

Introduction to Programming with Scientific Applications

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Department of Computer Science
Aarhus University



Course evaluation
*“The first lecture was intimidating
and overwhelming”*

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

Lectures: English. TA classes: Danish/English.

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) Chemistry
- 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 your 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



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

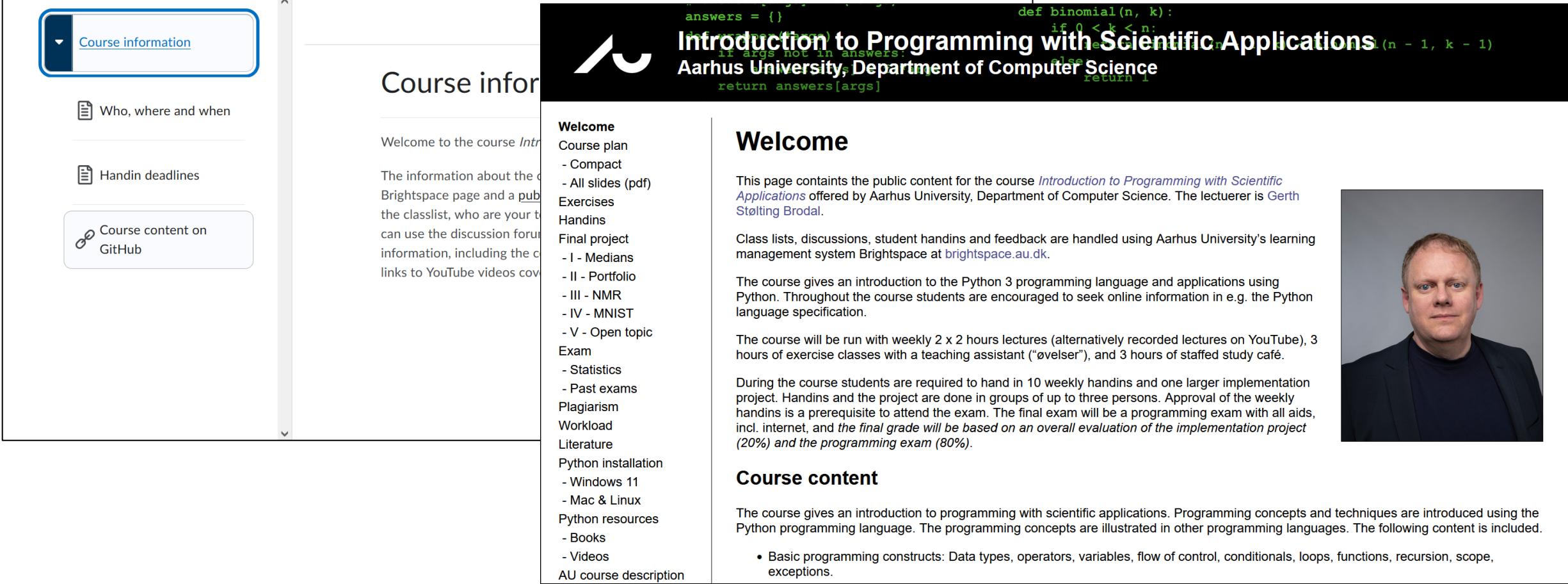


Week	Monday	Tuesday	Wednesday	Thursday	Friday
5	F1	no TA class	F2		
6	F3	TØ1	TØ1 / F4	TØ1	TØ1
7	F5	TØ2	TØ2 / F6	TØ2	TØ2
8	F7	TØ3	TØ3 / F8	TØ3	TØ3
9	F9	TØ4	TØ4 / F10	TØ4	TØ4
10	F11	TØ5	TØ5 / F12	TØ5	TØ5
11	F13	TØ6	TØ6 / F14	TØ6	TØ6
12	F15	TØ7	TØ7 / F16	TØ7	TØ7
13	F17	TØ8	TØ8 / F18	TØ8	TØ8
14				Easter 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

Course page on Brightspace and GitHub



gsbrodal.github.io/ipsa



The screenshot shows a comparison between a Brightspace course page and a GitHub page for the same course. The GitHub page is a static website for the course "Introduction to Programming with Scientific Applications" offered by Aarhus University, Department of Computer Science. It includes a header with the university logo and a Python code snippet, a main content area with a "Welcome" section, course details, and a portrait of the lecturer, Gerth Stølting Brodal. The Brightspace page shows the course structure and various links, while the GitHub page provides a centralized, accessible resource for the course material.

Course information

Who, where and when

Handin deadlines

Course content on GitHub

Introduktion til programmering med videnskabelige an...

Course Home Content Course Tools Classlist Zoom Panopto Help

Gerth Stølting Brodal as Student

Course information

Welcome

- Course plan
- Compact
- All slides (pdf)

Exercises

Handins

Final project

- I - Medians
- II - Portfolio
- III - NMR
- IV - MNIST
- V - Open topic

Exam

- Statistics
- Past exams

Plagiarism

Workload

Literature

Python installation

- Windows 11
- Mac & Linux

Python resources

- Books
- Videos

AU course description

answers = {}
def binomial(n, k):
 if args not in answers:
 if 0 < k < n:
 answers[args] = n * binomial(n - 1, k - 1) / k
 else:
 answers[args] = 1
 return answers[args]

Introduction to Programming with Scientific Applications

Aarhus University, Department of Computer Science

Welcome

This page contains the public content for the course *Introduction to Programming with Scientific Applications* offered by Aarhus University, Department of Computer Science. The lecturer is Gerth Stølting Brodal.

Class lists, discussions, student handins and feedback are handled using Aarhus University's learning management system Brightspace at [brightspace.au.dk](#).

The course gives an introduction to the Python 3 programming language and applications using Python. Throughout the course students are encouraged to seek online information in e.g. the Python language specification.

The course will be run with weekly 2 x 2 hours lectures (alternatively recorded lectures on YouTube), 3 hours of exercise classes with a teaching assistant ("øvelser"), and 3 hours of staffed study café.

During the course students are required to hand in 10 weekly handins and one larger implementation project. Handins and the project are done in groups of up to three persons. Approval of the weekly handins is a prerequisite to attend the exam. The final exam will be a programming exam with all aids, incl. internet, and *the final grade will be based on an overall evaluation of the implementation project (20%) and the programming exam (80%)*.

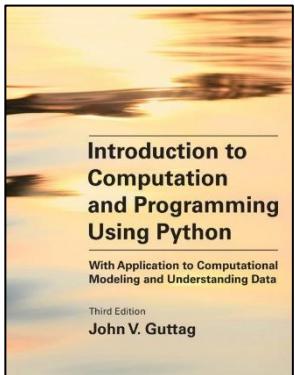
Course content

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.

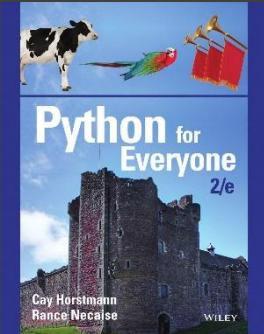


Course text book – optional



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.

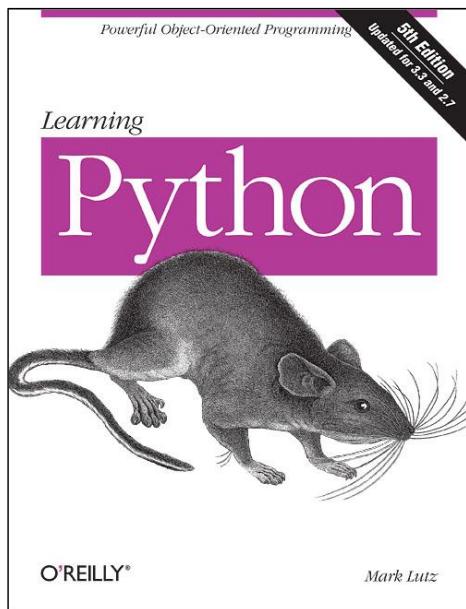
- *[Guttag, 2nd Ed., page 8] "The reader should be forewarned that this book is by no means a comprehensive introduction to Python". 3rd Ed. added about 80 pages on introduction to Python.*
- *Covers all basic features of Python enabling you to deal with data in Chapters 1-10 (212 pages) - remaining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



