Programming Languages and Techniques (CIS120)

Lecture 6

Jan 23, 2013

Datatypes and Trees

Announcements

- Homework 2 is up
  - On-time due date: Tuesday, Jan 29th at 11:59:59pm
  - Get started early, and seek assistance if you get stuck!

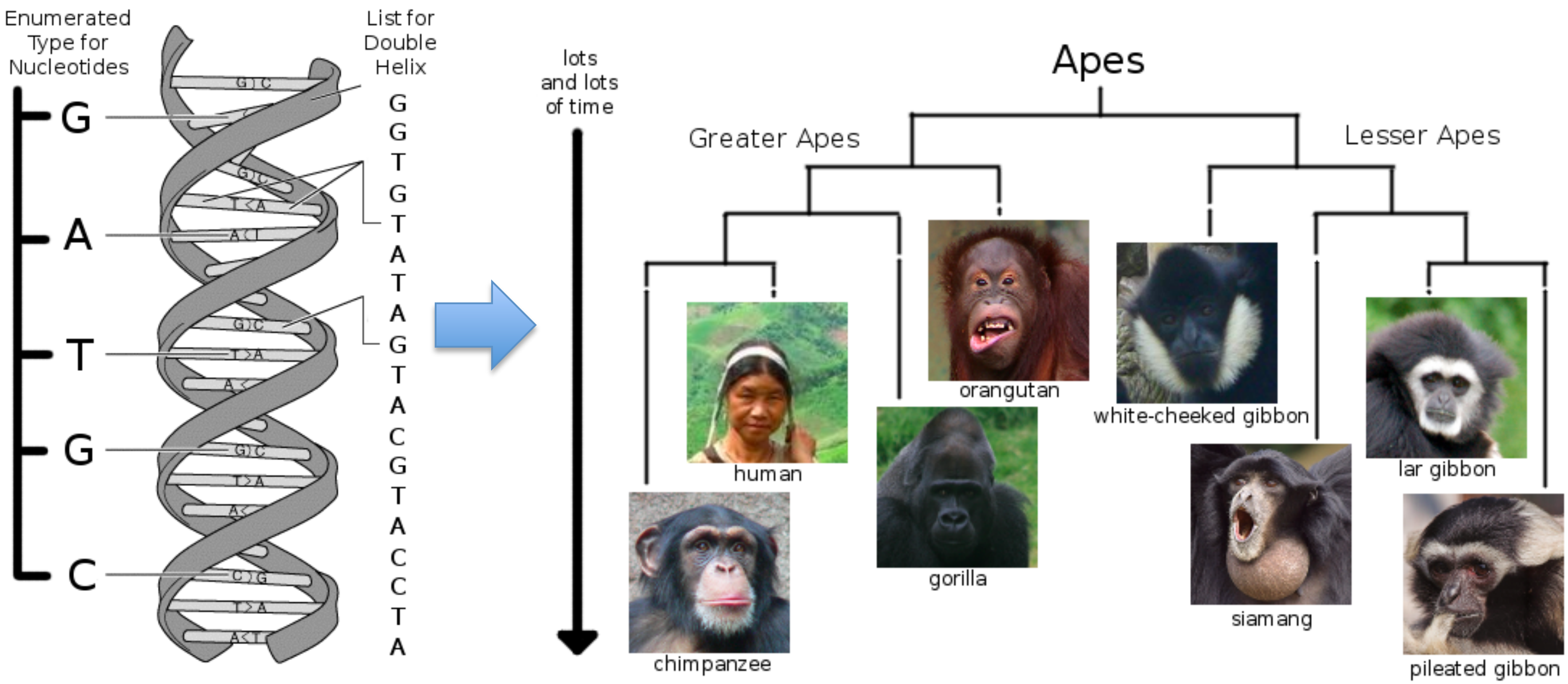
- Weirich OH today cancelled, email if you would like an appointment (see schedule for TA OH tonight)

- Ask questions on Piazza, but be kind to your TAs.

- Lecture Notes for ch. 1-6 will be posted after class.

Case Study: DNA and Evolutionary Trees

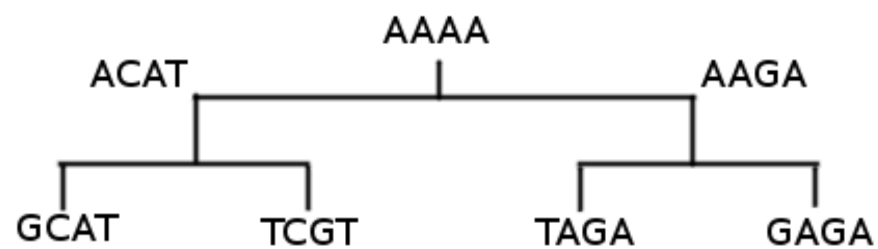
- Problem: reconstruct evolutionary trees from biological data.
  - What are the relevant abstractions?
  - How can we use the language features to define them?
  - How do the abstractions help shape the program?



