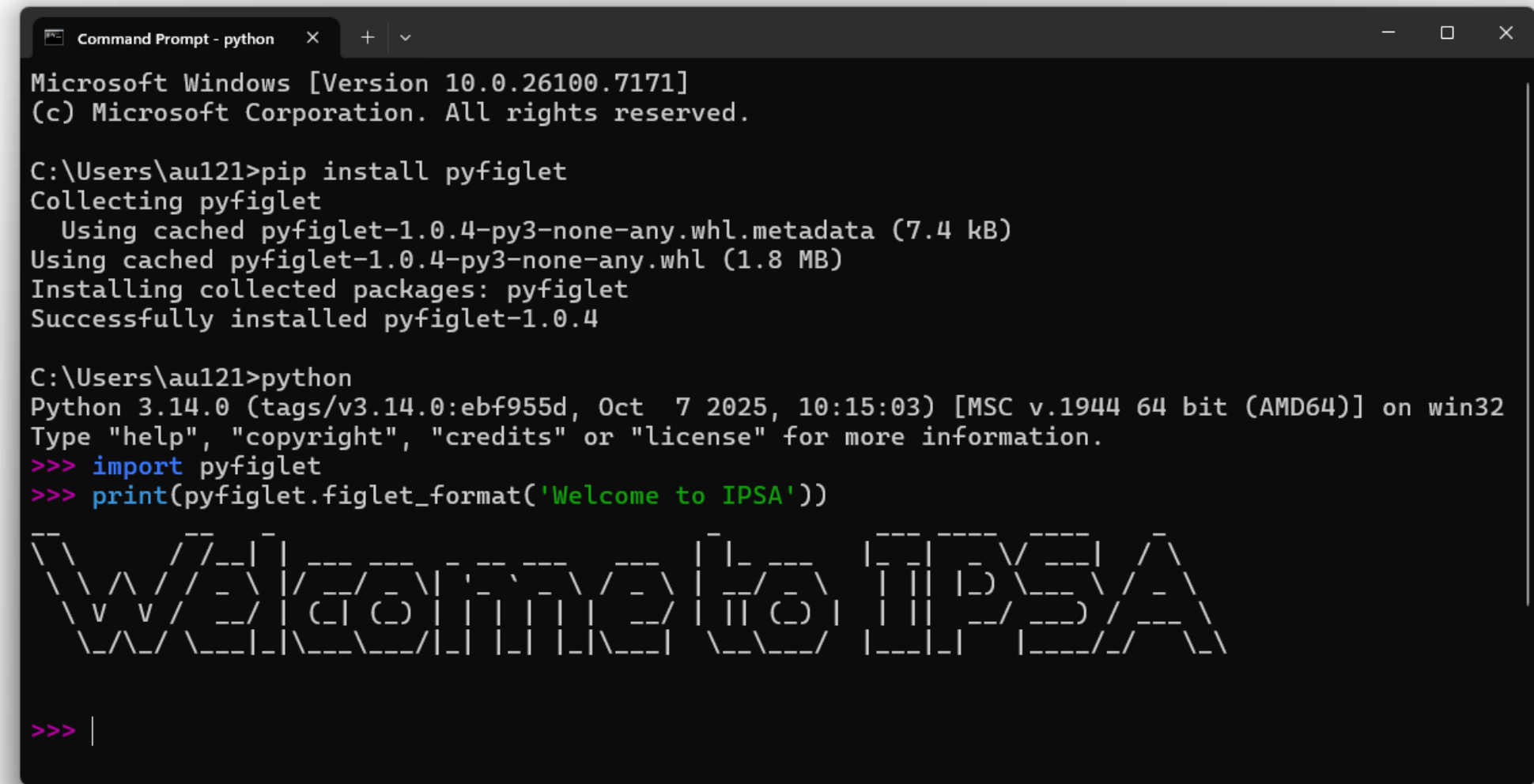
Introduction to Programming with Scientific Applications

Gerth Stølting Brodal
Department of Computer Science
Aarhus University

Course evaluation

”The first lecture was intimidating and overwhelming”


Command Prompt - python
Microsoft Windows [Version 10.0.26100.7171]
(c) Microsoft Corporation. All rights reserved.
C:\Users\au121>pip install pyfiglet
Collecting pyfiglet
Using cached pyfiglet-1.0.4-py3-none-any.whl.metadata (7.4 kB)
Using cached pyfiglet-1.0.4-py3-none-any.whl (1.8 MB)
Installing collected packages: pyfiglet
Successfully installed pyfiglet-1.0.4
C:\Users\au121>python
Python 3.14.0 (tags/v3.14.0:ebf955d, Oct 7 2025, 10:15:03) [MSC v.1944 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
>>> import pyfiglet
>>> print(pyfiglet.figlet_format('Welcome to IPSA'))
>>>

Lecturer

Name	Gerth Stølting Brodal
Research	Algorithms and Data Structures (Computer Science)
Teaching	
2018 -	BSc course on Introduction to Programming with Scientific Applications
2003 -	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	Advanced Beginner

Course description – kursuskatalog.au.dk/en/course/138411/

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 without Internet, no AI
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. Project counts 20% and written exam counts 80%

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?

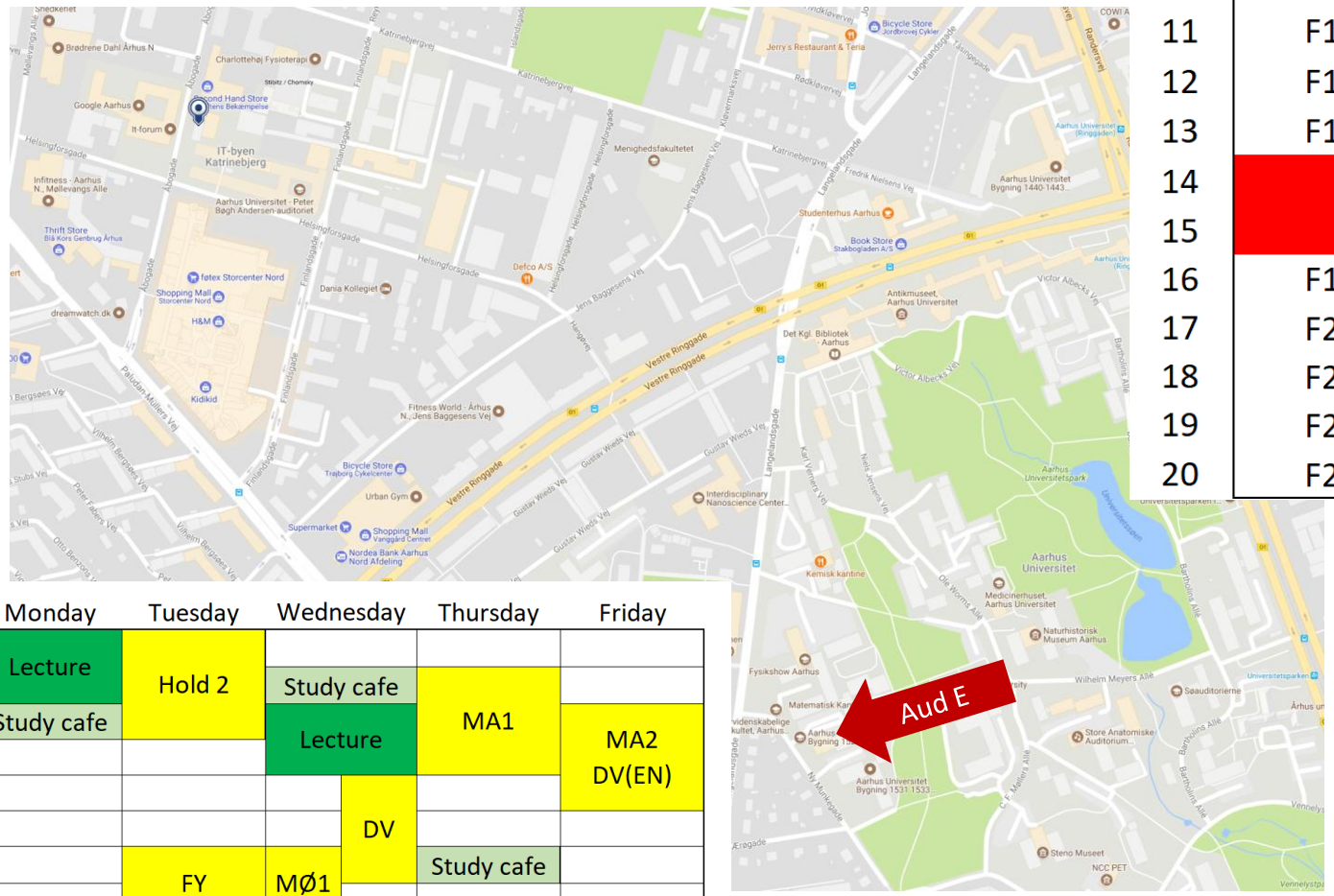
For the programming language you know best (if any) please state you proficiency level within the language.

