

# Programming Techniques for Scientific Simulations I: A Comprehensive Introduction to Python

Based on lecture slides

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# 1 Introduction to Python

Python is a high-level, interpreted programming language that has become one of the most popular choices for scientific computing, data analysis, web development, and general-purpose programming. Created by Guido van Rossum and first released in 1991, Python emphasizes code readability and simplicity, allowing programmers to express concepts in fewer lines of code than would be possible in languages such as C++ or Java.

The language's design philosophy, often summarized in the *Zen of Python* (accessible by typing `import this` in any Python interpreter), emphasizes principles such as "Beautiful is better than ugly," "Explicit is better than implicit," and "Readability counts." These principles have guided Python's development and contributed to its widespread adoption across diverse domains.

This comprehensive guide introduces Python programming from the ground up, with a particular focus on techniques applicable to scientific simulations and computational research. We will explore Python's fundamental concepts, syntax, data structures, object-oriented programming features, and the ecosystem of scientific computing libraries that make Python an excellent choice for research and simulation work.

## 1.1 Why Python for Scientific Computing?

Python has emerged as a dominant force in scientific computing for several compelling reasons:

- **Ease of Learning:** Python's clean syntax and readable code make it accessible to researchers and scientists who may not have extensive programming backgrounds.
- **Rich Ecosystem:** The availability of powerful libraries such as NumPy, SciPy, Matplotlib, and pandas provides ready-made solutions for numerical computing, data visualization, and analysis.
- **Rapid Prototyping:** Python's interpreted nature allows for quick testing of ideas without lengthy compilation cycles.
- **Integration Capabilities:** Python can easily interface with code written in other languages (C, C++, Fortran), allowing performance-critical sections to be optimized while maintaining Python's ease of use for the rest of the application.
- **Community Support:** A large, active community provides extensive documentation, tutorials, and packages for virtually any computational task.

## 2 Understanding Execution Models: Interpreted vs. Compiled Languages

One of the fundamental distinctions in programming languages is how they transform human-readable source code into machine-executable instructions.

Understanding this distinction is crucial for comprehending Python's behavior, performance characteristics, and development workflow.

## 2.1 Compiled Languages: The C++ Model

A **compiled language** like C++ follows a multi-stage process before code execution:

1. **Preprocessing:** The preprocessor handles directives (lines beginning with #), such as `#include` statements, expanding them and preparing the code for compilation.
2. **Compilation:** The compiler translates the preprocessed source code into assembly language or directly into machine code, creating object files.
3. **Linking:** The linker combines multiple object files and libraries into a single executable binary file.
4. **Execution:** The resulting binary file can be run directly by the operating system, executing machine instructions native to the processor.

**Analogy:** Think of compiled languages like translating an entire book from English into Japanese before anyone reads it. Once translated, Japanese readers can read the book directly without needing the English original or a translator present.

### Advantages of Compiled Languages:

- **Performance:** Direct machine code execution is typically faster than interpreted execution.
- **Early Error Detection:** Many errors are caught at compile time, before the program runs.
- **Optimization:** Compilers can perform sophisticated optimizations during the translation process.

### Disadvantages:

- **Compilation Time:** Every code change requires recompilation, which can be time-consuming for large projects.
- **Platform Dependence:** Binaries are typically platform-specific; code must be recompiled for different operating systems or architectures.
- **Development Cycle:** The edit-compile-run cycle can slow down development and debugging.

## 2.2 Interpreted Languages: The Python Model

An **interpreted language** like Python follows a different approach:

1. **Source Code:** The programmer writes Python code in plain text files.
2. **Interpretation:** The Python interpreter reads the source code line by line (or statement by statement), translating it into bytecode and executing it on the fly.



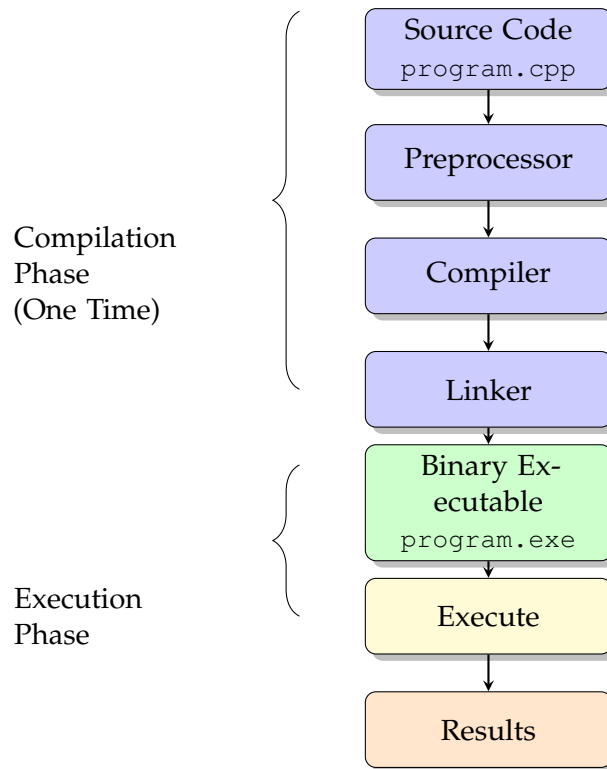


Figure 1: The compilation workflow for C++: source code passes through pre-processor, compiler, and linker stages to produce a binary executable that is then run to generate results.

3. **Results:** Output is generated directly during interpretation without creating a separate executable file.

**Analogy:** Think of interpreted languages like having a simultaneous translator at a conference. As the English speaker talks, the translator immediately translates each sentence into Japanese. There's no pre-translated document; translation happens in real-time during execution.

**Advantages of Interpreted Languages:**

- **Rapid Development:** No compilation step means immediate testing of code changes.
- **Portability:** The same source code runs on any platform with a compatible interpreter.
- **Dynamic Features:** Runtime interpretation enables powerful dynamic features like reflection and dynamic typing.
- **Interactive Mode:** Interpreters often provide interactive shells (REPLs - Read-Eval-Print Loops) for experimentation.

**Disadvantages:**

- **Performance:** Interpreted code typically runs slower than compiled code due to the overhead of runtime interpretation.
- **Runtime Errors:** Some errors only appear during execution, which might

## Interpreted Language Workflow

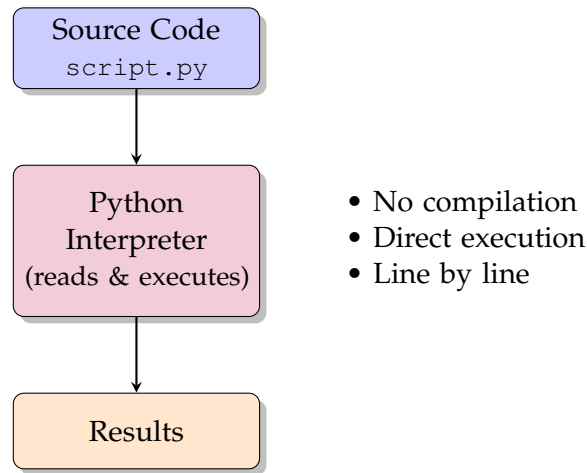


Figure 2: The interpretation workflow for Python: source code is directly processed by the interpreter, which executes it immediately to produce results, without an intermediate binary compilation stage.

not happen until specific code paths are triggered.

- **Interpreter Dependency:** The program requires an interpreter to be installed on any system where it runs.

**Note:** In practice, the distinction is more nuanced. Python actually compiles source code to bytecode (stored in `.pyc` files), which is then interpreted by the Python Virtual Machine. This hybrid approach balances some benefits of both models. Additionally, tools like PyPy use Just-In-Time (JIT) compilation to improve performance, while projects like Cython allow compilation of Python-like code to C extensions.

## 3 Type Systems: Static vs. Dynamic Typing

Type systems represent another fundamental difference between programming languages, affecting how variables are declared, used, and checked for correctness.

### 3.1 Static Typing: The C++ Approach

C++ employs **static typing**, which means:

1. **Explicit Type Declaration:** Variable types must be declared explicitly when variables are created.
2. **Compile-Time Type Checking:** The compiler verifies that all operations are type-safe before the program runs.

3. **Type Immutability:** Once a variable is declared with a specific type, it cannot change to a different type.

#### Example in C++:

```
1 int x = 5;           // x is declared as an integer
2 x = 10;              // Valid: assigning another integer
3 x = "hello";         // COMPILATION ERROR: cannot assign string to int
4 double y = 3.14;     // y is declared as a double
5 y = 42;              // Valid: 42 is converted to 42.0
```

Listing 1: Static typing in C++: explicit type declarations and compile-time enforcement

**Analogy:** Think of statically typed variables like labeled storage boxes in a warehouse. A box labeled "Integers Only" can only contain integers. If you try to put a string in that box, the warehouse management system (compiler) will reject it before the warehouse even opens for business.

#### Advantages of Static Typing:

- **Early Error Detection:** Type mismatches are caught at compile time, preventing many runtime errors.
- **Performance:** The compiler can optimize code based on known types, often resulting in faster execution.
- **Documentation:** Type declarations serve as inline documentation, making code intent clearer.
- **Tooling Support:** IDEs can provide better autocomplete, refactoring, and error detection based on type information.

## 3.2 Dynamic Typing: The Python Approach

Python uses **dynamic typing**, characterized by:

1. **No Explicit Type Declaration:** Variables are created simply by assignment; no type specification is required.
2. **Runtime Type Checking:** Type compatibility is verified during program execution.
3. **Type Flexibility:** Variables can be reassigned to values of completely different types.

#### Example in Python:

```
1 x = 5                # x refers to an integer object
2 print(type(x))      # <class 'int'>
3 x = "hello"          # Perfectly valid: x now refers to a string object
4 print(type(x))      # <class 'str'>
5 x = [1, 2, 3]        # Also valid: x now refers to a list object
6 print(type(x))      # <class 'list'>
```

Listing 2: Dynamic typing in Python: no type declarations and flexible type reassignment

**Analogy:** Think of dynamically typed variables like flexible containers. The container (variable name) doesn't care what's inside it—integers, strings, lists, or any other object. You can empty it and fill it with something completely different at any time.

**Advantages of Dynamic Typing:**

- **Flexibility:** Code can work with different types without modification (duck typing).
- **Conciseness:** Less boilerplate code; no need for verbose type declarations.
- **Rapid Prototyping:** Quick experimentation without worrying about type systems.
- **Generic Programming:** Easier to write code that works with multiple types.

**Disadvantages:**

- **Runtime Errors:** Type errors only appear during execution, potentially in production.
- **Performance:** Runtime type checking and flexibility can slow execution.
- **Less IDE Support:** Harder for tools to provide accurate autocomplete without explicit types.
- **Implicit Documentation:** Type information isn't immediately visible from variable declarations.

**Modern Python:** Python 3.5+ introduced optional type hints, allowing developers to annotate types without enforcing them at runtime. Tools like `mypy` can perform static type checking on annotated code, combining benefits of both approaches:

```
1 def add_numbers(a: int, b: int) -> int:
2     """Add two integers and return the result."""
3     return a + b
4
5 result: int = add_numbers(5, 10) # Type hints are optional
   documentation
```

Listing 3: Python type hints provide optional static type checking

## 4 Python Versions: Python 2 vs. Python 3

Understanding Python's version history is important for navigating the ecosystem and making informed decisions about which version to use.

### 4.1 Python 2.x: The Legacy Version

**Python 2.x** was the dominant version from approximately 2000 to 2010, with Python 2.7 being the final release in this series.

**Key Facts:**

- **Timeline:** Released around 2000; Python 2.7 (the last 2.x version) was released in 2010.
- **Extended Support:** Python 2.7 received extended support until 2020, with the final release (2.7.18) in April 2020.

- **End of Life:** Official support ended on January 1, 2020 (see <https://pythonclock.org/>).
- **Legacy Codebases:** Many older projects and libraries were written in Python 2.
- **Current Status:** No longer recommended for new projects; considered obsolete.

**Why Python 2 Still Matters:** While Python 2 is officially deprecated, you may encounter it in:

- Legacy systems and older scientific code
- Older tutorials and documentation
- Some embedded systems that haven't been updated
- Systems where updating would break critical dependencies

## 4.2 Python 3.x: The Modern Standard

**Python 3.x** represents the present and future of the language, with the first release in 2008.

**Key Facts:**

- **Timeline:** First released in December 2008 (Python 3.0).
- **Breaking Changes:** Not backward compatible with Python 2, requiring code migration.
- **Improvements:** Cleaner design, better Unicode support, improved consistency.
- **Ecosystem:** Virtually all major libraries now support Python 3.
- **Current Dominance:** According to the 2025 Stack Overflow Developer Survey, Python 3 is overwhelmingly the standard.

**Major Differences Between Python 2 and 3:**

### 1. Print Statement vs. Function:

```

1 # Python 2
2 print "Hello, World!" # Statement
3
4 # Python 3
5 print("Hello, World!") # Function
6

```

Listing 4: Print differences between Python 2 and 3

### 2. Integer Division:

```

1 # Python 2
2 5 / 2 # Result: 2 (integer division)
3
4 # Python 3
5 5 / 2 # Result: 2.5 (true division)
6 5 // 2 # Result: 2 (floor division)
7

```

Listing 5: Division behavior differences

### 3. Unicode Strings:

- Python 2: Strings are bytes by default; Unicode requires `u"string"` prefix.
- Python 3: Strings are Unicode by default; bytes require `b"string"` prefix.

### 4. Range Function:

- Python 2: `range()` returns a list; `xrange()` returns an iterator.
- Python 3: `range()` returns an iterator; `xrange()` doesn't exist.

**Recommendation:** Always use Python 3.x for new projects. As of 2025, Python 3.10+ is widely adopted, with Python 3.11 and 3.12 offering significant performance improvements and new features.

## 5 Installing and Setting Up Python

Python's availability across different operating systems makes it accessible to virtually any developer. However, installation methods vary by platform.

### 5.1 Installation on Linux

Most modern Linux distributions come with Python pre-installed, though it may be necessary to install additional packages or ensure Python 3 is the default version.

#### Installation Steps:

#### 1. Check Existing Installation:

```
1 python3 --version # Check Python 3 version
2 which python3     # Find Python 3 location
3
```

Listing 6: Checking Python installation on Linux

#### 2. Install via Package Manager: Different distributions use different package managers:

```
1 # Debian/Ubuntu
2 sudo apt update
3 sudo apt install python3 python3-pip python3-dev
4
5 # Fedora/RHEL/CentOS
6 sudo yum install python3 python3-pip
7
8 # OpenSUSE
9 sudo zypper install python3 python3-pip
10
```

Listing 7: Installing Python on various Linux distributions

3. **Install Additional Packages:** You may need to install additional packages for a "full" Python environment:

```
1 sudo apt install python3-numpy python3-scipy python3-matplotlib
2
```

Listing 8: Installing additional Python packages

## 5.2 Installation on macOS

macOS typically includes a basic Python installation, but you should verify it's Python 3 and consider using a package manager for better control.

### Installation Methods:

1. **Built-in Python:**

```
1 python3 --version # Verify Python 3 is available
2
```

Listing 9: Checking macOS Python installation

2. **Homebrew (Recommended):**

```
1 # Install Homebrew if not already installed
2 /bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/
   Homebrew/install/HEAD/install.sh)"
3
4 # Install Python 3
5 brew install python3
6
```

Listing 10: Installing Python via Homebrew

3. **MacPorts:**

```
1 sudo port install python310 # Install Python 3.10
2 sudo port select --set python python310 # Set as default
3
```

Listing 11: Installing Python via MacPorts

4. **Python Distributions:**

- **Anaconda:** (<https://www.anaconda.com/download/>) - Comprehensive distribution with scientific packages
- **Canopy:** (<https://assets.enthought.com/downloads/edm/>) - Enthought's scientific distribution

## 5.3 Installation on Windows

Windows doesn't include Python by default, so it must be explicitly installed.

### Installation Methods:

1. **Official Python Installer:**

- Download from <https://www.python.org>
- Run installer and ensure "Add Python to PATH" is checked
- Verify installation in Command Prompt or PowerShell

## 2. Microsoft Store:

- Search for "Python" in Microsoft Store
- Install directly with automatic PATH configuration

## 3. Windows Subsystem for Linux (WSL):

```
1 # Install WSL2 first, then:
2 sudo apt update
3 sudo apt install python3 python3-pip
4
```

Listing 12: Using Python in WSL

For graphical applications, you may need an X11 server:

- Windows 11+ with WSL2 includes built-in X11 support
- Older versions can use VcXsrv or similar X servers

## 4. Python Distributions: Same as macOS: Anaconda or Canopy provide comprehensive scientific computing environments.

**Important Note:** Some older operating systems may still have Python 2.x as the default. Always verify you're using Python 3 by running `python -version` or `python3 -version`.

## 5.4 Python Distribution Recommendations

For scientific computing, specialized Python distributions offer significant advantages over standard installations:

### Anaconda/Miniconda:

- Includes 250+ pre-installed scientific packages
- Conda package manager simplifies dependency management
- Environment management for project isolation
- Cross-platform consistency
- Free and open source

### Enthought Canopy:

- Curated collection of scientific packages
- Integrated development environment
- Package management tools
- Educational resources and documentation

For most scientific computing purposes, Anaconda is the recommended distribution due to its comprehensive package collection and excellent environment management capabilities.



## 6 Python's Library Ecosystem

One of Python's greatest strengths is its extensive ecosystem of libraries and packages, which extend the language's capabilities far beyond what's built into the core.

### 6.1 The Python Standard Library

The **Python Standard Library** consists of over 100 modules that ship with Python, providing functionality for common programming tasks without requiring external installation.

**Categories of Standard Library Modules:**

- **Text Processing:** `string`, `re` (regular expressions), `textwrap`
- **Data Types:** `collections`, `array`, `copy`, `enum`
- **Mathematics:** `math`, `random`, `statistics`, `decimal`
- **File and Directory Access:** `os`, `pathlib`, `glob`, `shutil`
- **Data Persistence:** `pickle`, `json`, `sqlite3`
- **Networking:** `socket`, `http`, `urllib`, `ftplib`
- **Internet Protocols:** `email`, `xml`, `html`
- **Concurrency:** `threading`, `multiprocessing`, `asyncio`
- **Debugging and Testing:** `unittest`, `pdb`, `timeit`

**Documentation:** Complete documentation available at <https://docs.python.org/3/library/index.html>

**Installation Note:** While the standard library comes with Python, some Linux distributions may split it into separate packages. You may need to use your OS package manager to install the complete library.

**Exploring the Standard Library:** The Python Module of the Week (PyMOTW-3) provides excellent tutorials and examples for standard library modules: <https://pymotw.com/3/index.html>

### 6.2 The Python Package Index (PyPI)

The **Python Package Index** (PyPI, pronounced "pie-pee-eye") is a repository of software packages for Python, containing over 500,000 projects as of 2025.

**Key Facts:**

- **URL:** <https://pypi.org/>
- **Scope:** Covers virtually every domain: web development, data science, machine learning, automation, games, and more
- **Installation Tool:** `pip` (Python Package Installer)
- **Open Source:** Most packages are open source and free to use

**Installing Packages with pip:**

```
1 # Install a package
2 pip install numpy
3
4 # Install a specific version
5 pip install numpy==1.24.0
6
```

```

7 # Upgrade a package
8 pip install --upgrade numpy
9
10 # Uninstall a package
11 pip uninstall numpy
12
13 # List installed packages
14 pip list
15
16 # Show information about a package
17 pip show numpy

```

Listing 13: Basic pip usage for installing packages

**Virtual Environments:** Best practice involves using virtual environments to isolate project dependencies:

```

1 # Create a virtual environment
2 python3 -m venv myproject_env
3
4 # Activate the environment (Linux/macOS)
5 source myproject_env/bin/activate
6
7 # Activate the environment (Windows)
8 myproject_env\Scripts\activate
9
10 # Install packages in the virtual environment
11 pip install numpy scipy matplotlib
12
13 # Deactivate when done
14 deactivate

```

Listing 14: Creating and using virtual environments

### Why Use Virtual Environments?

- **Dependency Isolation:** Different projects can use different versions of the same package
- **Reproducibility:** Easily recreate exact environments using `requirements.txt`
- **System Protection:** Avoid conflicts with system Python packages
- **Clean Testing:** Start with a clean slate for each project

## 6.3 Comparing Python and C++ Library Ecosystems

While Python’s package ecosystem is centralized through PyPI, C++ has a more fragmented landscape:

- **C++ Libraries:** Often distributed through various channels (system package managers, source repositories, dedicated sites)
- **Reference:** <https://en.cppreference.com/w/cpp/links/libs>
- **Installation:** Typically more complex, often requiring manual compilation
- **Header-Only Libraries:** Many C++ libraries are header-only, simplifying distribution

Python's centralized package management through PyPI and pip provides a significantly more streamlined experience for installing and managing dependencies compared to C++'s more fragmented ecosystem.

## 7 Essential Scientific Computing Packages

Python's dominance in scientific computing is largely due to a core set of mature, well-designed packages that provide efficient numerical computing capabilities.

### 7.1 NumPy: Numerical Python

**NumPy** is the foundational package for numerical computing in Python, providing:

- **Multi-dimensional Arrays:** Efficient storage and manipulation of arrays and matrices
- **Mathematical Functions:** Comprehensive collection of mathematical operations
- **Linear Algebra:** Basic linear algebra operations
- **Random Number Generation:** Statistical distributions and random sampling
- **Fourier Transforms:** Fast Fourier Transform (FFT) operations

**Installation:**

```
1 pip install numpy
```

**Basic Example:**

```
1 import numpy as np
2
3 # Create arrays
4 a = np.array([1, 2, 3, 4, 5])
5 b = np.array([[1, 2, 3], [4, 5, 6]])
6
7 # Mathematical operations (vectorized)
8 c = a * 2           # Multiply all elements by 2
9 d = np.sin(a)       # Apply sine to all elements
10 e = a + a           # Element-wise addition
11
12 # Statistical operations
13 mean = np.mean(a)
14 std = np.std(a)
15
16 print(f"Array a: {a}")
17 print(f"Doubled: {c}")
18 print(f"Mean: {mean}, Std: {std}")
```

Listing 15: NumPy array operations

**Why NumPy Matters:** NumPy arrays are implemented in C, making operations much faster than pure Python lists. This forms the foundation for virtually all scientific computing in Python.

