Introduction to Programming with Scientific Applications

Course evaluation

”Den første forelæsning var meget ***skræmmende*** *og overvældende”*

Course description – kursuskatalog.au.dk/en/course/104083/

Introduction to Programming with Scientific Applications

Description of qualifications

After the course the participants will have knowledge of principles and techniques for systematic **construction** of **programs**.

At the end of the course, the participants will be able to:

- apply constructions of a common programming language,
- develop **well-structured** programs and perform **testing** and **debugging** of these,
- explain fundamental programming concepts and basic algorithmic techniques,
- apply standard **tools for scientific applications**,
- use the documentation for a programming language and available software packages.

Contents

The course gives an introduction to programming with scientific applications. Programming concepts and techniques are introduced using the **Python** programming language. The programming concepts are **illustrated in other programming languages**. The following content is included.

Basic programming constructs: Data types, operators, variables, flow of control, conditionals, loops, functions, recursion, scope, exceptions. *Object orientation*: Abstract data types, classes, inheritance, encapsulation. *Basic algorithmic techniques*: Sorting, binary search, dynamic programming. *Systematic development of programs*: Testing and debugging. File-based input/output, numerical analysis, functional programming. Scientific computing using standard packages for Python.

ECTS 10

Hours - weeks - periods
Lectures 2 x 2 hours/week
TA sessions 1 x 3 hours/week
Study café 3 x 1 hour/week

Language of instruction
Danish

Instructor
Gerth Stølting Brodal

Academic prerequisites
(Some) Linear algebra

Exam
5 hour programming
Aid: Computer and Internet
7-point grading scale

Prerequisites for examination participation
Submission and approval of 10 mandatory assignments and submission of **1 implementation project**

Notes Grade reflects an overall assessment of implementation project and written examination.

Lecturer

Name	Gerth Stølting Brodal
Research	Algorithms and Data Structures (Computer Science)
Teaching	
2018 -	BSc course on Introduction to Programming with Scientific Applications
2004 -	BSc course on Introduction to Algorithms and Data Structures
1999 - 17	MSc courses on Computational Geometry, Algorithm Engineering, Advanced Data Structures, External Memory Algorithms and Data Structures
Python	Beginner

Question – Primary Education?

a) Mathematics
b) Mathematics-Economics
c) Data Science
d) Chemestry
e) Physics
f) Other Science-Technology
g) Other

Question – Programming languages you know?

+750 listed on en.wikipedia.org/wiki/List_of_programming_languages

Question – Programming experience?

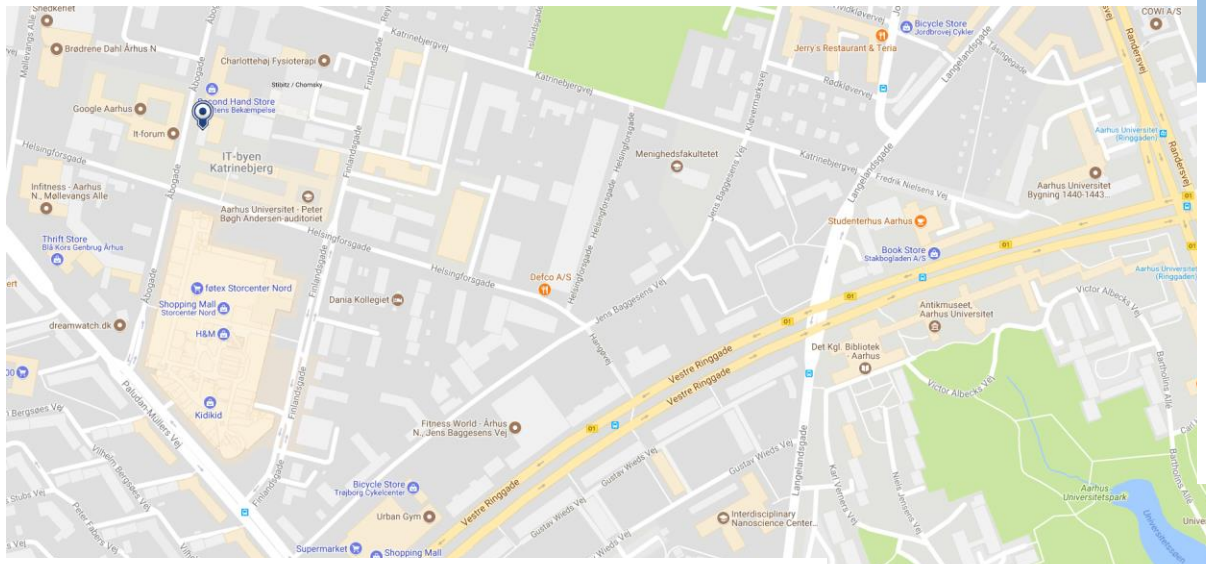
For the programming language you know best (if any) please state you proficiency level within the language.

a) None
b) Fundamental awareness (basic knowledge)
c) Novice (limited experience)
d) Intermediate (practical application)
e) Advanced (applied theory)
f) Expert (recognized authority)

Some course practicalities

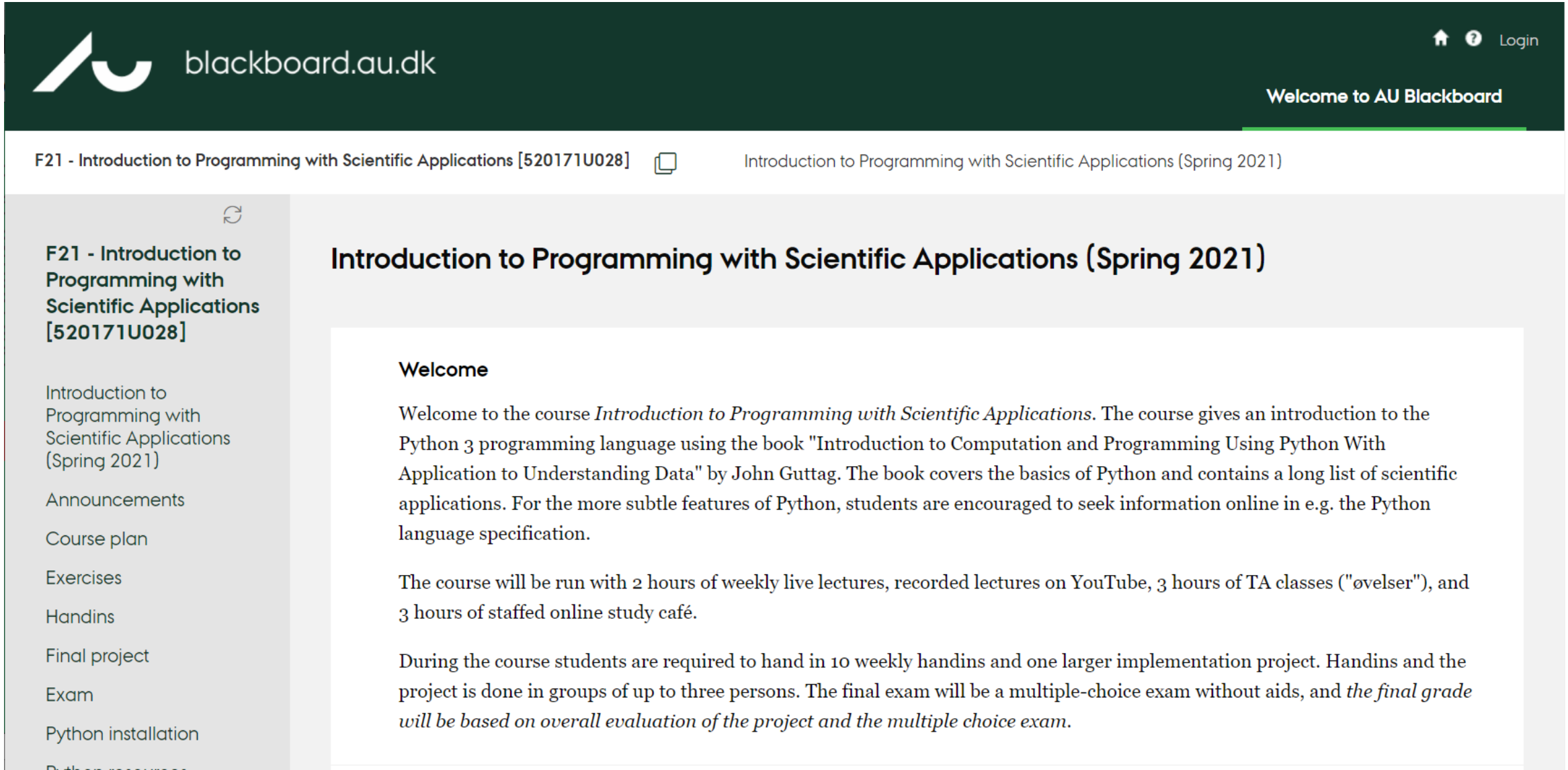
Primary lecture material = YouTube videos

	Week	Monday	Tuesday	Wednesday		Thursday	
online	5	(no TA classes)		/ F1	Live Lecture 14-16		F2 /
	6	TØ1	TØ1	TØ1 / F3		TØ1	F4 / TØ1
	7	TØ2	TØ2	TØ2 / F5		TØ2	F6 / TØ2
	8	TØ3	TØ3	TØ3 / F7		TØ3	F8 / TØ3
	9	TØ4	TØ4	TØ4 / F9		TØ4	F10 / TØ4
	10	TØ5	TØ5	TØ5 / F11		TØ5	F12 / TØ5
	11	TØ6	TØ6	TØ6 / F13		TØ6	F14 / TØ6
	12	TØ7	TØ7	TØ7 / F15		TØ7	F16 / TØ7
	13						
	14		-	- / F17		TØ8	F18 / TØ8
	15	TØ8	TØ8	TØ8 / F19		TØ9	F20 / TØ9
	16	TØ9	TØ9	TØ9 / F21		TØ10	F22 / TØ10
	17	TØ10	TØ10	TØ10 / F23		TØ11	Prayer Day
	18	TØ11	TØ11	TØ11 / F24		TØ12	F25 / TØ11
	19	TØ12	TØ12	TØ12 / F26		Ascension Day	- / TØ12
	20	TØ13	TØ13	TØ13 / F27		TØ13	- / TØ13

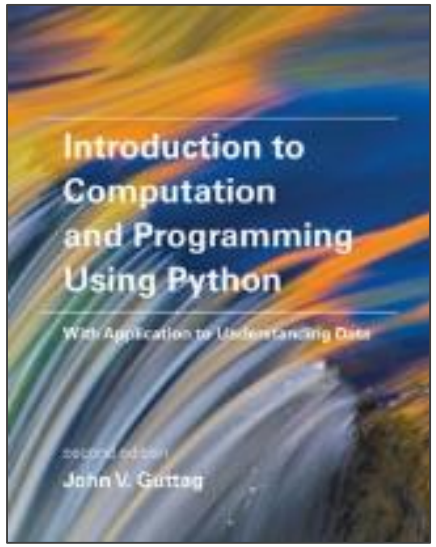


	Monday	Tuesday	Wednesday	Thursday	Friday
8:15-9:00	Studiecafé			Hold MA1	
9:15-10:00	Hold MA2 Hold DV1				Studiecafé
10:15-11:00					
11:15-12:00					Hold MØ2 Hold TV
12:15-13:00					
13:15-14:00					
14:15-15:00	Hold KE		Lecture	Hold DV2 Hold MØ1	
15:15-16:00					
16:15-17:00			Studiecafé		
17:15-18:00					

