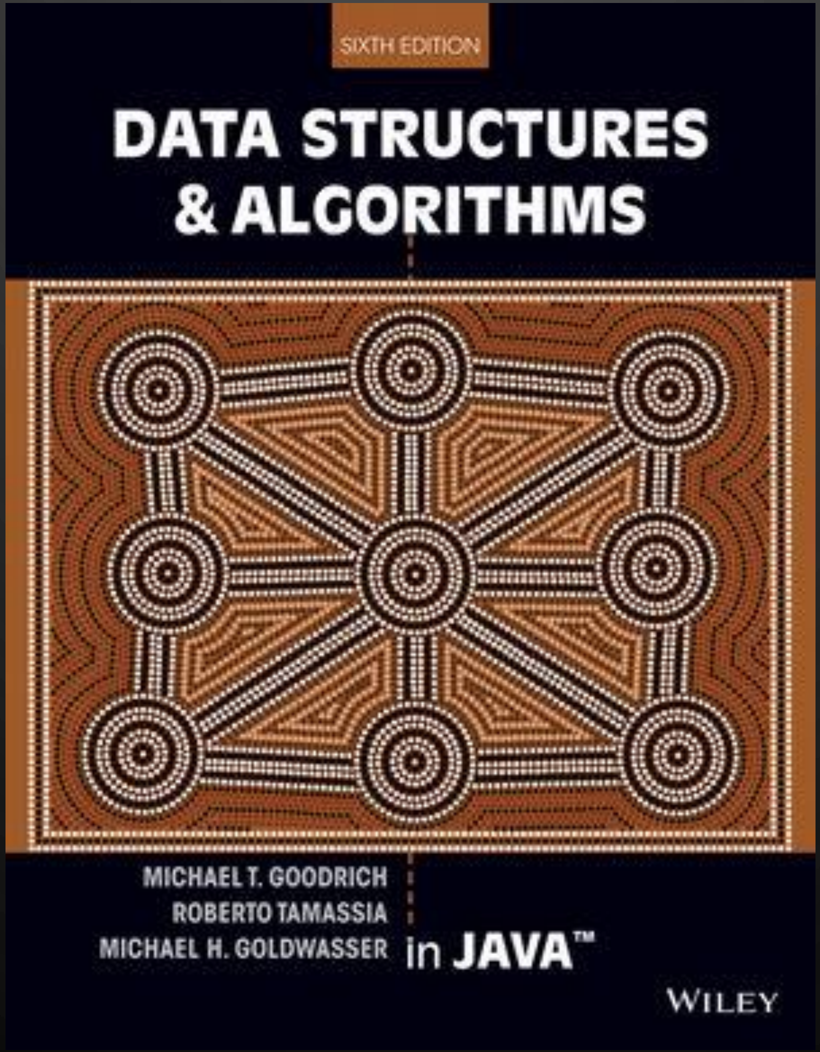
WELCOME TO
CSCE 221: DATA STRUCTURES

SYLLABUS


SIXTH EDITION
DATA STRUCTURES & ALGORITHMS
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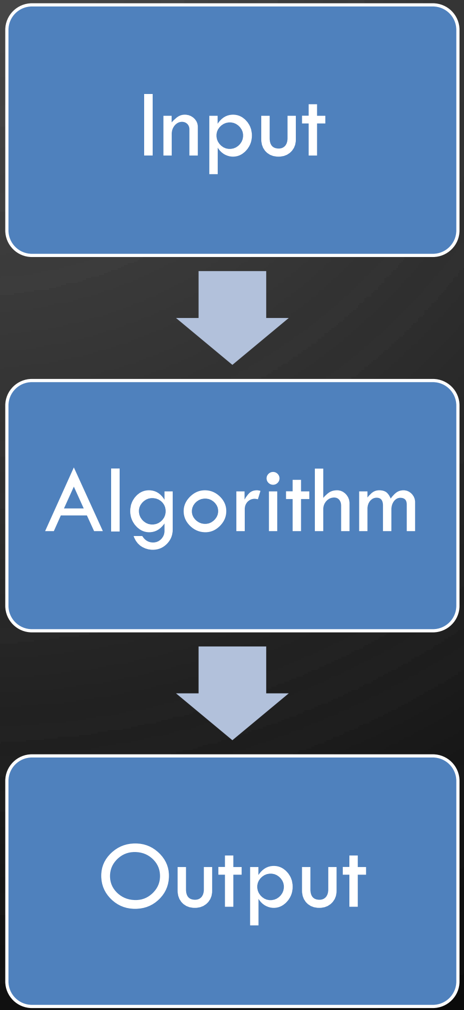
ROBERTO TAMASSIA
MICHAEL H. GOLDWASSER
in JAVA™
WILEY

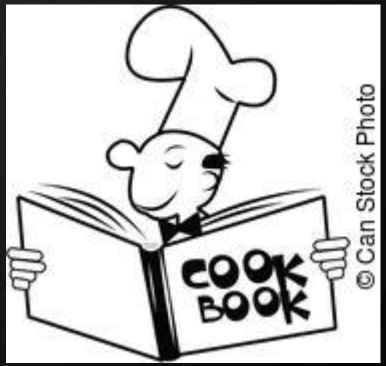
REVIEW

COMPUTING, DATA, AND MEMORY

COMPUTER SCIENCE

- Study of algorithms
- Study of computing tools
- It is not just:
  - Programming
  - Electronics
  - Etc.
- In this class, we formalize this study of algorithms through the basics of data structures – a bread-and-butter component of almost all algorithms





PSEUDOCODE

- High-level description of an algorithm
- More structured than English prose
- Less detailed than a program
- Preferred notation for describing algorithms
- Hides program design issues

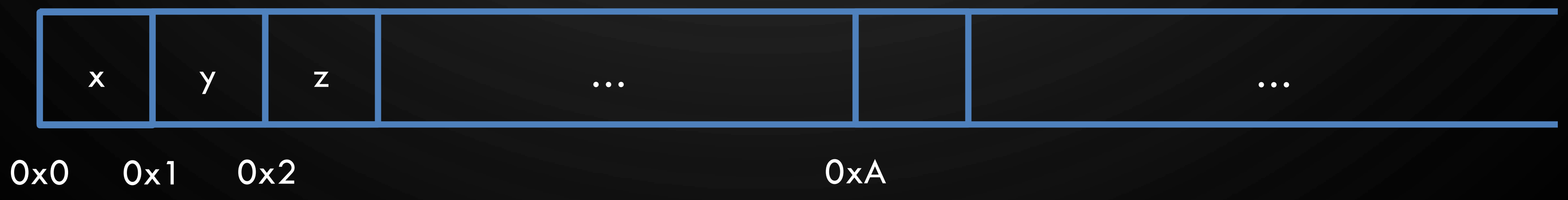
- Basic rundown
  - Use common math notations
  - Use $\leftarrow$ vs $=$ for assignment
  - Do not use (), {}, ;, etc.
  - Let indenting denote scope
  - Use objects and functions without having to define them
- Look at my website LaTex tutorial for more info

