ETH Zürich

Chair of Software Engineering

Einführung in die Programmierung
Introduction to Programming

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Exercise Session 9

Today

- Feedback on the mock exam

- Recursion
  - Recursion
    - Recursion
      - Recursion
        - Recursion

- Basic data structures
  - Arrays
  - Linked Lists
  - Hashtables

Recursion: an example

- Fibonacci sequence:

  0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, ...

- How can we calculate the n-th Fibonacci number?

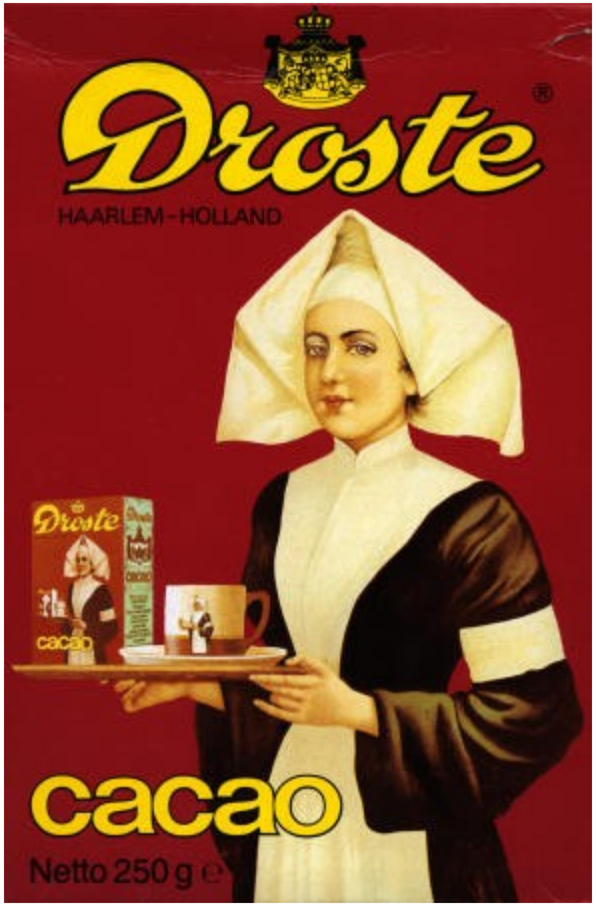
- Recursive formula:

$$F(n) = F(n-1) + F(n-2) \quad \text{for } n > 1$$

$$\text{with } F(0) = 0,\ F(1) = 1$$

Recursion: a second example

- Another example of recursion



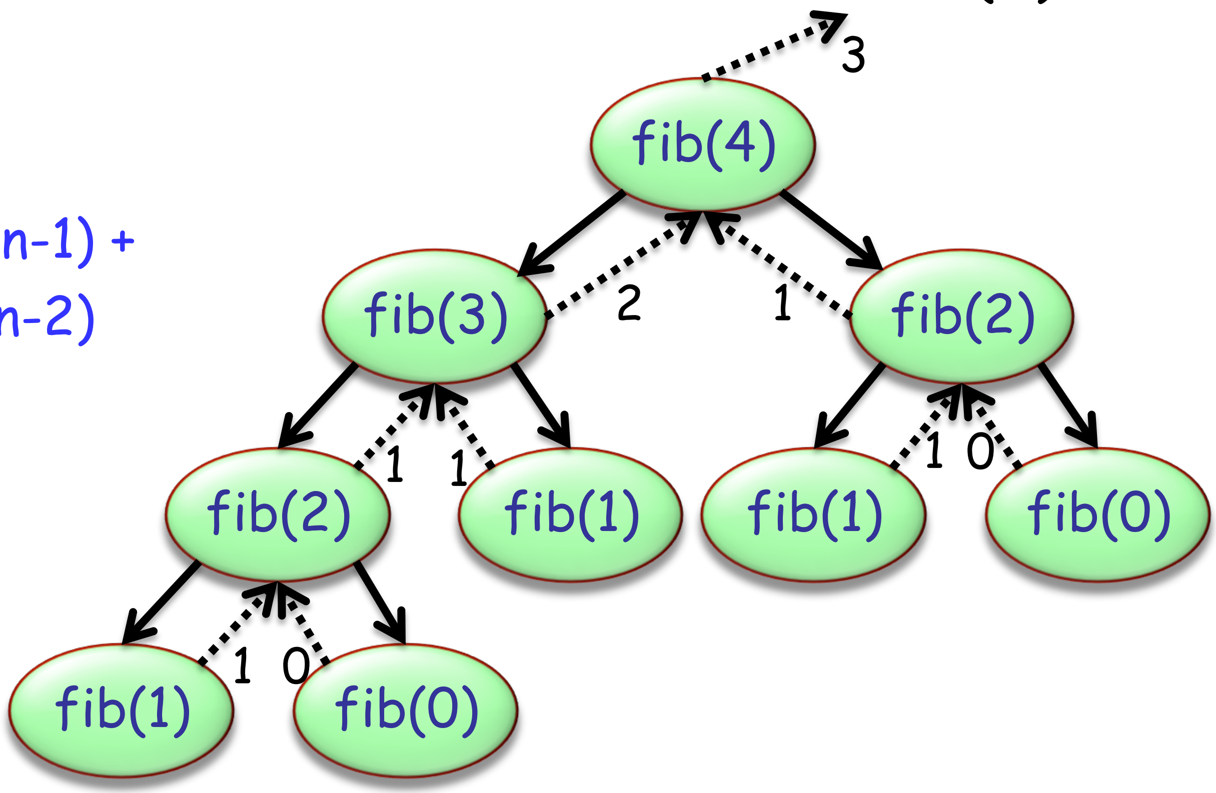
Source: en.wikipedia.org/wiki/Recursion

https://www.flickr.com/photos/tin-g

A recursive feature

```
fibonacci(n: INTEGER): INTEGER
  do
    if n = 0 then
      Result := 0
    elseif n = 1 then
      Result := 1
    else
      Result := fibonacci(n-1) +
                fibonacci(n-2)
    end
  end
```

- Calculate fibonacci(4)



The general notion of recursion

A definition for a concept is recursive
if it involves an instance of the concept itself

- The definition may *use "instances of concept itself* "
- *Recursion* is the use of a recursive definition

Thoughts

„To iterate is human, to recurse - divine!"

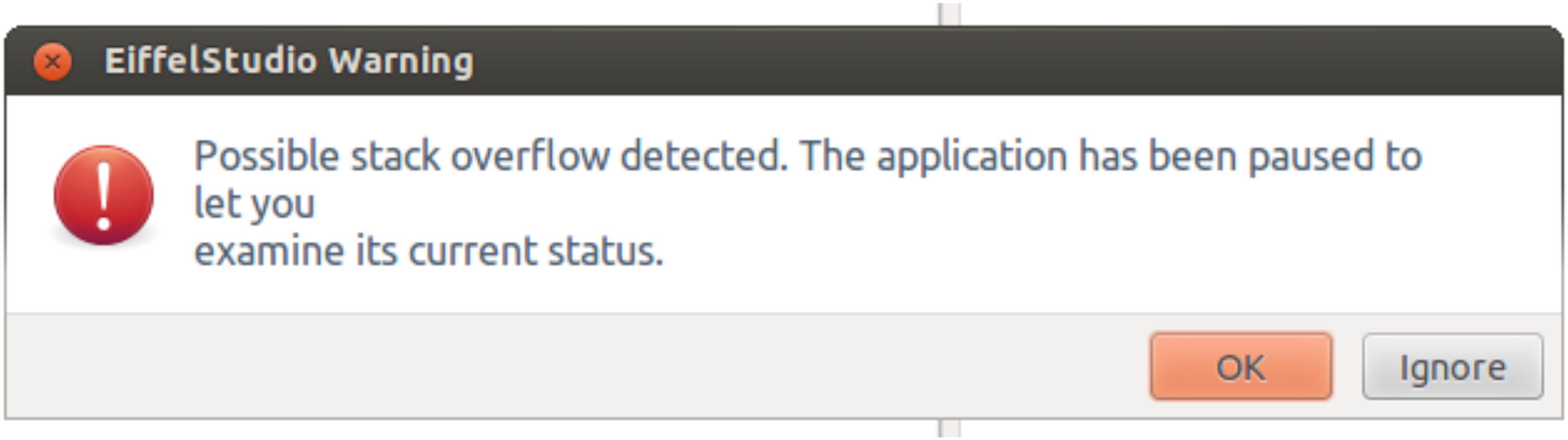
but ... computers are built by humans 

Better use iterative approach if reasonable?

Iteration vs. recursion

- Every recursion could be rewritten as an iteration and vice versa.
- Recursion is slower because all functions calls must be stored in memory to allow the return back to the caller functions.
- It's more intuitive in cases where it mimics our approach to the problem, e.g. generating Fibonacci numbers.
- Data structures such as trees are easier to explor with recursion.

Be careful when using recursion!



- Stack: a region of memory that store temporary data created by your program.

Exercise: Printing numbers

Hands-On

- If we pass n = 4, what will be printed?

```
print_int (n: INTEGER)
    do
        print (n)
        if n > 1 then
            print_int (n - 1)
        end
    end
```

4321

```
print_int (n: INTEGER)
    do
        if n > 1 then
            print_int (n - 1)
        end
        print (n)
    end
```

1234

Exercise: Reverse string

Hands-On

- Print a given string in reverse order using a recursive function.

Exercise: Solution

```
class APPLICATION

create
    make

feature
    make
        local
            s: STRING
        do
            create s.make_from_string ("poldomangia")
            invert(s)
        end

    invert (s: STRING)
        require
            s /= Void
        do
            if not s.is_empty then
                invert (s.substring (2, s.count))
                print (s[1])
            end
        end
end
```

Exercise: Sequences

Hands-On

- Write a recursive and an iterative program to print the following:

  111,112,113,121,122,123,131,132,133,
  211,212,213,221,222,223,231,232,233,
  311,312,313,321,322,323,331,332,333,

- Note that the recursive solution can use loops too.