## 7.2 SciPy: Scientific Python

SciPy builds on NumPy to provide higher-level scientific computing functionality:

- **Optimization:** Function minimization, curve fitting, root finding
- **Integration:** Numerical integration and differential equation solvers
- **Interpolation:** Data interpolation and smoothing
- **Linear Algebra:** Advanced linear algebra operations beyond NumPy
- **Statistics:** Statistical distributions, tests, and functions
- **Signal Processing:** Filtering, convolution, Fourier analysis
- **Image Processing:** Basic image manipulation and filtering
- **Sparse Matrices:** Efficient handling of sparse matrix operations

**Installation:**

```
1 pip install scipy
```

**Example:**

```
1 import numpy as np
2 from scipy import optimize
3
4 # Define a function to minimize
5 def f(x):
6     return (x - 3)**2 + 5
7
8 # Find the minimum
9 result = optimize.minimize(f, x0=0)
10 print(f"Minimum at x = {result.x[0]:.4f}")
11 print(f"Minimum value = {result.fun:.4f}")
```

Listing 16: SciPy optimization example

## 7.3 Matplotlib: Visualization

Matplotlib is Python's primary plotting library, providing publication-quality figures:

- **2D Plots:** Line plots, scatter plots, bar charts, histograms
- **3D Plots:** Surface plots, wireframes, 3D scatter plots
- **Customization:** Fine control over every element of a figure
- **Multiple Formats:** Export to PNG, PDF, SVG, and more
- **Interactive Plotting:** Zooming, panning, and updating plots dynamically

**Installation:**

```
1 pip install matplotlib
```

**Example:**

```
1 import numpy as np
2 import matplotlib.pyplot as plt
3
4 # Generate data
5 x = np.linspace(0, 2*np.pi, 100)
6 y1 = np.sin(x)
```

```

7 y2 = np.cos(x)
8
9 # Create plot
10 plt.figure(figsize=(10, 6))
11 plt.plot(x, y1, label='sin(x)', linewidth=2)
12 plt.plot(x, y2, label='cos(x)', linewidth=2)
13 plt.xlabel('x')
14 plt.ylabel('y')
15 plt.title('Trigonometric Functions')
16 plt.legend()
17 plt.grid(True)
18 plt.savefig('trig_functions.png', dpi=300)
19 plt.show()

```

Listing 17: Creating plots with Matplotlib

## 7.4 H5py: HDF5 Interface

H5py provides a Pythonic interface to the HDF5 binary data format:

- **Hierarchical Data Format:** Organize data in tree-like structures
- **Large Datasets:** Efficiently store and access datasets larger than RAM
- **Metadata:** Attach arbitrary metadata to datasets
- **Compression:** Built-in data compression support
- **Cross-Platform:** HDF5 files are portable across systems

**Installation:**

```
1 pip install h5py
```

**Use Cases:**

- Storing simulation results
- Managing large scientific datasets
- Sharing data between different programming languages

## 7.5 mpi4py: Parallel Computing

mpi4py provides Python bindings for the Message Passing Interface (MPI):

- **Distributed Computing:** Run Python programs across multiple processors or nodes
- **High-Performance Computing:** Essential for large-scale scientific simulations
- **Standard Interface:** Uses the widely-adopted MPI standard

**Installation:**

```
1 pip install mpi4py
```

**Note:** Requires an MPI implementation (OpenMPI, MPICH, etc.) to be installed on the system. This topic is covered extensively in High-Performance Computing courses.

## 7.6 SymPy: Symbolic Mathematics

**SymPy** is a computer algebra system written entirely in Python:

- **Symbolic Computation:** Algebraic manipulation of mathematical expressions
- **Equation Solving:** Solve equations symbolically
- **Calculus:** Symbolic differentiation and integration
- **Linear Algebra:** Matrix operations with symbolic entries
- **Pretty Printing:** Beautiful mathematical output

**Installation:**

```
1 pip install sympy
```

**Example:**

```
1 from sympy import symbols, diff, integrate, sin, cos, exp
2
3 # Define symbolic variables
4 x, y = symbols('x y')
5
6 # Define an expression
7 expr = x**2 + 2*x*y + y**2
8
9 # Differentiate
10 dx = diff(expr, x) # Result: 2*x + 2*y
11 dy = diff(expr, y) # Result: 2*x + 2*y
12
13 # Integrate
14 integral = integrate(sin(x)*exp(x), x)
15
16 print(f"Expression: {expr}")
17 print(f"d/dx: {dx}")
18 print(f"Integral: {integral}")
```

Listing 18: Symbolic mathematics with SymPy

These packages form the core of Python's scientific computing ecosystem. Together, they provide functionality comparable to commercial systems like MATLAB while remaining free and open source.

## 8 Python Execution Environments

Python offers multiple ways to write and execute code, each suited to different workflows and purposes.

### 8.1 The Standard Python Interactive Shell

The basic Python interpreter provides an interactive Read-Eval-Print Loop (REPL):

**Starting the Shell:**

```
1 $ python
2 Python 3.10.8 (main, Oct 12 2022, 09:46:29) [Clang 14.0.0] on darwin
```

```

3 Type "help", "copyright", "credits" or "license" for more information.
4 >>>

```

Listing 19: Launching the Python interactive shell

#### Features:

- **Interactive Execution:** Enter code line by line and see immediate results
- **Experimentation:** Quick testing of ideas and syntax
- **Learning:** Explore language features interactively
- **Prompt:** The `>>>` prompt indicates Python is ready for input

#### Example Session:

```

1 >>> x = 5
2 >>> y = 10
3 >>> x + y
4 15
5 >>> print("Hello, World!")
6 Hello, World!
7 >>> import math
8 >>> math.sqrt(16)
9 4.0

```

Listing 20: Using the Python interactive shell

#### Limitations:

- No syntax highlighting
- Limited command history
- No tab completion
- Code not easily saved

## 8.2 Running Python Scripts

For programs longer than a few lines, code should be saved in files with the `.py` extension and executed as scripts:

**Creating a Script:** Create a file named `script.py`:

```

1 #!/usr/bin/env python3
2 """
3 A simple demonstration script.
4 """
5
6 def greet(name):
7     """Print a greeting message."""
8     return f"Hello, {name}!"
9
10 def main():
11     """Main function."""
12     message = greet("World")
13     print(message)
14
15     # Perform calculations
16     result = sum(range(1, 11))
17     print(f"Sum of 1-10: {result}")
18
19 if __name__ == "__main__":

```

```
20 main()
```

Listing 21: A simple Python script (script.py)

### Running the Script:

```
1 $ python script.py
2 Hello, World!
3 Sum of 1-10: 55
```

Listing 22: Executing a Python script

**The Shebang Line:** The first line (`#!/usr/bin/env python3`) allows the script to be executed directly on Unix-like systems:

```
1 $ chmod +x script.py # Make executable
2 $ ./script.py        # Run directly
```

## 8.3 IPython: Enhanced Interactive Shell

**IPython** is an enhanced interactive Python shell with powerful features for productive development and exploration:

### Starting IPython:

```
1 $ ipython
2 Python 3.13.5 (main, Jun 25 2025, 18:55:22) [GCC 14.2.0]
3 Type 'copyright', 'credits' or 'license' for more information
4 IPython 9.8.0 -- An enhanced Interactive Python. Type '?' for help.
5
6 In [1]:
```

Listing 23: Launching IPython

### Key Features:

- **Syntax Highlighting:** Color-coded code for readability
- **Tab Completion:** Press Tab to autocomplete variable names, functions, and module members
- **Magic Commands:** Special commands prefixed with % or %%
- **History:** Advanced command history with search and replay
- **Help System:** Type ?object for documentation, ??object for source code
- **Shell Commands:** Execute system commands with !command
- **Numbered Prompts:** Input and output are numbered for easy reference

### Example IPython Session:

```
1 In [1]: import numpy as np
2
3 In [2]: arr = np.array([1, 2, 3, 4, 5])
4
5 In [3]: arr.
6 arr.T          arr.all          arr.argmin        arr.astype
7 arr.any         arr.argmax        arr.argsort       ...
8
9 In [4]: %timeit sum(range(1000))
10 5.23 s          123 ns per loop (mean    std. dev. of 7 runs, 100000 loops
    each)
```



```

11
12 In [5]: np.sqrt?
13 Signature: np.sqrt(x, /, out=None, *, where=True, casting='same_kind',
...      ...)
14 Docstring:
15 Return the non-negative square-root of an array, element-wise.
16 ...
17
18 In [6]: %hist
19 1: import numpy as np
20 2: arr = np.array([1, 2, 3, 4, 5])
21 ...

```

Listing 24: Using IPython’s enhanced features

#### Useful Magic Commands:

- `%timeit`: Measure execution time of statements
- `%run`: Execute a Python script
- `%hist`: Display command history
- `%pwd`: Print working directory
- `%cd`: Change directory
- `%load`: Load code from file into cell
- `%save`: Save input history to file
- `%%writefile`: Write cell contents to file

#### Installation:

```

1 pip install ipython

```

## 8.4 Jupyter Notebooks: Interactive Computing Environment

**Jupyter Notebooks** provide a web-based interactive computing environment that combines code execution, rich text, mathematics, plots, and media in a single document.

#### Starting Jupyter:

```

1 # Classic Notebook interface
2 $ jupyter notebook
3
4 # JupyterLab (next-generation interface)
5 $ jupyter lab

```

Listing 25: Launching Jupyter Notebook or JupyterLab

Both commands start a local web server and open a browser window with the Jupyter interface.

#### Key Features:

- **Notebook Format**: Documents contain code cells, markdown cells, and output
- **Interactive Execution**: Run cells individually, in any order
- **Rich Output**: Plots, images, videos, and formatted text display inline
- **Markdown Support**: Write formatted text, equations (LaTeX), and documentation

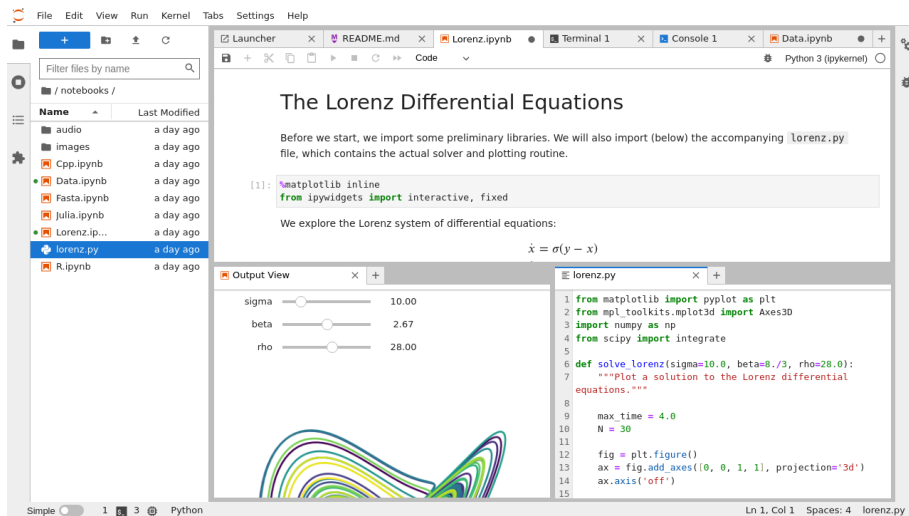


Figure 3: The Jupyter Notebook interface showing code cells, output, and mark-down text combined in a single document. The browser-based interface allows for interactive computing with immediate visual feedback.

- **Sharing:** Notebooks are JSON files that can be easily shared and version-controlled
- **Export:** Convert notebooks to HTML, PDF, slides, or Python scripts
- **Kernels:** Support for multiple languages beyond Python (R, Julia, etc.)

### Cell Types:

1. **Code Cells:** Contain executable Python code
2. **Markdown Cells:** Contain formatted text, equations, and documentation
3. **Raw Cells:** Contain unformatted text (rarely used)

### Example Notebook Content:

```

1 # Markdown Cell
2 # Analysis of Sine Function
3 This notebook explores properties of the sine function.
4
5 # Code Cell 1
6 import numpy as np
7 import matplotlib.pyplot as plt
8
9 x = np.linspace(0, 2*np.pi, 100)
10 y = np.sin(x)
11
12 # Code Cell 2
13 plt.figure(figsize=(10, 6))
14 plt.plot(x, y)
15 plt.title('Sine Function')
16 plt.xlabel('x')
17 plt.ylabel('sin(x)')
18 plt.grid(True)

```

```

19 plt.show()
20
21 # Markdown Cell
22 ## Observations
23 - The sine function is periodic with period  $2\pi$ 
24 - Maximum value is 1, minimum is -1

```

Listing 26: Example Jupyter Notebook cells

#### Use Cases:

- Data exploration and analysis
- Scientific research documentation
- Teaching and tutorials
- Reproducible research
- Presentation of results with code

#### Installation:

```
1 pip install jupyter notebook jupyterlab
```

#### JupyterLab vs. Notebook:

- **Notebook:** Classic, simpler interface
- **JupyterLab:** Modern, extensible interface with multiple panes, terminal, text editor, and more

## 8.5 Note on Python vs. Python3 Command

The command used to invoke Python (`python` vs. `python3`) varies across systems:

#### System-Dependent Behavior:

- **Modern Systems:** `python` typically refers to Python 3
- **Legacy Systems:** `python` might still refer to Python 2
- **Safe Approach:** Use `python3` to explicitly invoke Python 3

**PEP 394:** Python Enhancement Proposal 394 provides guidelines on this topic:

<https://peps.python.org/pep-0394/>

#### Checking Your System:

```

1 python --version    # Check what 'python' refers to
2 python3 --version   # Check Python 3 version

```

## 9 Getting Help in Python

Python includes a comprehensive built-in help system, making it easy to learn about functions, classes, and modules without leaving the interpreter.

### 9.1 The `help()` Function

The `help()` function provides interactive access to Python's documentation:

#### General Help:

```

1 >>> help()
2 Welcome to Python 3.10's help utility!
3 ...
4 help> quit

```

Listing 27: Starting the interactive help system

### Help on Specific Objects:

```

1 >>> help(int)
2 Help on class int in module builtins:
3
4 class int(object)
5 |   int([x]) -> integer
6 |   int(x, base=10) -> integer
7 |
8 |   Convert a number or string to an integer...
9   ...
10
11 >>> help(print)
12 Help on built-in function print in module builtins:
13
14 print(...)
15     print(value, ..., sep=' ', end='\n', file=sys.stdout, flush=False)
16
17     Prints the values to a stream, or to sys.stdout by default.
18     ...
19
20 >>> import math
21 >>> help(math.sqrt)
22 Help on built-in function sqrt in module math:
23
24 sqrt(x, /)
25     Return the square root of x.

```

Listing 28: Getting help on specific objects

### What help() Shows:

- Function signatures (parameters and return types)
- Docstrings (documentation written by developers)
- Available methods and attributes
- Usage examples (if provided)

## 9.2 IPython's Enhanced Help

IPython provides an even more convenient help system:

### Quick Help:

```

1 In [1]: import numpy as np
2
3 # Append ? for quick help
4 In [2]: np.sqrt?
5 Signature: np.sqrt(x, /, out=None, *, where=True, ...)
6 Docstring:
7 Return the non-negative square-root of an array, element-wise.
8 ...
9

```

```

10 # Append ?? for source code
11 In [3]: np.sqrt??
12 Signature: np.sqrt(x, /, out=None, *, where=True, ...)
13 Source:
14 # C function - source not available
15
16 # Tab completion for methods
17 In [4]: np.arr<Tab>
18 np.array      np.array_equal    np.array_repr
19 np.array_api  np.array_equiv    np.array_split

```

Listing 29: IPython's help shortcuts

### 9.3 Online Documentation

While built-in help is convenient, online documentation often provides more comprehensive information:

- **Official Python Docs:** <https://docs.python.org/3/>
- **Library References:** Each major package has detailed documentation
- **Stack Overflow:** Community Q&A for specific problems
- **Real Python:** Tutorials and guides

## 10 Python Syntax Fundamentals

Now that we understand Python's ecosystem and execution environments, let's dive into the language's syntax and fundamental programming constructs.

### 10.1 A First Complete Example

Let's examine a complete Python program that demonstrates several key syntactic features:

```

1 x = 11/3 - 9//2 # this is a comment
2 y = "Hola"
3 z = 3.14        # another comment
4
5 if y == "Hola" or z >= 3:
6     x = x + 2
7     y = y + " mundo!" # string concatenation
8
9 print(y)
10 print(f"{x = :5.3f}") # f-string formatting
11
12 year, month, day = 1943, 6, 15
13 hour, minute, second = 23, 6, 54
14
15 if 1900 < year < 2100 and 1 <= month <= 12 \
16     and 1 <= day <= 31 and 0 <= hour < 24 \
17     and 0 <= minute < 60 and 0 <= second < 60:
18     print("Looks like a valid date!",
19           "Indeed!")

```

Listing 30: A comprehensive Python syntax example

### Syntactic Elements Demonstrated:

1. **Comments:** Lines beginning with # are ignored by Python
2. **Dynamic Typing:** Variables don't require type declarations
3. **Operators:**
  - / performs floating-point division ( $11/3 = 3.666\dots$ )
  - // performs floor division ( $9//2 = 4$ )
4. **Conditional Statements:** if blocks with Boolean expressions
5. **Logical Operators:** or, and, comparison operators
6. **Indentation:** Code blocks are defined by indentation (4 spaces is standard)
7. **String Operations:** Concatenation with +
8. **Formatted Output:** f-strings for flexible string formatting
9. **Multiple Assignment:** Assign several variables in one statement
10. **Chained Comparisons:** `1900 < year < 2100` is valid Python
11. **Line Continuation:** Backslash (\) continues long lines
12. **Implicit Line Joining:** Lines can continue inside parentheses without backslash

### Output:

```
1 Hola mundo!
2 x = 1.667
3 Looks like a valid date! Indeed!
```

## 10.2 Comments

Comments are text that Python ignores, used to document code for human readers.

### Single-Line Comments:

```
1 # This is a comment
2 x = 5 # This is also a comment (following code)
```

Listing 31: Single-line comments in Python

**Multi-Line Comments:** Python doesn't have a specific multi-line comment syntax, but multi-line strings can serve this purpose:

```
1 """
2 This is a multi-line comment.
3 It can span multiple lines.
4 It's technically a string, but if not assigned,
5 it's ignored by Python.
6 """
```

```

7
8 '''
9 Single quotes work too for multi-line strings.
10 '''

```

Listing 32: Multi-line comments using triple-quoted strings

#### Best Practices:

- Use comments to explain *why*, not *what*
- Keep comments up-to-date with code changes
- Avoid obvious comments (`# increment x for x += 1`)
- Use docstrings (covered later) for function/class documentation

### 10.3 Line Continuation

Python statements typically end at the line's end, but long statements can be continued across lines:

#### Explicit Continuation (Backslash):

```

1 total = 1 + 2 + 3 + \
2         4 + 5 + 6 + \
3         7 + 8 + 9
4
5 # Conditional spanning multiple lines
6 if condition1 and condition2 \
7     and condition3:
8     print("All conditions met")

```

Listing 33: Explicit line continuation with backslash

**Implicit Continuation (Inside Delimiters):** Lines automatically continue inside parentheses, brackets, and braces:

```

1 # Inside parentheses (preferred method)
2 total = (1 + 2 + 3 +
3         4 + 5 + 6 +
4         7 + 8 + 9)
5
6 # Function call with many arguments
7 result = some_function(arg1, arg2,
8                        arg3, arg4,
9                        arg5, arg6)
10
11 # List spanning multiple lines
12 numbers = [1, 2, 3,
13            4, 5, 6,
14            7, 8, 9]
15
16 # Print with multiple arguments
17 print("This is a long message",
18       "that spans multiple lines",
19       "without needing backslashes")

```

Listing 34: Implicit line continuation inside delimiters

**Best Practice:** Prefer implicit continuation (using parentheses) over explicit continuation (backslashes), as it's cleaner and less error-prone.

## 11 Basic Built-In Data Types

Python provides several built-in data types that form the foundation of all Python programs.

### 11.1 Boolean Type

Booleans represent truth values:

```
1 x = True    # Note: Capital T
2 y = False   # Note: Capital F
3
4 # Boolean operations
5 a = True and False # False
6 b = True or False  # True
7 c = not True       # False
8
9 # Comparison operations return booleans
10 d = 5 > 3          # True
11 e = 10 == 10       # True
12 f = "hello" != "world" # True
```

Listing 35: Boolean values in Python

#### Key Points:

- Must be capitalized: True and False, not true and false
- Different from C++, where true and false are lowercase
- Many values are "truthy" or "falsy" when used in Boolean contexts

#### Truthiness in Python:

```
1 # Falsy values (evaluate to False in boolean context)
2 bool(0)          # False
3 bool(0.0)        # False
4 bool("")         # False (empty string)
5 bool([])         # False (empty list)
6 bool({})        # False (empty dictionary)
7 bool(None)       # False
8
9 # Truthy values (evaluate to True)
10 bool(1)          # True
11 bool(-1)         # True
12 bool("hello")    # True (non-empty string)
13 bool([1, 2])     # True (non-empty list)
```

Listing 36: Truthy and falsy values

### 11.2 Integer Type

Integers are whole numbers without size limits in Python 3:

```
1 x = 1
2 y = 42
3 z = -17
4
5 # Python integers have arbitrary precision
6 big = 12345678901234567890123456789012345678901234567890
```



```

7 bigger = big ** 2 # No overflow!
8
9 # Common operations
10 addition = 5 + 3 # 8
11 subtraction = 5 - 3 # 2
12 multiplication = 5 * 3 # 15
13 division = 5 / 3 # 1.6666... (float result)
14 floor_division = 5 // 3 # 1 (integer result, rounded down)
15 modulo = 5 % 3 # 2 (remainder)
16 power = 2 ** 10 # 1024
17
18 # Different number bases
19 binary = 0b1010 # 10 in decimal
20 octal = 0o12 # 10 in decimal
21 hexadecimal = 0xA # 10 in decimal

```

Listing 37: Integer operations in Python

#### Important Differences from C++:

- **No Size Limits:** Python 3 integers grow as needed (no overflow)
- **Division Behavior:** / always returns float; use // for integer division
- **No Type Variants:** No separate short, long, long long, etc.