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)
- Codon
  - three nucleotides : e.g. (A,A,T) or (T,G,C)
  - codons map to amino acids and other markers
- Helix
  - a sequence of nucleotides: e.g.   AGTCCGATTACAGAGA…
- Phylogenetic tree
  - Binary (2-child) tree with helices (species) at the nodes and leaves



Building Datatypes

- Programming languages provide means of creating and manipulating structured data
- We have already seen
  - *primitive datatypes* (int, string, bool, …)
  - *immutable lists* (int list,   string list, string list list, …)
  - *tuples* (int * int, int * string, …)
  - *functions* (that define relationships among values)

- How do we build new datatypes from these?

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

- Datatypes 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
- 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
    i.e. it doesn't make sense to do arithmetic like:
    `Wednesday - Monday = Tuesday`
  - There are *more* integers than days, i.e. "17" isn't a valid day under the representation above, so you must be careful never to pass such invalid "days" to functions that expect days.
- Conflating integers with days can lead to many bugs.
- All modern languages (Java, C#, C++, OCaml,…) provide user-defined types for this reason.

Type Abbreviations

- OCaml also lets us *name* types, like this:

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

type keyword

type name

definition in terms of existing types

- i.e. a `codon` is just a triple of `nucleotides`
- Its scope is the rest of the program.

Datatypes Can Also Carry Data

- 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
```

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

Recursive User-defined Datatypes

- Datatypes can mention themselves!
  - There should be at least one non-recursive ‘base case’
    - Otherwise, how would you build a value for such a datatype?

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

base case (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
```

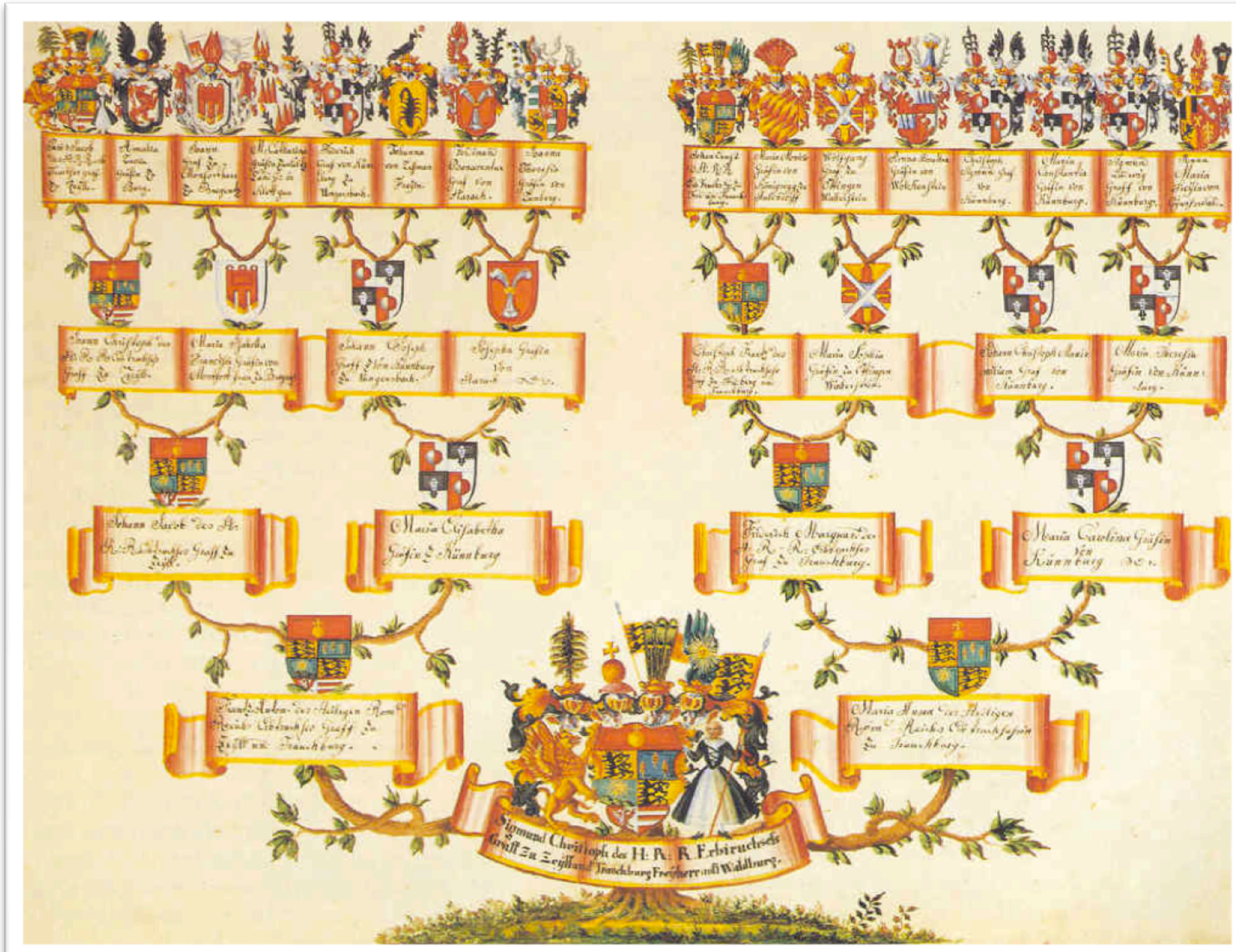
- Example values of type `tree`

```
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 []))
```

