CSCI 136
Data Structures &
Advanced Programming

Lecture 18

Fall 2017

Instructor: Bills

Administrative Details

- Lab 7 today
  - No partners this week
  - Review before lab; come to lab with design doc
  - Check out the javadoc pages for the 3 provided classes
    - Token – A wrapper for semantic PS elements,
    - Reader – An iterator to produce a stream of Tokens from standard input or a List of Tokens,
    - SymbolTable – A dictionary with String keys and Token values: For user-defined names

Last Time

- Iterators Recap
- Iterating over Iterators
- Ordered Structures
  - OrderedVector

Today: Ordered Structures & Introduction to Trees

- Ordered Structures
  - OrderedVector wrap-up
  - OrderedList
- Tree-like Structures

Ordered Vectors

- We implement a new class (OrderedVector)
  - Start with Comparable elements
  - Goal: Only provide operations that keep the Vector sorted at all times
    - So, for example, no `add(int index, E item);`
- OrderedVector will implement OrderedStructure
  - An Interface extending Structure
  - Merely forces items to be Comparable

```
public interface OrderedStructure<K extends
Comparable<K>> extends Structure<K> {}
```

- Generalize to use Comparators instead of Comparables

OrderedVector Methods

```
public class OrderedVector<E extends Comparable<E>>
    implements OrderedStructure<E> {
    protected Vector<E> data;

    public OrderedVector() {
        data = new Vector<E>();
    }

    public void add(E value) {
        int pos = locate(value);
        data.add(pos, value);
    }

    protected int locate(E value) {
        //use modified binary search to find position of value
        //return position
        //uses iterative version of binary search (see text)
    }
```

OrderedVector : locate

```
protected int locate(E target){
        Comparable<E> midValue;
        int low = 0;  int high = data.size();
        int mid = (low + high)/2;

        while (low < high) {
            midValue = data.get(mid);
            if (midValue.compareTo(target) < 0)
                    low = mid+1;
            else
                    high = mid;

            mid = (low+high)/2;
        }
        return low;  // low = high so return either!
    }
```

OrderedVector Methods

```
public boolean contains(E value) {
    int pos = locate(value);
    return pos < size() && data.get(pos).equals(value);
}

public E remove (E value) {
    if (contains(value)) {
        int pos = locate(value);
        return data.remove(pos);
    }
    else return null;
}
```

Performance:

- add - O(n)
- contains - O(log n)
- remove - O(n)

Adding Flexibility with Comparators

- We would like to be able to allow ordered structures to use different orders
- Idea: Add constructor that has a Comparator parameter
- Q: How does structure know whether to use the Comparator or the Comparable ordering?
- A: The NaturalComparator class....

An Aside: Natural Comparators

- NaturalComparators bridge the gap between Comparators and Comparables

```
class NaturalComparator<E extends Comparable<E>>
implements Comparator<E> {
    public int compare(E a, E b) {
        return a.compareTo(b);
    }
}
```

- Full disclosure
  - The following is what OrderedVector *could do*
  - But it doesn't….

Generalizing OrderedVector

```
public class OrderedVector<E extends Comparable<E>>
    implements OrderedStructure<E> {
   protected Vector<E> data;
   protected Comparator<E> comp;

   public OrderedVector() {
        data = new Vector<E>();
        this.comp = new NaturalComparator<E>();
   }

   public OrderedVector(Comparator<E> comp) {
        data = new Vector<E>();
        this.comp = comp;
   }

   protected int locate(E value) {
        //use modified binary search to find position of value
        //return position
        //use comp.compare instead of compareTo
   }

   //rest stays same…
```

Generalizing OrderedVector

```
public class OrderedVector<E extends Comparable<E>>
    implements OrderedStructure<E> {
   protected Vector<E> data;
   protected Comparator<? super E> comp; // Even better!

   public OrderedVector() {
        data = new Vector<E>();
        this.comp = new NaturalComparator<E>();
   }

   public OrderedVector(Comparator<E> comp) {
        data = new Vector<E>();
        this.comp = comp;
   }

   protected int locate(E value) {
        //use modified binary search to find position of value
        //return position
        //use comp.compare instead of compareTo
   }

   //rest stays same…
```

Ordered Lists

- Similar to OrderedVector
- Can't easily use SinglyLinkedList like OrderedVector used Vector (Why?)
- So, we just build a SinglyLinkedList-like structure
- Let's look at some code…
- add, contains, remove runtime?
  - All O(n)…why?

OrderedList Methods

```
public class OrderedList<E extends Comparable<E>>
    extends AbstractStructure<E> implements
OrderedStructure<E> {

    protected Node<E> data; // smallest value
    protected int count;    // size of list
    protected Comparator<? super E> ordering;

    public OrderedList() {
        this(new NaturalComparator<E>());
    }
    public OrderedList(Comparator<? super E> ordering){
        this.ordering = ordering;
        clear();
    }
```

OrderedList Methods

```
public void clear() {
      data = null;
      count = 0;
}
public boolean contains(E value) {
   Node<E> finger = data; // target

   while ((finger != null) &&
      ordering.compare(finger.value(),value)<0)

      finger = finger.next();

  return finger!=null && value.equals(finger.value());
}
```

Type Safety & Generic Types

- Question: Since String extends Object, does List<String> extend List<Object>?
  - I.e., can I say List<Object> l = new List<String>()?
- No. It would compromise the type system:

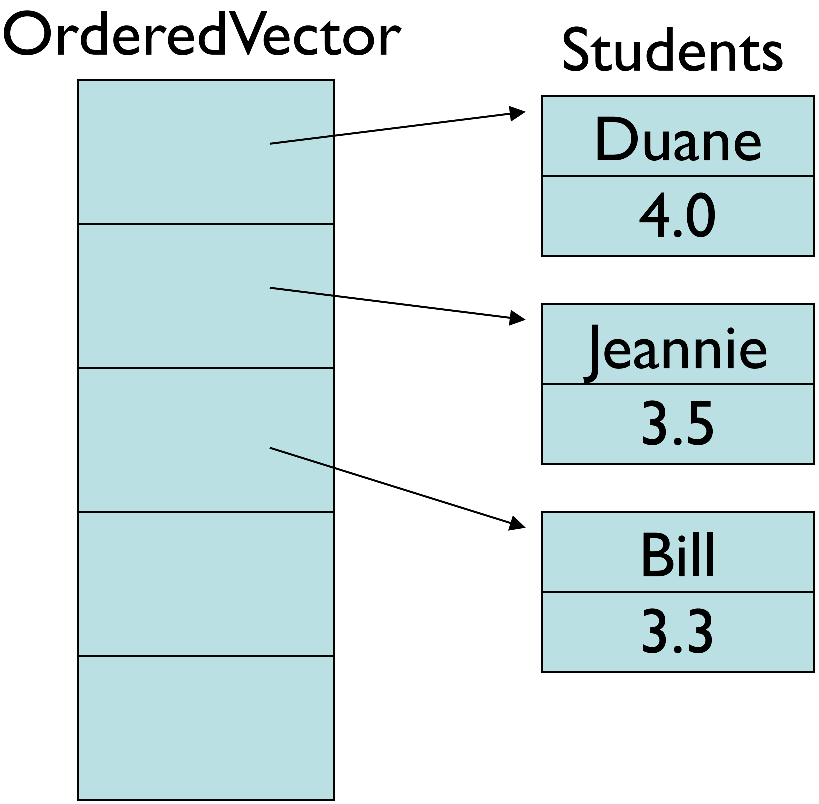
```
List<String> slist = new List<String>();
List<Object> olist = slist;     // If this were possible
olist.add(new Object());        // This would be bad!
```

- It generates a compiler error.
- On the other hand…

```
String[] sa = {“I”, “love”, “java”, “!”};
Object[] oa = sa;
oa[1] = new Object()); // This would be bad!
```

- …actually compiles
  - But causes a run-time error!

What Could Go Wrong?



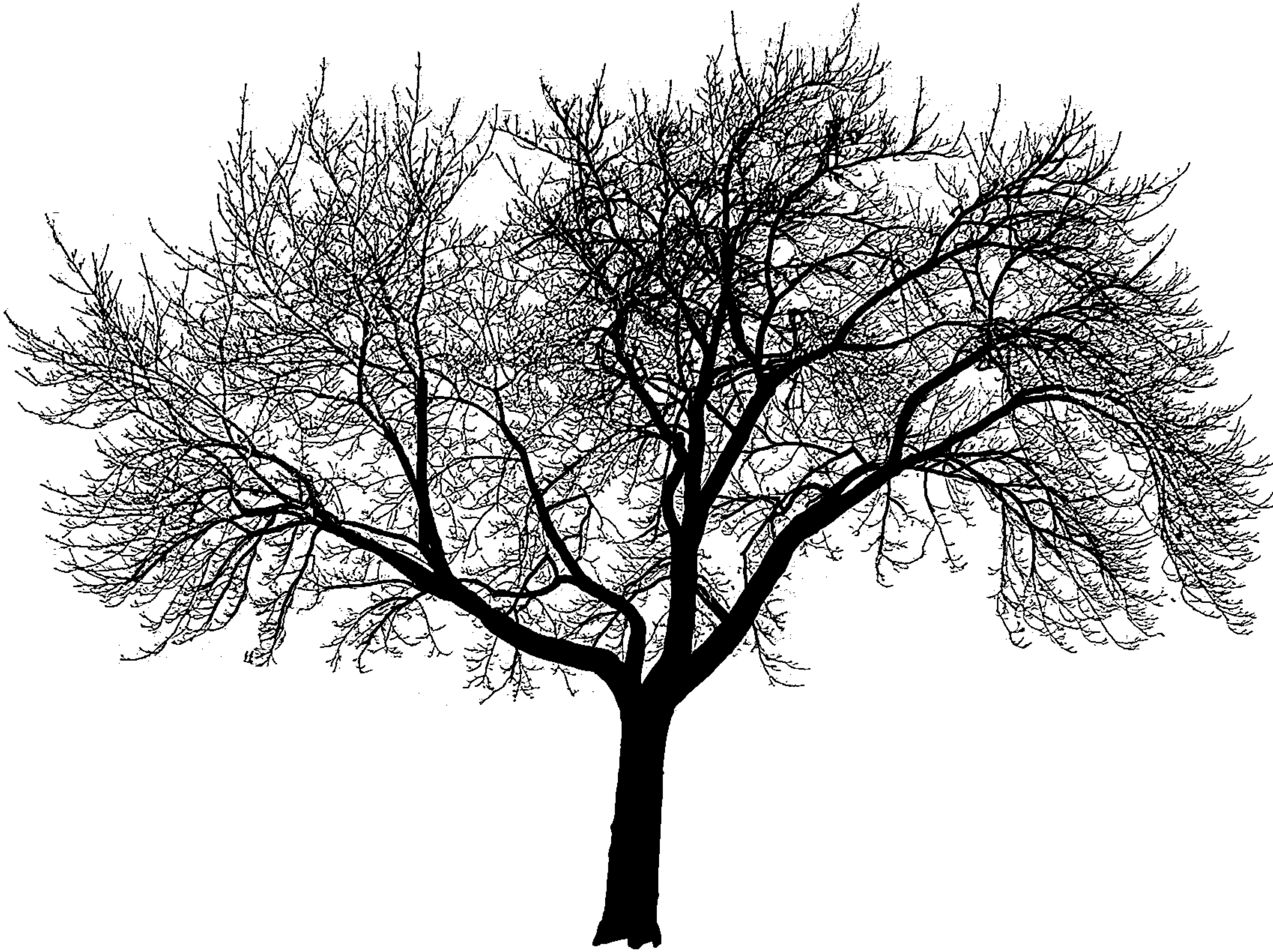
- Students compared to each other by GPA
- Suppose next semester I get a 3.7 and Jeannie gets a 3.3