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

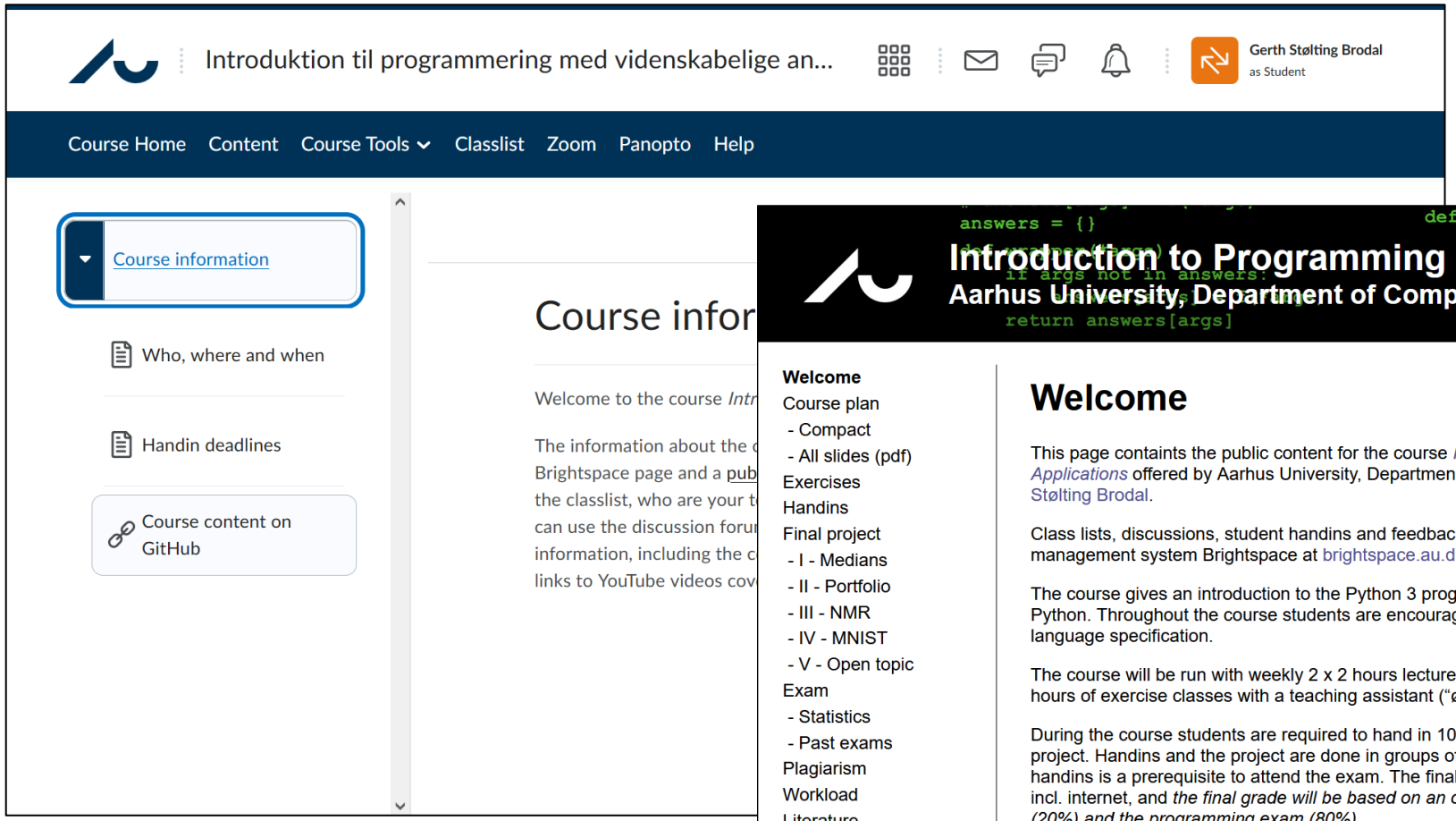
Primary lecture material = slides

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

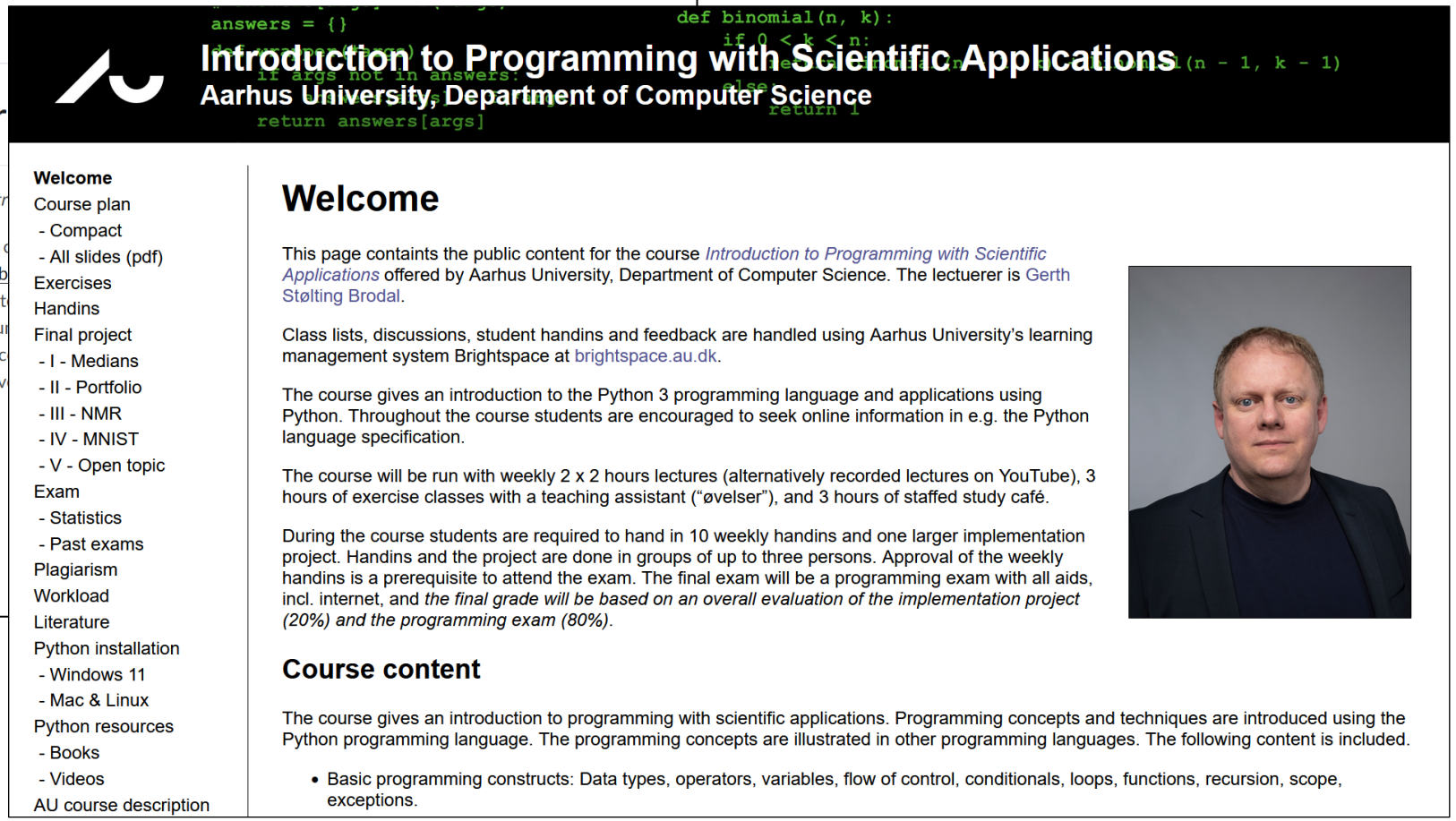


	Monday	Tuesday	Wednesday	Thursday	Friday
8:15-9:00	Lecture	Hold 2			
9:15-10:00			Study cafe	MA1	
10:15-11:00	Study cafe		Lecture		MA2 DV(EN)
11:15-12:00					
12:15-13:00					
13:15-14:00				DV	
14:15-15:00		FY Hold 1	MØ1 MØ2	Study cafe	
15:15-16:00					
16:15-17:00					
17:15-18:00					

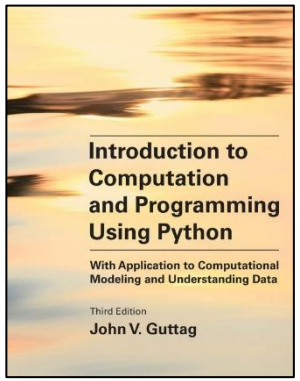
Course page on Brightspace and GitHub



gsbrodal.github.io/ipsa

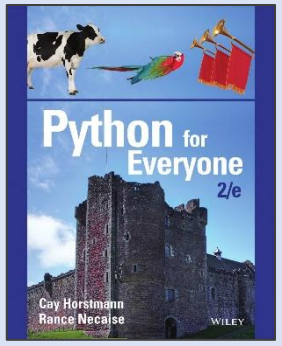


Course text book – optional



John V. Guttag: **Introduction to Computation and Programming Using Python, Third Edition With Application to Computational Modeling and Understanding Data**. Third Edition. 664 pages. MIT Press, 2021.

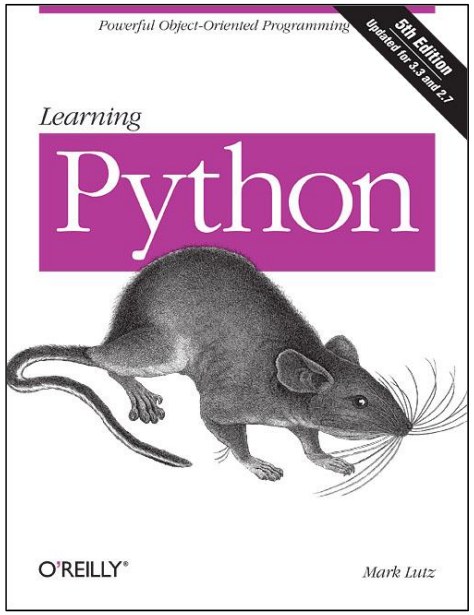
- *[Guttag, 2nd Ed., page 8] "The reader should be forewarned that this book is by no means a comprehensive introduction to Python". 3rd Ed. added about 80 pages on introduction to Python.*
- *Covers all basic features of Python enabling you to deal with data in Chapters 1-10 (212 pages) - remaining chapters are applications*
- *Other resources: Google, stackoverflow, Python.org, YouTube, AIs...*



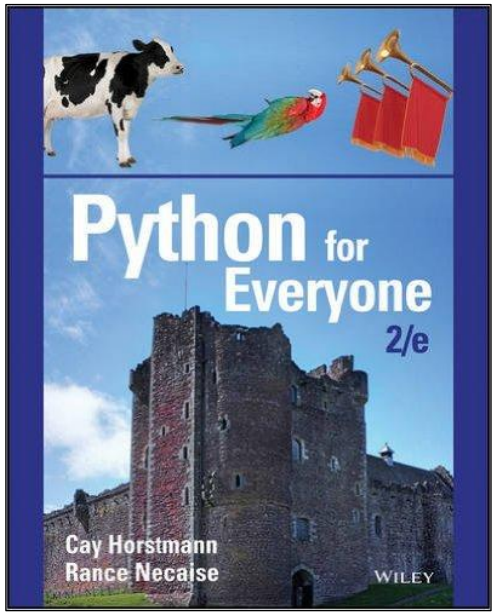
Comparison to a standard text book on the *programming language* Python by Cay Horstmann and Rance Necaise:

Topic **recursion** is covered by Guttag on page 123 (2nd edition on page 50), Horstmann and Necaise do it on page 611

