Recursive data types
Lambda expressions

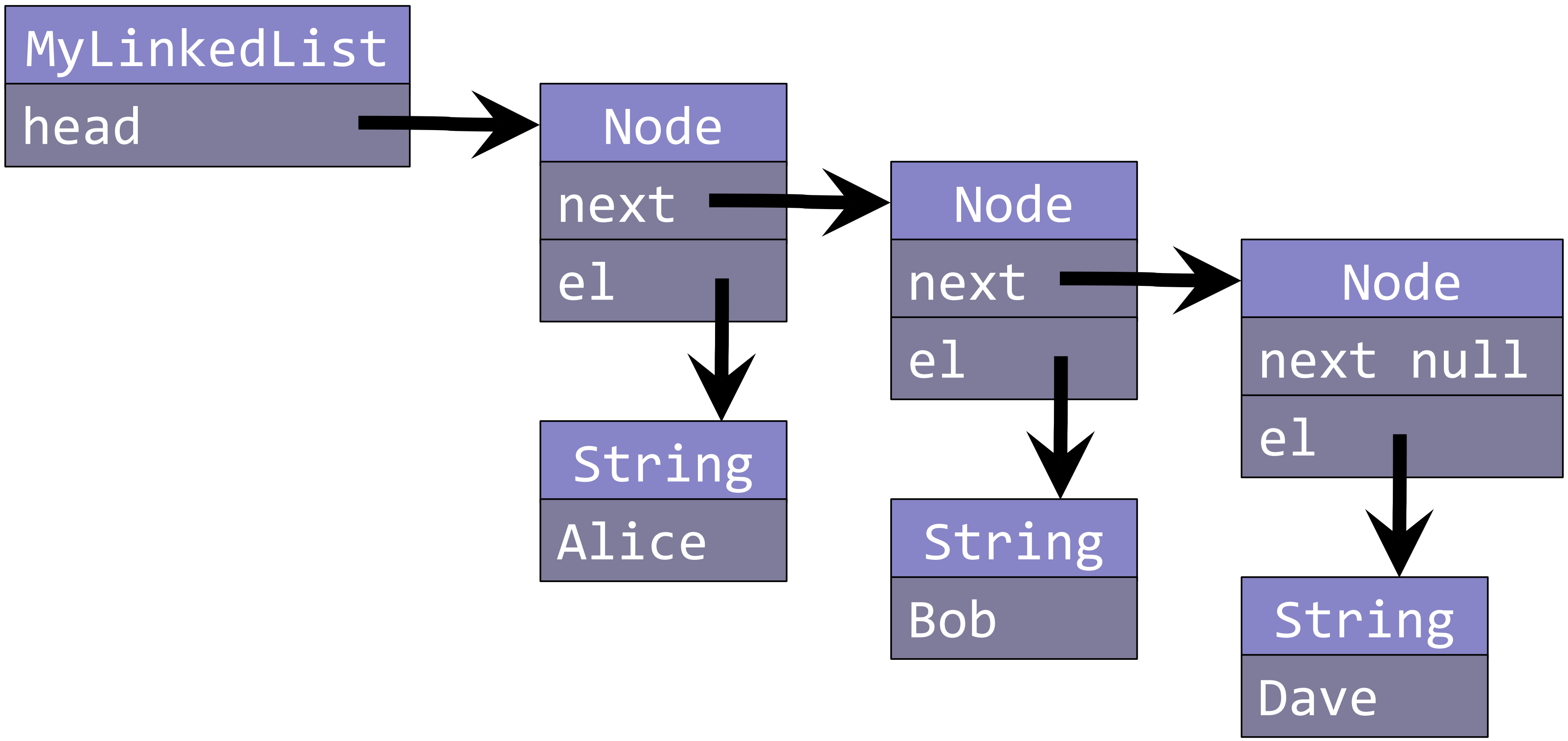
Lecture 7

Recursive data types: trees

Generic Recursive Type with multiple children per node: **Tree**

Linked List

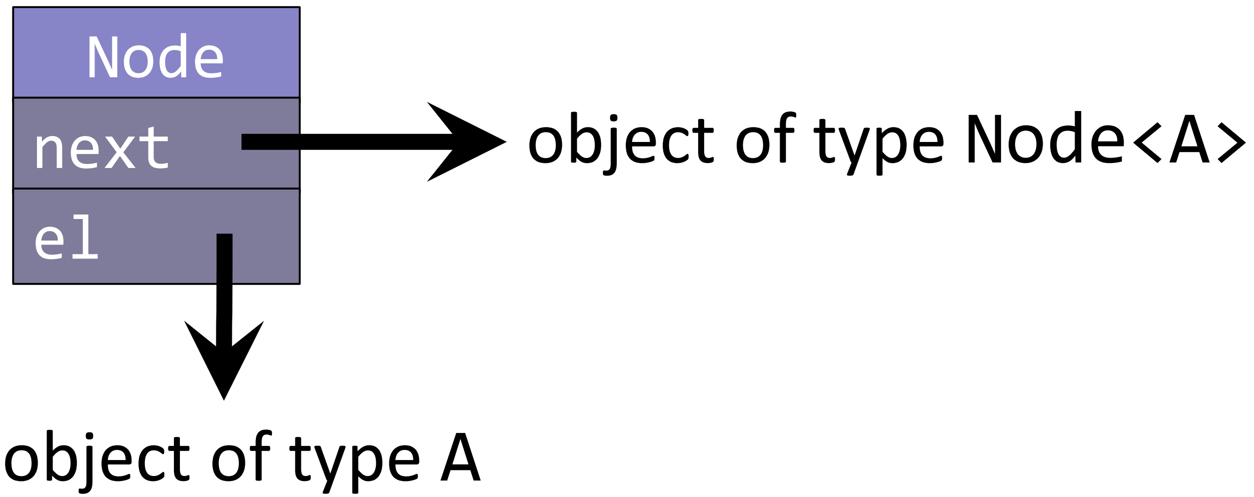
In the previous lecture we saw how we can represent the linked lists