THE BASIC METHODS TO STORE DATA FROM 150

1. One variable per data element – does not associate data together and can be very verbose
2. Arrays – group a large amount of data all of the same type
3. Objects – group a large amount of data all of different types

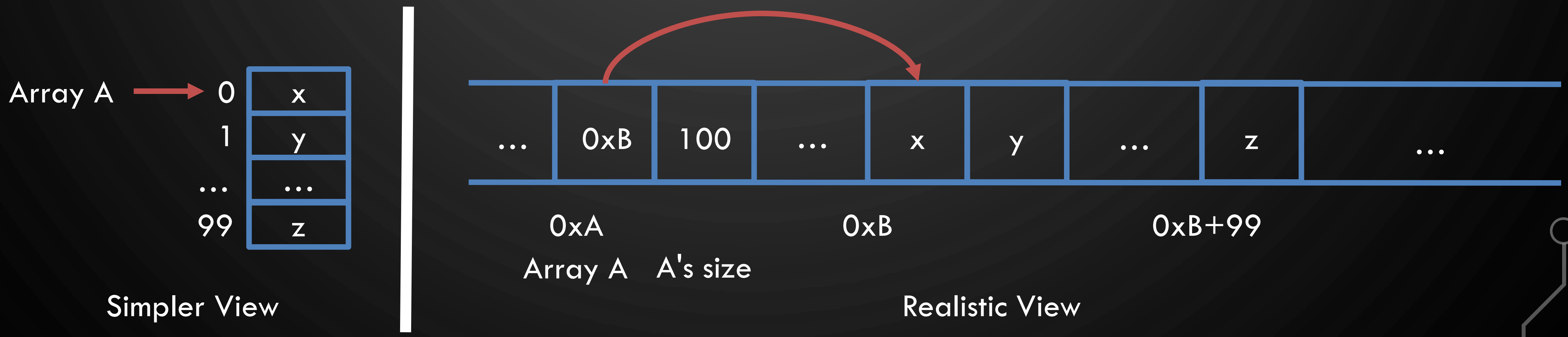
MEMORY

- **Memory** is storage for data and programs
- We will pretend that memory is an infinitely long piece of **tape** separated into different **cells**
- Each cell has an **address**, i.e., a location, and a **value**
- In the computer these values are represented in **binary** (0s and 1s) and addresses are located in **hexadecimal** (base 16, 0x)



MEMORY
ARRAYS

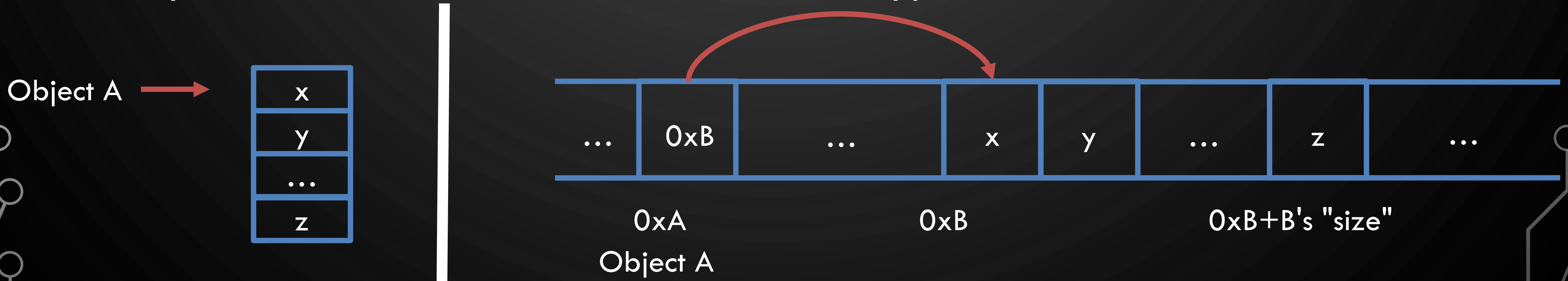
- We will review arrays in Java later today
- **Arrays** are a sequential piece of memory all of the same type



- **Pointer** (e.g., Java reference) – a variable that stores a memory location

MEMORY
OBJECTS

- We will review objects in Java and learn new concepts/syntax about objects tomorrow
- **Objects** are entities in your program. Another way to think about them is that they are collections of data of unassociated types.



Simpler View

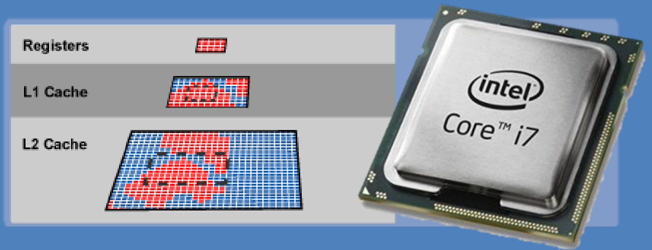
Realistic View

- Objects are stored as pointers in Java, always.

BASIC COMPUTER ORGANIZATION

Input
- Files
- Keyboard
- Mouse
- Etc.

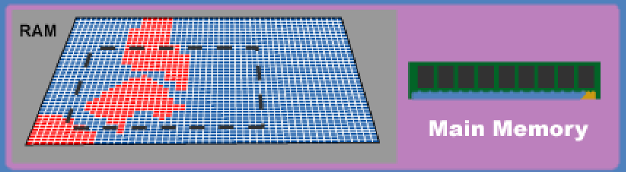
Central Processing Unit (CPU)
- Processes commands as 0's and 1's
- Performs arithmatic
- Requests (reads) and writes to/from memory



Output
- Monitor
- Force feedback
- Files
- Etc.

