



Functions and abstraction

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Functions

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

In Python:

- 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, print**

Using (“calling”) a function

```
len("hello")
```

```
len("")
```

```
round(2.718)
```

```
round(3.14)
```

```
pow(2, 3)
```

```
range(1, 5)
```

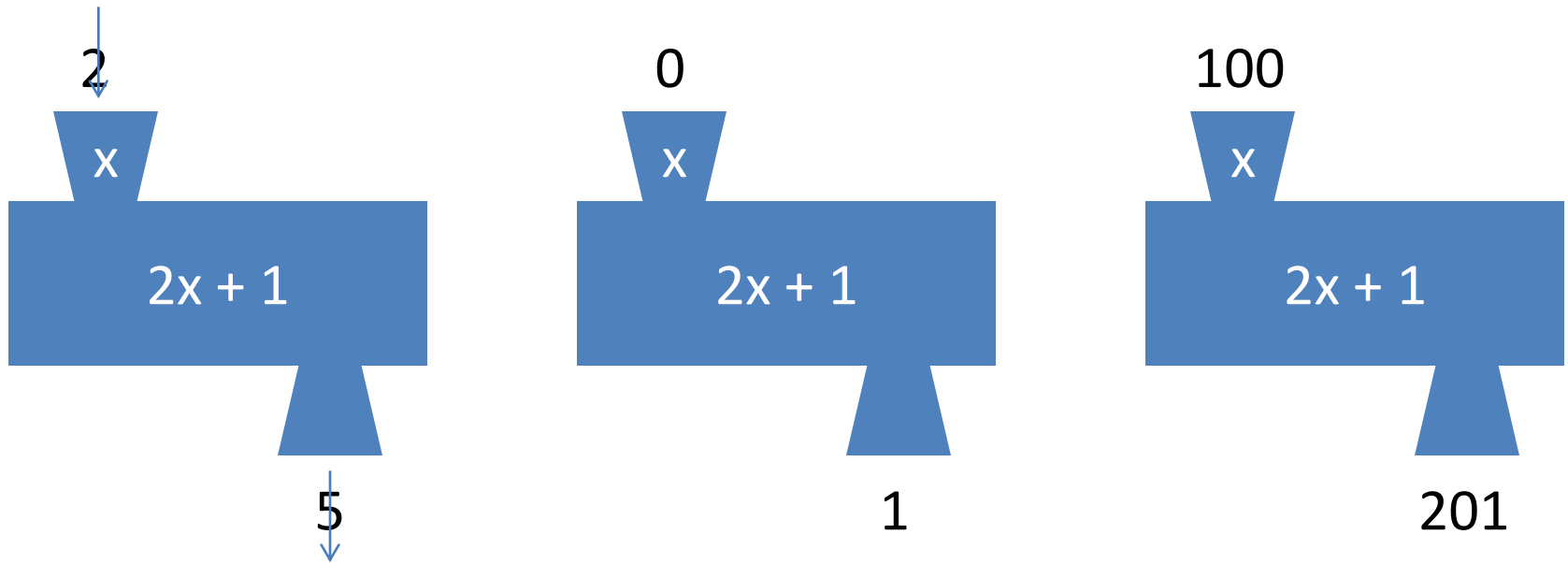
```
math.sin(0)
```

```
str(17)
```

- Some need no input: `random.random()`
- All of the functions above “return” a value

A function is a machine

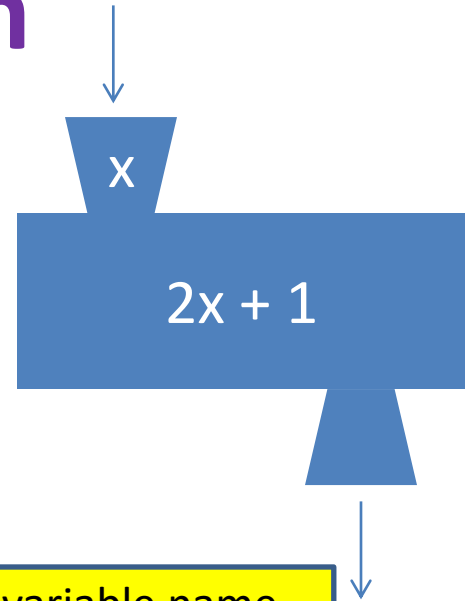
- You give it input
- It produces a result, “returns” a value