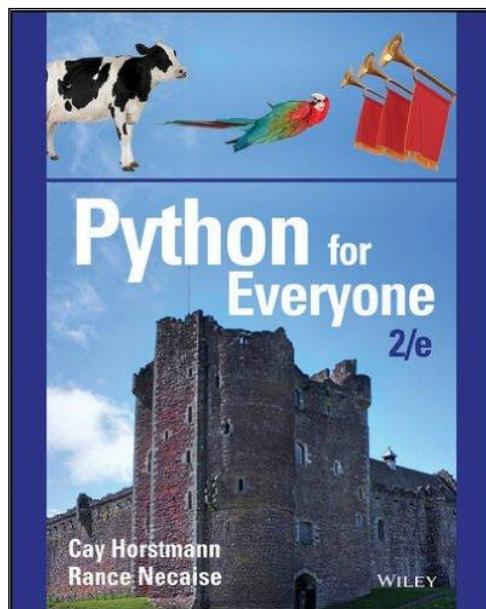
Comparison to a standard text book on the *programming language* Python by Cay Horstmann and Rance Necaise:

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

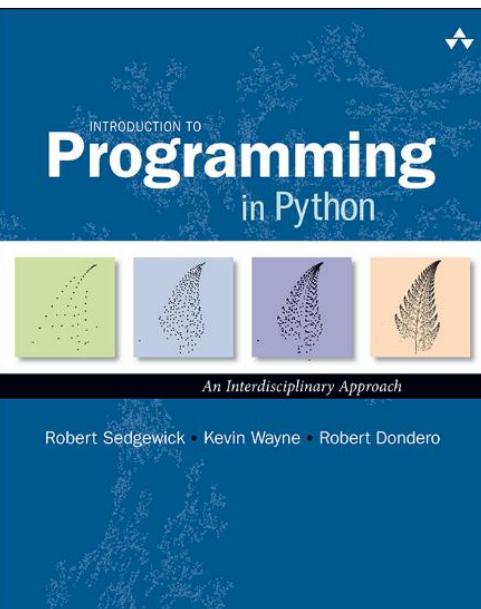
Some other books on Python



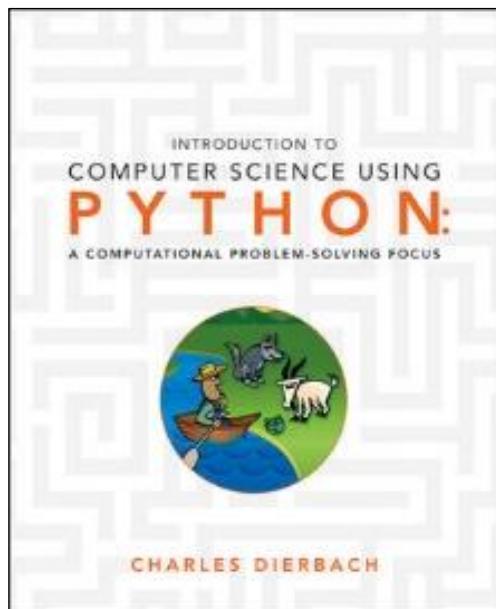
O'Reilly, 2013
1684 pages



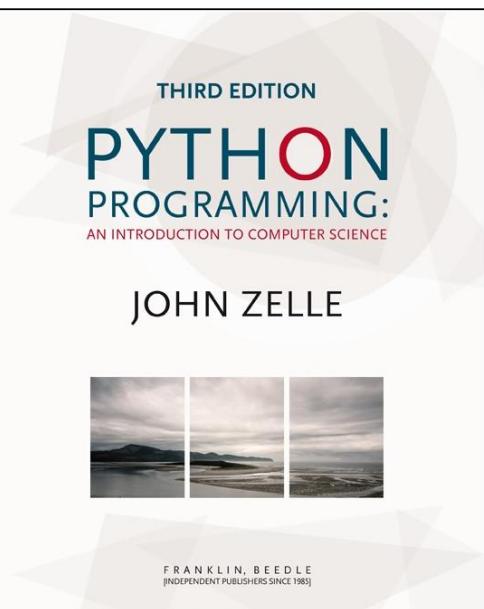
Wiley, 2016
752 pages



Addison-Wesley, 2015
794 pages



Wiley, 2013
580 pages



FRANKLIN, BEEDLE
[INDEPENDENT PUBLISHERS SINCE 1985]

Franklin & Beedle, 2016
552 pages

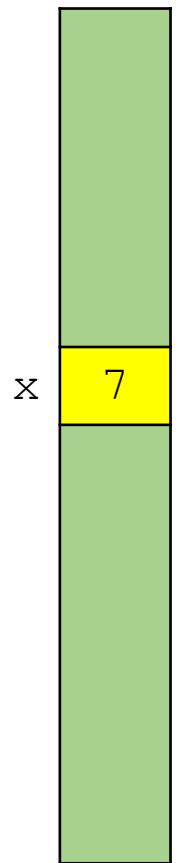
... numerous online introduction texts/courses/videos on Python

Two Python programs

A Python program

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

Memory



- 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

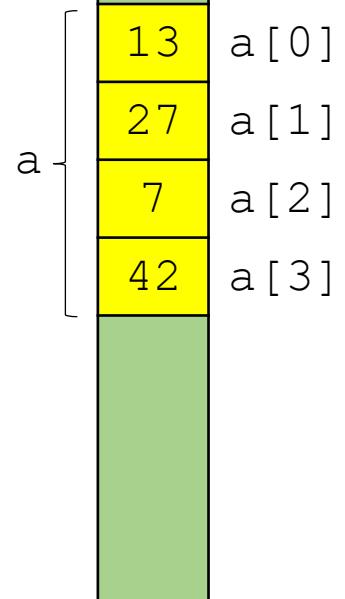
- a) 10
- b) 15
- c) 25
- d) [15, 10]
- e) Error
- f) Don't know

Another Python program using lists

Python shell

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

Memory



- `[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` can also 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



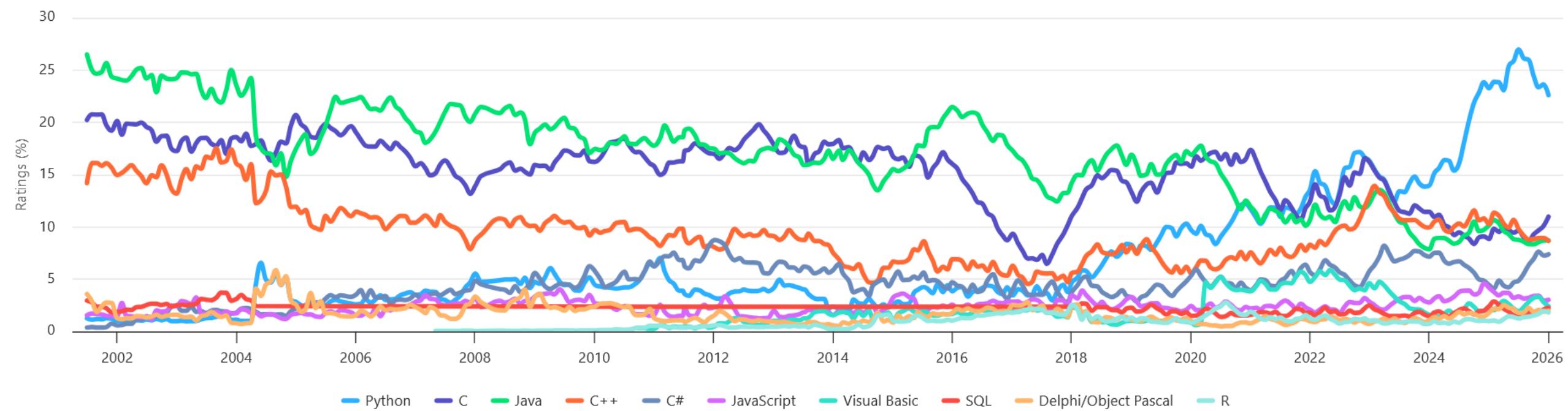
Jan 2026	Jan 2025	Change	Programming Language	Ratings	
1	1		Python	22.61%	-0.61%
2	4		C	10.99%	+2.13%
3	3		Java	8.71%	-1.44%
4	2		C++	8.67%	-1.62%
5	5		C#	7.39%	+2.94%
6	6		JavaScript	3.03%	-1.17%
7	9		Visual Basic	2.41%	+0.04%
8	8		SQL	2.27%	-0.14%
9	11		Delphi/Object Pascal	1.98%	+0.19%
10	18		R	1.82%	+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.