## 11.3 Floating-Point Type

Floats represent decimal numbers:

```

1 x = 1.0 # Float with decimal point
2 y = 1. # Also valid
3 z = .5 # Also valid (0.5)
4
5 # Scientific notation
6 a = 1e0 # 1.0
7 b = 1.5e3 # 1500.0
8 c = 2e-4 # 0.0002
9 d = 3.14E2 # 314.0 (capital E also works)
10
11 # Float operations
12 result = 0.1 + 0.2 # 0.30000000000000004 (floating-point imprecision!)
13
14 # Mathematical functions (requires import math)
15 import math
16 root = math.sqrt(2.0) # 1.414...
17 sine = math.sin(math.pi) # ~0 (numerical approximation)

```

Listing 38: Floating-point numbers in Python

#### Key Points:

- Python floats typically map to C's double (64-bit, double precision)
- Subject to floating-point imprecision (cannot exactly represent all decimals)
- Scientific notation uses e or E for powers of 10

#### Floating-Point Caution:

```

1 # Dangerous: direct equality comparison
2 if 0.1 + 0.2 == 0.3: # This may be False!

```

```

3     print("Equal")
4
5 # Better: compare with tolerance
6 tolerance = 1e-9
7 if abs((0.1 + 0.2) - 0.3) < tolerance:
8     print("Approximately equal")
9
10 # Or use math.isclose() (Python 3.5+)
11 import math
12 if math.isclose(0.1 + 0.2, 0.3):
13     print("Close enough")

```

Listing 39: Floating-point comparison pitfalls

## 11.4 Complex Numbers

Python has built-in support for complex numbers:

```

1 # Creating complex numbers (j or J for imaginary unit)
2 z1 = 1 + 1j
3 z2 = 2 + 3j
4 z3 = complex(4, 5) # Alternative: 4 + 5j
5
6 # Operations
7 sum = z1 + z2      # (3+4j)
8 product = z1 * z2  # (-1+5j)
9 power = 1j ** 2    # (-1+0j) = -1
10
11 # Accessing components
12 real_part = z1.real      # 1.0
13 imag_part = z1.imag      # 1.0
14 conjugate = z1.conjugate() # (1-1j)
15
16 # Magnitude
17 import math
18 magnitude = abs(z1) # sqrt(1^2 + 1^2) = sqrt(2)

```

Listing 40: Complex number operations

**Mathematical Notation:** Python uses  $j$  (or  $J$ ) for  $\sqrt{-1}$ , following electrical engineering convention, rather than the mathematical  $i$ .

## 11.5 String Type

Strings represent text and are immutable sequences of characters:

**Creating Strings:**

```

1 # Single quotes
2 s1 = 'string'
3
4 # Double quotes (equivalent to single quotes)
5 s2 = "string"
6
7 # Choosing quotes based on content
8 s3 = "Hello! I'm a string!" # Contains single quote
9 s4 = 'Hi! I\'m "another" string!' # Escaping quotes

```

```

10
11 # Triple quotes for multi-line strings
12 s5 = """String spanning
13 multiple lines
14 with preserved formatting"""
15
16 s6 = '''Single quotes
17 also work for
18 multi-line strings'''

```

Listing 41: Various ways to create strings

### String Operations:

```

1 # Concatenation
2 greeting = "Hello" + " " + "World" # "Hello World"
3
4 # Repetition
5 repeated = "Ha" * 3 # "HaHaHa"
6
7 # Length
8 length = len("hello") # 5
9
10 # Indexing (zero-based)
11 first = "Python"[0] # 'P'
12 last = "Python"[-1] # 'n'
13
14 # Slicing
15 substring = "Python"[0:4] # "Pyth"
16
17 # Methods
18 upper = "hello".upper() # "HELLO"
19 lower = "HELLO".lower() # "hello"
20 stripped = " text ".strip() # "text"
21 replaced = "hello".replace("l", "L") # "heLLo"
22 split = "a,b,c".split(",") # ['a', 'b', 'c']

```

Listing 42: Common string operations

### Escape Sequences:

```

1 newline = "Line 1\nLine 2" # Newline character
2 tab = "Column1\tColumn2" # Tab character
3 backslash = "Path\\to\\file" # Literal backslash
4 quote = "She said \"Hello\"" # Escaped quote
5 unicode = "\u03B1" # Unicode character ( )
6
7 # Raw strings (no escape processing)
8 path = r"C:\new\folder" # Backslashes treated literally

```

Listing 43: Common escape sequences in strings

### String Immutability:

```

1 s = "hello"
2 s[0] = "H" # TypeError: 'str' object does not support item assignment
3
4 # Instead, create a new string
5 s = "H" + s[1:] # "Hello"

```

Listing 44: Strings cannot be modified in-place

**String Encoding:** Python 3 strings are Unicode by default, supporting characters from any language:

```
1 chinese = "      "
2 arabic = "      "
3 emoji = "      "
4 mixed = "Hello,      " # Mix languages freely
```

Listing 45: Unicode support in Python 3 strings

## 12 Operators and Expressions

Python provides a rich set of operators for performing calculations and comparisons.

### 12.1 Arithmetic Operators

```
1 # Basic operations
2 addition = 5 + 7          # 12
3 subtraction = 5 - 2      # 3
4 multiplication = 5 * 7   # 35
5
6 # Division always returns float
7 true_division = 5 / 2    # 2.5
8
9 # Floor division returns integer (rounds down)
10 floor_division = 5 // 2  # 2
11 negative_floor = -5 // 2 # -3 (rounds toward negative infinity)
12
13 # Modulo (remainder)
14 modulo = 5 % 2           # 1
15 modulo2 = 17 % 5         # 2
16
17 # Exponentiation (power)
18 power = 3 ** 4           # 81 (3^4)
19 square_root = 9 ** 0.5   # 3.0 (sqrt using fractional exponent)
20
21 # Complex number operations
22 complex_power = (1j) ** 2 # (-1+0j)
```

Listing 46: Arithmetic operations in Python

**Operator Precedence:** (highest to lowest)

1. Parentheses: `()`
2. Exponentiation: `**`
3. Unary plus/minus: `+x`, `-x`
4. Multiplication, division: `*`, `/`, `//`, `%`
5. Addition, subtraction: `+`, `-`

```

1 result1 = 2 + 3 * 4      # 14 (not 20)
2 result2 = (2 + 3) * 4    # 20
3 result3 = 2 ** 3 ** 2    # 512 (2^(3^2), right-associative)
4 result4 = (2 ** 3) ** 2  # 64

```

Listing 47: Operator precedence examples

## 12.2 Using the Math Module

For more advanced mathematical operations, import the `math` module:

```

1 import math
2
3 # Constants
4 pi = math.pi      # 3.141592653589793
5 e = math.e         # 2.718281828459045
6
7 # Roots and powers
8 sqrt_2 = math.sqrt(2.0)      # 1.4142135623730951
9 cube_root = 8 ** (1/3)       # 2.0 (or math.pow(8, 1/3))
10
11 # Trigonometric functions (angles in radians)
12 sine = math.sin(math.pi)     # ~0 (numerical approximation)
13 cosine = math.cos(0)         # 1.0
14 tangent = math.tan(math.pi/4) # ~1.0
15
16 # Logarithms
17 natural_log = math.log(math.e) # 1.0 (ln)
18 log_base_10 = math.log10(100)  # 2.0
19 log_base_2 = math.log2(8)      # 3.0
20
21 # Rounding
22 ceiling = math.ceil(4.3)      # 5
23 floor = math.floor(4.7)      # 4
24
25 # Absolute value and sign
26 absolute = math.fabs(-5.5)    # 5.5
27 absolute2 = abs(-5)           # 5 (built-in, works with integers too)

```

Listing 48: Mathematical functions from the `math` module

## 12.3 Random Number Generation

The `random` module provides functions for generating random numbers:

```

1 import random
2
3 # Random float in [0.0, 1.0)
4 r1 = random.random()
5
6 # Random integer in range [a, b] (inclusive)
7 r2 = random.randint(1, 10) # Integer from 1 to 10
8
9 # Random float in range [a, b)
10 r3 = random.uniform(0.0, 10.0)
11

```

```

12 # Random choice from a sequence
13 color = random.choice(['red', 'green', 'blue'])
14
15 # Shuffle a list in-place
16 deck = list(range(52))
17 random.shuffle(deck)
18
19 # Random sample without replacement
20 sample = random.sample(range(100), 5) # 5 unique numbers
21
22 # Set seed for reproducibility
23 random.seed(42) # Same seed produces same sequence

```

Listing 49: Random number generation

**Scope and Modules:** When importing modules, access their contents using the dot operator:

```

1 import math
2 import random
3
4 # Access with module.member syntax
5 result1 = math.sqrt(16) # math is the module, sqrt is the
    function
6 result2 = random.random() # random is the module, random is the
    function
7
8 # Alternative: import specific items
9 from math import sqrt, pi
10 result3 = sqrt(16) # Can use directly without module prefix
11
12 # Import with alias
13 import numpy as np
14 arr = np.array([1, 2, 3]) # np is the alias for numpy

```

Listing 50: Module scope and the dot operator

## 13 Compound Data Types: Lists

Lists are one of Python's most versatile and commonly used data structures. They are ordered, mutable sequences that can contain elements of any type.

### 13.1 Creating and Accessing Lists

```

1 # Creating lists with square brackets
2 x = [0, 1, 2, 3, 3]
3
4 # Zero-based indexing
5 first = x[0] # 0
6 second = x[1] # 1
7 third = x[2] # 2
8
9 # Negative indexing (from the end)
10 last = x[-1] # 3 (last element)

```

```

11 second_last = x[-2] # 3 (second-to-last)
12
13 # Length of list
14 size = len(x) # 5
15
16 # Lists can contain mixed types
17 mixed = [0, 1, 2, 'three'] # integers and string
18 nested = [1, [2, 3], 4] # list within list

```

Listing 51: Creating and accessing Python lists

**Why Negative Indexing?** Negative indices provide a convenient way to access elements from the end without knowing the list's length:

```

1 numbers = [10, 20, 30, 40, 50]
2
3 # Without negative indexing
4 last = numbers[len(numbers) - 1] # 50 (verbose)
5
6 # With negative indexing
7 last = numbers[-1] # 50 (concise)

```

Listing 52: Comparing positive and negative indexing

## 13.2 Modifying Lists

Lists are mutable, meaning their contents can be changed:

```

1 x = [0, 1, 2, 3, 4]
2
3 # Modify element
4 x[2] = 99 # x = [0, 1, 99, 3, 4]
5
6 # Insert at specific position
7 x.insert(0, -1) # x = [-1, 0, 1, 99, 3, 4]
8
9 # Append to end
10 x.append(5) # x = [-1, 0, 1, 99, 3, 4, 5]
11
12 # Remove by index (returns removed value)
13 removed = x.pop(3) # removes 99, returns 99
14 # x = [-1, 0, 1, 3, 4, 5]
15
16 # Remove by value (first occurrence)
17 x.remove(3) # x = [-1, 0, 1, 4, 5]
18
19 # Extend list with another list
20 x.extend([6, 7]) # x = [-1, 0, 1, 4, 5, 6, 7]
21
22 # Clear all elements
23 x.clear() # x = []

```

Listing 53: Modifying list contents

## 13.3 List Concatenation and Repetition

```

1 # Concatenation with +
2 list1 = [1, 2, 3]
3 list2 = [4, 5, 6]
4 combined = list1 + list2 # [1, 2, 3, 4, 5, 6]
5
6 # In-place concatenation with +=
7 x = [0, 1, 2, 'three']
8 x += [4, 5, 6] # x = [0, 1, 2, 'three', 4, 5, 6]
9
10 # Repetition with *
11 repeated = [0] * 5 # [0, 0, 0, 0, 0]
12 pattern = [1, 2] * 3 # [1, 2, 1, 2, 1, 2]

```

Listing 54: List concatenation and repetition

### 13.4 List Slicing

Slicing extracts portions of a list, creating a new list:

**Syntax:** `list[start:stop:step]`

- start: Starting index (inclusive)
- stop: Ending index (exclusive - not included!)
- step: Step size (optional, default 1)

```

1 x = [0, 1, 2, 'three', 4, 5, 6]
2
3 # Basic slicing [start:stop]
4 slice1 = x[1:4] # [1, 2, 'three'] (indices 1, 2, 3)
5
6 # From start to position
7 slice2 = x[:3] # [0, 1, 2] (omit start = begin from 0)
8
9 # From position to end
10 slice3 = x[1:] # [1, 2, 'three', 4, 5, 6] (omit stop = until end)
11
12 # Slice from end
13 slice4 = x[:-1] # [0, 1, 2, 'three', 4, 5] (all but last)
14 slice5 = x[-3:] # [4, 5, 6] (last three)
15
16 # Slicing with step [start:stop:step]
17 slice6 = x[::2] # [0, 2, 4, 6] (every second element)
18 slice7 = x[1::2] # [1, 'three', 5] (every second, starting at 1)
19
20 # Negative step (reverse)
21 slice8 = x[::-1] # [6, 5, 4, 'three', 2, 1, 0] (reversed)
22 slice9 = x[::-2] # [6, 4, 2, 0] (reversed, every second)
23
24 # Complex slicing
25 slice10 = x[1:6:2] # [1, 'three', 5] (from 1 to 5, step 2)

```

Listing 55: List slicing operations

**Key Insight:** The stop index is always exclusive. Think of slice indices as pointing between elements:



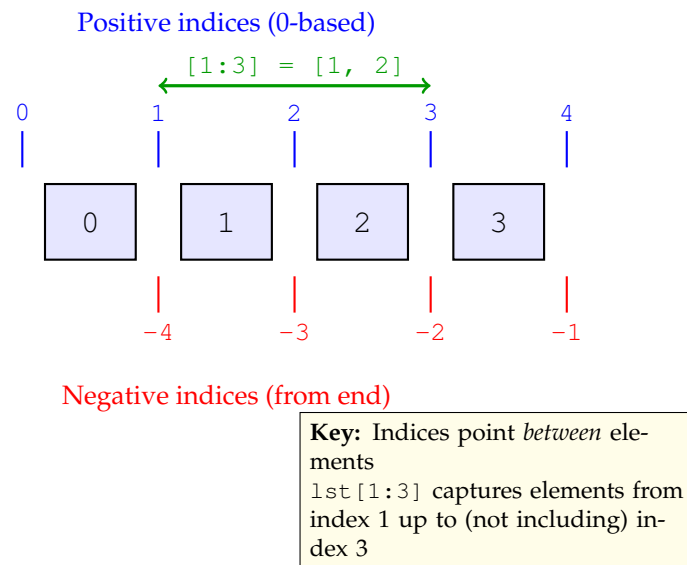


Figure 4: Visualization of list indexing: indices point between elements. For a list `[0, 1, 2, 3]`, index positions are at 0, 1, 2, 3, 4, with the slice `[1:3]` capturing elements between positions 1 and 3 (elements 1 and 2).

**Guido van Rossum’s Explanation:** Python’s creator explained the rationale for slice semantics on Stack Overflow (<https://stackoverflow.com/a/21481885>):

- Makes `len(s[a:b]) == b-a` when valid
- Easy to split at position: `s[:n] + s[n:] == s`
- Makes `s[:n]` and `s[n:]` complementary

### 13.5 Common List Operations

```

1 numbers = [3, 1, 4, 1, 5, 9, 2, 6]
2
3 # Check membership
4 contains = 4 in numbers # True
5 not_contains = 7 not in numbers # True
6
7 # Count occurrences
8 count = numbers.count(1) # 2
9
10 # Find index of first occurrence
11 index = numbers.index(4) # 2
12
13 # Sort list in-place
14 numbers.sort() # numbers = [1, 1, 2, 3, 4, 5, 6, 9]
15
16 # Sort in reverse
17 numbers.sort(reverse=True) # [9, 6, 5, 4, 3, 2, 1, 1]
18
19 # Return sorted copy (original unchanged)
20 original = [3, 1, 4]

```

```

21 sorted_copy = sorted(original) # [1, 3, 4]
22 # original is still [3, 1, 4]
23
24 # Reverse list in-place
25 numbers.reverse() # Reverses order
26
27 # Min, max, sum
28 minimum = min(numbers) # Smallest value
29 maximum = max(numbers) # Largest value
30 total = sum(numbers) # Sum of all elements
31
32 # Copy a list
33 shallow_copy = numbers.copy() # or numbers[:]

```

Listing 56: Additional list operations and methods

## 14 Tuples: Immutable Sequences

Tuples are similar to lists but with one crucial difference: they are immutable.

### 14.1 Creating and Using Tuples

```

1 # Create tuple with parentheses
2 t = (1, 2, 3)
3
4 # Access elements (same as lists)
5 first = t[0] # 1
6 last = t[-1] # 3
7
8 # Slicing works too
9 slice_t = t[1:] # (2, 3)
10
11 # Tuples can contain mixed types
12 mixed = (1, "two", 3.0, [4, 5])
13
14 # Single element tuple (note the comma!)
15 single = (1,) # Tuple with one element
16 not_tuple = (1) # This is just an integer with parentheses
17
18 # Tuple without parentheses (tuple packing)
19 coords = 3, 4, 5 # Creates tuple (3, 4, 5)
20
21 # Empty tuple
22 empty = ()
23 empty2 = tuple()

```

Listing 57: Creating and using tuples

### 14.2 Tuple Immutability

The defining characteristic of tuples is that they cannot be modified after creation:

```

1 t = (1, 2, 3)
2
3 # Attempting modification causes error
4 t[1] = 99 # TypeError: 'tuple' object does not support item
    assignment
5
6 # Also cannot append, insert, remove, etc.
7 t.append(4) # AttributeError: 'tuple' object has no attribute 'append'
8
9 # Can create new tuple by concatenation
10 new_t = t + (4, 5) # (1, 2, 3, 4, 5) (new tuple, original unchanged)

```

Listing 58: Tuples are immutable

**Important Subtlety:** While tuples themselves are immutable, they can contain mutable objects:

```

1 t = (1, 2, [3, 4])
2
3 # Cannot replace the list
4 t[2] = [5, 6] # TypeError
5
6 # But can modify the list in-place
7 t[2].append(5) # Works! t = (1, 2, [3, 4, 5])

```

Listing 59: Tuples containing mutable objects

### 14.3 When to Use Tuples vs. Lists

#### Use Tuples When:

- Data shouldn't change (coordinates, RGB colors, database records)
- Need to use as dictionary keys (lists can't be keys)
- Want to convey intent that data is fixed
- Slight performance advantage (tuples are faster)
- Unpacking multiple values from functions

#### Use Lists When:

- Data will change over time
- Need to add/remove elements
- Need mutability for algorithms (sorting, filtering)

### 14.4 Tuple Packing and Unpacking

One of tuples' most powerful features is automatic packing and unpacking:

```

1 # Tuple packing (creating tuple without parentheses)
2 coords = 3, 4, 5 # Creates (3, 4, 5)
3
4 # Tuple unpacking (multiple assignment)
5 x, y, z = coords # x=3, y=4, z=5
6
7 # Swap variables elegantly
8 a = 1
9 b = 2

```

```

10 a, b = b, a # Swaps values (no temp variable needed!)
11
12 # Function returning multiple values (actually returns tuple)
13 def get_dimensions():
14     return 1920, 1080 # Returns tuple
15
16 width, height = get_dimensions() # Unpack return value
17
18 # Unpacking with * (Python 3.0+)
19 first, *middle, last = [1, 2, 3, 4, 5]
20 # first = 1, middle = [2, 3, 4], last = 5

```

Listing 60: Tuple packing and unpacking

## 15 Dictionaries: Key-Value Mappings

Dictionaries are unordered collections of key-value pairs, similar to hash maps or associative arrays in other languages.

### 15.1 Creating Dictionaries

```

1 # Method 1: dict() constructor with keyword arguments
2 d1 = dict(a=1, b=2, c='three')
3
4 # Method 2: Dictionary literal with braces
5 d2 = {'a': 1, 'b': 2, 'c': 'three'}
6
7 # Method 3: From list of tuples
8 d3 = dict([('a', 1), ('b', 2), ('c', 'three')])
9
10 # Method 4: Dictionary comprehension (covered later)
11 d4 = {x: x**2 for x in range(5)} # {0:0, 1:1, 2:4, 3:9, 4:16}
12
13 # Empty dictionary
14 empty = {}
15 empty2 = dict()
16
17 # Keys can be any hashable type
18 mixed_keys = {
19     'string_key': 1,
20     42: 'integer key',
21     (1, 2): 'tuple key',
22     frozenset([1, 2]): 'frozen set key'
23 }

```

Listing 61: Creating dictionaries

### 15.2 Accessing and Modifying Dictionaries

```

1 person = {'name': 'Alice', 'age': 30, 'city': 'New York'}
2
3 # Access values by key

```

```

4 name = person['name'] # 'Alice'
5
6 # Safe access with get() (returns None if key missing)
7 country = person.get('country') # None (no KeyError)
8 country = person.get('country', 'USA') # 'USA' (default value)
9
10 # Check if key exists
11 has_name = 'name' in person # True
12 has_country = 'country' in person # False
13
14 # Add new key-value pair
15 person['email'] = 'alice@example.com'
16
17 # Modify existing value
18 person['age'] = 31
19
20 # Remove key-value pair
21 removed = person.pop('city') # Returns 'New York', removes from dict
22 # Or use del
23 del person['email']
24
25 # Remove with default if key doesn't exist
26 value = person.pop('nonexistent', 'default') # Returns 'default'
27
28 # Get keys, values, items
29 keys = person.keys() # dict_keys(['name', 'age'])
30 values = person.values() # dict_values(['Alice', 31])
31 items = person.items() # dict_items([('name', 'Alice'), ('age', 31)])
32
33 # Update dictionary with another dictionary
34 person.update({'city': 'Boston', 'country': 'USA'})
35
36 # Clear all entries
37 person.clear()

```

Listing 62: Dictionary operations

## 15.3 Iterating Over Dictionaries

```

1 grades = {'Alice': 90, 'Bob': 85, 'Charlie': 92}
2
3 # Iterate over keys (default)
4 for student in grades:
5     print(student) # Alice, Bob, Charlie
6
7 # Explicitly iterate over keys
8 for student in grades.keys():
9     print(student)
10
11 # Iterate over values
12 for grade in grades.values():
13     print(grade) # 90, 85, 92
14
15 # Iterate over key-value pairs (most common)
16 for student, grade in grades.items():

```

```

17 print(f"{student}: {grade}")
18 # Alice: 90
19 # Bob: 85
20 # Charlie: 92

```

Listing 63: Iterating over dictionaries

## 15.4 Dictionary Constraints

### Key Requirements:

- **Hashable:** Keys must be immutable types (strings, numbers, tuples)
- **Unique:** Each key can appear only once
- **No Lists:** Lists cannot be keys (they're mutable)

```

1 # Valid keys
2 valid = {
3     'string': 1,
4     42: 2,
5     (1, 2): 3,
6     3.14: 4
7 }
8
9 # Invalid keys
10 invalid = {
11     [1, 2]: 'value' # TypeError: unhashable type: 'list'
12 }
13
14 # But lists can be values
15 valid_values = {
16     'key1': [1, 2, 3],
17     'key2': {'nested': 'dict'}
18 }

```

Listing 64: Valid and invalid dictionary keys

## 15.5 Dictionary Ordering

### Historical Note:

- **Python < 3.7:** Dictionaries had no guaranteed order
- **Python 3.7+:** Dictionaries maintain insertion order as a language feature

```

1 # Python 3.7+: Order is preserved
2 d = {}
3 d['first'] = 1
4 d['second'] = 2
5 d['third'] = 3
6
7 for key in d:
8     print(key) # Always prints: first, second, third (in order)

```

Listing 65: Dictionary ordering in modern Python

## 16 Mutability: A Fundamental Concept

Understanding mutability is crucial for mastering Python's behavior, especially when working with functions and data structures.

