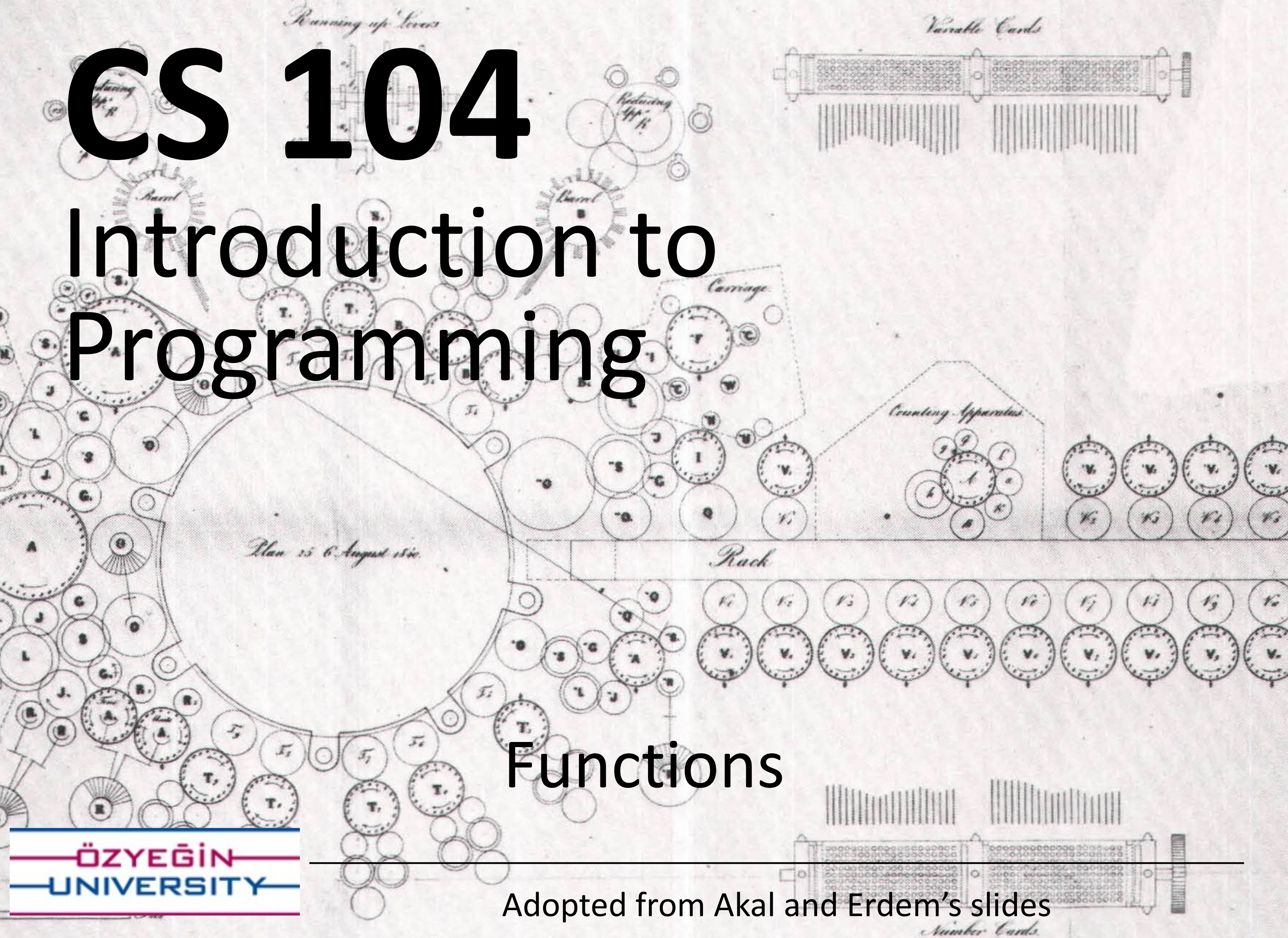
Drawing of Analytical Engine. Image: University of Cambridge