Popularity of programming languages

TIOBE Programming Community Index

Source: www.tiobe.com



“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

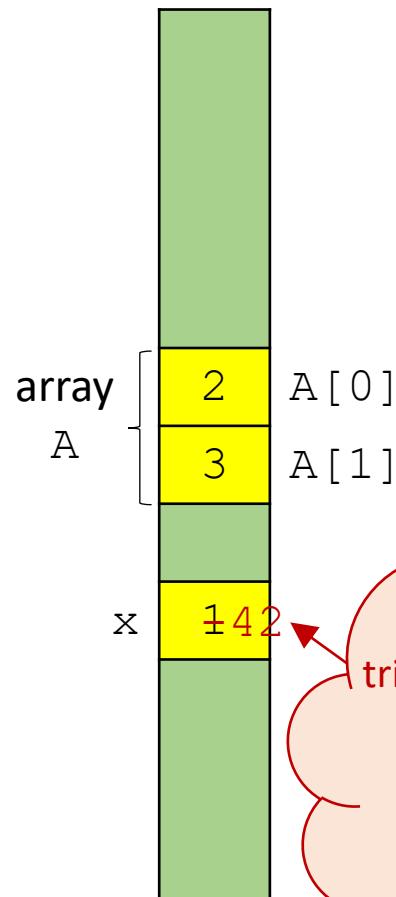
(C developed by Dennis Ritchie 1969-73)

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

Memory



"A" only has size 2, but tries to update the 4th entry.
No warning is giving.
Something unexpected is overridden in memory.
Have fun debugging!

indexing.c

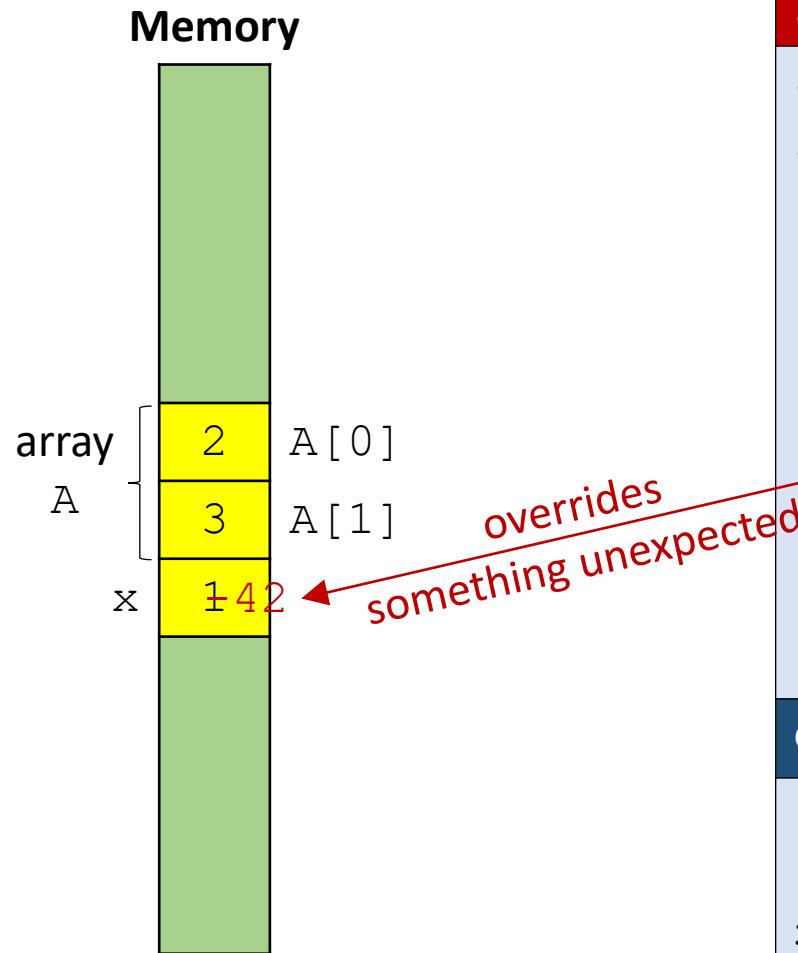
```
#include <stdio.h>
int main() {
    int x = 1;
    int A[2] = {2, 3}; // A[0] = 2, A[1] = 3
    printf("x = %d, A = {%d, %d}\n", x, A[0], A[1]);
    A[3] = 42; // index A[3] out of bounds
    printf("x = %d, A = {%d, %d}\n", x, A[0], A[1]);
    return 0;
}
```

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

... and C++ index out of bounds



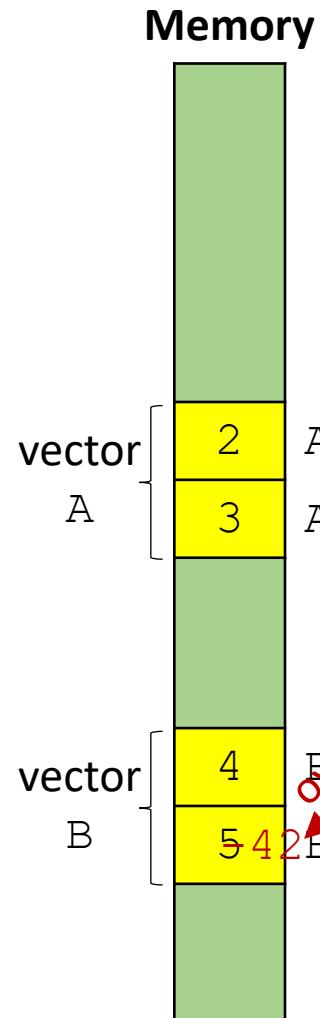
indexing.cpp

```
#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>

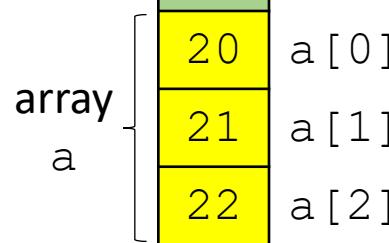
int main() {
    std::vector<int> A = {2, 3}; // A[0] = 2, A[1] = 3
    std::vector<int> B = {4, 5}; // B[0] = 4, B[1] = 5
    std::cout << "A={" << A[0] << ", " << A[1] << "}, ";
    std::cout << "B={" << B[0] << ", " << B[1] << "}" << std::endl;
    A[9]=42; // index A[9] out of bounds
    std::cout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

... and Java index out of bounds exception

Memory



indexing.java

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

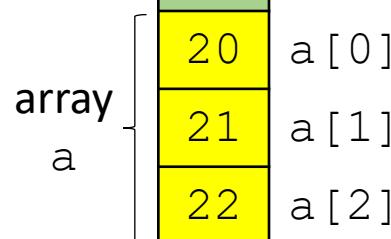
Output

```
$ 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

... and Python index out of bounds exception

Memory



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

Memory safety

The White House 2024 | Press Release: “Future Software Should Be Memory Safe” (www.whitehouse.gov)

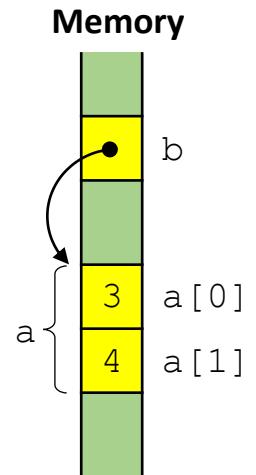
National Security Agency 2022 | Cybersecurity Information Sheet: Software Memory Safety (media.defense.gov)