Course page on Blackboard

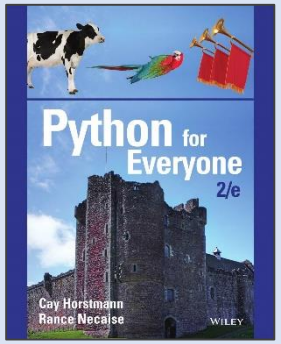


Course text book – optional



John V. Guttag. **Introduction to Computation and Programming Using Python With Application to Understanding Data**.
Second Edition. 472 pages. MIT Press, 2016

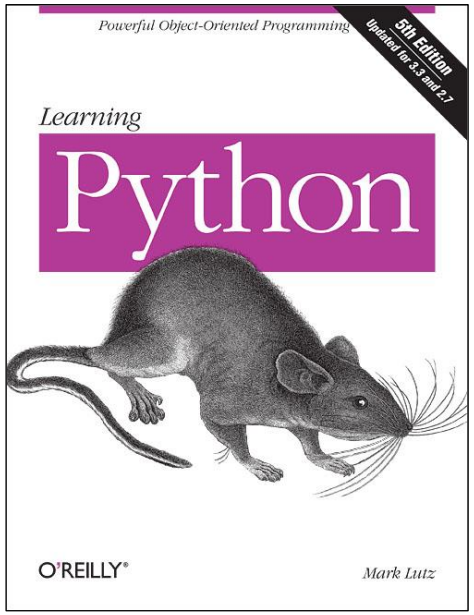
- *[Guttag, page 8] The reader should be forewarned that this book is by no means a comprehensive introduction to Python*
- *Covers all basic features of Python enabling you to deal with data in Chapters 1-8 (134 pages) - remaining chapters are applications*
- *Other resources: Google, stack**overflow**, Python.org, YouTube, ...*



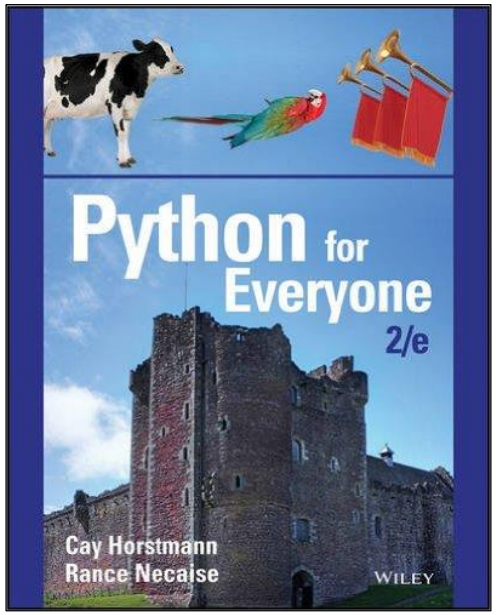
Comparison to a standard text book on the *programming language* Python by Cay Horstmann and Rance Necaise:

Topic **recursion** is covered by Guttag on page 50, Horstmann and Necaise do it on page 611

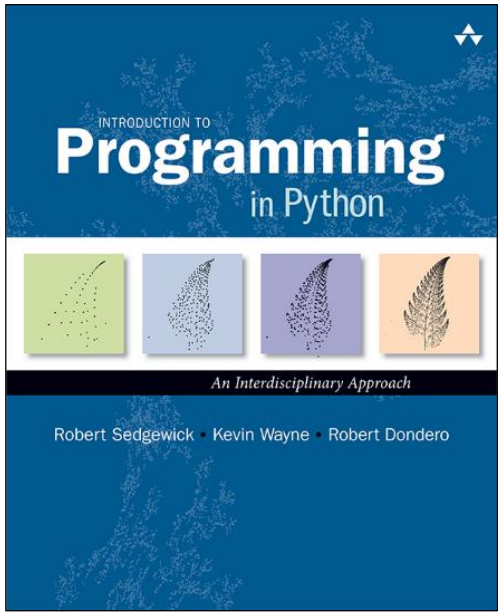
Some other books on Python



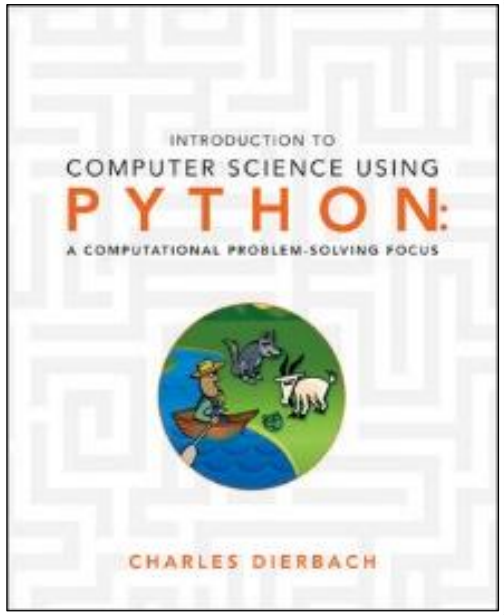
O'Reilly, 2013
1684 pages



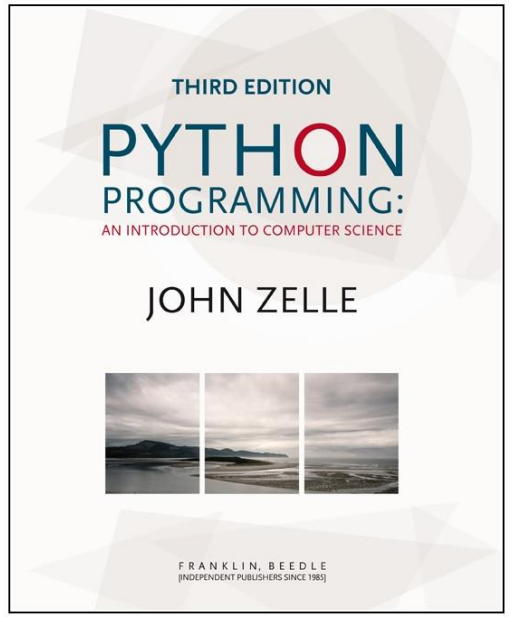
Wiley, 2016
752 pages



Addison-Wesley, 2015
794 pages



Wiley, 2013
580 pages



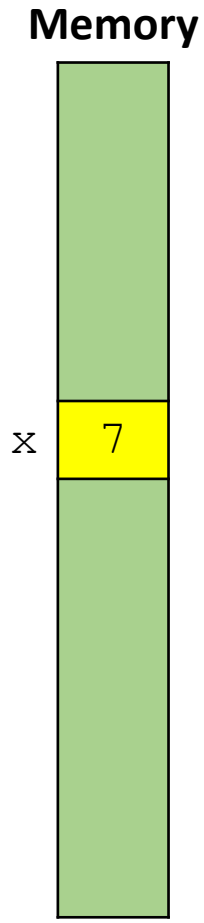
Franklin & Beedle, 2016
552 pages

... numerous online introduction texts/courses/videos on Python

Two Python programs

A Python program

```
Python shell
> x = 7
> print(x * x)
| 49
```



- `7` is an *integer literal* – in Python denoted an "`int`"
- `x` is the name of a *variable* that can hold some value
- `=` is assigning a value to a variable
- `*` denotes multiplication
- `print` is the name of a built-in *function*,
  here we call `print` to print the result of 7*7
- A program consists of a sequence of *statements*, executed sequentially

Question – What is the result of this program?

Python shell

```
> x = 3
> y = 5
> x = 2
> print(x * y)
```

x assigned new value

a) 10

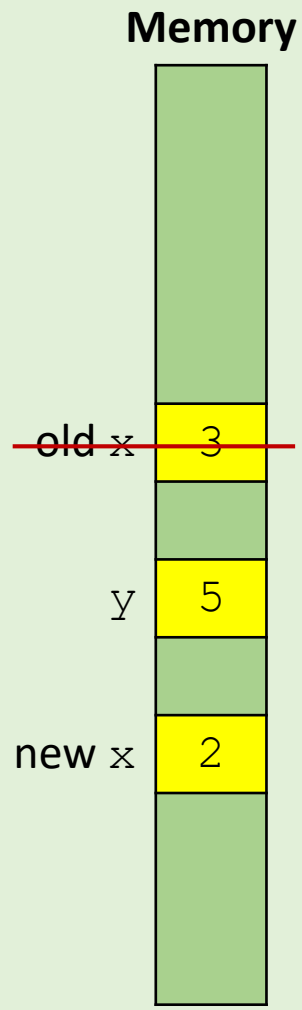
b) 15

c) 25

d) [15, 10]

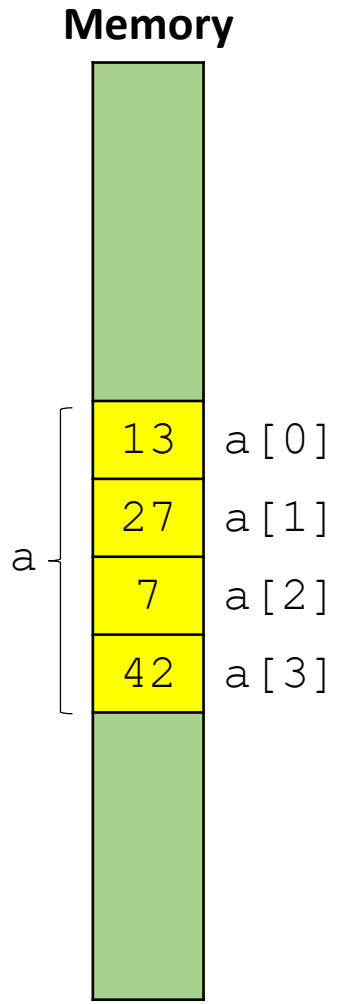
e) Error

f) Don't know



Another Python program using lists

```
Python shell
> a = [13, 27, 7, 42]
> print(a)
| [13, 27, 7, 42]
> print(a[2])
| 7
```



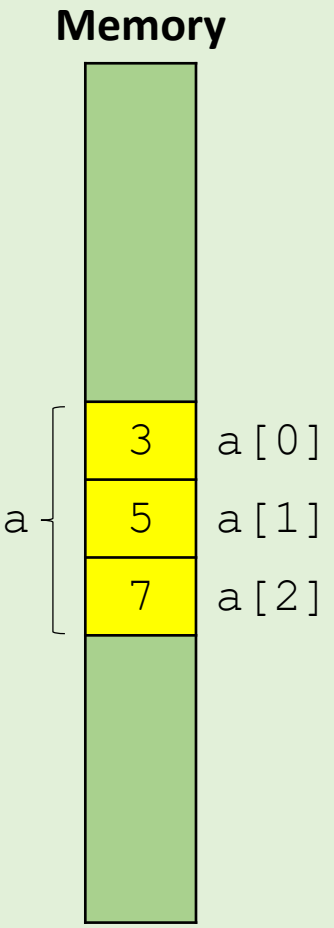
- `[13, 27, 7, 42]` is a *list* containing four integers
- `a[2]` refers to the entry in the list with *index* 2
  (the first element has index 0, i.e. `a[2]` is the 3rd element of the list)
- Note that `print` also can print a list

Question – What is the result of this program?

Python shell

```
> a = [3, 5, 7]
> print(a[1] + a[2])
```

a) 8
b) 10
c) 12
d) 15
e) Don’t know



Why Python ?

