

Data Science and Advanced Programming — Lecture 3

Python Fundamentals I

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Roadmap

- ▶ Let's get started with Python (*Introduction to Computation and Programming Using Python, J. Guttag*)
 1. Python Basics
 2. Control flow: Branching and Loops
 3. String Manipulation
 4. Examples

Covered in the TA session/Videos:
- ▶ Version Control (git)
- ▶ Coding Style
- ▶ Enabling Collaboration, Replicability, and Code Enhancement

Recall — What does a Computer do?

- ▶ Fundamentally:
 - ▶ performs **calculations**:
several billion calculations per second even on a Laptop!
 - ▶ **remembers results**:
~ terabytes of storage even on a Laptop!
- ▶ What kinds of calculations?
 - ▶ **built-in** to the language (**basic types**: additions, subtraction,...)
 - ▶ Some calculations that **you define** as the programmer (built on top of the basic operations).

computers only know what you tell them.

→ They only do what you tell them to do (REALLY FAST)!

Algorithm: A Basic Example – compute $\text{sqrt}(x)$

- Find the square root of a number x is g such that $g * g = x$
- Algorithm (= recipe) for deducing square root of the number $x = 16$
 1. Start with a guess, g
 2. If $g * g$ is close enough to x , stop and say g is the answer
 3. Otherwise make a new guess by averaging g and x/g
 4. Using the new guess, repeat process until close enough

| g | $g * g$ | x/g | $(g + x/g) / 2$ |
|--------|---------|-------|-----------------|
| 3 | 9 | 16/3 | 4.17 |
| 4.17 | 17.36 | 3.837 | 4.0035 |
| 4.0035 | 16.0277 | 3.997 | 4.000002 |

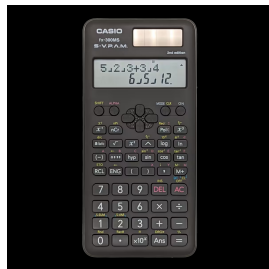
Recall — Algorithms

- ▶ sequence of simple steps.
- ▶ flow of control process that specifies when each step is executed.
- ▶ a means of determining when to stop (finite compute time).

→ $1 + 2 + 3 =$ an algorithm!

Comuters => Machines

- ▶ **fixed program** computer
 - ▶ Pocket calculator (very limited in terms of capabilities).
- ▶ **stored program** computer
 - ▶ machine stores and executes instructions.
 - ▶ the computers we know nowadays.



Recall — a computer

A computer is a machine that can:

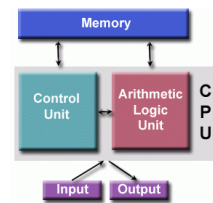
- ▶ **Accept input.** Input could be entered by a human **typing at a keyboard**, **received over a network**, or provided automatically by **sensors** attached to the computer.
- ▶ **Execute a (mechanical) procedure**, that is, a **procedure where each step can be executed without any thought**.
- ▶ **Produce output.** Output could be data displayed to a human, but it could also be anything that effects the world outside the computer such as electrical signals that control how a device operates.



Basics: von Neumann Architecture

https://computing.llnl.gov/tutorials/parallel_comp

- ▶ Virtually all computers have followed this basic design. Comprised of **four main components**: **Memory**, **Control Unit**, **Arithmetic Logic Unit**, **Input/Output**.
- ▶ **Read/write, random access memory** is used to store both program instructions and data:
 - ▶ Program instructions are coded data which tell the computer to do something.
 - ▶ Data is simply information to be used by the program.
- ▶ **Control unit**
 - ▶ fetches instructions/data from memory, decodes the instructions and then sequentially coordinates operations to accomplish the programmed task.
- ▶ **Arithmetic unit**
 - ▶ performs basic arithmetic operations.
- ▶ **Input/Output**
 - ▶ interface to the human operator.



A (Python) Program

- ▶ A **program** is a **sequence of definitions** and **commands**
 - ▶ **definitions** evaluated.
 - ▶ **commands** executed by Python interpreter in a shell.
- ▶ **Commands** (statements) instruct **interpreter** to do something.
- ▶ can be **typed directly in a shell** or **stored in a file** that is read into the shell and evaluated.