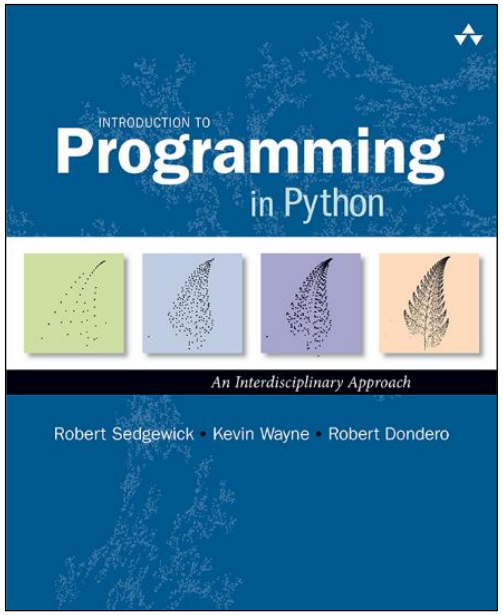
Some other books on Python



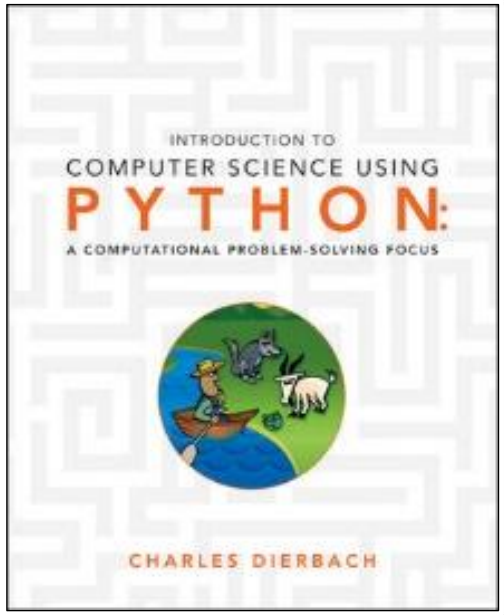
O'Reilly, 2013
1684 pages



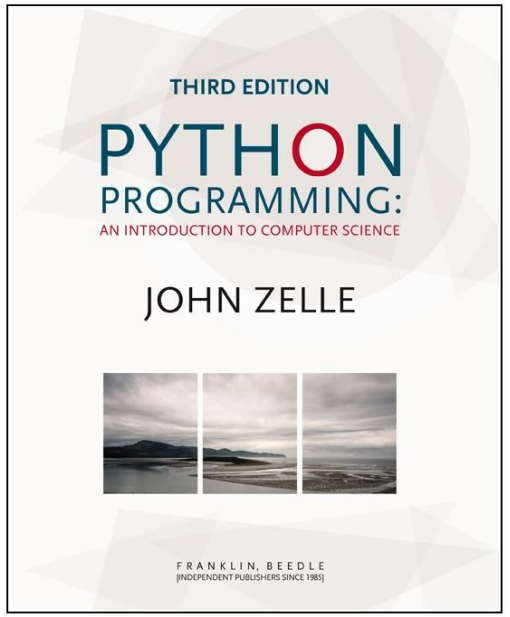
Wiley, 2016
752 pages



Addison-Wesley, 2015
794 pages



Wiley, 2013
580 pages



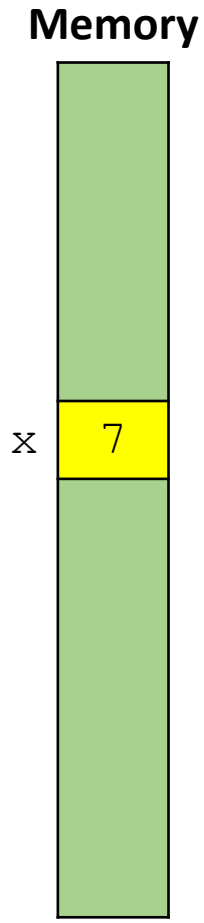
Franklin & Beedle, 2016
552 pages

... 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?

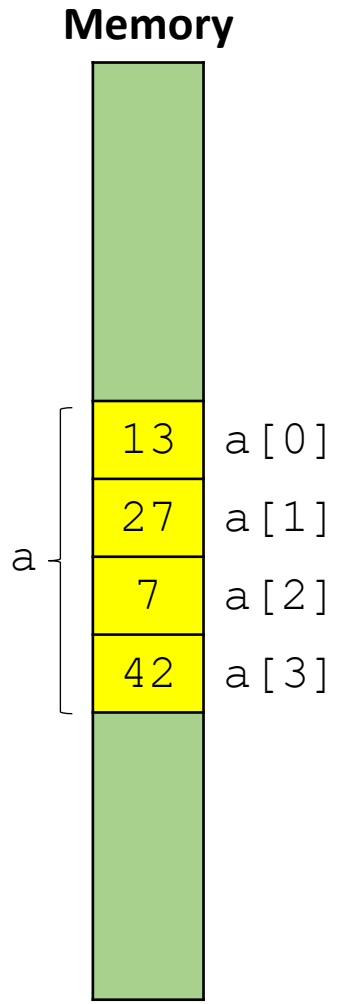
Python shell

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

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

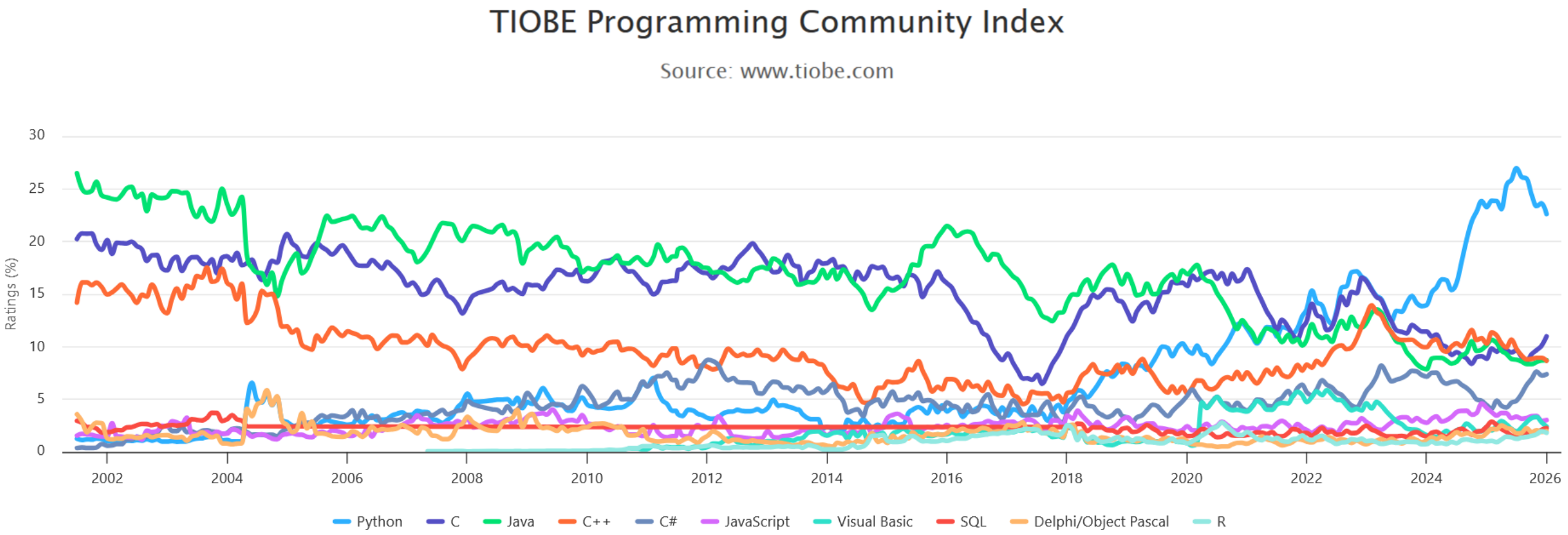
TIOBE Index January 2026

Python #1 Since November 2021

Jan 2026	Jan 2025	Change	Programming Language	Ratings	
1	1		Python	22.61%	-0.6%
2	4	↑	C	10.99%	+2.13%
3	3		Java	8.71%	-1.44%
4	2	↓	C++	8.67%	-1.62%
5	5		C#	7.39%	+2.94%
6	6		JavaScript	3.03%	-1.17%
7	9	↑	Visual Basic	2.41%	+0.04%
8	8		SQL	2.27%	-0.14%
9	11	↑	Delphi/Object Pascal	1.98%	+0.19%
10	18	⇈	R	1.82%	+0.81%

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 1958 – 2025 (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 ?

