Arrays & Linked Lists

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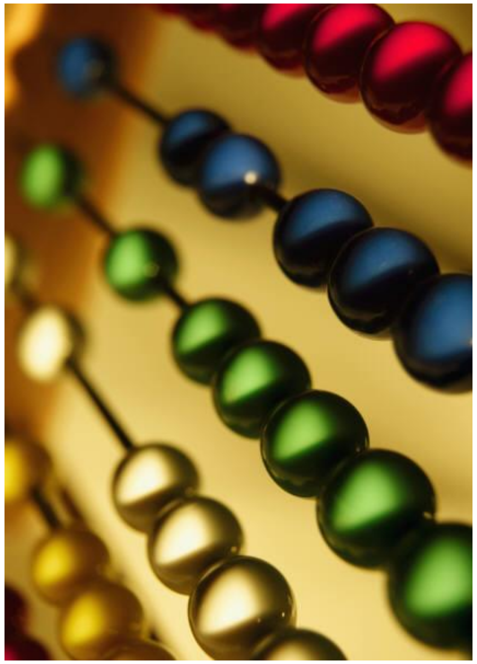
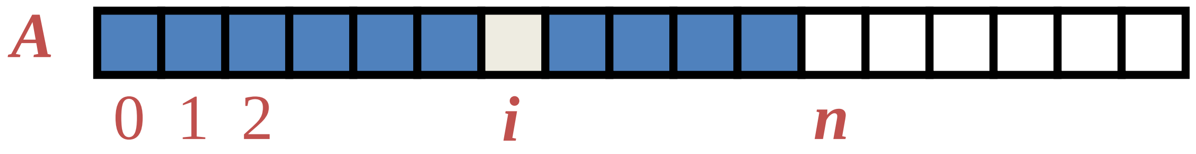
Part 1: Arrays



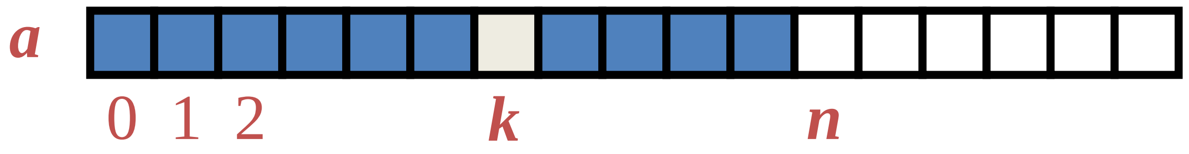
Array Definition

- 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, …, *a*.length−1, and the cell with index *k* can be accessed with syntax *a*[*k*].



Declaring Arrays (first way)

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

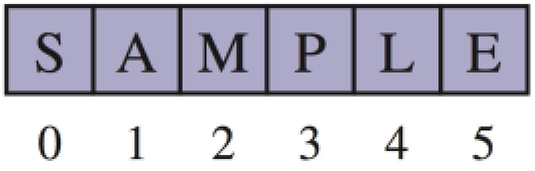
Declaring Arrays (second way)

- 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:

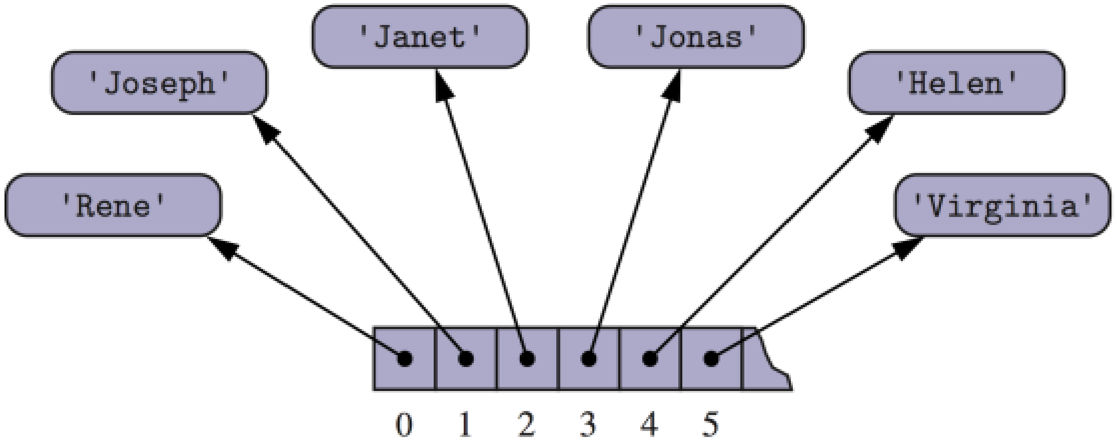
    new *elementType*[*length*]
- *length* is a positive integer denoting the length of the new array.
- The **new** operator returns a reference to the new array, and typically this would be assigned to an array variable.

Arrays of Characters or Object References

- An array can store primitive elements, such as characters.



- An array can also store references to objects.



Java Example: Game Entries

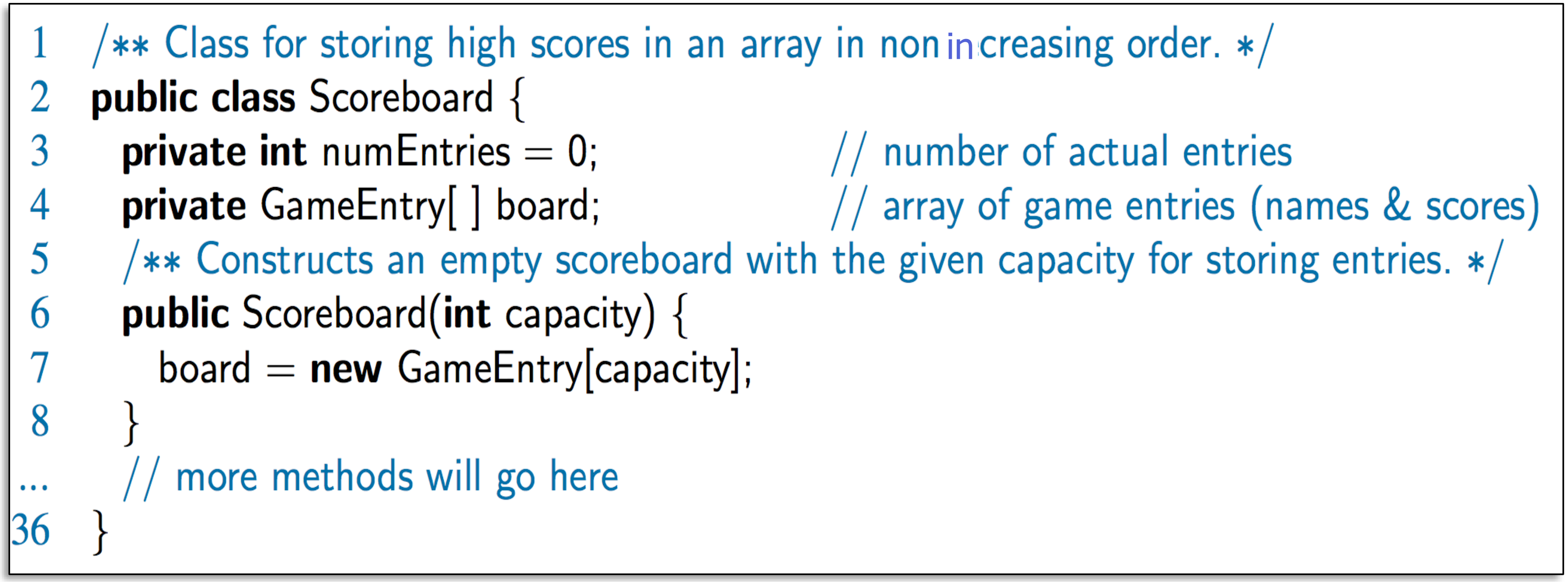
A game entry stores the name of a player and her best score so far in a game

```
public class GameEntry {
  private String name;                         // name of the person earning this score
  private int score;                           // the score value
  /** Constructs a game entry with given parameters.. */
  public GameEntry(String n, int s) {
    name = n;
    score = s;
  }
  /** Returns the name field. */
  public String getName() { return name; }
  /** Returns the score field. */
  public int getScore() { return score; }
  /** Returns a string representation of this entry. */
  public String toString() {
    return "(" + name + ", " + score + ")";
  }
}
```