MyLinkedList<E>: Node class

```
public class MyLinkedList<E> extends AbstractList<E> {
  ...

  private static class Node<A> {
    private A el;
    private Node<A> next;
    public Node(A e, Node<A> n) {
      el   = e;
      next = n;
    }

    public Node(A e) {
      this(e, null);
    }
  }  ...
}
```

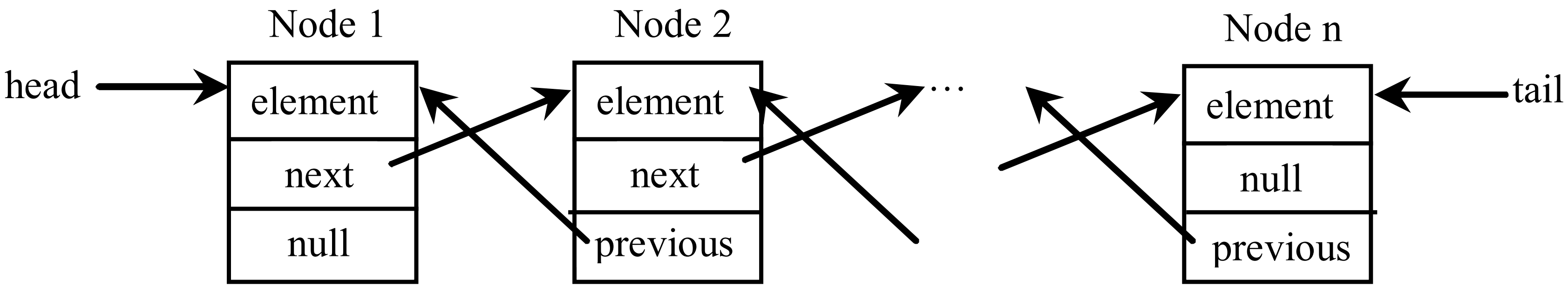
recursive datatype/class



Doubly Linked Lists

- A *doubly linked list* contains the nodes with two pointers.
  - One points to the *next* node and the other points to the *previous* node.
- A doubly linked list can be traversed forward and backward.

```
private static class Node<A> {
  private A el;
  private Node<A> next, previous;
  public Node(A e, Node<A> n, Node<A> p) {
    this.el       = e;
    this.next     = n;
    this.previous = p;
  }

}  ...
```



Trees

in the same spirit we can make nodes with two *successors* (children)