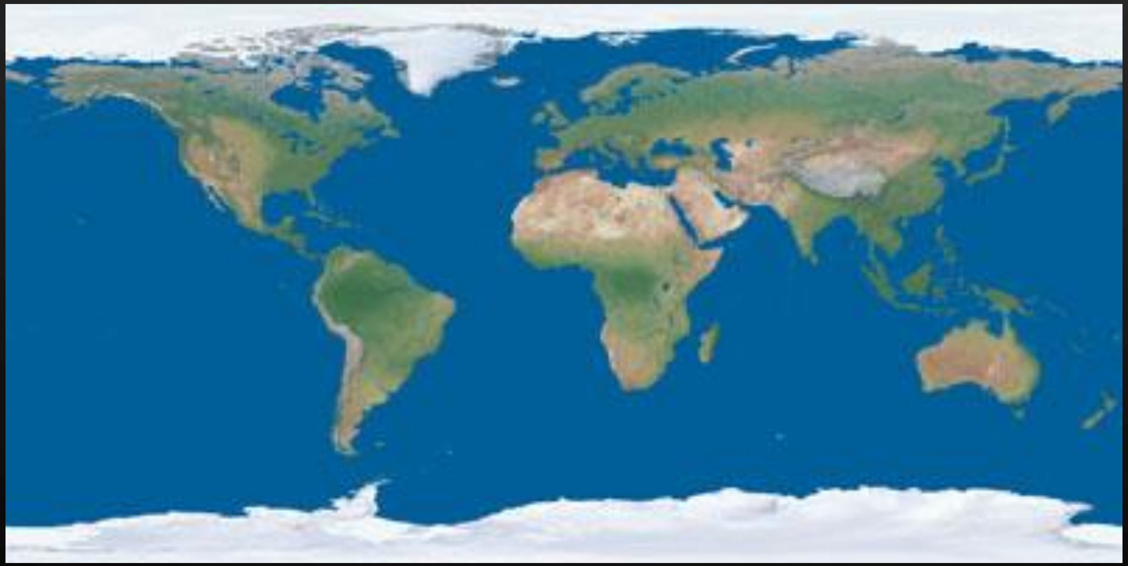
Bus

Memory
- Data encoded as 0s and 1s
- Cache
- Random Access Memory (RAM)
- Hard drive



TAKEAWAYS ABOUT MEMORY

- Programs can operate more efficiently when data is close together, e.g., arrays. This is called **locality** of data. The reason it works better is the cache.
- Pointers are not usually located close to the data. They hurt locality.



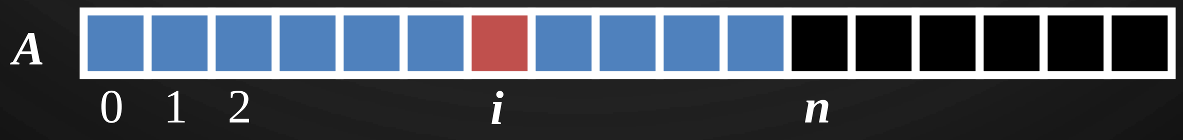
CH3.
FUNDAMENTAL DATA STRUCTURES

ACKNOWLEDGEMENT: THESE SLIDES ARE ADAPTED FROM SLIDES PROVIDED WITH DATA STRUCTURES AND ALGORITHMS IN JAVA, GOODRICH, TAMASSIA AND GOLDWASSER (WILEY 2016)

CH 3.1 ARRAYS

ARRAY DEFINITION

- An **array** is a sequenced collection of variables all of the same type. Each variable, or **cell**, in an array has an **index**, which uniquely refers to the value stored in that cell. The cells of an array, A, are numbered 0, 1, 2, and so on.
- Each value stored in an array is often called an **element** of that array.



ARRAY LENGTH AND CAPACITY

- Since the length of an array determines the maximum number of things that can be stored in the array, we will sometimes refer to the length of an array as its **capacity**.
- In Java, the length of an array named `a` can be accessed using the syntax `a.length`. Thus, the cells of an array, `a`, are numbered 0, 1, 2, and so on, up through `a.length−1`, and the cell with index k can be accessed with syntax `a[k]`.

DECLARING ARRAYS (FIRST WAY)

- The first way to create an array is to use an assignment to a literal form when initially declaring the array, using a syntax as:

`ElementType``[] arrayName =`
`{`$initialValue_0, initialValue_1, \ldots, initialValue_{N-1}$`};`

- The **`ElementType`** can be any Java base type or class name, and `arrayName` can be any valid Java identifier. The initial values must be of the same type as the array.

DECLARING ARRAYS (SECOND WAY)

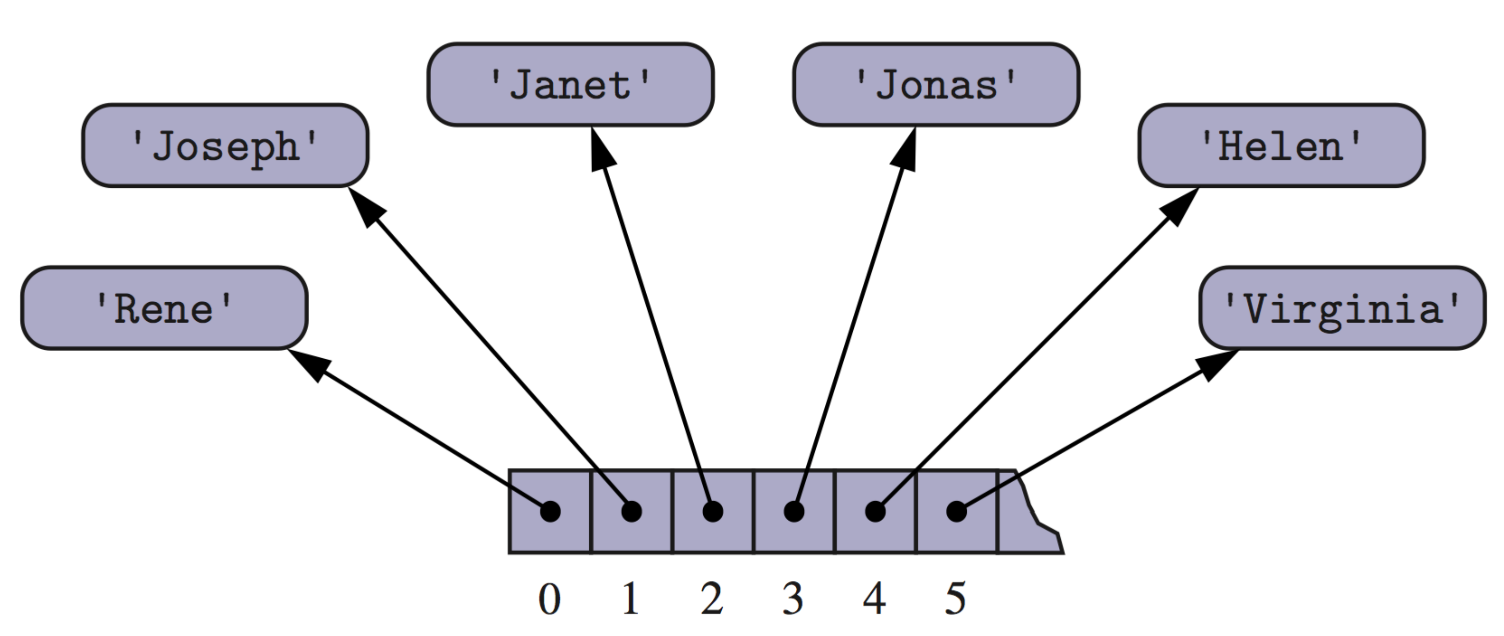
- The second way to create an array is to use the **new** operator.
  - However, because an array is not an instance of a class, we do not use a typical constructor. Instead we use the syntax:

    `new ElementType[length]`

- `length` is a positive integer denoting the length of the new array.
- The **new** operator returns a reference to the new array, and typically this would be assigned to an array variable.