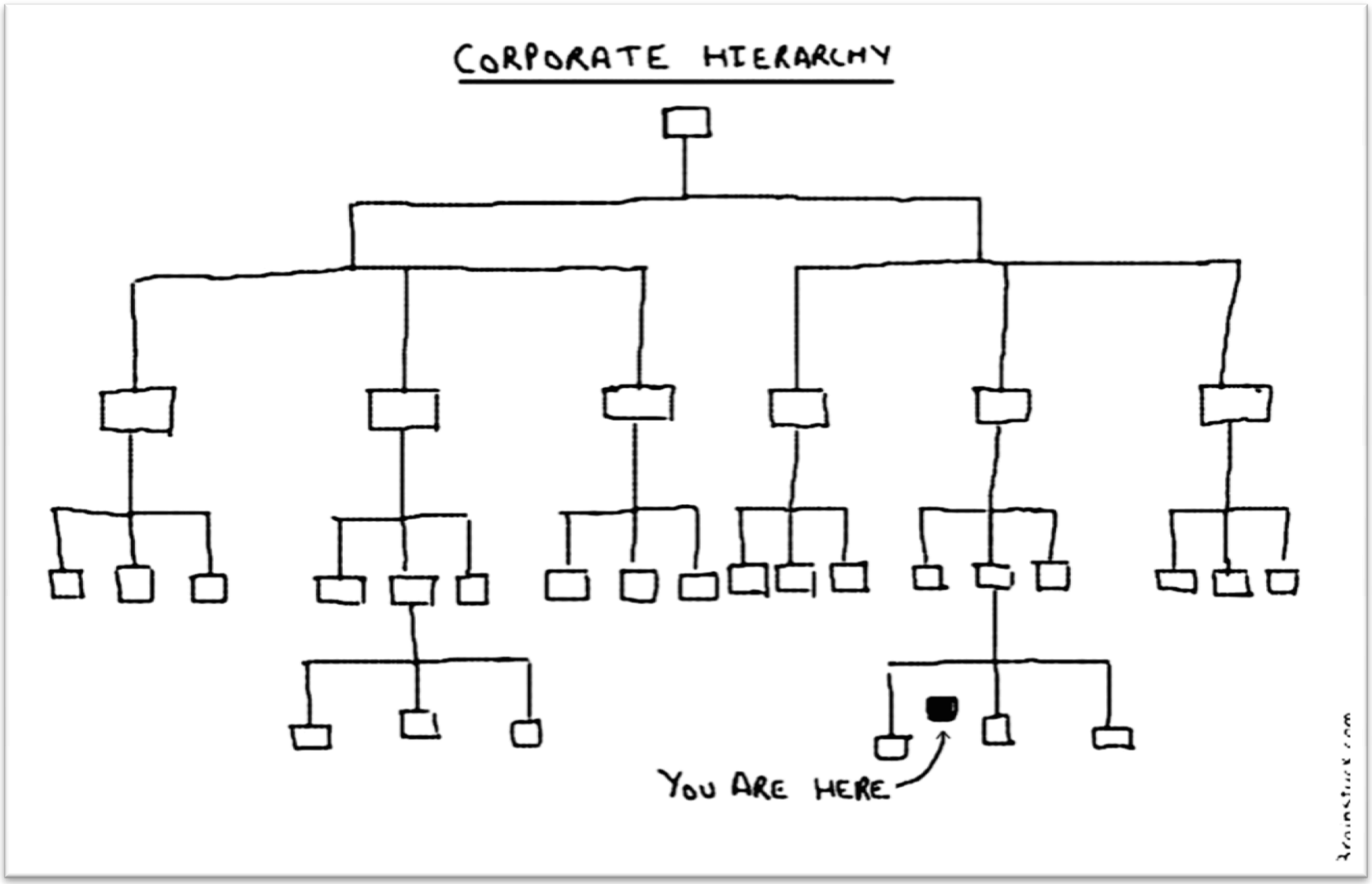
Constructors (note the capitalization)