- 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**

```
$ 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++/ios: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>::operator<<(std::basic_ostream<_CharT, _Traits>::__ostream_type& __os, const _Tp& __x) [with _CharT = char; _Traits = std::basic_ostream<_CharT, _Traits>::__ostream_type = std::basic_ostream<char>]
        operator<<(_ostream_type& __pf) (_ostream_type& __x)
                           ^
/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& __ios, const _Tp& __x) [with _CharT = char; _Traits = std::basic_ostream<_CharT, _Traits>::__ios_type = std::basic_ios<char>]
        operator<<(_ios_type& __pf) (_ios_type& __x)
                           ^
/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& __ios_base) [with _CharT = char; _Traits = std::char_traits<char>; std::basic_ostream<_CharT, _Traits>::__ostream_type = std::ios_base]
        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<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(long __n)
        operator<<(long __n)
                           ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:166:7: 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:170:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(_unsigned long __n)
        operator<<(_unsigned long __n)
                           ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:170:7: 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:174:7: note: candidate: std::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(_bool __n)
        operator<<(_bool __n)
                           ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:174:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::ios_base& (*)(std::ios_base)'
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_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(_unsigned short __n)
        operator<<(_unsigned short __n)
                           ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/bits/ostream.tcc:91:5: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::ios_base& (*)(std::ios_base)'
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<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(_unsigned short __n)
        operator<<(_unsigned short __n)
                           ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/ostream:181:7: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::ios_base& (*)(std::ios_base)'
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::basic_ostream<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(_long long __n)
        operator<<(_long long __n)
                           ^
/usr/lib/gcc/x86_64-pc-cygwin/5.4.0/include/c++/bits/ostream.tcc:105:5: note:   no known conversion for argument 1 from 'std::vector<int>' to 'std::ios_base& (*)(std::ios_base)'
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<_CharT, _Traits>::__ostream_type& std::basic_ostream<_CharT, _Traits>::operator<<(_long long __n)
        operator<<(_long long __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 'std::ios_base& (*)(std::ios_base)'
/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 'std::long long unsigned int'
/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_ostream<_CharT, _Traits>::operator<<(_double __f)
        operator<<(_double __f)
                           ^
/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 'std::double'
/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_ostream<_CharT, _Traits>::operator<<(_float __f)
        operator<<(_float __f)
                           ^
/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 'std::float'
/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<<(_long double __f)
        operator<<(_long 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 'std::long 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<<(_const void* __ptr)
        operator<<(_const void* __ptr)
                           ^
/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 'std::const void*'
/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<<(_void* __ptr)
        operator<<(_void* __ptr)
                           ^
/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 'std::void*'
```

C++ how not to print a vector

print-vector.cpp

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

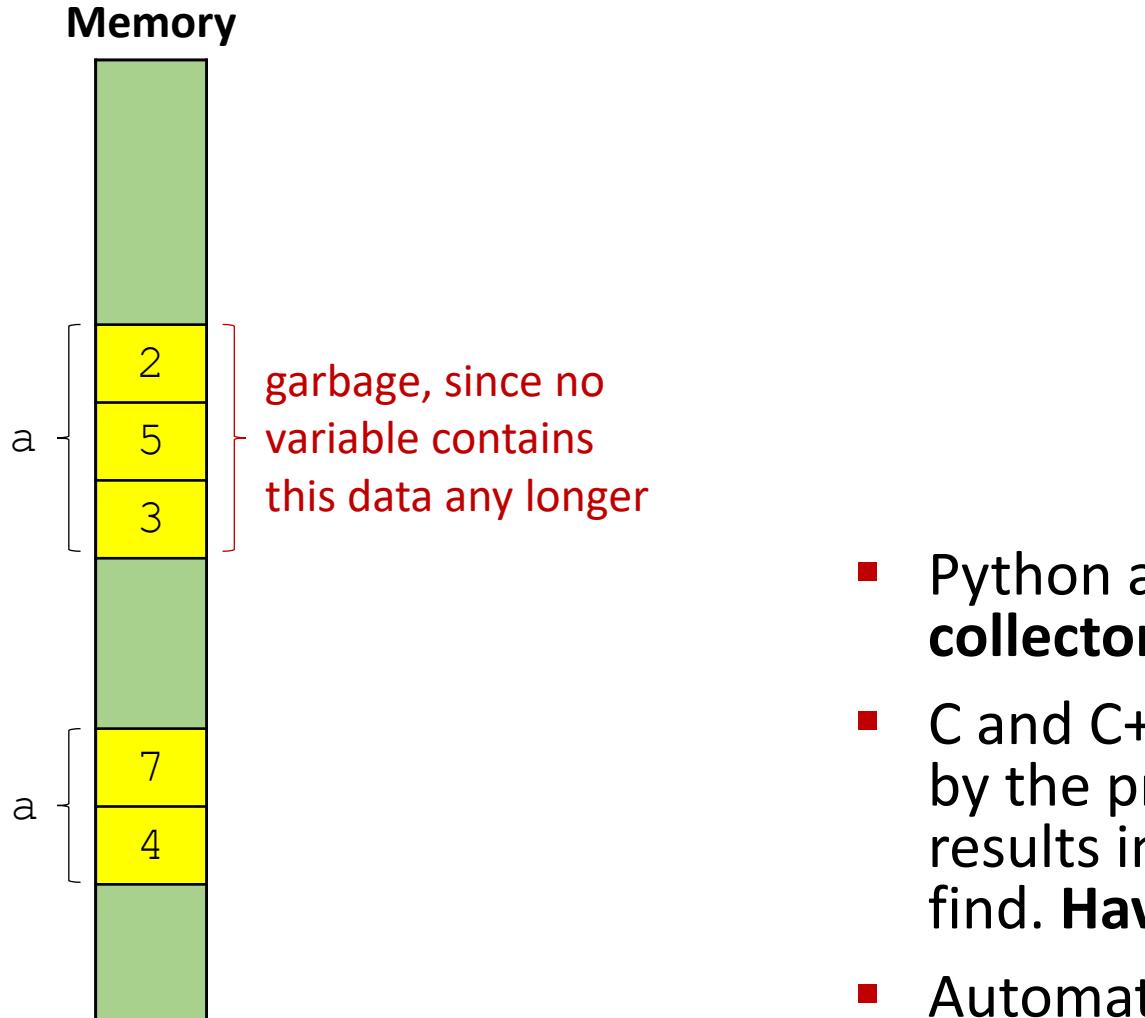
int main() {
    std::vector<int> A = {2, 3};
    std::cout << A << std::endl;
    return 0;
}
```

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

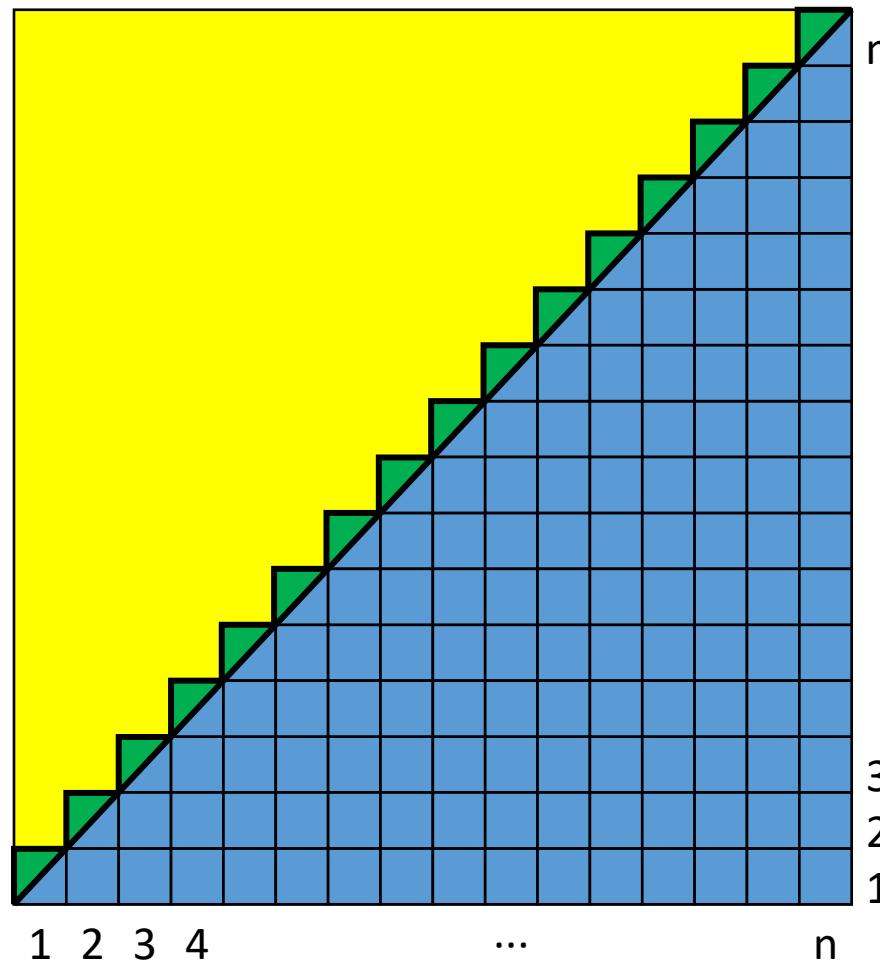
- Python and e.g. Java, C# and JavaScript have a **garbage collector** to automatically recycle garbage
- C and C++ garbage collection must be done explicitly by the program; forgetting to **free** memory again results in **memory leaks** – which can be really hard to find. **Have fun debugging!**
- 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 $1 + 2 + 3 + \dots + n = \frac{n^2}{2} + \frac{n}{2}$



$$1 + 2 + \cdots + n$$

add.py