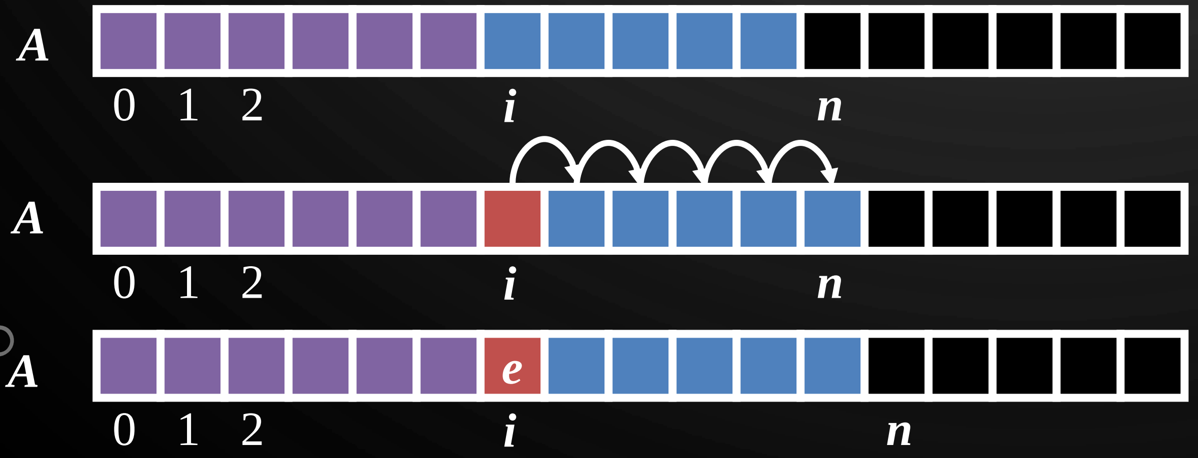
ARRAYS OF OBJECTS

- Recall an array of objects is an array of pointers to objects



ADDING AN ENTRY

- To add an entry e into array A at index i, we need to make room for it by shifting forward the $n - i$ entries $A[i], \ldots, A[n-1]$



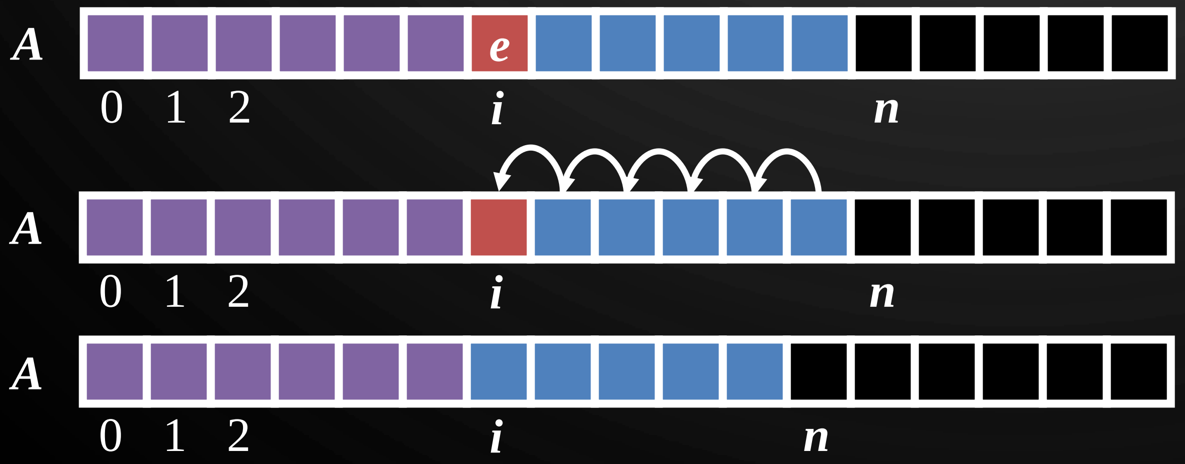
Algorithm Add

Input: Array A, index i, element e

1. **for** $k \leftarrow n$ **to** $i + 1$ **do**
2. $\quad A[k] \leftarrow A[k-1]$
3. $A[i] \leftarrow e$
4. $n \leftarrow n + 1$

REMOVING AN ENTRY

- To remove the entry e at index i, we need to fill the hole left by e by shifting backward the $n - i - 1$ elements $A[i + 1], \dots, A[n - 1]$



Algorithm Remove

Input: Array A, index i, element e

for $k \leftarrow i + 1$ **to** $n - 1$ **do**

$A[k - 1] \leftarrow A[k]$

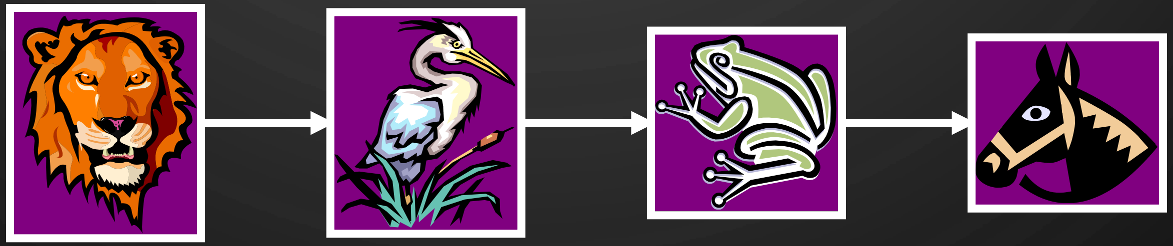
$A[n - 1] \leftarrow null$

$n \leftarrow n - 1$

EXERCISE

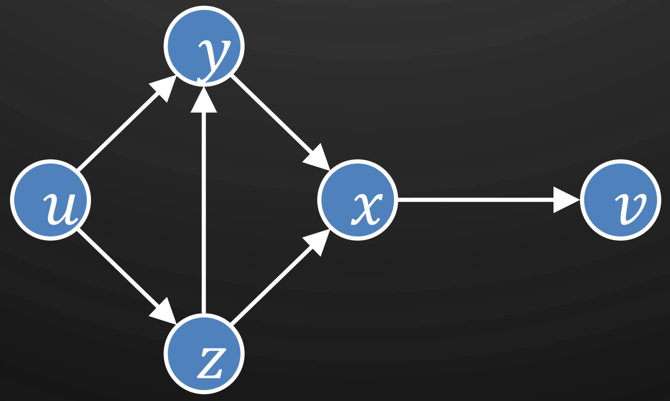
- With a partner, write an algorithm in pseudocode to compare the equality of two arrays A and B. Use '$=$' for equality checking in pseudocode, not '$==$'.