Trees are everywhere

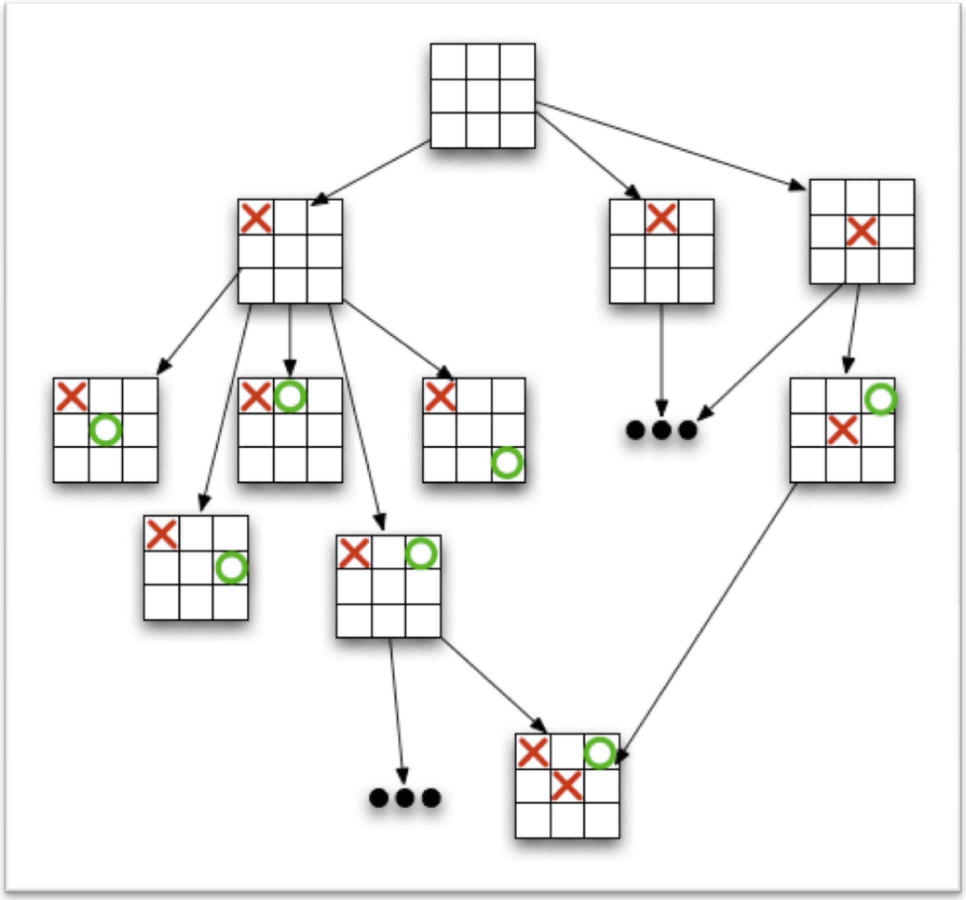
Family trees



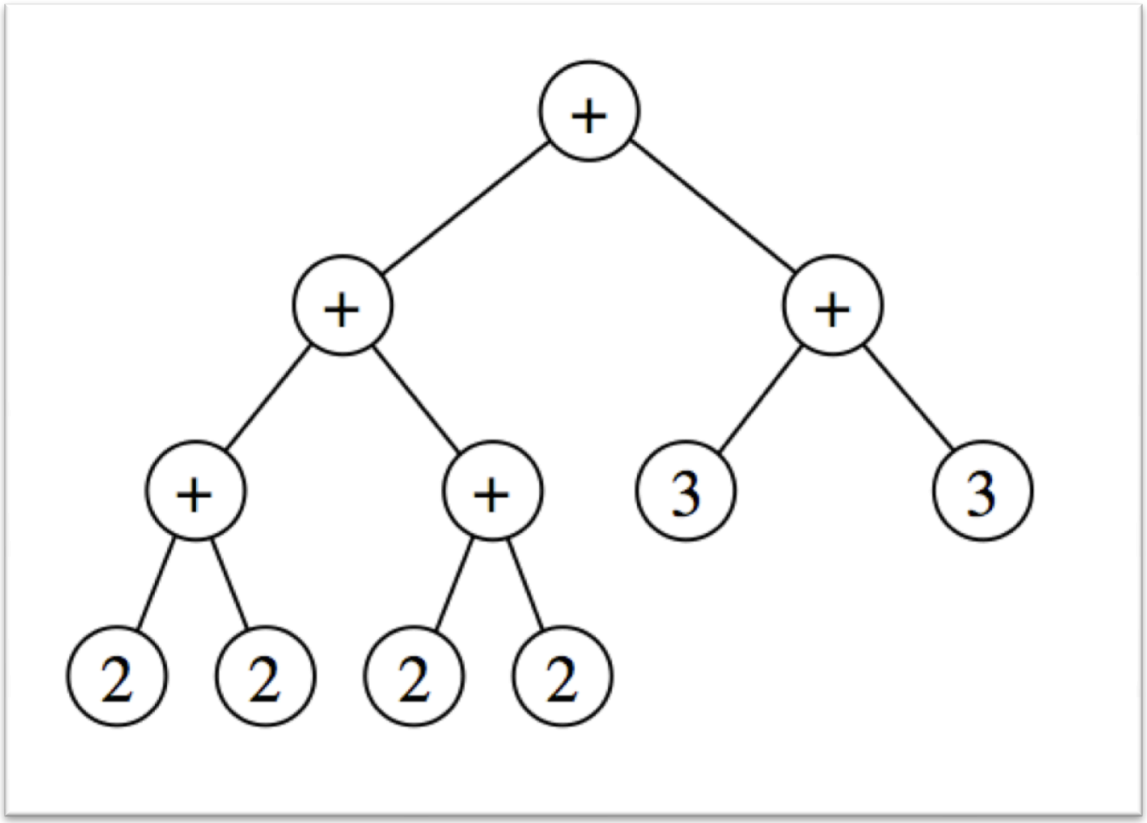
Organizational charts



