

Functions and Abstraction

BBM 101 - Introduction to Programming I

Hacettepe University
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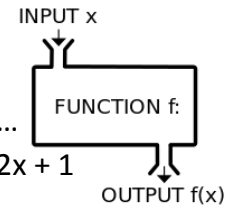
Fuat Akal, Aykut Erdem, Erkut Erdem, Vahid Garousi

Slides based on material prepared by Ruth Anderson, Michael Ernst and Bill Howe in the course CSE 140 University of Washington

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Functions

- In math, you **use** functions: sine, cosine, ...
- In math, you **define** functions: $f(x) = x^2 + 2x + 1$



- A function packages up and names a computation
- Enables re-use of the computation (generalization)
- **Don't Repeat Yourself** (DRY principle)
- Shorter, easier to understand, less error-prone

- Python lets you **use** and **define** functions
- We have already seen some Python functions:
 - **len, float, int, str, range**

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Using (“calling”) a Function

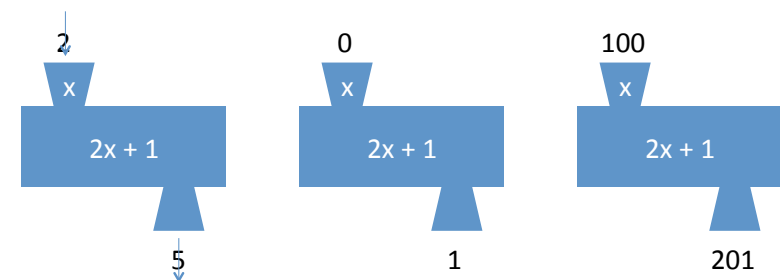
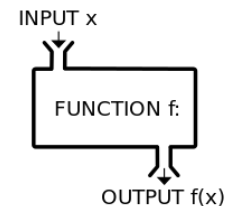
```
len("hello")      len("")
round(2.718)      round(3.14)
pow(2, 3)         range(1, 5)
math.sin(0)       math.sin(math.pi / 2)
```

- Some need no input: `random.random()`
- All produce output

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A Function is a Machine

- You give it input
- It produces a result (output)

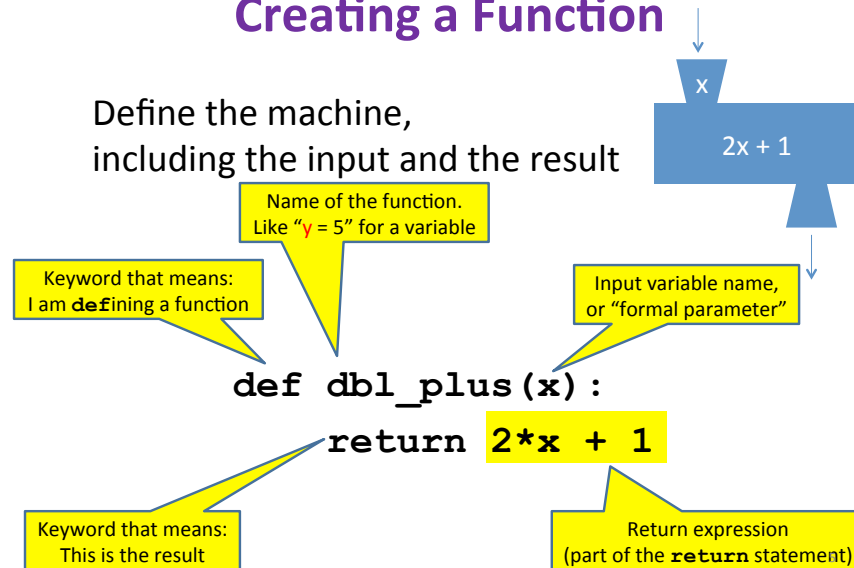


In math: $\text{func}(x) = 2x + 1$

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Creating a Function

Define the machine,
including the input and the result



More Function Examples

Define the machine, including the input and the result

```
def square(x):
    return x * x

def fahr_to_cent(fahr):
    return (fahr - 32) / 9.0 * 5

def cent_to_fahr(cent):
    result = cent / 5.0 * 9 + 32
    return result

def abs(x):
    if x < 0:
        return -x
    else:
        return x

def print_hello():
    print "Hello, world"

def print_fahr_to_cent(fahr):
    result = fahr_to_cent(fahr)
    print result
```

Annotations:

- `print "Hello, world"`: No return statement. Returns the value None. Are also called 'procedures'.

