BBM 101
Introduction to Programming I

Lecture #05 – Control Flow, Functions
Last time… Introduction to Python

Programming in Python

1. Python is like a calculator

2. A variable is a container

3. Different types cannot be compared

4. A program is a recipe
Lecture Overview

• Control Flow

• Functions

Disclaimer: Much of the material and slides for this lecture were borrowed from
—Ruth Anderson, Michael Ernst and Bill Howe’s CSE 140 class
Lecture Overview

• Control Flow

• Functions
Repeating yourself

Making decisions
Temperature Conversion Chart

Recall the exercise from the previous lecture

```python
fahr = 30
cent = (fahr - 32)/9.0*5
print(fahr, cent)
fahr = 40
cent = (fahr - 32)/9.0*5
print(fahr, cent)
fahr = 50
cent = (fahr - 32)/9.0*5
print(fahr, cent)
fahr = 60
cent = (fahr - 32)/9.0*5
print(fahr, cent)
fahr = 70
cent = (fahr - 32)/9.0*5
print(fahr, cent)
Print("All done")
```

Output:

<table>
<thead>
<tr>
<th>Fahrenheit</th>
<th>Celsius</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-1.11</td>
</tr>
<tr>
<td>40</td>
<td>4.44</td>
</tr>
<tr>
<td>50</td>
<td>10.0</td>
</tr>
<tr>
<td>60</td>
<td>15.55</td>
</tr>
<tr>
<td>70</td>
<td>21.11</td>
</tr>
</tbody>
</table>

All done
Temperature Conversion Chart

A better way to repeat yourself:

```python
for f in [30, 40, 50, 60, 70]:
    print(f, (f - 32) / 9.0 * 5)
print("All done")
```

Output:

<table>
<thead>
<tr>
<th>f</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-1.11</td>
</tr>
<tr>
<td>40</td>
<td>4.44</td>
</tr>
<tr>
<td>50</td>
<td>10.0</td>
</tr>
<tr>
<td>60</td>
<td>15.55</td>
</tr>
<tr>
<td>70</td>
<td>21.11</td>
</tr>
</tbody>
</table>

All done
How a Loop is Executed: Transformation Approach

Idea: convert a `for` loop into something we know how to execute

1. Evaluate the sequence expression
2. Write an assignment to the loop variable, for each sequence element
3. Write a copy of the loop after each assignment
4. Execute the resulting statements

```python
for i in [1,4,9]:
    print(i)
```

State of the computer:

<table>
<thead>
<tr>
<th>i:</th>
<th>4</th>
</tr>
</thead>
</table>

Printed output:

<table>
<thead>
<tr>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>
How a Loop is Executed: Direct Approach

1. Evaluate the sequence expression
2. While there are sequence elements left:
   a) Assign the loop variable to the next remaining sequence element
   b) Execute the loop body

```python
for i in [1, 4, 9]:
    print(i)
```

State of the computer:

Printed output:

```
1
4
9
```
The Body can be Multiple Statements

Execute whole body, then execute whole body again, etc.

```python
for i in [3, 4, 5]:
    print("Start body")
    print(i)
    print(i*i)
```

Output:
- Start body
- 3
- 9
- Start body
- 4
- 16
- Start body
- 5
- 25

NOT:
- Start body
- Start body
- Start body
- 3
- 4
- 5
- 9
- 16
- 25

Convention: often use *i* or *j* as loop variable if values are integers

This is an exception to the rule that variable names should be descriptive
Indentation in Loop is **Significant**

- Every statement in the body must have exactly the same indentation
- That's how Python knows where the body ends

```python
for i in [3,4,5]:
    print("Start body")
    print(i)
    print(i*i)
```

**Error!**

```python
for f in [30,40,50,60,70]:
    print(f, (f-32)/9.0*5)
print("All done")
```

- Compare the results of these loops:

```python
for f in [30,40,50,60,70]:
    print(f, (f-32)/9.0*5)
print("All done")
```

```python
for f in [30,40,50,60,70]:
    print(f, (f-32)/9.0*5)
print("All done")
```
The Body can be Multiple Statements

How many statements does this loop contain?

```python
for i in [0,1]:
    print("Outer", i)
    for j in [2,3]:
        print(" Inner", j)
        print(" Sum", i+j)
    print("Outer", i)
```

What is the output?

