Imperative programming with Python

January 2012 project: Class #3

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Functions: DIY

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```
def is_even(n):
    if n % 2 == 0:
        return True
    else:
        return False
```

- The argument passed to `is_even(n)` will be assigned to `n`.
- The `return` keyword sets the return value and exits the function immediately. It can also be used without a value (just `return`).

Functions: DIY

- Functions are defined with the `def` keyword.

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def is_even(n):
    if n % 2 == 0:
        return True
    else:
        return False
```

- The argument passed to `is_even(n)` will be assigned to `n`.
- The `return` keyword sets the return value and exits the function immediately. It can also be used without a value (just `return`).
- *Good practice tip*: reduce the number of return points. If possible, have only one.

```
def is_even(n):
    return (n % 2 == 0)
```

Functions: local variables

- Variables inside function definitions have a *local* scope.

```
def average(n, m):
    thesum = float(n + m)
    return thesum/2
```

- You can only use the function as a *black box*

```
>>> print average(3,4)
3.5
>>> print thesum
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name ’thesum’ is not defined
```

- Design tip: thinking of functions as black boxes performing a certain action is the way to go.

Functions: execution and the call stack

-
  ```
  def cat_twice_and_print(part1, part2):
      cat = part1 + part2
      print_twice(cat)

  def print_twice(msg):
      print msg
      print msg

  line1 = 'welcome␣'
  line2 = 'to␣the␣jungle'
  cat_twice_and_print(line1, line2)
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line1 ↦ 'welcome '
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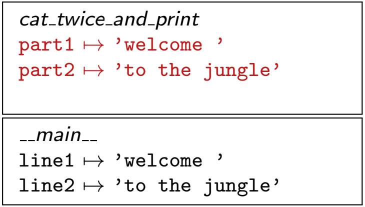

cat_twice_and_print
part1 ↦ 'welcome '
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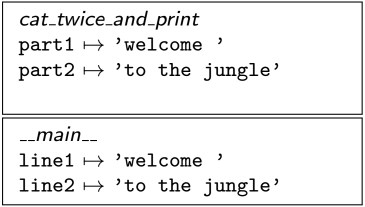

cat_twice_and_print

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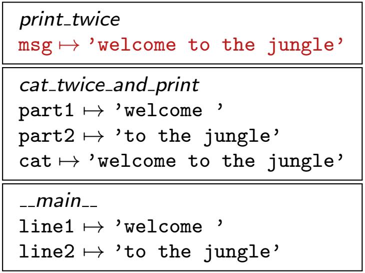

print_twice

msg ↦ 'welcome to the jungle'

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welcome to the jungle
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Functions: recursion

- Functions can call *themselves* in their definition.

```
# calculates n * m (in a complicated way)
def multiply(n, m):
    if n == 0:
        return 0
    else:
        return m + multiply(n - 1, m)
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n ↦ 2, m ↦ 7
ret ↦ 7 + ...

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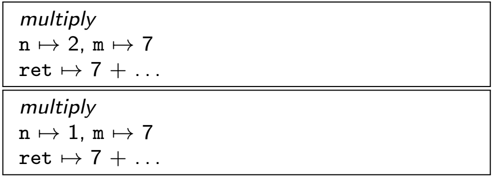

multiply
n $\mapsto$ 2, m $\mapsto$ 7
ret $\mapsto$ 7 + ...

multiply
n $\mapsto$ 1, m $\mapsto$ 7
ret $\mapsto$ 7 + ...

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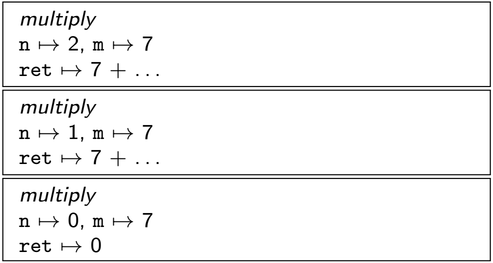

multiply
$\mathtt{n} \mapsto 2$, $\mathtt{m} \mapsto 7$
$\mathtt{ret} \mapsto 7 + \ldots$

multiply
$\mathtt{n} \mapsto 1$, $\mathtt{m} \mapsto 7$
$\mathtt{ret} \mapsto 7 + \ldots$

multiply
$\mathtt{n} \mapsto 0$, $\mathtt{m} \mapsto 7$
$\mathtt{ret} \mapsto 0$

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$\texttt{n} \mapsto 2$, $\texttt{m} \mapsto 7$
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multiply
$\texttt{n} \mapsto 1$, $\texttt{m} \mapsto 7$
$\texttt{ret} \mapsto 7 + 0 = 7$

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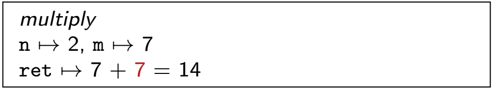

multiply

$\mathtt{n} \mapsto 2$, $\mathtt{m} \mapsto 7$

$\mathtt{ret} \mapsto 7 + 7 = 14$

Functions: recursion

- It is crucial that the arguments of a recursive call are in some sense ‘smaller’ than the arguments of the function call itself.
- What happens if we write `multiply` as follows

```
def multiply(n, m):
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```
>>> multiply(2, 7)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 5, in multiply
  File "<stdin>", line 5, in multiply
...
  File "<stdin>", line 5, in multiply
RuntimeError: maximum recursion depth exceeded
```

- Stack overflow!

Functions: recursion

- You can also have many recursive calls

```
def fib(n):
    if n == 0:
        return n
    else:
        return fib(n - 1) + fib(n - 2)
```

- Is it well defined?