CS 104

Introduction to Programming

Functions

Adopted from Akal and Erdem’s slides

ÖZYEĞİN UNIVERSITY

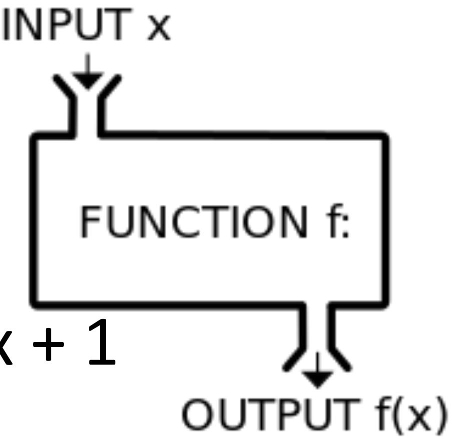
Exam Announcement

- Online midterm will be on 30 October 2021, between 15.40-17.40
- Detailed exam instructions will be sent this week

Lecture Overview

- Functions

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)
- **D**on't **R**epeat **Y**ourself (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`**

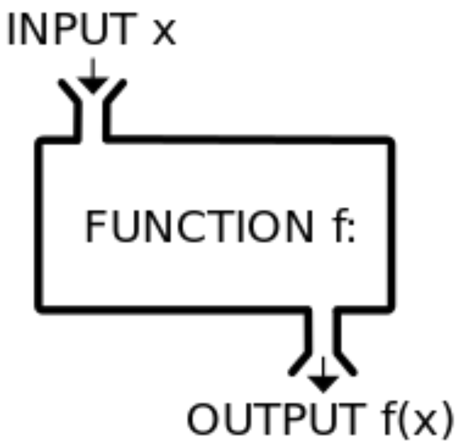
Using ("calling") a Function

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

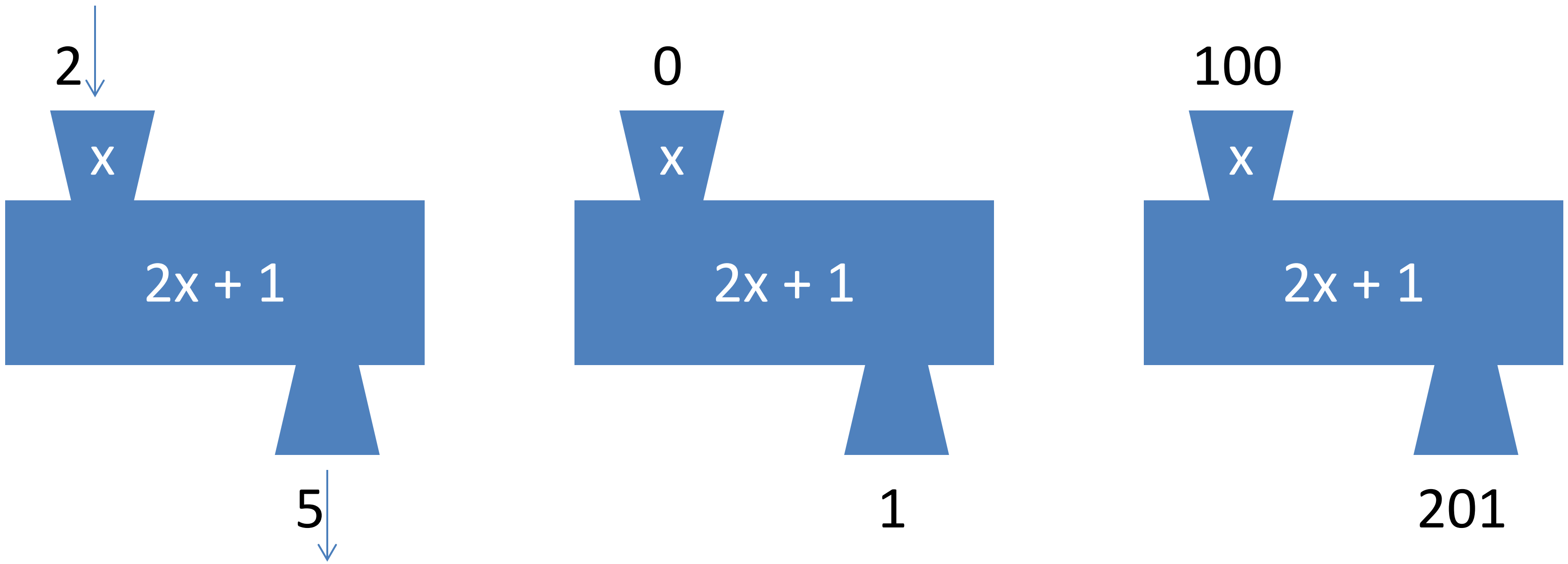
- Some need no input:
  `random.random()`