```
import sys

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

add.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

```
#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

```
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)	CPython (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 5000000050000000

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



Bit position	6666666665555555444444443333333332222222211111111000000000 987654321098765432109876543210987654321098765432109876543210
bin(10**9)	11101110011010110010100000000
bin(50000005000000)	101101011100110001000100101101011010000000
bin(-2004260032+2**32)	100010001000100101101011010000000
bin(5000000050000000)	11011100001011010110011110010110010100000000
bin(-243309312+2**32)	1111000101111110110010100000000

Timing results

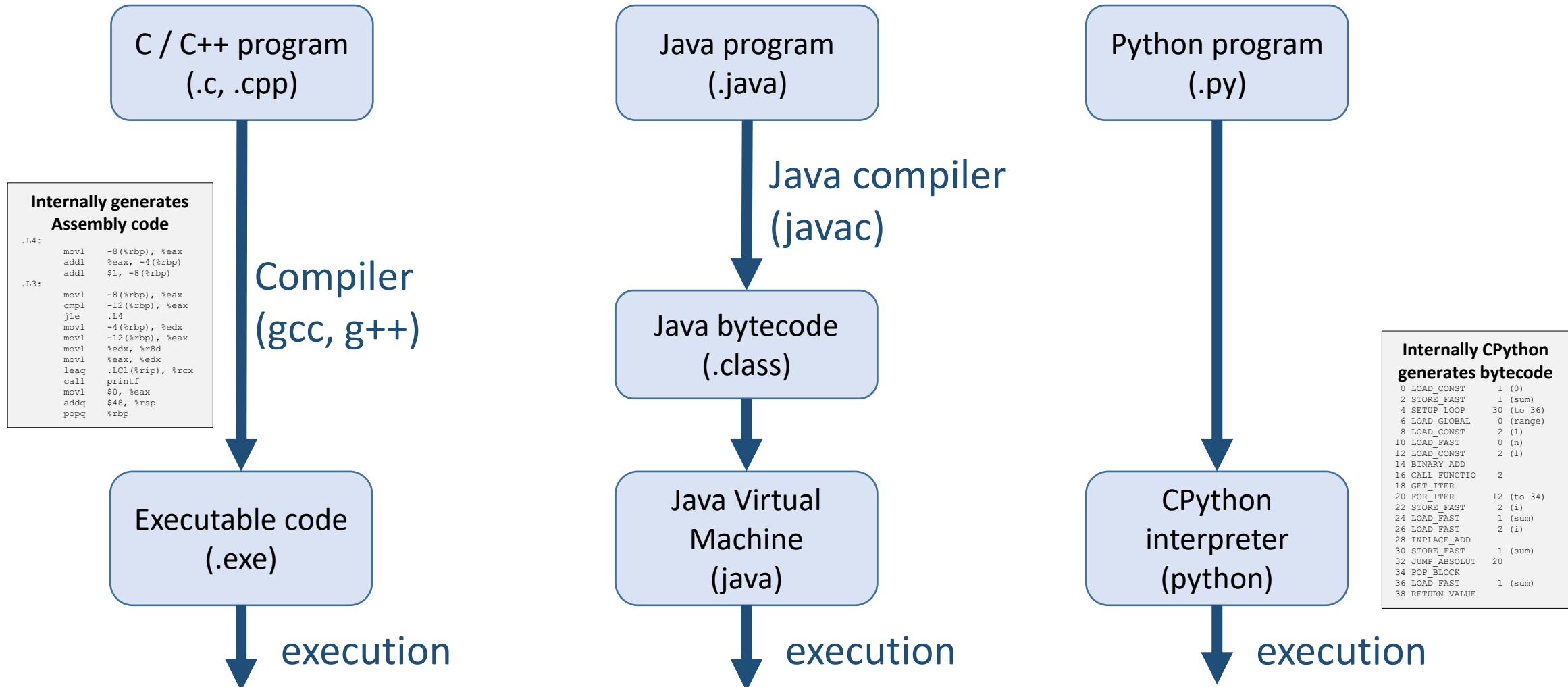
n	C (gcc 9.2)	C++, int (g++ 9.2)	C++, long (g++ 9.2)	Java (12.0)	CPython (3.8.1)	PyPy (7.3.0)	Python
10^7	0.001 sec*	0.001 sec*	0.003 sec	0.006 sec*	1.5 sec	0.27 sec	0.002 sec
10^9	0.10 sec**	0.10 sec**	0.30 sec	0.40 sec**	145 sec	27 sec	0.2 sec**

- Relative speed

C ≈ C++ > Java >> Python

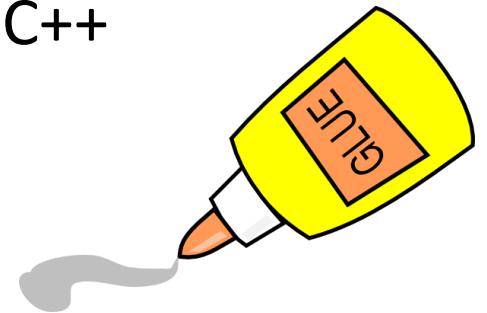
- C, C++, Java need to care about integer overflows – select integer representation carefully with sufficient number of bits (8, 16, 32, 64, 128)
- Python natively works with arbitrary long integers (as memory on your machine allows). Also possible in Java using the class `java.math.BigInteger`
- Python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

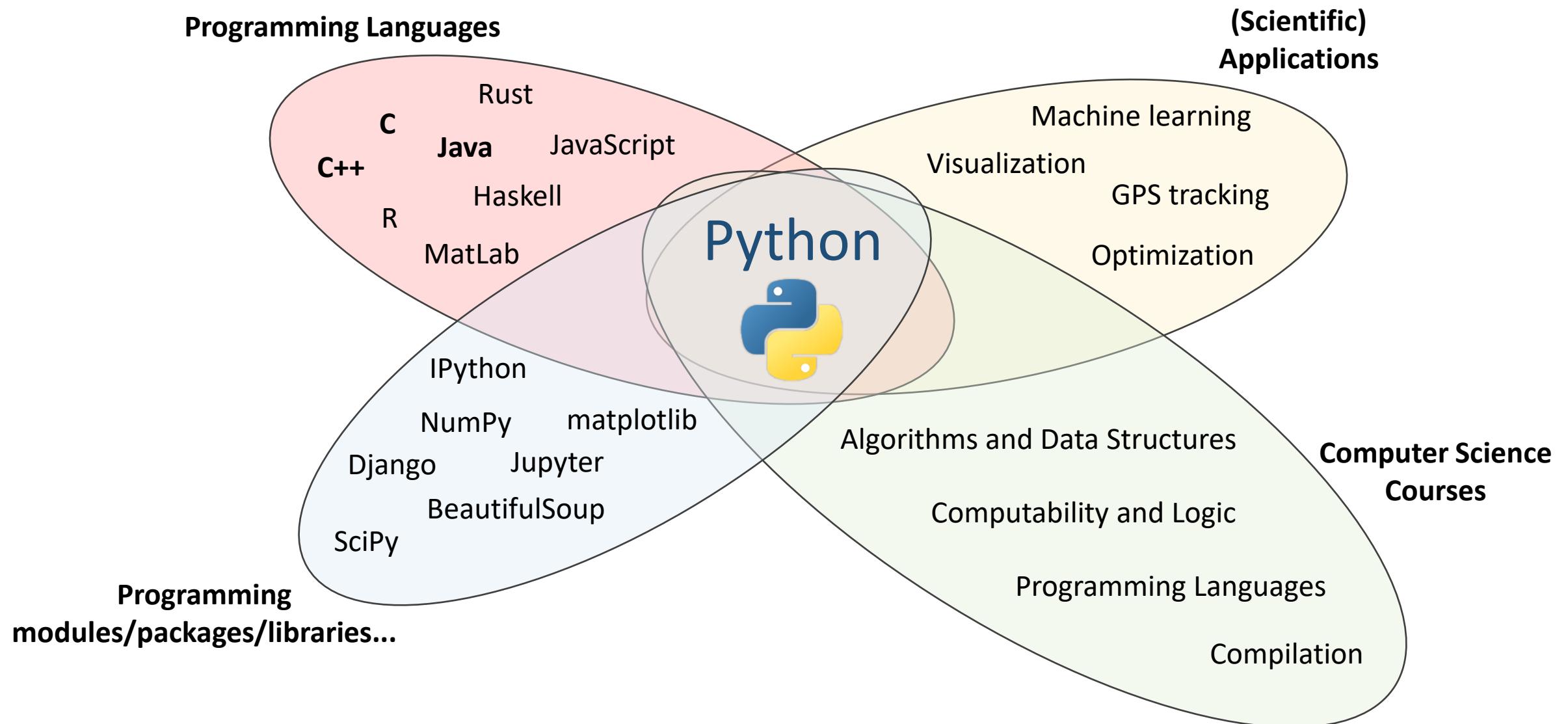


Why Python ?