- or even 3 or *n* children

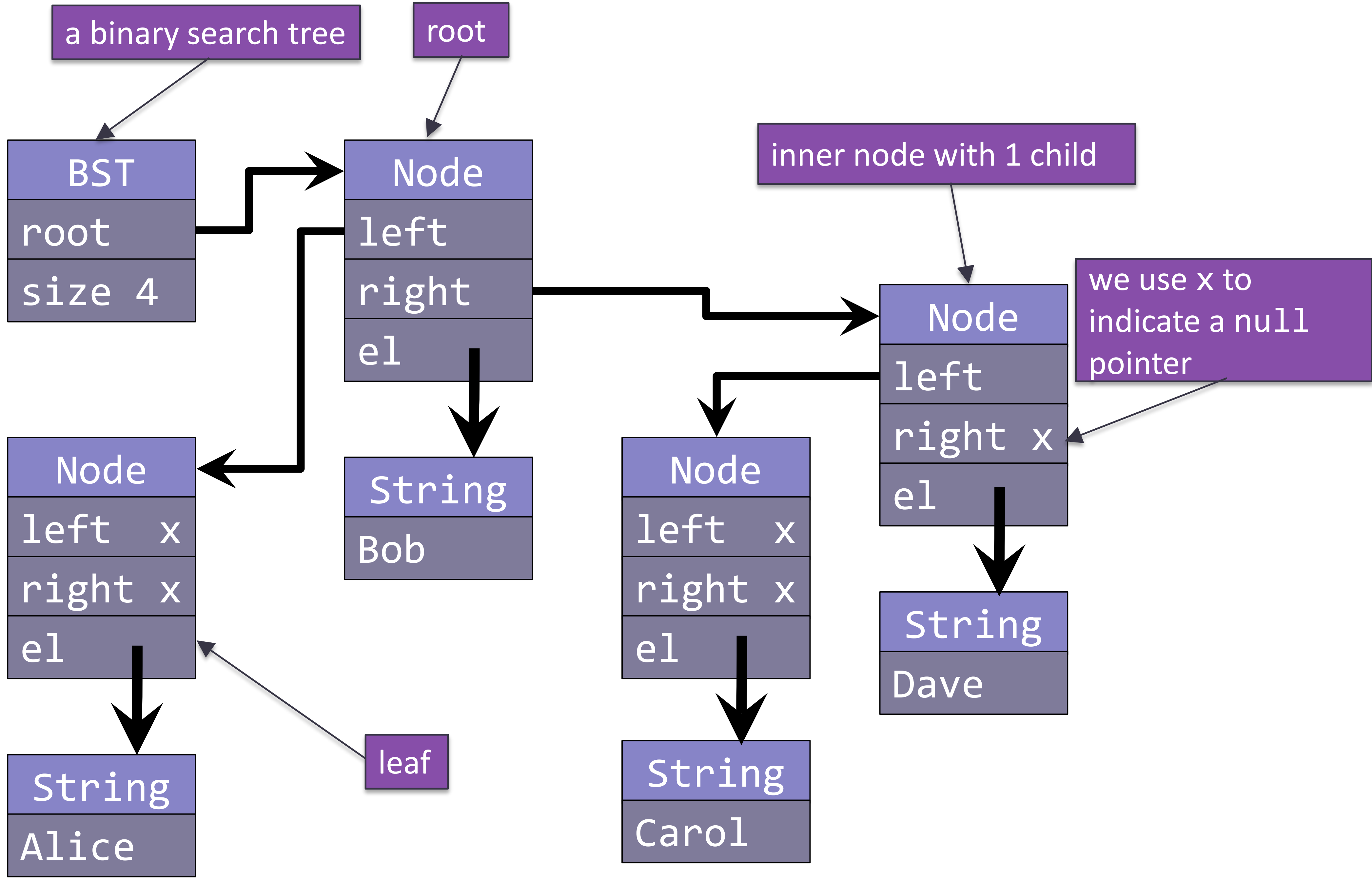
these data structures are called trees

- sometimes we use different kinds of nodes
  e.g. Leaf (no children) and Fork (with children)
- binary trees (2 children) are most common

a frequently used variant is binary search tree

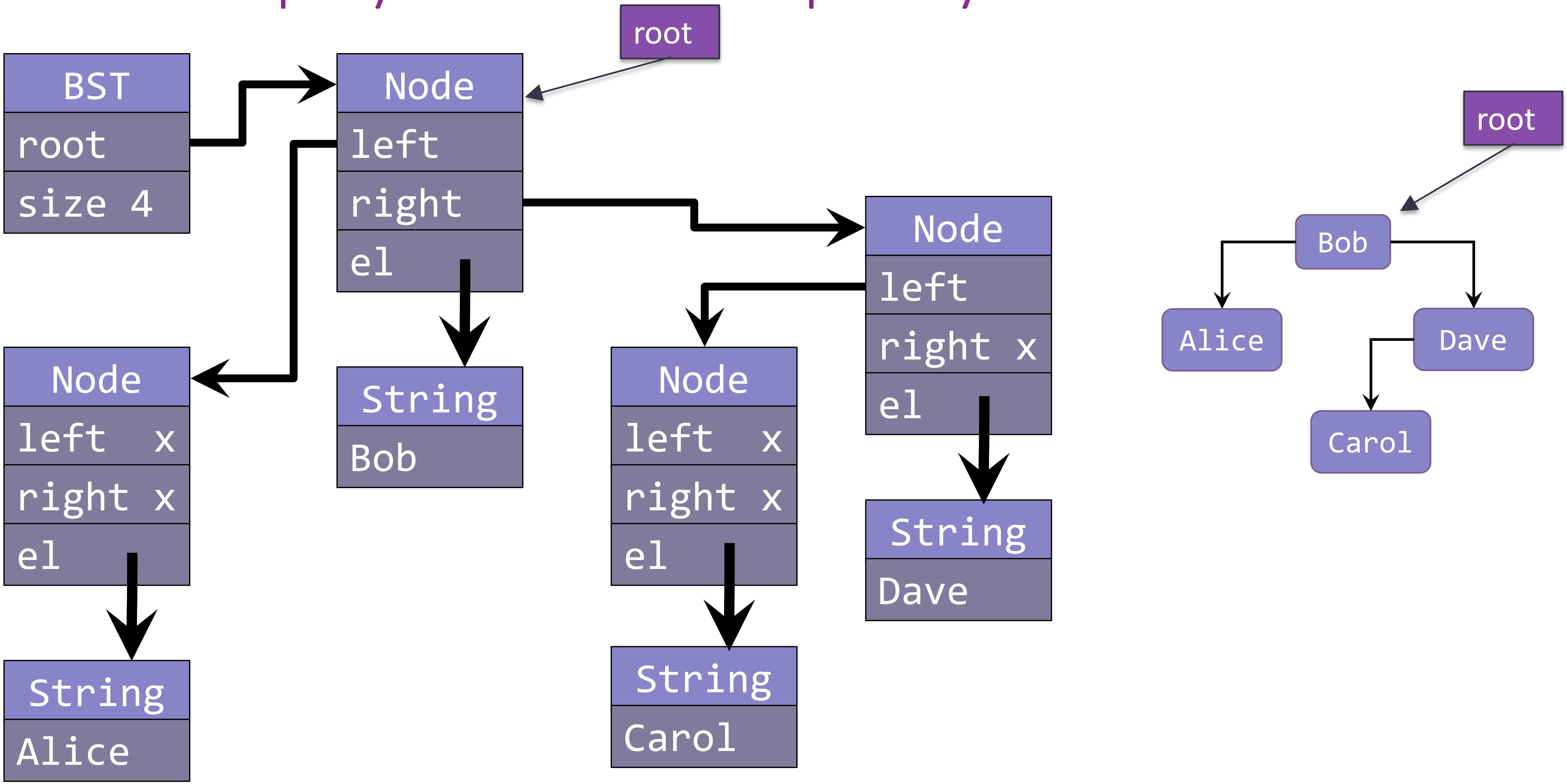
- each node has (at most) two children
- all elements in the left subtree are smaller than element in node
- all elements in right subtree are bigger