Exercise: Recursive solution

```
cells: ARRAY [INTEGER]

handle_cell (n: INTEGER)
    local
        i: INTEGER
    do
        from
            i := 1
        until
            i > 3
        loop
            cells [n] := i
            if (n < 3) then
                handle_cell (n+1)
            else
                print (cells [1].out+cells [2].out+cells [3].out+",")
            end
            i := i + 1
        end
    end
```

Exercise: Iterative solution

```
from
    i := 1
until
    i > 3
loop
    from
        j := 1
    until
        j > 3
    loop
        from
            k := 1
        until
            k > 3
        loop
            print (i.out+j.out+k.out+",")
            k := k + 1
        end
        j := j + 1
    end
    i := i + 1
end
```

Arrays

An array is a very fundamental data-structure, which is very close to how your computer organizes its memory. An array is characterized by:

- Constant time for random reads/writes
- Costly to resize (including inserting elements in the middle of the array)
- Must be indexed by an integer
- Generally very space efficient.

In Eiffel the basic array class is generic, *V_ARRAY [G]*.

Using Arrays

Hands-On

Which of the following lines are valid?
Which can fail, and why?

- my_array : V_ARRAY [STRING] — Valid, can't fail
- my_array ["Fred"] := "Sam" — Invalid
- my_array [10] + "'s Hat" — Valid, can fail
- my_array [5] := "Ed" — Valid, can fail
- my_array.force ("Constantine", 9) — Valid, can't fail

Which is not a constant-time array operation?

Linked Lists

- Linked lists are one of the simplest data-structures
- They consist of linkable cells

```
class LINKABLE [G]

create
    set_value

feature
    set_value (v : G)
        do
            value := v
        end

    value : G

    set_next (n : LINKABLE[G])
        do
            next := n
        end

    next : LINKABLE [G]
end
```

Using Linked Lists

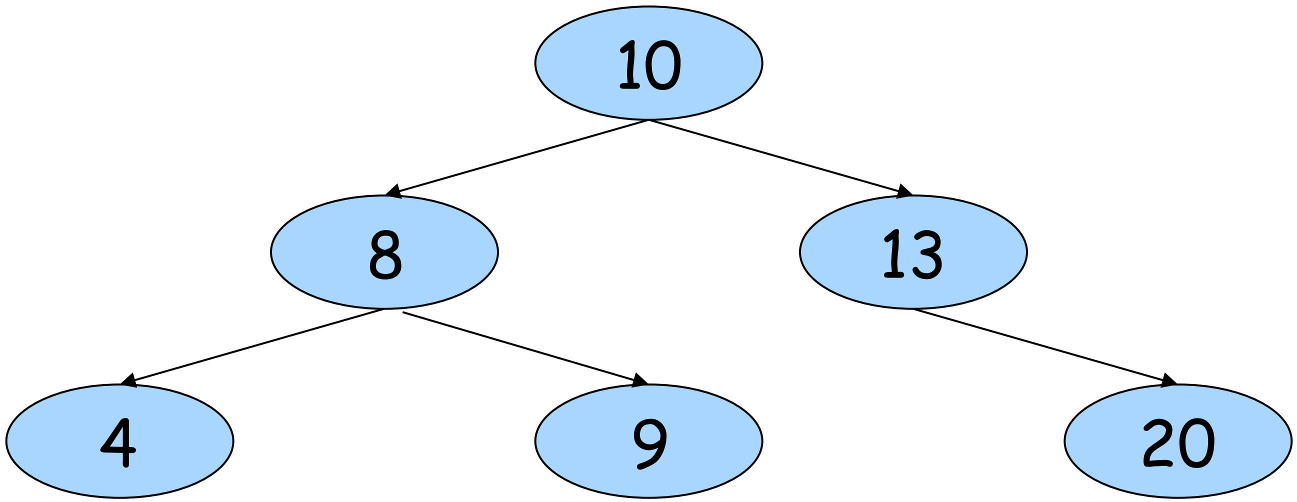
Hands-On

Suppose you keep a reference to only the head of the linked list, what is the running time (using big O notation) to:

- Insert at the beginning — O (1)
- Insert in the middle — O (n)
- Insert at the end — O (n)
- Find the length of the list — O (n)

What simple optimization could be made to make end-access faster?

Binary search tree



- A binary search tree is a binary tree where each node has a *COMPARABLE* value.
- Left sub-tree of a node contains only values less than the node's value.
- Right sub-tree of a node contains only values greater than or equal to the node's value.

Exercise: Adding nodes

Hands-On

- Implement command *put (n: INTEGER)* in class *NODE* which creates a new *NODE* object at the correct place in the binary search tree rooted by **Current**.
- Test your code with a class *APPLICATION* which builds a binary search tree using put and prints out the values using the traversal feature.
- Hint: You might need to adapt the traversal feature such that the values are printed out in order.

Exercise: Solution

- See code in IDE.

Exercise: Searching

Hands-On

- Implement feature *has (n: INTEGER): BOOLEAN* in class *NODE* which returns true if and only if *n* is in the tree rooted by **Current**.
- Test your code with a class *APPLICATION* which builds a binary search tree and calls *has*.

Exercise: Solution

- See code in IDE.