Programming Languages and Techniques (CIS120)

Lecture 6

January 27th, 2016

Datatypes and Trees

Announcements

- Great job on HW1!
- Homework 2 is available
  - due Tuesday, February 2nd
- Lecture attendance grade (i.e. clickers)
  - Flexibility for occasional missed lectures due to minor emergencies (i.e. it's OK to miss a few lectures)
- Please complete the CIS 120 Demographics Survey
  - See Piazza (or this week's labs)
- Read Chapter 6 and 7

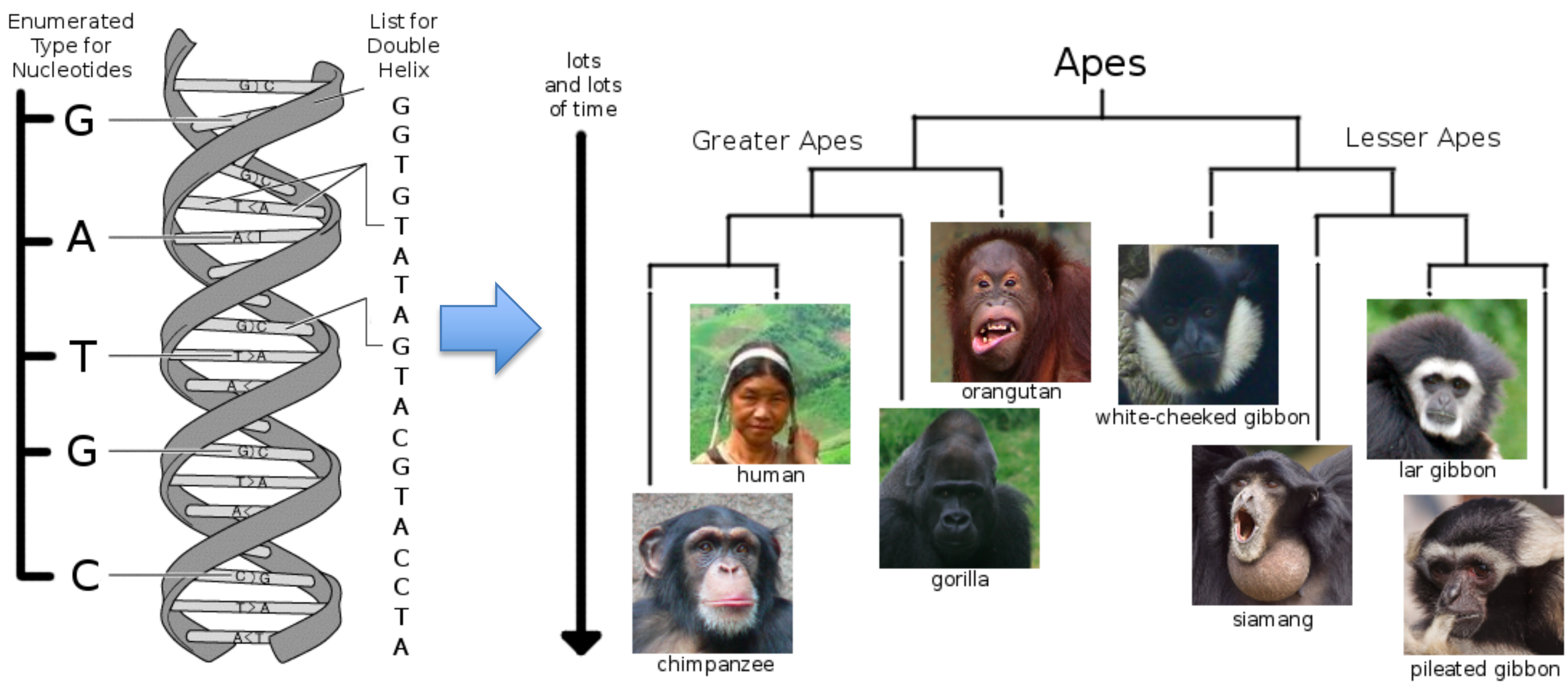
Datatypes and Trees

Building Datatypes

- Programming languages provide a variety of ways of creating and manipulating structured data
- We have already seen:
  - *primitive datatypes* (int, string, bool, …)
  - *lists* (int list, string list, string list list, …)
  - *tuples* (int * int, int * string, …)
- Rest of Today:
  - user-defined datatypes
  - type abbreviations

HW 2 Case Study: Evolutionary Trees

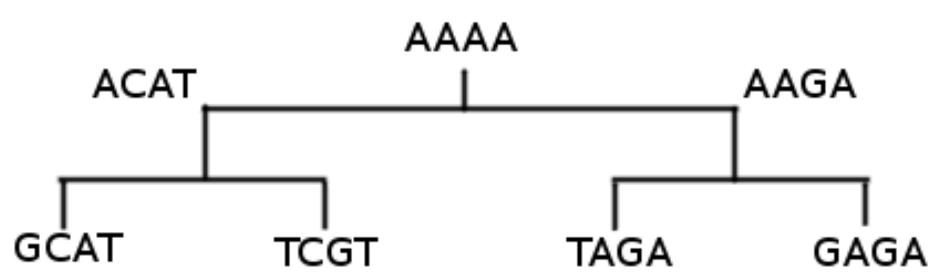
- Problem: reconstruct evolutionary trees from biological data.
  - What are the relevant abstractions?
  - How can we use the language features to define them?
  - How do the abstractions help shape the program?