CH 3.2 SINGLY LINKED LISTS



LINKED STRUCTURES

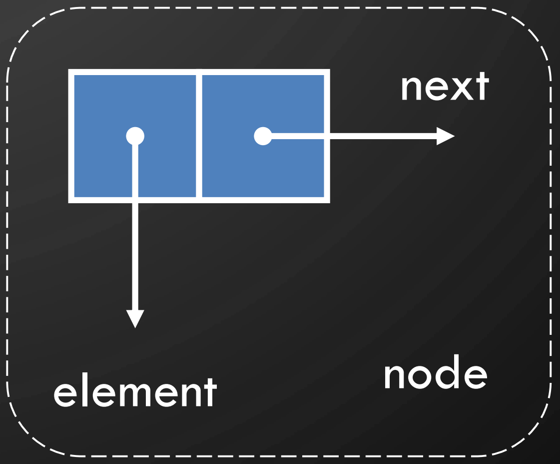
- A **linked data structure** stores **nodes** that contain data and pointers to other nodes in the structure
  - Compare this to an array!

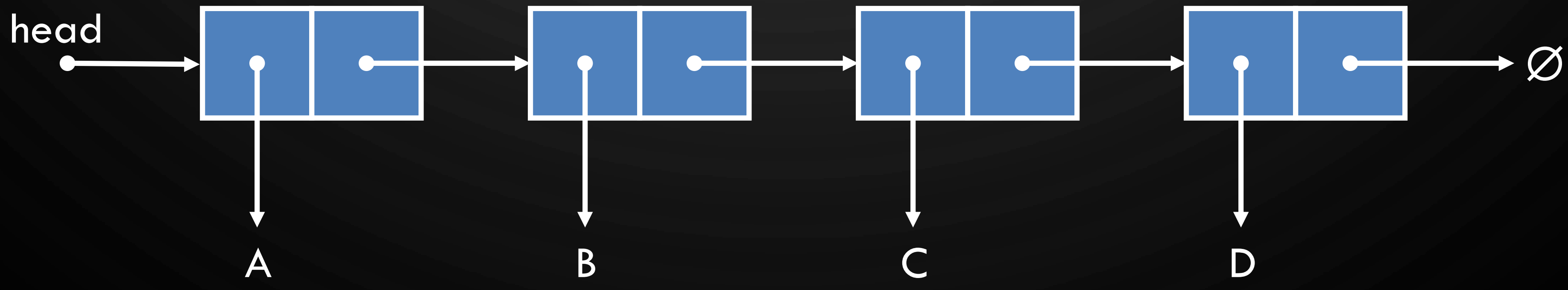


Example of a linked structure – graph (Ch 14)

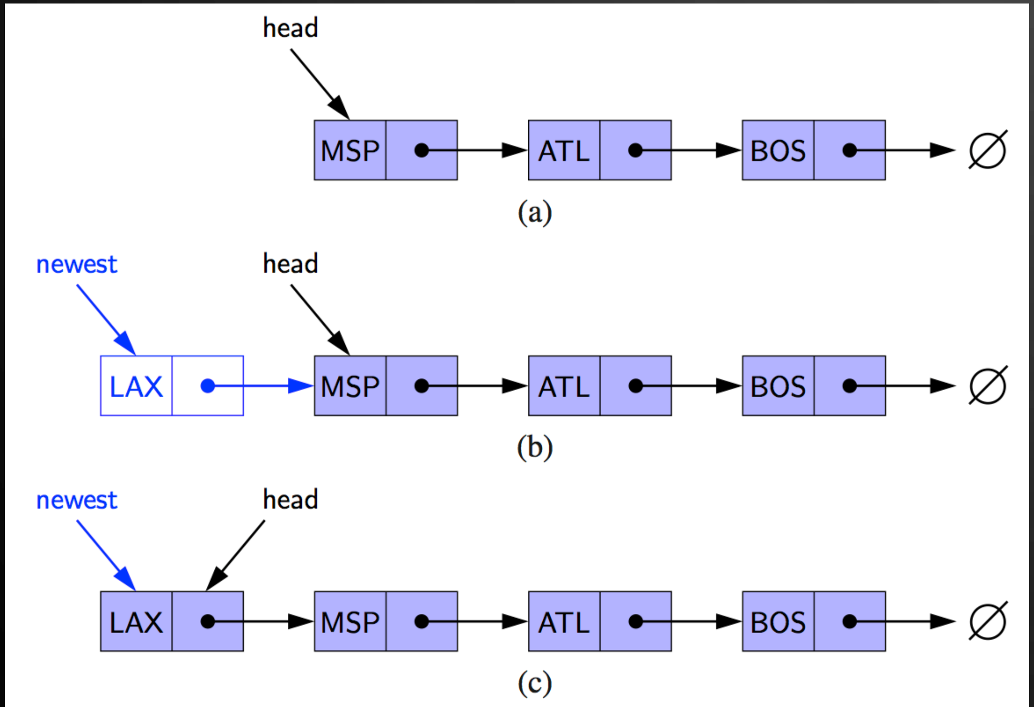
SINGLY LINKED LIST

- A **singly linked list** is a concrete data structure consisting of a sequence of nodes, starting from a head pointer
- Each node stores
  - element
  - link to the next node





INSERTING AT THE HEAD



Algorithm AddFirst

Input: List l, Element e

1. Node $n \leftarrow$ new Node(e) //Allocate new node n to contain element e
2. $n.next \leftarrow l.head$ //Have new node point to old head
3. $l.head \leftarrow n$ //Update head to point to new node