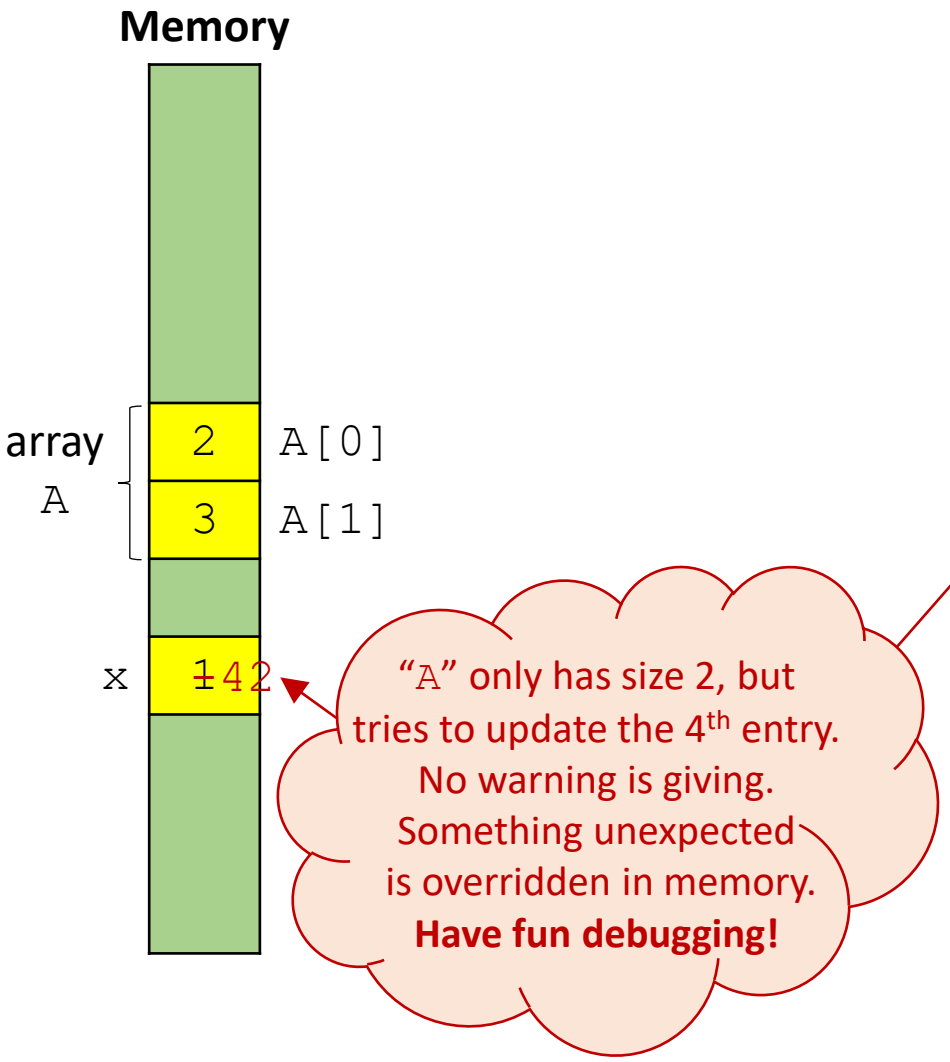
- **Short concise code**

(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;
}
```

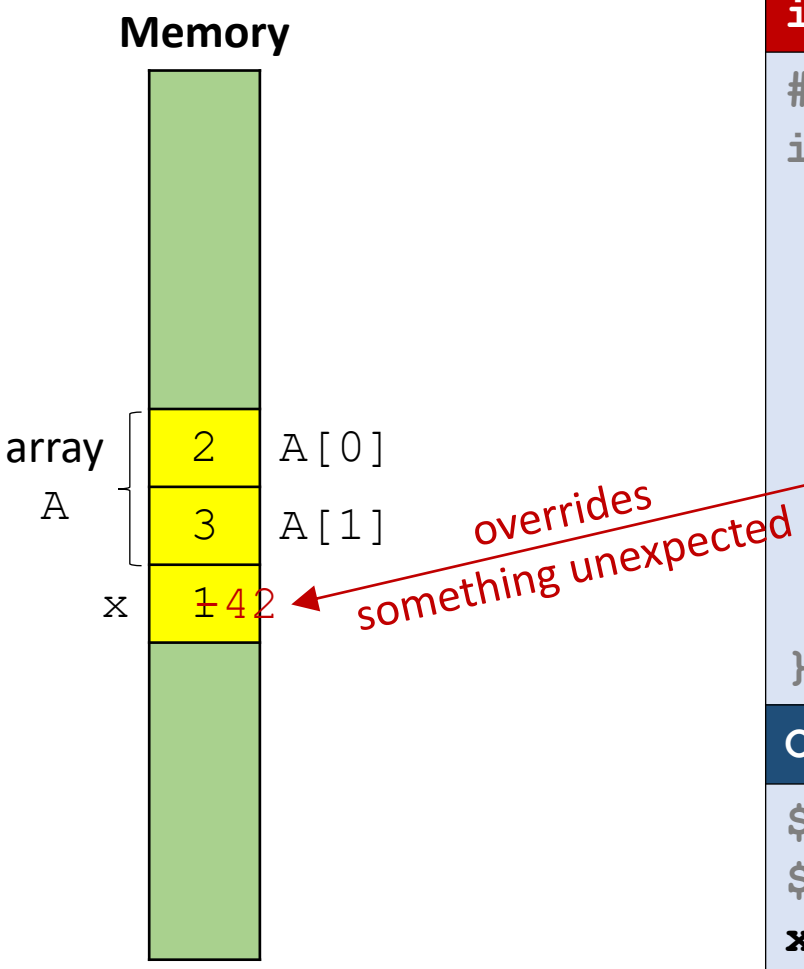
Output

```
$ 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



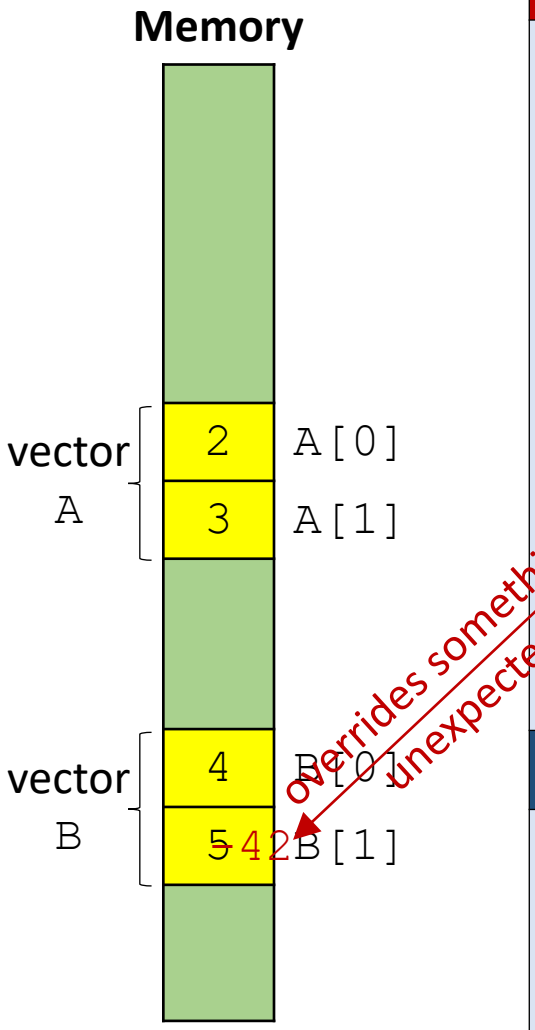
indexing.cpp

```
#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

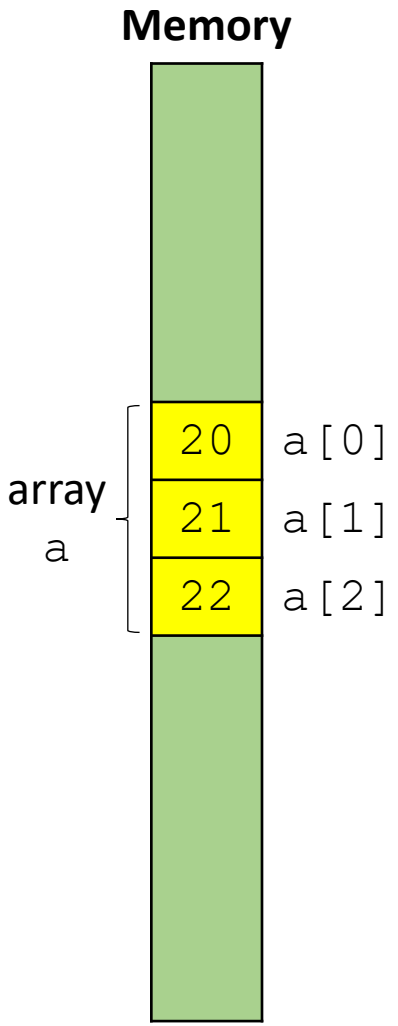
```
#include <iostream>
#include <vector>
int main() {
  std::vector<int> A = {2, 3};  // A[0] = 2, A[1] = 3
  std::vector<int> B = {4, 5};  // B[0] = 4, B[1] = 5
  std::cout << "A={" << A[0] << ", " << A[1] << "}, ";
  std::cout << "B={" << B[0] << ", " << B[1] << "}" << std::endl;
  A[9]=42; // index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

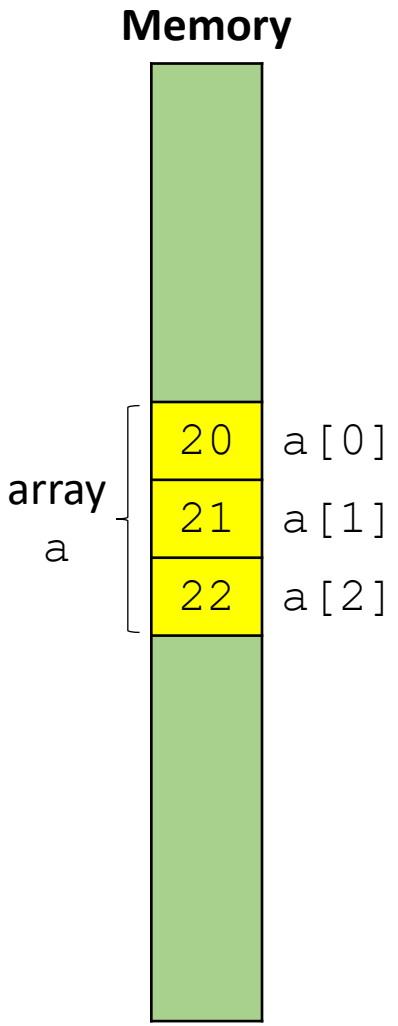
Output

```
$ 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

(Rust created by Graydon Hoare 2006)

Memory safety

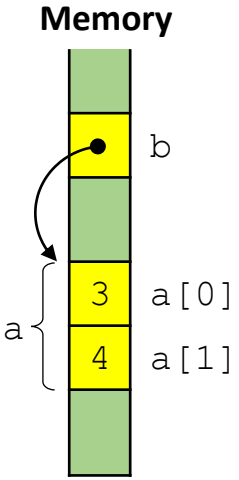
The White House 2024 | Press Release: "*Future Software Should Be Memory Safe*" (www.whitehouse.gov)
National Security Agency 2022 | Cybersecurity Information Sheet: *Software Memory Safety* (media.defense.gov)

- C and C++ are flexible but **memory unsafe** programming languages
  - Unintended writes or reads to memory can be exploited by malicious cyber actors
- Python, Java, Rust are examples of memory safe languages
- Rust aims at achieving the efficiency of C by slightly restricting flexibility

indexing.rs

```
fn main() {
    let mut a = [3, 4];
    a[2] = 7;  // Compile error: this operation will panic at runtime
    for i in 2..3 { a[i] = 7 }  // Run-time panic: index out of bounds
    let b = &mut a;
    a[1] = 6;  // Compile error: cannot use `a` because it was mutably borrowed
    (*b)[0] = 5;
    for i in  0..2 { println!("a[{}] = {}", i, a[i]) }
}
```

www.rust-lang.org



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

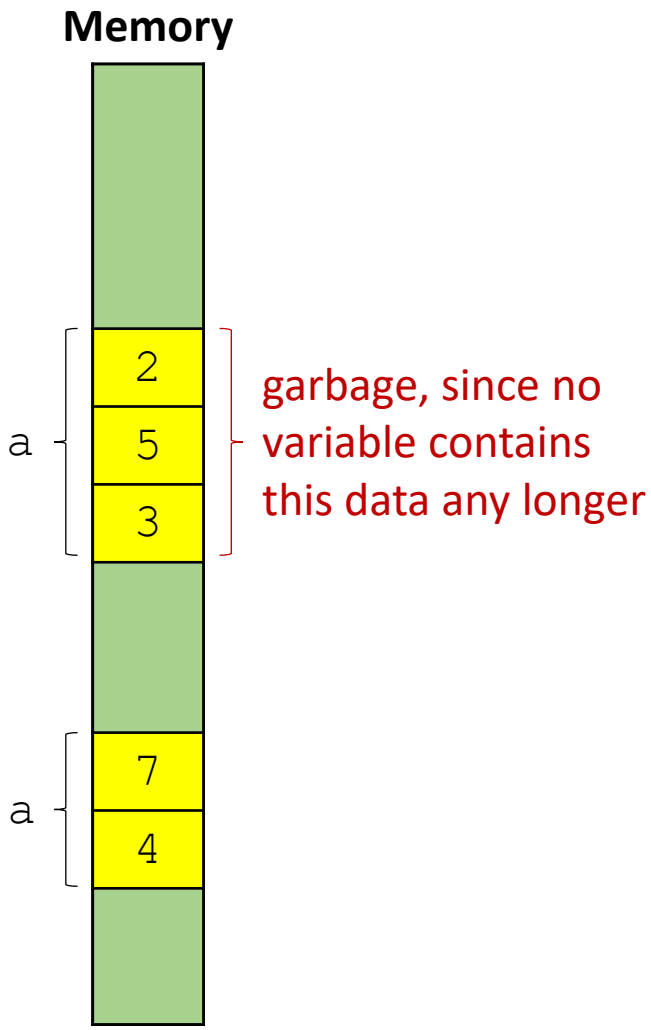
```
#include <iostream>
#include <vector>