Java Example: Scoreboard

Keep track of players and their best scores in an array, board

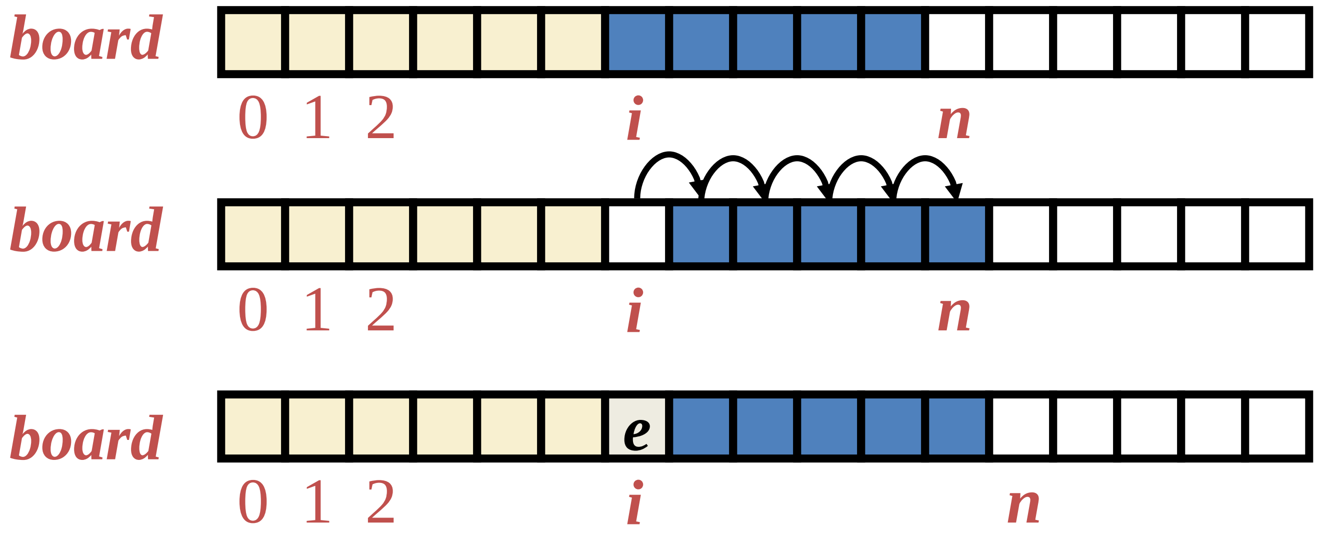
- The elements of board are objects of class GameEntry
- Array board is sorted by score



```java
/** Class for storing high scores in an array in nonincreasing order. */
public class Scoreboard {
  private int numEntries = 0;                  // number of actual entries
  private GameEntry[ ] board;                  // array of game entries (names & scores)
  /** Constructs an empty scoreboard with the given capacity for storing entries. */
  public Scoreboard(int capacity) {
    board = new GameEntry[capacity];
  }
  // more methods will go here
}
```

Adding an Entry

- To add an entry e into array board at index i, we need to make room for it by shifting forward the ***n*** - ***i*** entries ***board***[***i***], …, ***board***[***n*** – 1]

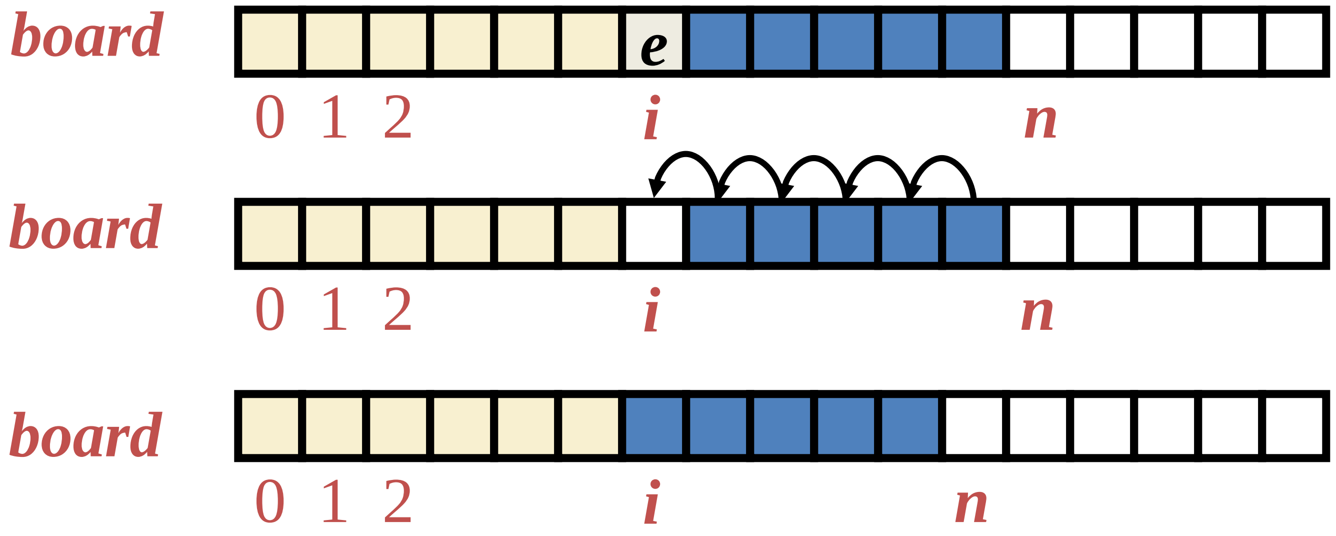


Java Example

```java
/** Attempt to add a new score to the collection (if it is high enough) */
public void add(GameEntry e) {
  int newScore = e.getScore();
  // is the new entry e really a high score?
  if (numEntries < board.length || newScore > board[numEntries−1].getScore()) {
    if (numEntries < board.length)                  // no score drops from the board
      numEntries++;                                 // so overall number increases
    // shift any lower scores rightward to make room for the new entry
    int j = numEntries − 1;
    while (j > 0 && board[j−1].getScore() < newScore) {
      board[j] = board[j−1];                        // shift entry from j-1 to j
      j−−;                                          // and decrement j
    }
    board[j] = e;                                   // when done, add new entry
  }
}
```