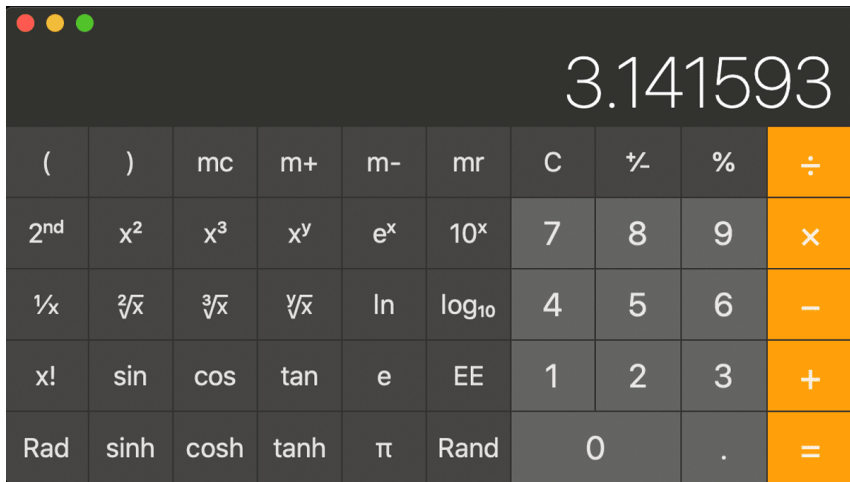
Recall — Some features

- ▶ Python is a **high level language** suitable for rapid development.
- ▶ It has a relatively small core language **supported by many libraries.**
- ▶ A **multi-paradigm language**, in that multiple programming styles are supported (**procedural**, **object-oriented**, **functional**,...).
- ▶ **Interpreted rather than compiled.**

Recall — Syntax and Design

- ▶ One nice feature of Python is its **elegant syntax** — we'll see many examples later on.
- ▶ **Elegant code** might sound superfluous but in fact it's highly beneficial because it makes the syntax **easy to read and easy to remember**.
- ▶ **Remembering** how to read from files, sort dictionaries and other such routine tasks means that **you don't need to break your flow** in order to hunt down correct syntax.
- ▶ Closely related to **elegant syntax** is **elegant design**.
- ▶ Features like iterators, generators, list comprehensions, etc. make Python highly expressive, **allowing you to get more done with less code**.

1. Python Basics



Python Setup

A bare-bones development environment consists of:

- A text editor (e.g., `gedit`, `emacs`, `vim`)
- The Python interpreter (it is installed by default on Ubuntu and almost any other Linux distribution)
- A terminal application to run the interpreter in.

See <http://wiki.python.org/moin/IntegratedDevelopmentEnvironments> for a commented list of IDEs with Python support.

Python Basics I

Python is an interpreted language.

It also features an interactive “shell” for evaluating expressions and statements immediately.

The Python shell is started by invoking the command `python` in a terminal window.

Python Basics II

Expressions can be entered at the Python shell prompt (the `>>>` at the start of a line); they are evaluated and the result is printed:

```
>>> 2+2
4
```

A line can be continued onto the next by ending it with the character `\`; for example:

```
>>> "hello" + \
... " world!"
'hello world!'
```

The prompt changes to `...` on continuation lines.

Reference:

http://docs.python.org/reference/lexical_analysis.html#line-structure

Objects

- ▶ Programs manipulate **data objects**.
- ▶ objects have a **type** that defines the kinds of operations ($*$, $+$, $-$, ...) programs can do to them:
 - ▶ \rightarrow *Simon is a human: he can walk, speak French with an accent Fédérale, etc.*
 - ▶ \rightarrow *3 is an integer, so we can $+$, $-$, $*$, $/$, $**$...*
- ▶ **Objects** are
 - ▶ **scalar** (cannot be subdivided into smaller “sub-items”, e.g., $a = 1$).
 - ▶ **non-scalar** (have internal structure that can be accessed, e.g., $b = [1, 2, 3]$).

Scalar Objects

- ▶ `int` - represent **integers**, for example 666
- ▶ `float` - represent **real numbers**, eg., 6.66
- ▶ `bool` - represent **Boolean values** `True` and `False`
- ▶ `NoneType` - special and has one value: `None` (absence of a type)
- ▶ use `type()` to see the type of an object

Action required:

```
>>> type(10)
<type 'int'>

>>> type(10.0)
<type 'float'>
```

What you type
into the Python shell

What shows after
pressing enter

Action required: Type conversions

- ▶ Python can convert object of one type to another
- ▶ `float(10)` converts integer 10 to float 10.0
- ▶ `int(10.9)` truncates float 10.9 to integer 10 (**rounding towards zero**)

```
>>> float(10)
10.0
>>> int(10.9)
10
```

Print to the Terminal

demo/example1a.py

- ▶ In order to show output from code to a user, use print command

```
>>> 10 + 2
12
>>> print(10+2)
12
```