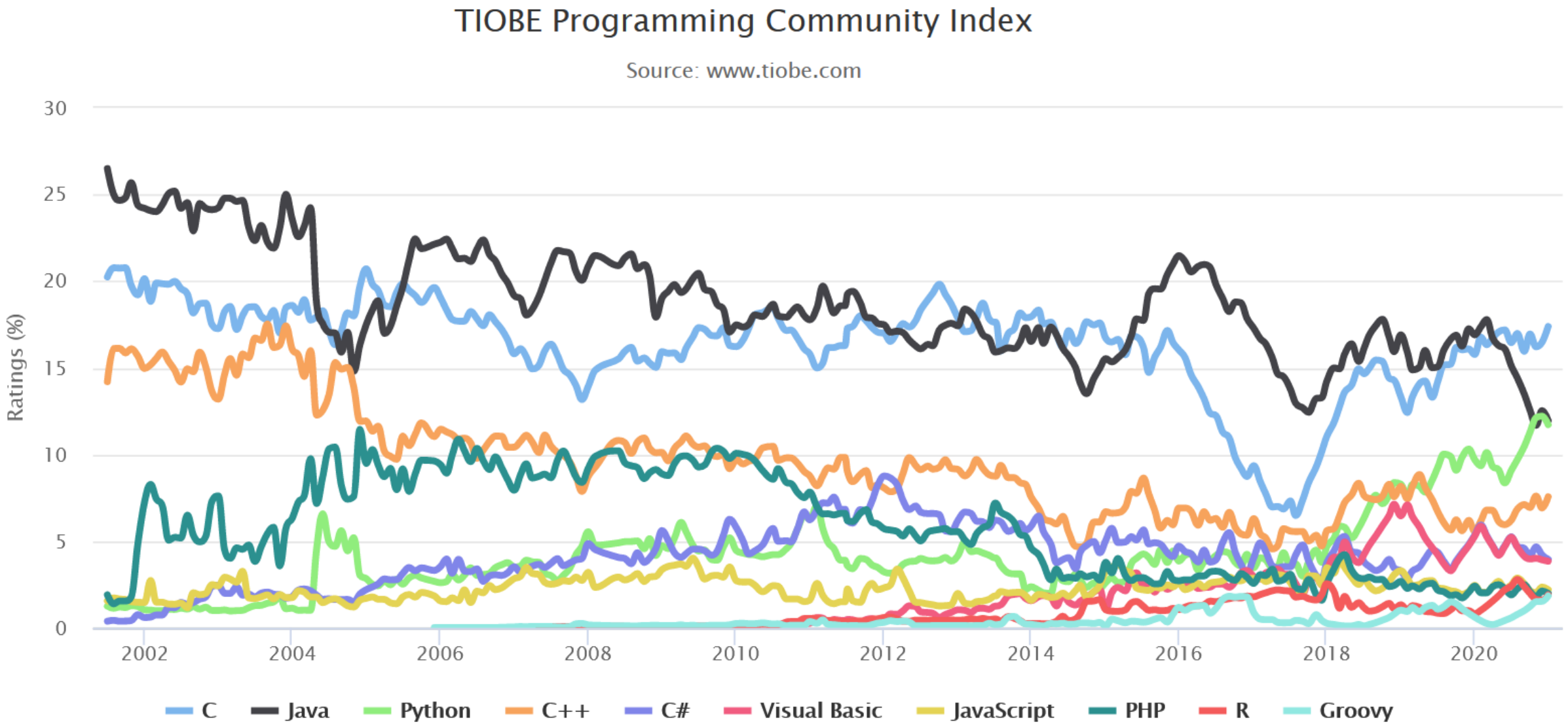
 the next slides will be technical

TIOBE Index January 2021

Jan 2021	Jan 2020	Change	Programming Language	Ratings	Change
1	2	↑	C	17.38%	+1.61%
2	1	↓	Java	11.96%	-4.93%
3	3		Python	11.72%	+2.01%
4	4		C++	7.56%	+1.99%
5	5		C#	3.95%	-1.40%
6	6		Visual Basic	3.84%	-1.44%
7	7		JavaScript	2.20%	-0.25%
8	8		PHP	1.99%	-0.41%
9	18	⇈	R	1.90%	+1.10%
10	23	⇈	Groovy	1.84%	+1.23%

The TIOBE Programming Community index is an indicator of the *popularity of programming languages*. The index is updated once a month. The ratings are based on the number of skilled engineers world-wide, courses and third party vendors. Popular search engines such as Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube and Baidu are used to calculate the ratings. It is important to note that the TIOBE index is not about the *best* programming language or the language in which *most lines of code* have been written. www.tiobe.com

Popularity of programming languages



Most Popular Programming Languages 1965 – 2019 (YouTube)

“Hello World”

- In Java, C, C++ a lot of “{“, “}” and “;” are needed
- Java tends to have a lot of “public...” details that need to be spelled out
- Python is concise

Java

```
public class HelloWorld {
    public static void main( String[] args ) {
        System.out.println( "Hello World!" );
        System.exit( 0 );
    }
}
```

C

```
#include <stdio.h>

int main(int argc, char **argv) {
    printf("Hello World");
    return 0;
}
```

C++

```
#include <iostream>
using namespace std;

int main(int argc, char** argv) {
    cout << "Hello, World!";
    return 0;
}
```

Python 2

```
print "Hello world"
```

Python 3

```
print("Hello world")
```

Why Python ?

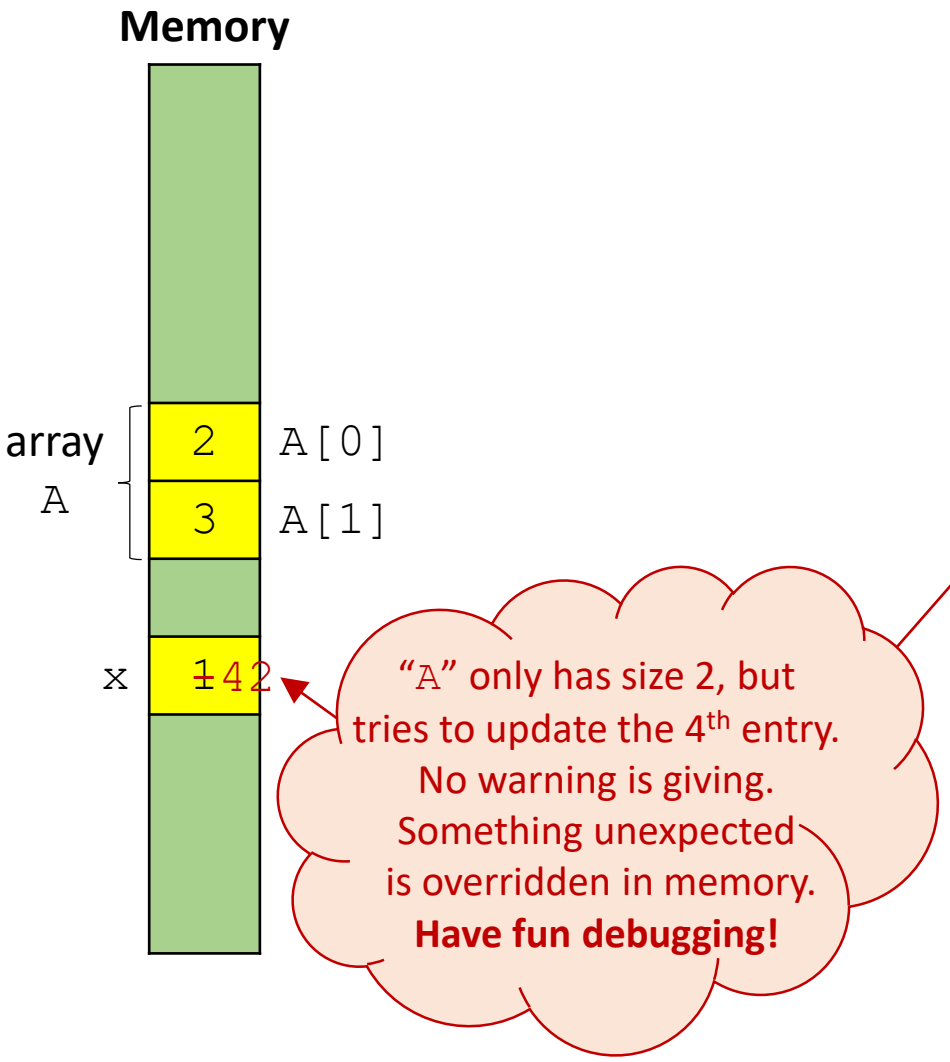
- **Short concise code**

(C developed by Dennis Ritchie 1969-73)

C index out of bounds

Debugging is the process of finding and resolving defects or problems within a computer program that prevent correct operation of computer software or a system.

en.wikipedia.org/wiki/Debugging



indexing.c

```
#include <stdio.h>
int main() {
  int x = 1;
  int A[2] = {2, 3}; // A[0] = 2, A[1] = 3
  printf("x = %d, A = {%d, %d}\n", x, A[0], A[1]);
  A[3] = 42; // index A[3] out of bounds
  printf("x = %d, A = {%d, %d}\n", x, A[0], A[1]);
  return 0;
}
```

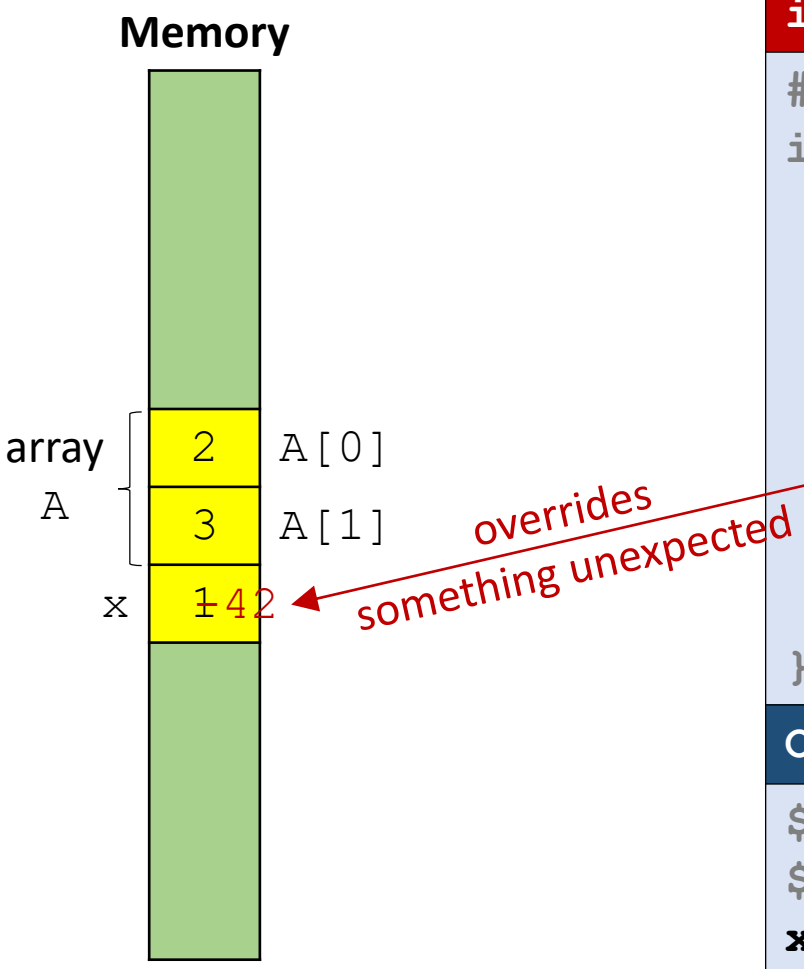
Output

```
$ gcc indexing.c
$ ./a.exe
x = 1, A = {2, 3}
x = 42, A = {2, 3}
```

Skipping checking for invalid indexing makes programs faster, but also requires disciplined programming

(C++ was developed by Bjarne Stroustrup 1985)