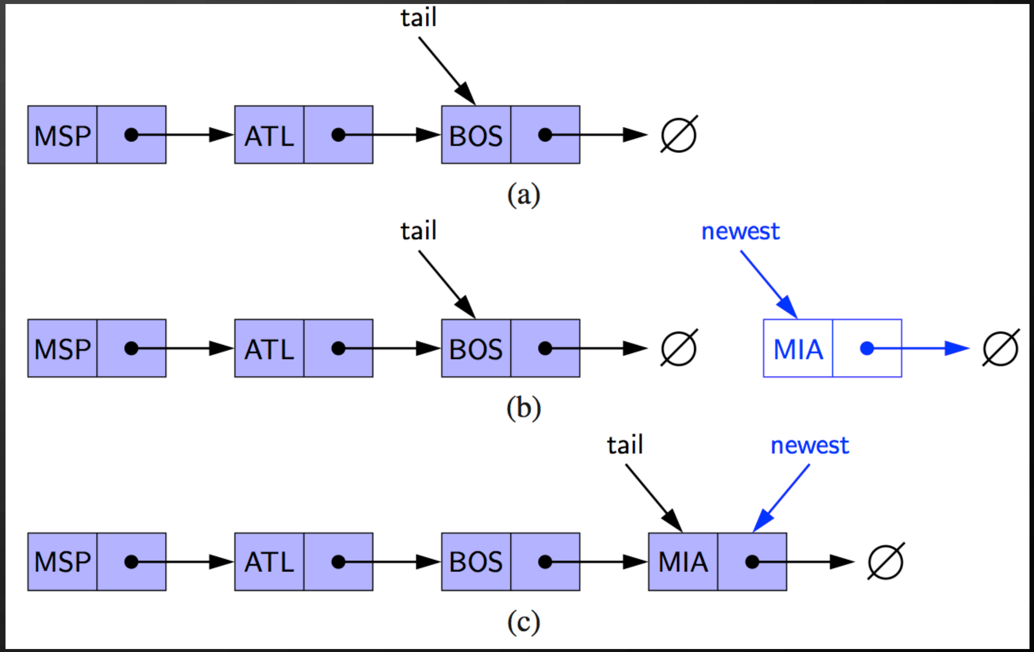
Note, for simplicity, this algorithm assumes the list has elements in it. A special case would need to be introduced for an empty list to set up the tail pointer.

INSERTING AT THE TAIL

Algorithm AddLast

Input: List l, Element e

1. Node $n \leftarrow$ new Node(e) //Allocate a new node to contain element e
2. $n.next \leftarrow null$ //Have new node point to null
3. $l.tail.next \leftarrow n$ //Have old last node point to new node
4. $l.tail \leftarrow n$ //Update tail to point to new node



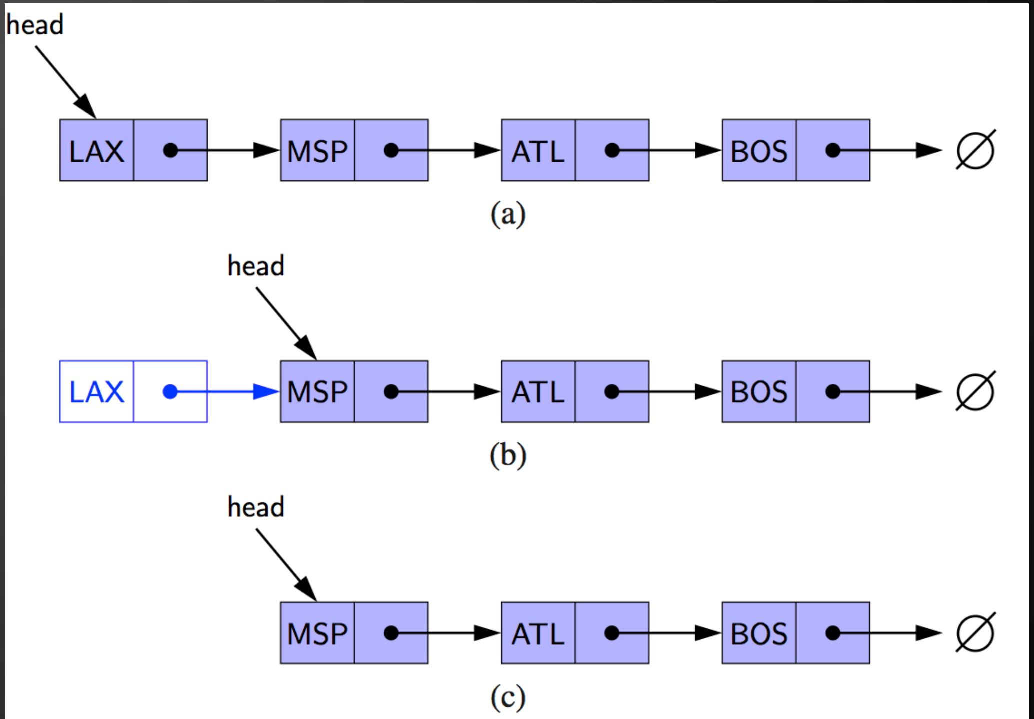
Note, for simplicity, this algorithm assumes the list has elements in it. A special case would need to be introduced for an empty list to set up the head pointer.

REMOVING AT THE HEAD

Algorithm RemoveFirst

Input: List l

1. $l.head \leftarrow l.head.next$ //Update head to point to next node in the list
2. Allow garbage collector to reclaim the former first node



Note, a garbage collector is not found in all languages you may need to deal with memory deallocation yourself. In this class, we will stick to the Java way. However, note, the garbage collector is complex, so to help it perform at its best you typically set all pointers of a node to null.

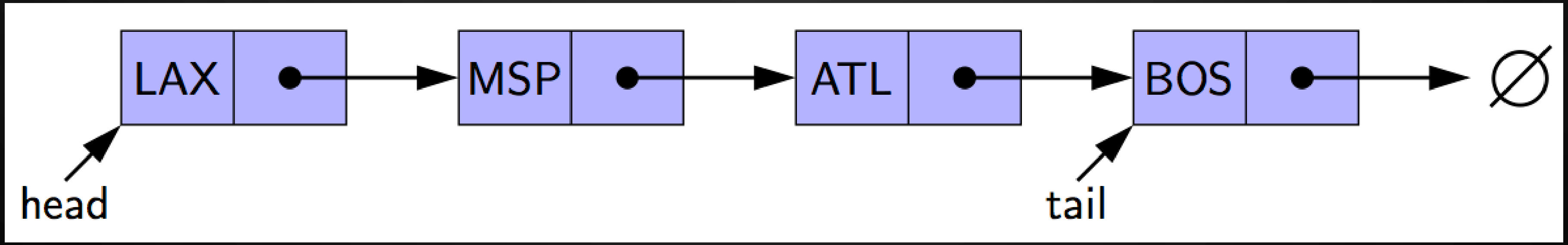
Note, for simplicity, this algorithm assumes the list has elements in it and does not return the removed element. Extra logic would be added in a real implementation..

EXERCISE

- Write an algorithm for finding the second-to-last node in a singly-linked list. The last node is indicated by a null next reference.