- ▶ You see the output only in an interactive shell.
- ▶ **If you use a *.py file, you explicitly need to enforce output.**
- ▶ Try this in a file print.py

```
a = 3+4
print('no printout so far')
print('here we go')
print(a)
```

Action Required

- ▶ Run demo/example1a.py:
`python example1a.py`
- ▶ Run demo/example1b.py:
`python example1b.py`

```
a = 3  
b = 2
```

```
sum = a + b  
print('no printout of the result so far')
```

```
a = 3  
b = 2
```

```
sum = a + b  
print('no printout of the result so far')  
print("here we go with the result")  
print(sum)
```

Create Expressions

- ▶ Combine objects and operators to form expressions
- ▶ An expression has a value, which has a type
- ▶ syntax for a simple expression:

`<object> <operator> <object>`

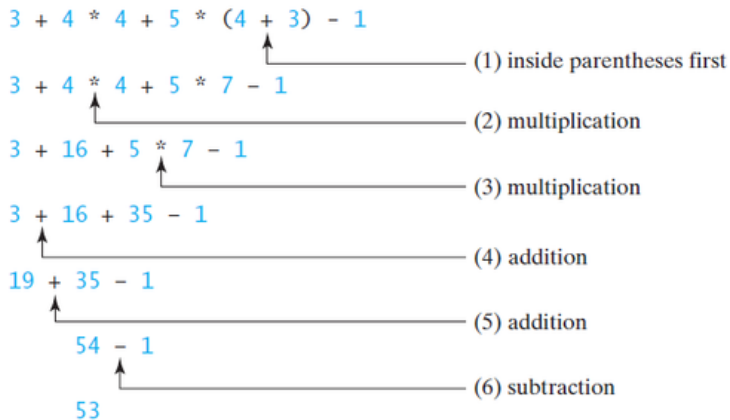
- ▶ `i + j` a sum
- ▶ `i - j` the difference
- ▶ `i * j` the product
- ▶ `i / j` division (be careful with result: `type(1 / 2)`, `type(1/2.0)`)
 - ▶ Note: if both `i`, `j` are `int`, the result is `int`, if either or both are floats, result is a `float`
- ▶ `i % j` the remainder when `i` is divided by `j`
- ▶ `i ** j` \rightarrow `i` to the power of `j`

Summary: Numeric Operators

- ▶ Parentheses are used to tell Python to do these operations first
- ▶ Operator precedence without parentheses
- ▶ “+” and “-” are executed **left to right**, as appear in expression

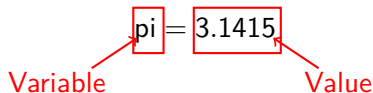
| Name | Meaning | Example | Result |
|------|------------------|------------|--------|
| + | Addition | 34 + 1 | 35 |
| - | Subtraction | 34.0 - 0.1 | 33.9 |
| * | Multiplication | 300 * 30 | 9000 |
| / | Float Division | 1 / 2 | 0.5 |
| // | Integer Division | 1 // 2 | 0 |
| ** | Exponentiation | 4 ** 0.5 | 2.0 |
| % | Remainder | 20 % 3 | 2 |

Order of Expressions



Assignments

- ▶ The equal sign (=) is an **assignment** of a **value to a variable name**


Variable Value

- ▶ Its value is stored in the computer memory
- ▶ An assignment **binds a name to value**.
- ▶ You can **retrieve** the value associated with name or variable by invoking the name, by **typing pi**.

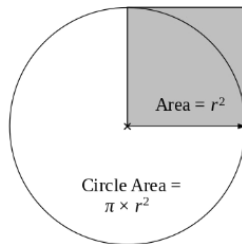
```
>>> pi = 3.1415  
>>> pi  
3.1415
```


Expressions

demo/example2.py

- ▶ Why should you give names to values of expressions?
 - ▶ → to reuse names instead of values
 - ▶ → code is easier to read
 - ▶ → easier to change code later

```
>>> pi = 3.14159
>>> radius = 2.0
>>> area = pi * (radius**2)
```



Programming logic vs. math logic

In programming, we do not “solve for x”

```
>>> pi = 3.14159
>>> radius = 2.0
>>> area = pi * (radius**2)
>>> radius = radius + 1
>>> radius
3.0
```

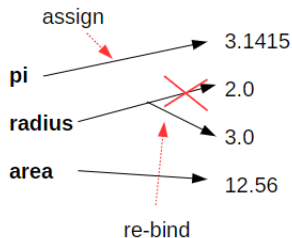
- ▶ → “=” is an assignment.
- ▶ → It strictly means “the expression on the right evaluated to a value on the left.”