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 ***board***[***i*** + 1], …, ***board***[***n*** – 1]



Java Example

```
/** Remove and return the high score at index i. */
public GameEntry remove(int i) throws IndexOutOfBoundsException {
  if (i < 0 || i >= numEntries)
    throw new IndexOutOfBoundsException("Invalid index: " + i);
  GameEntry temp = board[i];                   // save the object to be removed
  for (int j = i; j < numEntries − 1; j++)     // count up from i (not down)
    board[j] = board[j+1];                     // move one cell to the left
  board[numEntries −1 ] = null;                // null out the old last score
  numEntries−−;
  return temp;                                 // return the removed object
}
```

Multidimensional arrays

- **int**[ ][ ] data = **new int** [2][3];

  data = { {6, 13, 17} , {45 , 67, 82} };

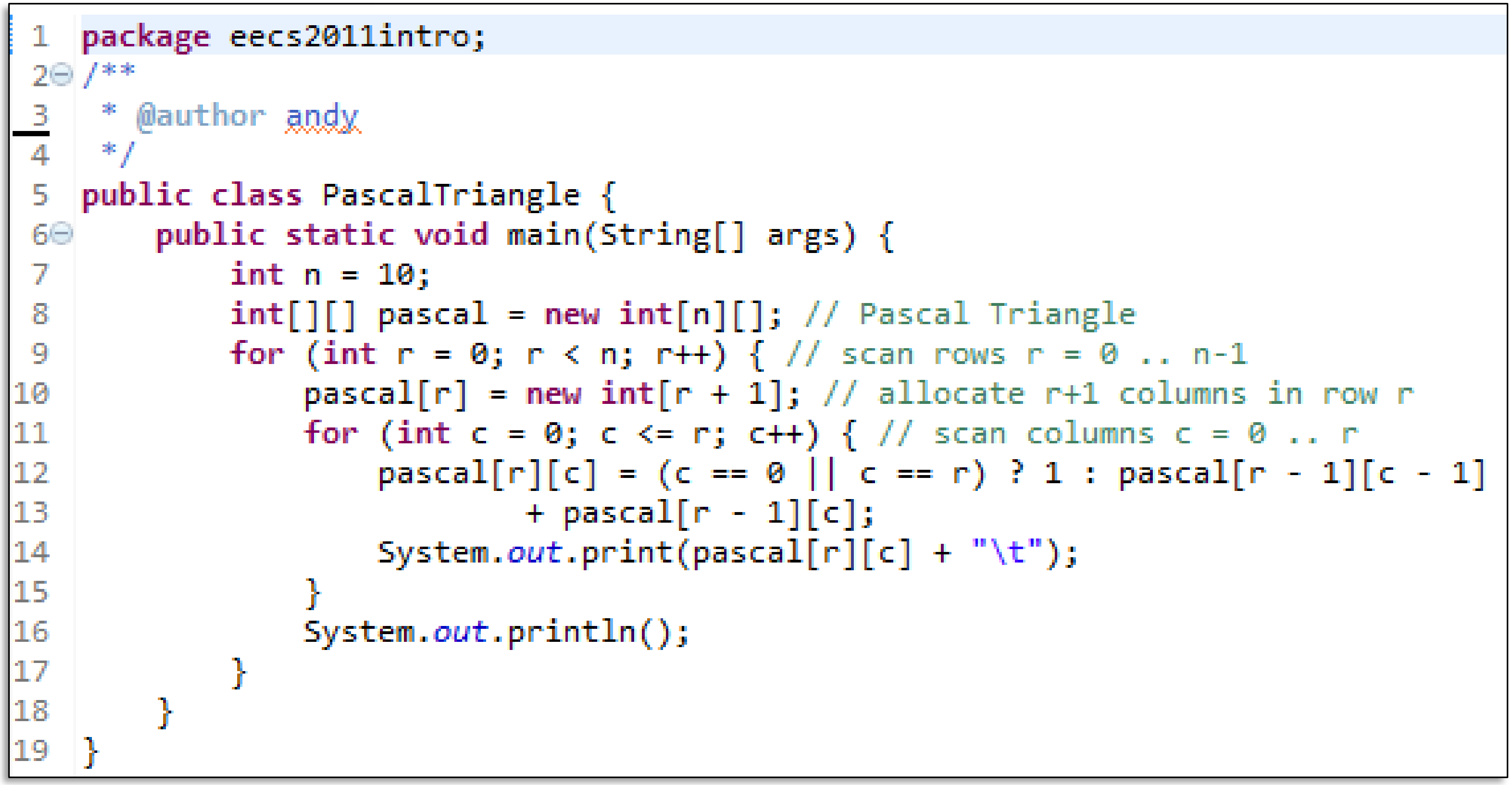
  data[0][2] = 3; // 17 replaced by 3

- String[][] irregular2DArray = {

      {“Friends:” , “Merry” , “Bob” , “Chris”},
      {“Games:” , “baseball” , “soccer”},
      {“Places:” , “Toronto” , “Boston” , “Barcelona” , “Beijing”}

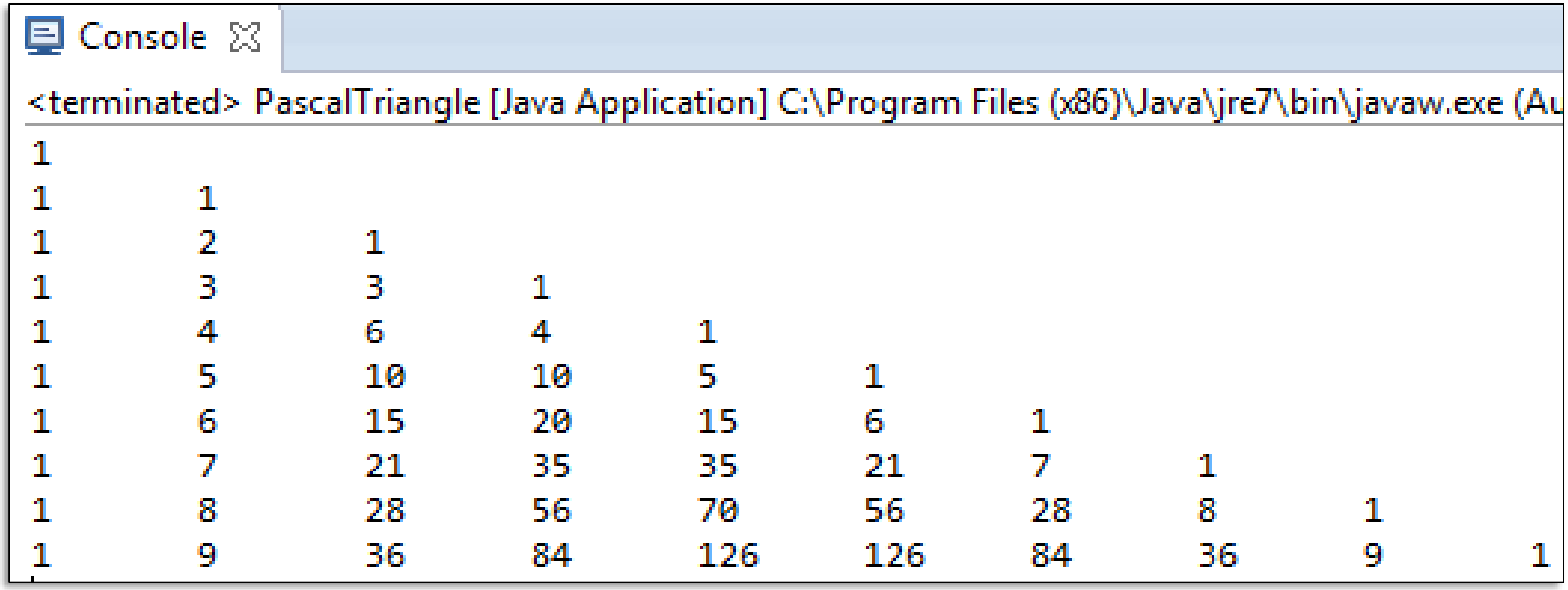
  };