… and C++ index out of bounds



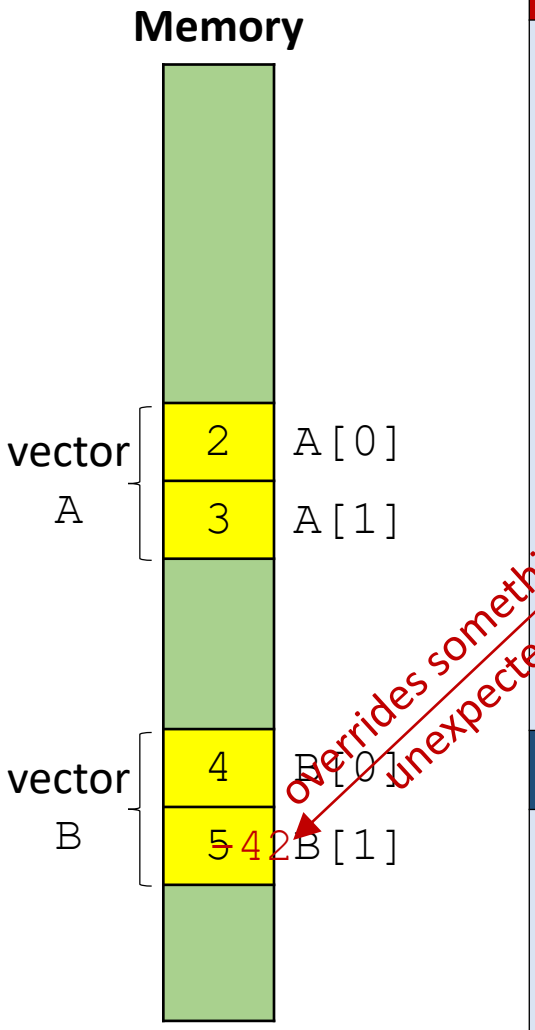
indexing.cpp

```
#include <iostream>
int main() {
  int x = 1;
  int A[2] = {2, 3}; // A[0] = 2, A[1] = 3
  std::cout << "x = " << x << ", A = {"
            << A[0] << ", " << A[1] << "}" << std::endl;
  A[2] = 42; // index A[2] out of bounds
  std::cout << "x = " << x << ", A = {"
            << A[0] << ", " << A[1] << "}" << std::endl;
  return 0;
}
```

Output

```
$ g++ indexing.cpp
$ ./a.exe
x = 1, A = {2, 3}
x = 42, A = {2, 3}
```

… and C++ `vector` index out of bounds



indexing.cpp

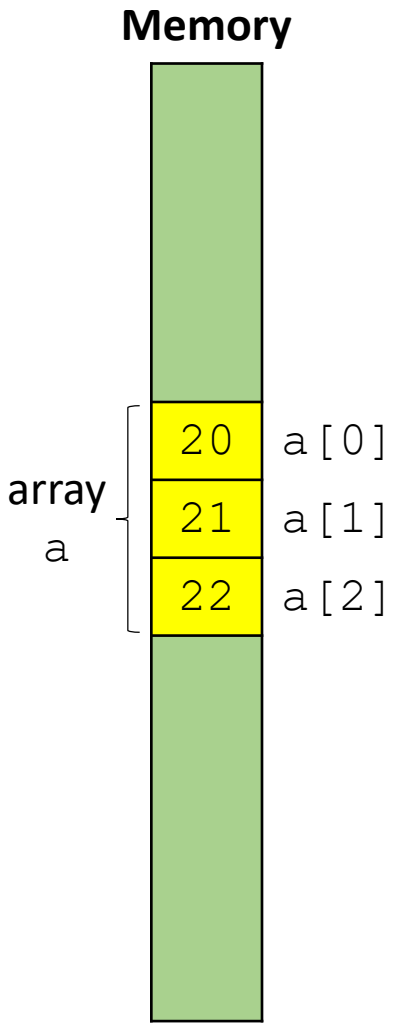
```
#include <iostream>
#include <vector>
int main() {
  std::vector<int> A = {2, 3};  // A[0] = 2, A[1] = 3
  std::vector<int> B = {4, 5};  // B[0] = 4, B[1] = 5
  std::cout << "A={" << A[0] << ", " << A[1] << "}, ";
  std::cout << "B={" << B[0] << ", " << B[1] << "}" << std::endl;
  A[9]=42; // index A[9] out of bounds
  std::cout << "A={" << A[0] << ", " << A[1] << "}, ";
  std::cout << "B={" << B[0] << ", " << B[1] << "}" << std::endl;
  return 0;
}
```

Output

```
$ g++ -std=c++11 indexing-vector.cpp
$ ./a.exe
A={2, 3}, B={4, 5}
A={2, 3}, B={4, 42}
```

(Java was developed by James Gosling 1995)

… and Java index out of bounds exception



indexing.java

```
class IndexingTest{
    public static void main(String args[]){
       int a[] = {20, 21, 22};
       a[5] = 42; // index a[5] out of bounds
    }
}
```

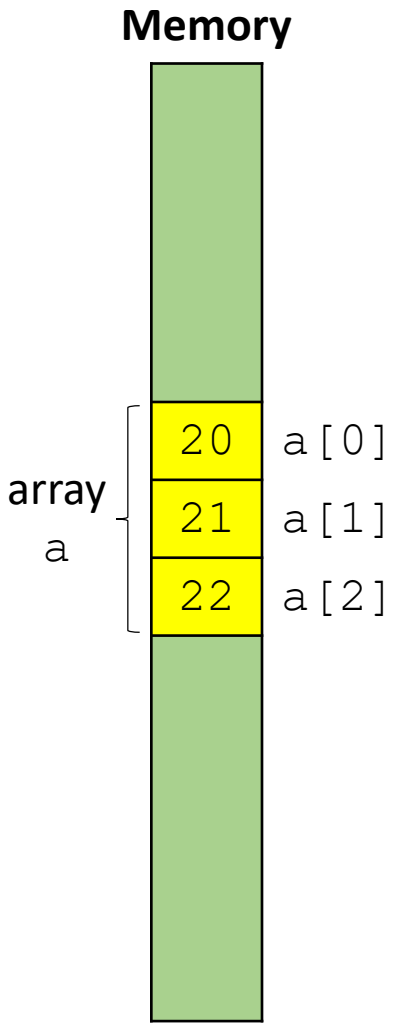
Output

```
$ javac indexing.java
$ java IndexingTest
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 5
        at IndexingTest.main(indexing.java:5)
```

Java provides error message when running the program

(Python first release by Guido van Rossum 1991)

… and Python index out of bounds exception



indexing.py

```
a = [20, 21, 22]
a[5] = 42 # index a[5] out of bounds
```

Output

```
$ python indexing.py
Traceback (most recent call last):
  File "indexing.py", line 3, in <module>
    a[5] = 42
IndexError: list assignment index out of range
```

Python provides error message when running the program

Why Python ?

- Short concise code
- **Index out-of-range exceptions**

C++ different ways to print a vector

vector-iterator.cpp

```
#include <iostream>
#include <vector>
int main() {
  // Vector is part of STL (Standard Template Library)
  std::vector<int> A = {20, 23, 26};
  // "C" indexing - since C++98
  for (int i = 0; i < A.size(); i++)
    std::cout << A[i] << std::endl;
  // iterator - since C++98
  for (std::vector<int>::iterator it = A.begin(); it != A.end(); ++it)
    std::cout << *it << std:: endl;
  // "auto" iterator - since C++11
  for (auto it = A.begin(); it != A.end(); ++it)
    std::cout << *it << std:: endl;
  // Range-based for-loop - since C++11
  for (auto e : A)
    std::cout << e << std:: endl;
}
```

elegant

Java - different ways to print a vector

vector-iterator.java

```
import java.util.Vector;
import java.util.Iterator;

class IteratorTest{
   public static void main(String[] args) {
       Vector<Integer> a = new Vector<Integer>();
       a.add(7);
       a.add(42);
       // "C" for-loop & get method
       for (int i=0; i<a.size(); i++)
          System.out.println(a.get(i));
       // iterator
       for (Iterator it = a.iterator(); it.hasNext(); )
          System.out.println(it.next());
       // for-each loop - since Java 5
       for (Integer e : a)
          System.out.println(e);
   }
}
```

elegant

The Python way to print a list

print-list.py

```
a = [20, 23, 26]

for e in a:
    print(e)
```

Output

```
$ python print-list.py
20
23
26
```

Why Python ?

- Short concise code
- Index out of range exceptions
- **Elegant for-each loop**

C++ how not to print a vector

```
$ g++ -std=c++11 print-vector.cpp
cpp-error-message.cpp: In function 'int main()':
cpp-error-message.cpp:7:13: error: no match for 'operator<<' (operand types are 'std::ostream {aka std::basic_ostream<char>}' and 'std::vector<int>')
   std::cout << A << std::endl;
             ^
In file included from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/iostream:39:0,
                 from cpp-error-message.cpp:1:
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:628:5: note: candidate: std::basic_ostream<_CharT, _Traits>& std::operator<<(std::basic_ostream<_CharT, _Traits>&&, const _Tp&) [with _CharT = char; _Traits = std::char_traits<char>; _Tp = std::vector<int>] <near match>
     operator<<(basic_ostream<_CharT, _Traits>&& __os, const _Tp& __x)
     ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:628:5: note:   conversion of argument 1 would be ill-formed:
cpp-error-message.cpp:7:16: error: cannot bind 'std::ostream {aka std::basic_ostream<char>}' lvalue to 'std::basic_ostream<char>&&'
   std::cout << A << std::endl;
                ^
In file included from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/iostream:39:0,
                 from cpp-error-message.cpp:1:
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:108:7: note: candidate: std::basic_ostream<_CharT, _Traits>& std::basic_ostream<_CharT, _Traits>::operator<<(std::basic_ostream<_CharT, _Traits>::__ostream_type& (*)(std::basic_ostream<_CharT, _Traits>::__ostream_type&)) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostream<char>]
       operator<<(__ostream_type& (*__pf)(__ostream_type&))
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:108:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::basic_ostream<char>::__ostream_type& (*)(std::basic_ostream<char>::__ostream_type&) {aka std::basic_ostream<char>& (*)(std::basic_ostream<char>&)}'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:117:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(std::basic_ostream<_CharT, _Traits>::__ios_type& (*)(std::basic_ostream<_CharT, _Traits>::__ios_type&)) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostream<char>; std::basic_ostream<_CharT, _Traits>::__ios_type = std::basic_ios<char>]
       operator<<(__ios_type& (*__pf)(__ios_type&))
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:117:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::basic_ostream<char>::__ios_type& (*)(std::basic_ostream<char>::__ios_type&) {aka std::basic_ios<char>& (*)(std::basic_ios<char>&)}'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:127:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(std::ios_base& (*)(std::ios_base&)) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream
       operator<<(ios_base& (*__pf) (ios_base&))
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:127:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::ios_base& (*)(std::ios_base&)'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:166:7: note: candidate: std::basic_ostream
       operator<<(long __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:166:7: note:   no known conversion for arg
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:170:7: note: candidate: std::basic_ostream
       operator<<(unsigned long __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:170:7: note:   no known conversion for arg
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:174:7: note: candidate: std::basic_ostream
       operator<<(bool __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:174:7: note:   no known conversion for arg
In file included from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:638:0,
                 from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/iostream:39,
                 from cpp-error-message.cpp:1:
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/bits/ostream.tcc:91:5: note: candidate: std::basic
     basic_ostream<_CharT, _Traits>::
     ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/bits/ostream.tcc:91:5: note:   no known conversion
In file included from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/iostream:39:0,
                 from cpp-error-message.cpp:1:
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:181:7: note: candidate: std::basic_ostream
       operator<<(unsigned short __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:181:7: note:   no known conversion for arg
In file included from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:638:0,
                 from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/iostream:39,
                 from cpp-error-message.cpp:1:
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/bits/ostream.tcc:105:5: note: candidate: std::basi
     basic_ostream<_CharT, _Traits>::
     ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/bits/ostream.tcc:105:5: note:   no known conversio
In file included from /usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/iostream:39:0,
                 from cpp-error-message.cpp:1:
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:192:7: note: candidate: std::basic_ostream
       operator<<(unsigned int __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:192:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'unsigned
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:201:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_
       operator<<(long long __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:201:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'long long
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:205:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_
       operator<<(unsigned long long __n)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:205:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'long long unsigned int'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:220:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(double) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostream<c
       operator<<(double __f)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:220:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'double'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:224:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(float) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostream<ch
       operator<<(float __f)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:224:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'float'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:232:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(long double) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostr
       operator<<(long double __f)
       ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:232:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'long double'
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:245:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(const void*) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostr
```