What's the problem?

- We have to recompute GPAs each semester
- What happens if the values are allowed to change?
- We may need to resort vector
  - But since this isn't part of the interface, it may be forgotten
- Options:
  - Avoid changing values in OrderedStructures
  - Incorporate an update method that repositions element
  - Incorporate a resort method
    - This invites adding a "setComparator" method....
  - No perfect solution

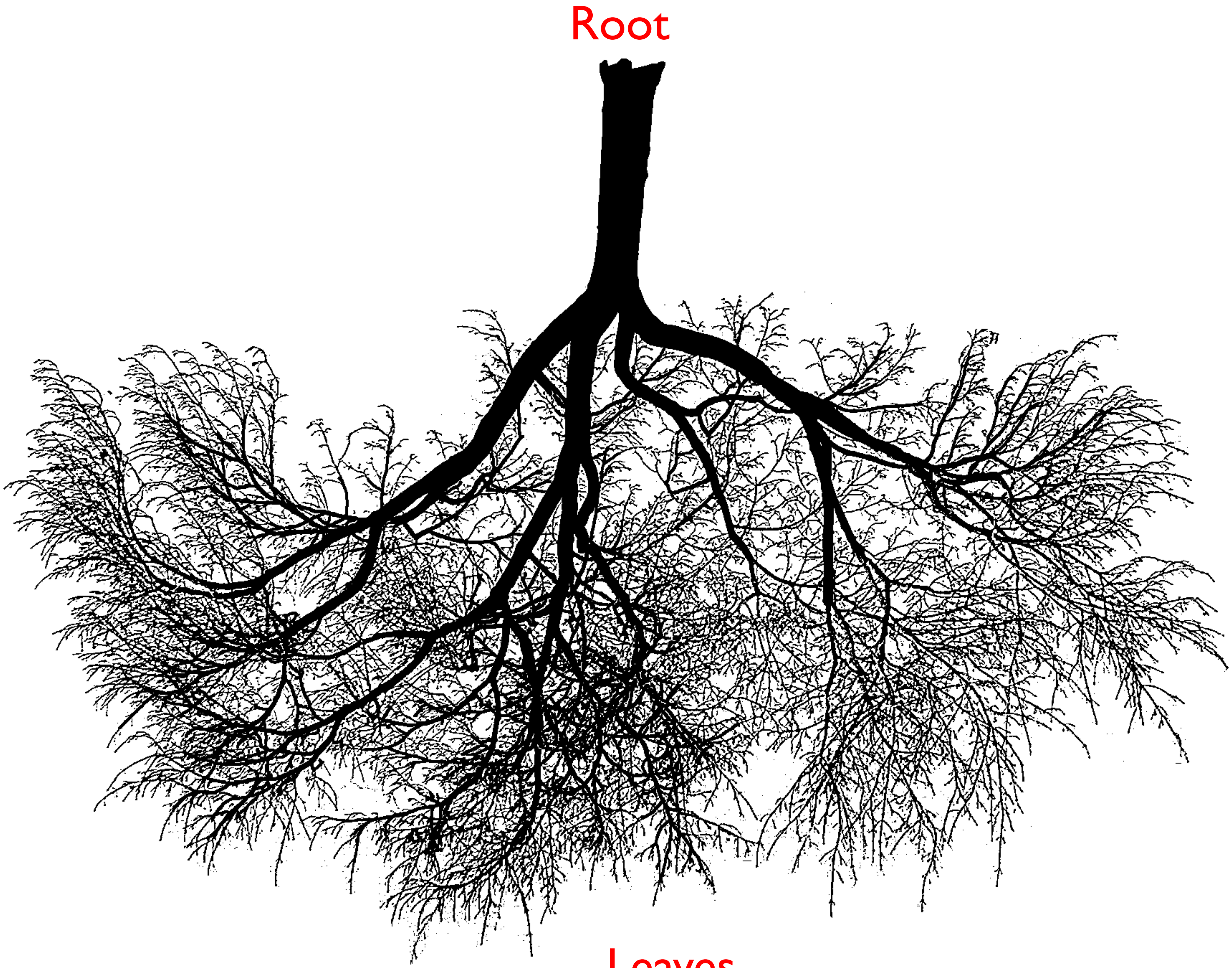
Introducing Trees

- Our structures have had a linear organization
  - Stacks, queues
  - Even ordered vectors, ordered lists, arrays, vectors, lists are visualized linearly
- By linear we essentially mean that each element has at most one successor and at most one predecessor…