Example: Pascal Triangle



```java
package eecs2011intro;
/**
 * @author andy
 */
public class PascalTriangle {
    public static void main(String[] args) {
        int n = 10;
        int[][] pascal = new int[n][]; // Pascal Triangle
        for (int r = 0; r < n; r++) { // scan rows r = 0 .. n-1
            pascal[r] = new int[r + 1]; // allocate r+1 columns in row r
            for (int c = 0; c <= r; c++) { // scan columns c = 0 .. r
                pascal[r][c] = (c == 0 || c == r) ? 1 : pascal[r - 1][c - 1]
                        + pascal[r - 1][c];
                System.out.print(pascal[r][c] + "\t");
            }
            System.out.println();
        }
    }
}
```

Example: Pascal Triangle output



Console

```
<terminated> PascalTriangle [Java Application] C:\Program Files (x86)\Java\jre7\bin\javaw.exe (Au
1
1	1
1	2	1
1	3	3	1
1	4	6	4	1
1	5	10	10	5	1
1	6	15	20	15	6	1
1	7	21	35	35	21	7	1
1	8	28	56	70	56	28	8	1
1	9	36	84	126	126	84	36	9	1
```

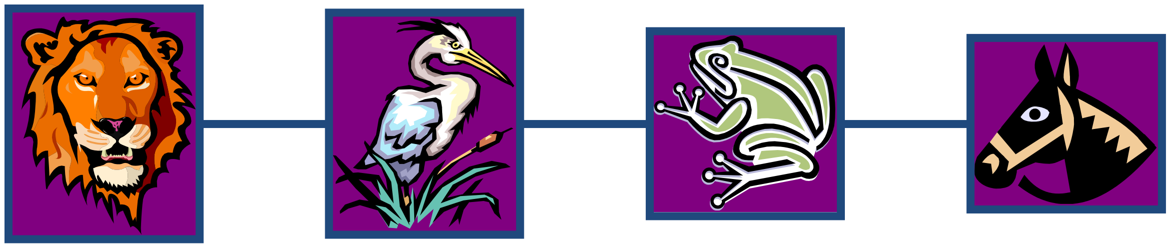
Some Built-in Methods in java.util.Arrays Class

static int	binarySearch(int[] a, int key) Searches the specified array of ints for the specified value using the binary search algorithm.
static int[]	copyOf(int[] original, int newLength) Copies the specified array, truncating or padding with zeros (if necessary) so the copy has the specified length.
static int[]	copyOfRange(int[] original, int from, int to) Copies the specified range of the specified array into a new array.
static boolean	equals(int[] a, int[] a2) Returns true if the two specified arrays of ints are *equal* to one another.
static void	sort(int[] a) Sorts the specified array into ascending numerical order.
static String	toString(int[] a) Returns a string representation of the contents of the specified array.

Part 1: Summary

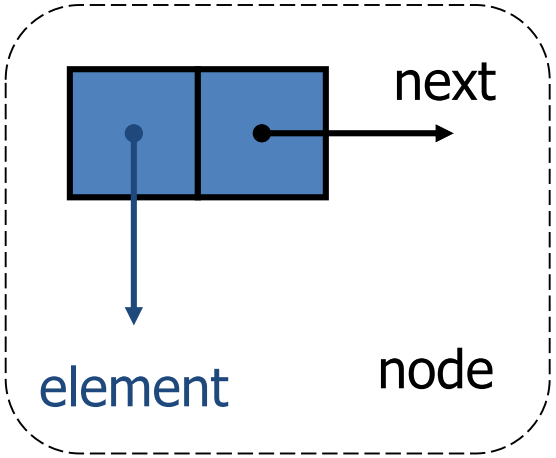
- Arrays:
  - Definition
  - Declaration
  - Element types
  - Java examples
  - Adding & removing entries
  - Multidimensional arrays
  - Built-in Methods in java.util.Arrays Class

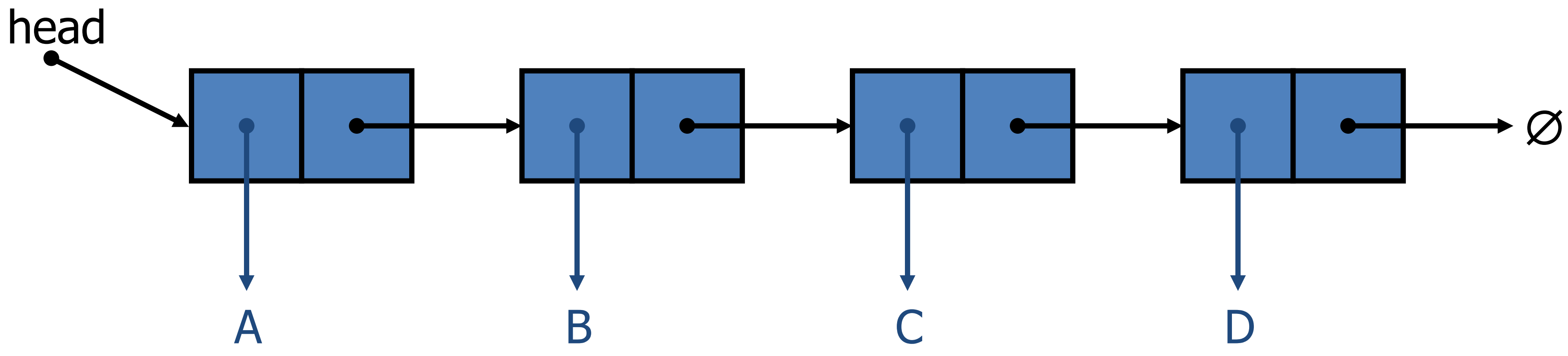
Part 2: Singly Linked Lists



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





A Nested Node Class

```
public class SinglyLinkedList<E> {
  //---------------- nested Node class ----------------
  private static class Node<E> {
    private E element;            // reference to the element stored at this node
    private Node<E> next;         // reference to the subsequent node in the list
    public Node(E e, Node<E> n) {
      element = e;
      next = n;
    }
    public E getElement( ) { return element; }
    public Node<E> getNext( ) { return next; }
    public void setNext(Node<E> n) { next = n; }
  } //----------- end of nested Node class -----------
  ... rest of SinglyLinkedList class will follow ...
```