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

Creating a function

Define the machine,
including the input and the result



Name of the function.
Like “y = 5” for a variable

Keyword that means:
I am **def**ining a function

Input variable name,
or “formal parameter”

```
def dbl_plus (x) :
```

```
return 2 * x + 1
```

Keyword that means:
This is the result

Return expression
(part of the **return** statement)

How Python executes a function call

Function definition

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

Formal parameter
(a variable)

square(3 + 4)

Actual argument

Function call or function invocation, the "call site"

Current expression:

1 + square(3 + 4)

1 + square(7)

evaluate this expression

1 + 49

50

return x * x

return 7 * x

return 7 * 7

return 49

Variables:

x: 7

1. Evaluate the **argument** at the "call site" – the place where we are calling the function from in our program
2. Assign the actual argument's value to the **formal parameter name**
 - A new variable, not reuse of any existing variable of the same name
3. Evaluate the **statements** in the body of the function one by one
4. At a **return** statement:
 - Formal parameter variable disappears – exists only during the call!
 - The call expression evaluates to the "returned" value

[See in python tutor](#)

Function examples

```
def dbl_plus(x):  
    return 2 * x + 1
```

```
def instructor_name():  
    return "Rob Thompson"
```

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

```
def print_greeting():  
    print("Hello, world")
```

```
def print_grade(points):  
    grade = points * 10  
    print("Grade is:", grade)
```

```
def calc_grade(points):  
    grade = points * 10  
    return grade
```

No **return** statement
Returns the value **None**
Executed for side effect

No **return** statement
Returns the value **None**
Executed for side effect

[See in python tutor](#)

[See in python tutor](#)

More function examples

```
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")
```

No **return** statement
Returns the value **None**
Executed for side effect

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

What is the result of:

```
x = 42  
print(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))
```


Digression: Two types of output

- An expression evaluates to a value
 - Which can be used by the containing expression or statement
- A **print** 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

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)

x: 3

x: 3

x: 3

x: 3

(none)

x: 4

x: 4

x: 4

x: 4

(none)

(none)

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)

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 * x  
    return 3 * 3  
    return 9
```

```
square(9)  
    return x * x  
    return 9 * x  
    return 9 * 9  
    return 81
```

81

Variables:

(none)

x: 3

x: 3

x: 3

x: 3

(none)

x: 9

x: 9

x: 9

x: 9

(none)

Function that invokes another function:

Both function invocations are active

```
def square(z):
```

```
    return z * z
```

```
def hypotenuse(x, y):
```

```
    return math.sqrt(square(x) + square(y))
```

```
hypotenuse(3, 4)
```

```
    return math.sqrt(square(x) + square(y))
```

```
    return math.sqrt(square(3) + square(y))
```

```
        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
```

Variables:

(none)

x: 3 y:4

x: 3 y:4

z: 3 x: 3 y:4

z: 3 x: 3 y:4

z: 3 x: 3 y:4

x: 3 y:4

x: 3 y:4

z: 4 x: 3 y:4

z: 4 x: 3 y:4

z: 4 x: 3 y:4

x: 3 y:4

x: 3 y:4

x: 3 y:4

(none)

Shadowing of formal variable names

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

Same formal parameter name,
but two completely different variables

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