print-vector.cpp

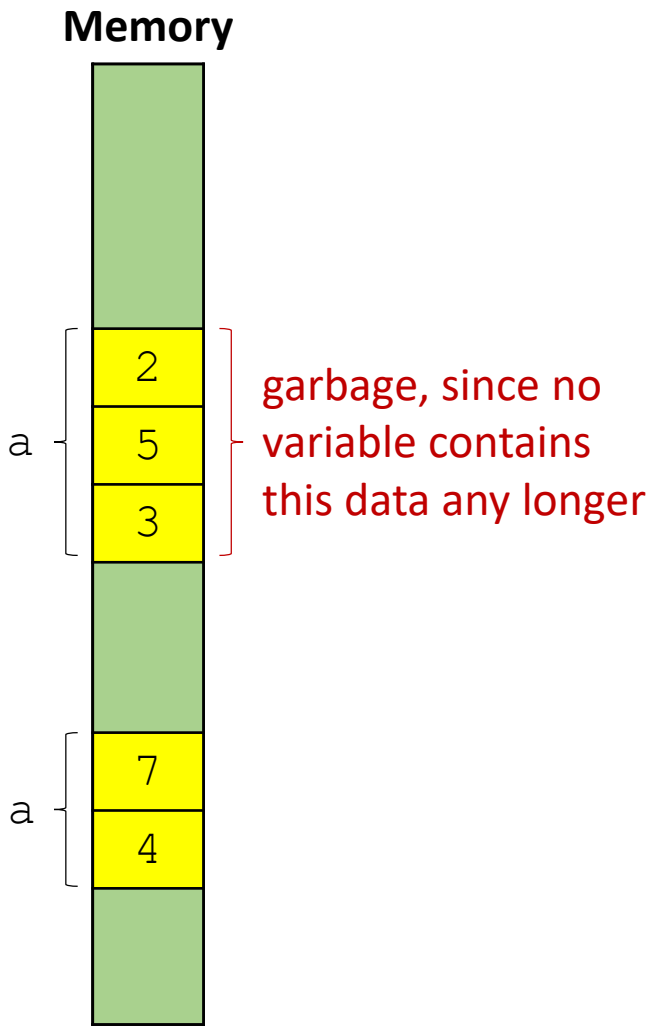
```
#include <iostream>
#include <vector>

int main() {
   std::vector<int> A = {2, 3};
   std::cout << A << std::endl;
   return 0;
}
```

C++ vectors cannot be printed directly –
mistake results in +200 lines of error messages

Why Python ?

- Short concise code
- Index out of range exceptions
- Elegant for-each loop
- **Python hopefully better error messages than C++**

Python and garbage collection




```
garbage.py
a = [2, 5, 3]
a = [7,4]
```

a gets new value

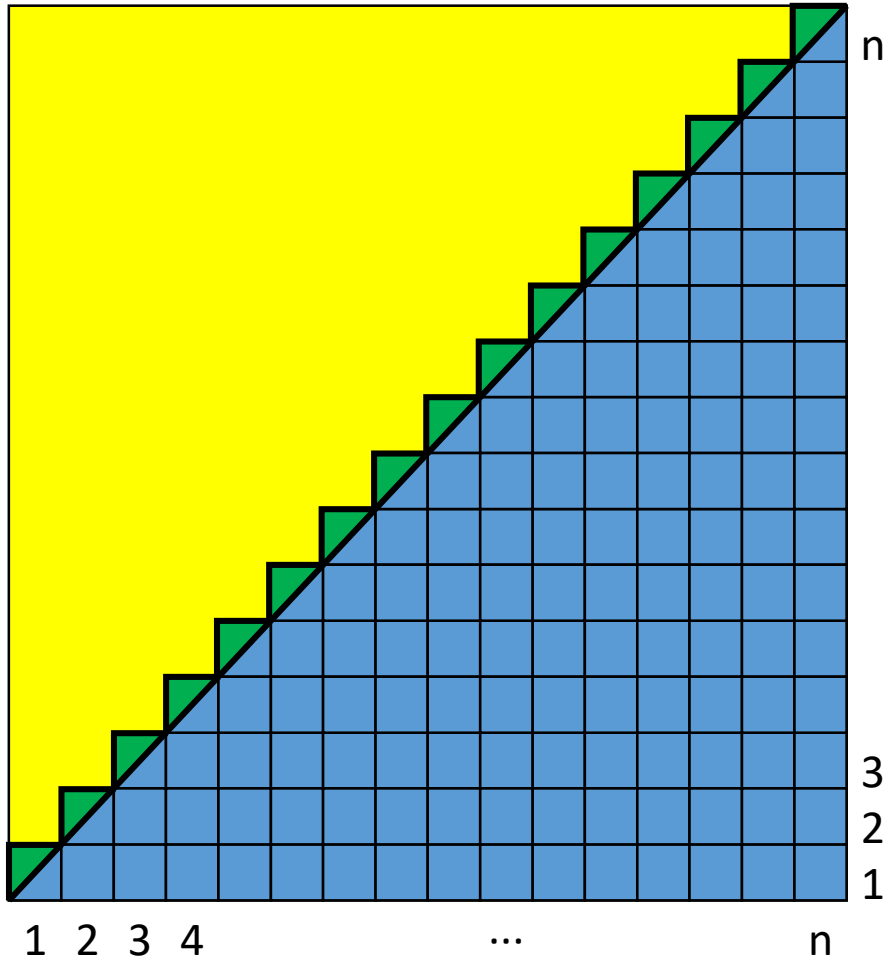
- Python and e.g. Java, C# and JavaScript have a **garbage collector** to automatically recycle garbage
- C and C++ garbage collection must be done explicitly by the program; forgetting to **free** memory again results in **memory leaks** – which can be really hard to find. **Have fun debugging!**

Why Python ?

- Short concise code
- Index out of range exceptions
- Elegant for-each loop
- Python hopefully better error messages than C++
- **Garbage collection is done automatically**

Python performance vs C, C++ and Java

Compute sum $1 + 2 + 3 + \cdots + n = n^2/2 + n/2$



1 + 2 + … + n

add.py

```python
import sys

n = int(sys.argv[1])
sum = 0
for i in range(1, n + 1):
    sum += i
print("Sum = %d" % sum)
```

add.c

```c
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char *argv[]) {
  int n = atoi(argv[1]);
  int sum = 0;
  for (int i=1; i<=n; i++)
    sum += i;
  printf("Sum = %d\n", sum);
}
```

add.cpp

```cpp
#include <iostream>
#include <cstdlib>
using namespace std;

int main(int argc, char *argv[]) {
  int n = atoi(argv[1]);
  int sum = 0;
  for (int i=1; i<=n; i++)
    sum += i;
  cout << "Sum = " << sum << endl;
}
```

add.java

```java
class Add{
    public static void main(String args[]){
        int n = Integer.parseInt(args[0]);
        int sum = 0;
        for (int i=1; i<=n; i++)
            sum += i;
        System.out.println("Sum = " + sum);
    }
}
```

Timing results

Python

n	C (gcc 9.2)	C++, int (g++ 9.2)	C++, long (g++ 9.2)	Java (12.0)	Python (3.8.1)	PyPy (7.3.0)	Numba, int64
10^7	0.001 sec*	0.001 sec*	0.003 sec	0.006 sec*	1.5 sec	0.27 sec	0.002 sec
10^9	0.10 sec**	0.10 sec**	0.30 sec	0.40 sec**	145 sec	27 sec	0.2 sec

Wrong output (overflow)

* -2004260032 instead of 50000005000000

** -243309312 instead of 500000000500000000

- since C, C++, and Java only uses 32 bits to represent integers (and 64 bits for ”long” integers)

Have fun debugging!

```
Bit             6666666666555555555544444444443333333332222222222111111111100000000000
position        9876543210987654321098765432109876543210987654321098765432109876543210

bin(10**9)                                                      111011100110101100101000000000

bin(50000005000000)                        10110101111001100010001000100101101011010000000
bin(-2004260032+2**32)                                          100010001000100101101011010000000

bin(500000000500000000)    11011110000010110110101100111110001011111110110010100000000
bin(-243309312+2**32)                                           111100010111111011001010000000
```

Try Google: civilization gandhi overflow

Timing results

Python

n	C (gcc 9.2)	C++, int (g++ 9.2)	C++, long (g++ 9.2)	Java (12.0)	Python (3.8.1)	PyPy (7.3.0)	Numba, int64
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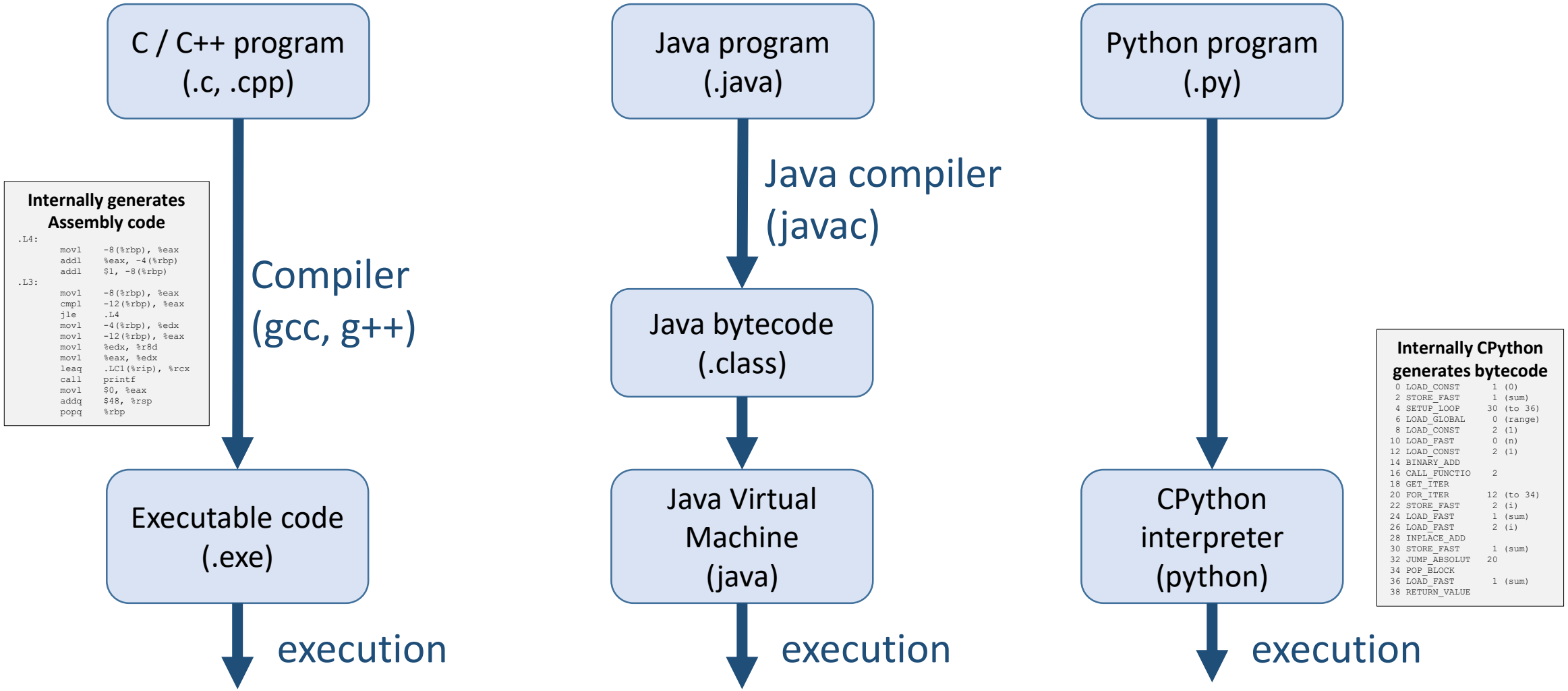
10^9	0.10 sec**	0.10 sec**	0.30 sec	0.40 sec**	145 sec	27 sec	0.2 sec