Suggested reading:
Dawkins, The Ancestor's Tale: A Pilgrimage to the Dawn of Evolution

DNA Computing Abstractions

- Nucleotide
  - Adenine (A), Guanine (G), Thymine (T), or Cytosine (C)
- Helix
  - a sequence of nucleotides: e.g. AGTCCGATTACAGAGA…
  - genetic code for a particular species (human, gorilla, etc)
- Phylogenetic tree
  - Binary tree with helices (species) at the nodes and leaves



Simple User-Defined Datatypes

- OCaml lets programmers define *new* datatypes

```
type day =
    | Sunday
    | Monday
    | Tuesday
    | Wednesday
    | Thursday
    | Friday
    | Saturday
```

'type' keyword

type name (must be lowercase)

```
type nucleotide =
| A
| C
| G
| T
```

constructor names (*tags*) (*must* be capitalized)

- The constructors *are* the values of the datatype
  - e.g. `A` *is* a nucleotide and `[A; G; C]` *is* a nucleotide list

Pattern Matching Simple Datatypes

- Datatype values can be analyzed by pattern matching:

```
let string_of_n (n:nucleotide) : string =
  begin match n with
  | A -> "adenine"
  | C -> "cytosine"
  | G -> "guanine"
  | T -> "thymine"
  end
```

- There is one case per constructor
  - you will get a warning if you leave out a case or list one twice
- As with lists, the pattern syntax follows that of the datatype values (i.e. the constructors)

A Point About Abstraction

- We *could* represent data like this by using integers:
  - Sunday = 0, Monday = 1, Tuesday = 2, etc.
- But:
  - Integers support different operations than days do:
    Wednesday - Monday = Tuesday
  - There are *more* integers than days (What day is 17?)
- Confusing integers with days can lead to bugs
  - Many *scripting* languages (PHP, Javascript, Perl, Python,…) violate such abstractions (true == 1 == "1"), leading to pain and misery…

Most modern languages (Java, C#, C++, OCaml,…) provide user-defined types for this reason.

Type Abbreviations

- OCaml also lets us *name* types without make new abstractions:

```
type helix = nucleotide list
type codon = nucleotide * nucleotide
                        * nucleotide
```

type keyword

type name

definition in terms of existing types
no constructors!

- i.e. a `codon` is the same thing a triple of `nucleotide`s

```
let x : codon = (A,C,C)
```

- Makes code easier to read & write

Data-Carrying Constructors

- Datatype constructors can also carry values

```
type measurement =
  | Missing
  | NucCount   of nucleotide * int
  | CodonCount of codon * int
```

keyword 'of'

Constructors may take a tuple of arguments

- Values of type '**measurement**' include:

```
Missing
NucCount(A, 3)
CodonCount((A,G,T), 17)
```

Pattern Matching Datatypes

- Pattern matching notation combines syntax of tuples and simple datatype constructors:

```
let get_count (m:measurement) : int =
  begin match m with
  | Missing              -> 0
  | NucCount(_, n)       -> n
  | CodonCount(_, n)     -> n
  end
```

- Datatype patterns *bind* variables (e.g. ‘n’) just like lists and tuples

Clickers, please…

```
type nucleotide = | A | C | G | T
type helix = nucleotide list
```

What is the type of this expression?

```
[A;C]
```

1. nucleotide
2. helix
3. nucleotide list
4. string * string
5. nucleotide * nucleotide
6. *none (expression is ill typed)*

Answer: both 2 and 3

Clickers, please…

```
type nucleotide = | A | C | G | T
type helix = nucleotide list
```

What is the type of this expression?

```
(A, "A")
```

1. nucleotide
2. nucleotide list
3. helix
4. nucleotide * string
5. string * string
6. *none (expression is ill typed)*

Answer: 4

Recursive User-defined Datatypes

- Datatypes can mention themselves!

```
type tree =
  | Leaf of helix
  | Node of tree * helix * tree
```

base constructor (nonrecursive)

Node carries a tuple of values

recursive definition

- Recursive datatypes can be taken apart by pattern matching (and recursive functions).

Syntax for User-defined Types

```
type tree =
  | Leaf of helix
  | Node of tree * helix * tree
```

- Example values of type `tree`

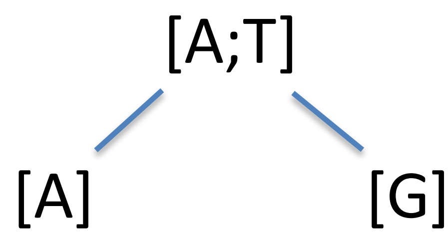
```
let t1 = Leaf [A;G]
let t2 = Node (Leaf [G], [A;T], Leaf [A])
let t3 =
  Node (Leaf [T],
        [T;T],
        Node (Leaf [G;C], [G], Leaf []))
```

Constructors (note capitalization)

```
type tree =
  | Leaf of helix
  | Node of tree * helix * tree
```

Clickers, please…

How would you construct this tree in OCaml?




```
1. Leaf [A;T]
2. Node (Leaf [G], [A;T], Leaf [A])
3. Node (Leaf [A], [A;T], Leaf [G])
4. Node (Leaf [T], [A;T],
         Node (Leaf [G;C], [G], Leaf []))
5. None of the above
```