Tree



a binary search tree
root
BST
root
size 4
Node
left
right
el
inner node with 1 child
we use x to indicate a null pointer
Node
left
right x
el
Node
left x
right x
el
String
Bob
Node
left x
right x
el
String
Dave
String
Alice
leaf
String
Carol

Tree displayed more compactly



Representing Binary Trees: class **TreeNode<E>**

- A binary tree can be represented using a set of *linked nodes*.
- Each node contains a value and two links named `left` and `right` that reference the left child and right child.

```
private static class TreeNode<A> {
  private A element;
  private TreeNode<A> left, right;

  public TreeNode(A element) {
    this(element, null, null);
  }

  public TreeNode(A element, TreeNode<A> left, TreeNode<A> right) {
    this.element = element;
    this.left    = left;
    this.right   = right;
  }
}
```

Representing Binary (Search) Trees: class **BST**

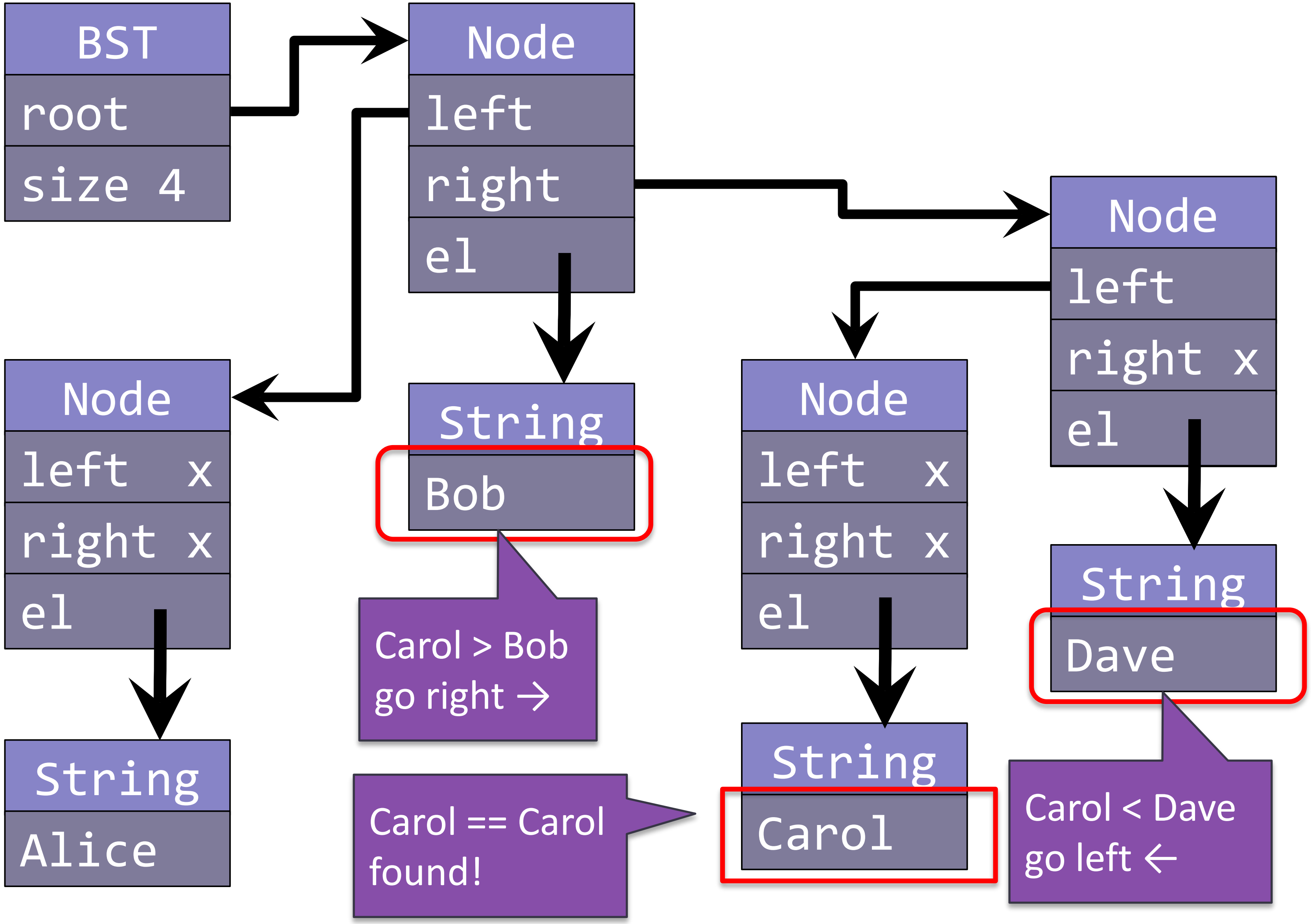
Analogous to the list implementations, we don't want to give users direct access to the tree structure itself.

- For that reason, we are introducing a wrapper class BST that hides the internal structure.