What is the result of:

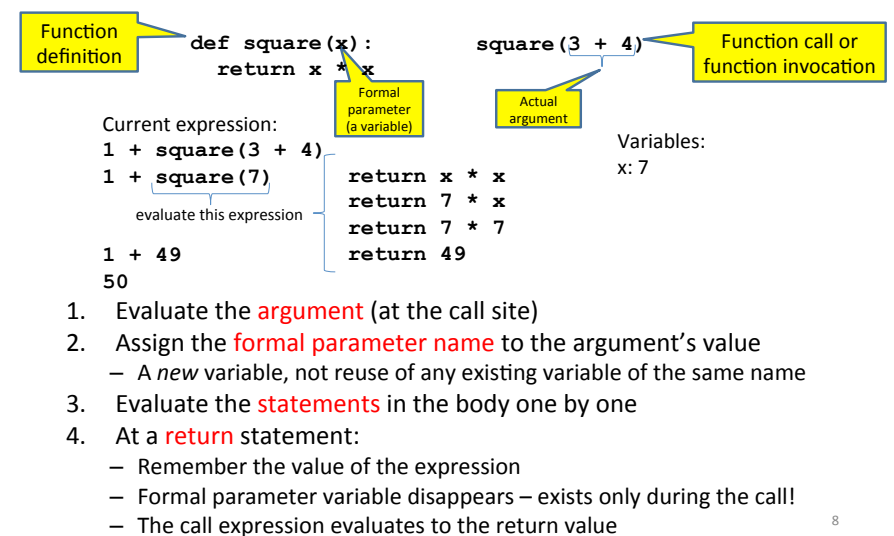
```
x = 42
square(3) + square(4)
print x
boiling = fahr_to_cent(212)
cold = cent_to_fahr(-40)
Print(result)
print(abs(-22))
print(print_fahr_to_cent(32))
```

Python Interpreter

- An expression evaluates to a value
 - Which can be used by the containing expression or statement
- `print("test")` statement writes text to the screen
- The Python interpreter (command shell) reads statements and expressions, then executes them
- If the interpreter executes an expression, it prints its value
- In a program, evaluating an expression does not print it
- In a program, printing an expression does not permit it to be used elsewhere

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How Python Executes a Function Call



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Example of Function Invocation

```
def square(x):
    return x * x
```

```
square(3) + square(4)
```

```
return x * x
return 3 * 3
return 3 * 3
return 9
```

```
9 + square(4)
```

```
return x * x
return 4 * 4
return 4 * 4
return 16
```

```
9 + 16
```

```
25
```

Variables:

(none)

(none)

x: 4

x: 4

x: 4

x: 4

(none)

(none)

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Expression with Nested Function Invocations: Only One Executes at a Time

```
def fahr_to_cent(fahr):
    return (fahr - 32) / 9.0 * 5
```

```
def cent_to_fahr(cent):
    return cent / 5.0 * 9 + 32
```

```
fahr_to_cent(cent_to_fahr(20))
return cent / 5.0 * 9 + 32
return 20 / 5.0 * 9 + 32
return 68
```

```
fahr_to_cent(68)
return (fahr - 32) / 9.0 * 5
return (68 - 32) / 9.0 * 5
return 20
20
```

Variables:

(none)

cent: 20

cent: 20

cent: 20

(none)

fahr: 68

fahr: 68

fahr: 68

(none)