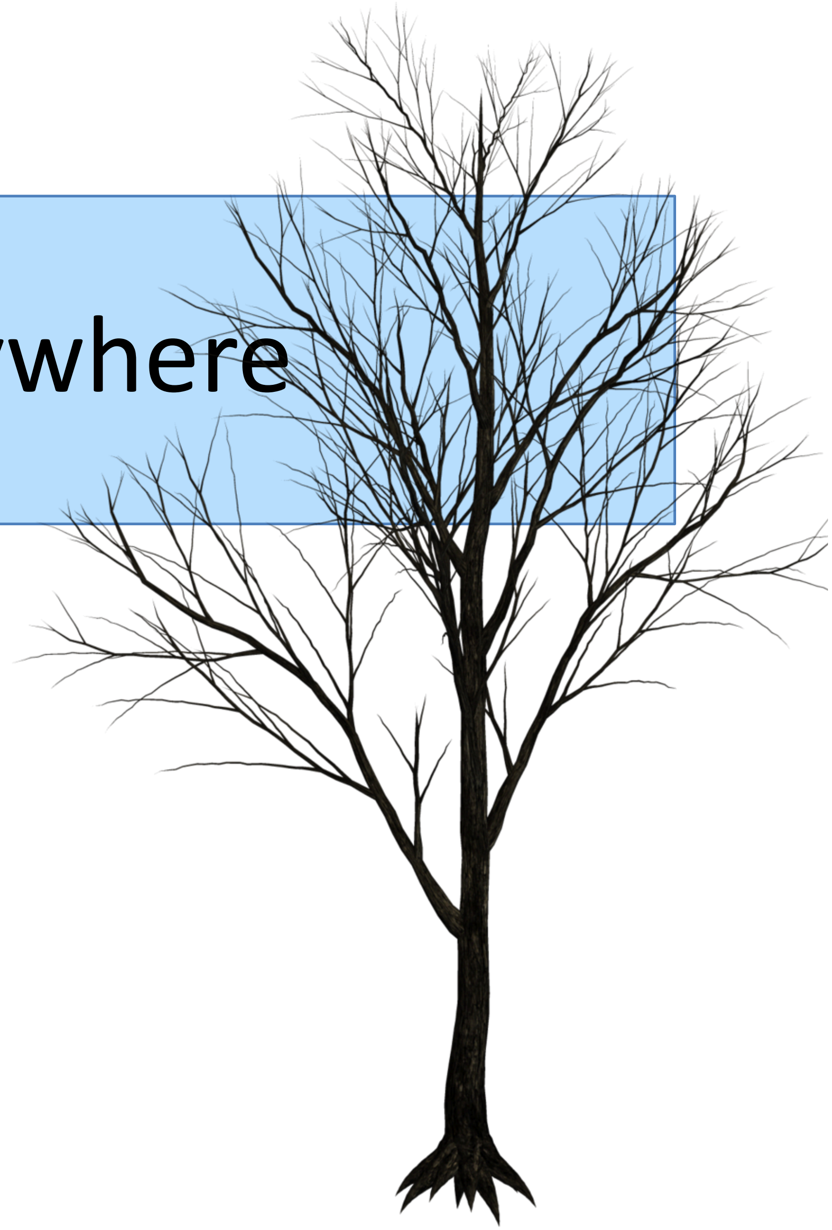
Answer: 3

Clickers, please…

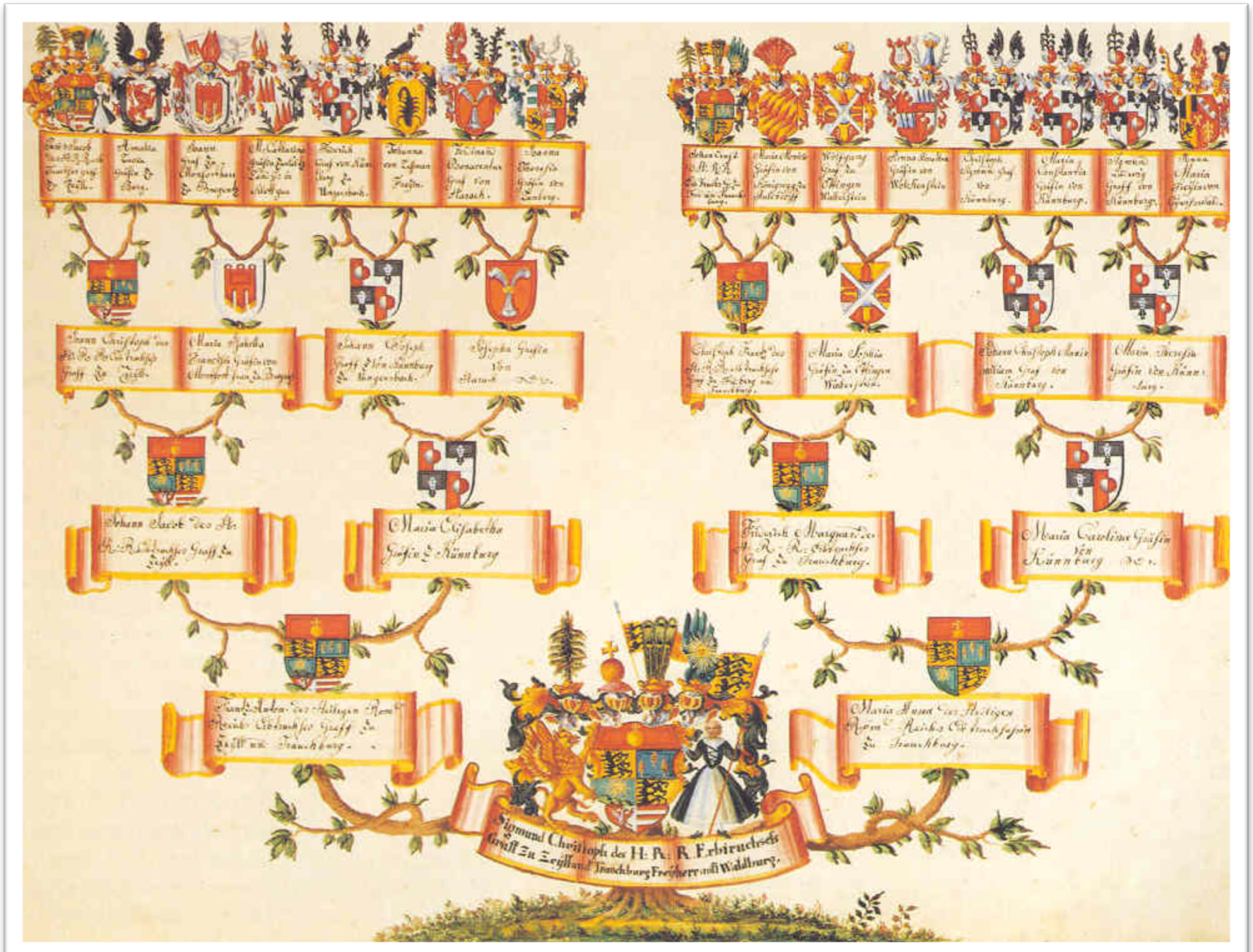
Have you ever programmed with trees before?