Output:
- Outer 0
- Inner 2
- Sum 2
- Inner 3
- Sum 3
- Outer 0
- Outer 1
- Inner 2
- Sum 3
- Inner 3
- Sum 4
- Outer 1
Understand Loops Through the Transformation Approach

Key idea:

1. Assign each sequence element to the loop variable
2. Duplicate the body

```python
for i in [0,1]:
    i = 0
    print("Outer", i)
    for j in [2,3]:
        print(" Inner", j)
    i = 1
    print("Outer", i)
    for j in [2,3]:
        print(" Inner", j)
for i in [0,1]:
    i = 0
    print("Outer", i)
    for j in [2,3]:
        j = 2
        print(" Inner", j)
        j = 3
        print(" Inner", j)
    i = 1
    print("Outer", i)
    for j in [2,3]:
        print(" Inner", j)
```
Fix This Loop

# Goal: print 1, 2, 3, ..., 48, 49, 50
for tens_digit in [0, 1, 2, 3, 4]:
    for ones_digit in [1, 2, 3, 4, 5, 6, 7, 8, 9]:
        print(tens_digit * 10 + ones_digit)

What does it actually print?
How can we change it to correct its output?

Moral: Watch out for edge conditions (beginning or end of loop)
Some Fixes

# Goal: print 1, 2, 3, …, 48, 49, 50

for tens_digit in [0, 1, 2, 3, 4]:
    for ones_digit in [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]:
        print(tens_digit * 10 + ones_digit + 1)

for tens_digit in [0, 1, 2, 3, 4]:
    for ones_digit in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]:
        print(tens_digit * 10 + ones_digit)

• Analyze each of the above
Test Your Understanding of Loops

Puzzle 1:
```python
for i in [0,1]:
    print(i)
print(i)
```

Puzzle 2:
```python
i = 5
for i in []:  # Empty list
    print(i)
```

Puzzle 3:
```python
for i in [0,1]:
    print("Outer", i)
    for i in [2,3]:
        print(" Inner", i)
    print("Outer", i)
```

Output:
```
0
1
(Inner loop body)
```

Reusing loop variable (don’t do this!)
The Range Function

As an implicit list:

```python
for i in range(5):
    ... body ...
```

- `range(5)` = [0,1,2,3,4]
- `range(1,5)` = [1,2,3,4]
- `range(1,10,2)` = [1,3,5,7,9]
Decomposing a List Computation

• To compute a value for a list:
  – Compute a partial result for all but the last element
  – Combine the partial result with the last element

Example: sum of a list:

\[
[3, 1, 4, 1, 5, 9, 2, 6, 5]
\]

\[
\begin{align*}
\text{sum(List a)} &= \text{sum(List b)} + 5 \\
\text{sum(List b)} &= \text{sum(List c)} + 6 \\
\quad&\quad\vdots \\
\text{sum(List y)} &= \text{sum(List z)} + 3 \\
\text{sum(\text{empty list})} &= 0
\end{align*}
\]
How to Process a List: One Element at a Time

• A common pattern when processing a list:

```python
result = initial_value
for element in list:
    result = updated result
use result
```

• `initial_value` is a correct result for an empty list

• As each element is processed, `result` is a correct result for a prefix of the list

• When all elements have been processed, `result` is a correct result for the whole list

```python
# Sum of a list
result = 0
for element in mylist:
    result = result + element
print result
```
# Sum of a list of values, what values?
result = 0
for element in range(5):  # [0,1,2,3,4]
    result = result + element
print("The sum is: " + str(result))

# Sum of a list of values, what values?
result = 0
for element in range(5,1,-1):
    result = result + element
print("The sum is:", result)

# Sum of a list of values, what values?
result = 0
for element in range(0,8,2):
    result = result + element
print("The sum is:", result)

# Sum of a list of values, what values?
result = 0
size = 5
for element in range(size):
    result = result + element
print("When size = " + str(size) + ", the result is " + str(result))

The sum is: 10

5, 4, 3, 2
The sum is: 14

0, 2, 4, 6
The sum is: 12

0, 1, 2, 3, 4
When size = 5, the result is 10
Examples of List Processing

- Product of a list:
  ```python
  result = 1
  for element in mylist:
      result = result * element
  ```

- Maximum of a list:
  ```python
  result = mylist[0]
  for element in mylist:
      result = max(result, element)
  ```

- Approximate the value 3 by
  \[1 + \frac{2}{3} + \frac{4}{9} + \frac{8}{27} + \frac{16}{81} + \ldots = \left(\frac{2}{3}\right)^0 + \left(\frac{2}{3}\right)^1 + \left(\frac{2}{3}\right)^2 + \left(\frac{2}{3}\right)^3 + \ldots + \left(\frac{2}{3}\right)^{10}\]
  ```python
  result = 0
  for element in range(11):
      result = result + (2.0/3.0)**element
  ```