Change Assignments

demo/example2b.py

- ▶ You can re-assign (re-bind) variable names using new assignment statements.
- ▶ Previous value may still stored in memory but **lost the handle** for it.
- ▶ The value for area does not change until **you tell the computer to do the calculation again.**

```
>>> pi = 3.14159
>>> radius = 2.0
>>> area = pi * (radius**2)
>>> radius = radius + 1
```



Augmented Assignments

demo/example2c.py

| <i>Operator</i> | <i>Example</i> | <i>Equivalent</i> |
|-----------------|-----------------------|--------------------------|
| <code>+=</code> | <code>i += 8</code> | <code>i = i + 8</code> |
| <code>-=</code> | <code>f -= 8.0</code> | <code>f = f - 8.0</code> |
| <code>*=</code> | <code>i *= 8</code> | <code>i = i * 8</code> |
| <code>/=</code> | <code>i /= 8</code> | <code>i = i / 8</code> |
| <code>%=</code> | <code>i %= 8</code> | <code>i = i % 8</code> |

Another helpful online tool

The **Online Python Tutor** is a free tool to visualize the execution of programs step-by-step.

Python Tutor: Visualize code in [Python](#), [JavaScript](#), [C](#), [C++](#), and [Java](#)

The screenshot displays the Python Tutor interface for Python 3.6. The code editor on the left shows a script with variables x, y, z, and a function foo. The execution is paused at line 18. The right-hand side shows the state of memory, including frames and objects. The 'Frames' section lists the Global frame, x, y, z, foo, and bar. The 'Objects' section shows a list object containing [0, 1, 2, 3, 4, 5, 6, 7] and another list object containing [0, 1, 2, 3, 4, 5]. Arrows indicate the references between the frames and the objects.

```
Python 3.6  
View limitations  
1 x = [1, 2, 3]  
2 y = [4, 5, 6]  
3 z = y  
4 y = x  
5 x = z  
6  
7 x = [1, 2, 3] # a different [1, 2, 3] list!  
8 y = x  
9 x.append(4)  
10 y.append(5)  
11 z = [1, 2, 3, 4, 5] # a different list!  
12 x.append(6)  
13 y.append(7)  
14 y = "hello"  
15  
16  
17 def foo(lst):  
18     lst.append("hello")  
19     bar(lst)  
20  
21 def bar(myList):  
22     pass  
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```

Object: Characters, Strings

demo/example3.py

- ▶ **Sequences of Characters:** Letters, special characters, spaces, digits
- ▶ **Enclose in quotation marks or single quotes (be consistent!)**

```
>>> hi = "hello there"
```

- ▶ To **concatenate** strings, use +

```
>>> name = "Mickey"  
>>> greet = hi + name  
>>> greeting = hi + " " + name
```

- ▶ Do some operations (*) on a string as defined in Python docs

```
>>> nonsense = "howdy" + " " + name * 5
```

Input and Output

demo/example4.py

- “print” is used to output (text messages, numbers,...) to the console.

```
x = 666
print(x)
x_str = str(x)    #Cast the number to a string
print("my favorite number is", x, ".", "x =", x)  # use commas -> different objects
print("my favorite number is " + x_str + ". " + "x = " + x_str) # one big string object
```

Interactive Program: Input and Output (II)

demo/example5.py

- ▶ `Input(" ")` reads whatever is inside the quotation marks.
- ▶ The user types in something and presses enter.
- ▶ `Input(" ")` binds that value to a variable

```
>>> text = input("Type some meaningful text string... ")  
>>> print(5*text)
```

- ▶ The input gives you a string so must cast if working with numbers

```
>>> num = int(input("Type a number... "))  
>>> print(5*num)
```


Add tests to the Code: Comparison operators

- ▶ Assume *i* and *j* are variable names
- ▶ Comparisons shown below evaluate to a Boolean (logical)
 - ▶ *i* > *j*
 - ▶ *i* >= *j*
 - ▶ *i* < *j*
 - ▶ *i* <= *j*
 - ▶ *i* == *j* → equality test, True if *i* is the same as *j*
 - ▶ *i* != *j* → inequality test, True if *i* is NOT the same as *j*
- ▶ These tests work on int, float, string

```
>>> i = 3
>>> j = 5

>>> j < i
False
```

Testing: Logical operations

- ▶ Assume a and b are variable names (with Boolean values)
- ▶ `not a` — True if a is False, False if a is True
- ▶ `a and b` — True if both are True
- ▶ `a or b` — True if either or both are True