- All produce output

A Function is a Machine



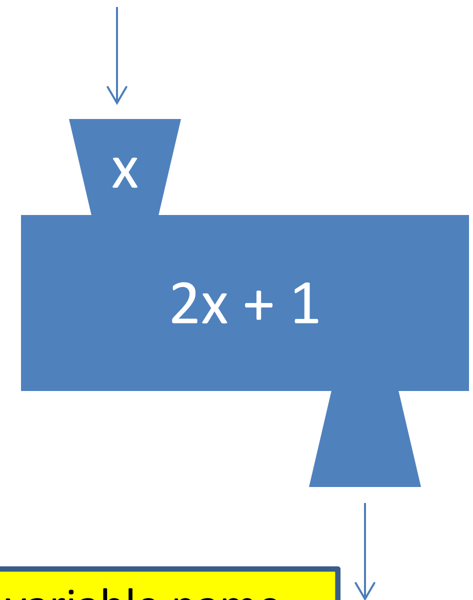
- You give it input
- It produces a result (output)



In math: $func(x) = 2x + 1$

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)

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")
```

No `return` statement
Returns the value `None`
Are also called ‘procedures’

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

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

An example

```
def lyrics():
    print("The very first line")
print(lyrics())
```

```
The very first line
None
```

How Python Executes a Function Call

Function definition

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

Formal parameter (a variable)

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

Actual argument

Function call or function invocation

Current expression:

```
1 + square(3 + 4)
1 + square(7)
```

evaluate this expression

```
return x * x
return 7 * x
return 7 * 7
return 49
```

```
1 + 49
50
```

Variables:
x: 7

1. Evaluate the **argument** (at the call site)
2. Assign the **formal parameter name** to the argument's value
   - A *new* variable, not reuse of any existing variable of the same name
3. Evaluate the **statements** in the body one by one
4. At a **return** statement:
   - Remember the value of the expression
   - Formal parameter variable disappears – exists only during the call!
   - The call expression evaluates to the return value

Example of Function Invocation

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

	Variables:
`square(3) + square(4)`	(none)
`return x * x`	`x: 3`
`return 3 * x`	`x: 3`
`return 3 * 3`	`x: 3`
`return 9`	`x: 3`
`9 + square(4)`	(none)
`return x * x`	x: 4
`return 4 * x`	x: 4
`return 4 * 4`	x: 4
`return 16`	x: 4
`9 + 16`	(none)
`25`	(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
```

	Variables:
`fahr_to_cent(cent_to_fahr(20))`	(none)
`return cent / 5.0 * 9 + 32`	cent: 20
`return 20 / 5.0 * 9 + 32`	cent: 20
`return 68`	cent: 20
`fahr_to_cent(68)`	(none)
`return (fahr – 32) / 9.0 * 5`	fahr: 68
`return (68 – 32) / 9.0 * 5`	fahr: 68
`return 20`	fahr: 68
`20`	(none)

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

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

	Variables:
`square(square(3))`	(none)
`return x * x`	x=3
`return 3 * x`	x=3
`return 3 * 3`	x=3
`return 9`	x=3
`square(9)`	(none)
`return x * x`	x=9
`return 9 * x`	x=9
`return 9 * 9`	x=9
`return 81`	x=9
`81`	(none)