- 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



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 3.14.2
- 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)

Python.org

The screenshot shows the Python.org homepage with several red arrows pointing to specific features:

- A red arrow points from the top right towards the search bar and the text "+700.000 Python packages".
- A red arrow points from the middle right towards the "Functions Defined" section.
- A large red arrow points diagonally from the bottom left towards the "Download Python and IDLE" button.

Navigation Bar: Python, PSF, Docs, PyPI, Jobs, Community, GO, Socialize.

Header: python™ logo, Search bar, +700.000 Python packages.

Menu Bar: About, Downloads, Documentation, Community, Success Stories, News, Events.

Content Area:

- Code Snippet:** A Python script for generating a Fibonacci series up to 1000.
- Section:** Functions Defined
- Text:** The core of extensible programming is defining functions. Python allows mandatory and optional arguments, keyword arguments, and even arbitrary argument lists. [More about defining functions in Python 3](#).
- Buttons:** 1, 2, 3, 4, 5.

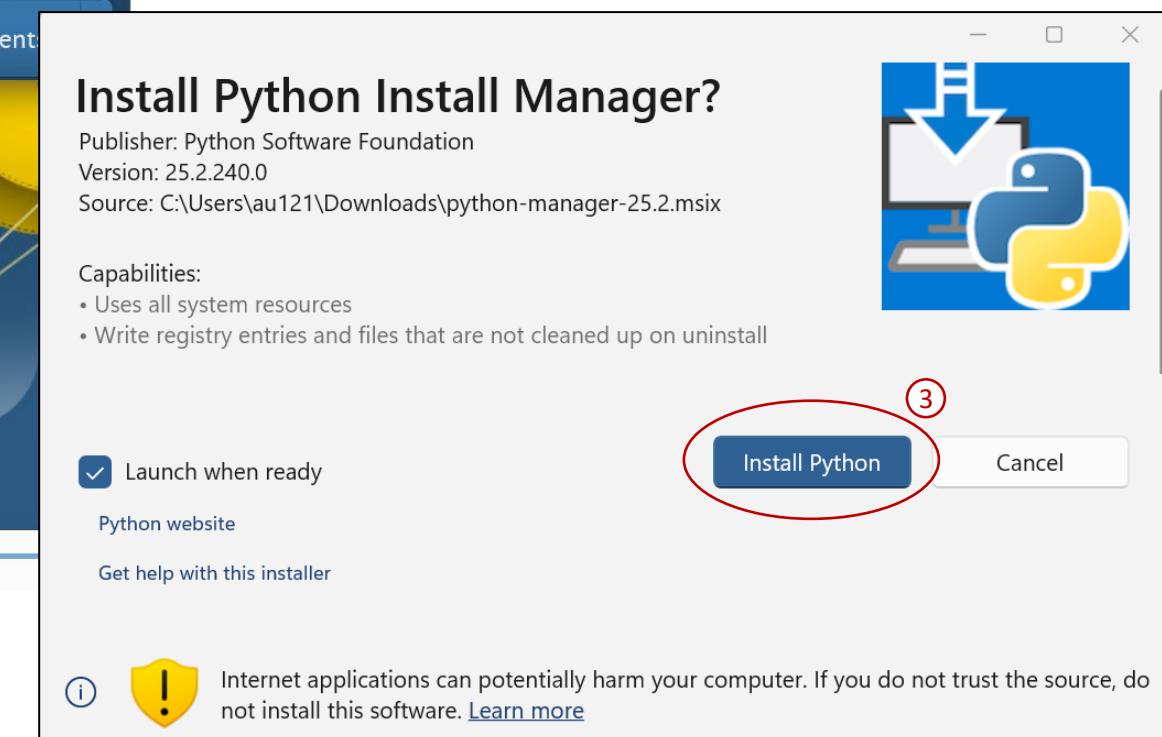
Main Message: Python is a programming language that lets you work quickly and integrate systems more effectively. [»»» Learn More](#)

Footer Sections:

- 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 3.14.2](#)
- 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 from Python.org

The screenshot shows the Python.org homepage with a dark blue header. The navigation bar includes links for Python, PSF, Docs, PyPI, Jobs, and Community. Below the header is the Python logo and a search bar with a magnifying glass icon. A red circle labeled '1' highlights the 'Downloads' tab in the main menu. The 'Downloads' section on the left has a sidebar with links for All releases, Source code, Windows, macOS, Android, Other Platforms, License, and Alternative Implementations. A red circle labeled '2' highlights the 'Python install manager' button under the 'Download for Windows' heading.

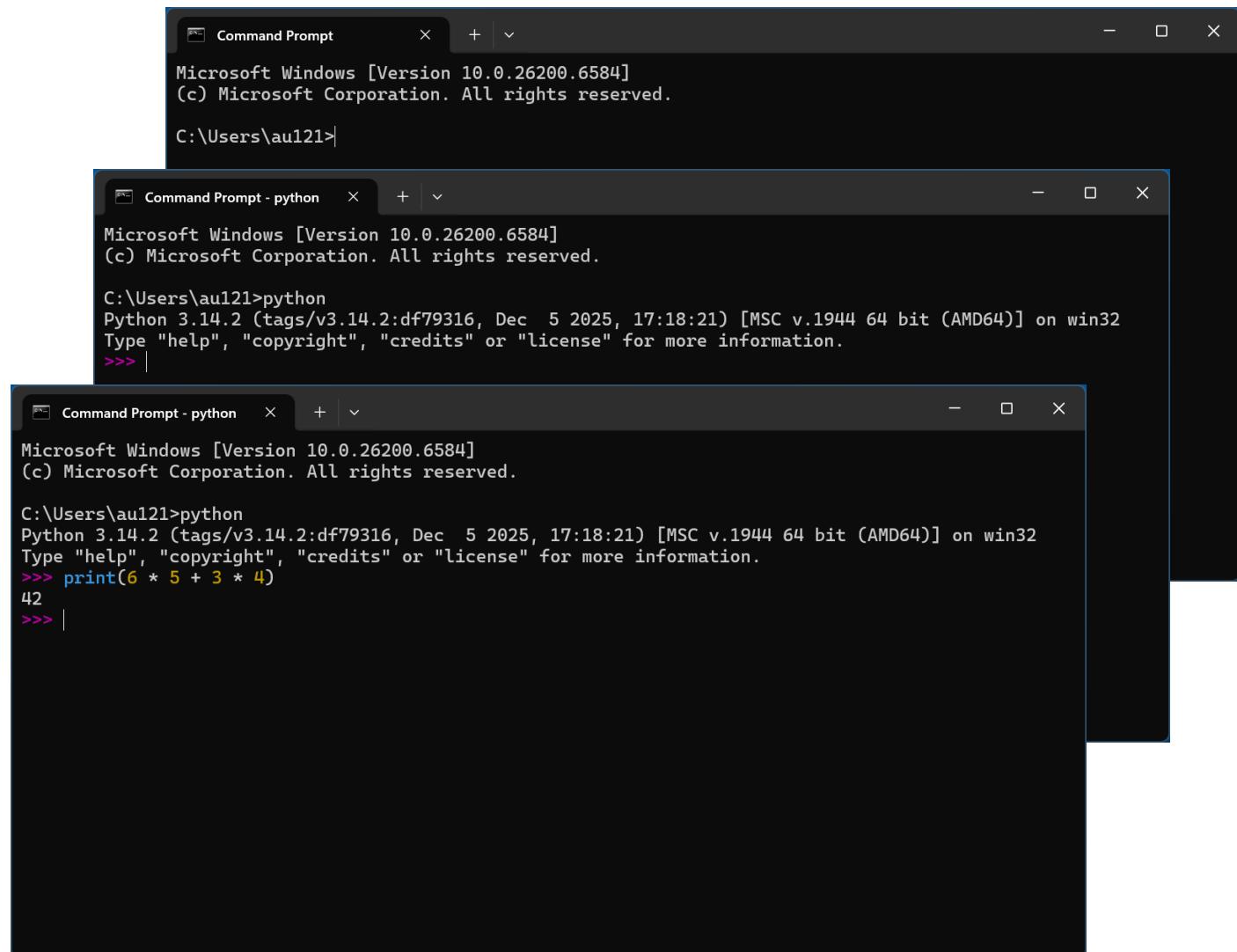


IMPORTANT

Add commands directory to your PATH now? [y/N] **y**⁴

Running the Python Interpreter from a terminal

- Open Command Prompt (Windows-key + cmd) or Windows PowerShell (Windows-key + powershell)
- Type “python” + return
- Start executing Python statements
- To exit shell:
Ctrl-d *or*
exit() + return
- Note: Sometimes “python” is installed as “python3”



The image shows three overlapping Microsoft Windows Command Prompt windows. Each window has a dark theme with white text. The top window is titled "Command Prompt" and shows the command "C:\Users\au121>". The middle window is titled "Command Prompt - python" and shows the Python interpreter prompt "C:\Users\au121>python" followed by the Python version information and help text. The bottom window is also titled "Command Prompt - python" and shows the command "C:\Users\au121>python" followed by the Python version information and help text, with a specific print statement being run: "42".