```
>>> a='true'  
>>> b='true'  
>>> a==b  
Out[17]: True  
>>> a!=b  
Out[18]: False
```

2. Control flow: Branching and Loops



Control flow in the real world

100
times

```
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")
```

...

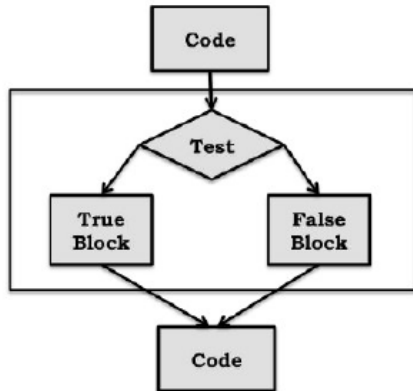
...

...

```
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")
```



Branching



Branching: if-else statements

if-elif-else statements:

```
if x < 0:
    print("x is less than zero")

if x < 0:
    print("x is less than zero")
else:
    print("x is greater or equal zero")

if x < 0:
    print("x is less than zero")
elif x > 0:
    print("x is greater than zero")
else:
    print("x is zero")
```

Indentation matters in Python to denote blocks of code

demo/example6.py

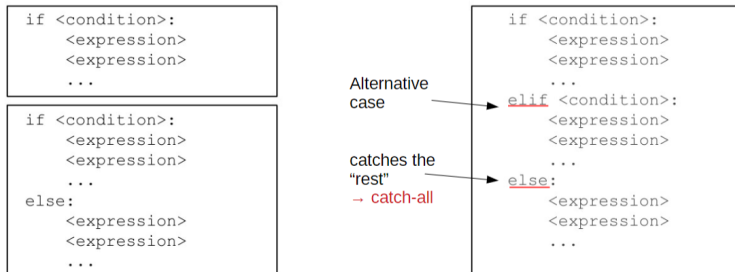
```
if x < 0: ← Colon required!
    print("x is less than zero")

if x < 0:
    print("x is less than zero")
else:
    print("x is greater or equal zero")

if x < 0:
    print("x is less than zero")
elif x > 0:
    print("x is greater than zero")
else:
    print("x is zero")
```

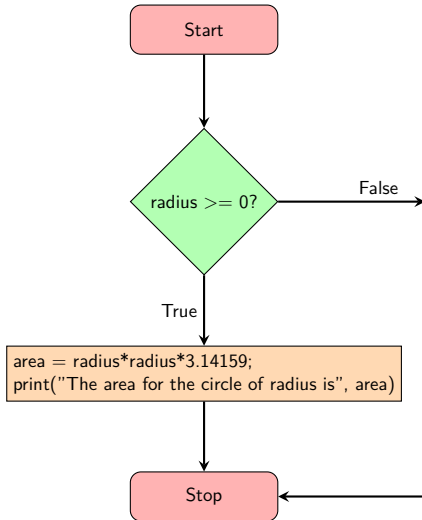
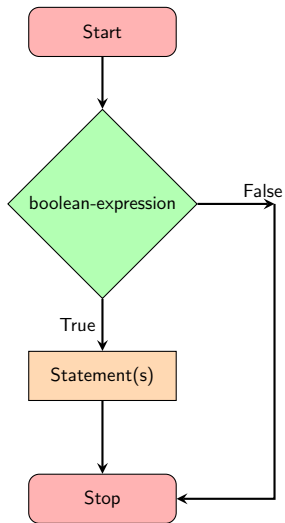
PLEASE: 4 spaces indentation

if-else branching in general



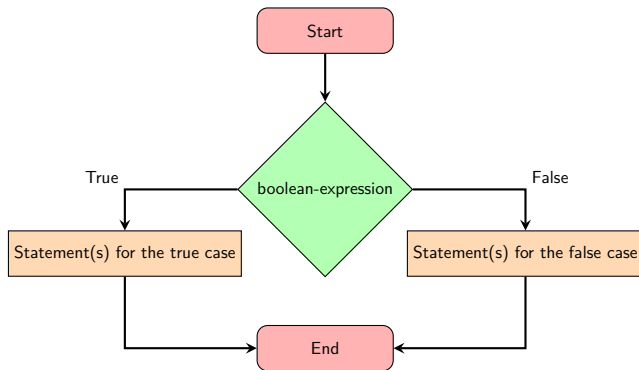
- ▶ <condition> has a value **True** or **False**
- ▶ evaluate expressions in that code block if <condition> is True

Visualized: One-way if-statements



Visualized: Two-way if-statements