1. yes
2. no
3. *not sure*

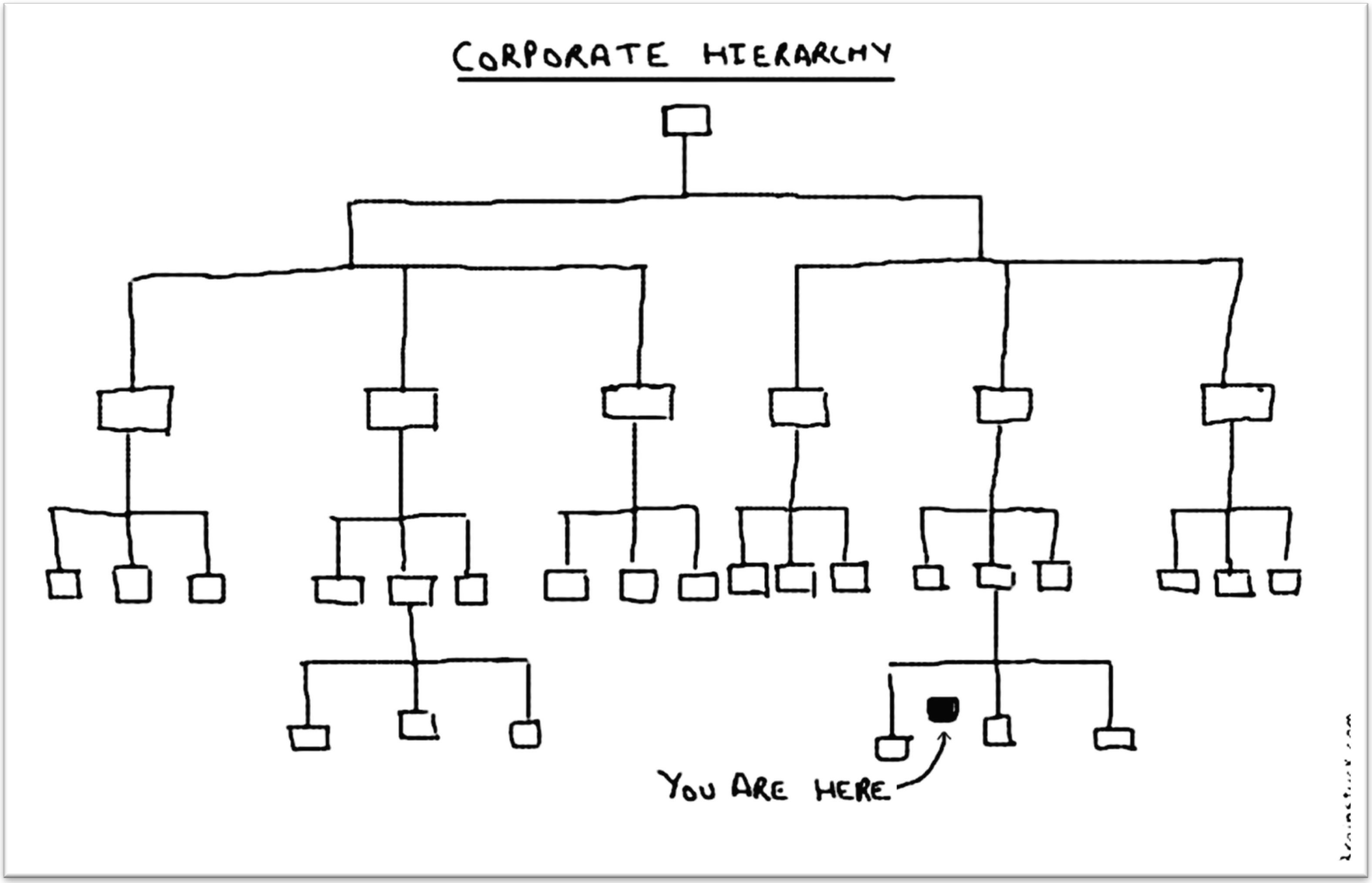
Trees are everywhere



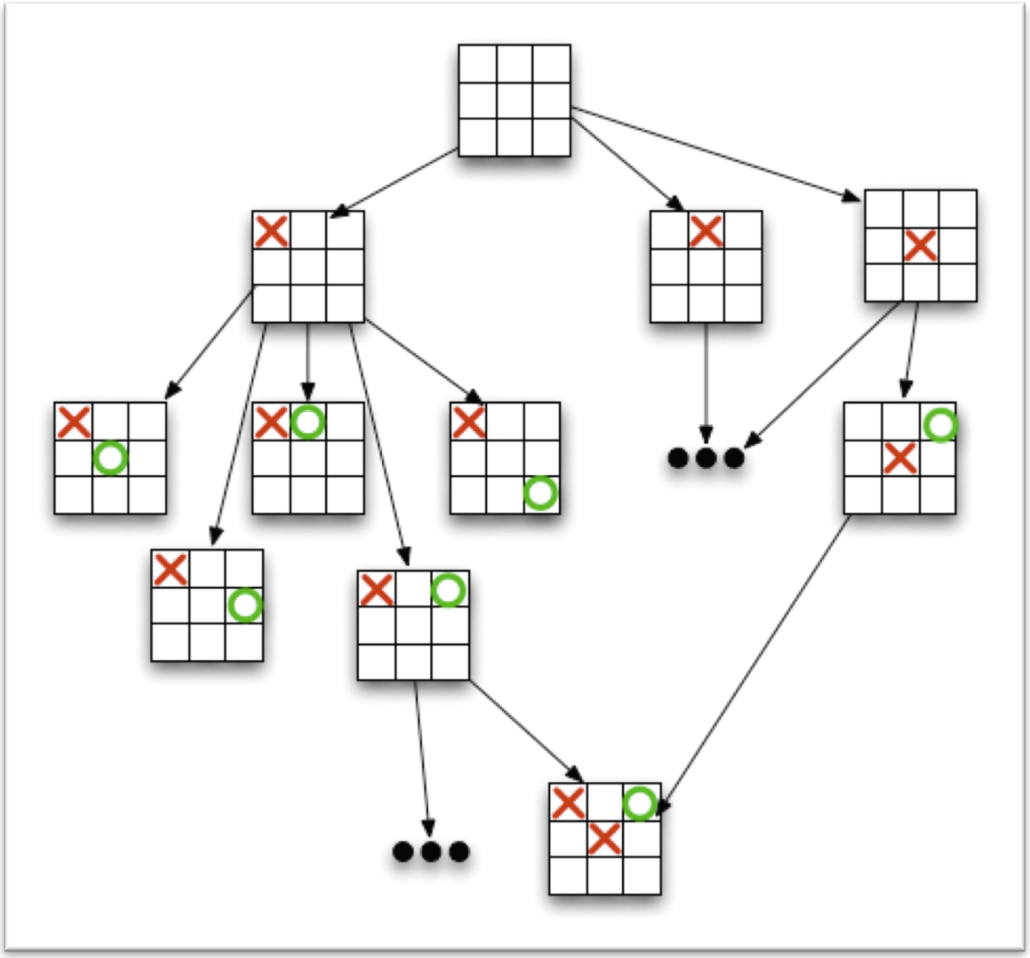
Family trees