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Expression with Nested Function Invocations: Only One Executes at a Time

```
def square(x):
    return x * x
```

```
square(square(3))
```

```
return x * x
return 3 * 3
return 3 * 3
return 9
```

```
square(9)
```

```
return x * x
return 9 * 9
return 9 * 9
return 81
```

```
81
```

Variables:

(none)

(none)

(none)

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Function that Invokes Another Function: Both Function Invocations are Active

```
def square(z):
    return z*z
def hypoten_use(x, y):
    return math.sqrt(square(x) + square(y))
```

```
Hypoten_use(3, 4)
return math.sqrt(square(x) + square(y))
return math.sqrt(square(3) + square(4))
return z*z
return 3*3
return 9
return math.sqrt(9 + square(y))
return math.sqrt(9 + square(4))
return z*z
return 4*4
return 16
return math.sqrt(9 + 16)
return math.sqrt(25)
return 5
5
```

Variables:

(none)

y: 4

y: 4

z: 3 y: 4

z: 3 y: 4

z: 3 y: 4

y: 4

y: 4

z: 4 y: 4

z: 4 y: 4

z: 4 y: 4

y: 4

y: 4

y: 4

(none)

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Shadowing of Formal Variable Names

```
def square(x):
    return x*x
def hypotenuse(x, y):
    return math.sqrt(square(x) + square(y))
```

Same formal parameter name

```
hypotenuse(3, 4)
return math.sqrt(square(x) + square(y))
return math.sqrt(square(3) + square(y))
return x*x
return 3*3
return 9
return math.sqrt(9 + square(y))
return math.sqrt(9 + square(4))
return x*x
return 4*4
return 16
return math.sqrt(9 + 16)
return math.sqrt(25)
return 5
```

Variables:

```
(none)
y:4
y:4
y:4
y:4
y:4
y:4
x: 4 y:4
x: 4 y:4
x: 4 y:4
y:4
y:4
y:4
y:4
(none)
```

Formal parameter is a new variable

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Shadowing of Formal Variable Names

```
def square(x):
    return x*x
def hypotenuse(x, y):
    return math.sqrt(square(x) + square(y))
```

Same diagram, with variable scopes or environment frames shown explicitly

```
hypotenuse(3, 4)
return math.sqrt(square(x) + square(y))
return math.sqrt(square(3) + square(y))
return x*x
return 3*3
return 9
return math.sqrt(9 + square(y))
return math.sqrt(9 + square(4))
return x*x
return 4*4
return 16
return math.sqrt(9 + 16)
return math.sqrt(25)
return 5
```

Variables:

```
(none) hypotenuse()
y:4
y:4
y:4
y:4
y:4
square()
square()
x: 4
x: 4
x: 4
y:4
y:4
y:4
y:4
y:4
y:4
(none)
```

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In a Function Body, Assignment Creates a Temporary Variable (like the formal parameter)

```
stored = 0
def store_it(arg):
    stored = arg
    return stored
```

★ `y = store_it(22)`
★ `print y`
★ `print stored`

Show evaluation of the starred expressions:

```
y = store_it(22)
    stored = arg; return stored
    stored = 22; return stored
    return stored
    return 22
y = 22
print stored
print 0
```

Variables:

Global or top level

```
store_it()
arg: 22
arg: 22
arg: 22 stored: 22
arg: 22 stored: 22
stored: 0
stored: 0
stored: 0
stored: 0 y: 22
stored: 0 y: 22
stored: 0 y: 22
stored: 0 y: 22
```

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How to Look Up a Variable

Idea: find the nearest variable of the given name

1. Check whether the variable is defined in the **local scope**
2. ... check any intermediate scopes (**none** in CSE 140!) ...
3. Check whether the variable is defined in the **global scope**

If a local and a global variable have the **same name**, the global variable is inaccessible ("**shadowed**")

This is confusing; try to avoid such shadowing

```
x = 22
stored = 100
def lookup():
    x = 42
    return stored + x
lookup()
x = 5
stored = 200
lookup()
```

```
def lookup():
    x = 42
    return stored + x
x = 22
stored = 100
lookup()
x = 5
stored = 200
lookup()
```

What happens if we define **stored** after **lookup**?