The first element of the list (counting from zero)
Exercise with Loops

• Write a simple program to add values between two given inputs a, b
• e.g., if a=5, b=9, it returns sum of (5+6+7+8+9)
• **Hint:** we did some ‘algorithmic thinking’ and ‘problem solving’ here!

```python
a, b = 5, 9
total = 0
for x in range(a, b+1):
    total += x
print(total)
```

Notice this form of the assignment statement!
Another Type of Loops – **while**

• The **while** loop is used for repeated execution as long as an expression is true

```python
n = 100
s = 0
counter = 1
while counter <= n:
    s = s + counter
    counter += 1

print("Sum of 1 until " + str(n) + ": " + str(s))
```

Sum of 1 until 100: 5050
Making Decisions

- How do we compute absolute value?

\[
\begin{align*}
\text{abs}(5) &= 5 \\
\text{abs}(0) &= 0 \\
\text{abs}(-22) &= 22
\end{align*}
\]
Absolute Value Solution

**If** the value is negative, negate it. **Otherwise**, use the original value.

```python
val = -10

# calculate absolute value of val
if val < 0:
    result = -val
else:
    result = val

print(result)
```

In this example, `result` will always be assigned a value.

Another approach that does the same thing without using `result`:

```python
val = -10

if val < 0:
    print(-val)
else:
    print(val)
```
Absolute Value Solution

As with loops, a sequence of statements could be used in place of a single statement inside an if statement:

```python
val = -10

# calculate absolute value of val
if val < 0:
    result = -val
    print("val is negative!")
    print("I had to do extra work!")
else:
    result = val
    print("val is positive")
print(result)
```
Absolute Value Solution

What happens here?

```python
val = 5

# calculate absolute value of val
if val < 0:
    result = -val
    print("val is negative!")
else:
    for i in range(val):
        print("val is positive!")
    result = val
print(result)
```
Another if

It is **not required that anything happens**...

```python
val = -10
if val < 0:
    print("negative value!")
```

What happens when `val = 5`?
Execution gets here only if "height > 100" is false AND "height > 50" is true.

The if Body can be Any Statements

# height is in km
if height > 100:
    print("space")
else:
    if height > 50:
        print("mesosphere")
    else:
        if height > 20:
            print("stratosphere")
        else:
            print("troposphere")

Written differently, but more efficient!

# height is in km
if height > 50:
    if height > 100:
        print("space")
    else:
        print("mesosphere")
else:
    if height > 20:
        print("stratosphere")
    else:
        print("troposphere")

Written differently, but more efficient!
Version 1

```python
# height is in km
if height > 100:
    print("space")
else:
    if height > 50:
        print("mesosphere")
    else:
        if height > 20:
            print("stratosphere")
        else:
            print("troposphere")
```

Execution gets here only if "height <= 100" is true
Execution gets here only if "height <= 100" is true AND "height > 50" is true

---

troposphere | stratosphere | mesosphere | space
---|---|---|---
0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100
# height is in km
if height > 100:
    print("space")
else:
    if height > 50:
        print("mesosphere")
    else:
        if height > 20:
            print("stratosphere")
        else:
            print("troposphere")
if height > 50:
    if height > 100:
        print("space")
    else:
        print("mesosphere")
else:
    if height > 20:
        print("stratosphere")
    else:
        print("troposphere")
```python
if height > 100:
    print("space")
elif height > 50:
    print("mesosphere")
elif height > 20:
    print("stratosphere")
else:
    print("troposphere")
```

ONE of the print statements is guaranteed to execute: whichever condition it encounters **first** that is true.
Order Matters

# version 3
if height > 100:
    print("space")
elif height > 50:
    print("mesosphere")
elif height > 20:
    print("stratosphere")
else:
    print("troposphere")

# broken version 3
if height > 20:
    print("stratosphere")
elif height > 50:
    print("mesosphere")
elif height > 100:
    print("space")
else:
    print("troposphere")

Try height = 72 on both versions, what happens?
Version 3

# incomplete version 3

```python
if height > 100:
    print("space")
elif height > 50:
    print("mesosphere")
elif height > 20:
    print("stratosphere")
```

In this case it is possible that nothing is printed at all, when?

[Diagram showing atmospheric layers: troposphere, stratosphere, mesosphere, and space with height markers 0 to 100 km above earth.]
What Happens Here?