Accessor Methods

```
public class SinglyLinkedList<E> {
  (nested Node class goes here)
  // instance variables of the SinglyLinkedList
  private Node<E> head = null;            // head node of the list (or null if empty)
  private Node<E> tail = null;            // last node of the list (or null if empty)
  private int size = 0;                   // number of nodes in the list
  public SinglyLinkedList( ) { }          // constructs an initially empty list
  // access methods
  public int size( ) { return size; }
  public boolean isEmpty( ) { return size == 0; }
  public E first( ) {                 // returns (but does not remove) the first element
    if (isEmpty( )) return null;
    return head.getElement( );
  }
  public E last( ) {                  // returns (but does not remove) the last element
    if (isEmpty( )) return null;
    return tail.getElement( );
  }
```

Inserting at the Head

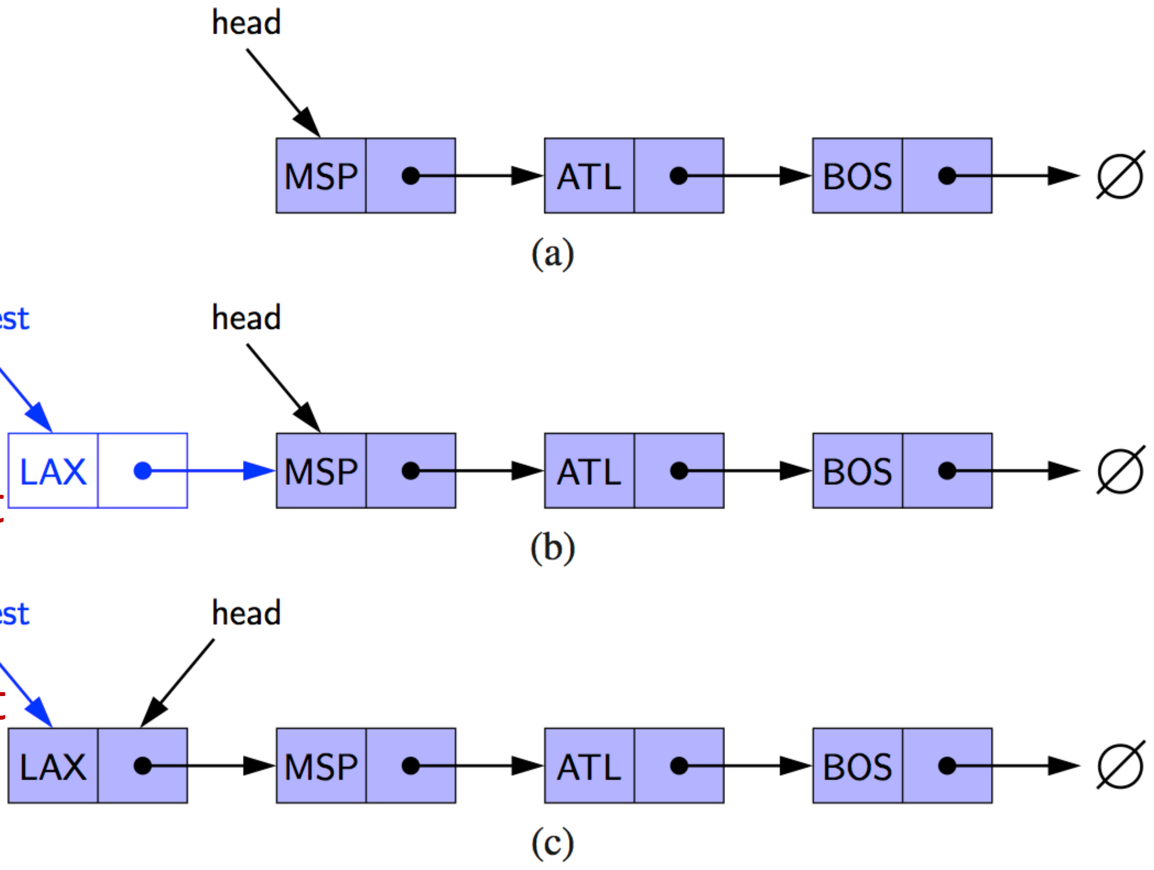
a) Current list

b) Allocate new node

Insert new element

Have new node point to old head

c) Update head to point to new node

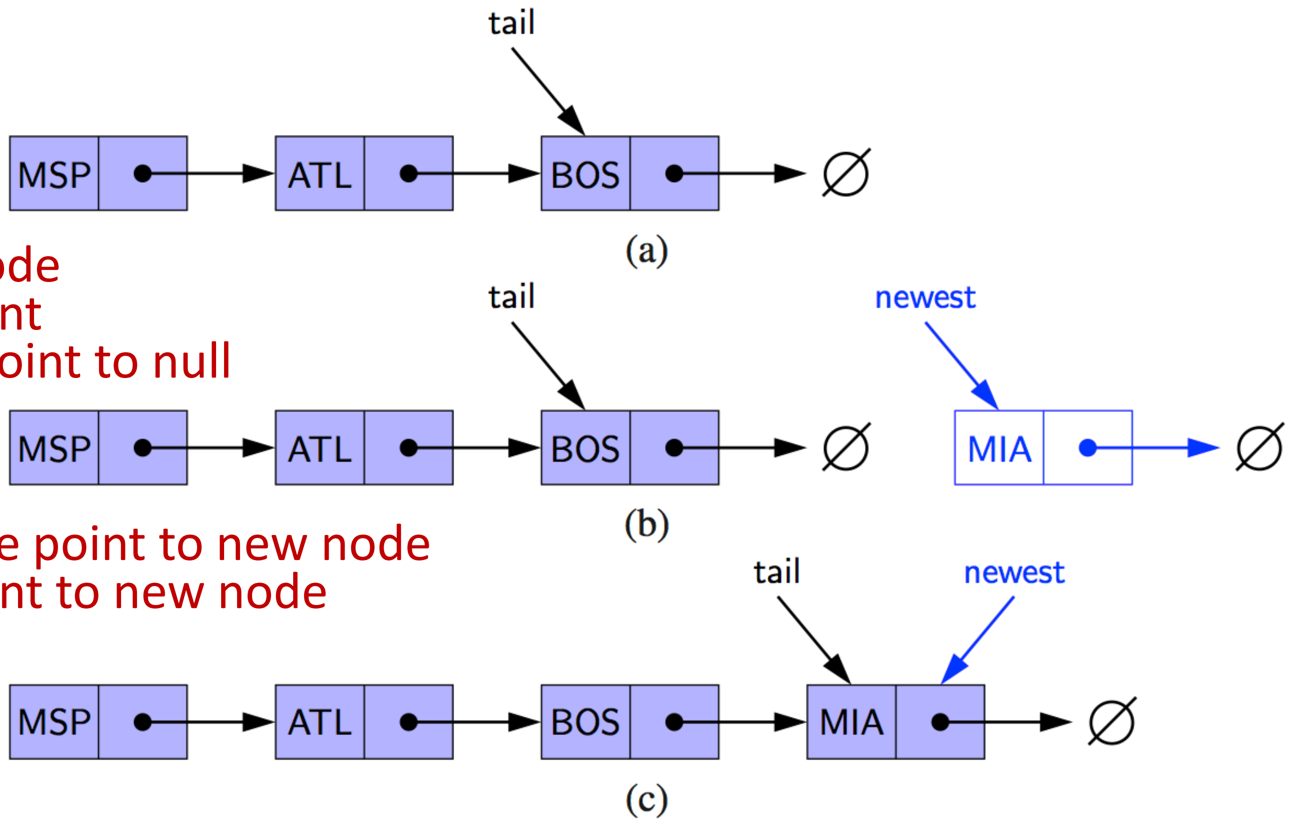


Inserting at the Tail

a) Current list

b) Allocate a new node
Insert new element
Have new node point to null

c) Have old last node point to new node
Update tail to point to new node



Java Methods

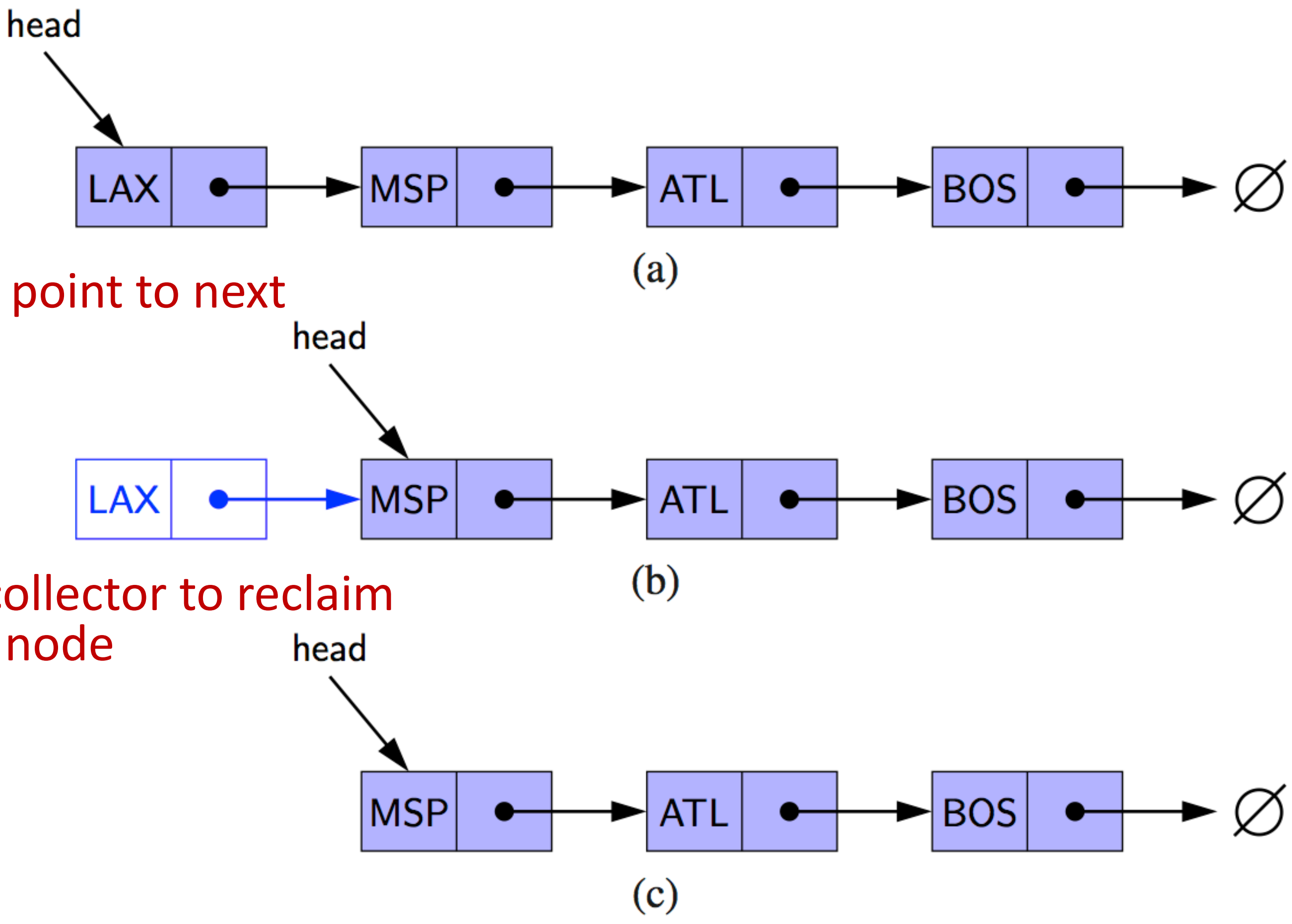
```
public void addFirst(E e) {                 // adds element e to the front of the list