- Relative speed

C ≈ C++ > Java >> Python

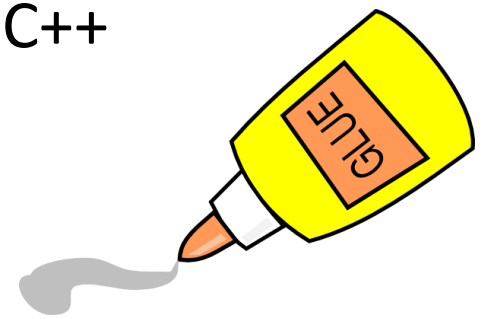
- C, C++, Java need to care about integer overflows – select integer representation carefully with sufficient number of bits (8, 16, 32, 64, 128)
- Python natively works with arbitrary long integers (as memory on your machine allows). Also possible in Java using the class java.math.BigInteger
- Python programs can (sometimes) run faster using PyPy
- Number crunching in **Python** should be delegated to **specialized modules (e.g. Numpy, CPLEX, Numba)** – often written in C or C++

Interpreter vs Compiler

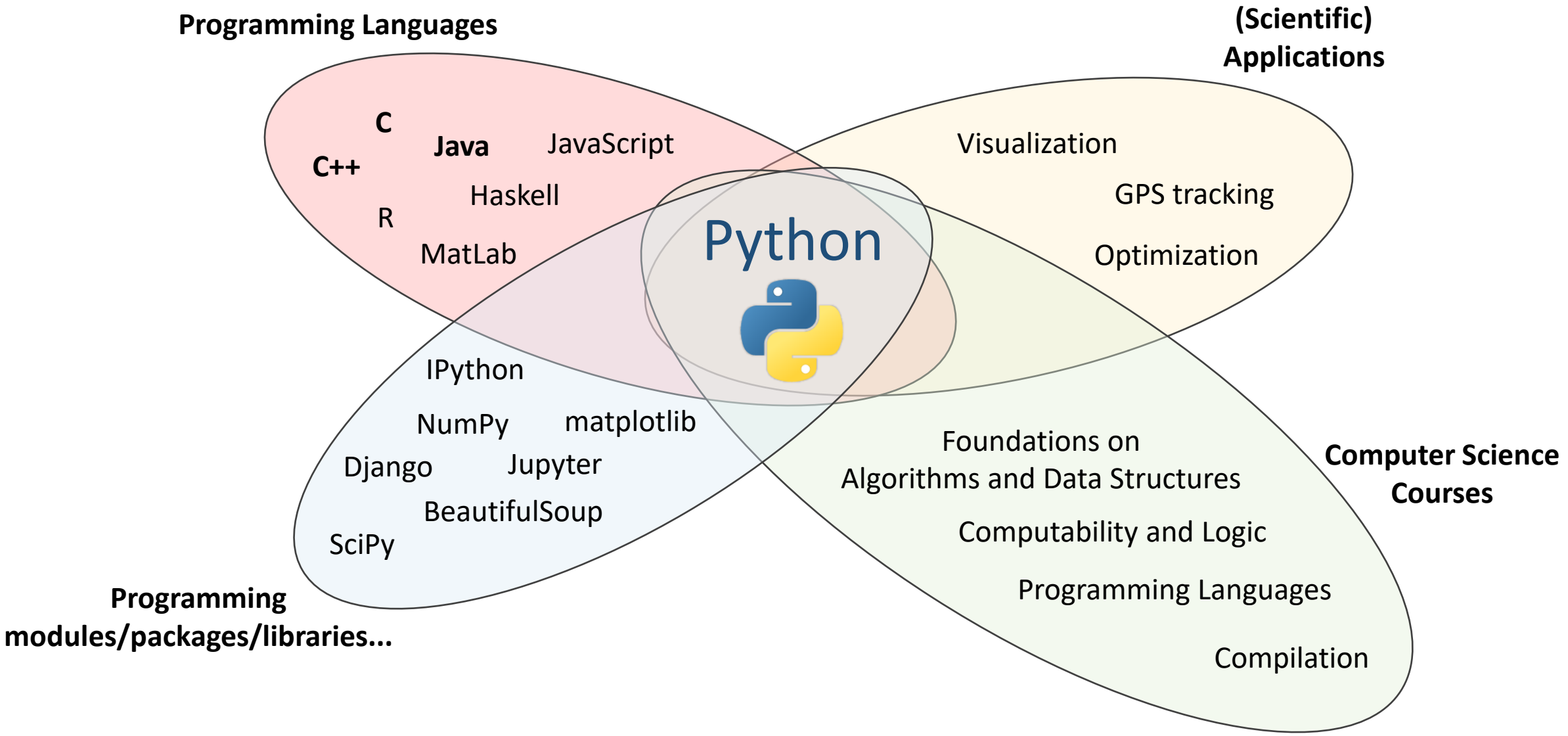


Why Python ?

- Short concise code
- Index out of range exceptions
- Elegant for-each loop
- Python hopefully better error messages than C++
- Garbage collection is done automatically
- **Exact integer arithmetic (no overflows)**
- **Can delegate number crunching to C, C++, ...**



This course


Programming Languages
C
C++
Java
JavaScript
Haskell
R
MatLab
(Scientific) Applications
Visualization
GPS tracking
Optimization
Python
IPython
NumPy
matplotlib
Django
Jupyter
BeautifulSoup
SciPy
Programming modules/packages/libraries...
Foundations on Algorithms and Data Structures
Computability and Logic
Programming Languages
Compilation
Computer Science Courses

Course overview

Basic programming
Advanced / specific python
Libraries & applications

1. Introduction to Python	10. Functions as objects	19. Linear programming
2. Python basics / if	11. Object oriented programming	20. Generators, iterators, with
3. Basic operations	12. Class hierarchies	21. Modules and packages
4. Lists / while / for	13. Exceptions and files	22. Working with text
5. Tuples / comprehensions	14. Doc, testing, debugging	23. Relational data
6. Dictionaries and sets	15. Decorators	24. Clustering
7. Functions	16. Dynamic programming	25. Graphical user interfaces (GUI)
8. Recursion	17. Visualization and optimization	26. Java vs Python
9. Recursion and Iteration	18. Multi-dimensional data	27. Final lecture

10 handins
1 final project (last 1 month)

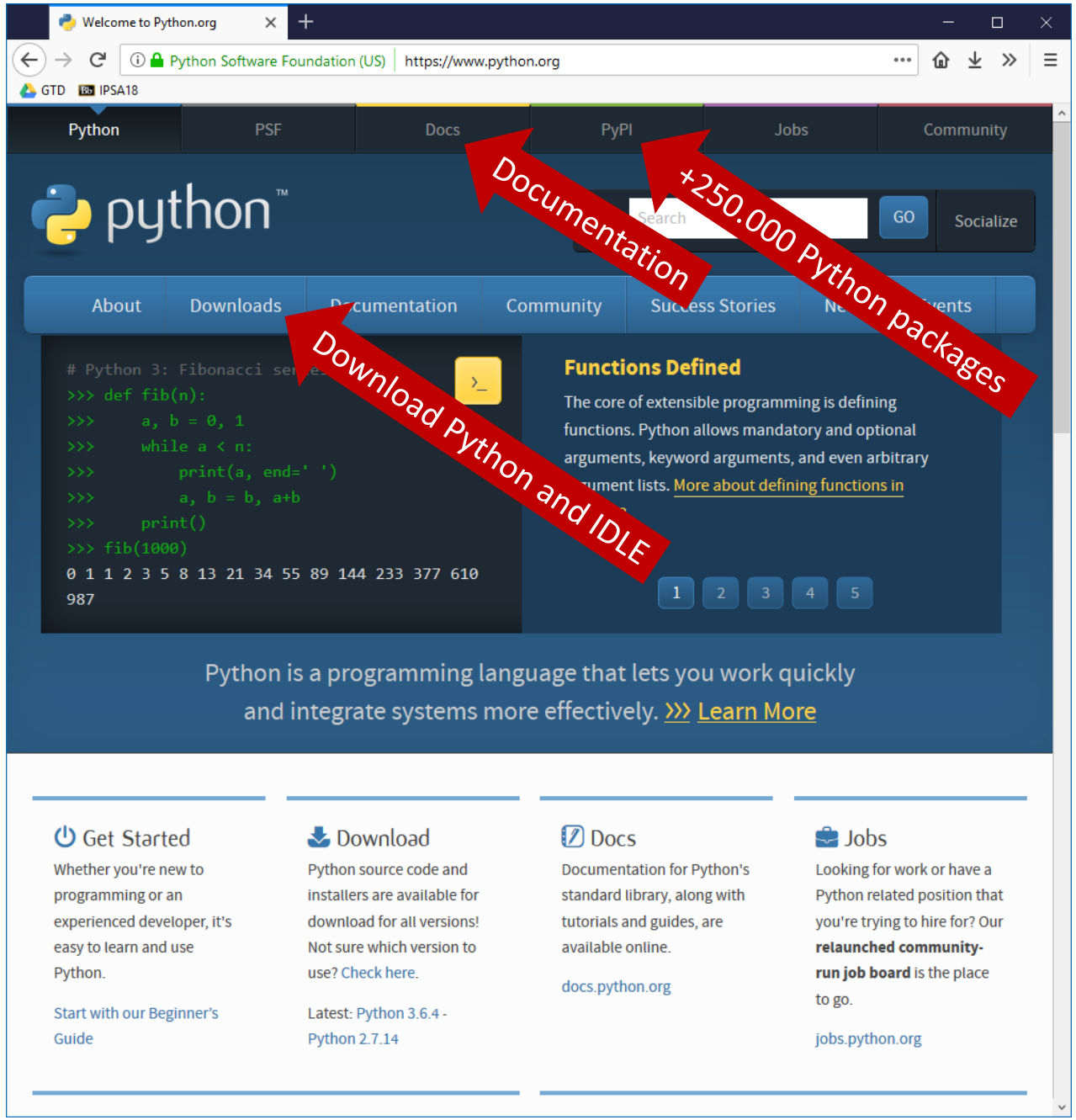
History of Python development

- Python created by Guido van Rossum in 1989, first release 0.9.0 1991
- Python 2 → Python 3 (clean up of Python 2 language)
  - Python 2 – version 2.0 released 2000, final version 2.7 released mid-2010
  - Python 3 – released 2008, current release 3.9.1
- Python 3 is *not* backward compatible, libraries incompatible