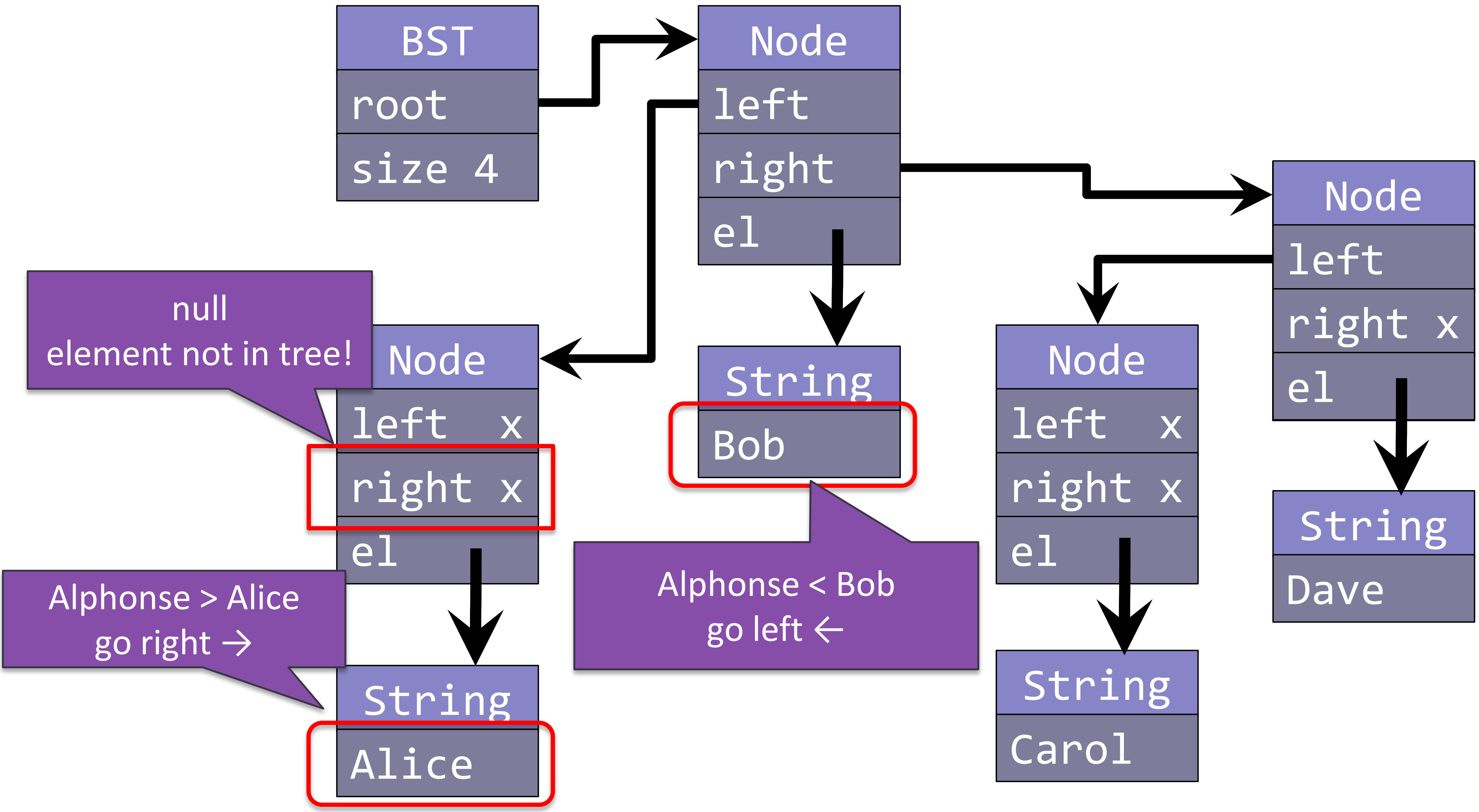
ensures comparability of elements

```
public class BST <E extends Comparable<E>> {
  private TreeNode<E> root;
  private int size;
  ...
}
```

Tree: search for Carol



Tree: search for Alphonse



Search in search tree (iteratively)

```java
public boolean search(E e) {
  TreeNode<E> current = root; // Start from the root

  while (current != null) {
    int cmp = e.compareTo(current.element);
    if (cmp < 0) {
      current = current.left;
    }
    else if (cmp > 0) {
      current = current.right;
    }
    else // element matches current.element
      return true; // Element is found
  }
  return false;
}
```

smaller: search left subtree

bigger: search right subtree

equal: found!