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

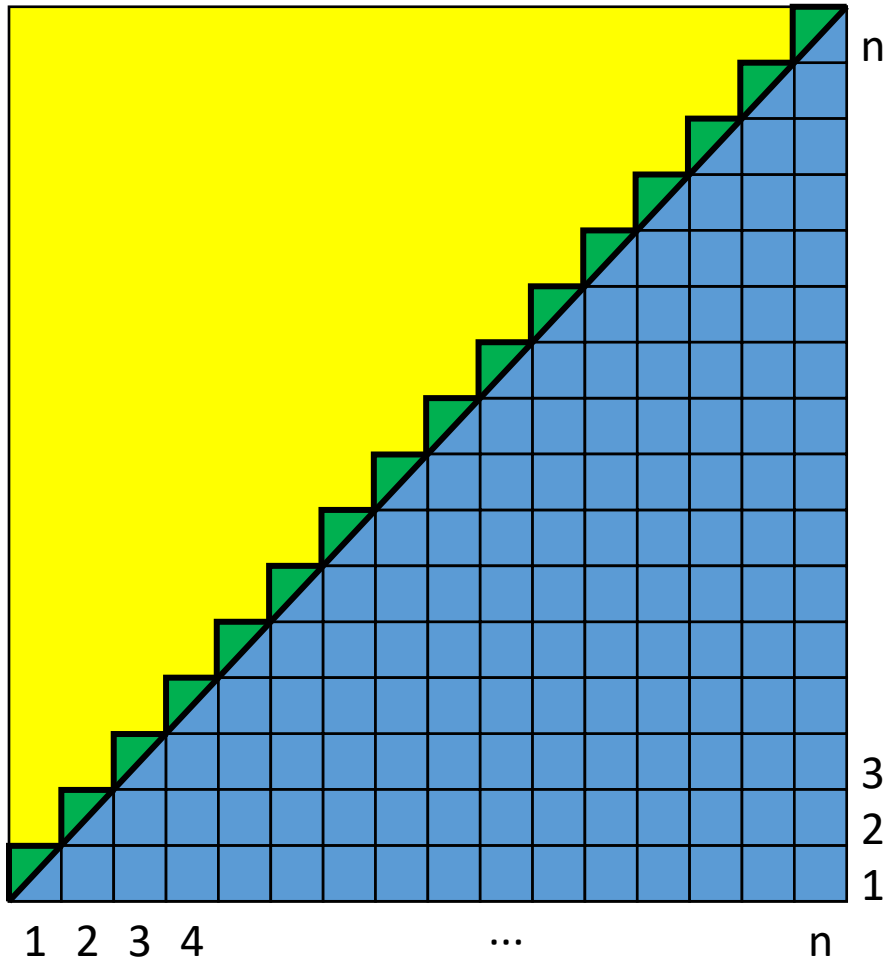
- Python and e.g. Java, C# and JavaScript have a **garbage collector** to automatically recycle garbage
- C and C++ garbage collection must be done explicitly by the program; forgetting to **free** memory again results in **memory leaks** – which can be really hard to find. **Have fun debugging!**
-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

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 + ⋯ + 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 =", 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

n	C (gcc 9.2)	C++, int (g++ 9.2)	C++, long (g++ 9.2)	Java (12.0)	Python: CPython (3.8.1)	Python: PyPy (7.3.0)	Python: 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              666666666655555555554444444444333333333322222222221111111111000000000
position         987654321098765432109876543210987654321098765432109876543210987654321

bin(10**9)                                                  1110111001101011001010000000000

bin(50000005000000)                          1011010111100110001000100010010110101101000000
bin(-2004260032+2**32)                                     1000100010001001011010110100000