### 16.1 Defining Mutability

**Mutable Objects:** Objects whose contents can be changed after creation:

- Lists: [1, 2, 3]
- Dictionaries: {'a': 1}
- Sets: {1, 2, 3}
- User-defined classes (usually)

**Immutable Objects:** Objects whose contents cannot be changed after creation:

- Numbers: int, float, complex
- Strings: "hello"
- Tuples: (1, 2, 3)
- Frozen sets: frozenset({1, 2})
- Booleans: True, False
- None

### 16.2 Demonstrating Mutability

```
1 # Mutable: Lists
2 lst = [1, 2, 3]
3 lst[0] = 99      # Modifies the list in-place
4 lst.append(4)    # Adds to existing list
5 print(lst)       # [99, 2, 3, 4]
6
7 # Immutable: Strings
8 s = "hello"
9 s[0] = "H"       # TypeError: 'str' object does not support item
                  # assignment
10
11 # With strings, you must create new objects
12 s = "H" + s[1:]  # Creates new string "Hello"
13
14 # Immutable: Tuples
15 t = (1, 2, 3)
16 t[0] = 99       # TypeError: 'tuple' object does not support item
                  # assignment
17
18 # Immutable: Numbers
19 x = 5
20 x += 1          # Creates new integer object 6, rebinds x to it
```

Listing 66: Mutable vs immutable behavior

### 16.3 Why Mutability Matters

**Performance:**

- Mutable objects can be modified efficiently without creating copies

- Immutable objects require creating new objects for any "change"

#### Safety:

- Immutable objects are safer in concurrent programs (no race conditions)
- Immutable objects can be dictionary keys and set members

#### Semantics:

- Mutability affects how objects behave when passed to functions (covered in detail later)
- Mutability affects aliasing and copying behavior

## 16.4 The Identity vs Equality Distinction

Python distinguishes between object identity and value equality:

```

1 # Equality: same value
2 a = [1, 2, 3]
3 b = [1, 2, 3]
4 print(a == b)      # True (same contents)
5 print(a is b)      # False (different objects)
6
7 # Identity: same object
8 c = a
9 print(a == c)      # True (same contents)
10 print(a is c)      # True (same object!)
11
12 # Modifying c affects a (they're the same object)
13 c.append(4)
14 print(a)           # [1, 2, 3, 4]
15
16 # Immutable objects: Python optimizes by reusing
17 x = 100
18 y = 100
19 print(x is y)      # True (Python reuses small integer objects)
20
21 # Strings too
22 s1 = "hello"
23 s2 = "hello"
24 print(s1 is s2)    # Often True (string interning)

```

Listing 67: Identity (is) vs equality (==)

#### Guidelines:

- Use == to compare values
- Use is to check if two names refer to the same object
- Use is None to check for None (by convention)

## 17 Control Flow: Conditional Statements

Control flow structures allow programs to make decisions and execute different code based on conditions.

### 17.1 The if Statement

#### Syntax:



```

1 if condition:
2     # Code executes if condition is True
3     statement1
4     statement2

```

Listing 68: Basic if statement syntax

### Example:

```

1 temperature = 25
2
3 if temperature > 30:
4     print("It's hot today!")
5     print("Drink plenty of water.")

```

Listing 69: Simple if statement

## 17.2 The if-else Statement

```

1 x = -5
2
3 if x < 0:
4     print("x is negative")
5 else:
6     print("x is non-negative")

```

Listing 70: if-else statement

## 17.3 The if-elif-else Statement

For multiple conditions, use `elif` (else-if):

```

1 score = 85
2
3 if score >= 90:
4     grade = 'A'
5     print("Excellent!")
6 elif score >= 80:
7     grade = 'B'
8     print("Good job!")
9 elif score >= 70:
10    grade = 'C'
11    print("Satisfactory")
12 elif score >= 60:
13    grade = 'D'
14    print("Need improvement")
15 else:
16    grade = 'F'
17    print("Failed")
18
19 print(f"Your grade: {grade}")

```

Listing 71: if-elif-else chain

### Key Points:

- Only the first True condition's block executes

- `elif` and `else` are optional
- Can have multiple `elif` blocks
- No limit on number of conditions

## 17.4 Comparison Operators

```

1 x = 10
2 y = 20
3
4 # Equality and inequality
5 x == y    # False (equal to)
6 x != y    # True (not equal to)
7
8 # Ordering
9 x < y     # True (less than)
10 x > y    # False (greater than)
11 x <= y   # True (less than or equal to)
12 x >= y   # False (greater than or equal to)
13
14 # Identity
15 x is y    # False (same object)
16 x is not y # True (different objects)
17
18 # Membership (for sequences)
19 'a' in 'abc'      # True
20 'x' not in 'abc'   # True
21 2 in [1, 2, 3]    # True

```

Listing 72: Comparison operators

## 17.5 Logical Operators

Combine multiple conditions:

```

1 age = 25
2 has_license = True
3
4 # and: Both must be True
5 if age >= 18 and has_license:
6     print("Can drive")
7
8 # or: At least one must be True
9 is_weekend = True
10 is_holiday = False
11
12 if is_weekend or is_holiday:
13     print("No work today!")
14
15 # not: Negates boolean
16 is_raining = False
17
18 if not is_raining:
19     print("Can go outside")
20
21 # Complex conditions

```

```

22 temperature = 28
23 humidity = 70
24
25 if (temperature > 25 and humidity > 60) or temperature > 35:
26     print("Uncomfortable weather")

```

Listing 73: Logical operators: and, or, not

## 17.6 Chained Comparisons

Python allows elegant chained comparisons:

```

1 x = 15
2
3 # Instead of:
4 if x > 10 and x < 20:
5     print("x is between 10 and 20")
6
7 # Python allows:
8 if 10 < x < 20:
9     print("x is between 10 and 20")
10
11 # Multiple chains
12 year = 2024
13 month = 3
14 day = 15
15
16 if 1900 < year < 2100 and 1 <= month <= 12 and 1 <= day <= 31:
17     print("Valid date range")
18
19 # Even works with different operators
20 a = 1
21 b = 2
22 c = 3
23
24 if a < b < c: # True
25     print("Ascending order")
26
27 if a < b == b < c: # Can mix operators
28     print("Complex chain")

```

Listing 74: Chained comparison operators

## 17.7 Indentation: Python's Block Structure

**Critical Rule:** Python uses indentation to define code blocks, not braces.

```

1 if condition:
2     # This is inside the if block (indented)
3     statement1
4     statement2
5 # This is outside the if block (not indented)
6 statement3

```

Listing 75: Indentation defines code structure

### Standard Convention:

- Use 4 spaces per indentation level
- Never mix tabs and spaces
- Configure your editor to insert spaces when Tab is pressed

### Nested Blocks:

```
1 x = 15
2 y = 20
3
4 if x > 10:
5     print("x is greater than 10")
6     if y > 15:
7         print("y is also greater than 15")
8         if x < y:
9             print("x is less than y")
10    print("Still in outer if block")
11 print("Outside all if blocks")
```

Listing 76: Nested indentation

### Why Indentation?

- **Enforces Readability:** Code is naturally formatted correctly
- **Reduces Clutter:** No need for braces
- **Prevents Errors:** Indentation errors are caught immediately
- **Consistency:** All Python code looks similar

## 18 Control Flow: Loops

Loops allow code to be executed repeatedly, either a specific number of times or while a condition remains true.

### 18.1 The while Loop

The while loop repeats as long as its condition is True:

#### Syntax:

```
1 while condition:
2     # Code block executes while condition is True
3     statements
```

Listing 77: while loop syntax

#### Example:

```
1 x = 0
2 while x < 5:
3     print(f"x = {x}")
4     x += 1
5
6 print("Loop finished")
7 # Output:
8 # x = 0
9 # x = 1
10 # x = 2
11 # x = 3
```

```

12 # x = 4
13 # Loop finished

```

Listing 78: Basic while loop

## 18.2 Loop Control: break and continue

**break:** Immediately exits the loop **continue:** Skips the rest of the current iteration and continues with the next

```

1 x = 0
2 while x < 10:
3     if x == 2:
4         x += 1
5         continue # Skip when x is 2
6
7     if x == 7:
8         break # Exit loop when x is 7
9
10    print(f"x = {x}")
11    x += 1
12
13 # Output:
14 # x = 0
15 # x = 1
16 # (skips 2)
17 # x = 3
18 # x = 4
19 # x = 5
20 # x = 6
21 # (breaks at 7)

```

Listing 79: break and continue in loops

### Common Use Cases:

```

1 # User input validation
2 while True:
3     password = input("Enter password: ")
4     if len(password) >= 8:
5         break
6     print("Password too short. Try again.")
7
8 # Process until sentinel value
9 while True:
10    value = input("Enter number (or 'quit'): ")
11    if value == 'quit':
12        break
13    process(value)
14
15 # Countdown
16 count = 10
17 while count > 0:
18    print(count)
19    count -= 1
20 print("Liftoff!")

```

Listing 80: Practical while loop examples

## 18.3 The for Loop: Iteration Over Sequences

Python's for loop is fundamentally different from C++'s. It's always a "for-each" or "range-based" loop that iterates over elements of a sequence.

**Syntax:**

```
1 for item in sequence:
2     # Code executes once for each item in sequence
3     statements
```

Listing 81: for loop syntax

**Iterating Over Lists:**

```
1 fruits = ['apple', 'banana', 'cherry']
2
3 for fruit in fruits:
4     print(f"I like {fruit}")
5
6 # Output:
7 # I like apple
8 # I like banana
9 # I like cherry
```

Listing 82: Iterating over list elements

**Iterating Over Strings:**

```
1 for letter in "Python":
2     print(letter)
3
4 # Output:
5 # P
6 # y
7 # t
8 # h
9 # o
10 # n
```

Listing 83: Iterating over string characters

**Iterating Over Mixed-Type Lists:**

```
1 mixed = [0, "a", 7, 1j]
2
3 for item in mixed:
4     print(f"Item: {item}, Type: {type(item).__name__}")
5
6 # Output:
7 # Item: 0, Type: int
8 # Item: a, Type: str
9 # Item: 7, Type: int
10 # Item: 1j, Type: complex
```

Listing 84: Iterating over mixed-type sequences

## 18.4 The range() Function

For iterating over numbers, Python provides the `range()` function:

**Syntax:**

- `range(stop)`: Numbers from 0 to stop-1
- `range(start, stop)`: Numbers from start to stop-1
- `range(start, stop, step)`: Numbers from start to stop-1, incrementing by step

```

1 # range(stop)
2 for i in range(5):
3     print(i) # 0, 1, 2, 3, 4
4
5 # range(start, stop)
6 for i in range(2, 6):
7     print(i) # 2, 3, 4, 5
8
9 # range(start, stop, step)
10 for i in range(0, 10, 2):
11     print(i) # 0, 2, 4, 6, 8
12
13 # Negative step (counting down)
14 for i in range(10, 0, -1):
15     print(i) # 10, 9, 8, ..., 1
16
17 # range() is memory efficient (doesn't create list)
18 big_range = range(1000000) # Uses constant memory

```

Listing 85: Using `range()` for numeric iteration

## 18.5 Iterating with Indices

When you need both the index and the element:

**Method 1: Using `range()` and `len()`:**

```

1 fruits = ['apple', 'banana', 'cherry']
2
3 for i in range(len(fruits)):
4     print(f"Index {i}: {fruits[i]}")
5
6 # Output:
7 # Index 0: apple
8 # Index 1: banana
9 # Index 2: cherry

```

Listing 86: Iterating with indices using `range()`

**Method 2: Using `enumerate()` (Preferred):**

```

1 fruits = ['apple', 'banana', 'cherry']
2
3 for i, fruit in enumerate(fruits):
4     print(f"Index {i}: {fruit}")
5
6 # Start enumeration at different number
7 for i, fruit in enumerate(fruits, start=1):
8     print(f"Item {i}: {fruit}")
9
10 # Output:
11 # Item 1: apple
12 # Item 2: banana

```

```
13 # Item 3: cherry
```

### Listing 87: Iterating with enumerate() - Pythonic approach

#### Why enumerate() is Better:

- More Pythonic and readable
- Slightly more efficient
- Works with any iterable, not just sequences with len()
- Can specify starting index

## 18.6 Nested Loops

Loops can be nested to iterate over multi-dimensional data:

```
1 # Multiplication table
2 for i in range(1, 6):
3     for j in range(1, 6):
4         product = i * j
5         print(f"{i} {j} = {product:2d}", end=" ")
6     print() # New line after each row
7
8 # Nested iteration over 2D list
9 matrix = [
10     [1, 2, 3],
11     [4, 5, 6],
12     [7, 8, 9]
13 ]
14
15 for row in matrix:
16     for element in row:
17         print(element, end=" ")
18     print()
```

### Listing 88: Nested loop example

## 18.7 Loop else Clause

Python loops can have an else clause that executes if the loop completes normally (not via break):

```
1 # Search for element
2 numbers = [1, 3, 5, 7, 9]
3 target = 6
4
5 for num in numbers:
6     if num == target:
7         print(f"Found {target}!")
8         break
9 else:
10     # Executes only if loop didn't break
11     print(f"{target} not found in list")
12
13 # Practical example: checking primality
14 def is_prime(n):
15     if n < 2:
```



```

16         return False
17     for i in range(2, int(n**0.5) + 1):
18         if n % i == 0:
19             return False # Found divisor
20     else:
21         return True # No divisor found

```

Listing 89: Loop else clause

## 19 List and Dictionary Comprehensions

Comprehensions provide a concise way to create lists and dictionaries from existing iterables.

### 19.1 List Comprehensions

#### Syntax:

```

1 [expression for variable in iterable if condition]

```

Listing 90: List comprehension syntax

#### Basic Examples:

```

1 # Square numbers
2 numbers = [1, 2, 3, 4, 5]
3 squares = [x**2 for x in numbers]
4 # [1, 4, 9, 16, 25]
5
6 # Add 1 to each element
7 incremented = [x + 1 for x in numbers]
8 # [2, 3, 4, 5, 6]
9
10 # Convert to strings
11 str_numbers = [str(x) for x in numbers]
12 # ['1', '2', '3', '4', '5']

```

Listing 91: Basic list comprehensions

#### With Conditions:

```

1 numbers = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
2
3 # Only even numbers
4 evens = [x for x in numbers if x % 2 == 0]
5 # [2, 4, 6, 8, 10]
6
7 # Squares of odd numbers
8 odd_squares = [x**2 for x in numbers if x % 2 != 0]
9 # [1, 9, 25, 49, 81]
10
11 # Skip specific value
12 x = [1, 2, 3]
13 result = [val + 1 for val in x if val != 2]
14 # [2, 4]

```

Listing 92: List comprehensions with filtering

### Comparison with Traditional Approach:

```
1 # Traditional approach
2 result = []
3 for x in numbers:
4     if x % 2 == 0:
5         result.append(x**2)
6
7 # List comprehension (equivalent, more concise)
8 result = [x**2 for x in numbers if x % 2 == 0]
```

Listing 93: Comprehension vs traditional loop

### Complex Comprehensions:

```
1 # Nested loops
2 matrix = [[i*j for j in range(1, 4)] for i in range(1, 4)]
3 # [[1, 2, 3], [2, 4, 6], [3, 6, 9]]
4
5 # Flattening nested lists
6 nested = [[1, 2], [3, 4], [5, 6]]
7 flat = [item for sublist in nested for item in sublist]
8 # [1, 2, 3, 4, 5, 6]
9
10 # With function calls
11 words = ['hello', 'world', 'python']
12 uppercase = [word.upper() for word in words]
13 # ['HELLO', 'WORLD', 'PYTHON']
14
15 # Conditional expression (ternary operator)
16 numbers = [1, 2, 3, 4, 5]
17 labels = ['even' if x % 2 == 0 else 'odd' for x in numbers]
18 # ['odd', 'even', 'odd', 'even', 'odd']
```

Listing 94: Advanced list comprehensions

## 19.2 Dictionary Comprehensions

### Syntax:

```
1 {key_expression: value_expression for variable in iterable if
   condition}
```

Listing 95: Dictionary comprehension syntax

### Examples:

```
1 # Square mapping
2 squares_dict = {x: x**2 for x in range(1, 6)}
3 # {1: 1, 2: 4, 3: 9, 4: 16, 5: 25}
4
5 # From existing dictionary
6 prices = {'apple': 0.50, 'banana': 0.30, 'cherry': 0.75}
7
8 # Double all prices
9 doubled = {fruit: price * 2 for fruit, price in prices.items()}
10 # {'apple': 1.0, 'banana': 0.6, 'cherry': 1.5}
11
12 # Filter dictionary
```

```

13 expensive = {fruit: price for fruit, price in prices.items() if price
    > 0.40}
14 # {'apple': 0.5, 'cherry': 0.75}
15
16 # Transform keys and values
17 y = dict(x=1, y=2, z=3)
18 transformed = {key + '_a': val + 1 for key, val in y.items() if val !=
    3}
19 # {'x_a': 2, 'y_a': 3}
20
21 # Swap keys and values
22 inverted = {value: key for key, value in prices.items()}
23 # {0.5: 'apple', 0.3: 'banana', 0.75: 'cherry'}

```

Listing 96: Dictionary comprehensions

### 19.3 Set Comprehensions

Similar syntax for creating sets:

```

1 #Set of squares (duplicates automatically removed)
2 numbers = [1, 2, 2, 3, 3, 3, 4, 5]
3 unique_squares = {x**2 for x in numbers}
4 # {1, 4, 9, 16, 25}
5
6 # Characters in string (no duplicates)
7 letters = {char for char in "hello"}
8 # {'h', 'e', 'l', 'o'}

```

Listing 97: Set comprehensions

### 19.4 Generator Expressions

Use parentheses instead of brackets for memory-efficient iteration:

```

1 # List comprehension (creates entire list in memory)
2 squares_list = [x**2 for x in range(1000000)] # Uses lots of memory
3
4 # Generator expression (computes on-the-fly)
5 squares_gen = (x**2 for x in range(1000000)) # Uses constant memory
6
7 # Use in iteration
8 for square in squares_gen:
9     if square > 100:
10         break
11
12 # Use with functions that accept iterables
13 total = sum(x**2 for x in range(100)) # No brackets needed

```

Listing 98: Generator expressions

### 19.5 When to Use Comprehensions

Use Comprehensions When:

- Creating a new list/dict from an existing iterable

- Logic is simple and fits on one line
- Filtering and transforming data
- Makes code more readable

#### Use Traditional Loops When:

- Logic is complex or multi-step
- Need to handle exceptions
- Performing actions (not creating new collections)
- Comprehension would be too long or nested

## 20 Functions

Functions are reusable blocks of code that perform specific tasks. They are fundamental to organizing code and avoiding repetition.