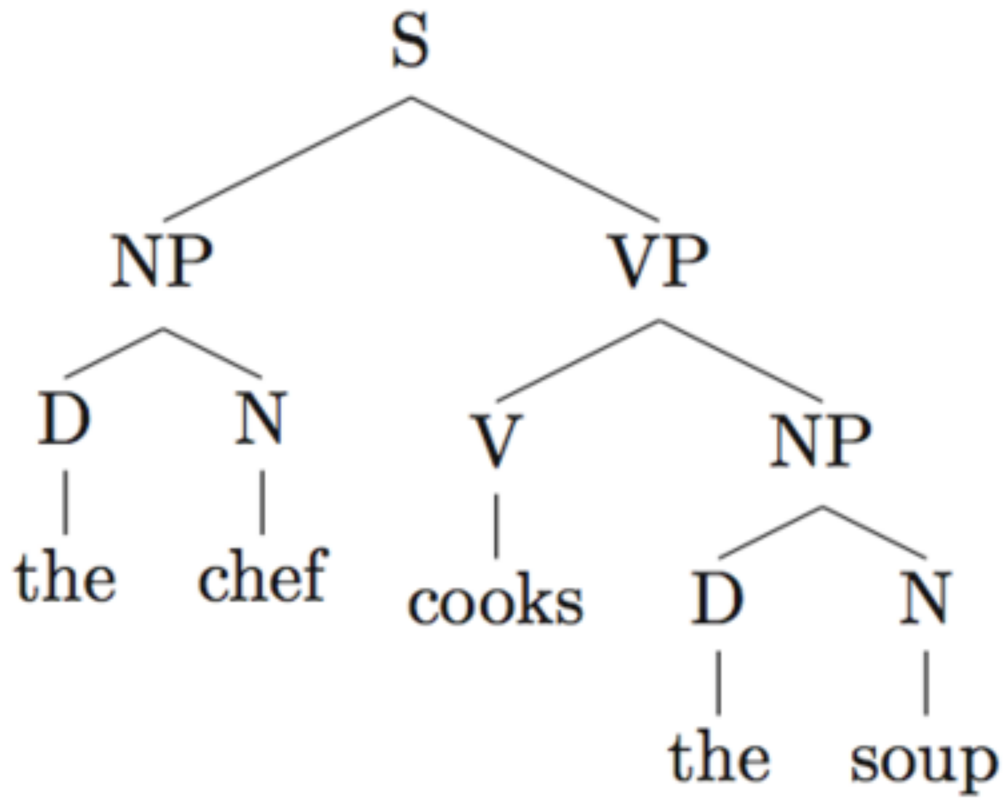
Game trees



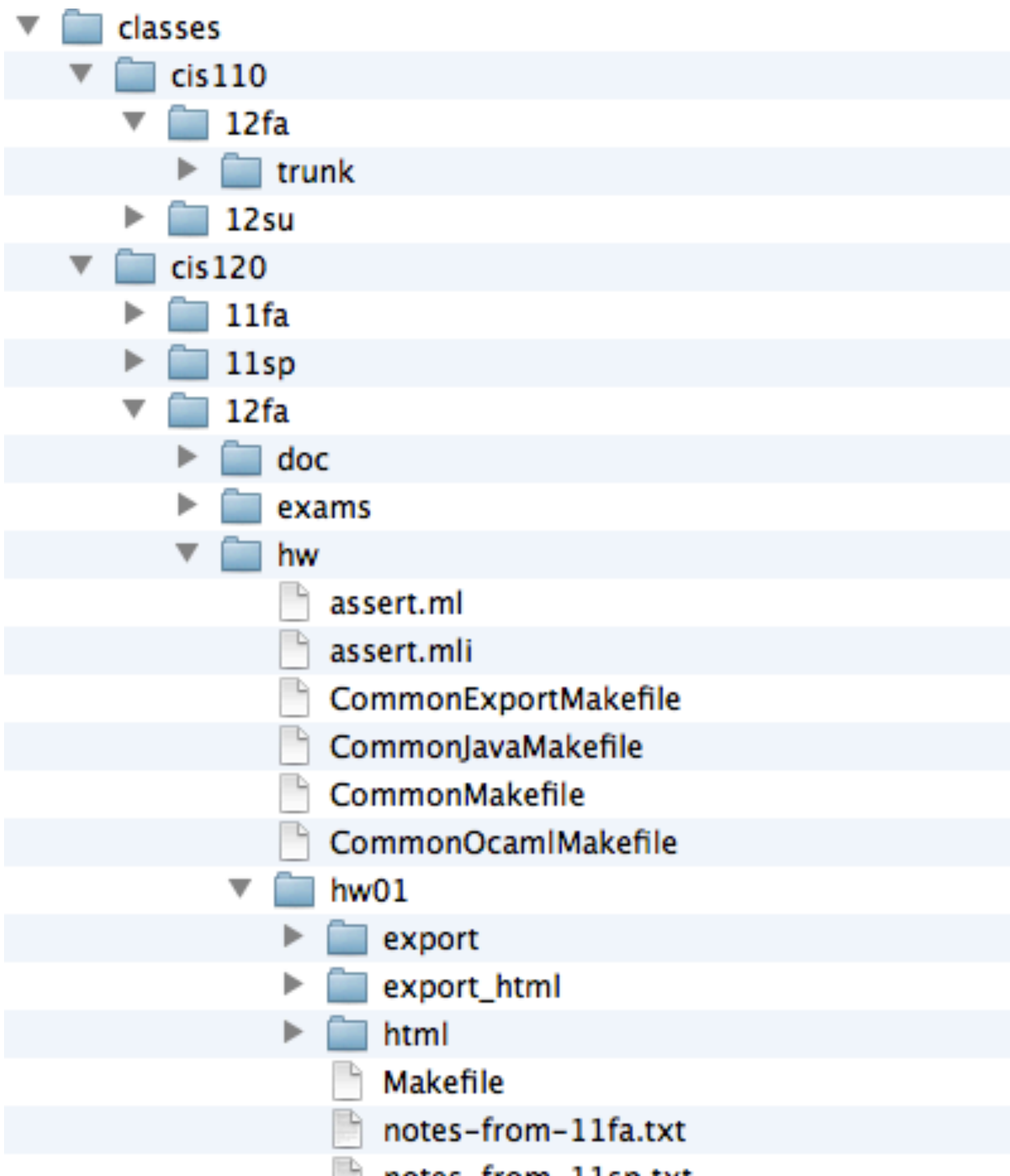
Expression trees



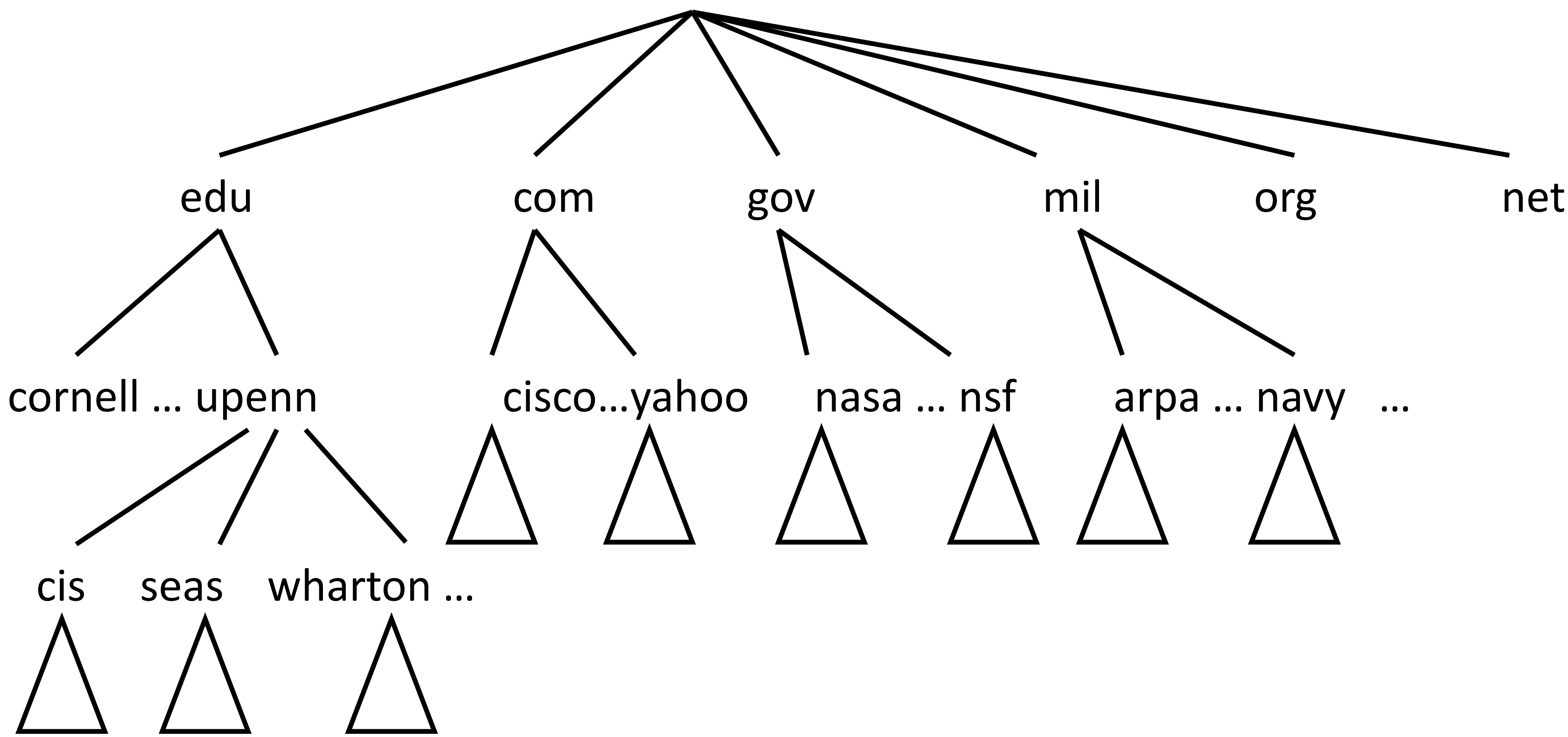