bin(500000000500000000)     1101111000001011011010110011111000101111111101100101000000000
bin(-243309312+2**32)                                      1111000101111111011001010000000
```

Try Google: civilization gandhi overflow

Timing results

Python

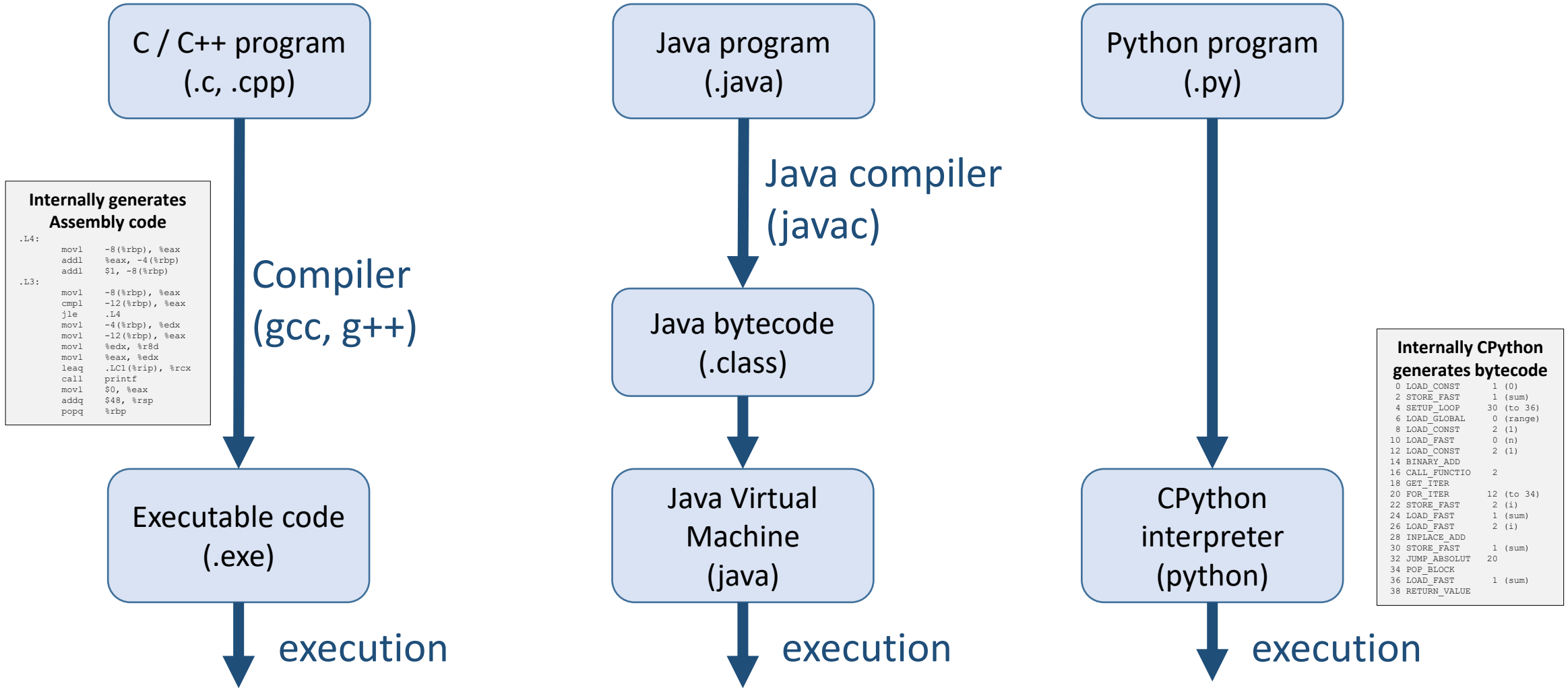
n	C (gcc 9.2)	C++, int (g++ 9.2)	C++, long (g++ 9.2)	Java (12.0)	Python (3.8.1)	PyPy (7.3.0)	Numba, int64
10^7	0.001 sec*	0.001 sec*	0.003 sec	0.006 sec*	1.5 sec	0.27 sec	0.002 sec
10^9	0.10 sec**	0.10 sec**	0.30 sec	0.40 sec**	145 sec	27 sec	0.2 sec

- Relative speed

C ≈ C++ > Java >> Python

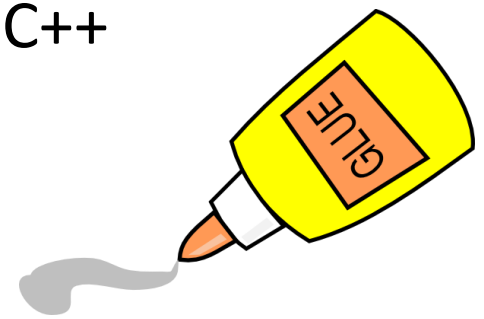
- C, C++, Java need to care about integer overflows – select integer representation carefully with sufficient number of bits (8, 16, 32, 64, 128)
- Python natively works with arbitrary long integers (as memory on your machine allows). Also possible in Java using the class java.math.BigInteger
- Python 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++ and requires selecting right integer representation

Interpreter vs Compiler

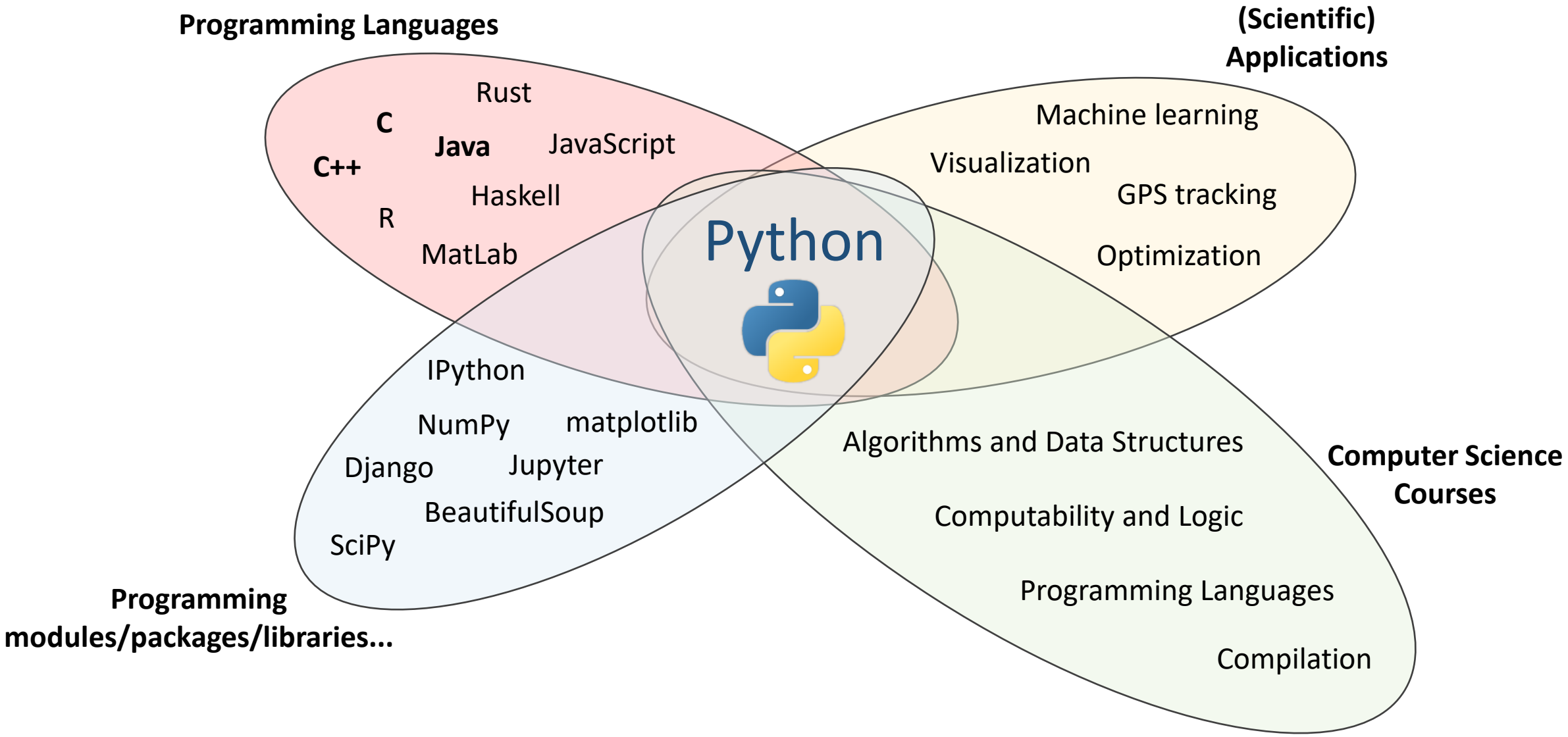


Why Python ?

- 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
Rust
C
C++
Java
JavaScript
Haskell
R
MatLab
(Scientific) Applications
Machine learning
Visualization
GPS tracking
Optimization
Python
IPython
NumPy
matplotlib
Django
Jupyter
BeautifulSoup
SciPy
Programming modules/packages/libraries...
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)

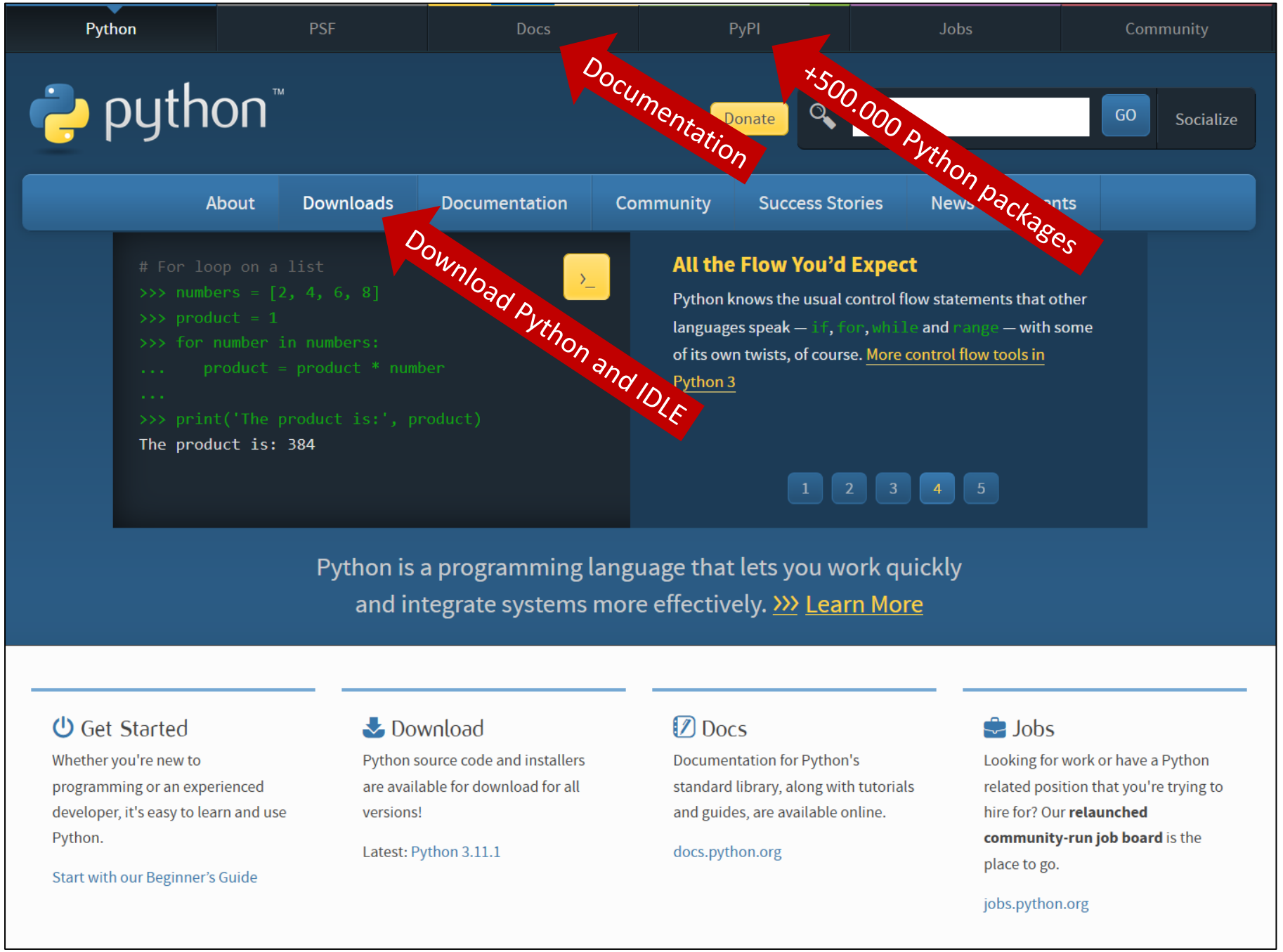
History of Python development

- 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 3.13.1