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Local Variables Exist Only while the Function is Executing

```
def cent_to_fahr(cent):  
    result = cent / 5.0 * 9 + 32  
    return result
```

```
tempf = cent_to_fahr(15)  
print result
```

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Use Only the Local and the Global Scope

```
myvar = 1  
  
def outer():  
    myvar = 1000  
    return inner()  
  
def inner():  
    return myvar  
  
print outer()
```

The handouts have a more precise rule, which applies when you define a function inside another function.

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Abstraction



- Abstraction = ignore some details
- Generalization = become usable in more contexts
- Abstraction over **computations**:
 - functional abstraction, a.k.a. procedural abstraction
- As long as you know what the function **means**, you don't care **how** it computes that value
 - You don't care about the *implementation* (the function body)

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Defining Absolute Value

```
def abs(x):  
    if val < 0:  
        return -1 * val  
    else:  
        return 1 * val
```

```
def abs(x):  
    if val < 0:  
        return - val  
    else:  
        return val
```

```
def abs(x):  
    if val < 0:  
        result = - val  
    else:  
        result = val  
    return result
```

```
def abs(x):  
    return math.sqrt(x*x)
```

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Defining Round (for positive numbers)

```
def round(x):  
    return int(x+0.5)
```

```
def round(x):  
    fraction = x - int(x)  
    if fraction >= .5:  
        return int(x) + 1  
    else:  
        return int(x)
```

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Two Types of Documentation

1. Documentation for **users/clients/callers**
 - Document the *purpose* or *meaning* or *abstraction* that the function represents
 - Tells **what** the function does
 - Should be written for *every* function
2. Documentation for **programmers** who are reading the code
 - Document the *implementation* – specific code choices
 - Tells **how** the function does it
 - Only necessary for tricky or interesting bits of the code

For **users**: a string as the first element of the function body

For **programmers**: arbitrary text after #

```
def square(x):  
    """Returns the square of its argument."""  
    # "x*x" can be more precise than "x**2"  
    return x*x
```

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Multi-line strings

- New way to write a string – surrounded by three quotes instead of just one
 - "hello"
 - 'hello'
 - """hello"""
 - '''hello'''
- Any of these works for a documentation string
- Triple-quote version:
 - can include newlines (carriage returns), so the string can span multiple lines
 - can include quotation marks

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Don't write useless comments

- Comments should give information that is not apparent from the code
- Here is a counter-productive comment that merely clutters the code, which makes the code *harder* to read:

```
# increment the value of x  
x = x + 1
```

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Where to write comments

- By convention, write a comment *above* the code that it describes (or, more rarely, on the same line)
 - First, a reader sees the English intuition or explanation, then the possibly-confusing code
- ```
The following code is adapted from
"Introduction to Algorithms", by Cormen et
al.,
section 14.22.
while (n > i):
 ...
```
- A comment may appear anywhere in your program, including at the end of a line:  

```
x = y + x # a comment about this line
```
- For a line that starts with #, indentation must be consistent with surrounding code

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## Each variable should represent one thing

```
def atm_to_mbar(pressure):
 return pressure * 1013.25

def mbar_to_mmHg(pressure):
 return pressure * 0.75006

Confusing
pressure = 1.2 # in atmospheres
pressure = atm_to_mbar(pressure)
pressure = mbar_to_mmHg(pressure)
print pressure

Better
in_atm = 1.2
in_mbar = atm_to_mbar(in_atm)
in_mmHg = mbar_to_mmHg(in_mbar)
print in_mmHg

Best
def atm_to_mmHg(pressure):
 in_mbar = atm_to_mbar(pressure)
 in_mmHg = mbar_to_mmHg(in_mbar)
 return in_mmHg
print atm_to_mmHg(1.2)

Legal, but confusing: don't do this!
x = 3
...
x = "hello"
...
x = [3, 1, 4, 1, 5]
...
```