### 20.1 Defining Functions

#### Syntax:

```
1 def function_name(parameters):
2     """Docstring describing the function."""
3     # Function body
4     statements
5     return value
```

Listing 99: Function definition syntax

#### Components:

1. **def keyword:** Begins function definition
2. **function\_name:** Identifier following Python naming conventions
3. **parameters:** Comma-separated list of inputs (can be empty)
4. **Docstring:** First line after definition, documenting the function
5. **Function body:** Indented code block
6. **return statement:** Optional, sends value back to caller

#### Simple Example:

```
1 def greet(name):
2     """Print a greeting message."""
3     message = f"Hello, {name}!"
4     return message
5
6 # Call the function
7 result = greet("Alice")
8 print(result) # "Hello, Alice!"
```

Listing 100: A simple function example

#### Fibonacci Example:

```

1 def fib(n):
2     """Return the nth Fibonacci number.
3
4     The Fibonacci sequence is: 0, 1, 1, 2, 3, 5, 8, 13, ...
5     where each number is the sum of the two preceding ones.
6
7     Args:
8         n: The index of the Fibonacci number to compute (0-based)
9
10    Returns:
11        The nth Fibonacci number
12    """
13    a = 0
14    b = 1
15    for i in range(n):
16        tmp = a
17        a = a + b
18        b = tmp
19    return a
20
21 # Test the function
22 print(fib(0))    # 0
23 print(fib(1))    # 1
24 print(fib(5))    # 5
25 print(fib(10))   # 55

```

Listing 101: Fibonacci sequence function

## 20.2 Function Characteristics

### No Type Declarations:

```

1 # Python (no types)
2 def add(a, b):
3     return a + b
4
5 # C++ (with types)
6 // int add(int a, int b) {
7 //     return a + b;
8 // }
9
10 # Python function works with any types that support +
11 print(add(5, 3))          # 8
12 print(add(2.5, 1.5))      # 4.0
13 print(add("Hello", "!"))  # "Hello!"
14 print(add([1], [2]))      # [1, 2]

```

Listing 102: Python functions don't declare types

### Always Have Return Value:

```

1 def no_explicit_return():
2     print("No return statement")
3
4 result = no_explicit_return()
5 print(result)    # None
6

```

```

7 # Explicit return of None
8 def explicit_none():
9     return None
10
11 # Early return
12 def absolute(x):
13     if x < 0:
14         return -x
15     return x

```

Listing 103: Functions always return something

### Functions are Objects:

```

1 def square(x):
2     return x ** 2
3
4 def cube(x):
5     return x ** 3
6
7 # Store functions in list
8 operations = [square, cube]
9
10 # Call functions from list
11 for op in operations:
12     print(op(3)) # 9, then 27
13
14 # Pass function as argument
15 def apply_twice(func, value):
16     return func(func(value))
17
18 result = apply_twice(square, 2) # square(square(2)) = 16
19
20 # Return function from function
21 def make_multiplier(n):
22     def multiplier(x):
23         return x * n
24     return multiplier
25
26 times_three = make_multiplier(3)
27 print(times_three(5)) # 15

```

Listing 104: Functions as first-class objects

### No Function Overloading:

```

1 # In C++, you can have:
2 // int add(int a, int b);
3 // double add(double a, double b);
4 // int add(int a, int b, int c);
5
6 # In Python, later definition replaces earlier
7 def add(a, b):
8     return a + b
9
10 def add(a, b, c): # This REPLACES the previous add()
11     return a + b + c
12

```

```
13 result = add(1, 2) # TypeError: missing required argument 'c'
```

Listing 105: Python doesn't support function overloading

**Note:** Operator overloading for classes works differently and is supported through magic methods (covered later).

## 20.3 Default Parameter Values

Functions can specify default values for parameters:

```
1 def greet(name, greeting="Hello", punctuation="!"):
2     """Greet someone with customizable message.
3
4     Args:
5         name: Person's name (required)
6         greeting: Greeting word (default: "Hello")
7         punctuation: Ending punctuation (default: "!")
8     """
9     return f"{greeting}, {name}{punctuation}"
10
11 # Use all defaults
12 print(greet("Alice")) # "Hello, Alice!"
13
14 # Override greeting
15 print(greet("Bob", "Hi")) # "Hi, Bob!"
16
17 # Override all
18 print(greet("Charlie", "Hey", ".")) # "Hey, Charlie."
```

Listing 106: Functions with default parameters

### Rules for Default Parameters:

1. Parameters with defaults must come after those without defaults
2. Default values are evaluated once at function definition time
3. Mutable default arguments can cause surprising behavior (discussed later)

```
1 # Valid
2 def func1(a, b, c=0, d=1):
3     pass
4
5 # Invalid: non-default after default
6 def func2(a, b=0, c): # SyntaxError
7     pass
8
9 # Valid: all have defaults
10 def func3(a=1, b=2, c=3):
11     pass
```

Listing 107: Valid and invalid parameter ordering

## 20.4 Keyword Arguments

Parameters can be passed by name (keyword arguments) rather than position:

```
1 def describe_pet(animal, name, age=1):
2     """Describe a pet."""
3     return f"{name} is a {age}-year-old {animal}"
4
5 # Positional arguments
6 print(describe_pet("dog", "Rex", 3))
7
8 # Keyword arguments (any order)
9 print(describe_pet(name="Whiskers", animal="cat", age=2))
10
11 # Mix positional and keyword (positional first)
12 print(describe_pet("bird", name="Tweety"))
13
14 # Skip optional parameters
15 print(describe_pet("hamster", "Fuzzy")) # Uses default age=1
16
17 # Can skip middle parameters with keywords
18 def config(host, port=8080, timeout=30, retry=3):
19     pass
20
21 config("localhost", retry=5) # Skips port and timeout
```

Listing 108: Using keyword arguments

### Benefits of Keyword Arguments:

- Makes function calls self-documenting
- Allows skipping optional parameters
- Order-independent
- Reduces errors when functions have many parameters

## 20.5 Variable-Length Arguments

Functions can accept variable numbers of arguments:

### \*args (Variadic Positional Arguments):

```
1 def sum_all(*args):
2     """Sum any number of arguments."""
3     total = 0
4     for num in args:
5         total += num
6     return total
7
8 print(sum_all(1, 2, 3)) # 6
9 print(sum_all(1, 2, 3, 4, 5)) # 15
10 print(sum_all()) # 0
11
12 # args is a tuple
13 def print_args(*args):
14     print(f"Received {len(args)} arguments:")
15     print(f"Type: {type(args)}") # <class 'tuple'>
16     for i, arg in enumerate(args):
17         print(f" arg[{i}] = {arg}")
```



```

18
19 print_args(1, "two", 3.0)

```

Listing 109: Using \*args for variable positional arguments

### **\*\*kwargs (Variadic Keyword Arguments):**

```

1 def print_config(**kwargs):
2     """Print configuration options."""
3     print("Configuration:")
4     for key, value in kwargs.items():
5         print(f" {key} = {value}")
6
7 print_config(host="localhost", port=8080, debug=True)
8
9 # kwargs is a dictionary
10 def collect_kwargs(**kwargs):
11     print(f"Type: {type(kwargs)}") # <class 'dict'>
12     return kwargs
13
14 config = collect_kwargs(a=1, b=2, c=3)
15 print(config) # {'a': 1, 'b': 2, 'c': 3}

```

Listing 110: Using \*\*kwargs for variable keyword arguments

### **Complete Parameter Syntax:**

```

1 def complex_function(a, b=2, *args, c, d=4, e, **kwargs):
2     """Demonstrate all parameter types.
3
4     Args:
5         a: Required positional argument
6         b: Positional argument with default
7         *args: Variable positional arguments
8         c: Required keyword-only argument
9         d: Keyword-only argument with default
10        e: Required keyword-only argument
11        **kwargs: Variable keyword arguments
12    """
13    print(f"a={a}, b={b}")
14    print(f"args={args}")
15    print(f"c={c}, d={d}, e={e}")
16    print(f"kwargs={kwargs}")
17
18 # Example call
19 complex_function(1, 3, 5, 6, c=7, e=8, x=9, y=10)
20 # Output:
21 # a=1, b=3
22 # args=(5, 6)
23 # c=7, d=4, e=8
24 # kwargs={'x': 9, 'y': 10}

```

Listing 111: All parameter types together

### **Parameter Order Rules:**

1. Regular positional parameters
2. Positional parameters with defaults

3. `*args` (variadic positional)
4. Keyword-only parameters (with or without defaults)
5. `**kwargs` (variadic keyword)

## 20.6 Unpacking Arguments

Use `*` and `**` to unpack sequences and dictionaries:

```

1 def add_three(a, b, c):
2     return a + b + c
3
4 # Unpack list with *
5 numbers = [1, 2, 3]
6 result = add_three(*numbers) # Same as add_three(1, 2, 3)
7
8 # Unpack dictionary with **
9 config = {'a': 1, 'b': 2, 'c': 3}
10 result = add_three(**config) # Same as add_three(a=1, b=2, c=3)
11
12 # Practical example: combining lists
13 list1 = [1, 2, 3]
14 list2 = [4, 5, 6]
15 combined = [*list1, *list2] # [1, 2, 3, 4, 5, 6]
16
17 # Combining dictionaries
18 dict1 = {'a': 1, 'b': 2}
19 dict2 = {'c': 3, 'd': 4}
20 combined = {**dict1, **dict2} # {'a': 1, 'b': 2, 'c': 3, 'd': 4}

```

Listing 112: Unpacking arguments with `*` and `**`

## 20.7 Lambda Functions

Lambda functions are small anonymous functions:

**Syntax:**

```

1 lambda parameters: expression

```

Listing 113: Lambda function syntax

**Examples:**

```

1 # Simple lambda
2 square = lambda x: x ** 2
3 print(square(5)) # 25
4
5 # Equivalent to:
6 def square(x):
7     return x ** 2
8
9 # Multiple parameters
10 add = lambda a, b: a + b
11 print(add(3, 5)) # 8
12
13 # Use in sorting

```

```

14 students = [('Alice', 85), ('Bob', 92), ('Charlie', 78)]
15 students.sort(key=lambda student: student[1]) # Sort by grade
16 print(students) # [('Charlie', 78), ('Alice', 85), ('Bob', 92)]
17
18 # Use with map()
19 numbers = [1, 2, 3, 4, 5]
20 doubled = list(map(lambda x: x * 2, numbers))
21 print(doubled) # [2, 4, 6, 8, 10]
22
23 # Use with filter()
24 evens = list(filter(lambda x: x % 2 == 0, numbers))
25 print(evens) # [2, 4]
26
27 # Passing function as argument
28 def apply(func, x):
29     return func(x)
30
31 result = apply(lambda z: z ** 2, 5) # 25

```

Listing 114: Lambda function examples

#### When to Use Lambda:

- Single, simple expressions
- As arguments to higher-order functions
- Short-lived functions not reused elsewhere

#### When NOT to Use Lambda:

- Complex logic requiring multiple statements
- Functions that will be reused (use `def` instead)
- When debugging (named functions are clearer)
- When documentation is important (lambdas can't have docstrings)

## 21 Coding Style and Conventions

Python places exceptional emphasis on code readability and consistency. Following established conventions makes code easier to read, maintain, and collaborate on.

### 21.1 PEP 8: The Python Style Guide

PEP 8 is the official style guide for Python code, and adherence to it is considered essential in the Python community.

URL: <https://www.python.org/dev/peps/pep-0008/>

#### Core Rules:

##### 1. Indentation:

- Use 4 spaces per indentation level
- NEVER use tabs
- NEVER mix tabs and spaces

##### 2. Line Length:

- Maximum 79 characters for code
- Maximum 72 characters for docstrings/comments

### 3. Blank Lines:

- Two blank lines between top-level functions and classes
- One blank line between methods inside a class
- Use blank lines sparingly to separate logical sections

### 4. Imports:

- Each import on separate line
- Imports at top of file
- Group imports: standard library, third-party, local
- Use absolute imports when possible

### 5. Whitespace:

- No spaces inside parentheses, brackets, or braces
- Space around binary operators
- No space before function call parentheses

### 6. Naming Conventions:

- lowercase\_with\_underscores for functions and variables
- UPPERCASE\_WITH\_UNDERSCORES for constants
- CapitalizedWords for class names
- `_leading_underscore` for internal/private

### 7. Documentation:

- Use docstrings for all public modules, functions, classes, and methods
- Use inline comments sparingly
- Keep comments up-to-date

### Example of Good Style:

```

1  """Module for geometric calculations.
2
3  This module provides functions for calculating areas and volumes
4  of basic geometric shapes.
5  """
6
7  import math
8  import sys
9
10 # Constants
11 PI = 3.14159265359
12 GOLDEN_RATIO = 1.618
13
14
15 class Circle:
16     """Represent a circle with radius and center coordinates."""
17
18     def __init__(self, radius, center_x=0, center_y=0):
19         """Initialize circle with radius and optional center.
```

```

20
21     Args:
22         radius: Circle radius (must be positive)
23         center_x: X coordinate of center (default: 0)
24         center_y: Y coordinate of center (default: 0)
25     """
26     self.radius = radius
27     self.center_x = center_x
28     self.center_y = center_y
29
30     def area(self):
31         """Calculate and return the circle's area."""
32         return math.pi * self.radius ** 2
33
34
35 def calculate_rectangle_area(width, height):
36     """Calculate the area of a rectangle.
37
38     Args:
39         width: Rectangle width
40         height: Rectangle height
41
42     Returns:
43         The area as a float
44
45     Raises:
46         ValueError: If width or height is negative
47     """
48     if width < 0 or height < 0:
49         raise ValueError("Dimensions must be non-negative")
50
51     return width * height
52
53
54 def main():
55     """Main program entry point."""
56     circle = Circle(5.0)
57     area = circle.area()
58     print(f"Circle area: {area:.2f}")
59
60
61 if __name__ == "__main__":
62     main()

```

Listing 115: Well-styled Python code following PEP 8

## 21.2 Enforcing Style with Tools

Rather than manually checking style, use automated tools:

### Code Formatters (Automatic Formatting):

- **Black:** Opinionated formatter, very popular

```

1 pip install black
2 black myfile.py # Formats file in-place
3

```

- **autopep8:** Formats to conform to PEP 8

```
1 pip install autopep8
2 autopep8 --in-place --aggressive myfile.py
3
```

- **yapf:** Google's formatter

#### Linters (Style Checking):

- **pylint:** Comprehensive style and error checker

```
1 pip install pylint
2 pylint myfile.py
3
```

- **flake8:** Combines pycodestyle, pyflakes, and McCabe complexity

```
1 pip install flake8
2 flake8 myfile.py
3
```

- **mypy:** Optional static type checker

```
1 pip install mypy
2 mypy myfile.py
3
```

**Complete List:** <https://github.com/life4/awesome-python-code-formatters>

## 21.3 Editor Configuration

Configure your editor to help maintain style:

- Set tab key to insert 4 spaces
- Enable visible whitespace characters
- Install Python syntax highlighting
- Enable automatic PEP 8 checking
- Configure automatic formatting on save
- Set line length marker at 79 characters

## 21.4 Interesting Style-Related Facts

#### Spaces vs. Tabs:

- Stack Overflow 2017: Developers using spaces earn more (<https://stackoverflow.blog/2017/06/15/developers-use-spaces-make-money-use-tabs/>)
- Correlation, not causation (likely reflects attention to detail)
- Python 3 explicitly disallows mixing

**Coding Horror:** "Death to the Space Infidels" - <https://blog.codinghorror.com/death-to-the-space-infidels/>

## 22 How Function Arguments Work: Pass by Assignment

Understanding how Python passes arguments to functions is crucial for avoiding common pitfalls and understanding unexpected behavior.

## 22.1 The Mystery

Consider these two functions:

```
1 # Function 1: Incrementing an integer
2 def incr(x):
3     x += 1
4
5 x = 0
6 incr(x)
7 print(x) # Prints: 0 (unchanged!)
8
9 # Function 2: Incrementing first element of list
10 def incr_first(x):
11     x[0] += 1
12
13 x = [0, 1, 2]
14 incr_first(x)
15 print(x) # Prints: [1, 1, 2] (changed!)
```

Listing 116: A puzzling behavior

The first looks like "pass by value" (value unchanged), the second like "pass by reference" (value changed). What's really happening?

## 22.2 Understanding Python's Object Model

Python uses a unique approach called "pass by assignment" or "call by object reference":

**Key Concepts:**

1. **Variables are names, not containers**
  - Variables don't "contain" values; they're labels that "refer to" objects
  - Like name tags stuck on objects
2. **Objects live in a separate space**
  - All objects exist in memory (the "object space")
  - Variables are just names that point to these objects
3. **Assignment doesn't copy data**
  - Assignment makes a name refer to an object
  - Multiple names can refer to the same object

## 22.3 Step-by-Step: The Integer Example

**Step 1: Initial assignment**

```
1 x = 0
```

## Python's Object Model

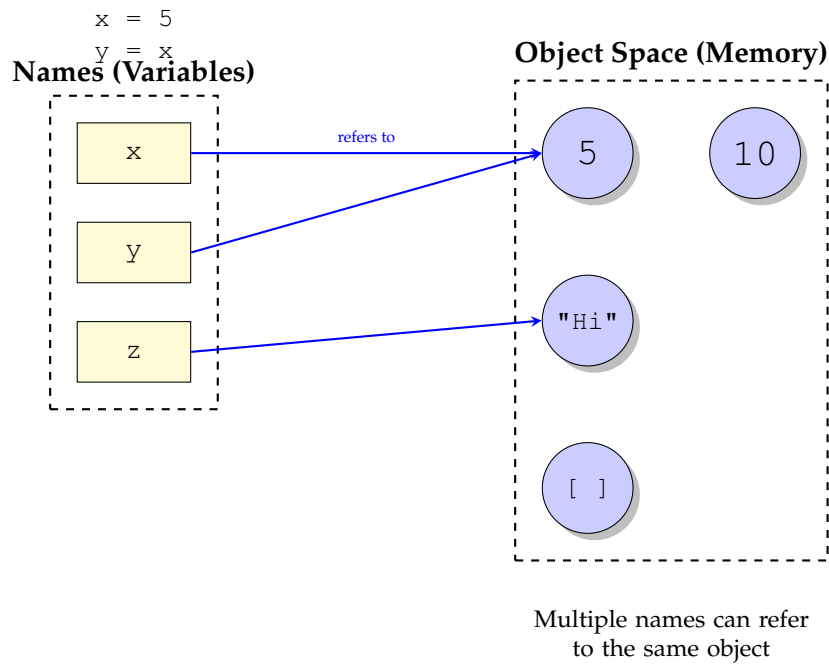


Figure 5: Python's object model: Variables are labels (names) that bind to objects in memory. The same object can have multiple names referring to it. When you write `x = 5`, you're creating a label 'x' that points to an integer object 5 in memory.

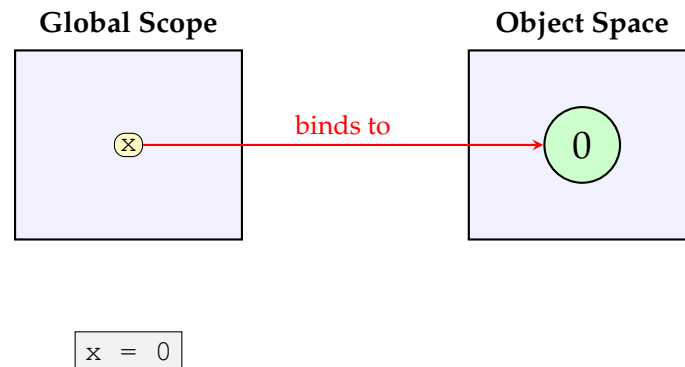


Figure 6: Global scope contains name 'x' pointing to integer object 0 in object space.

### Step 2: Function called

```
1 incr(x) # Call the function
```



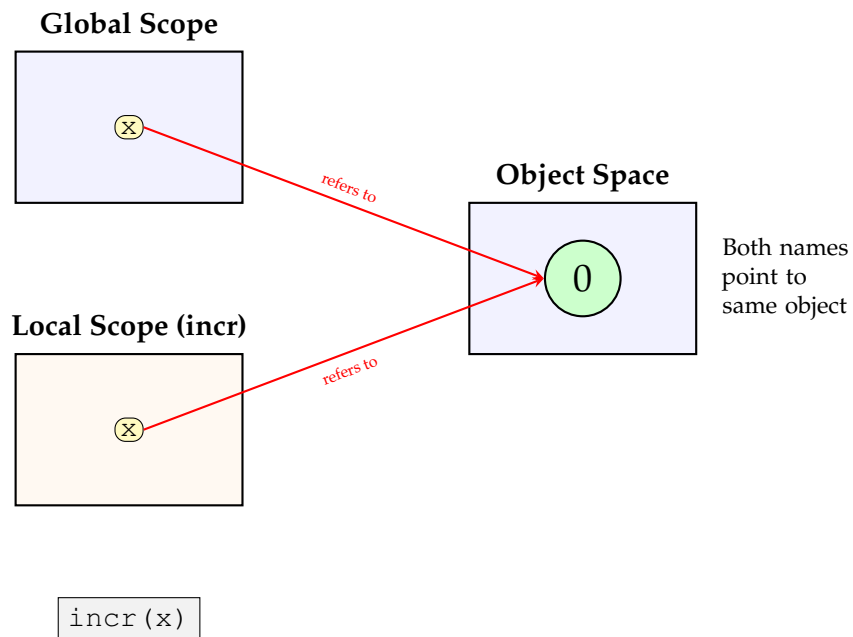


Figure 7: Local scope created with parameter 'x' pointing to the same integer object 0. Both global and local 'x' refer to the same object.

### Step 3: Inside function - increment

```
1 def incr(x):  
2     x += 1 # This line executes
```

Because integers are IMMUTABLE, this creates a NEW object:

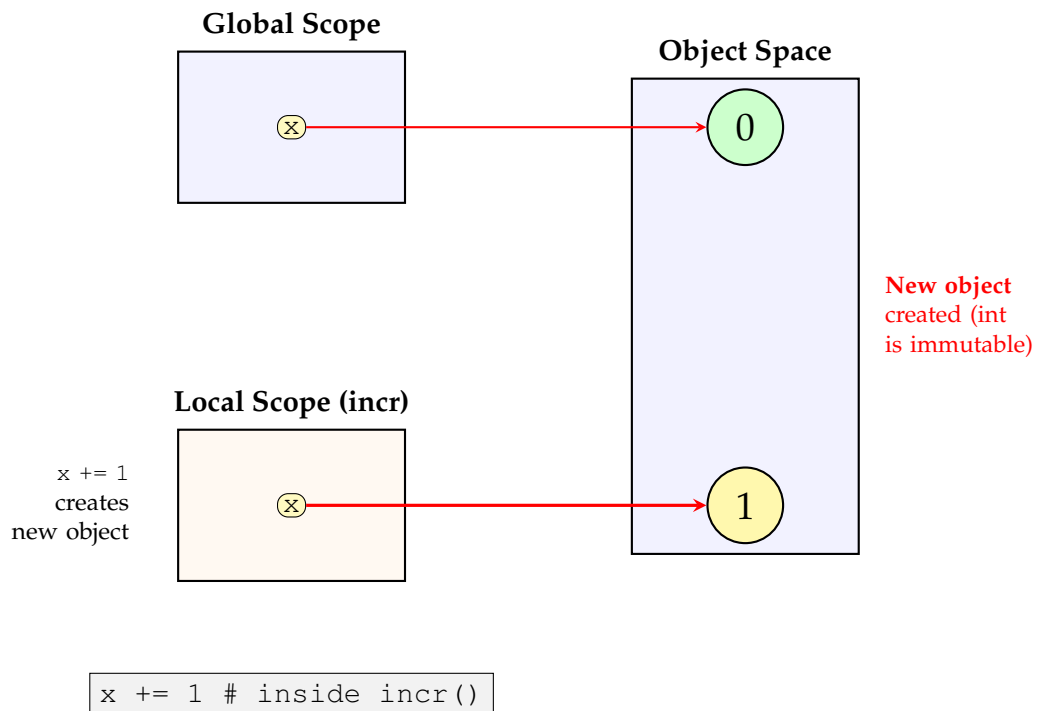


Figure 8: Integer 0 cannot be modified. Python creates new integer object 1, and local 'x' now points to it. Global 'x' still points to 0.

