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)
- **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`

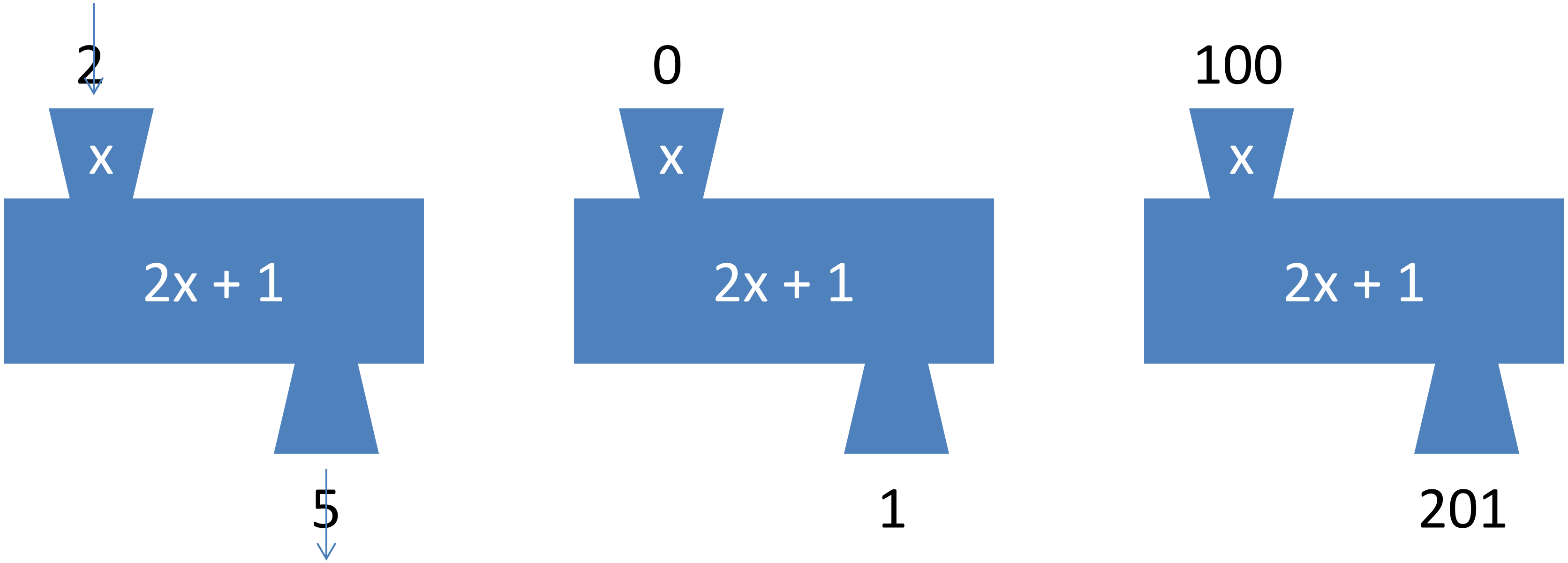
Using ("calling") a function

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



2
x
2x + 1
5

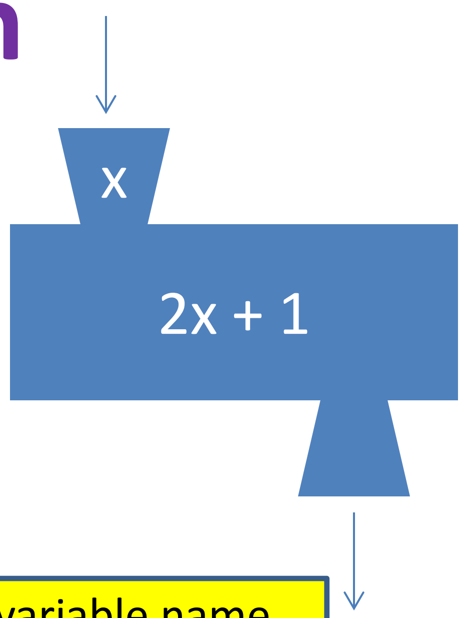
0
x
2x + 1
1

100
x
2x + 1
201

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)

See in python tutor

See in python tutor

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**
Executed for side effect

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

What is the result of:

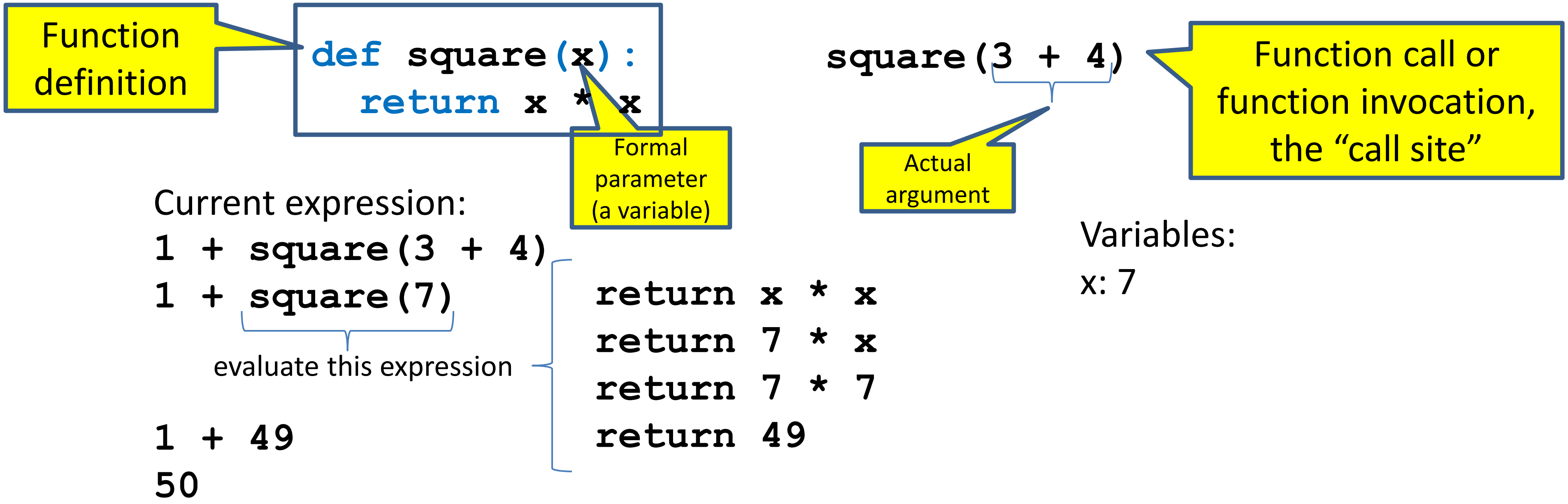
```
x = 42
print square(3) + square(4)
print x
boiling = fahr_to_cent(212)
cold = cent_to_fahr(-40)
print result
print abs(-22)
print print_fahr_to_cent(32)
```