not present

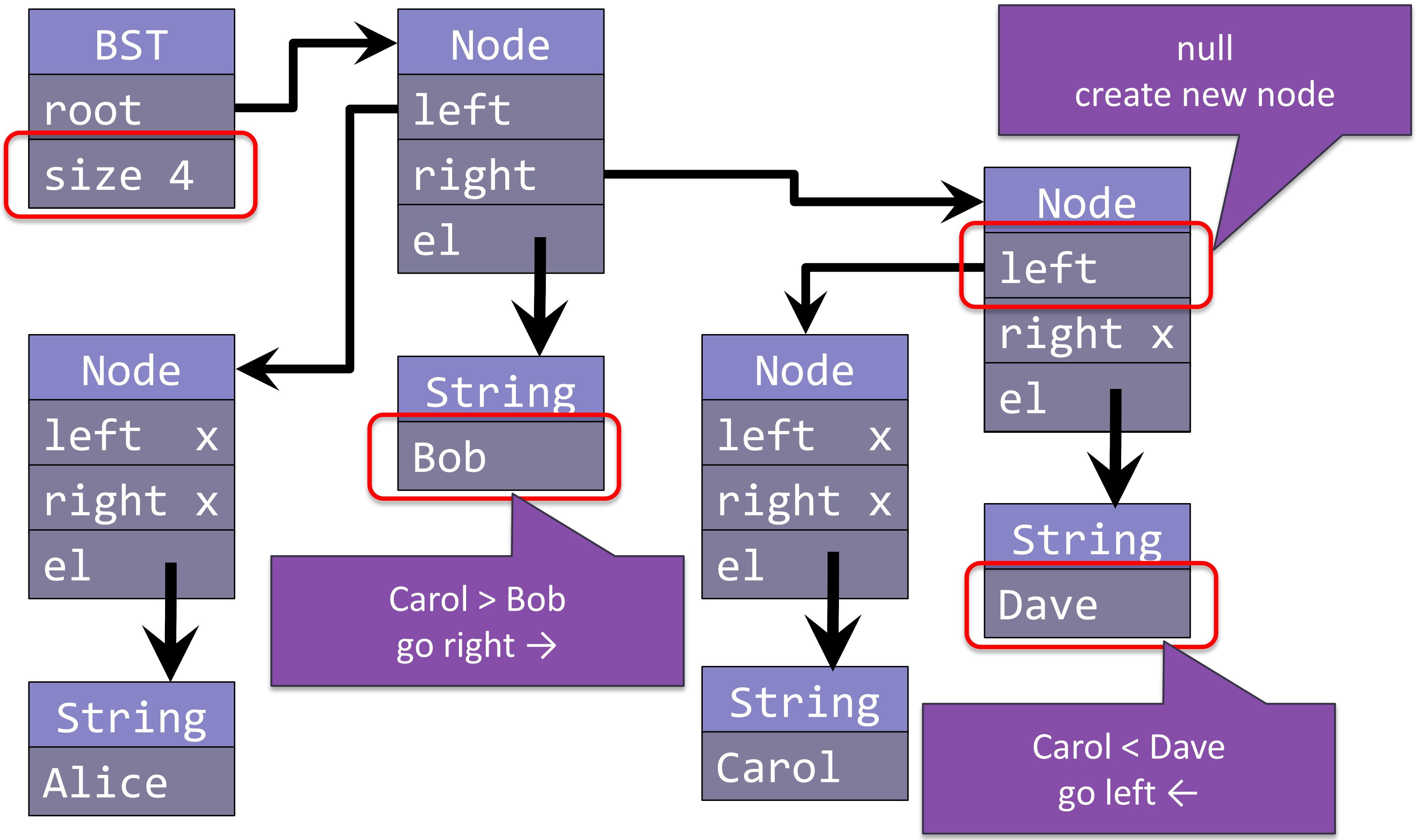
Search in search tree (recursively)

```
public boolean search(E e) {
  return search(root, e);
}

private static <E extends Comparable<E>> boolean search (TreeNode<E> n, E e) {
  if (n == null) {
    return false;
  } else {
    int comp = e.compareTo(n.element);
    if (comp < 0) {
      return search(n.left, e);
    } else if (comp > 0) {
      return search(n.right, e);
    } else { // comp == 0
      return true;
    }
  }
}
```

static recursive helper method

search is called recursively

Tree: adding Carol



Add to a search tree (iteratively)

```
public void insert(E e) {
  if ( root == null ) {
    root = new TreeNode<>(e);
    size = 1;
  } else {
    TreeNode<E> previous = null, current = root;
    while (current != null) {
      int cmp = e.compareTo(current.element);
      if (cmp < 0) {
        previous = current;
        current = current.left;
      }
      else if (cmp > 0) {
        previous = current;
        current = current.right;
      }
      else
        return;
    }
    if ( e.compareTo(previous.element) < 0 ) {
      previous.left  = new TreeNode<>(e);
    } else {
      previous.right = new TreeNode<>(e);
    }
    size++;
  }
}
```

no duplicates

Add to a search tree (recursively)

```
public void insert(E e) {
  root = insert(root, e);
}


private TreeNode<E> insert(TreeNode<E> n, E e) {
  if (n == null) {
    size++;
    return new TreeNode<>(e);
  } else {
    int comp = e.compareTo(n.element);
    if (comp < 0) {
      n.left  = insert(n.left, e);
    } else if (comp > 0) {
      n.right = insert(n.right, e);
    }
    return n;
  }
}
```

not static because the size is possibly adjusted

Converting a BST to a list (recursively)

```
public List<E> toList() {
  List<E> list = new LinkedList<>();
  toList(root, list);
  return list;
}

private static <E> void toList(TreeNode<E> n, List<E> list) {
  if (n != null) {
    toList(n.left, list);
    list.add(n.element);
    toList(n.right, list);
  }
}
```

can be static again

in-order traversal

Testing BST

```
private static void run(){
  int[] items = { 1, 5, 2, 8, 3, 12, 2 };
  BST<Integer> bst = new BST();
  for (int it: items) {
    bst.insert(it);
  }
  List<Integer> elems = bst.toList();
  System.out.println(elems);
  System.out.println(bst.getSize());
}
```

RUN

```
[1, 2, 3, 5, 8, 12]
6
```

Inner classes & lambda expressions

Inner classes & lambda expressions

One-method interfaces

- Often, an interface models just one functionality by defining a single method.
- Example

```
public interface Comparator<T> {
  public int compare(T o1, T o2);
}
```

- Creating standard implementations of these interfaces is a hassle.
- Java offers some alternatives