#### Step 4: Function returns

```
1 print(x) # Back in global scope
```

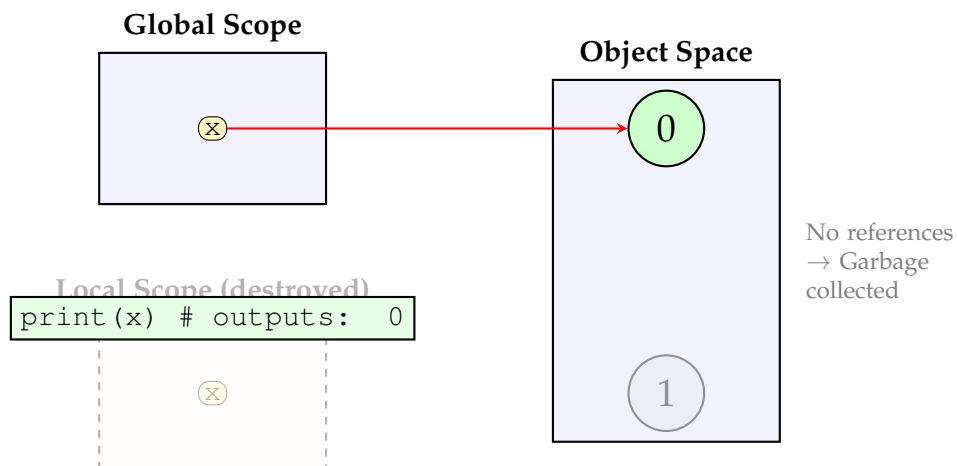


Figure 9: Local scope destroyed. Global 'x' still points to 0 (unchanged). The integer object 1 has no references and will be garbage collected.

**Result:** Global `x` is unchanged because integers are immutable, and the local

reassignment created a new object that the global name never saw.

## 22.4 Step-by-Step: The List Example

### Step 1: Initial assignment

```
1 x = [0, 1, 2]
```

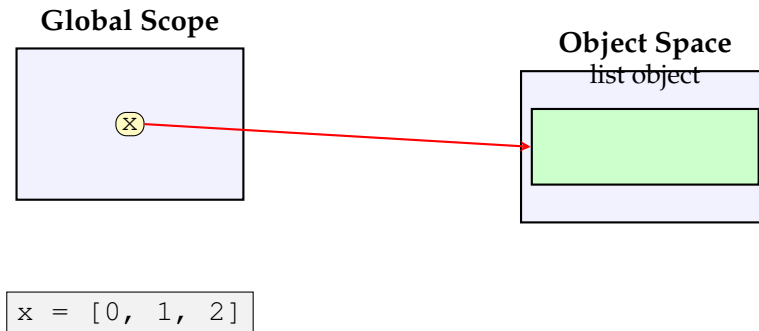


Figure 10: Global 'x' points to a list object containing three elements.

### Step 2: Function called

```
1 incr_first(x)
```

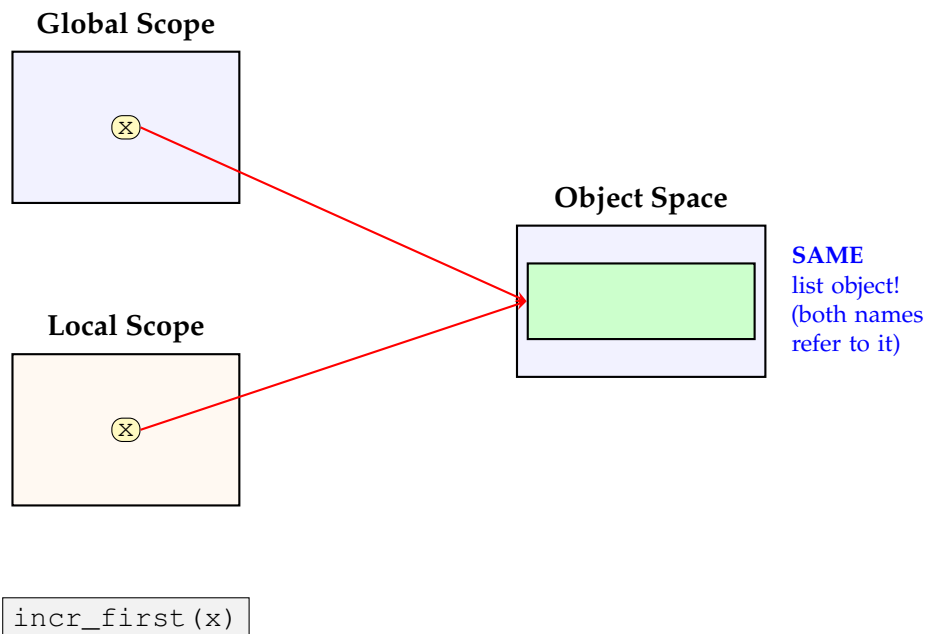


Figure 11: Local 'x' created, pointing to the SAME list object as global 'x'.

### Step 3: Inside function - modify

```

1 def incr_first(x):
2     x[0] += 1 # This line executes

```

Because lists are MUTABLE, this modifies the existing object:

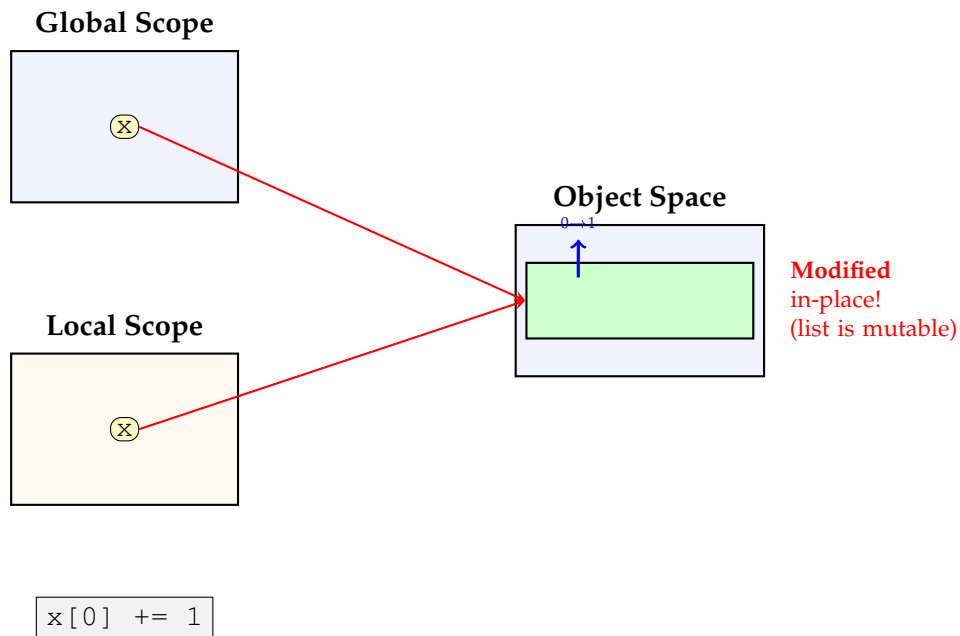


Figure 12: The list object itself is modified in-place. The first element changes from 0 to 1. Both local and global 'x' point to this same modified list.

#### Step 4: Function returns

```

1 print(x) # Back in global scope

```

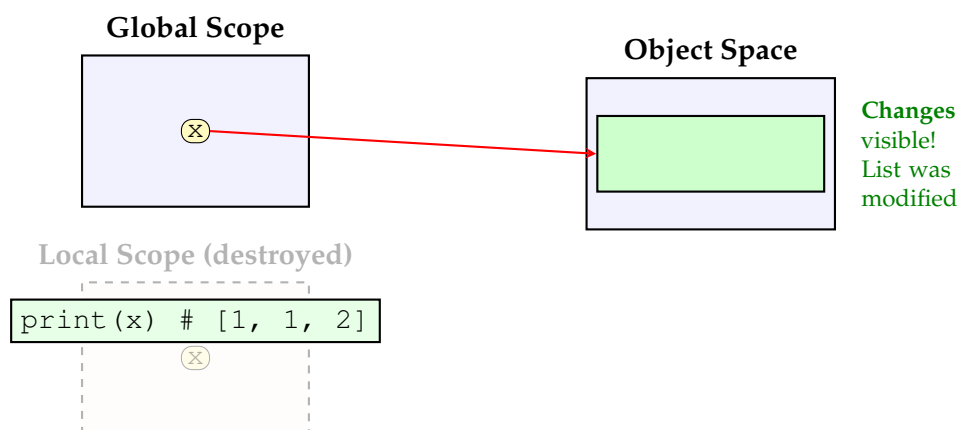


Figure 13: Local scope destroyed. Global 'x' points to the list, which was modified. Changes are visible!

**Result:** Global `x` reflects the change because lists are mutable, and both names pointed to the same list object that was modified in-place.

## 22.5 The Critical Distinction

The key is **mutability**:

**Immutable Objects (int, float, str, tuple):**

- Any "modification" creates a new object
- Local reassignment doesn't affect global variables
- Behaves like "pass by value"

**Mutable Objects (list, dict, set):**

- Can be modified in-place
- Modifications are visible to all names referencing the object
- Behaves like "pass by reference"

## 22.6 Assignment and Aliasing

This same behavior applies to simple assignment:

```
1 # Lists (mutable)
2 x = [1, 2, 3]
3 y = x # y refers to the SAME list as x
4
5 y[0] = 99
6 print(x) # [99, 2, 3] - x is affected!
7 print(y) # [99, 2, 3]
8
9 # Integers (immutable)
10 a = 5
11 b = a # b refers to the SAME integer as a
12
13 b += 1 # Creates NEW integer, rebinds b
14 print(a) # 5 - a is unchanged
15 print(b) # 6
```

Listing 117: Assignment creates references, not copies

## 22.7 Copying Objects

To create independent copies, use the `copy` module:

**Shallow Copy:**

```
1 import copy
2
3 x = [1, 2, 3]
4 y = copy.copy(x) # or y = x.copy() or y = x[:]
5
6 y[0] = 99
7 print(x) # [1, 2, 3] - x unchanged
8 print(y) # [99, 2, 3]
```

Listing 118: Shallow copying

**Shallow Copy Limitation:** Shallow copy only copies the top level:

```

1 import copy
2
3 x = [1, 2, [3, 4]]
4 y = copy.copy(x)
5
6 y[2][0] = 99
7 print(x) # [1, 2, [99, 4]] - inner list still shared!
8 print(y) # [1, 2, [99, 4]]

```

Listing 119: Shallow copy limitation with nested lists

**Deep Copy:** Deep copy recursively copies all nested objects:

```

1 import copy
2
3 x = [1, 2, [3, 4]]
4 y = copy.deepcopy(x)
5
6 y[2][0] = 99
7 print(x) # [1, 2, [3, 4]] - completely independent!
8 print(y) # [1, 2, [99, 4]]

```

Listing 120: Deep copying

**The copy module documentation states:** "The difference between shallow and deep copying is only relevant for compound objects (objects that contain other objects, like lists or class instances)."

## 22.8 Practical Implications

**Avoiding Unintended Modifications:**

```

1 def process_list(data):
2     """Process list without modifying original."""
3     # Make a copy to avoid side effects
4     data = data.copy()
5     data.sort()
6     # ... other operations
7     return data
8
9 original = [3, 1, 4, 1, 5]
10 result = process_list(original)
11 print(original) # [3, 1, 4, 1, 5] - unchanged
12 print(result)  # [1, 1, 3, 4, 5] - sorted

```

Listing 121: Defensive copying to avoid side effects

**Mutable Default Arguments: A common pitfall:**

```

1 # WRONG: Mutable default argument
2 def add_item(item, items=[]):
3     items.append(item)
4     return items
5
6 print(add_item(1)) # [1]
7 print(add_item(2)) # [1, 2] - Unexpected!
8 print(add_item(3)) # [1, 2, 3] - Shared list!
9
10 # RIGHT: Use None as default

```

```

11 def add_item_correct(item, items=None):
12     if items is None:
13         items = []
14         items.append(item)
15     return items
16
17 print(add_item_correct(1)) # [1]
18 print(add_item_correct(2)) # [2] - Fresh list
19 print(add_item_correct(3)) # [3] - Each call independent

```

Listing 122: Mutable default arguments pitfall

## 23 Object-Oriented Programming: Classes

Python supports object-oriented programming (OOP), allowing you to define custom types with their own data and behavior.

### 23.1 Defining Classes

#### Syntax:

```

1 class ClassName:
2     """Class docstring."""
3
4     def __init__(self, parameters):
5         """Constructor/initializer."""
6         self.attribute = value
7
8     def method(self, parameters):
9         """Instance method."""
10        # Method body

```

Listing 123: Basic class definition syntax

#### Simple Example:

```

1 class Point:
2     """Represent a 2D point with x and y coordinates."""
3
4     def __init__(self, x, y):
5         """Initialize point with coordinates.
6
7         Args:
8             x: X coordinate
9             y: Y coordinate
10        """
11        self.x = x
12        self.y = y
13
14 # Create instances
15 p1 = Point(1, 2)
16 p2 = Point(3, 4)
17
18 # Access attributes
19 print(p1.x) # 1

```

```

20 print(p1.y)    # 2
21
22 # Can add attributes dynamically
23 p1.z = 5    # Adds new attribute to p1 only
24 print(p1.z)    # 5
25 # print(p2.z)    # AttributeError - p2 doesn't have z

```

Listing 124: A simple Point class

## 23.2 The self Parameter

**Critical Convention:** The first parameter of instance methods is always `self`:

- Refers to the instance the method is called on
- Equivalent to C++'s implicit `this` pointer
- Name `self` is convention (could technically be anything, but ALWAYS use `self`)
- Must be explicit in Python (unlike C++)

```

1 class Counter:
2     def __init__(self):
3         self.count = 0
4
5     def increment(self):
6         self.count += 1    # self refers to the instance
7
8     def get_count(self):
9         return self.count
10
11 c1 = Counter()
12 c2 = Counter()
13
14 c1.increment()
15 c1.increment()
16 c2.increment()
17
18 print(c1.get_count())    # 2
19 print(c2.get_count())    # 1 (separate instance)
20
21 # When you call c1.increment():
22 # Python actually calls Counter.increment(c1)
23 # self parameter receives c1

```

Listing 125: Understanding self

## 23.3 The Constructor: `__init__`

The `__init__` method is the constructor, called when creating new instances:

```

1 class Rectangle:
2     """Represent a rectangle."""
3
4     def __init__(self, width, height):
5         """Initialize rectangle with dimensions.
6

```



```

7     Args:
8         width: Rectangle width
9         height: Rectangle height
10    """
11    self.width = width
12    self.height = height
13
14    def area(self):
15        """Calculate and return area."""
16        return self.width * self.height
17
18    def perimeter(self):
19        """Calculate and return perimeter."""
20        return 2 * (self.width + self.height)
21
22    # Create instance
23    rect = Rectangle(10, 5)
24
25    # Call methods
26    print(f"Area: {rect.area()}") # 50
27    print(f"Perimeter: {rect.perimeter()}") # 30

```

Listing 126: Constructor examples

#### Key Points:

- Name must be exactly `__init__` (double underscores)
- Called automatically when creating instance
- Doesn't return anything (implicitly returns `None`)
- Initializes instance attributes with `self.attribute = value`

## 23.4 Instance Methods

Methods are functions defined inside a class:

```

1 class BankAccount:
2     """Represent a simple bank account."""
3
4     def __init__(self, owner, balance=0):
5         """Initialize account.
6
7         Args:
8             owner: Account owner's name
9             balance: Initial balance (default: 0)
10        """
11        self.owner = owner
12        self.balance = balance
13
14    def deposit(self, amount):
15        """Deposit money into account.
16
17        Args:
18            amount: Amount to deposit
19
20        Raises:
21            ValueError: If amount is negative
22        """

```

```

23         if amount < 0:
24             raise ValueError("Cannot deposit negative amount")
25         self.balance += amount
26
27     def withdraw(self, amount):
28         """Withdraw money from account.
29
30         Args:
31             amount: Amount to withdraw
32
33         Returns:
34             True if successful, False if insufficient funds
35         """
36         if amount > self.balance:
37             return False
38         self.balance -= amount
39         return True
40
41     def get_balance(self):
42         """Return current balance."""
43         return self.balance
44
45 # Usage
46 account = BankAccount("Alice", 1000)
47 account.deposit(500)
48 account.withdraw(200)
49 print(account.get_balance()) # 1300

```

Listing 127: Instance methods

## 23.5 Python vs. C++ Classes

### Key Differences:

```

1 # Python
2 class Point:
3     def __init__(self, x, y):
4         self.x = x # Attributes created in __init__
5         self.y = y
6
7 p = Point(1, 2)
8 p.z = 3 # Can add attributes dynamically!
9
10 # C++
11 // struct Point {
12 //     Point(double x, double y) : x(x), y(y) {}
13 //     double x, y; // Members declared in class
14 // };
15 //
16 // Point p(1, 2);
17 // p.z = 3; // ERROR: z not declared

```

Listing 128: Comparing Python and C++ classes

### Comparison Table:

Feature	Python	C++
Member declaration	Implicitly in <code>__init__</code>	Explicitly in class body
self/this parameter	Explicit <code>self</code>	Implicit <code>this</code>
Adding attributes	Can add dynamically	Fixed at compile time
Privacy	Convention-based	Enforced by compiler
Constructor name	<code>__init__</code>	Class name
Type checking	Runtime	Compile time

Table 1: Python vs C++ class features

## 24 Privacy in Python Classes

Python's approach to privacy is fundamentally different from C++.

### 24.1 Convention-Based Privacy

Python has no enforced privacy mechanism. Instead, it relies on conventions:

**The Convention:**

- Names with leading underscore (`_name`) are considered "internal" or "private"
- This is a signal to other programmers, not a restriction
- Python programmers follow the philosophy: "We're all consenting adults here"

```

1 class BankAccount:
2     """A bank account with conventional privacy."""
3
4     def __init__(self, owner, balance):
5         """Initialize account."""
6         self._owner = owner      # "Private" by convention
7         self._balance = balance  # "Private" by convention
8
9     def deposit(self, amount):
10        """Public method to deposit money."""
11        self._balance += amount
12
13    def get_balance(self):
14        """Public method to access balance."""
15        return self._balance
16
17 # Usage
18 account = BankAccount("Alice", 1000)
19
20 # Proper usage (through public methods)
21 account.deposit(500)
22 print(account.get_balance()) # 1500
23
24 # Can still access "private" attributes (not recommended!)
25 print(account._balance)     # 1500 - works, but shouldn't do this
26 account._balance = 0        # Can modify directly (bad practice!)

```

Listing 129: Privacy by convention in Python

## 24.2 Python vs. C++ Privacy

```
1 # Python
2 class Point:
3     def __init__(self, x, y):
4         self._x = x # Convention: private
5         self._y = y
6
7     def get_x(self):
8         return self._x
9
10 p = Point(1, 2)
11 print(p._x) # Works, but violates convention
12
13 # C++
14 // class Point {
15 // public:
16 //     Point(double x, double y) : x(x), y(y) {}
17 //     double get_x() const { return x; }
18 // private:
19 //     double x, y;
20 // };
21 //
22 // Point p(1, 2);
23 // p.x; // COMPILATION ERROR - truly private
```

Listing 130: Privacy comparison: Python vs C++

## 24.3 Name Mangling

Python provides a stronger privacy mechanism for class-internal names:

```
1 class MyClass:
2     def __init__(self):
3         self.__private = "truly private" # Double underscore
4         self._internal = "semi-private"  # Single underscore
5
6     def __private_method(self):
7         """Private method."""
8         return "secret"
9
10 obj = MyClass()
11
12 # Single underscore (accessible)
13 print(obj._internal) # Works
14
15 # Double underscore (name mangled)
16 # print(obj.__private) # AttributeError
17
18 # But can still access via mangled name (if you really want to)
19 print(obj._MyClass__private) # Works (mangled to _ClassName__name)
```

Listing 131: Name mangling with double underscores

### Name Mangling Rules:

- Names starting with `__` (but not ending with `__`) are mangled

- Mangled to `_ClassName__name`
- Helps avoid name conflicts in inheritance
- Not true privacy, just harder to access accidentally

## 24.4 Why No True Privacy?

Python's philosophy emphasizes:

- **Trust:** Programmers are expected to respect conventions
- **Flexibility:** Can access internals for debugging or testing
- **Simplicity:** Less language complexity
- **Pragmatism:** Sometimes you need to bend the rules

**Official Documentation:** <https://docs.python.org/3/tutorial/classes.html#private-variables>

## 25 Class Variables and Static Data

Class variables are shared by all instances of a class:

### 25.1 Defining Class Variables

```

1 class Point:
2     """A 2D point class."""
3
4     # Class variable (shared by all instances)
5     dimensions = 2
6
7     def __init__(self, x, y):
8         """Initialize point."""
9         # Instance variables (unique to each instance)
10        self.x = x
11        self.y = y
12
13 # Access class variable through class
14 print(Point.dimensions) # 2
15
16 # Access through instances
17 p1 = Point(1, 2)
18 p2 = Point(3, 4)
19 print(p1.dimensions) # 2
20 print(p2.dimensions) # 2
21
22 # Modify class variable
23 Point.dimensions = 3
24 print(p1.dimensions) # 3 (all instances see change)
25 print(p2.dimensions) # 3

```

Listing 132: Class variables (static data)

### 25.2 Class Variables vs. Instance Variables

```

1 class Counter:
2     """Track instances and individual counts."""
3
4     # Class variable - shared by all instances
5     total_instances = 0
6
7     def __init__(self):
8         """Initialize counter."""
9         # Increment class variable
10        Counter.total_instances += 1
11
12        # Instance variable - unique to this instance
13        self.count = 0
14
15    def increment(self):
16        """Increment this counter."""
17        self.count += 1
18
19 # Create instances
20 c1 = Counter()
21 c2 = Counter()
22 c3 = Counter()
23
24 print(Counter.total_instances) # 3
25
26 c1.increment()
27 c1.increment()
28 c2.increment()
29
30 print(c1.count) # 2 (instance-specific)
31 print(c2.count) # 1 (instance-specific)
32 print(c3.count) # 0 (instance-specific)

```

Listing 133: Distinguishing class and instance variables

### Warning - Shadowing:

```

1 class Point:
2     dimensions = 2
3
4 p1 = Point()
5 p2 = Point()
6
7 # Modifying through instance creates instance variable!
8 p1.dimensions = 3 # Creates NEW instance variable
9
10 print(p1.dimensions) # 3 (instance variable)
11 print(p2.dimensions) # 2 (class variable)
12 print(Point.dimensions) # 2 (class variable)
13
14 # To modify class variable, use class name
15 Point.dimensions = 3
16 print(p2.dimensions) # 3 (now sees updated class variable)

```

Listing 134: Accidental shadowing of class variables

## 25.3 Comparing with C++

```
1 # Python
2 class Point:
3     dim = 2 # Class variable
4
5     def __init__(self, x, y):
6         self._x = x
7         self._y = y
8
9 Point.dim # Access class variable
10
11 # C++
12 // struct Point {
13 //     Point(double x, double y) : x(x), y(y) {}
14 //     double x, y;
15 //     static const int dim = 2; // Static member
16 // };
17 //
18 // Point::dim; // Access static member
```

Listing 135: Static members: Python vs C++

## 26 Magic Methods: Operator Overloading

Magic methods (also called "dunder methods" for double underscore) allow you to define how objects interact with Python's operators and built-in functions.