- Python 3 is *not* backward compatible, libraries incompatible

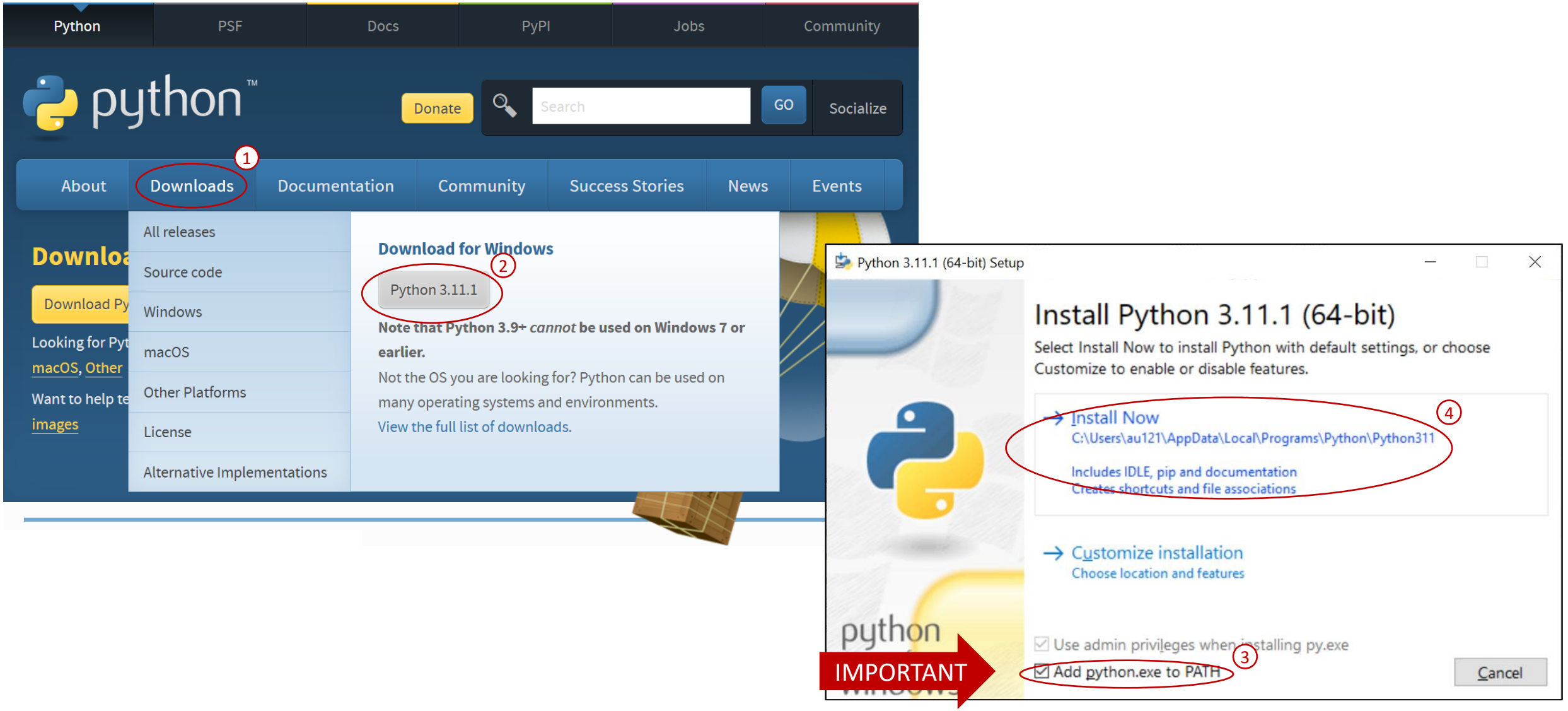
Python 2	Python 3
print 42	print(42)
int = C long (32 bits)	int = arbitrary number of digits (= named “long” in Python 2)
7/3 → 2 returns “int”	7/3 → 2.333... returns “float”
range() returns list (memory intensive)	range() returns iterator (memory efficient; xrange in Python 2)

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

Python.org


Python
PSF
Docs
PyPI
Jobs
Community
python™
Donate
GO
Socialize
About
Downloads
Documentation
Community
Success Stories
Documentation
+500.000 Python packages
Download Python and IDLE
# For loop on a list
>>> numbers = [2, 4, 6, 8]
>>> product = 1
>>> for number in numbers:
...   product = product * number
...
>>> print('The product is:', product)
The product is: 384
All the Flow You'd Expect
Python knows the usual control flow statements that other languages speak — if, for, while and range — with some of its own twists, of course. More control flow tools in Python 3
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!
Latest: Python 3.11.1
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

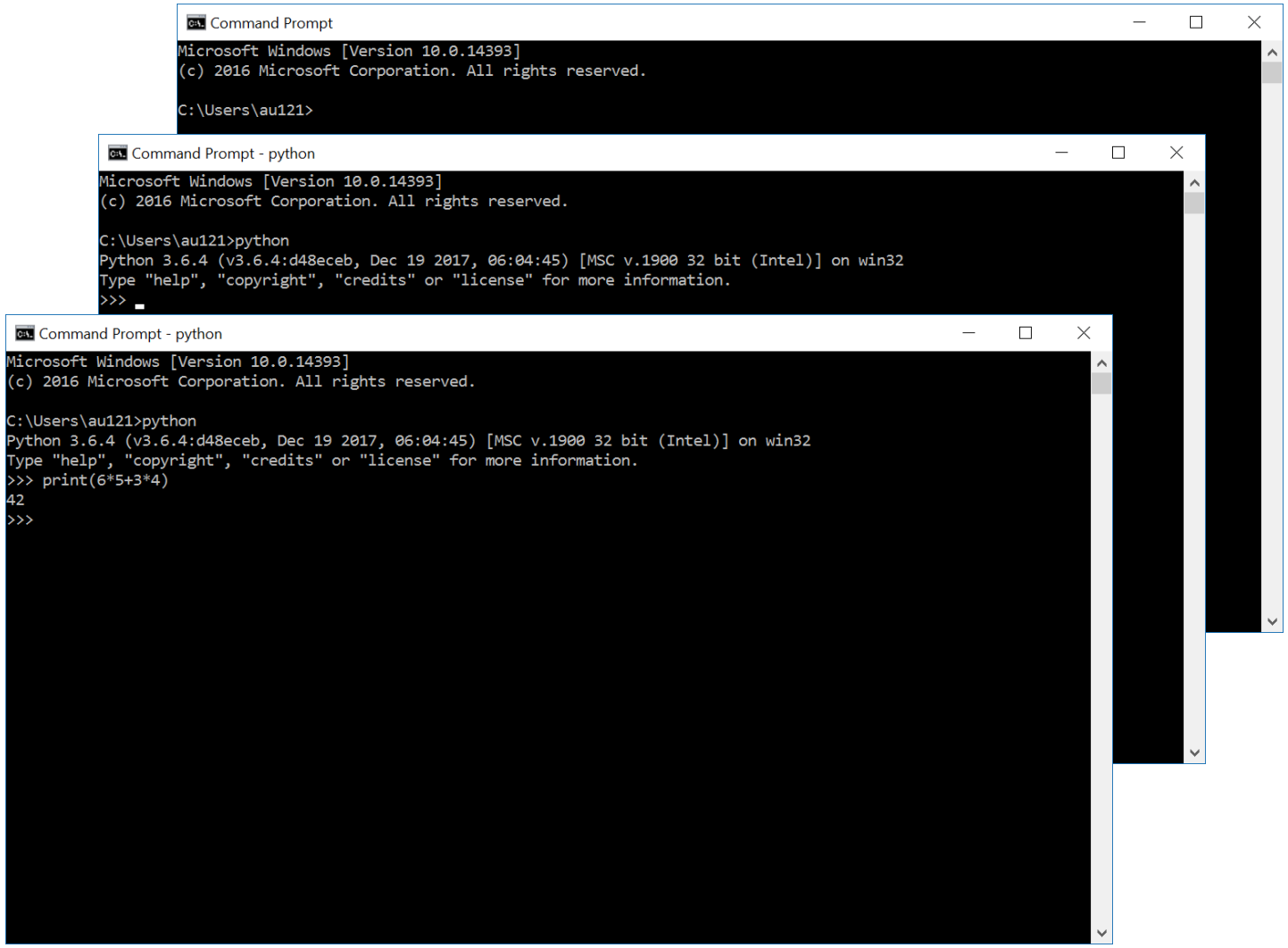


Running the Python Interpreter from a terminal

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

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

- Note: Sometimes “python” is installed as “python3”



Installing IPython –

A more powerful interactive Python shell

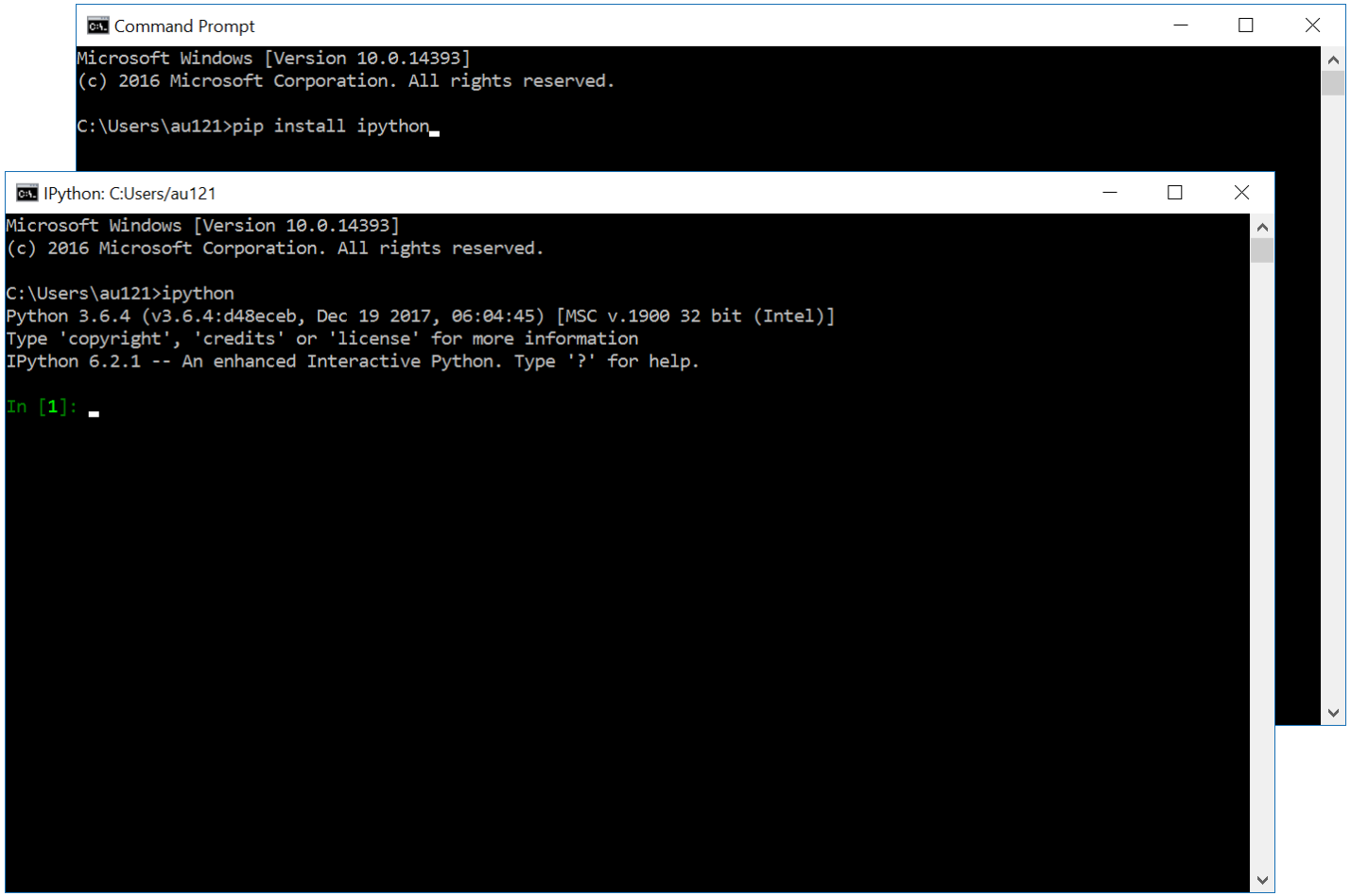
- Open Command Prompt
- Execute:

```
pip install ipython
```

- Start IPython

```
ipython
```

- pip = the Python package manager
- Note: Sometimes “pip” is installed as “pip3”

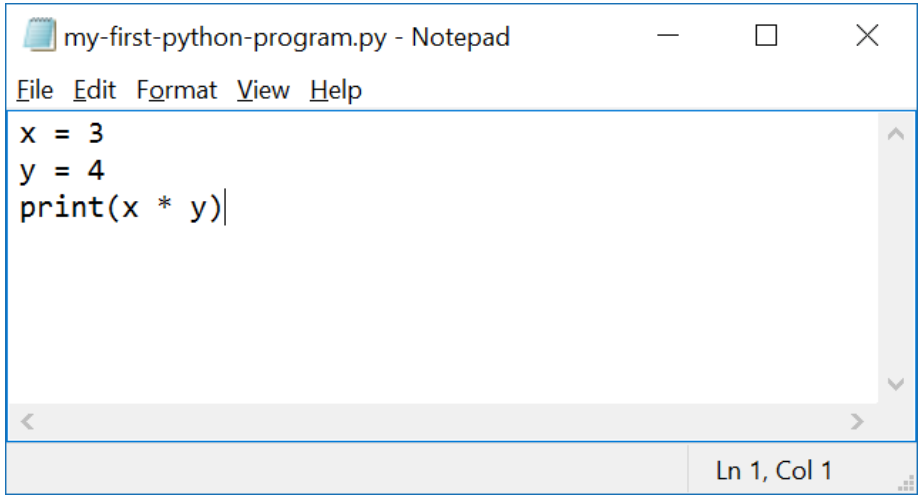


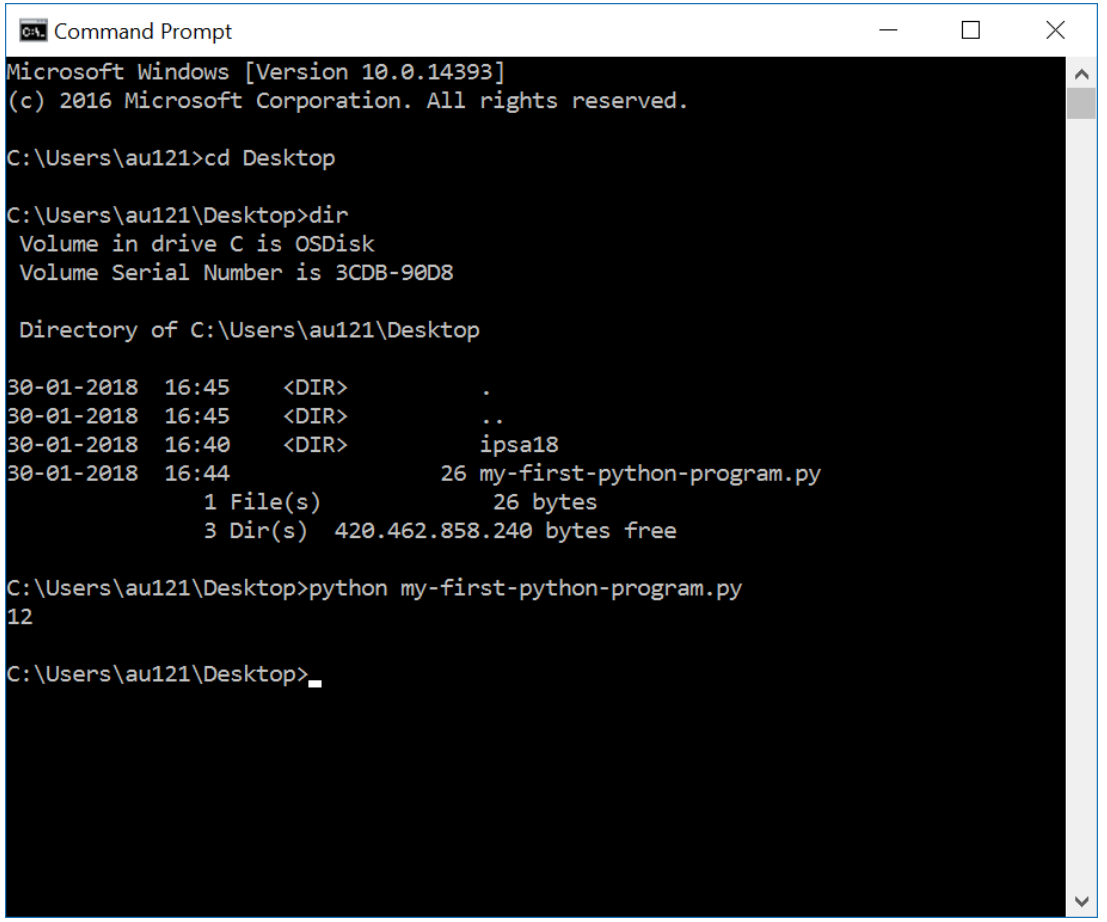
Some other usefull packages

- 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 and 3D plotting library
`pip install pylint`	Python source code analyzer enforcing a coding standard

Creating a Python program the very basic way



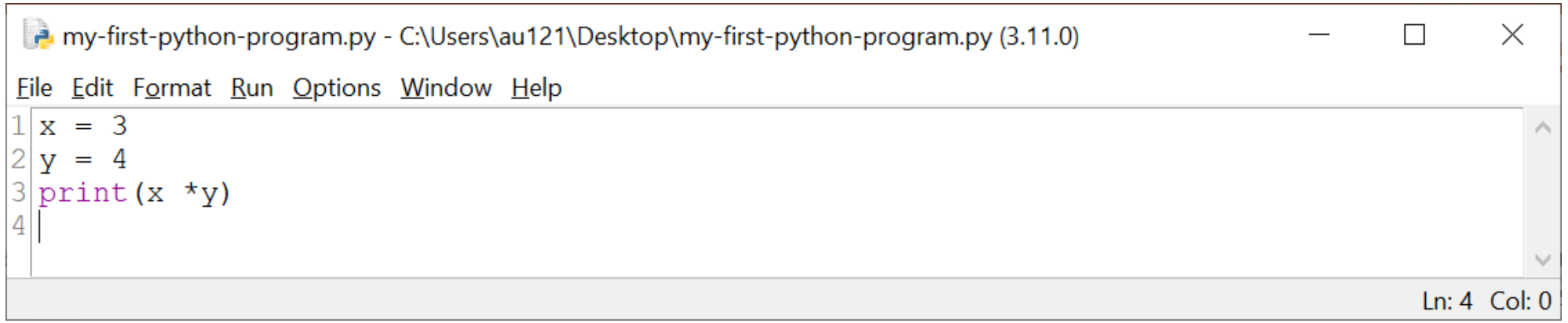


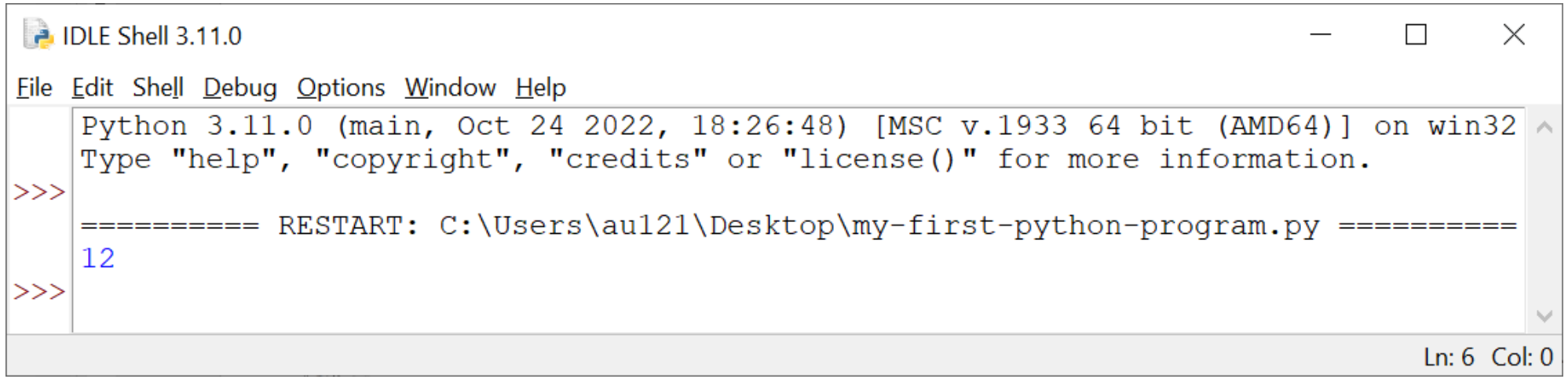
- Open Notepad (or TextEdit on Mac)
  - write a simple Python program
  - save it
- Open a command prompt
  - go to folder (using cd)
  - run the program using

    `python <program name>.py`

… or open IDLE and run program with F5

enable line numbers under options





- IDLE ships with Python from python.org
- Good beginner IDE (Integrated Development Environment)

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, Jupyter)**
- **Libraries/modules/packages**
  - pypi.python.org/pypi (PyPI - the Python Package Index, +500.000 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)
  - Visual Studio Code (code.visualstudio.com)
  - 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, …
- **Pair programming plugins (share your editor with others)**
  - PyCharm : Code With Me
  - Visual Studio Code : Live Share

Good beginer Python IDE

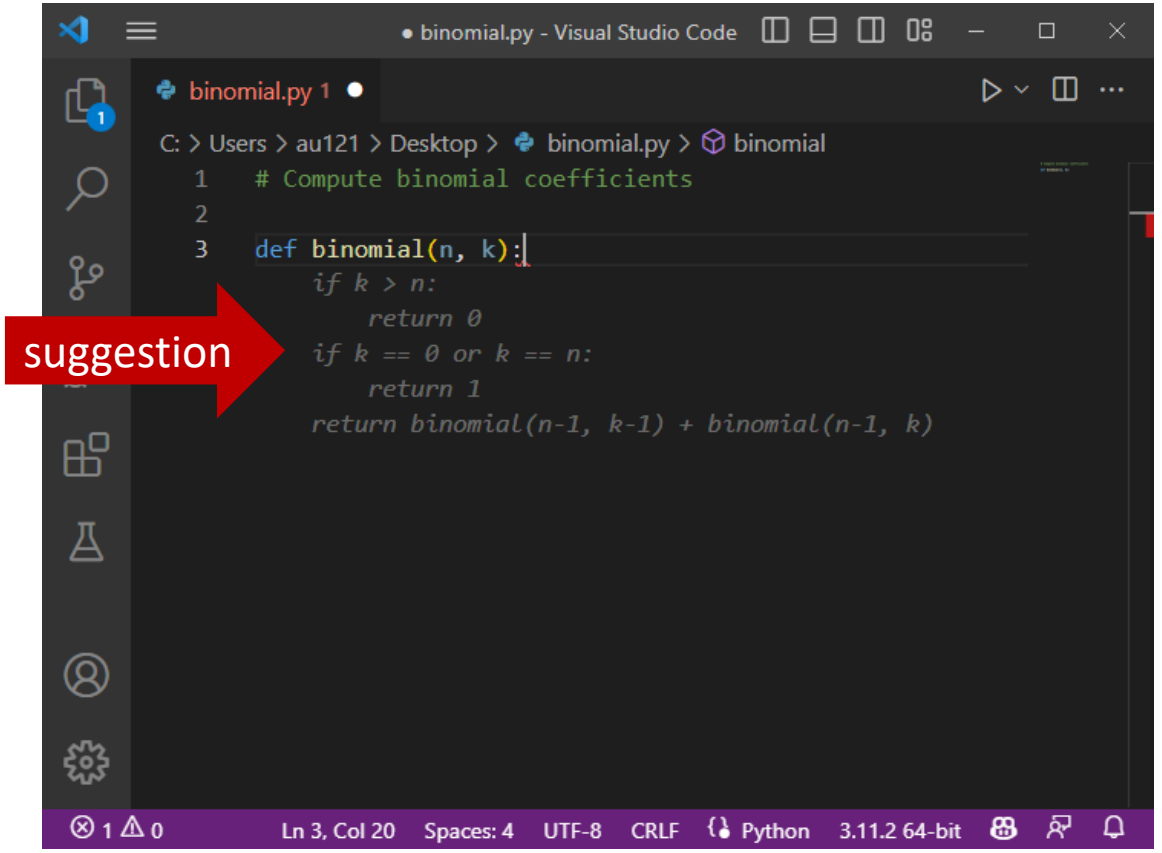
Visual Studio Code is used by more than twice as many developers than its nearest alternative, Stack overflow survey 2025

Try to google "best ide python"

IDEs and AI assistants

- Some IDEs integrate AI assistants to support code suggestions, e.g. GitHub Copilot in VS Code
- AI assistants increase productivity *if* you understand their output
- Interacting with an AI assistant can be a great programming tutor

- AI assistants are not allowed at the exam



Guido van Rossum, inventor of Python, on GitHub Copilot

"I use it every day. It writes a lot of code for me… and usually it is slightly wrong but it still saves me typing."

Python and the Future of Programming, Guido van Rossum interviewed by Lex Fridman

9gag.com