  head = new Node<>(e, head);               // create and link a new node
  if (size == 0)
    tail = head;                            // special case: new node becomes tail also
  size++;
}
public void addLast(E e) {                  // adds element e to the end of the list
  Node<E> newest = new Node<>(e, null);     // node will eventually be the tail
  if (isEmpty())
    head = newest;                          // special case: previously empty list
  else
    tail.setNext(newest);                   // new node after existing tail
  tail = newest;                            // new node becomes the tail
  size++;
}
```

Removing at the Head

a) Current list

b) Update head to point to next node in the list

c) Allow garbage collector to reclaim the former first node

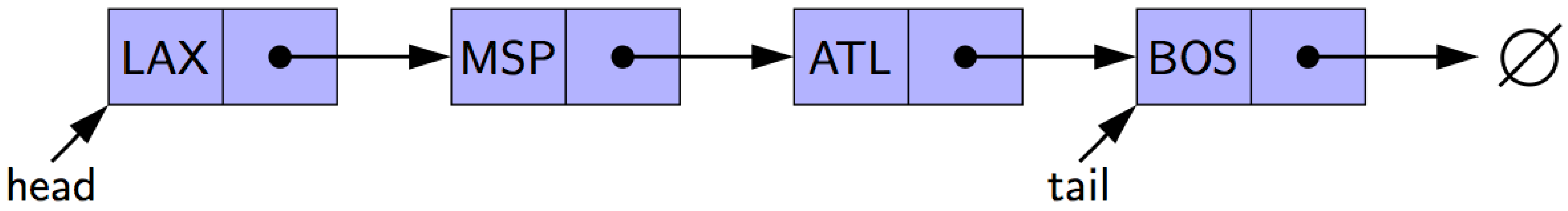


Java Method

```
  public E removeFirst() {              // removes and returns the first element
    if (isEmpty()) return null;         // nothing to remove
    E answer = head.getElement();
    head = head.getNext();              // will become null if list had only one node
    size--;
    if (size == 0)
      tail = null;                      // special case as list is now empty
    return answer;
  }
}
```

Removing at the Tail

- Removing at the tail of a singly linked list is **not efficient**!
- It’s impossible in constant-time to access the predecessor of the tail node.
- You need linear-time to scan through the list from head to tail.