REMOVING AT THE TAIL

- Removing at the tail of a singly linked list is not efficient!
- There is no constant-time way to update the tail to point to the previous node

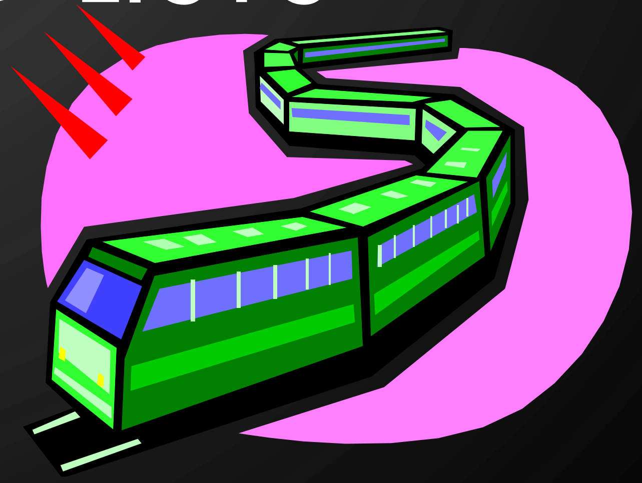


A JAVA SINGLY LINKED LIST OF INT

```java
// Nest this class inside of Linked list
private static class Node {
  // Private data
  private int elem;  // Element
  private Node next; // Next node (link)

  // Constructor
  public Node(int e, Node n) {
    elem = e;
    next = n;
  }

  // Accessors
  public int getElement() {return elem;}
  public Node getNext() {return next;}
}
```

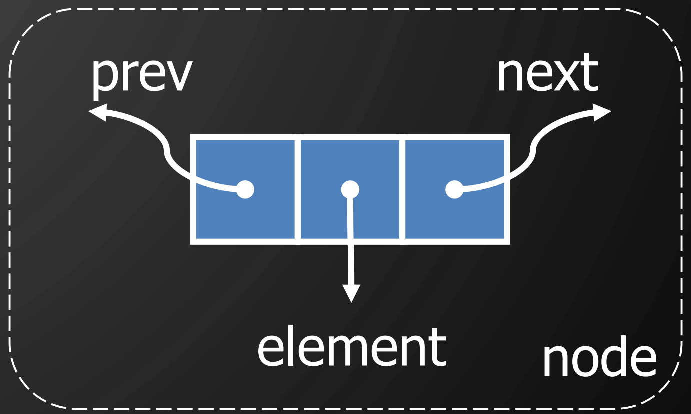
```java
public class LinkedList {
  /* Place node class here */

  // Private data
  private Node head = null; // List head
  private Node tail = null; // List tail
  private int size = 0;     // List size

  // Constructor
  public LinkedList() {}

  // Accessors
  public size() {return size;}

  // Modifiers
  public addFirst(int e) {
    head = new Node(e, head);
    if(size == 0)
      tail = head;
    ++size;
  }

  /* Other algorithms */
}
```