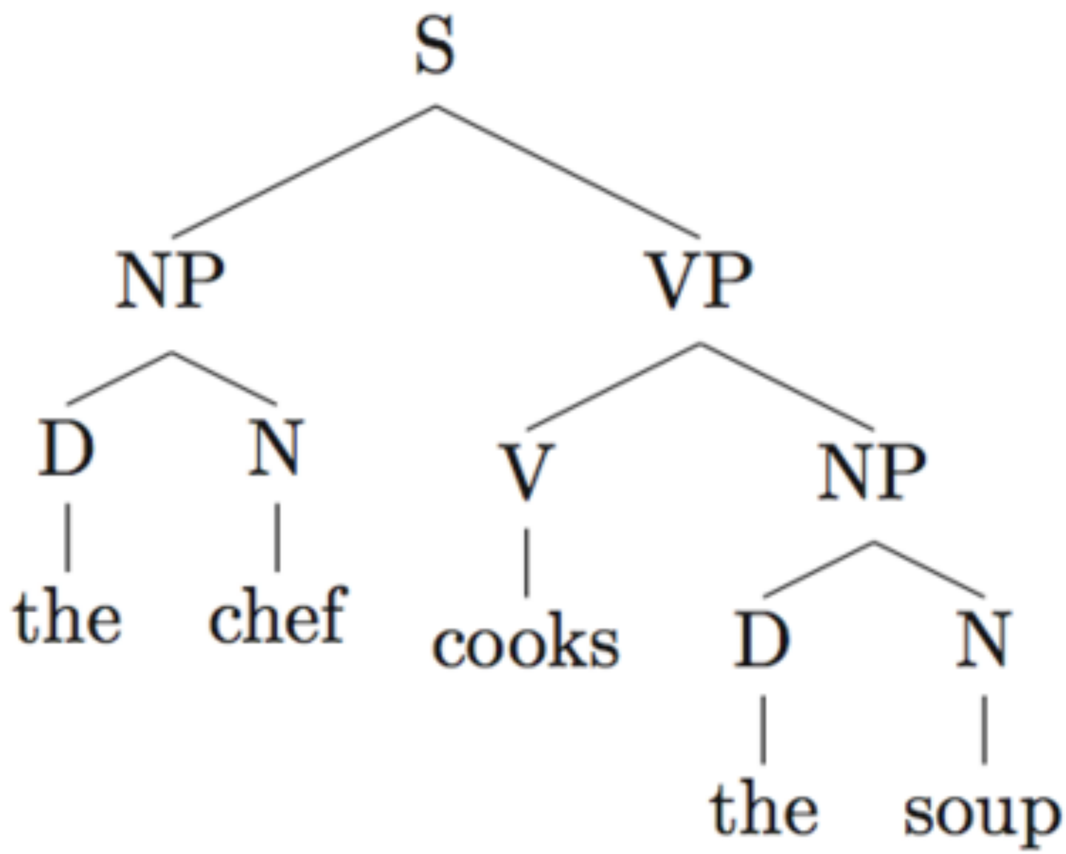
Organizational charts



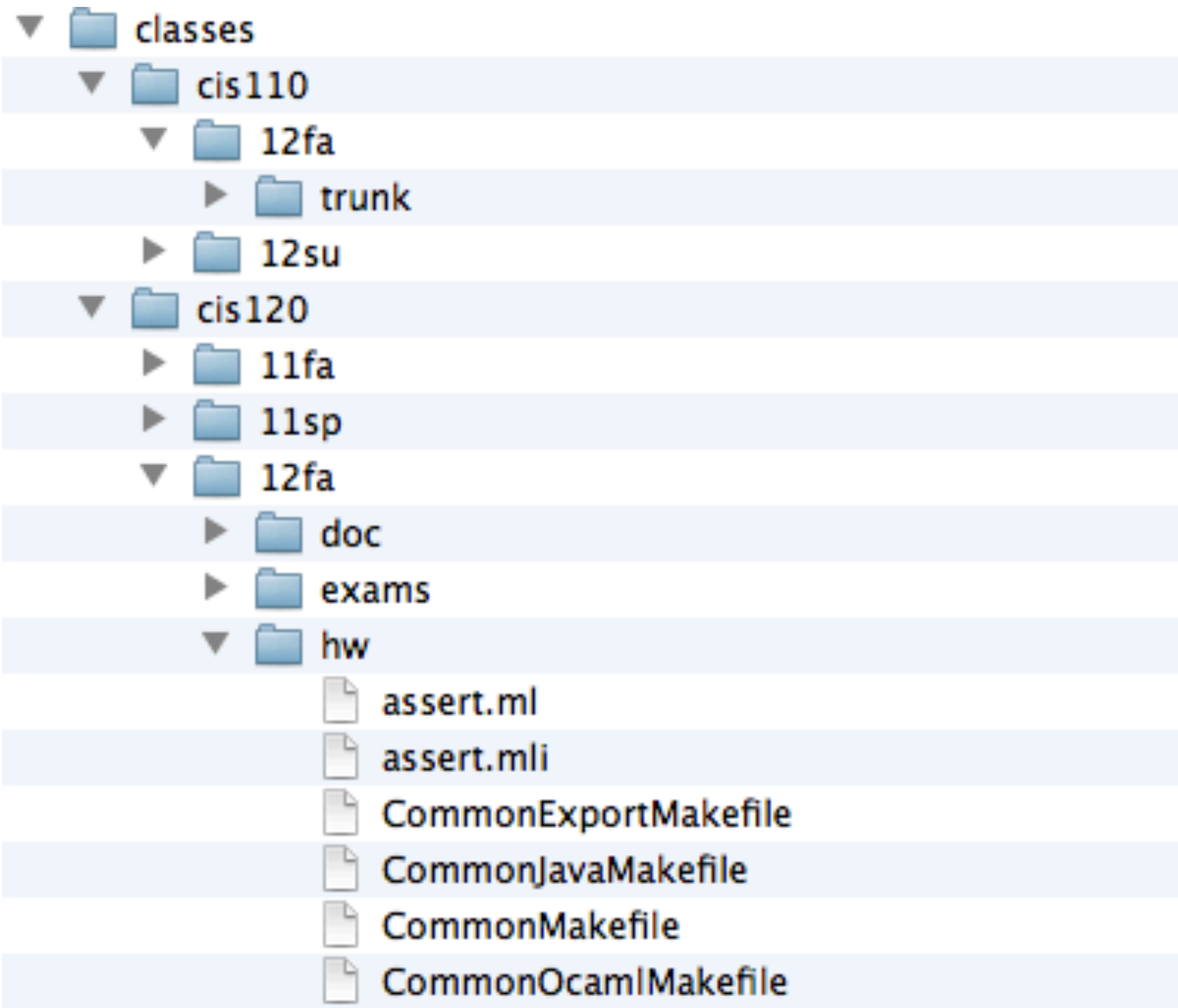
Game trees



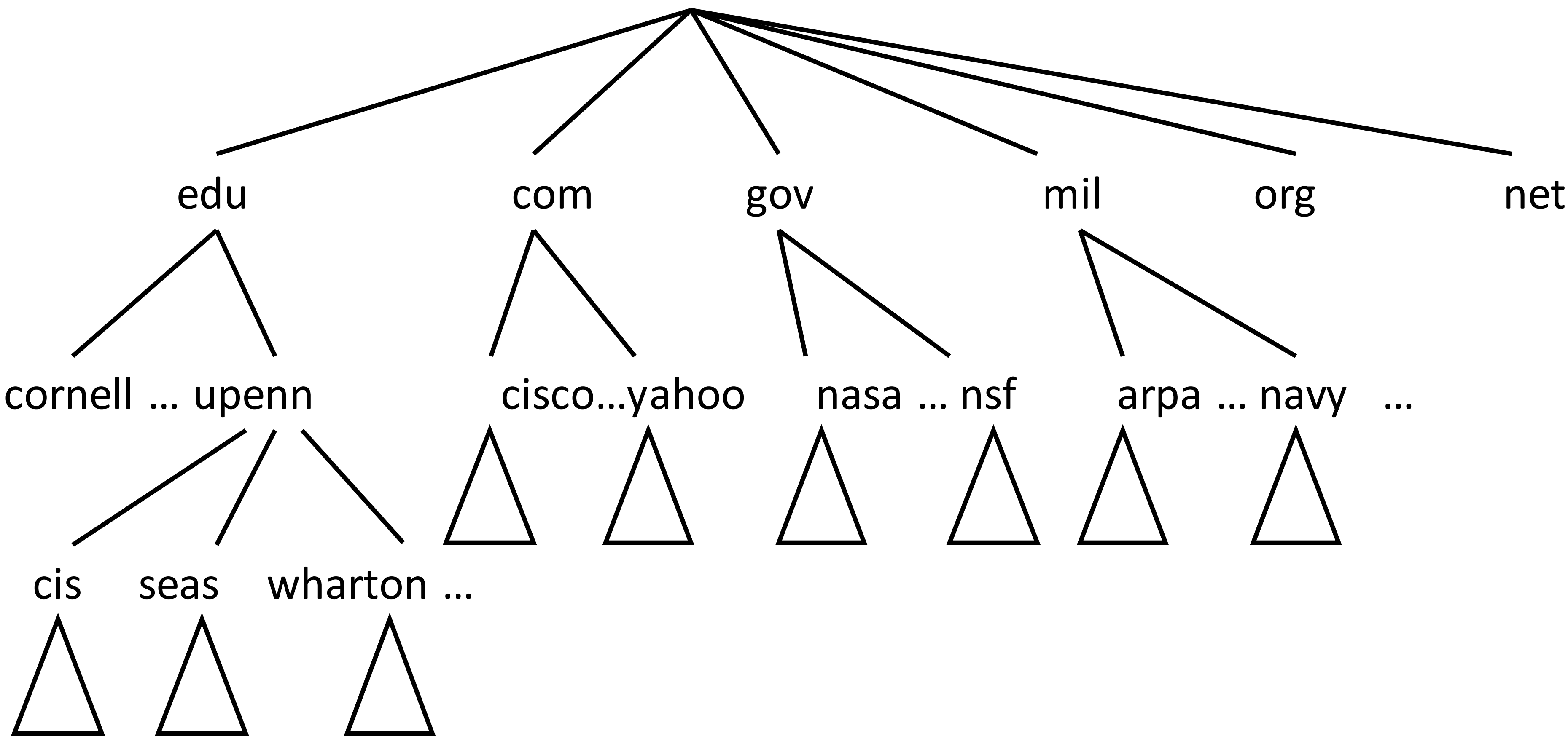