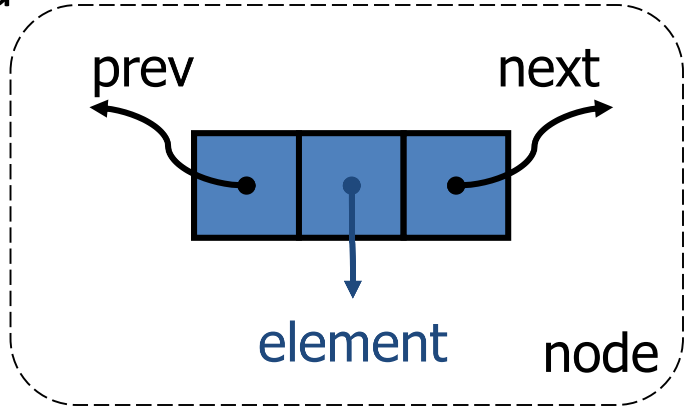
Part 2: Summary

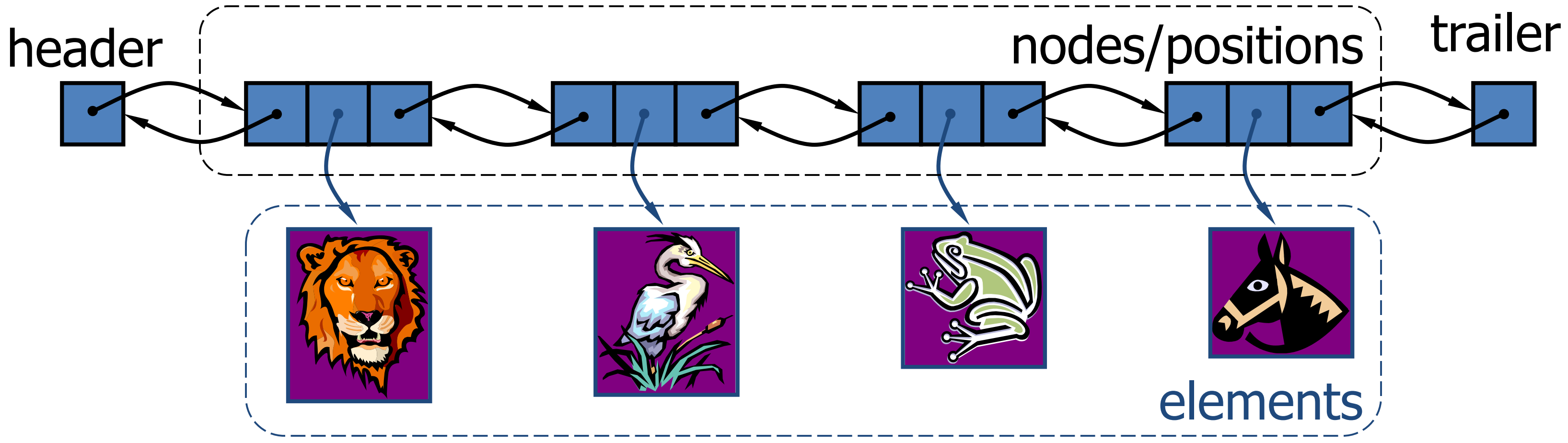
- Singly linked list structure
- A nested node class
- Accessor methods
- Insertion:
  - at the tail
  - at the head
- Removing
  - at the head
  - at the tail - inefficient

Part 3:
Doubly Linked Lists

Doubly Linked List

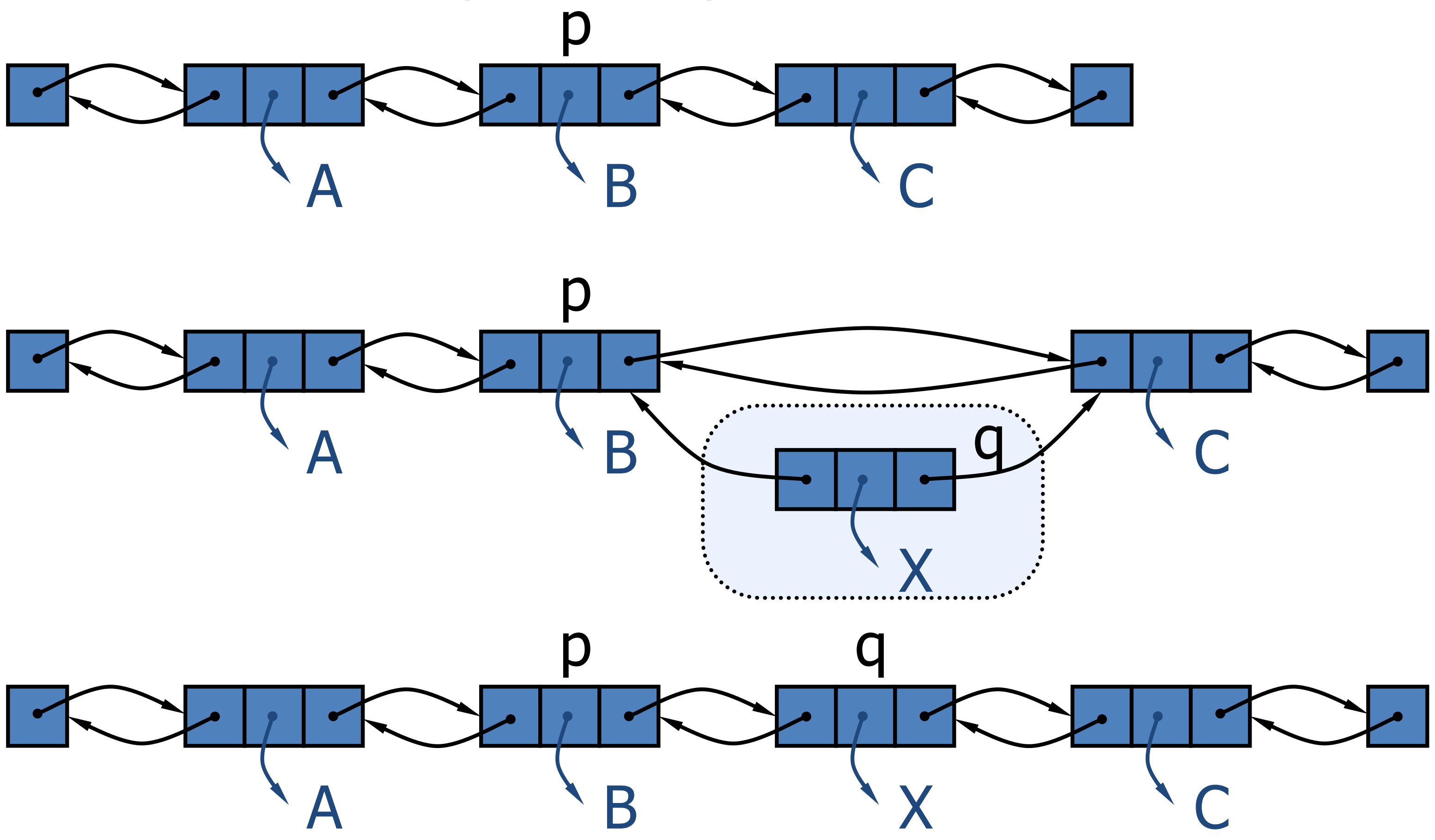
- A doubly linked list can be traversed forward and backward
- Nodes store:
  - element
  - link to the previous node
  - link to the next node
- Special trailer and header nodes