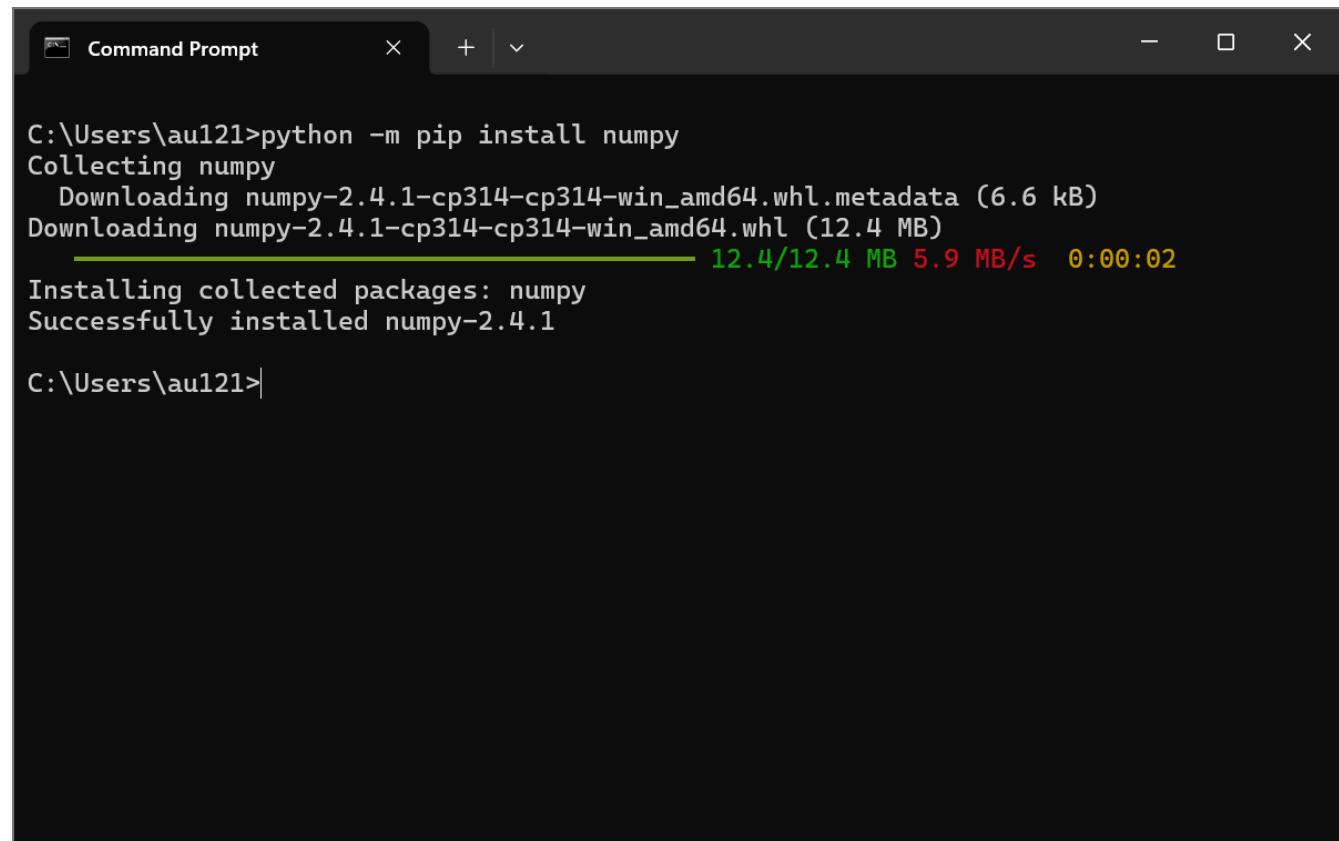
Python package installer – pip

Try to install Numpy package

- Open Command Prompt
- Execute one of the following:

```
py -m pip install numpy  
python -m pip install numpy  
python3 -m pip install numpy  
pip install numpy  
pip3 install numpy
```

Which works depends on your setup



A screenshot of a Windows Command Prompt window titled "Command Prompt". The window shows the command "C:\Users\au121>python -m pip install numpy" being run. The output indicates that numpy version 2.4.1 is being downloaded from two sources, with a total download speed of 5.9 MB/s over 0:00:02. After the download, it shows the successful installation of numpy-2.4.1.

```
C:\Users\au121>python -m pip install numpy  
Collecting numpy  
  Downloading numpy-2.4.1-cp314-cp314-win_amd64.whl.metadata (6.6 kB)  
  Downloading numpy-2.4.1-cp314-cp314-win_amd64.whl (12.4 MB)  
    12.4/12.4 MB 5.9 MB/s  0:00:02  
Installing collected packages: numpy  
Successfully installed numpy-2.4.1  
C:\Users\au121>
```