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def fib(n):
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```python
def fib(n):
    if n == 0 or n == 1:
        return n
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        return fib(n - 1) + fib(n - 2)
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Functions: recursion

- You can also have many recursive calls

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def fib(n):
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```

- Is it well defined? Yes.

Functions: recursion

- The argument itself *can* increase. . .

```
def reverse_string(s):
    return reverse_from_n(s, 0)

def reverse_from_n(s, i):
    if i == len(s):
        return ''
    else:
        return reverse_from_n(s, i+1) + s[i]
```

Functions: recursion

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```

- But if you look closer `len(s) - i` is strictly decreasing.

Functions: recursion

- Is the folowing function well defined (for $n > 0$)?

```python
def collatz(n):
    if n == 1:
        return 0
    elif n % 2 == 0:
        return 1 + collatz(n/2)
    else:
        return 1 + collatz(3*n+1)
```

Functions: recursion

- Is the folowing function well defined (for $n > 0$)?

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def collatz(n):
    if n == 1:
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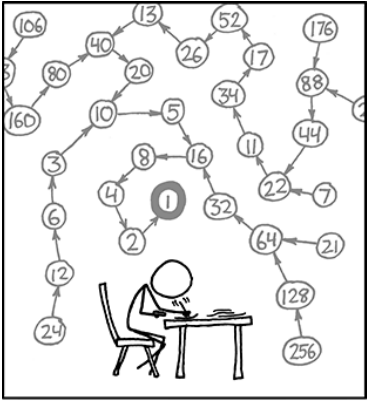
```

- Who knows! It has been an open problem for years.

The collatz conjecture

By the XKCD webcomic



THE COLLATZ CONJECTURE STATES THAT IF YOU PICK A NUMBER, AND IF IT'S EVEN DIVIDE IT BY TWO AND IF IT'S ODD MULTIPLY IT BY THREE AND ADD ONE, AND YOU REPEAT THIS PROCEDURE LONG ENOUGH, EVENTUALLY YOUR FRIENDS WILL STOP CALLING TO SEE IF YOU WANT TO HANG OUT.

Repetition

- Suppose we want to make a function that given n calculates $\sum_{i=1}^{n} i$.

```
def sum_up_to(n):
    res = 1 + 2 + ... + n
    return res
```

This is not a valid program, for many reasons.

Repetition

- Suppose we want to make a function that given n calculates $\sum_{i=1}^{n} i$.

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def sum_up_to(n):
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This is not a valid program, for many reasons.

- Luckily, computers are very good at doing repetitive things. We have the `while` statement to aid us.

```
def sum_up_to(n):
    i = 1
    v = 0
    while i <= n:
        v = v + i
        i = i + 1
    return v
```

The body gets repeated while the condition evaluates to *true*.

Repetition

- Another handy construction is the `for` statement
- It goes through so called 'iterable' objects, e.g. strings

```
>>> for letter in 'hello':
...   print 'Give me an "' + letter + '"!'
...
Give me an "h"!
Give me an "e"!
Give me an "l"!
Give me an "l"!
Give me an "o"!
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- ‘Lists’ are also iterable (we will see them later)

```
>>> range(3)
[0, 1, 2]
>>> for i in range(3):
...   print i**2
...
0
1
4
```

Repetition: while loops

- `while` loops are a powerful but tricky construction.
- They can run forever and make our program hang!

```
while True:
    x = x + 1
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while True:
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ok, we would not write that, but what about...

```
x = int(raw_input())
sum = 0
while x != 100:
    sum = sum + x
    x = x + 2
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  ```
  x = int(raw_input())
  sum = 0
  while x != 100:
      sum = sum + x
      x = x + 2
  ```

- If $x > 100$ or x is odd this loop never ends.

Repetition: loop invariants

- A *loop invariant* is an invariant used to prove properties of loops.
- For example, correctness and termination of loops.
- Connected to pre and post-conditions.

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E.g.: `count(c:String, sentence:String)` → `res:Int`

- `pre:` `True`
- `post:` $res = |[1 : i \in \{0, \ldots, |sentence| - 1\}, \mathtt{sentence}_i = \mathtt{c}]|$

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- `pre:` `True`
- `post:` $res = |[1 : i \in \{0, \ldots, |sentence| - 1\}, \texttt{sentence}_i = \texttt{c}]|$

Suppose we have the following implementation

```
def count(c, sentence):
    i = 0; n = 0
    while i < len(sentence):
        if sentence[i] == c: n = n + 1
        i = i + 1
    return n
```

Repetition: loop invariants

post: $res = |[1 : i \in \{0, \ldots, |sentence| - 1\}, \mathtt{sentence}_i = \mathtt{c}]|$

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Repetition: loop invariants

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        i = i + 1
    return n
```

Let **C** be our loop condition and **I** be our loop invariant, a theorem says:

$$\frac{\{C \land I\}\ \text{body}\ \{I\}}{\{I\}\ \textbf{while}\ (C)\ \text{body}\ \{\neg C \land I\}}$$

- **C:**

Repetition: loop invariants

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Let **C** be our loop condition and **I** be our loop invariant, a theorem says:

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If we chose correctly our invariant, with $\neg C \wedge I$ we should be able to prove the postcondition.

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- But, if you don't use `while` you can only write 'some' of them.
- In fact, you could write any program using just ONE `while`.

The estimation game

- Building software in the real world is a lot about planning.
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- Average pages of an ILLC MoL thesis → 77.

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