1. a locally defined class (in contrast to global public classes having their own file)
2. an anonymous class
3. a lambda expression

a Person record

```java
public record Person(String name, int id) implements Comparable<Person> {
  @Override
  public int compareTo(Person p) {
    return name.compareTo(p.name);
  }
}
```

```java
public interface Comparable<T> {
  public int compareTo(T o);
}
```

compare persons by their name

< 0: this < p
= 0: this equals p
> 0: this > p

- Notice the difference with

```java
public interface Comparator<T> {
  public int compare(T o1, T o2);
}
```

```java
public record Person(String name, int pnum) implements Comparator<Person>{
  @Override
  public int compare(      , Person p2) {
    return p1.name.compa eTo(p2.name);
  }
}
```

sorting a list of Persons

```
public static <T extends Comparable<? super T>> void sort(List<T> list)
```

```
public class OOlecture7 {
  public static void main(String[] args) {
    run(new Person("Alice",7), new Person("Dave",9),
        new Person("Bob",2), new Person("Carol",6));
  }

  private static void run(Person ... persons){
    List<Person> group = Arrays.asList(persons);
    Collections.sort(group);
    System.out.println(group);
  }
}
```

Java syntax for an arbitrary numbers of arguments (of the same type)

these arguments are passed as an array

uses natural ordering of persons

RUN

```
[Alice (7), Bob (2), Carol (6), Dave (9)]
```

ad-hoc sorting

```
public static <T> void sort(List<T> list, Comparator<? super T> c)
```

extra argument used by sort to compare elements

```
public class OOlecture7 {
  public static void main(String[] args) {
    run(new Person("Alice",7),new Person("Dave",9),new Person("Bob",2),new Person("Carol",6));
  }
  private static void run(Person ... persons){
    List<Person> group = Arrays.asList(persons);
    Collections.sort(group, new CompareById());
    System.out.println(group);
  }

  private static class CompareById implements Comparator<Person> {
    @Override
    public int compare(Person p1, Person p2) {
      return p1.id() - p2.id();
    }
  }
}
```

```
public interface Comparator<T> {
  public int compare(T o1, T o2);
}
```

to sort persons on id we need a Comparator object

the nested class

RUN

```
[Bob (2), Carol (6), Alice (7), Dave (9)]
```

reversed sorting

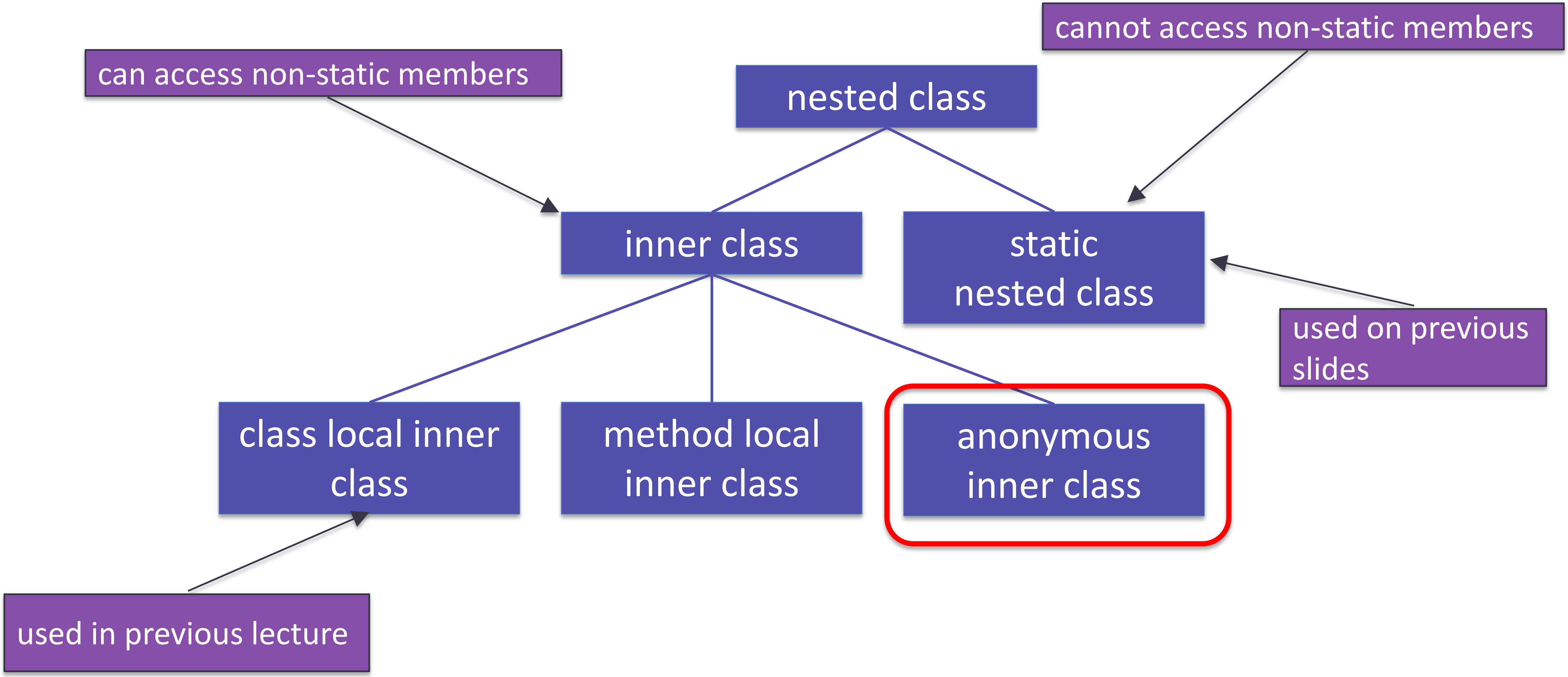
```java
public class OOlecture7 {
  public static void main(String[] args) {
    run(new Person("Alice",7),new Person("Dave",9),new Person("Bob",2),new Person("Carol",6));
  }
  private static void run(Person ... persons){
    List<Person> group = Arrays.asList(persons);
    Collections.sort(group, new CompareById().reversed());
    System.out.println(group);
  }

  private static class CompareById implements Comparator<Person> {
    @Override
    public int compare(Person p1, Person p2) {
      return p1.id() - p2.id();
    }
  }
}
```