```
if boolean-expression:  
    statement(s)-for-the-true-case  
else:  
    statement(s)-for-the-false-case
```



Multiple alternative if-statements

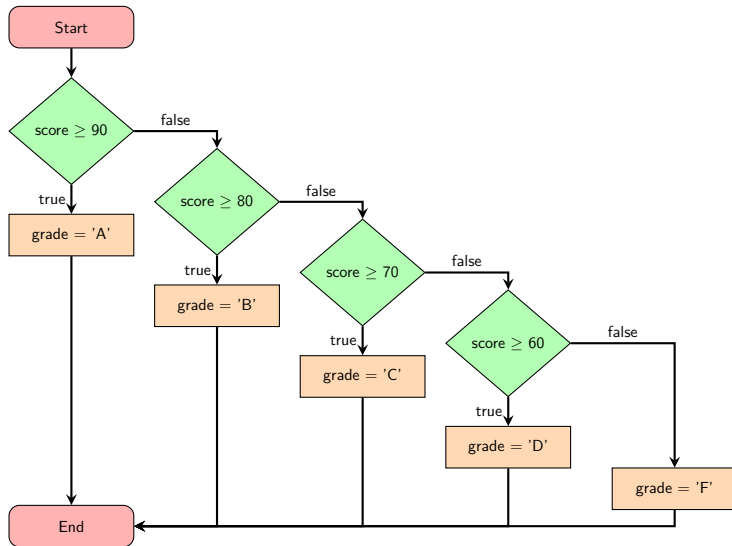
```
if score >= 90.0:
    grade = 'A'
else:
    if score >= 80.0:
        grade = 'B'
    else:
        if score >= 70.0:
            grade = 'C'
        else:
            if score >= 60.0:
                grade = 'D'
            else:
                grade = 'F'
```

Equivalent

This is better

```
if score >= 90.0:
    grade = 'A'
elif score >= 80.0:
    grade = 'B'
elif score >= 70.0:
    grade = 'C'
elif score >= 60.0:
    grade = 'D'
else:
    grade = 'F'
```

Flowchart



Another Example

demo/example6a.py

```
x = float(input("Enter a number for x: "))
y = float(input("Enter a number for y: "))
if x == y:
    print("x and y are equal")
    if y != 0:
        print("therefore, x / y is", x/y)
elif x < y:
    print("x is smaller")
elif x > y:
    print("y is smaller")
```

Another Example

demo/example6c.py

```
x = 12/3 - 2      # this is a comment
y = "Hola"
z = 3.14          # another comment

if (y == "Hola" or z >= 3):
    x = x + 2
    y = y + " mundo!" # string concatenation
    print(y)
    print(x)

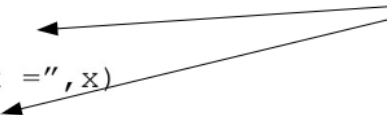
year, month , day = 1943, 6, 15
hour, minute, second = 23, 6, 54
if 1900 < year < 2100 and 1 <= month <= 12 \
    and 1 <= day <= 31 and 0 <= hour < 24 \
    and 0 <= minute < 60 and 0 <= second < 60:
    print("Looks like a valid date!")
```

Control flow: while loop

[demo/example7.py](#)

while loop

```
x = 0
while x < 7:
    print("x =", x)
    x += 1
```

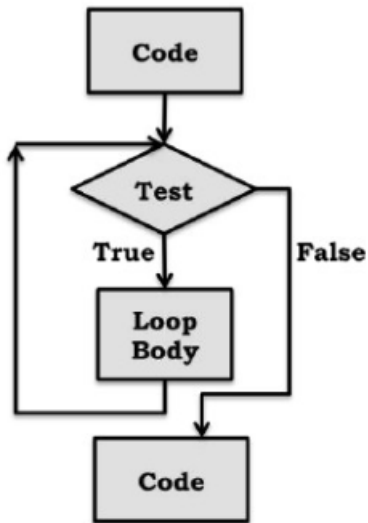


Avoid an infinite loop



[demo/example7a.py](#)

While loop — iteration



Control flow: while loop in general

```
while <condition>:  
    <expression>  
    <expression>  
    ...
```

- ▶ `<condition>` evaluates to a Boolean
- ▶ if `<condition>` is `True`, do all the steps inside the while code block
- ▶ check `<condition>` again
- ▶ repeat until `<condition>` is `False`

Loops — the Motivation

- ▶ Suppose that you need to print a string (e.g., "Programming is fun!") a hundred times.
- ▶ It would be tedious to have to write the following statement a hundred times:

```
print("Programming is fun!")
```

- ▶ So, how do you solve this problem?

Opening Problem



100
times

```
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")  
...  
...  
...  
print("Programming is fun!")  
print("Programming is fun!")  
print("Programming is fun!")
```

Control flow: for loops I

demo/example8.py

- ▶ To iterate through numbers in a sequence, use “for” loop

```
i = 0
while i < 10:
    print(i)
    i = i+1
```

- ▶ **Shortcut** for the for loop

```
for i in range(10):
    print(i)
```

Control flow: for loops II

demo/example8.py

- ▶ In general, we use: `range (start, stop, step)`
- ▶ The default values are `start=0` and `step=1` and are optional
- ▶ **The loop continues until the counter value is stop-1**

```
sum = 0
for i in range(5,7):
    sum += i
print(sum)
```

demo/example8a.py
demo/example8b.py

```
sum = 0
for i in range(40,50,2):
    sum += i
print(sum)
```

Control flow: for loops III

demo/example8.py

for loop: in python only “for-each” form of loops

```
for <item> in <collection>:  
    <statements>
```

```
for item in [0, "a", 7, 1j]:  
    print(item)
```

```
for letter in "StRinG":  
    print(letter)
```

Example

demo/example9.py

```
for item in [0,"a",7,1,j]:
    print(item)

for letter in "StRiNg":
    print(letter)

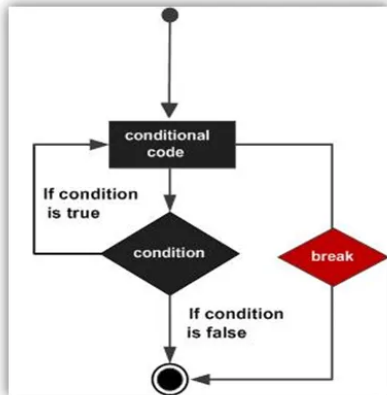
for i in range(5):
    print(i)

lst = ["Suzuki","Kawasaki","Aprilia","Ducati"]
# use enumerate below!!!
# for i in range(len(lst)):
#     print(i,lst[i])
for (i,item) in enumerate(lst):
    print(i,item)
```

Stop within a loop — break statement

- ▶ If you want to **immediately exit a loop** → **break**
- ▶ It **skips remaining expressions** in the code block.
- ▶ Note: it exits only innermost loop.

```
while <condition_1>:  
    while <condition_2>:  
        <expression_a>  
        break  
        <expression_b>  
    <expression_c>
```



break — an example

demo/example10.py

```
var = 10
while var > 0:
    print('Current variable value :', var)
    var = var - 1
    if var == 5:
        break

print ("Test done!")
```

3. String Manipulation



Strings → Sequences of Characters

Square brackets are used to perform indexing into a string to get the value at a certain index/position.

```
s = 'abcd'
```

indices: 012 → **indexing always starts at 0**

indices: -3 - 2 - 1 → **last element always at index -1**

- ▶ `s[0]` evaluates to "a"
- ▶ `s[1]` evaluates to "b"
- ▶ `s[2]` evaluates to "c"
- ▶ `s[3]` evaluates to "d"
- ▶ `s[4]` trying to index out of bounds, error
- ▶ `s[-1]` evaluates to "d"
- ▶ `s[-2]` evaluates to "c"
- ▶ `s[-3]` evaluates to "b"
- ▶ `s[-4]` evaluates to "a"

Mutable vs. Immutable types

▶ **Mutable types**

- ▶ Can change their contents / members
- ▶ `lists`, `dicts`, user-defined types

▶ **Immutable types**

- ▶ Cannot change their contents / members
- ▶ most built-in types (`int`, `float`, `bool`, `str`, `tuple`)

Recap: Strings and Loops

demo/example11.py

The two code snippets below do the same thing: they loop over the characters in the string.