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

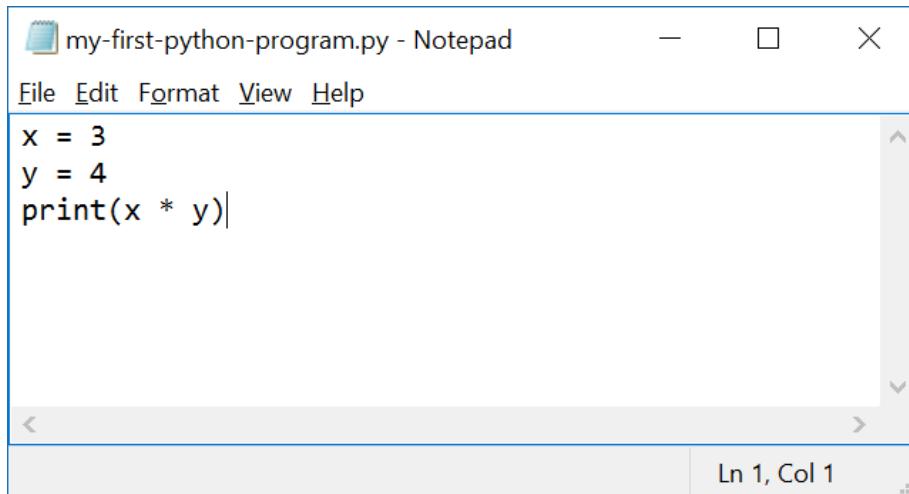
pip install matplotlib

2D and 3D plotting library

pip install pylint

Python source code analyzer enforcing a coding standard

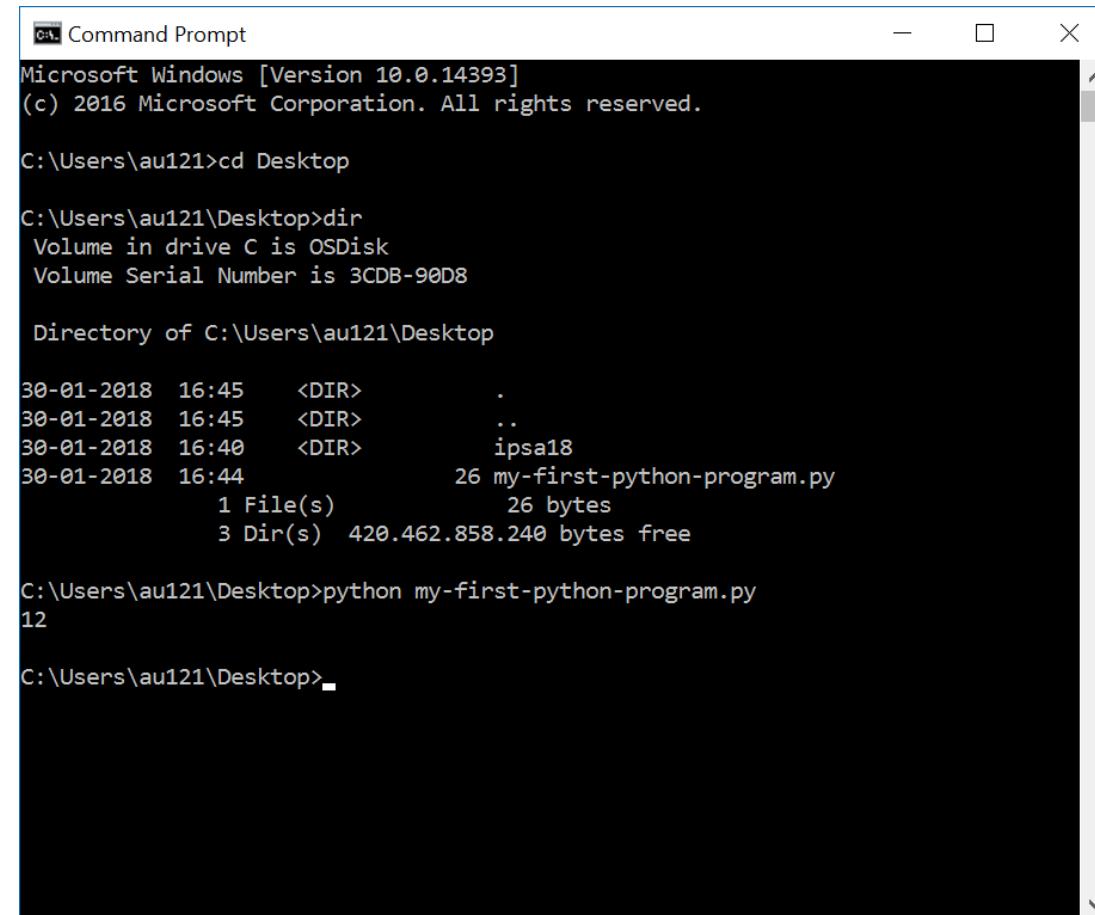
Creating a Python program the very basic way



A screenshot of a Windows Notepad window titled "my-first-python-program.py - Notepad". The window contains the following Python code:

```
x = 3
y = 4
print(x * y)
```

The status bar at the bottom right shows "Ln 1, Col 1".



A screenshot of a Windows Command Prompt window titled "Command Prompt". The window shows the following terminal session:

```
Microsoft Windows [Version 10.0.14393]
(c) 2016 Microsoft Corporation. All rights reserved.

C:\Users\au121>cd Desktop

C:\Users\au121\Desktop>dir
Volume in drive C is OSDisk
Volume Serial Number is 3CDB-90D8

Directory of C:\Users\au121\Desktop

30-01-2018  16:45    <DIR>      .
30-01-2018  16:45    <DIR>      ..
30-01-2018  16:40    <DIR>      ipsa18
30-01-2018  16:44            26 my-first-python-program.py
                           1 File(s)   26 bytes
                           3 Dir(s)  420.462.858.240 bytes free

C:\Users\au121\Desktop>python my-first-python-program.py
12

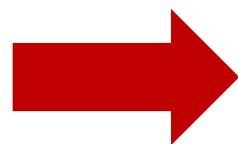
C:\Users\au121\Desktop>
```

- Open Notepad (orTextEdit 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



```
my-first-python-program.py - C:\Users\au121\Desktop\my-first-python-program.py (3.11.0)
File Edit Format Run Options Window Help
1 x = 3
2 y = 4
3 print(x *y)
4
Ln: 4 Col: 0
```

```
IDLE Shell 3.11.0
File Edit Shell Debug Options Window Help
Python 3.11.0 (main, Oct 24 2022, 18:26:48) [MSC v.1933 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license()" for more information.
>>>
===== RESTART: C:\Users\au121\Desktop\my-first-python-program.py =====
12
>>>
Ln: 6 Col: 0
```

- IDLE ships with Python from [python.org](https://www.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, +700.000 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++

Good beginner Python IDE

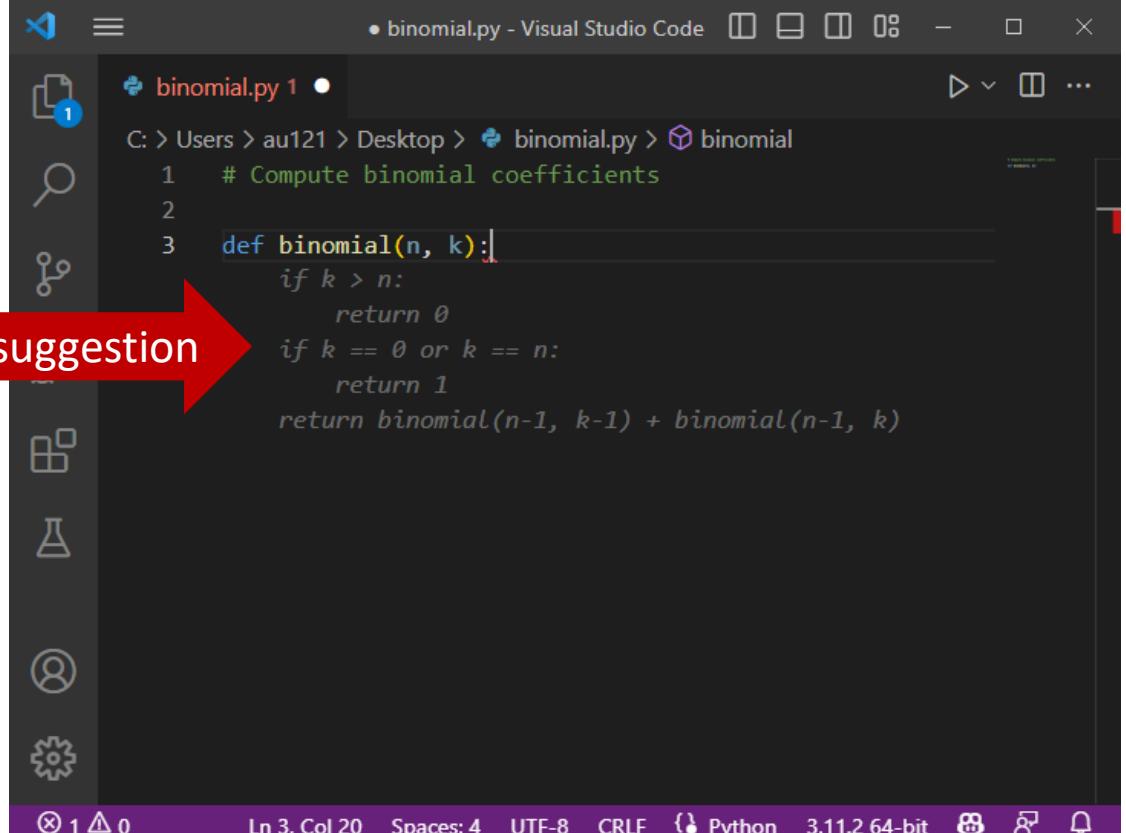
Visual Studio Code is used by more than twice as many developers than its nearest alternative, [Stack overflow survey 2025](#)
- **Python Style guide (PEP8)**
 - pylint, pep8, flake8
- **Python online**
 - Google colab (colab.research.google.com), repl.it, sagemath.org, ...
- **Pair programming plugins (share your editor with others)**
 - PyCharm : [Code With Me](#)
 - Visual Studio Code : [Live Share](#)

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



A screenshot of the Visual Studio Code interface. The title bar shows "binomial.py - Visual Studio Code". The left sidebar has a file icon with a blue dot (1) and a search icon. The main editor area contains Python code for calculating binomial coefficients:

```
C: > Users > au121 > Desktop > binomial.py > binomial
1 # Compute binomial coefficients
2
3 def binomial(n, k):
    if k > n:
        return 0
    if k == 0 or k == n:
        return 1
    return binomial(n-1, k-1) + binomial(n-1, k)
```

A red arrow points from the word "suggestion" to the code completion placeholder "def binomial(n, k):". The status bar at the bottom shows "Ln 3, Col 20" and "Python 3.11.2 64-bit".

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

PROGRAMMER'S PROBLEM