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

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

```
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” – 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

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

```
def square(z):
  return z * z
def hypotenuse(x, y):
  return math.sqrt(square(x) + square(y))
                                              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 z * z               z: 3  x: 3  y:4
                   return 3 * 3               z: 3  x: 3  y:4
                   return 9                   z: 3  x: 3  y:4
  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  x: 3  y:4
                       return 4 * 4           z: 4  x: 3  y:4
                       return 16              z: 4  x: 3  y: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

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

Same formal parameter name,
but two completely different variables

Formal parameter
is a *new* variable

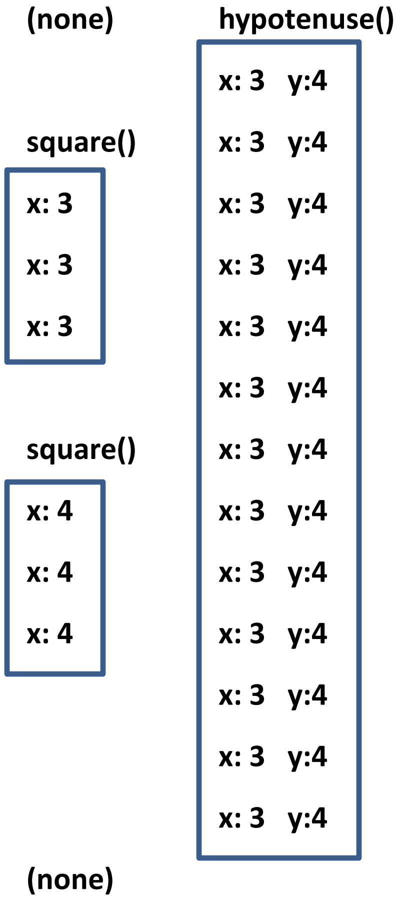
Shadowing of formal variable names

```
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
5
```

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

Variables:



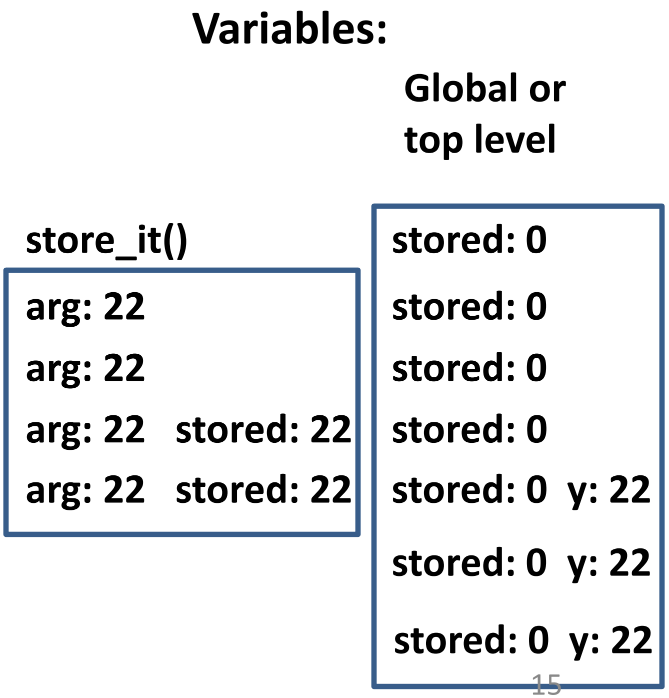
(none)	hypotenuse()
	x: 3 y:4
square()	x: 3 y:4
x: 3	x: 3 y:4
x: 3	x: 3 y:4
x: 3	x: 3 y:4
	x: 3 y:4
square()	x: 3 y:4
x: 4	x: 3 y:4
x: 4	x: 3 y:4
x: 4	x: 3 y:4
	x: 3 y:4
	x: 3 y:4
	x: 3 y:4
(none)	

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
```

Show evaluation of the starred expressions:

```
y = store_it(22)
        stored = arg
        stored = 22
        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

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 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
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`?

Local variables exist only while the function is executing

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

tempf = cent_to_fahr(15)
print result
```

Use only the local and the global scope!

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```
myvar = 1

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

def inner():
    return myvar

print outer()
```

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 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)
```

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)
```

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."""
    # Uses "x*x" instead of "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
```

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)
```

See in python tutor

What does this print?

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

print myfunc(4)
```

See in python tutor

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