group is now sorted in descending order

RUN

```
[Dave (9), Alice (7), Carol (6), Bob (2)]
```

kinds of nested classes in Java



ad-hoc sorting **with anonymous inner class**

class is used at one spot and it is not worthwhile giving it a name

```
public class OOlecture7 {
  public static void main(String[] args) {
   run(new Person("Alice",7),new Person("Dave",9),new Person("Bob",2),new Person("Carol",6));
  }
  private static void run(Person ... persons){
    List<Person> group = Arrays.asList(persons);
    Collections.sort(group, new Comparator<Person>() {
      @Override
      public int compare(Person p1, Person p2) {
        return p1.id() - p2.id();
      }
    });
    System.out.println(group);
  }
}
```

an interface or an (abstract) class

all methods of class or interface. Can have fields

anonymous class definition

like a constructor followed by a class body

syntax of this ***expression***:

- new operator
- name of interface or class to implement/extend
- arguments to the constructor,
  an interface has no constructor: use ()
- class declaration body: method + field definitions

useful for classes that are only needed at one place

- you make exactly one instance of this class,
  each time the expression is evaluated

anonymous classes can *capture variables*:

- access to all fields of enclosing class or (final) local variables of the enclosing method

ad-hoc sorting with lambda-expression

Alternatively, if there is a single method in an interface it is sufficient if we define only that method

```
public static void main(String[] args) {
   run(new Person("Alice",7), new Person("Dave",9),
       new Person("Bob",2), new Person("Carol",6));
}

private static void run( Person ... persons ) {
   List<Person> group = Arrays.asList(persons);
   Collections.sort(group, (p1,p2) -> p1.id() - p2.id() );
   System.out.println(group);
}
```

lambda expression

2nd arg of sort: this must be a Comparator instance

syntax of lambda expressions

- works only if we need exactly 1 method: functional interface
  - context should identify which interface is needed

1. list of parameters
   - you can omit the types of the parameters
   - if there is only 1 parameter without a type you can omit parentheses
2. the arrow token ->
3. body
   - single expression
     - does not need statement braces { and }
     - does not need the return keyword
   - statement block
     - needs statement braces { and }
     - multiple statements separated by ;

```
(x, y) -> x.compareTo(y)
```

```
p -> {
  int id = p.id();
  return id % 3 == 0;
}
```

more lambda expressions 1/3

- `filter` returns a list consisting of the elements of a given list that match the given predicate.

```
@FunctionalInterface
public interface Predicate<T> {
  boolean test(T t);
}
```

```
public static <T> List<T> filter (List<T> list, Predicate<T> p) {
  List<T> res = new LinkedList<> ();
  for (T t: list) {
    if (p.test(t)) {
      res.add(t);
    }
  }
  return res;
}
```

call to Predicate method test

more lambda expressions 2/3

```
public static void main(String[] args) {
  run(new Person("Alice",7), new Person("Dave",9),
      new Person("Bob",2), new Person("Carol",6));
}
```

```
@FunctionalInterface
public interface Predicate<T> {
  boolean test(T t);
}
```

```
private static void run( Person ... persons ) {
  List<Person> group  = Arrays.asList(persons);
  List<Person> group3 = filter(group, (Person p) -> p.id() % 3 == 0);
  System.out.println(group3);
}
```

anonymous implementation of Predicate method test

RUN

```
[Dave (9), Carol (6)]
```

more lambda expressions 2/3

```
public static void main(String[] args) {
  run(new Person("Alice",7), new Person("Dave",9),
      new Person("Bob",2), new Person("Carol",6));
}

private static void run( Person ... persons ) {
  List<Person> group  = Arrays.asList(persons);
  List<Person> group3 = filter(group, p -> { int pId = p.id();
                                             return pId > 4;
                                           }
                               );
  System.out.println(group3);
}
```

```
@FunctionalInterface
public interface Predicate<T> {
  boolean test(T t);
}
```

RUN

```
[Alice (7), Dave (9), Carol (6)]
```

more lambda expressions 3/3

lambda expressions are *expressions*

- e.g. their value can be assigned to a variable

```java
public static void main(String[] args) {
  run(new Person("Alice",7), new Person("Dave",9),
      new Person("Bob",2), new Person("Carol",6));
}
```

a variable of type Predicate<Person>

an expression of type Predicate<Person>

```java
private static void run( Person ... persons ) {
  Predicate<Person> idGT4 = (Person p) -> p.id() > 4;
  boolean idIsGT4 = idGT4.test(persons[2]);
  System.out.println(idIsGT4);
}
```

checks if the third person has an Id greater than 4

RUN

```
false
```

Lecture 8: GUI programming (`JavaFX`)