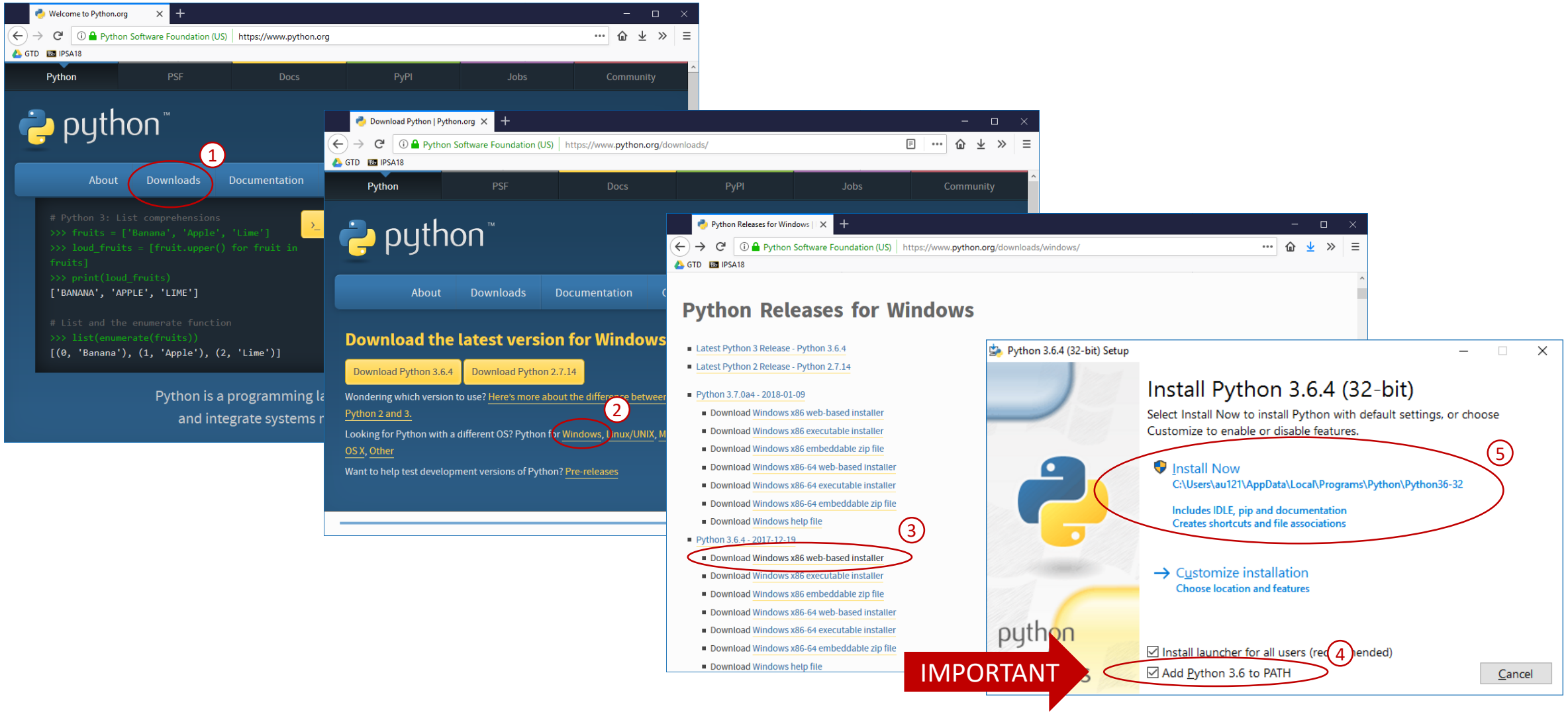
Python 2	Python 3
print 42	print(42)
int = C long (32 bits)	int = arbitrary number of digits (= named “long” in Python 2)
7/3 → 2 returns “int”	7/3 → 2.333... returns “float”
range() returns list (memory intensive)	range() returns iterator (memory efficient; xrange in Python 2)

100th episode of Talk Python To Me: **Python past, present, and future with Guido van Rossum**

Python.org

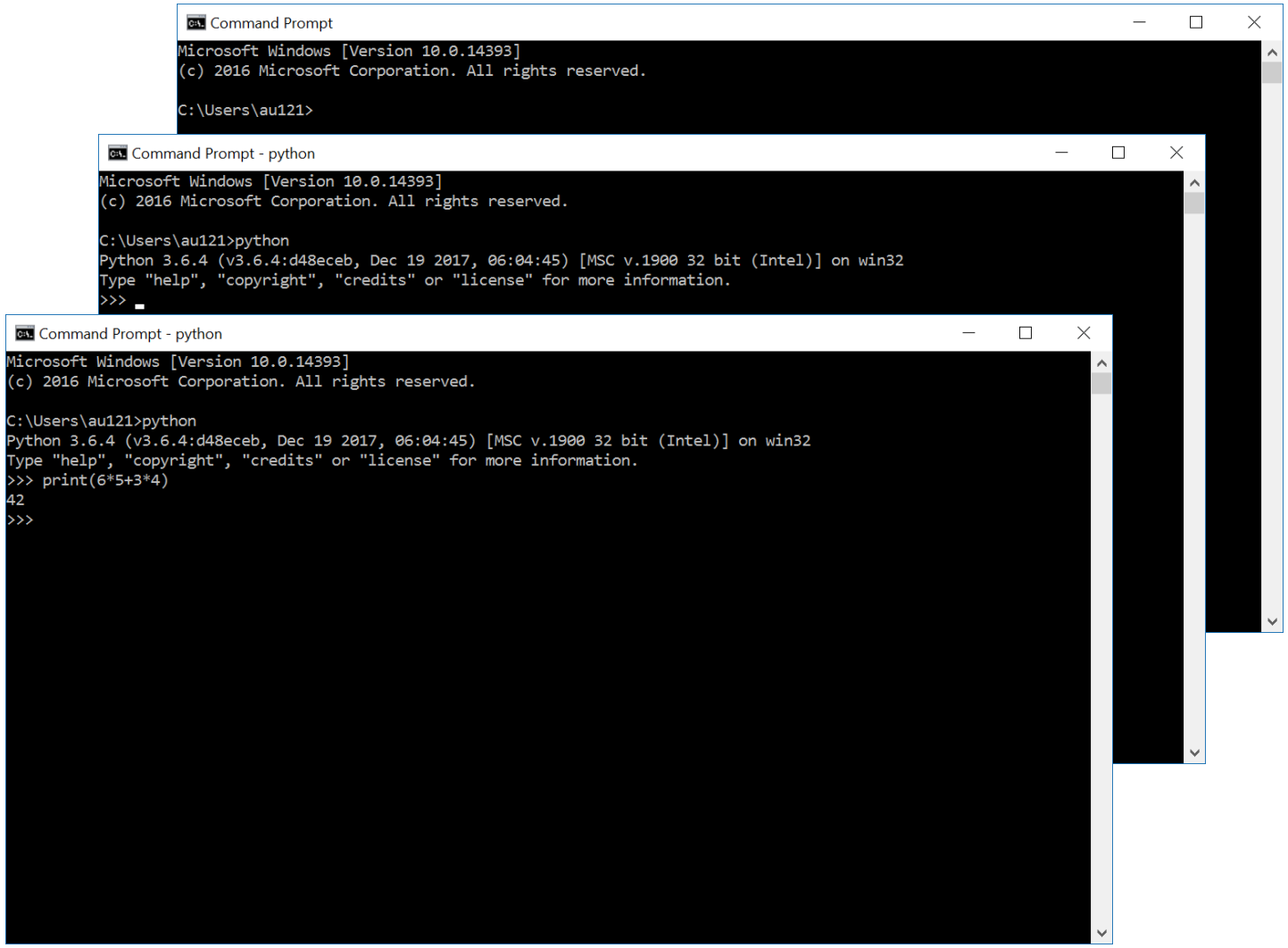

Welcome to Python.org
Python Software Foundation (US)
https://www.python.org
GTD
IPSA18
Python
PSF
Docs
PyPI
Jobs
Community
python
Search
GO
Socialize
About
Downloads
Documentation
Community
Success Stories
Documentation
+250.000 Python packages
Download Python and IDLE
>>> def fib(n):
>>> a, b = 0, 1
>>> while a < n:
>>> print(a, end=' ')
>>> a, b = b, a+b
>>> print()
>>> fib(1000)
0 1 1 2 3 5 8 13 21 34 55 89 144 233 377 610
987
Functions Defined
The core of extensible programming is defining functions. Python allows mandatory and optional arguments, keyword arguments, and even arbitrary
More about defining functions in
1 2 3 4 5
Python is a programming language that lets you work quickly and integrate systems more effectively. >>> Learn More
Get Started
Whether you're new to programming or an experienced developer, it's easy to learn and use Python.
Start with our Beginner's Guide
Download
Python source code and installers are available for download for all versions! Not sure which version to use? Check here.
Latest: Python 3.6.4 - Python 2.7.14
Docs
Documentation for Python's standard library, along with tutorials and guides, are available online.
docs.python.org
Jobs
Looking for work or have a Python related position that you're trying to hire for? Our relaunched community-run job board is the place to go.
jobs.python.org

Installing Python



Running the Python Interpreter

- Open Command Prompt (Windows-key + cmd)
- Type “python” + return
- Start executing Python statements



- To exit shell:
  Ctrl-Z + return *or*
  exit() + return

Installing IPython –

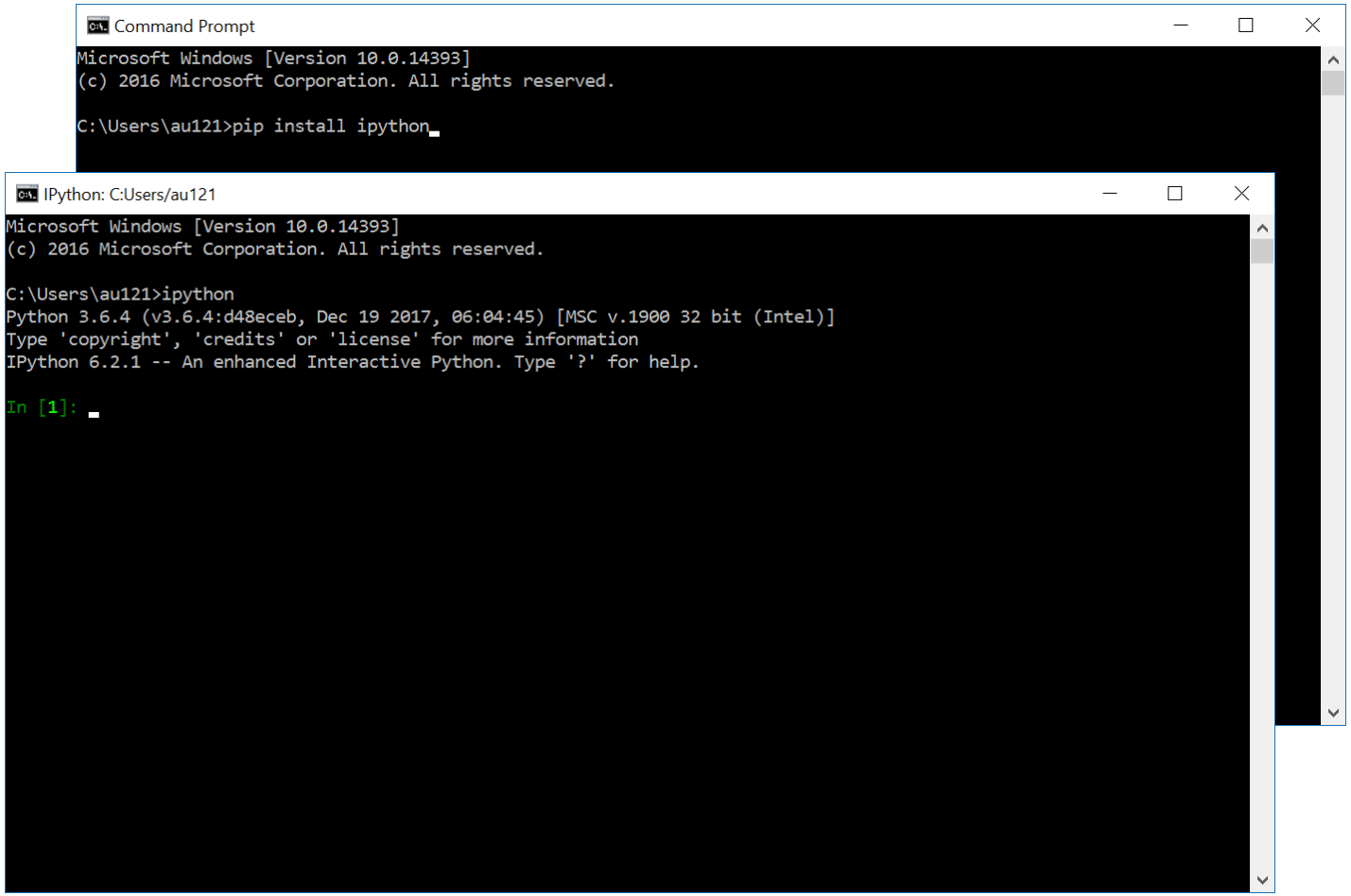
A more powerful interactive Python shell