Natural Language Parse Trees



File System Directory Structure

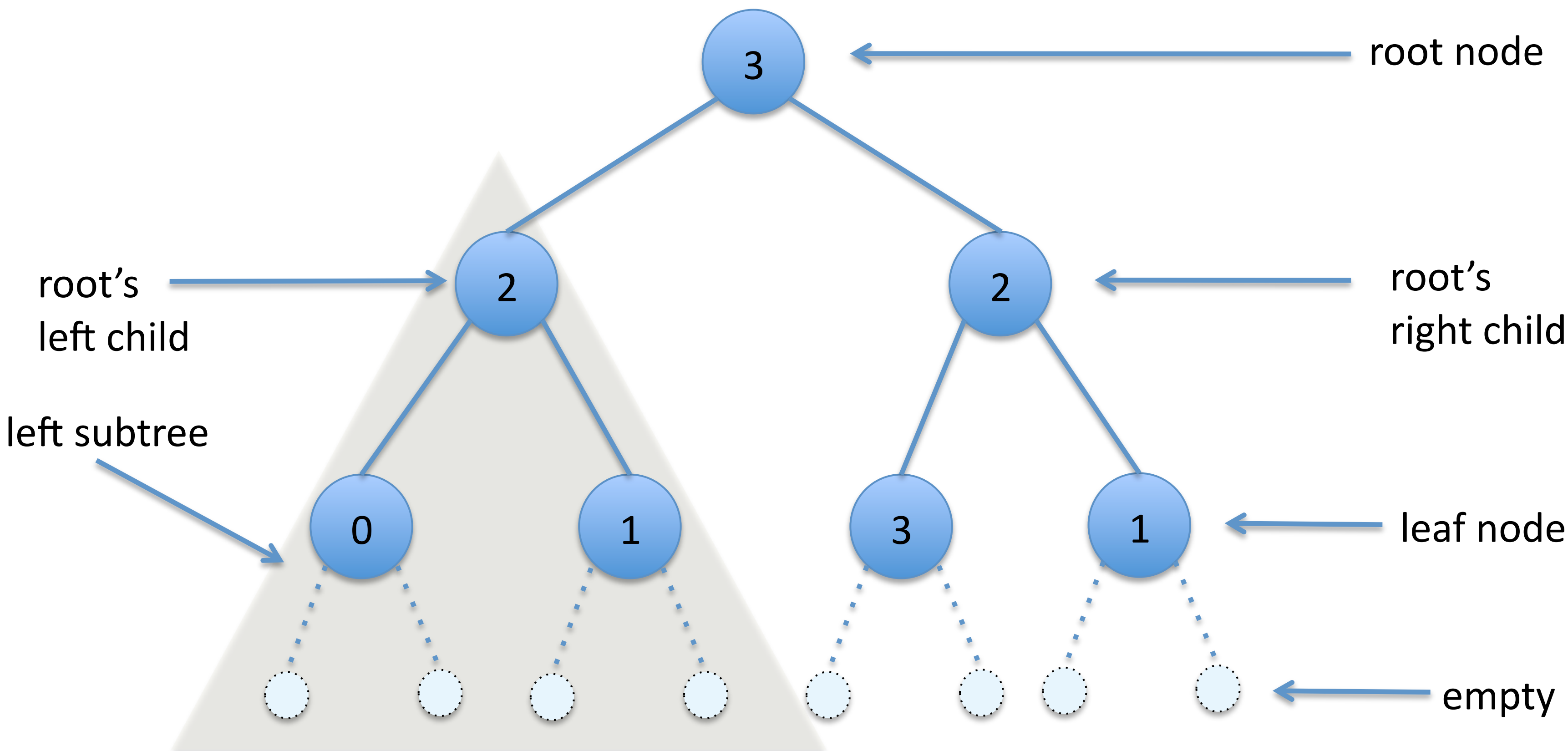


Domain Name Hierarchy



Binary Trees

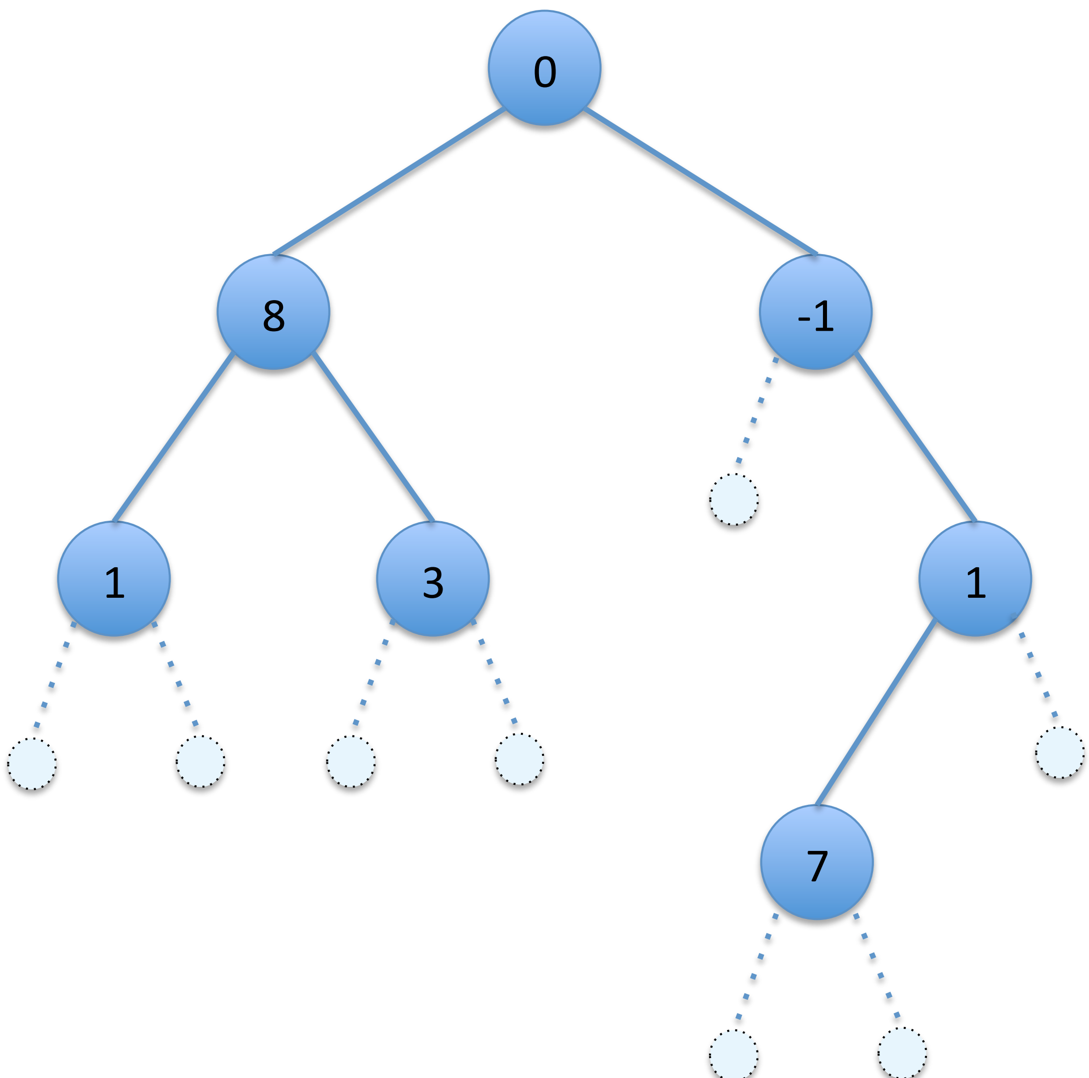