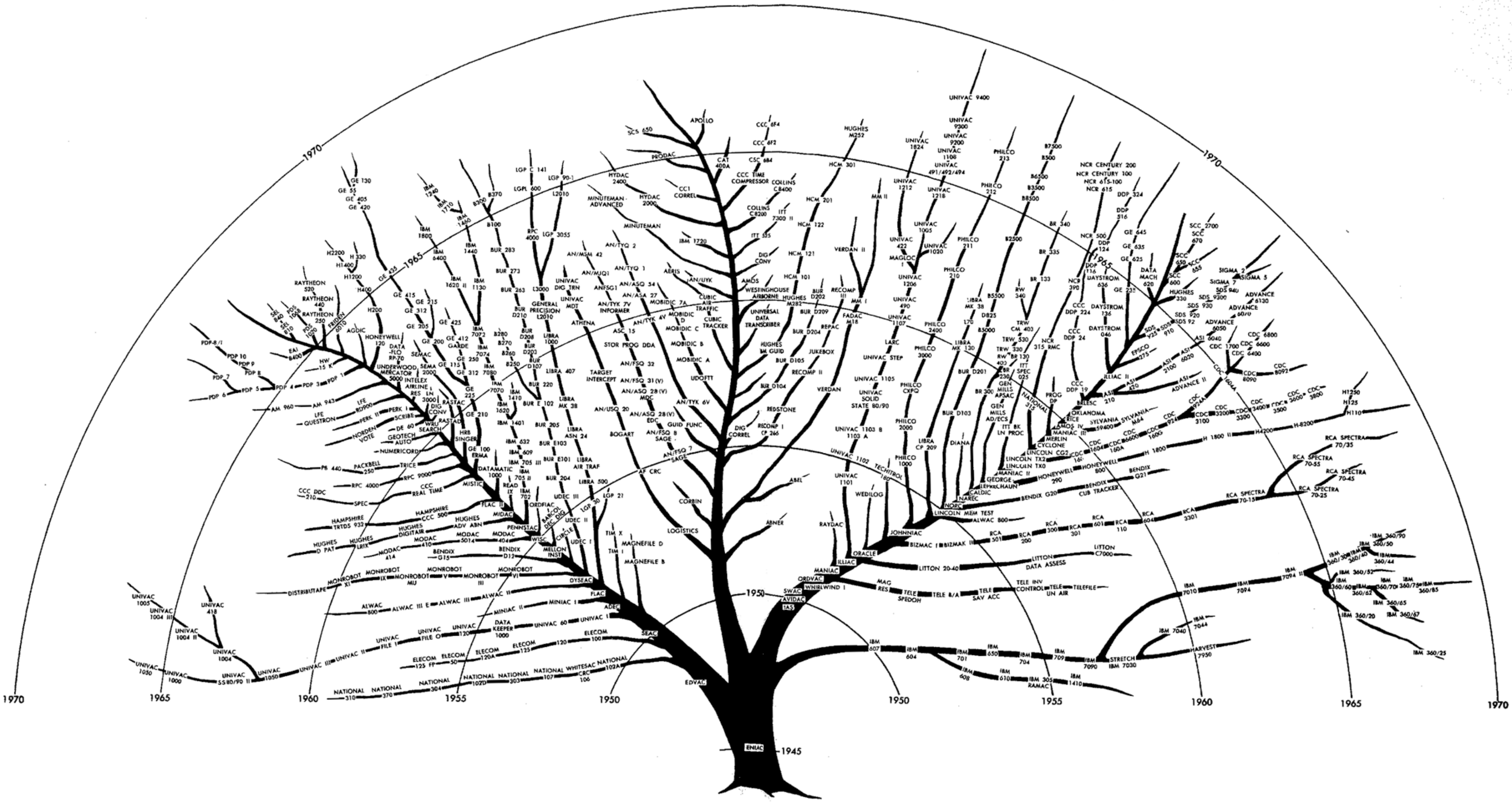


Branching Out: Trees

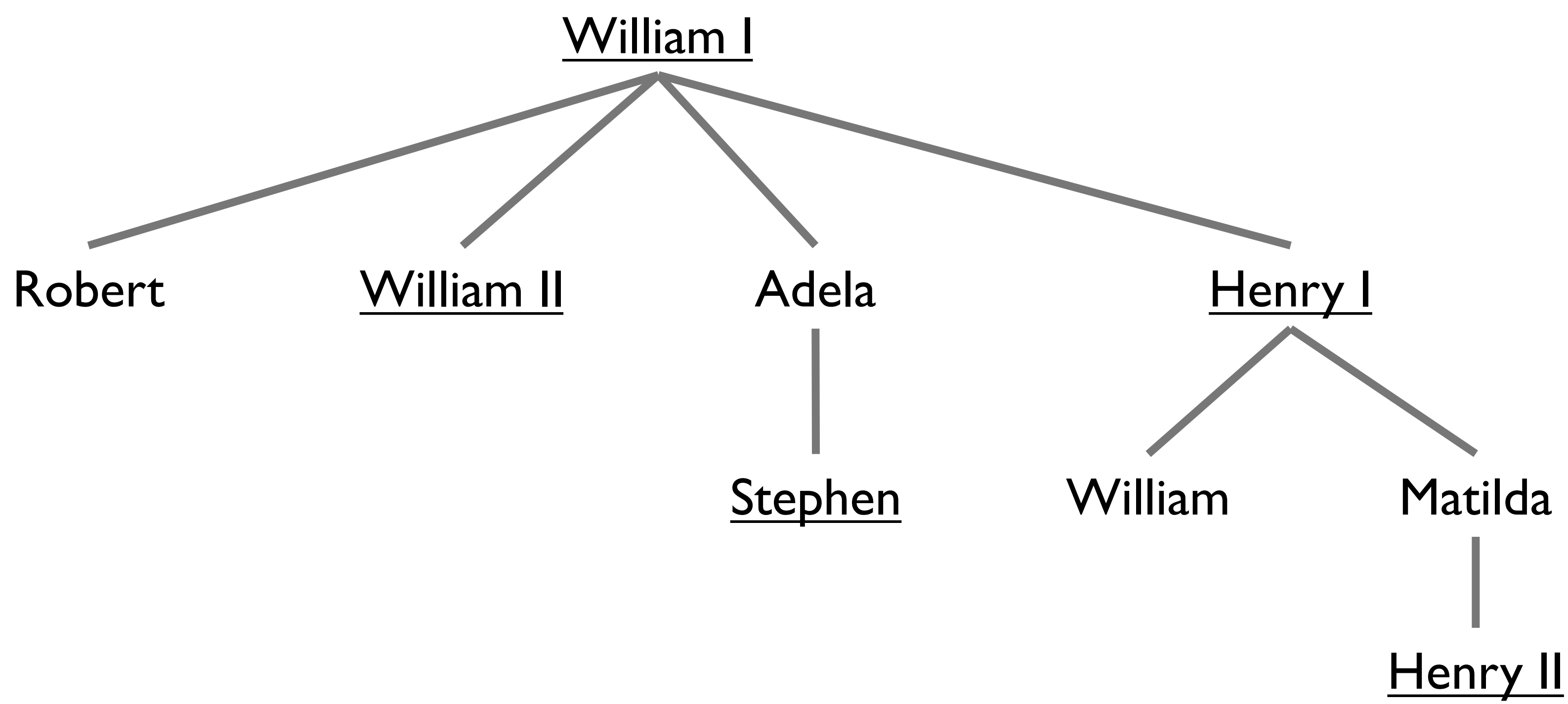
- A tree is a data structure where elements can have multiple successors (called children)
- But still only one predecessor (called parent)


Root
Leaves

“Computer Tree”