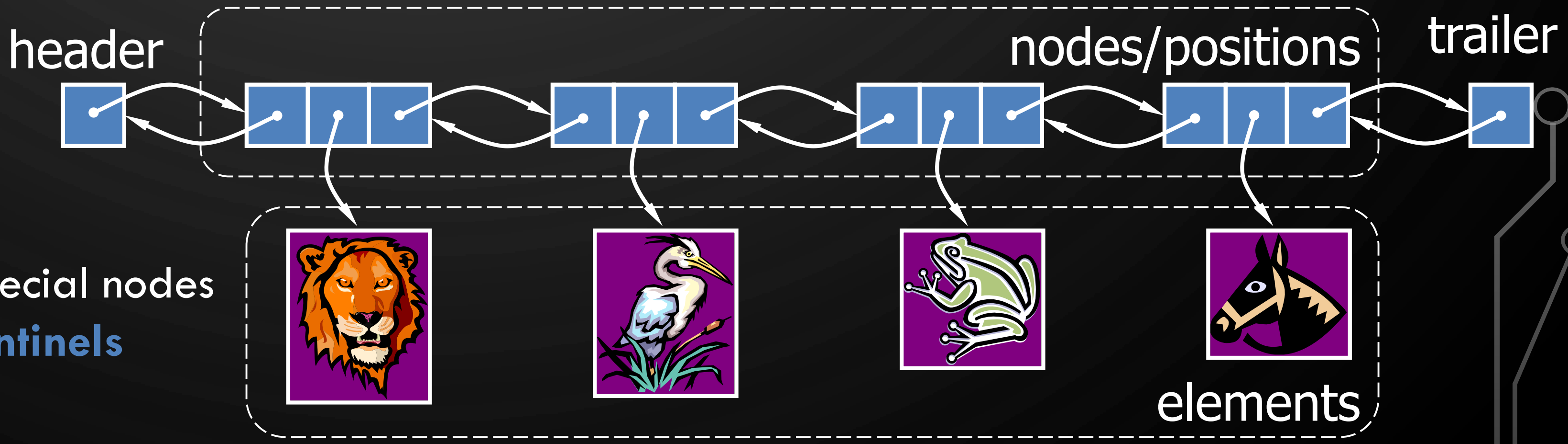
CH 3.4 DOUBLY LINKED LISTS



DOUBLY LINKED LIST

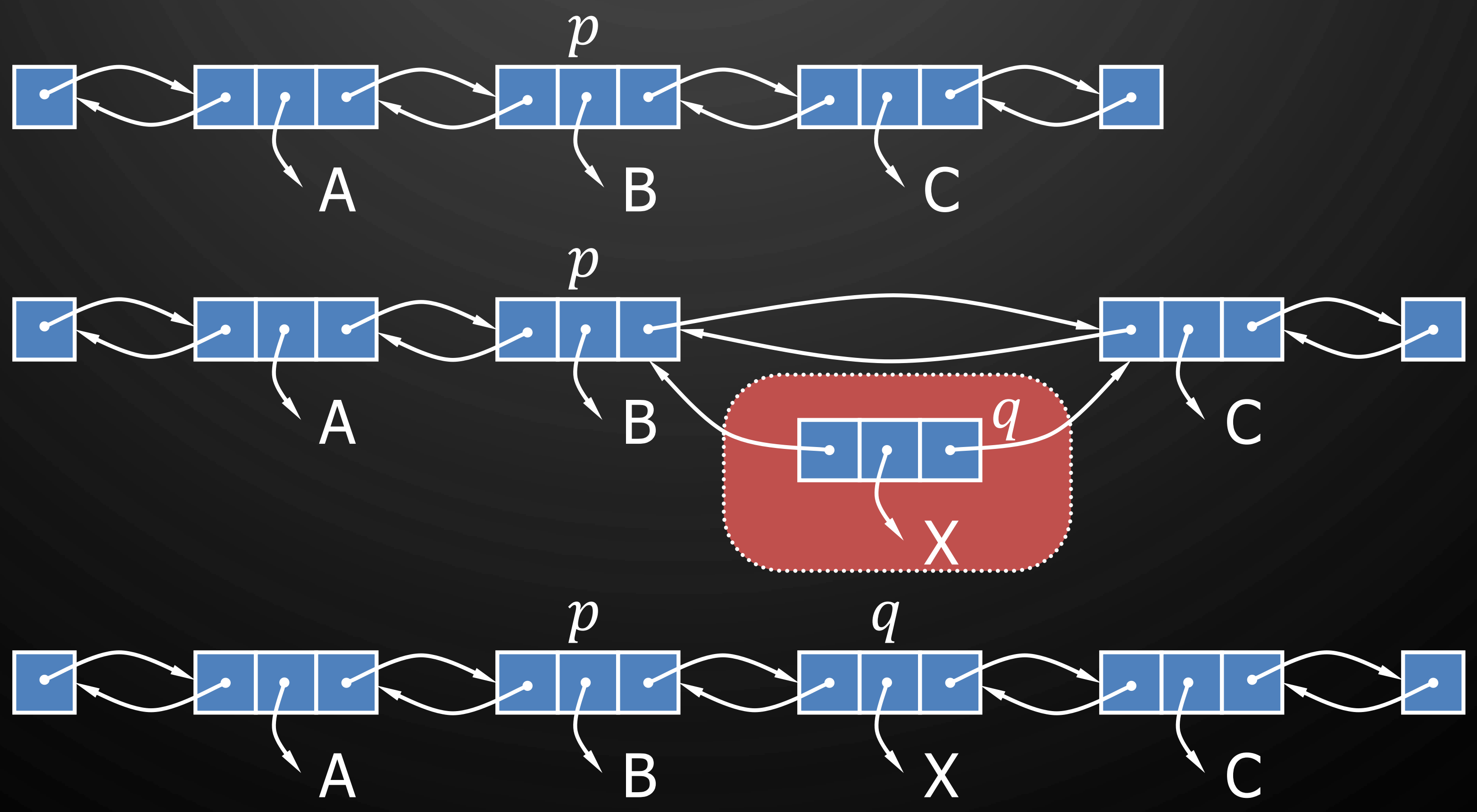
- A **doubly linked list** can be traversed forward and backward
- Nodes store:
  - element
  - link to the previous node
  - link to the next node
- Special trailer and header nodes that do not store data.
  - In linked structures, special nodes like this are called **sentinels**





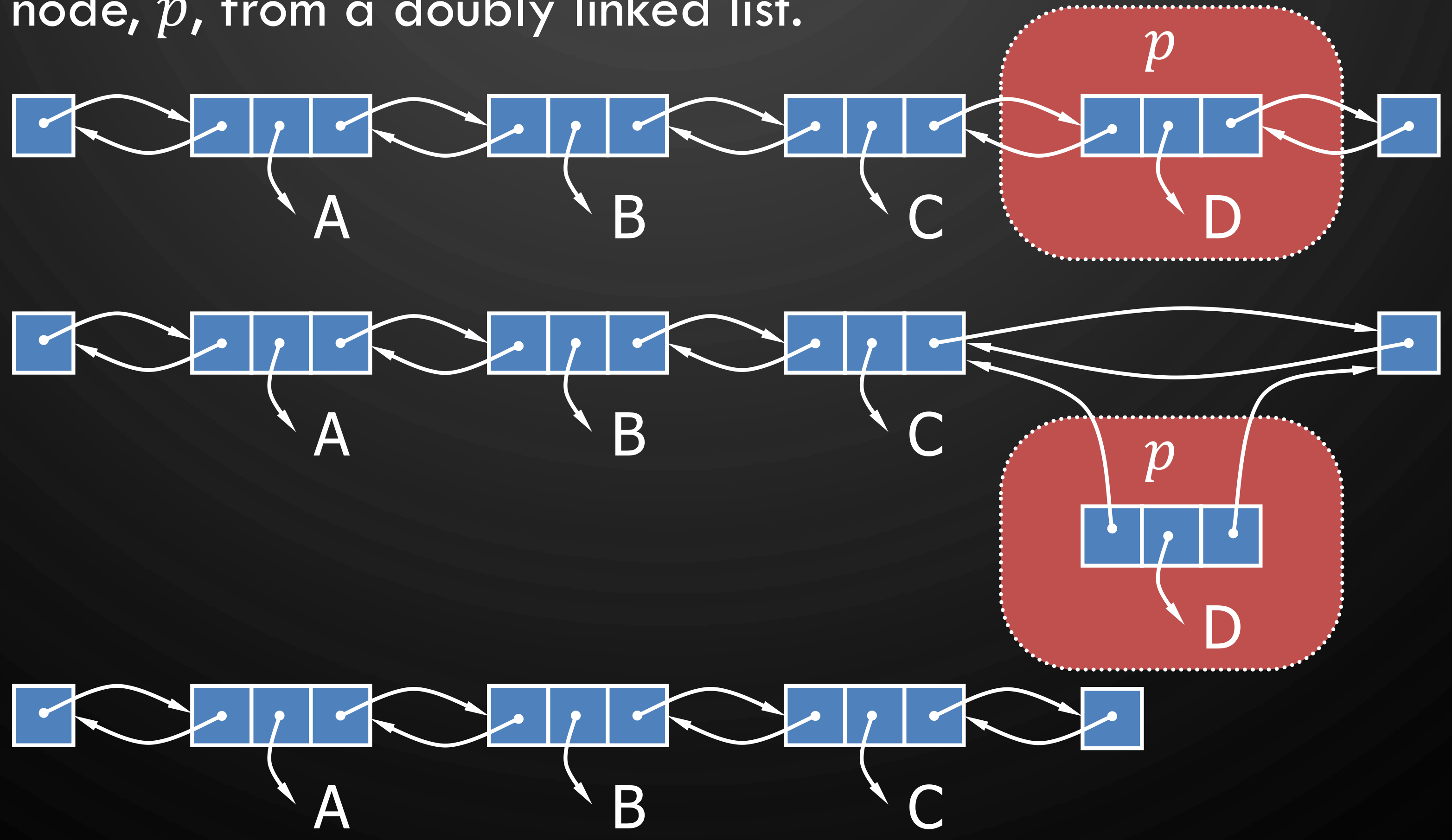
INSERTION

- Insert a new node, q, between p and its successor.



DELETION

- Remove a node, p, from a doubly linked list.



EXERCISE

- Write an algorithm for finding the middle node of a doubly linked-list
  - With access to a method `size()`
  - Without access to a method `size()`

SUMMARY

- Two major patterns of data storage
  - Consecutive memory – localized, through arrays or objects
  - Linked memory – not localized, through linked objects