```
s = "mickey"
for index in range(len(s)):
    if s[index] == 'i' or s[index] == 'y':
        print("There is an i or y")
```

```
for char in s:
    if char == 'i' or char == 'y':
        print("There is an i or y")
```

4. Examples



Example: Guess and Check

demo/example12.py

We want to guess the cube root:

```
cube = 8
for guess in range(abs(cube)+1):
    if guess**3 >= abs(cube):
        break
if guess**3 != abs(cube):
    print(cube, 'is not a perfect cube')

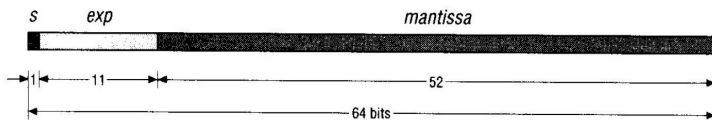
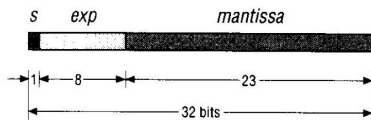
else:
    if cube < 0:
        guess = -guess
    print('Cube root of ' + str(cube) + ' is ' + str(guess))
```

Approximate Solutions

- ▶ We are performing **finite-precision arithmetic** on a computer.
- ▶ We need to define a **good enough solution**.
 - ▶ start with a guess and increment by some small value.
 - ▶ keep guessing if $|\text{guess}^3 - \text{cube}| \geq \varepsilon$ for some small ε .
 - ▶ decreasing increment size \implies slower program.
 - ▶ increasing $\varepsilon \implies$ less accurate answer.

Recall — IEEE Floating Point Representation

Single Precision



Double Precision

| Type | Exponent | Mantissa | Smallest | Largest | Base 10 accuracy |
|--------|----------|----------|----------|----------|------------------|
| float | 8 | 23 | 1.2E-38 | 3.4E+38 | 6-9 |
| double | 11 | 52 | 2.2E-308 | 1.8E+308 | 15-17 |

An approximate solution

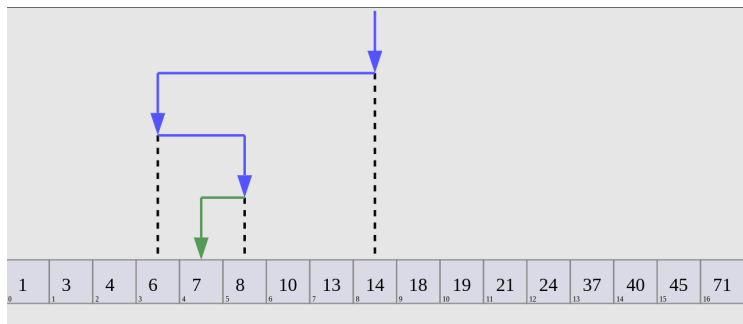
demo/example13.py

```
cube = 27.8
epsilon = 0.1
guess = 0.0
increment = 0.01
num_guesses = 0
# look for close enough answer and make sure
# didn't accidentally skip the close enough bound and thus overshoot
while abs(guess**3 - cube) >= epsilon and guess <= cube:
    guess += increment
    num_guesses += 1
print('num_guesses =', num_guesses)
if abs(guess**3 - cube) >= epsilon:
    print('Failed on cube root of', cube, "with these parameters.")
else:
    print(guess, 'is close to the cube root of', cube)
```

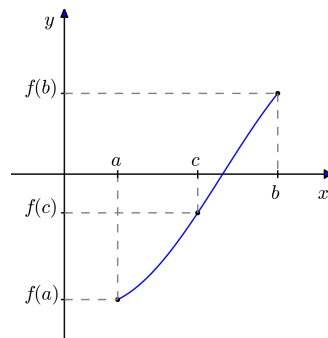
Another example: Bisection

Binary search algorithm - https://en.wikipedia.org/wiki/Binary_search_algorithm

- ▶ The idea of Bisection:
- ▶ half interval each iteration
- ▶ new guess is halfway in between



Visualization of the binary search algorithm where 7 is the target value.



Bisection applied to the cube root

demo/example14.py

```
cube = 27.8
# won't work with  $x < 1$  because initial upper bound is less than ans
#cube = 0.25
epsilon = 0.01
num_guesses = 0
low = 0
high = cube
guess = (high + low)/2.0
while abs(guess**3 - cube) >= epsilon:
    if guess**3 < cube:
        # look only in upper half search space
        low = guess
    else:
        # look only in lower half search space
        high = guess
    # next guess is halfway in search space
    guess = (high + low)/2.0
    num_guesses += 1
print('num_guesses =', num_guesses)
print(guess, 'is close to the cube root of', cube)
```

Bisection applied to the cube root

- ▶ search space of size N
 - ▶ first guess: $N/2$
 - ▶ second guess: $N/4$
 - ▶ k -th guess: $N/2^k$
- ▶ The guess converges on the order of $\log_2 N$ steps
- ▶ The Bisection search works when the value of function varies monotonically with input.
- ▶ The code as shown only works for positive cubes > 1 - why?

Summary → GIT next

When you don't know what it does



But are scared to delete it