Natural-Language Parse Trees



Filesystem Directory Structure



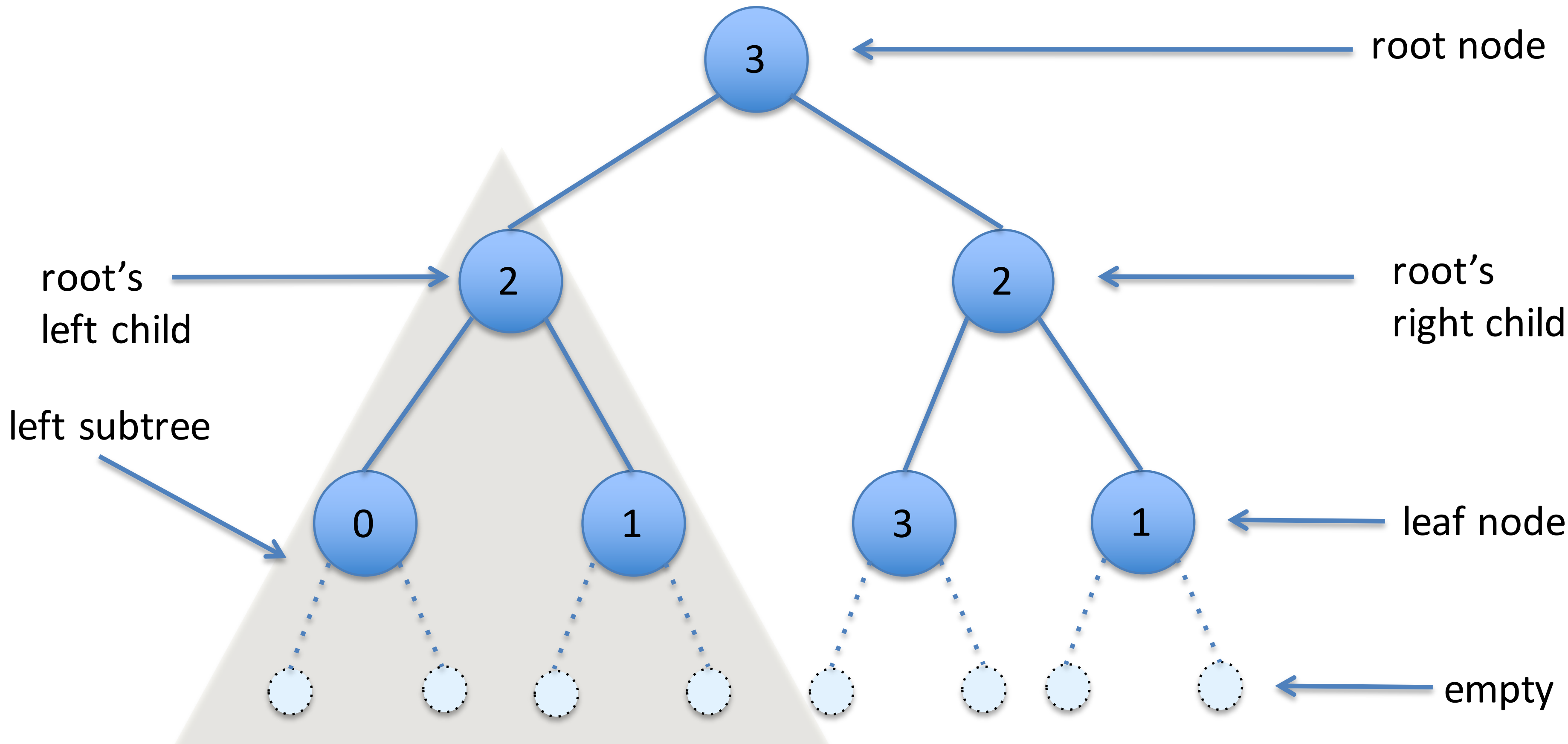
Domain Name Hierarchy



Binary Trees

A particular form of tree-structured data

Binary Trees



A binary tree is either *empty*, or a *node* with at most two children, both of which are also binary trees.