- Open Command Prompt
- Execute:

```
pip install ipython
```

- Start ipython

```
ipython
```



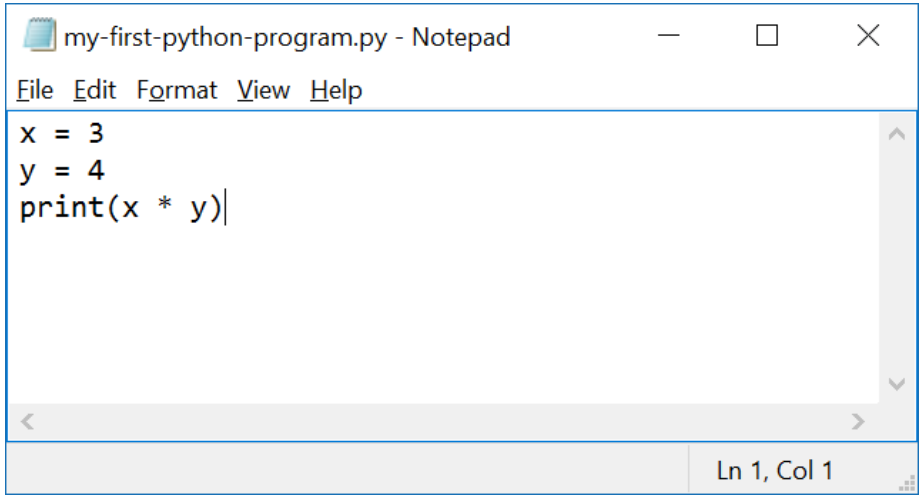
pip = the Python package manager

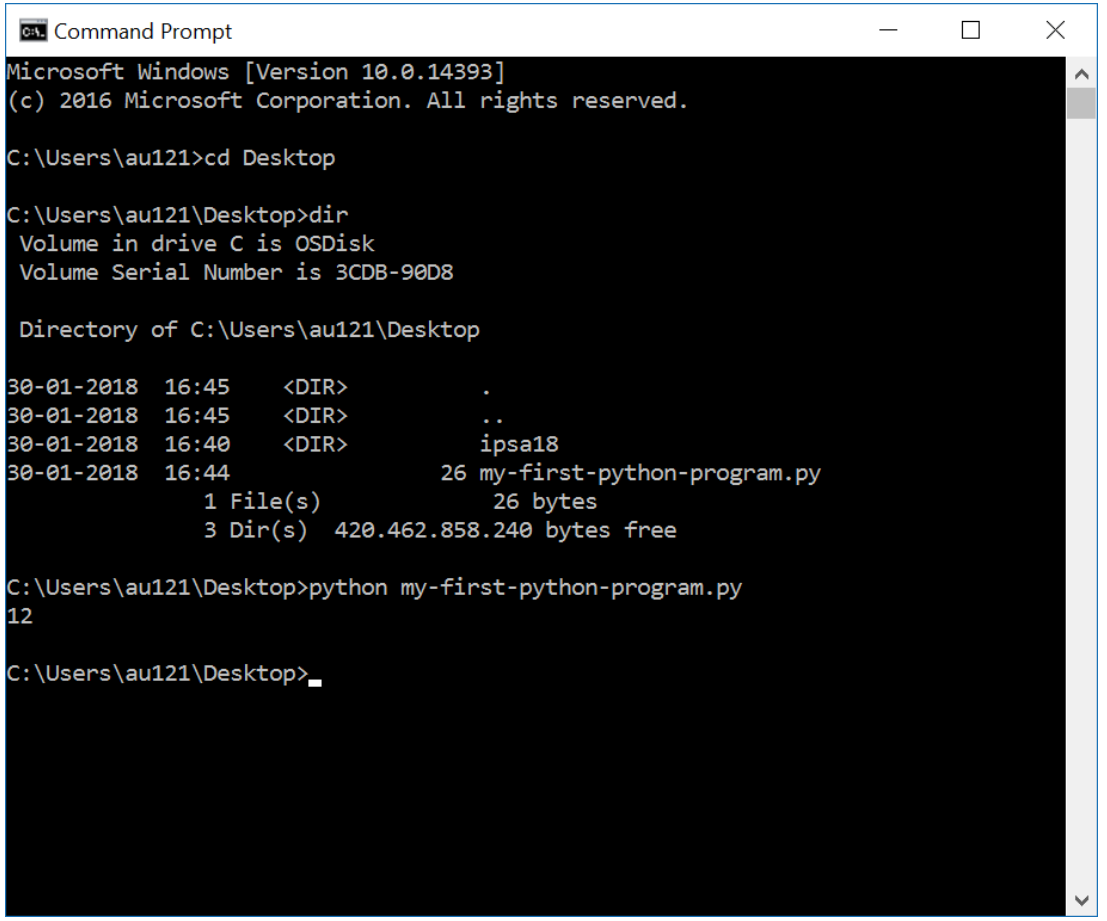
Some other usefull packages

- Try installing some more Python packages:

`pip install numpy`	linear algebra support (N-dimensional arrays)
`pip install scipy`	numerical integration and optimization
`pip install matplotlib`	2D plotting library
`pip install pylint`	Python source code analyzer enforcing a coding standard

Creating a Python program the very basic way

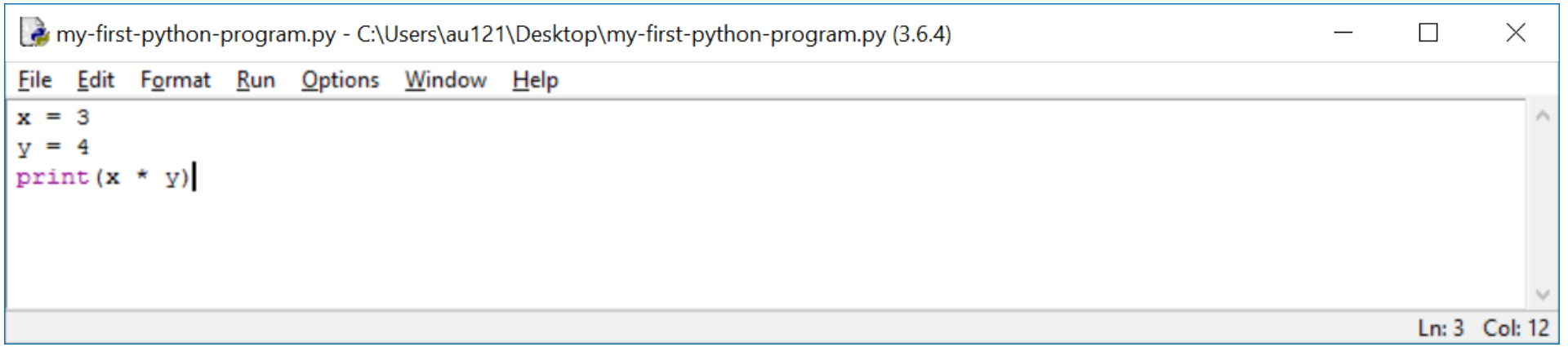


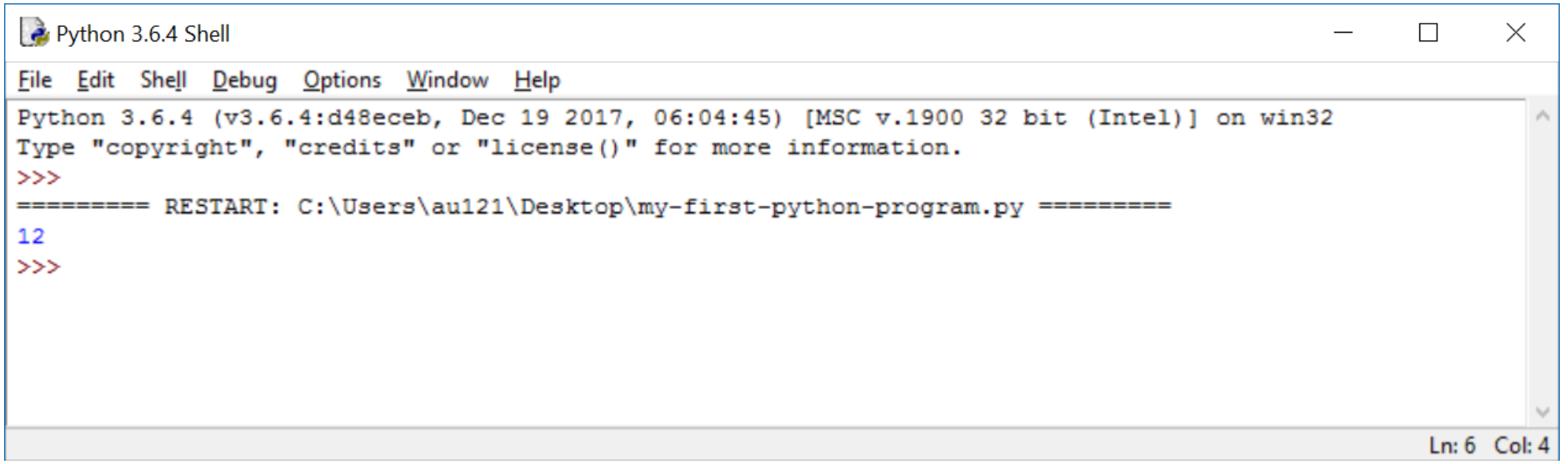


- Open Notepad
  - write a simple Python program
  - save it
- Open a command prompt
  - go to folder (using cd)
  - run the program using

```
python <program name>.py
```

… or open IDLE and run program with F5





The Python Ecosystem

- **Interpreters/compiler**
  - CPython – reference C implementation from python.org
  - PyPy – written in RPython (a subset of Python) – faster than Cpython
  - Jython – written in Java and compiles to Java bytecode, runs on the JVM
  - IronPython – written in C#, compiles to Microsoft's Common Language Runtime (CLR) bytecode
  - Cython – project translating Python-ish code to C
- **Shells (IPython, IDLE)**
- **Libraries/modules/packages**
  - pypi.python.org/pypi (PyPI - the Python Package Index, +250.000 packages)
- **IDEs (Integrated development environment)**
  - IDLE comes with Python (docs.python.org/3/library/idle.html)
  - Anaconda w. Spyder, IPython (www.anaconda.com/download)
  - Canopy (enthought.com/product/canopy)
  - Python tools for Visual Studio (github.com/Microsoft/PTVS)
  - PyCharm (www.jetbrains.com/pycharm/)
  - Emacs (Python mode and ElPy mode)
  - Notepad++
- **Python Style guide (PEP8)**
  - pylint, pep8, flake8
- **Python online**
  - Google colab (colab.research.google.com), repl.it, sagemath.org, …