### 26.1 Understanding Magic Methods

**Magic methods** are special methods with names surrounded by double underscores that Python calls automatically in response to certain operations.

```
1 class Point:
2     """2D point with operator overloading."""
3
4     def __init__(self, x, y):
5         """Initialize point."""
6         self._x = x
7         self._y = y
8
9     def __add__(self, other):
10         """Define point + point."""
11         return Point(self._x + other._x, self._y + other._y)
12
13     def __str__(self):
14         """Define string representation for print()."""
15         return f"({self._x}, {self._y})"
16
17     def __repr__(self):
18         """Define official string representation."""
19         return f"Point({self._x}, {self._y})"
20
21 # Usage
```

```

22 p1 = Point(1, 2)
23 p2 = Point(3, 4)
24
25 # Calls p1.__add__(p2)
26 p3 = p1 + p2
27 print(p3)  # Calls p3.__str__() -> "(4, 6)"
28
29 # In interpreter
30 # >>> p3
31 # Point(4, 6)  # Calls p3.__repr__()

```

Listing 136: Basic magic methods example

## 26.2 Common Magic Methods

### Object Lifecycle:

```

1 class Resource:
2     """Demonstrate lifecycle methods."""
3
4     def __init__(self, name):
5         """Constructor."""
6         self.name = name
7         print(f"Creating {self.name}")
8
9     def __del__(self):
10        """Destructor (finalizer)."""
11        print(f"Destroying {self.name}")
12
13 # Create and destroy
14 r = Resource("MyResource")
15 # ... use resource ...
16 del r  # Explicitly delete (or wait for garbage collection)

```

Listing 137: Lifecycle magic methods

### Arithmetic Operators:

```

1 class Vector:
2     """Simple vector class."""
3
4     def __init__(self, x, y):
5         self.x = x
6         self.y = y
7
8     def __add__(self, other):
9         """Vector addition: v1 + v2"""
10        return Vector(self.x + other.x, self.y + other.y)
11
12    def __sub__(self, other):
13        """Vector subtraction: v1 - v2"""
14        return Vector(self.x - other.x, self.y - other.y)
15
16    def __mul__(self, scalar):
17        """Scalar multiplication: v * scalar"""
18        return Vector(self.x * scalar, self.y * scalar)
19

```



```

20 def __truediv__(self, scalar):
21     """Scalar division: v / scalar"""
22     return Vector(self.x / scalar, self.y / scalar)
23
24 def __floordiv__(self, scalar):
25     """Floor division: v // scalar"""
26     return Vector(self.x // scalar, self.y // scalar)
27
28 def __neg__(self):
29     """Negation: -v"""
30     return Vector(-self.x, -self.y)
31
32 def __str__(self):
33     return f"Vector({self.x}, {self.y})"
34
35 # Usage
36 v1 = Vector(3, 4)
37 v2 = Vector(1, 2)
38
39 print(v1 + v2)    # Vector(4, 6)
40 print(v1 - v2)    # Vector(2, 2)
41 print(v1 * 2)     # Vector(6, 8)
42 print(v1 / 2)     # Vector(1.5, 2.0)
43 print(-v1)       # Vector(-3, -4)

```

Listing 138: Arithmetic operator overloading

### Comparison Operators:

```

1 class Point:
2     """Point with comparison based on distance from origin."""
3
4     def __init__(self, x, y):
5         self.x = x
6         self.y = y
7
8     def distance_from_origin(self):
9         """Calculate distance from origin."""
10        return (self.x**2 + self.y**2)**0.5
11
12    def __eq__(self, other):
13        """Equality: p1 == p2"""
14        return self.x == other.x and self.y == other.y
15
16    def __ne__(self, other):
17        """Inequality: p1 != p2"""
18        return not self.__eq__(other)
19
20    def __lt__(self, other):
21        """Less than: p1 < p2 (by distance)"""
22        return self.distance_from_origin() < other.
23            distance_from_origin()
24
25    def __le__(self, other):
26        """Less than or equal: p1 <= p2"""
27        return self.distance_from_origin() <= other.
28            distance_from_origin()

```

```

28     def __gt__(self, other):
29         """Greater than: p1 > p2"""
30         return self.distance_from_origin() > other.
           distance_from_origin()
31
32     def __ge__(self, other):
33         """Greater than or equal: p1 >= p2"""
34         return self.distance_from_origin() >= other.
           distance_from_origin()
35
36 # Usage
37 p1 = Point(1, 1)
38 p2 = Point(2, 2)
39
40 print(p1 == p2)    # False
41 print(p1 < p2)     # True (p1 closer to origin)
42 print(p1 <= p2)    # True

```

Listing 139: Comparison operator overloading

### Container Emulation:

```

1 class MyList:
2     """Simple list-like container."""
3
4     def __init__(self, items):
5         self._items = list(items)
6
7     def __len__(self):
8         """Return length: len(obj)"""
9         return len(self._items)
10
11    def __getitem__(self, index):
12        """Get item: obj[index]"""
13        return self._items[index]
14
15    def __setitem__(self, index, value):
16        """Set item: obj[index] = value"""
17        self._items[index] = value
18
19    def __delitem__(self, index):
20        """Delete item: del obj[index]"""
21        del self._items[index]
22
23    def __contains__(self, item):
24        """Membership test: item in obj"""
25        return item in self._items
26
27    def __iter__(self):
28        """Make iterable: for item in obj"""
29        return iter(self._items)
30
31 # Usage
32 ml = MyList([1, 2, 3, 4, 5])
33
34 print(len(ml))      # 5 - calls __len__
35 print(ml[2])        # 3 - calls __getitem__
36 ml[2] = 99          # calls __setitem__

```

```

37 print(3 in ml)      # False - calls __contains__
38 print(99 in ml)     # True
39
40 for item in ml:      # calls __iter__
41     print(item)

```

Listing 140: Container protocol magic methods

## 26.3 String Representation Methods

```

1 class Point:
2     """Point with both string representations."""
3
4     def __init__(self, x, y):
5         self.x = x
6         self.y = y
7
8     def __str__(self):
9         """Informal string for end users (print, str)."""
10        return f"Point at ({self.x}, {self.y})"
11
12    def __repr__(self):
13        """Official string for developers (repr, interactive)."""
14        return f"Point({self.x}, {self.y})"
15
16 p = Point(3, 4)
17
18 print(str(p))      # "Point at (3, 4)" - uses __str__
19 print(repr(p))     # "Point(3, 4)" - uses __repr__
20 print(p)           # "Point at (3, 4)" - print uses __str__
21
22 # In interactive interpreter:
23 # >>> p
24 # Point(3, 4)      # Uses __repr__

```

Listing 141: String representation magic methods

### Guidelines:

- `__str__`: Human-readable representation for end users
- `__repr__`: Unambiguous representation for developers (ideally, code that recreates the object)
- If only one is defined, `__repr__` is preferred as it's used as fallback

## 26.4 Complete Magic Methods Reference

### Table of Common Magic Methods:

**Complete Reference:** <https://docs.python.org/3/reference/datamodel.html>

## 27 Class Documentation with Docstrings

Proper documentation is crucial for maintainable code. Python uses docstrings for documentation.

Python Operation	Magic Method	C++ Equivalent
obj = Class()	<code>__init__</code>	Constructor
del obj	<code>__del__</code>	Destructor
str(obj)	<code>__str__</code>	N/A
repr(obj)	<code>__repr__</code>	N/A
a + b	<code>__add__</code>	operator+
a - b	<code>__sub__</code>	operator-
a * b	<code>__mul__</code>	operator*
a / b	<code>__truediv__</code>	operator/
a // b	<code>__floordiv__</code>	N/A
a % b	<code>__mod__</code>	operator%
a ** b	<code>__pow__</code>	N/A
a == b	<code>__eq__</code>	operator==
a != b	<code>__ne__</code>	operator!=
a < b	<code>__lt__</code>	operator<
a <= b	<code>__le__</code>	operator<=
a > b	<code>__gt__</code>	operator>
a >= b	<code>__ge__</code>	operator>=
len(obj)	<code>__len__</code>	N/A
obj[key]	<code>__getitem__</code>	operator[]
obj[key] = val	<code>__setitem__</code>	operator[]
del obj[key]	<code>__delitem__</code>	N/A
item in obj	<code>__contains__</code>	N/A
for x in obj	<code>__iter__</code>	N/A

Table 2: Common magic methods and their uses

## 27.1 Class and Method Docstrings

```

1 class Point:
2     """A simple two-dimensional Cartesian coordinate point.
3
4     This class represents a point in 2D space with x and y coordinates
5     .
6     It provides methods for common operations like scaling and
7     computing
8     distance.
9
10    Attributes:
11        _x: The x coordinate (private by convention)
12        _y: The y coordinate (private by convention)
13
14    Examples:
15        >>> p1 = Point(3, 4)
16        >>> p2 = Point(0, 0)
17        >>> p1.distance_to(p2)
18        5.0
19    """
20
21    # Class variable
22    dimensions = 2
23
24    def __init__(self, x, y):

```

```

23     """Create a point from two Cartesian coordinates.
24
25     Args:
26         x (float): The x coordinate
27         y (float): The y coordinate
28
29     Raises:
30         TypeError: If x or y are not numeric
31     """
32     self._x = float(x)
33     self._y = float(y)
34
35 def scale(self, sx=1, sy=1):
36     """Scale the point by factors in x and y directions.
37
38     Multiplies the x coordinate by sx and the y coordinate by sy.
39
40     Args:
41         sx (float): Scale factor for x direction (default: 1)
42         sy (float): Scale factor for y direction (default: 1)
43
44     Examples:
45         >>> p = Point(2, 3)
46         >>> p.scale(2, 3)
47         >>> print(p)
48         Point(4.0, 9.0)
49     """
50     self._x *= sx
51     self._y *= sy
52
53 def distance_to(self, other):
54     """Calculate Euclidean distance to another point.
55
56     Args:
57         other (Point): The point to measure distance to
58
59     Returns:
60         float: The Euclidean distance between the two points
61
62     Examples:
63         >>> p1 = Point(0, 0)
64         >>> p2 = Point(3, 4)
65         >>> p1.distance_to(p2)
66         5.0
67     """
68     dx = self._x - other._x
69     dy = self._y - other._y
70     return (dx**2 + dy**2)**0.5
71
72 def __str__(self):
73     """Return informal string representation."""
74     return f"Point({self._x}, {self._y})"

```

Listing 142: Comprehensive class documentation

## 27.2 Docstring Conventions

**PEP 257 - Docstring Conventions:** <https://www.python.org/dev/peps/pep-0257/>

### Key Rules:

- Use triple double quotes: `"""docstring"""`
- First line is a brief summary
- Blank line separates summary from detailed description
- Document all public modules, functions, classes, and methods
- Use imperative mood ("Return the..." not "Returns the...")

### Popular Docstring Styles:

1. **NumPy Style:** Used extensively in scientific Python
2. **Google Style:** Clear and readable
3. **Sphinx/reStructuredText:** For generating documentation

### Accessing Docstrings:

```
1 # Get class docstring
2 print(Point.__doc__)
3
4 # Get method docstring
5 print(Point.scale.__doc__)
6
7 # Use help() function
8 help(Point)
9 help(Point.scale)
10
11 # In IPython
12 # Point?
13 # Point.scale?
```

Listing 143: Accessing documentation

## 28 Inheritance

Inheritance allows classes to derive behavior from parent classes while adding or overriding functionality.

### 28.1 Basic Inheritance

```
1 class Animal:
2     """Base class for animals."""
3
4     def __init__(self, name, age):
5         """Initialize animal.
6
7         Args:
8             name: Animal's name
9             age: Animal's age
```

```

10     """
11     self.name = name
12     self.age = age
13
14     def speak(self):
15         """Make the animal speak."""
16         return "Some sound"
17
18     def info(self):
19         """Return animal information."""
20         return f"{self.name} is {self.age} years old"
21
22
23 class Dog(Animal):
24     """Dog class inheriting from Animal."""
25
26     def __init__(self, name, age, breed):
27         """Initialize dog.
28
29         Args:
30             name: Dog's name
31             age: Dog's age
32             breed: Dog's breed
33         """
34         # Call parent constructor
35         super().__init__(name, age)
36         self.breed = breed
37
38     def speak(self):
39         """Override speak method."""
40         return "Woof!"
41
42     def fetch(self):
43         """Dog-specific method."""
44         return f"{self.name} is fetching the ball!"
45
46
47 class Cat(Animal):
48     """Cat class inheriting from Animal."""
49
50     def __init__(self, name, age, color):
51         """Initialize cat."""
52         super().__init__(name, age)
53         self.color = color
54
55     def speak(self):
56         """Override speak method."""
57         return "Meow!"
58
59 # Usage
60 dog = Dog("Rex", 3, "Labrador")
61 cat = Cat("Whiskers", 2, "Orange")
62
63 print(dog.name)           # Inherited attribute
64 print(dog.info())         # Inherited method
65 print(dog.speak())        # Overridden method: "Woof!"
66 print(dog.fetch())        # Dog-specific method

```

```

67
68 print(cat.speak())      # "Meow!"
69 print(cat.info())      # Inherited method

```

Listing 144: Basic class inheritance

## 28.2 The super() Function

**Critical:** In Python, the parent class constructor is NOT called automatically. You must explicitly call it using `super()`.

```

1 class A:
2     """Base class."""
3
4     def __init__(self):
5         self.a = 1
6         print("A.__init__ called")
7
8     def print_A(self):
9         print(f"a = {self.a}")
10
11
12 class B(A):
13     """Derived class."""
14
15     def __init__(self):
16         # MUST call parent constructor explicitly
17         super().__init__()
18         # Now self.a exists
19         self.b = 2
20         print("B.__init__ called")
21
22     def print_B(self):
23         print(f"b = {self.b}")
24
25
26 # Create instance
27 b = B()
28 # Output:
29 # A.__init__ called
30 # B.__init__ called
31
32 b.print_A()  # 1 (inherited method)
33 b.print_B()  # 2 (own method)
34 print(b.a)   # 1 (inherited attribute)
35 print(b.b)   # 2 (own attribute)

```

Listing 145: Using `super()` to call parent methods

### What happens if you forget `super()`?

```

1 class B_Wrong(A):
2     def __init__(self):
3         # Forgot super().__init__()!
4         self.b = 2
5
6 b = B_Wrong()

```



```

7 # b.print_A() # AttributeError: 'B_Wrong' object has no attribute 'a'
8 print(b.b)    # 2 (own attribute exists)

```

Listing 146: Forgetting to call super()

## 28.3 Multiple Inheritance

Python supports multiple inheritance:

```

1 class Flyer:
2     """Mixin for flying ability."""
3
4     def fly(self):
5         return f"{self.name} is flying!"
6
7
8 class Swimmer:
9     """Mixin for swimming ability."""
10
11     def swim(self):
12         return f"{self.name} is swimming!"
13
14
15 class Duck(Animal, Flyer, Swimmer):
16     """Duck can fly and swim."""
17
18     def __init__(self, name, age):
19         super().__init__(name, age)
20
21     def speak(self):
22         return "Quack!"
23
24 # Usage
25 duck = Duck("Donald", 5)
26 print(duck.speak()) # "Quack!"
27 print(duck.fly())   # "Donald is flying!"
28 print(duck.swim())  # "Donald is swimming!"
29 print(duck.info())  # Inherited from Animal

```

Listing 147: Multiple inheritance

**Method Resolution Order (MRO):** Python uses the C3 linearization algorithm to determine method lookup order:

```

1 # View MRO
2 print(Duck.__mro__)
3 # (<class 'Duck'>, <class 'Animal'>, <class 'Flyer'>,
4 #  <class 'Swimmer'>, <class 'object'>)
5
6 # Or use mro() method
7 print(Duck.mro())

```

Listing 148: Viewing method resolution order

## 29 Decorators

Decorators are a powerful Python feature that allow you to modify the behavior of functions or classes.

### 29.1 Understanding Decorators

A decorator is a function that takes another function as input and returns a modified version of it.

```
1 def my_decorator(func):
2     """A simple decorator."""
3     def wrapper():
4         print("Something before the function")
5         func()
6         print("Something after the function")
7     return wrapper
8
9 # Apply decorator manually
10 def say_hello():
11     print("Hello!")
12
13 say_hello = my_decorator(say_hello)
14 say_hello()
15 # Output:
16 # Something before the function
17 # Hello!
18 # Something after the function
19
20 # Or use @ syntax (preferred)
21 @my_decorator
22 def say_goodbye():
23     print("Goodbye!")
24
25 say_goodbye()
26 # Output:
27 # Something before the function
28 # Goodbye!
29 # Something after the function
```

Listing 149: Basic decorator example

### 29.2 Decorators with Arguments

```
1 def smart_decorator(func):
2     """Decorator that preserves function arguments."""
3     def wrapper(*args, **kwargs):
4         print(f"Calling {func.__name__}")
5         result = func(*args, **kwargs)
6         print(f"{func.__name__} returned {result}")
7         return result
8     return wrapper
9
10 @smart_decorator
```

```

11 def add(a, b):
12     return a + b
13
14 result = add(3, 5)
15 # Output:
16 # Calling add
17 # add returned 8
18 print(result) # 8

```

Listing 150: Decorators handling function arguments

## 29.3 Practical Decorator Examples

### Timing Decorator:

```

1 import time
2
3 def timer(func):
4     """Measure execution time of function."""
5     def wrapper(*args, **kwargs):
6         start = time.time()
7         result = func(*args, **kwargs)
8         end = time.time()
9         print(f"{func.__name__} took {end - start:.4f} seconds")
10        return result
11    return wrapper
12
13 @timer
14 def slow_function():
15     time.sleep(1)
16     return "Done"
17
18 result = slow_function()
19 # Output: slow_function took 1.0001 seconds

```

Listing 151: Timing function execution

### Memoization Decorator:

```

1 def memoize(func):
2     """Cache function results."""
3     cache = {}
4     def wrapper(*args):
5         if args not in cache:
6             cache[args] = func(*args)
7         return cache[args]
8     return wrapper
9
10 @memoize
11 def fibonacci(n):
12     """Compute nth Fibonacci number."""
13     if n < 2:
14         return n
15     return fibonacci(n-1) + fibonacci(n-2)
16
17 # Much faster with memoization

```

```
18 print(fibonacci(100)) # Completes quickly!
```

Listing 152: Caching function results

## 30 Built-In Decorators for Classes

Python provides several built-in decorators specifically for use in classes.

### 30.1 @staticmethod

Static methods don't receive the instance (`self`) as the first argument:

```
1 class MathUtils:
2     """Utility class for math operations."""
3
4     @staticmethod
5     def add(a, b):
6         """Add two numbers.
7
8         No access to instance or class.
9         """
10        return a + b
11
12    @staticmethod
13    def multiply(a, b):
14        """Multiply two numbers."""
15        return a * b
16
17 # Call without creating instance
18 result = MathUtils.add(5, 3) # 8
19
20 # Can also call on instance (but unusual)
21 utils = MathUtils()
22 result = utils.multiply(4, 7) # 28
```

Listing 153: Using @staticmethod

#### Use Cases for @staticmethod:

- Utility functions related to the class
- Functions that don't need instance or class data
- Grouping related functions in a namespace

### 30.2 @classmethod

Class methods receive the class (not instance) as first argument:

```
1 class Point:
2     """Point with alternative constructors."""
3
4     def __init__(self, x, y):
5         self.x = x
6         self.y = y
7
8     @classmethod
```

```

9     def from_tuple(cls, coords):
10         """Create point from tuple.
11
12         Args:
13             coords: Tuple of (x, y)
14
15         Returns:
16             New Point instance
17         """
18         return cls(coords[0], coords[1])
19
20     @classmethod
21     def origin(cls):
22         """Create point at origin."""
23         return cls(0, 0)
24
25     @classmethod
26     def name(cls):
27         """Return class name."""
28         return cls.__name__
29
30 # Use alternative constructors
31 p1 = Point.from_tuple((3, 4))
32 p2 = Point.origin()
33
34 print(Point.name()) # "Point"

```

Listing 154: Using @classmethod

**Convention:** Use `cls` as the first parameter name for class methods (analogous to `self` for instance methods).

**Use Cases for @classmethod:**

- Alternative constructors (factory methods)
- Methods that work with class variables
- Methods that need access to the class itself

### 30.3 @property

Properties allow you to define methods that are accessed like attributes:

```

1 class Temperature:
2     """Temperature with Celsius and Fahrenheit conversions."""
3
4     def __init__(self, celsius):
5         self._celsius = celsius
6
7     @property
8     def celsius(self):
9         """Get temperature in Celsius."""
10        return self._celsius
11
12    @celsius.setter
13    def celsius(self, value):
14        """Set temperature in Celsius with validation."""
15        if value < -273.15:
16            raise ValueError("Temperature below absolute zero!")