Corollary: Each variable should contain values of only one type

If you use a descriptive variable name, you are unlikely to make these mistakes

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## Exercises

```
def cent_to_fahr(c):
 print cent / 5.0 * 9 + 32
print cent_to_fahr(20)
```

```
def myfunc(n):
 total = 0
 for i in range(n):
 total = total + i
 return total
print myfunc(4)
```

```
def c_to_f(c):
 print "c_to_f"
 return c / 5.0 * 9 + 32
```

```
def make_message(temp):
 print "make_message"
 return ("The temperature is "
+ str(temp))

for tempc in [-40,0,37]:
 tempf = c_to_f(tempc)
 message = make_message(tempf)
 print message
```

double(7)

abs(-20 - 2) + 20

Use the Python Tutor:

<http://>

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## What does this print?

```
def cent_to_fahr(cent):
 print cent / 5.0 * 9 + 32

print cent_to_fahr(20)
```

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## What does this print?

```
def myfunc(n):
 total = 0
 for i in range(n):
 total = total + i
 return total

print myfunc(4)
```

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## What does this print?

```
def c_to_f(c):
 print "c_to_f"
 return c / 5.0 * 9 + 32

def make_message(temp):
 print "make_message"
 return "The temperature is " + str(temp)

for tempc in [-40,0,37]:
 tempf = c_to_f(tempc)
 message = make_message(tempf)
 print message
```

c\_to\_f  
make\_message  
The temperature is -40.0  
c\_to\_f  
make\_message  
The temperature is 32.0  
c\_to\_f  
make\_message  
The temperature is 98.6

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## Decomposing a problem

- Breaking down a program into functions is *the fundamental activity* of programming!
- How do you decide when to use a function?
  - One rule: DRY (Don't Repeat Yourself)
  - Whenever you are tempted to copy and paste code, don't!
- Now, how do you design a function?

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## How to design a function

**1. Wishful thinking:**  
Write the program as if the function already exists

**2. Write a specification:**  
Describe the inputs and output, including their types  
No implementation yet!

**3. Write tests:** Example inputs and outputs

**4. Write the function body** (the implementation)  
First, write your plan in English, then translate to Python

```
print "Temperature in Farenheit:", tempf
tempc = fahr_to_cent(tempf)
print "Temperature in Celsius:", tempc

def fahr_to_cent(f):
 """Input: a number representing degrees Farenheit
 Return value: a number representing degrees
 centigrade
 """
 result = (f - 32) / 9.0 * 5
 return result

assert fahr_to_cent(32) == 0
assert fahr_to_cent(212) == 100
assert fahr_to_cent(98.6) == 37
assert fahr_to_cent(-40) == -40
```

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## Review: how to evaluate a function call

1. Evaluate the function and its arguments to values
  - If the function value is not a function, execution terminates with an error
2. Create a new stack frame
  - The parent frame is the one where the function is defined
    - In CSE 140, this is always the global frame
  - A frame has bindings from variables to values
  - Looking up a variable starts here
    - Proceeds to the next older frame if no match here
    - The oldest frame is the “global” frame
    - All the frames together are called the “environment”
  - Assignments happen here
3. Assign the actual argument values to the formal parameter variable
  - In the new stack frame
4. Evaluate the body
  - At a return statement, remember the value and exit
  - If at end of the body, return **None**
5. Remove the stack frame
6. The call evaluates to the returned value

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## Functions are values The function can be an expression

```
def double(x):
 return 2*x

print double
myfns = [math.sqrt, int, double, math.cos]
myfns[1](3.14)
myfns[2](3.14)
myfns[3](3.14)

def doubler():
 return double
doubler()(2.718)
```

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