Function that Invokes Another Function: Both Function Invocations are Active

```
import math

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

	Variables:
`hypoten_use(3, 4)`	(none)
`  return math.sqrt(square(x) + square(y))`	x:3 y:4
`  return math.sqrt(square(3) + square(y))`	x:3 y:4
`    return z*z`	z: 3
`    return 3*3`	z: 3
`    return 9`	z: 3
`  return math.sqrt(9 + square(y))`	x: 3 y:4
`  return math.sqrt(9 + square(4))`	x: 3 y:4
`    return z*z`	z: 4
`    return 4*4`	z: 4
`    return 16`	z: 4
`  return math.sqrt(9 + 16)`	x: 3 y:4
`  return math.sqrt(25)`	x: 3 y:4
`  return 5`	x:3 y:4
`5`	(none)

Shadowing of Formal Variable Names

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

Same formal parameter name

	Variables:
`hypotenuse(3, 4)`	(none)
`  return math.sqrt(square(x) + square(y))`	x: 3 y:4
`  return math.sqrt(square(3) + square(y))`	x: 3 y:4
`    return x*x`	x: 3
`    return 3*3`	x: 3
`    return 9`	x: 3
`  return math.sqrt(9 + square(y))`	x: 3 y:4
`  return math.sqrt(9 + square(4))`	x: 3 y:4
`    return x*x`	x: 4
`    return 4*4`	x: 4
`    return 16`	x: 4
`  return math.sqrt(9 + 16)`	x: 3 y:4
`  return math.sqrt(25)`	x: 3 y:4
`  return 5`	x:3 y:4
`5`	(none)

Formal parameter is a *new* variable

Shadowing of Formal Variable Names

```
import math
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
5
```

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

Variables:

(none)	hypotenuse()
	x:3 y:4
square()	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
square()	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)	

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)
```

Output:
22
0

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:

store_it()	Global or top level
	stored: 0
arg: 22	stored: 0
arg: 22	stored: 0
arg: 22 stored: 22	stored: 0
arg: 22 stored: 22	stored: 0 y: 22
	stored: 0 y: 22
	stored: 0 y: 22

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 …
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()**?

The global keyword

- The **global** keyword tells Python to use the globally defined variable instead of locally creating one.

```
greeting = "Hello"

def change_greeting(new_greeting):
    global greeting
    greeting = new_greeting

def greeting_world():
    world = "World"
    print(greeting, world)

change_greeting("Hi")
greeting_world()
```

Output:
Hi World

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)
```

```
NameError: name 'result' is not defined
```

Use Only the Local and the Global Scope

```
myvar = 1

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

def inner():
    return myvar

print(outer())
```

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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)

Defining Absolute Value

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

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

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

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

They all perform the same task.
Their implementations are different though.

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)
```

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(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)
```

```
float(7)
```

```
abs(-20 - 2) + 20
```

What Does This Print?

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

print(myfunc(4))
```

$\boxed{6}$

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
```

Question Break!

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?

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
   - 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

Functions are Values: The Function can be an Expression

```
import math

def double(x):
    return 2*x
print(double)                 <function double at 0x108cdeea0>
myfns = [math.sqrt, int, double, math.cos]
Myfns      [<function math.sqrt>, int, <function
           __main__.double(x)>, <function math.cos>]

myfns[0](16)                  4
myfns[1](3.14)                3
myfns[2](3.14)                6.28
myfns[3](3.14)                -0.9999987317275395

def doubler():
    return double
doubler()(2.25)               4.5
```

Nested Scopes

- In Python, one can always determine the scope of a name by looking at the program text.
  - **static** or **lexical scoping**

```
def f(x):
    def g():
        x = "abc"
        print("x =", x)
    def h():
        z = x
        print("z =", z)
    x = x+1
    print("x =", x)
    h()
    g()
    print("x =", x)
    return g

x = 3
z = f(x)
print("x =", x)
print("z =", z)
z()
```

```
x = 4
z = 4
x = abc
x = 4
x = 3
z = <function f.<locals>.g at
0x7f06d7fa2ea0>
x = abc
```

The nonlocal keyword

- The **nonlocal** keyword causes the variable to refer to the previously bound variable in the closest enclosing scope.
- It is useful in nested functions.

```
def outer():
    first_num = 1
    def inner():
        nonlocal first_num
        first_num = 0
        second_num = 1
        print("inner - second_num is: ", second_num)
    inner()
    print("outer - first_num is: ", first_num)

outer()
```

Output:
inner - second_num is: 1
outer - first_num is: 0

Anonymous (lambda) Functions

- Anonymous functions are also called lambda functions in Python because instead of declaring them with the standard **def** keyword, you use the **lambda** keyword.

```
double = lambda x: x*2
double(5)
```

lambda x: x*2 is the lambda function.
x is the argument
x*2 is the expression or instruction that gets evaluated and returned.

```
lambda x, y: x + y;

is equal to

def sum(x, y):
    return x+y
```

You use lambda functions when you require a nameless function for a short period of time, and that is created at runtime.

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 #

called docstring

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

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

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
```

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