House of Normandy, Battle of Hastings, 1066

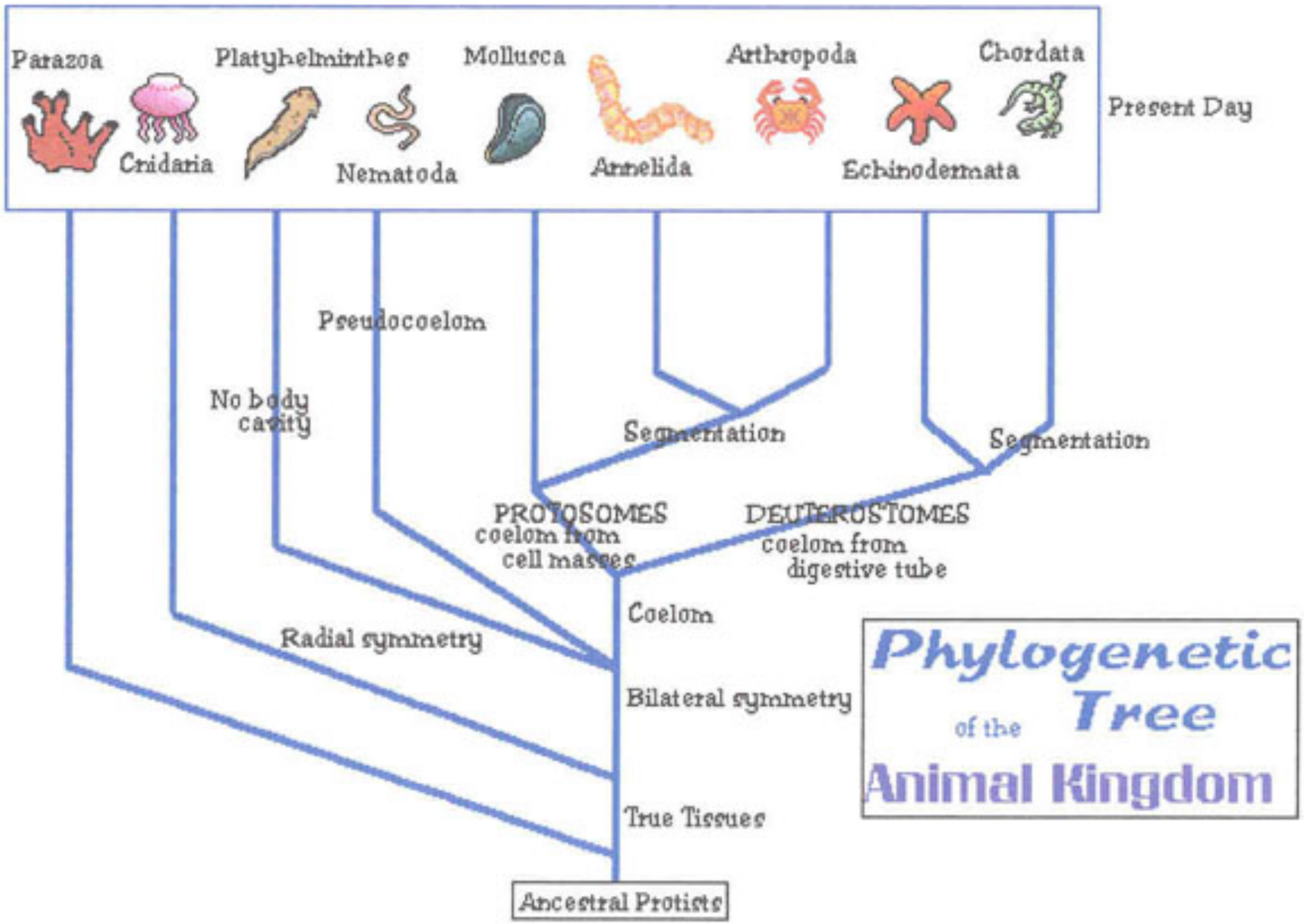


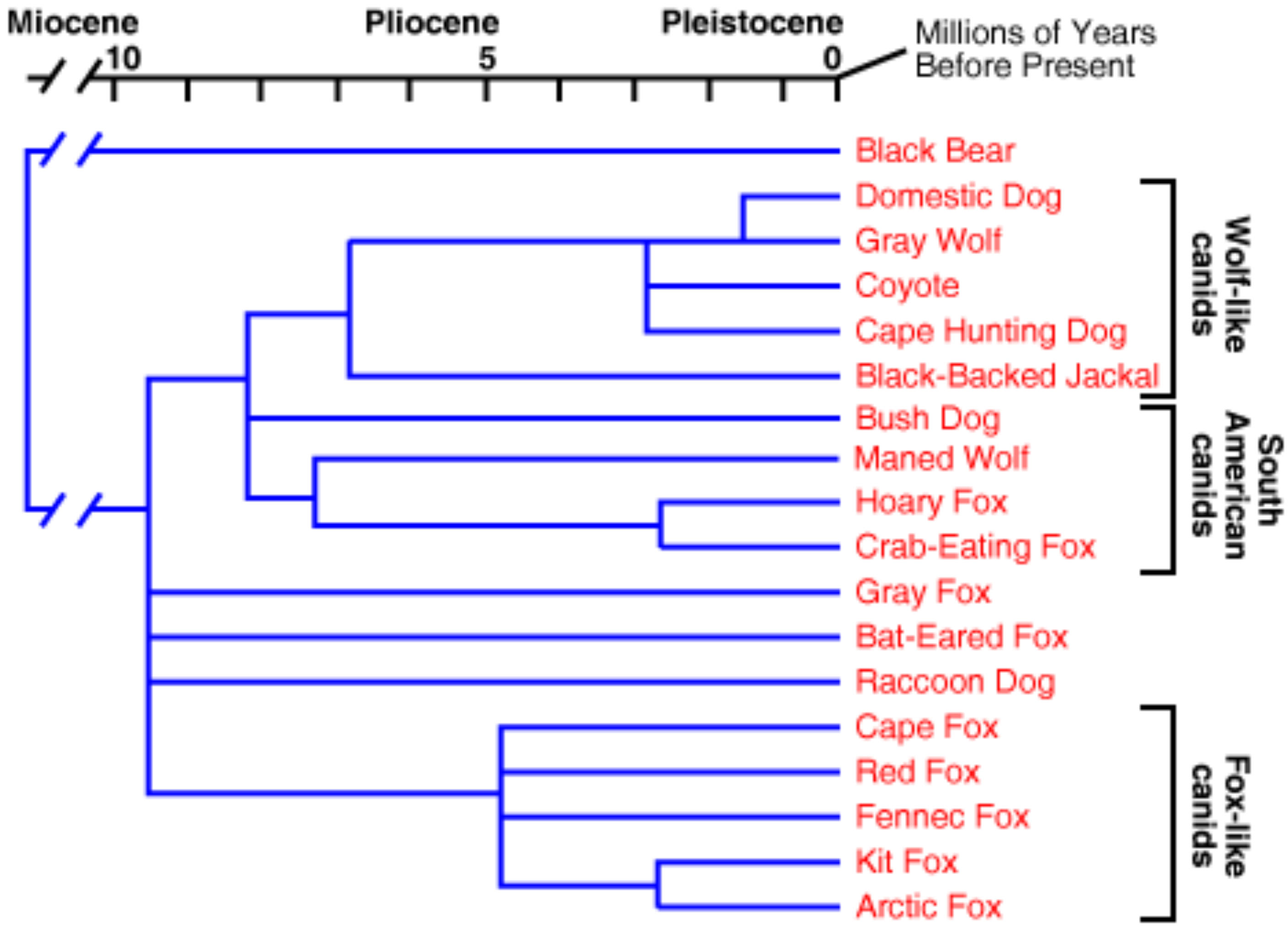
Tree Features

- Hierarchical relationship
- Root at the top
- Leaf at the bottom
- Interior nodes in middle
- Parents, children, ancestors, descendants, siblings
- Degree (of node): number of children of node
- Degree (of tree): maximum degree (across all nodes)
- Depth of node: number of *edges* from root to node
- Height: maximum depth (across all nodes)