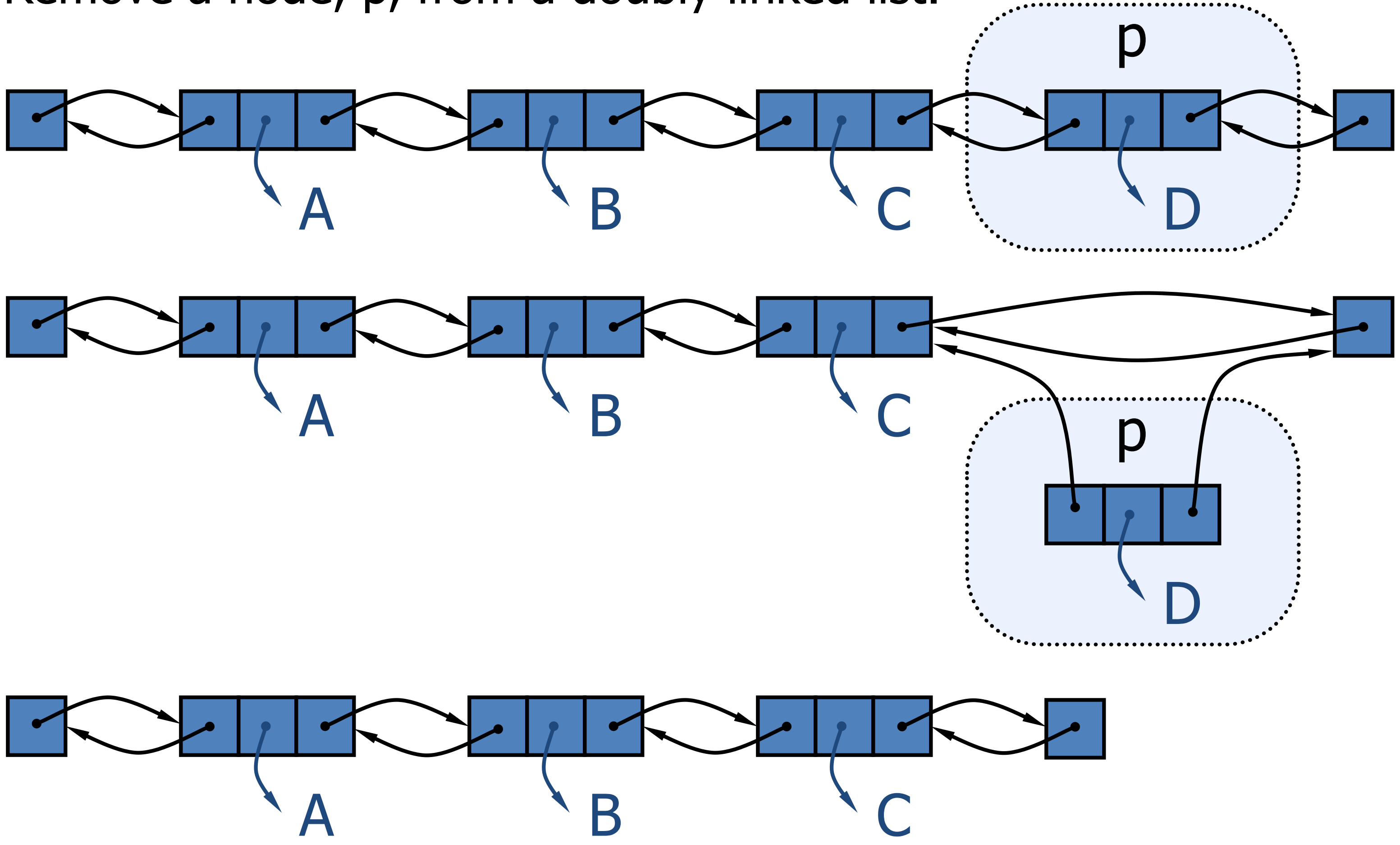
Insertion

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



Deletion

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



Doubly-Linked List in Java

```java
/** A basic doubly linked list implementation. */
public class DoublyLinkedList<E> {
  //---------------- nested Node class ----------------
  private static class Node<E> {
    private E element;               // reference to the element stored at this node
    private Node<E> prev;            // reference to the previous node in the list
    private Node<E> next;            // reference to the subsequent node in the list
    public Node(E e, Node<E> p, Node<E> n) {
      element = e;
      prev = p;
      next = n;
    }
    public E getElement() { return element; }
    public Node<E> getPrev() { return prev; }
    public Node<E> getNext() { return next; }
    public void setPrev(Node<E> p) { prev = p; }
    public void setNext(Node<E> n) { next = n; }
  } //----------- end of nested Node class -----------

```

Doubly-Linked List in Java, 2

```
    private Node<E> header;                          // header sentinel
    private Node<E> trailer;                         // trailer sentinel
    private int size = 0;                            // number of elements in the list
    /** Constructs a new empty list. */
    public DoublyLinkedList( ) {
      header = new Node<>(null, null, null);         // create header
      trailer = new Node<>(null, header, null);      // trailer is preceded by header
      header.setNext(trailer);                       // header is followed by trailer
    }
    /** Returns the number of elements in the linked list. */
    public int size( ) { return size; }
    /** Tests whether the linked list is empty. */
    public boolean isEmpty( ) { return size == 0; }
    /** Returns (but does not remove) the first element of the list. */
    public E first( ) {
      if (isEmpty( )) return null;
      return header.getNext( ).getElement( );        // first element is beyond header
    }
    /** Returns (but does not remove) the last element of the list. */
    public E last( ) {
      if (isEmpty( )) return null;
      return trailer.getPrev( ).getElement( );       // last element is before trailer
    }
```

Doubly-Linked List in Java, 3

```
// public update methods
/** Adds element e to the front of the list. */
public void addFirst(E e) {
  addBetween(e, header, header.getNext());         // place just after the header
}
/** Adds element e to the end of the list. */
public void addLast(E e) {
  addBetween(e, trailer.getPrev(), trailer);       // place just before the trailer
}
/** Removes and returns the first element of the list. */
public E removeFirst() {
  if (isEmpty()) return null;                     // nothing to remove
  return remove(header.getNext());                // first element is beyond header
}
/** Removes and returns the last element of the list. */
public E removeLast() {
  if (isEmpty()) return null;                     // nothing to remove
  return remove(trailer.getPrev());               // last element is before trailer
}
```

Doubly-Linked List in Java, 4

```
    // private update methods
    /** Adds element e to the linked list in between the given nodes. */
    private void addBetween(E e, Node<E> predecessor, Node<E> successor) {
      // create and link a new node
      Node<E> newest = new Node<>(e, predecessor, successor);
      predecessor.setNext(newest);
      successor.setPrev(newest);
      size++;
    }
    /** Removes the given node from the list and returns its element. */
    private E remove(Node<E> node) {
      Node<E> predecessor = node.getPrev( );
      Node<E> successor = node.getNext( );
      predecessor.setNext(successor);
      successor.setPrev(predecessor);
      size--;
      return node.getElement( );
    }
  } //----------- end of DoublyLinkedList class -----------
```

Circular Linked Lists

- We can form a circular linked list by identifying the header and trailer sentinel nodes.

- Varieties of Circular Linked Lists:
  - Singly Linked Circular Lists (SLCL).
  - Doubly Linked Circular Lists (DLCL).

- With DLCL it is possible to perform the following operations in constant time:
  - Inserting an item at any given position in the list.
  - Deleting an item from any given position in the list.
  - Concatenating two lists of same type (by interlacing).

Part 3: Summary

- Doubly linked list structure
- A nested node class
- Accessor methods
- Insertion at any given position
- Removal of any given node
- Singly & Doubly Linked Circular Lists