Binary Trees



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.

Another Example Tree

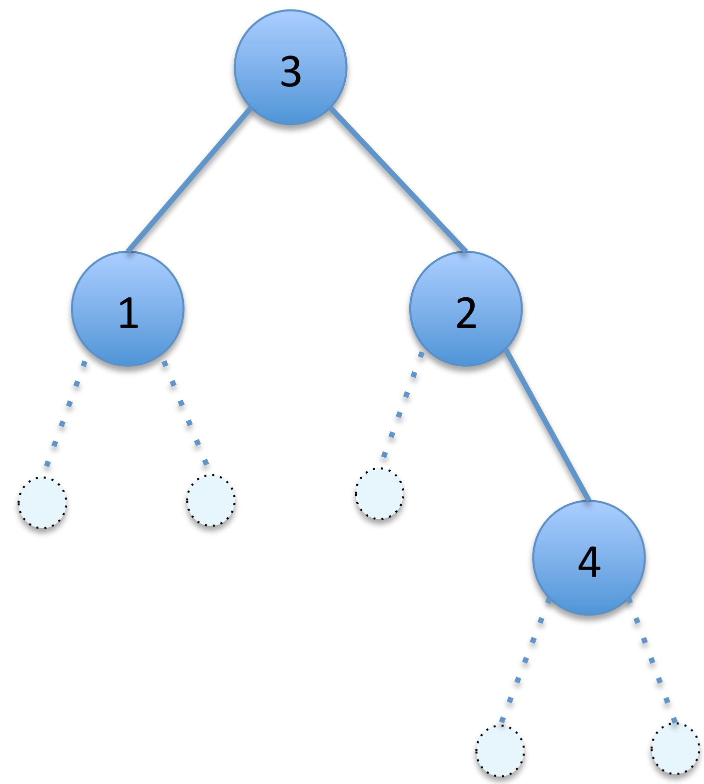


Integer Binary Trees in OCaml

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

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

=



Demo

see trees.ml