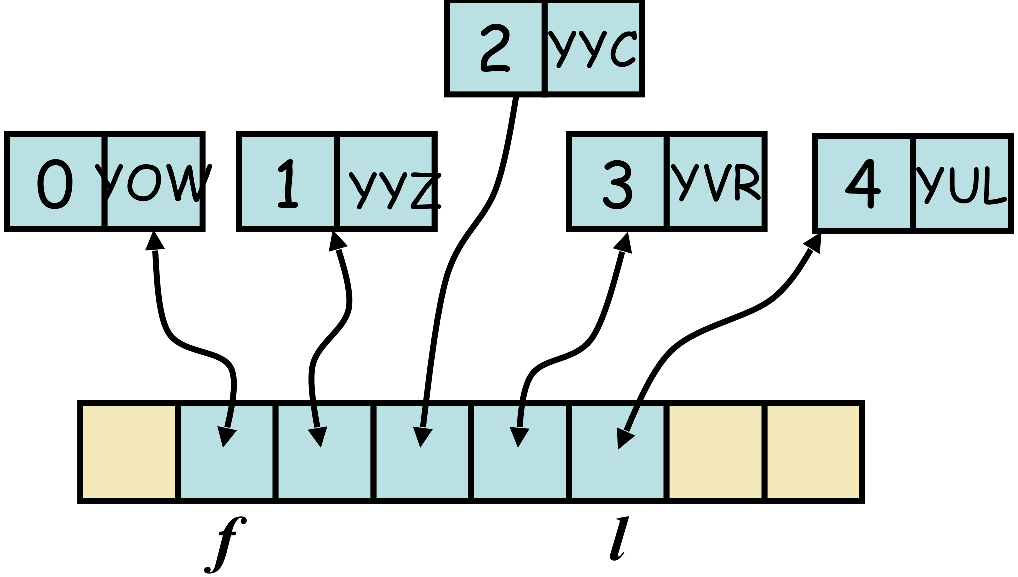



0
YOW
1
YYZ
2
YVR
3
YUL
f
l
2
YYC
add(2,YYC)


0
YOW
1
YYZ
2
YVR
3
YUL
2
YYC
f
l
Rank 2 at index f+2
add(2,YYC)

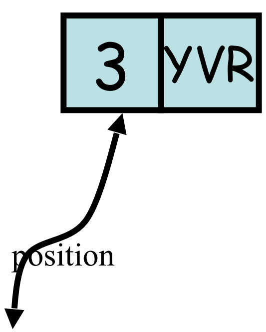


Change all other ranks



atIndex(i) Direct access to the position at index f+i

indexOf(position):



Immediate access to the corresponding index

Array-based Implementation

addFirst, addBefore, addAfter, remove

$O(n)$

Also: add, remove based on the index

$O(n)$

Other methods

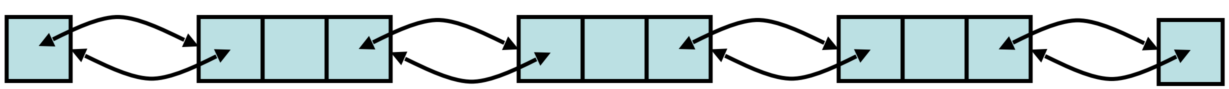
$O(1)$

Implementation with Doubly Linked List

All methods are inherited ….

Bridges:

atIndex(i), indexOf(p): O(n)



Must traverse the list

Summary: Array-based implementation of Sequences

Need to move elements

addFirst,addBefore,addAfter,add(i,e) ---- O(n)

remove(position) remove(index) ---- O(n)

Bridges: atIndex(i), indexOf(p): ---- O(1)

get(i), set(i,e) ----- O(1)

Because the position contains also the index

Summary: Implementation of Sequences by Doubly-linked lists

addFirst,addBefore,addAfter, remove(position) ---- O(1)

add(i,e)

remove(index) ---- O(n)

Bridges: atIndex(i), indexOf(p): ---- O(n)

Need to traverse to find an index

get(i), set(i,e) ----- O(n)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Hi Friend!
Poke!
http://TheFunnyPlace.net