# height is in km
if height > 100:
    print("space")
if height > 50:
    print("mesosphere")
if height > 20:
    print("stratosphere")
else:
    print("troposphere")

Try height = 72
divisorpattern.py: Accept integer command-line argument \( n \). Write to standard output an \( n \)-by-\( n \) table with an asterisk in row \( i \) and column \( j \) if either \( i \) divides \( j \) or \( j \) divides \( i \).

```python
import sys

n = int(sys.argv[1])
for i in range(1, n + 1):
    for j in range(1, n + 1):
        if (i % j == 0) or (j % i == 0):
            print('*', end='')
        else:
            print(' ', end='')
    print(i)
```

$ python divisorpattern.py 3
* * * 1
* * 2
* * 3

$ python divisorpattern.py 10
* * * * * * * * * * 1
* * * * * * * * * 2
* * * * * * * * 3
* * * * * * * 4
* * * * * * 5
* * * * * 6
* * * * * 7
* * * * * 8
* * * * * 9
* * * * * 10

Variable trace (\( n = 3 \))

<table>
<thead>
<tr>
<th>i</th>
<th>j</th>
<th>output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>* *</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>* *</td>
</tr>
</tbody>
</table>
| 1 | 3 | * 1
| 2 | 1 | * * |
| 2 | 2 | * * |
| 2 | 3 | * 2
| 3 | 1 | * * |
| 3 | 2 | * |
| 3 | 3 | * 3

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The **break** Statement

• The **break** statement terminates the current loop and resumes execution at the next statement

```python
for letter in 'hollywood':
    if letter == 'l':
        break
    print ('Current Letter :', letter)
```

Current Letter : h
Current Letter : o
The `continue` Statement

- The `continue` statement in Python returns the control to the beginning of the while loop.

```python
for letter in 'hollywood':
    if letter == 'l':
        continue
    print ('Current Letter :', letter)
```

- Output:
  
<table>
<thead>
<tr>
<th>Current Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>:-------------</td>
</tr>
<tr>
<td>h</td>
</tr>
<tr>
<td>o</td>
</tr>
<tr>
<td>y</td>
</tr>
<tr>
<td>w</td>
</tr>
<tr>
<td>o</td>
</tr>
<tr>
<td>o</td>
</tr>
<tr>
<td>d</td>
</tr>
</tbody>
</table>
Lecture Overview

• Control Flow

• 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)
• **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`
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: \( \text{func}(x) = 2x + 1 \)
Creating a Function

Define the machine, including the input and the result

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

Keyword that means: I am defining a function

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

Input variable name, or “formal parameter”

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

```python
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)
```

What is the result of:

```python
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

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

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

square(3) + square(4)
\[
\begin{align*}
\text{return } & x * x \\
\text{return } & 3 * x \\
\text{return } & 3 * 3 \\
\text{return } & 9 \\
\text{9 + square(4)} & \quad \text{Variables:} \\
\text{return } & x * x \\
\text{return } & 4 * x \\
\text{return } & 4 * 4 \\
\text{return } & 16 \\
9 + 16 & \quad \text{(none)} \\
25 & \quad \text{(none)}
\end{align*}
\]
```
Expression with Nested Function Invocations: Only One Executes at a Time

```python
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

(fnone)

(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

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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))

hypoten_use(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
Shadowing of Formal Variable Names

```python
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
```

Variables:

<table>
<thead>
<tr>
<th>Variables:</th>
<th>(none)</th>
<th>x: 3</th>
<th>y: 4</th>
<th>x: 3</th>
<th>y: 4</th>
<th>x: 3</th>
<th>y: 4</th>
<th>x: 3</th>
<th>y: 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hypotenuse(3, 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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Formal parameter is a new variable.

Same formal parameter name.
Shadowing of Formal Variable Names

```python
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
```

Same diagram, with variable scopes or environment frames shown explicitly

Variables:

```
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
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)
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.

```python
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

```python
myvar = 1

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

def inner():
    return myvar

print(outer())
```

1
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

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

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

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

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

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)

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

print(myfunc(4))

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))
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?
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

```python
import math

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

myfns = [math.sqrt, int, double, math.cos]
Myfns

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

```python
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()```

```python
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.

```python
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)
    inner()
    print("outer - first_num is: ", first_num)
```
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.

```python
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.

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

is equal to

```python
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

```python
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

```python
# 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:

```python
x = y + x  # a comment about this line
```

• For a line that starts with #, indentation must be consistent with surrounding code