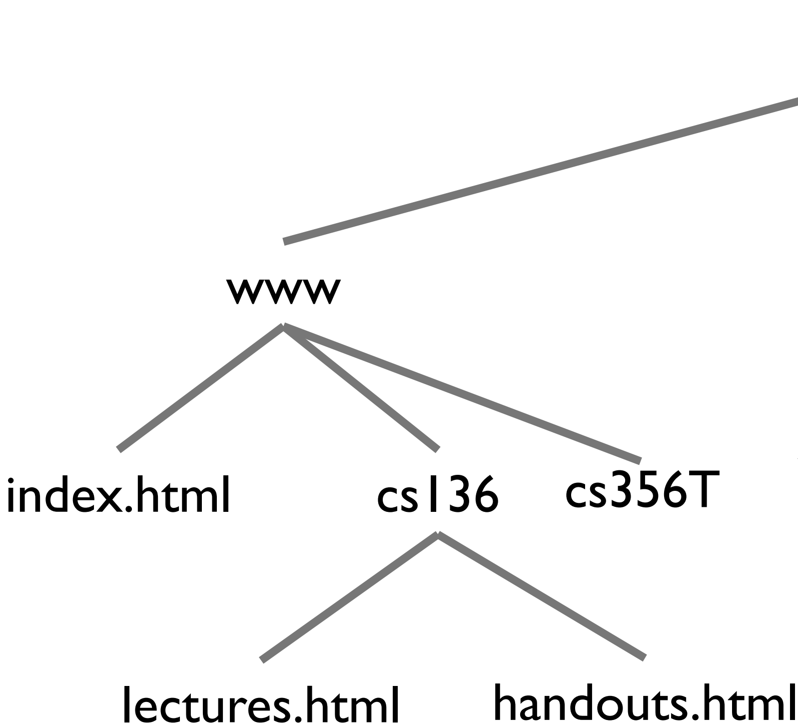
Other Trees

- Phylogenetic tree
- Directories of files
- Game trees
  - Build a tree
  - Search it for moves with high likelihood of winning
- Expression trees


Parazoa
Cnidaria
Platyhelminthes
Nematoda
Mollusca
Annelida
Arthropoda
Echinodermata
Chordata
Present Day
Pseudocoelom
No body cavity
Segmentation
Segmentation
PROTOSOMES
coelom from cell masses
DEUTEROSTOMES
coelom from digestive tube
Coelom
Radial symmetry
Bilateral symmetry
True Tissues
Ancestral Protists
Phylogenetic Tree of the Animal Kingdom