```
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)  
x:3 y:4  
x:3 y:4  
x:3 x:3 y:4  
x:3 x:3 y:4  
x:3 x:3 y:4  
x:3 y:4  
x:3 y:4  
x:4 x:3 y:4  
x:4 x:3 y:4  
x:4 x:3 y:4  
x:3 y:4  
x:3 y:4  
x:3 y:4  
(none)
```

Formal parameter
is a *new* variable

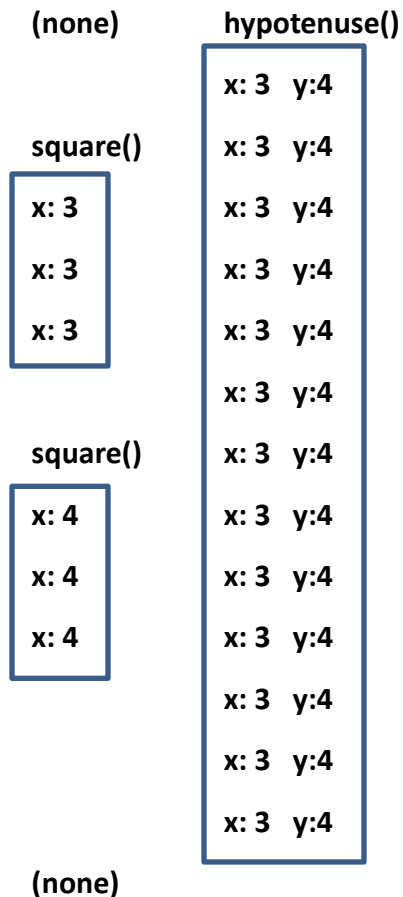
Shadowing of formal variable names

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

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
```

Same diagram, with *variable scopes* or *environment frames* shown explicitly

Variables:



In a function body, assignment creates a temporary variable (like the formal parameter)

```
stored = 0
```

[See in python tutor](#)

```
def store_it(arg):
```

```
    stored = arg
```

```
    return stored
```

```
★ y = store_it(22)
```

```
print(y)
```

```
★ print(stored)
```


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 160!) ...
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
val = lookup()
x = 5
stored = 200
val = lookup()
```

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

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

Local variables exist only while the function is executing

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

[See in python tutor](#)

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

Use only the local and the global scope!

```
myvar = 1

def outer():
    myvar = 1000
    temp = inner()
    return temp

def inner():
    return myvar

print(outer())
```

[See in python tutor](#)

Aside: The Evaluation Rules have a more precise rule, which applies when you define a function inside another function (which we will not be doing in this class!!!).

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)

Defining absolute value

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

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

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

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

Defining round (for positive numbers)

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

```
def round(x):  
    fraction = x - int(x)  
    if fraction >= 0.5:  
        return int(x) + 1  
    else:  
        return int(x)
```

Two types of documentation

1. Documentation for **users/clients/callers**
 - Document the *purpose* or *meaning* or *abstraction* that the function represents
 - Often called the “docstring”
 - 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."""  
    # Uses "x*x" instead of "x**2"  
    return x * x
```

Multi-line strings

- Ways to write strings:
 - `"hello"`
 - `'hello'`
 - `"""hello"""`
 - `'''hello'''`
- Triple-quote version:
 - can include newlines (carriage returns), so the string can span multiple lines
 - can include quotation marks
 - Use `"""hello"""` version for docstrings

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
```



DO NOT write comments like this.

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 should be consistent with surrounding code

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))
```

Corollary: Each variable should contain values of only one type

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

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

Exercises

```
def cent_to_fahr(cent):  
    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://pythontutor.com/>

What does this print?

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

What does this print?

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

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)
```

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

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?

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

```
def fahr_to_cent(fahr):  
    """Input: a number representing degrees Farenheit  
    Return value: a number representing degrees centigrade  
    """  
    result = (fahr - 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  
  
# Main program  
tempf = 32  
print("Temperature in Farenheit:", tempf)  
tempc = fahr_to_cent(tempf)  
print("Temperature in Celsius:", tempc)
```

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 160, this is always the global frame
 - A frame has bindings from variables to values
 - Looking up a variable starts in the local frame
 - Proceeds to its parent frame (the global frame) if no match in local frame
 - All the frames together are called the “environment”
3. Assign the actual argument values to the formal parameter variable
 - Add these as bindings in the new stack frame
4. Evaluate the body
 - Execute the statements in the function body
 - At a return statement, return the value and exit the function
 - If reach the end of the body of the function without encountering a return statement, then return the value **None**
(It is also fine to explicitly have a statement: **return None**)
5. Remove the stack frame
6. The call evaluates to the returned value

Aside: Functions are values

The function can be an expression

```
def double(x):  
    return 2 * x  
  
def doubler():  
    return double  
  
print(double)  
myfns = [math.sqrt, int, double, math.cos]  
print(myfns[1](3.14))  
print(myfns[2](3.14))  
print(myfns[3](3.14))  
print(doubler()(2.718))
```

[See in python tutor](#)