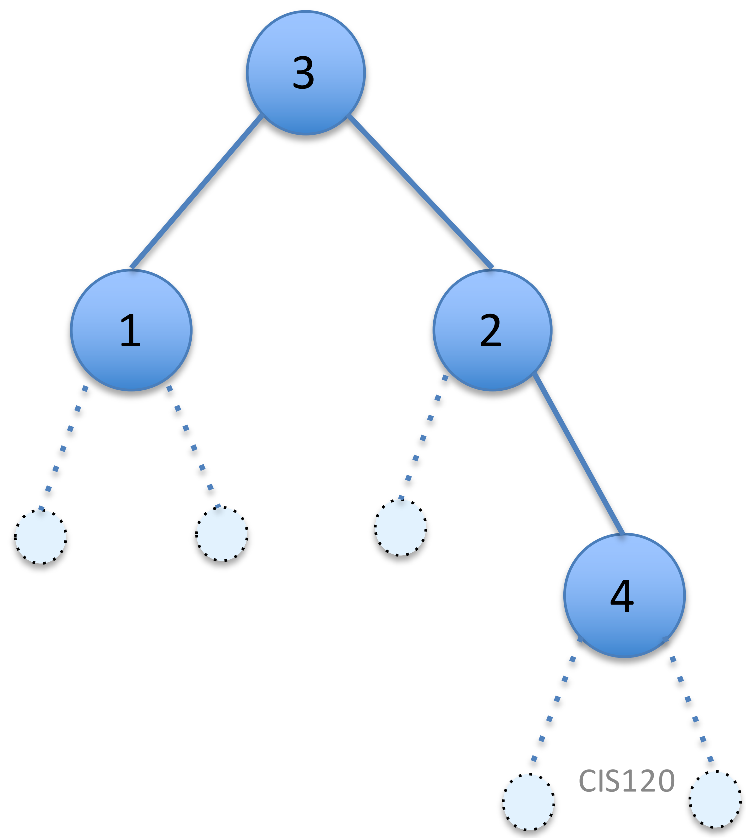
A *leaf* is a node whose children are both empty.

Binary Trees in OCaml

```ocaml
type tree =
| Empty
| Node of tree * int * tree
```

```ocaml
let t : tree =
  Node (Node (Empty, 1, Empty),
    3,
    Node (Empty, 2,
      Node (Empty, 4, Empty)))
```

=



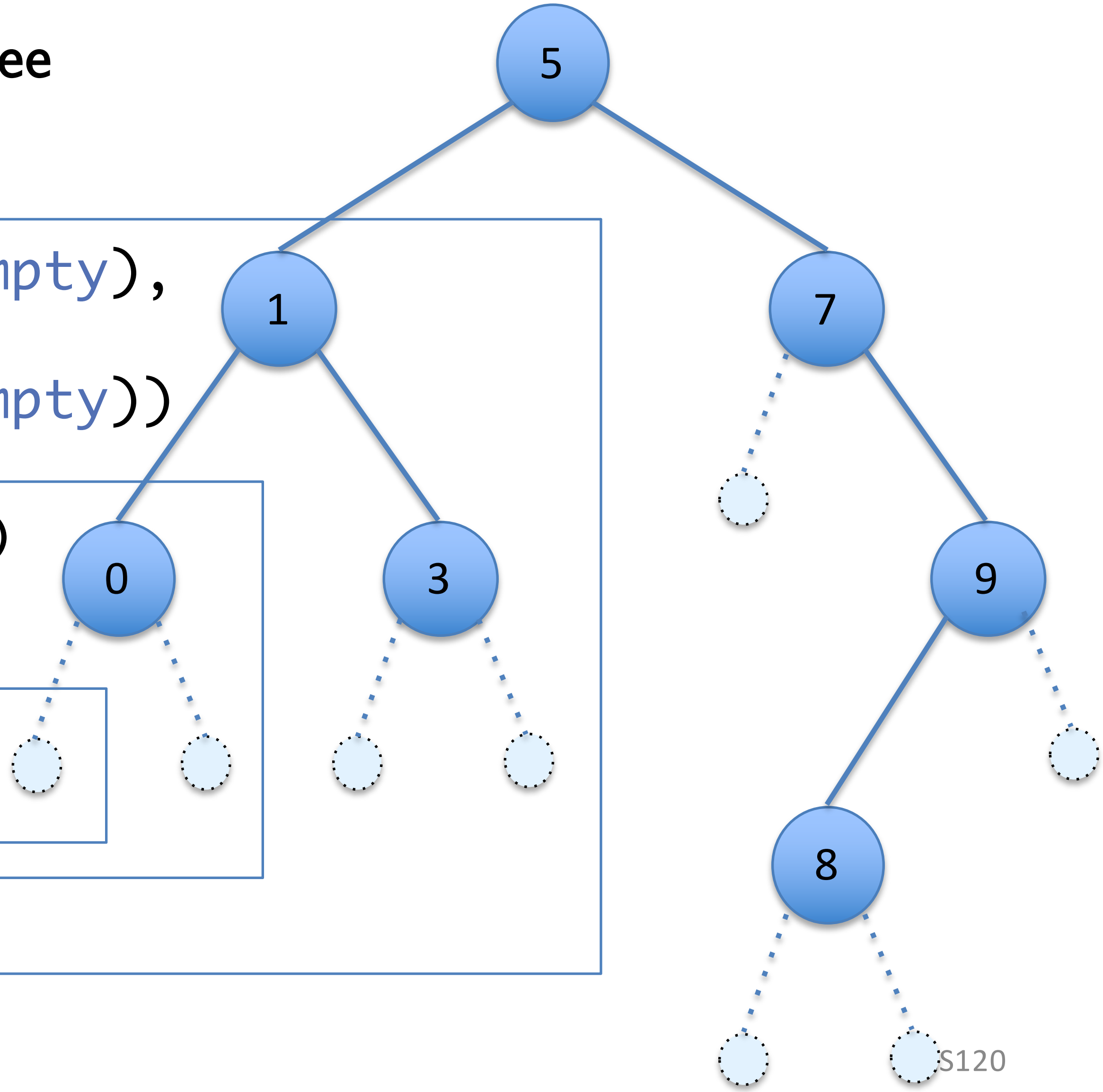
Representing trees

```
type tree =
| Empty
| Node of tree * int * tree
```

```
Node (Node (Empty, 0, Empty),
      1,
      Node (Empty, 3, Empty))
```

```
Node (Empty, 0, Empty)
```

```
Empty
```



Demo

see trees.ml

treeExamples.ml