Miocene
Pliocene
Pleistocene
10
5
0
Millions of Years Before Present
Black Bear
Domestic Dog
Gray Wolf
Coyote
Cape Hunting Dog
Black-Backed Jackal
Bush Dog
Maned Wolf
Hoary Fox
Crab-Eating Fox
Gray Fox
Bat-Eared Fox
Raccoon Dog
Cape Fox
Red Fox
Fennec Fox
Kit Fox
Arctic Fox
Wolf-like canids
South American canids
Fox-like canids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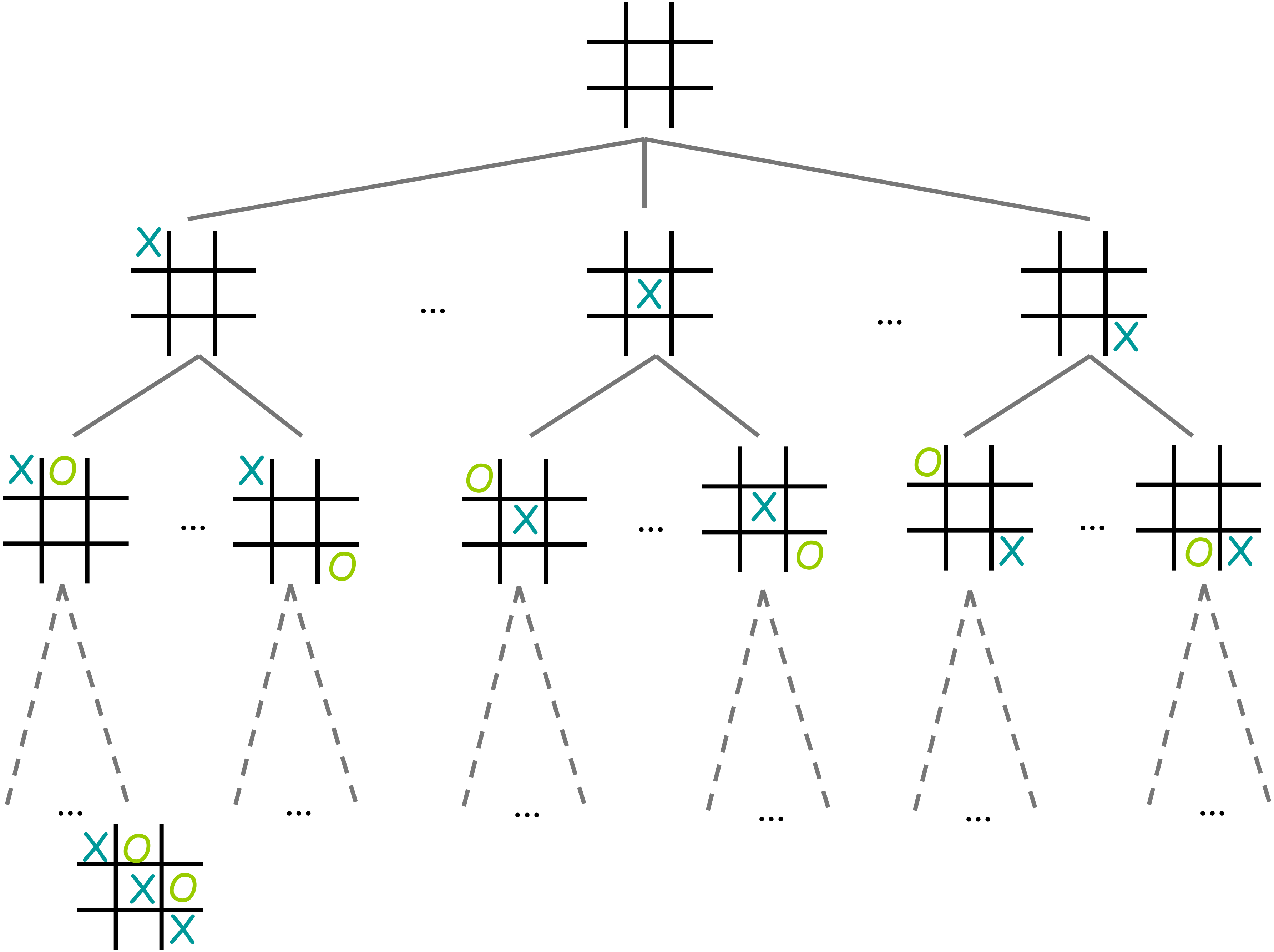
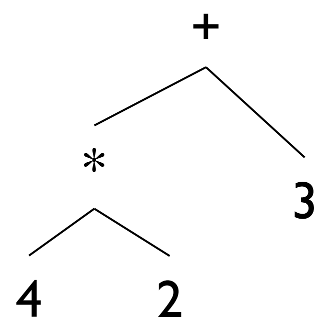
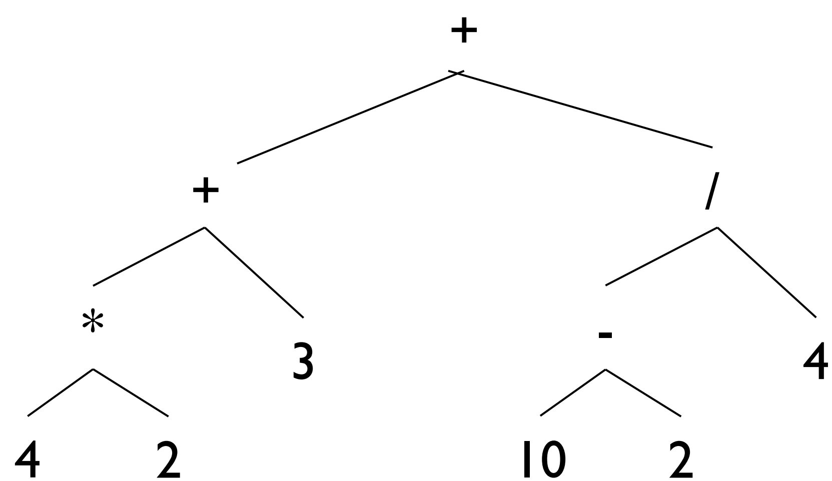


Expression Trees

4 * 2 + 3



(4 * 2 + 3) + ((10 – 2)/ 4)

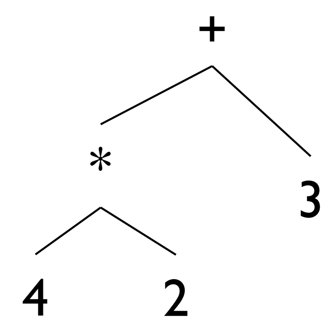


Introducing Binary Trees

- Degree of all nodes <= 2
- Recursive nature of tree
  - Empty
  - Root with left and right subtrees
- SLL: Recursive nature was captured by nodes (Node<E>) on inside
- Binary Tree: No "inner" node class; single BinaryTree class does it all

Expression Trees

4 * 2 + 3




```
BinaryTree<String> fourTimesTwo =
                    new BinaryTree<String>(“*”,
                    new BinaryTree<String>(“4”),
                    new BinaryTree<String>(“2”));

BinaryTree<String> fourTimesTwoPlusThree =
                    new BinaryTree<String>(“+”,
                    fourTimesTwo,
                    new BinaryTree<String>(“3”));
```

Or use Token class!

Expression Trees

- General strategy
  - Make a binary tree (BT) for each leaf node
  - Move from bottom to top, creating BTs
  - Eventually reach the root
  - Call "evaluate" on final BT
- Example
  - How do we make a binary expression tree for (((4+3)*(10-5))/2)
    - Postfix notation: 4 3 + 10 5 - * 2 /

```
int evaluate(BinaryTree<String> expr) {
      if (expr.height() == 0)
            return Integer.parseInt(expr.value());
      else {
            int left = evaluate(expr.left());
            int right = evaluate(expr.right());
            String op = expr.value();
            switch (op) {

                  case "+" : return left + right;
                  case "-" : return left - right;
                  case "*" : return left * right;
                  case "/" : return left / right;
            }

            Assert.fail("Bad op");
            return -1;
   }
}
```