Functional Programming
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Overview

Overview

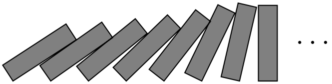
Mathematical Induction

Induction Principle

$$(\underbrace{P(m)}_{\text{base case}} \wedge \underbrace{\forall k \geq m.(P(k) \rightarrow P(k+1))}_{\text{step case}}) \rightarrow \forall n \geq m.P(n)$$

Example

- first domino will fall
- if a domino falls also its right neighbor falls



Induction on Lists

Induction Principle

$$\underbrace{(P([])}_{\text{base case}} \land \underbrace{\forall x : \alpha.\forall xs : \alpha \text{ list}.(P(xs) \to P(x :: xs)))}_{\text{step case}} \to \forall ls : \alpha \text{ list}.P(ls)$$

Lemma

@ is associative, i.e.,

$$xs \mathbin{@} (ys \mathbin{@} zs) = (xs \mathbin{@} ys) \mathbin{@} zs$$

Proof.

Blackboard □

Structural Induction

Usage

- can be used on every variant type
- base cases correspond to non-recursive constructors
- step cases correspond to recursive constructors

Example

- lists
- trees
- λ-terms
- ...

Overview

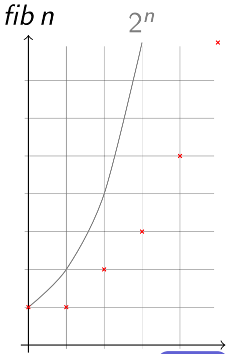
Mathematical

Definition (n-th Fibonacci number)

$$fib\ n \stackrel{\text{def}}{=} \begin{cases} 1 & \text{if } n \leq 1 \\ fib(n-1) + fib(n-2) & \text{otherwise} \end{cases}$$

Example

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, 1597, 2584, 4181 ,6765, 10946, 17711, 28657, 46368, 75025, 121393, 196418, 317811, 514229, 832040, 1346269, 2178309, 3524578, 5702887, 9227465, 14930352, 24157817, 39088169, 63245986, 102334155, 165580141, 267914296, 433494437, 701408733, 1134903170, 1836311903, 2971215073, 4807526976, 7778742049, 12586269025, . . .

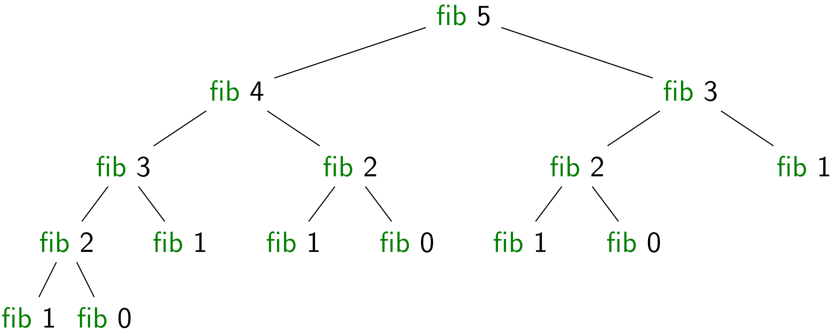


OCaml

Definition

```
let rec fib n = if n < 2 then 1 else fib (n - 1) + fib (n - 2);;
```

Example



Overview

Combining Several Results

Idea

- use tuples to return more than one result
- make results available as return values instead of recomputing them

Fibonacci Numbers

Example

```
let rec fibpair n =
  if n < 1 then (0, 1) else if n = 1 then (1, 1)
              else let (f1, f2) = fibpair (n - 1) in (f2, f1 + f2)
;;
```

- this function is linear

Lemma

$$\text{fibpair } n = (\text{fib } (n-1), \text{fib } n)$$

Proof.
Blackboard □

A Second Example

Goal

compute average value of an integer list

Approach 1

- **let** average xs = IntLst.sum xs / Lst.length xs;;
- 2 traversals of xs are done

Combined Function

- ```
  let rec sumlen = function
   | [] -> (0, 0)
   | x :: xs -> let (s, l) = sumlen xs in (x + s, l + 1)
  ;;
  ```
- one traversal of xs suffices
  ```

Overview

Recursion vs. Tail Recursion

Idea

- a function calling itself is recursive
- functions that mutually call each other are mutually recursive
- special kind of recursion is tail recursion

Definition (Tail recursion)

a function is called tail recursive if the last action in the function body is the recursive call

Examples

Length

- ```
  let rec length = function
   | [] -> 0
   | x :: xs -> 1 + length xs
  ;;
  ```
- not tail recursive
  ```

Examples (cont'd)

Even/Odd

- ```
  let rec is_even = function
    | 0 -> true
    | 1 -> false
    | n -> is_odd (n - 1)
  and is_odd = function
    | 0 -> false
    | 1 -> true
    | n -> is_even (n - 1)
  ;;
  ```
- mutually recursive (btw: also tail recursive)
  ```

Examples (cont'd)

Reverse

-
```
let rev xs =
 let rec rev acc = function
  | [] -> acc
  | x :: xs -> rev (x :: acc) xs
 in rev [] xs
;;
```
- tail recursive

Parameter Accumulation

Idea

- make function tail recursive
- provide data as input instead of computing it before recursive call
- Why? (tail recursive functions can automatically be transformed into space-efficient loops)

Example

Average

- ```
  let sumlen xs =
   let rec sumlen sum len = function
    | [] -> (sum, len)
    | x :: xs -> sumlen (x + sum) (len + 1) xs
   in sumlen 0 0 xs
  ;;
  ```
- tail recursive
  ```