```

```

17         self._celsius = value
18
19     @property
20     def fahrenheit(self):
21         """Get temperature in Fahrenheit (computed)."""
22         return self._celsius * 9/5 + 32
23
24     @fahrenheit.setter
25     def fahrenheit(self, value):
26         """Set temperature via Fahrenheit."""
27         self.celsius = (value - 32) * 5/9
28
29 # Usage - looks like attribute access
30 temp = Temperature(25)
31 print(temp.celsius)      # 25 (calls getter)
32 print(temp.fahrenheit)  # 77.0 (computed)
33
34 temp.celsius = 30        # Calls setter
35 print(temp.fahrenheit)  # 86.0
36
37 temp.fahrenheit = 32     # Sets via Fahrenheit
38 print(temp.celsius)     # 0.0
39
40 # temp.celsius = -300    # Raises ValueError

```

Listing 155: Using @property for computed attributes

### More Complex Example:

```

1 class Point:
2     """Point with properties."""
3
4     def __init__(self, x, y):
5         self._x = x
6         self._y = y
7
8     @property
9     def x(self):
10        """The point's x coordinate."""
11        return self._x
12
13    @x.setter
14    def x(self, value):
15        """Set x coordinate."""
16        self._x = value
17
18    @property
19    def y(self):
20        """The point's y coordinate."""
21        return self._y
22
23    @y.setter
24    def y(self, value):
25        """Set y coordinate."""
26        self._y = value
27
28    @property
29    def magnitude(self):

```

```

30         """Distance from origin (read-only)."""
31         return (self._x**2 + self._y**2)**0.5
32
33 p = Point(3, 4)
34 print(p.x)           # 3
35 print(p.magnitude)   # 5.0
36
37 p.x = 5
38 print(p.magnitude)   # 6.4031...
39
40 # p.magnitude = 10 # AttributeError - no setter defined

```

Listing 156: Property with validation and computation

#### Benefits of @property:

- Provides computed attributes
- Adds validation to attribute setting
- Can make read-only attributes
- Allows changing implementation without breaking interface
- Cleaner syntax than getter/setter methods

## 31 Modules and Code Organization

As programs grow, organizing code into modules becomes essential.

### 31.1 What is a Module?

A **module** is simply a Python file containing definitions (functions, classes, variables). The filename becomes the module name.

#### Example Module (mymath.py):

```

1  """Mathematical utility functions.
2
3  This module provides basic mathematical operations.
4  """
5
6  PI = 3.14159265359
7
8  def square(x):
9      """Return the square of x."""
10     return x ** 2
11
12 def cube(x):
13     """Return the cube of x."""
14     return x ** 3
15
16 class Circle:
17     """Represent a circle."""
18
19     def __init__(self, radius):
20         self.radius = radius
21
22     def area(self):
23         """Calculate area."""

```

```

24         return PI * self.radius ** 2
25
26 if __name__ == "__main__":
27     # This code only runs if module is executed directly
28     print("Testing mymath module")
29     print(f"square(5) = {square(5)}")
30     print(f"cube(3) = {cube(3)}")

```

Listing 157: A simple module - mymath.py

## 31.2 Importing Modules

### Method 1: Import Entire Module

```

1 import mymath
2
3 result = mymath.square(5)
4 circle = mymath.Circle(10)
5 print(mymath.PI)

```

Listing 158: Importing entire module

### Method 2: Import with Alias

```

1 import mymath as mm
2
3 result = mm.square(5)
4 print(mm.PI)

```

Listing 159: Importing with alias

### Method 3: Import Specific Items

```

1 from mymath import square, Circle
2
3 result = square(5) # Use directly without module name
4 circle = Circle(10)
5 # print(PI) # NameError - PI not imported

```

Listing 160: Importing specific items

### Method 4: Import Everything (Not Recommended)

```

1 from mymath import *
2
3 result = square(5)
4 circle = Circle(10)
5 print(PI)
6
7 # Warning: Can cause name conflicts and makes code less clear

```

Listing 161: Importing everything - use with caution

## 31.3 Module Search Path

Python searches for modules in this order:

1. Current directory



2. Directories in PYTHONPATH environment variable
3. Standard library directories
4. Site-packages directories (third-party packages)

```

1 import sys
2 print(sys.path)
3 # ['', '/usr/lib/python3.10', '/usr/lib/python3.10/site-packages',
   ...]

```

Listing 162: Viewing the module search path

### 31.4 Packages

A **package** is a directory containing Python modules and a special `__init__.py` file:

**Package Structure:**

```

mypackage/
  __init__.py
  module1.py
  module2.py
  subpackage/
    __init__.py
    module3.py

```

**Importing from Packages:**

```

1 # Import module from package
2 import mypackage.module1
3
4 # Import specific item from module in package
5 from mypackage.module1 import my_function
6
7 # Import from subpackage
8 from mypackage.subpackage.module3 import MyClass

```

Listing 163: Importing from packages

### 31.5 The `__init__.py` File

The `__init__.py` file:

- Marks a directory as a Python package
- Can be empty
- Can contain package initialization code
- Can define `__all__` to control `from package import *`

**Example `__init__.py`:**

```

1 """MyPackage - A collection of utilities.
2
3 This package provides mathematical and string utilities.

```

```

4 """
5
6 # Import commonly used items to package level
7 from .module1 import important_function
8 from .module2 import ImportantClass
9
10 # Define what gets imported with 'from mypackage import *'
11 __all__ = ['important_function', 'ImportantClass']
12
13 # Package version
14 __version__ = '1.0.0'

```

Listing 164: Package initialization file

## 32 Executing Modules as Scripts

Python modules can be both imported and executed as standalone scripts.

### 32.1 The `__name__` Variable

Python sets the `__name__` variable differently depending on how the file is used:

- When **executed directly**: `__name__ == "__main__"`
- When **imported**: `__name__ == module_name`

```

1 """whats_the_point.py - Demonstrate Point class usage."""
2
3 import point # Import our point module
4 import sys
5
6 def demonstrate_points():
7     """Demonstrate point operations."""
8     p1 = point.Point(1., 2.)
9     p2 = point.Point(0., 7.)
10    p3 = p1 + p2
11    print(f"p1 + p2 = {p3}")
12
13 if __name__ == "__main__":
14     # This code only runs when executed directly
15     print("Running whats_the_point.py as script")
16
17     # Can access command-line arguments
18     if len(sys.argv) > 1:
19         y_coord = int(sys.argv[1])
20         p1 = point.Point(1., y_coord)
21     else:
22         p1 = point.Point(1., 2.)
23
24     p2 = point.Point(0., 7.)
25     p3 = p1 + p2
26     print(f"Result: {p3}")
27 else:
28     # This code runs when imported

```

```
29 print("whats_the_point module imported")
```

Listing 165: Dual-use module with *name\_check*

### Running as Script:

```
1 $ python whats_the_point.py
2 Running whats_the_point.py as script
3 Result: (1.0, 9.0)
4
5 $ python whats_the_point.py 5
6 Running whats_the_point.py as script
7 Result: (1.0, 12.0)
```

### Importing as Module:

```
1 import whats_the_point
2 # Output: whats_the_point module imported
3
4 whats_the_point.demonstrate_points()
5 # Uses the functions, but __main__ block didn't run
```

Listing 166: When imported, main block doesn't run

## 32.2 Command-Line Arguments

Access command-line arguments via `sys.argv`:

```
1 import sys
2
3 def main():
4     """Main program function."""
5     print(f"Script name: {sys.argv[0]}")
6     print(f"Number of arguments: {len(sys.argv) - 1}")
7
8     if len(sys.argv) < 2:
9         print("Usage: python script.py <name> [age]")
10        sys.exit(1)
11
12    name = sys.argv[1]
13    age = int(sys.argv[2]) if len(sys.argv) > 2 else None
14
15    print(f"Hello, {name}!")
16    if age:
17        print(f"You are {age} years old.")
18
19 if __name__ == "__main__":
20    main()
```

Listing 167: Handling command-line arguments

### Better Approach: argparse Module

For complex command-line interfaces, use the `argparse` module:

```
1 import argparse
2
3 def main():
4     """Main program with argument parsing."""
5     parser = argparse.ArgumentParser()
```

```

6         description='Process some integers.'
7     )
8
9     parser.add_argument('name', help='Your name')
10    parser.add_argument('-a', '--age', type=int, help='Your age')
11    parser.add_argument('-v', '--verbose', action='store_true',
12                        help='Verbose output')
13
14    args = parser.parse_args()
15
16    print(f"Hello, {args.name}!")
17    if args.age:
18        print(f"You are {args.age} years old.")
19    if args.verbose:
20        print("Verbose mode enabled")
21
22 if __name__ == "__main__":
23     main()

```

Listing 168: Using argparse for command-line arguments

#### Usage:

```

1 $ python script.py Alice --age 30 --verbose
2 Hello, Alice!
3 You are 30 years old.
4 Verbose mode enabled
5
6 $ python script.py --help
7 usage: script.py [-h] [-a AGE] [-v] name
8 ...

```

**Reference:** <https://docs.python.org/3/library/argparse.html>

## 33 String Formatting

Python provides multiple methods for formatting strings, with f-strings being the modern recommended approach.

### 33.1 F-Strings (Format String Literals)

**Introduced in Python 3.6**, f-strings are the most readable and performant method:

```

1 import math
2
3 # Basic usage
4 name = "Alice"
5 age = 30
6 print(f"My name is {name} and I am {age} years old")
7
8 # Expressions inside braces
9 x = 10
10 y = 20
11 print(f"{x} + {y} = {x + y}") # "10 + 20 = 30"
12

```

```

13 # Format specifications
14 pi = math.pi
15 print(f"Pi = {pi:.2f}")      # "Pi = 3.14"
16 print(f"Pi = {pi:10.4f}")    # "Pi =      3.1416" (10 chars wide)
17
18 # Padding with zeros
19 number = 42
20 print(f"{number:05d}")       # "00042"
21
22 # Alignment
23 text = "hello"
24 print(f"{text:<10}")         # "hello      " (left-aligned)
25 print(f"{text:>10}")         # "      hello" (right-aligned)
26 print(f"{text:^10}")         # "  hello   " (centered)
27
28 # Number formatting
29 value = 1234567.89
30 print(f"{value:,.2f}")       # "1,234,567.89" (thousands separator)
31 print(f"{value:e}")          # "1.234568e+06" (scientific notation)
32
33 # Percentage
34 fraction = 0.85
35 print(f"{fraction:.1%}")     # "85.0%"
36
37 # Debug feature (Python 3.8+)
38 x = 42
39 print(f"{x = }")             # "x = 42"
40 print(f"{x = :5.2f}")         # "x = 42.00"

```

Listing 169: F-string formatting examples

## 33.2 Format String Method

The `.format()` method (Python 2.6+):

```

1 import math
2
3 # Positional arguments
4 print("{} + {} = {}".format(10, 20, 30)) # "10 + 20 = 30"
5
6 # Named arguments
7 print("{name} is {age} years old".format(name="Bob", age=25))
8
9 # Indexed arguments
10 print("{0} {1} {0}".format("hello", "world")) # "hello world hello"
11
12 # Format specifications
13 print("{:.2f}".format(math.pi)) # "3.14"
14 print("{:05d}".format(42))      # "00042"
15
16 # Number formatting
17 print("{:,.2f}".format(1234567.89)) # "1,234,567.89"

```

Listing 170: String format() method

### 33.3 Old-Style Formatting (printf-style)

C-style formatting (legacy, still works):

```
1 import math
2
3 # Basic usage
4 print("%s is %d years old" % ("Charlie", 35))
5
6 # Format specifications
7 print("%3.1f %4.2f" % (math.e, math.pi)) # "2.7 3.14"
8
9 # Multiple values
10 print("Name: %s, Age: %d, GPA: %.2f" % ("Diana", 20, 3.85))
11
12 # Padding
13 print("%05d" % 42) # "00042"
```

Listing 171: Old-style % formatting

### 33.4 Format Specification Mini-Language

**General Format:** {value:fill align sign width .precision type}

**Components:**

- **fill:** Character to use for padding (default: space)
- **align:** < (left), > (right), ^ (center), = (after sign)
- **sign:** + (always), - (negatives only), (space) (space for positive)
- **width:** Minimum field width
- **precision:** Number of decimal places (for floats) or max length (for strings)
- **type:** d (int), f (float), e (scientific), s (string), etc.

```
1 # Different types
2 print(f"{42:d}") # Integer: "42"
3 print(f"{42:b}") # Binary: "101010"
4 print(f"{42:x}") # Hexadecimal: "2a"
5 print(f"{42:o}") # Octal: "52"
6
7 # Floating point
8 print(f"{3.14159:f}") # Fixed point: "3.141590"
9 print(f"{3.14159:.2f}") # Two decimals: "3.14"
10 print(f"{3.14159:e}") # Scientific: "3.141590e+00"
11
12 # Alignment and padding
13 print(f"{'test':*<10}") # "test*****"
14 print(f"{'test':*>10}") # "*****test"
15 print(f"{'test':*^10}") # "****test***"
16
17 # Numbers with signs
18 print(f"{42:+d}") # "+42"
19 print(f"{-42:+d}") # "-42"
20 print(f"{42: d}") # " 42" (space for positive)
```

Listing 172: Format specification examples

**Complete Reference:**

- <https://docs.python.org/3/tutorial/inputoutput.html#fancier-output-formatting>
- <https://docs.python.org/3/library/string.html#formatspec>

## 34 File Input/Output

Working with files is essential for reading data, saving results, and persisting program state.

### 34.1 Opening Files

#### Basic Syntax:

```
1 # Open file
2 f = open("filename.txt", "r") # 'r' for read mode
3 # ... use file ...
4 f.close() # Always close when done!
```

Listing 173: Opening files with open()

#### File Modes:

- 'r': Read (default) - file must exist
- 'w': Write - creates new file or overwrites existing
- 'a': Append - adds to end of file
- 'x': Exclusive creation - fails if file exists
- 'r+': Read and write
- 'rb': Read binary
- 'wb': Write binary
- 'ab': Append binary

### 34.2 Writing to Files

```
1 # Write mode (overwrites existing file)
2 f = open("output.txt", "w")
3 f.write("Hello, World!\n")
4 f.write("Second line\n")
5 f.close()
6
7 # Append mode (adds to existing file)
8 f = open("output.txt", "a")
9 f.write("Third line\n")
10 f.close()
11
12 # Writing multiple lines
13 lines = ["Line 1\n", "Line 2\n", "Line 3\n"]
14 f = open("output.txt", "w")
15 f.writelines(lines)
16 f.close()
```

Listing 174: Writing to files

### 34.3 Reading from Files

```
1 # Read entire file
2 f = open("input.txt", "r")
3 content = f.read()
4 f.close()
5 print(content)
6
7 # Read line by line
8 f = open("input.txt", "r")
9 for line in f:
10     print(line.strip()) # strip() removes trailing newline
11 f.close()
12
13 # Read one line
14 f = open("input.txt", "r")
15 first_line = f.readline()
16 second_line = f.readline()
17 f.close()
18
19 # Read all lines into list
20 f = open("input.txt", "r")
21 lines = f.readlines()
22 f.close()
23 print(lines) # List of strings, each ending with \n
```

Listing 175: Reading from files

### 34.4 Context Managers: The with Statement

**Best Practice:** Always use the with statement for file operations:

```
1 # File automatically closed, even if exception occurs
2 with open("data.txt", "r") as f:
3     content = f.read()
4     # Process content
5 # File is automatically closed here
6
7 # Multiple files
8 with open("input.txt", "r") as infile, \
9     open("output.txt", "w") as outfile:
10     for line in infile:
11         outfile.write(line.upper())
12 # Both files automatically closed
13
14 # Writing
15 with open("numbers.txt", "w") as f:
16     for i in range(10):
17         f.write(f"{i}\n")
```

Listing 176: Using with statement for file handling

#### Why Use with?

- Automatically closes file, even if exception occurs
- Cleaner code (no explicit close needed)
- Prevents resource leaks



- Pythonic and recommended approach

## 34.5 Complete File I/O Examples

### Reading and Processing CSV:

```

1 # Simple CSV processing
2 with open("data.csv", "r") as f:
3     for line in f:
4         fields = line.strip().split(",")
5         # Process fields
6         print(fields)
7
8 # Better: use csv module
9 import csv
10
11 with open("data.csv", "r") as f:
12     reader = csv.reader(f)
13     headers = next(reader) # First row
14     for row in reader:
15         print(dict(zip(headers, row)))

```

Listing 177: Processing CSV files

### Reading and Writing JSON:

```

1 import json
2
3 # Write JSON
4 data = {
5     "name": "Alice",
6     "age": 30,
7     "scores": [85, 90, 95]
8 }
9
10 with open("data.json", "w") as f:
11     json.dump(data, f, indent=2)
12
13 # Read JSON
14 with open("data.json", "r") as f:
15     loaded_data = json.load(f)
16     print(loaded_data["name"])

```

Listing 178: JSON file operations

### Binary Files:

```

1 # Write binary
2 data = b"\x00\x01\x02\x03"
3 with open("data.bin", "wb") as f:
4     f.write(data)
5
6 # Read binary
7 with open("data.bin", "rb") as f:
8     data = f.read()
9     print(data) # b'\x00\x01\x02\x03'

```

Listing 179: Binary file operations

## 34.6 File Path Operations

Use `pathlib` for modern path handling:

```
1 from pathlib import Path
2
3 # Create path object
4 path = Path("data") / "files" / "input.txt"
5
6 # Check if file exists
7 if path.exists():
8     print("File exists")
9
10 # Get file information
11 print(path.name)      # "input.txt"
12 print(path.stem)      # "input"
13 print(path.suffix)     # ".txt"
14 print(path.parent)    # Path("data/files")
15
16 # Read/write with pathlib
17 content = path.read_text()
18 path.write_text("New content")
19
20 # Iterate over directory
21 data_dir = Path("data")
22 for file in data_dir.glob("*.txt"):
23     print(file)
```

Listing 180: Using `pathlib` for file paths

## 35 Exception Handling

Exceptions provide a mechanism for handling errors gracefully rather than crashing the program.

### 35.1 Understanding Exceptions

**The Concept:**

1. Function encounters error or exceptional condition
2. Cannot handle it locally
3. **Raises** (throws) an exception
4. Calling code can **catch** (except) the exception
5. If not caught, program terminates with traceback

### 35.2 Basic Exception Handling

```

1 try:
2     # Code that might raise exception
3     result = 10 / 0
4 except ZeroDivisionError:
5     # Handle specific exception
6     print("Cannot divide by zero!")
7     result = None
8
9 print(f"Result: {result}")

```

Listing 181: Basic try-except structure

### 35.3 Catching Multiple Exceptions

```

1 def safe_divide(a, b):
2     """Divide a by b with error handling."""
3     try:
4         result = a / b
5         return result
6     except ZeroDivisionError:
7         print("Error: Division by zero")
8         return None
9     except TypeError:
10        print("Error: Invalid types for division")
11        return None
12
13 # Test
14 print(safe_divide(10, 2))      # 5.0
15 print(safe_divide(10, 0))      # Error message, returns None
16 print(safe_divide(10, "2"))    # Error message, returns None
17
18 # Multiple exceptions in one except clause
19 def process_value(x):
20     try:
21         return int(x) * 2
22     except (ValueError, TypeError):
23         print("Error: Cannot convert to integer")
24         return None

```

Listing 182: Handling multiple exception types

### 35.4 Complete Exception Handling Structure

```

1 def read_number_from_file(filename):
2     """Read number from file with complete error handling."""
3     result = None
4
5     try:
6         # Code that might raise exception
7         with open(filename, "r") as f:
8             content = f.read().strip()
9             result = int(content)
10
11    except FileNotFoundError:

```

```

12     # Specific exception
13     print(f"File {filename} not found")
14
15     except ValueError:
16         # Another specific exception
17         print("File doesn't contain a valid number")
18
19     except Exception as e:
20         # Catch any other exception
21         print(f"Unexpected error: {e}")
22
23     else:
24         # Executes if NO exception occurred
25         print("Successfully read number")
26
27     finally:
28         # ALWAYS executes (cleanup code)
29         print("Finished processing file")
30
31     return result
32
33 # Test
34 number = read_number_from_file("data.txt")

```

Listing 183: Full try-except-else-finally structure

#### Execution Flow:

- try: Code that might raise exception
- except: Handles specific exception types
- else: Runs only if NO exception occurred
- finally: ALWAYS runs (for cleanup), even if exception occurs

## 35.5 Accessing Exception Information

```

1 try:
2     x = int("not a number")
3 except ValueError as e:
4     # Access exception object
5     print(f"Error occurred: {e}")
6     print(f"Exception type: {type(e).__name__}")
7
8 # Getting full traceback
9 import traceback
10
11 try:
12     result = 1 / 0
13 except ZeroDivisionError:
14     # Print full traceback
15     traceback.print_exc()

```

Listing 184: Getting exception details

## 35.6 Raising Exceptions

Functions can raise exceptions:

```

1 def validate_age(age):
2     """Validate age is positive."""
3     if age < 0:
4         raise ValueError("Age cannot be negative")
5     if age > 150:
6         raise ValueError("Age is unrealistically high")
7     return True
8
9 try:
10     validate_age(-5)
11 except ValueError as e:
12     print(f"Validation error: {e}")
13
14 # Re-raising exceptions
15 def process_file(filename):
16     """Process file with logging."""
17     try:
18         with open(filename) as f:
19             return f.read()
20     except FileNotFoundError:
21         print(f"Logging: {filename} not found")
22         raise # Re-raise the same exception

```

Listing 185: Raising exceptions

## 35.7 Common Built-In Exceptions

- Exception: Base class for all exceptions
- ValueError: Invalid value (e.g., `int("abc")`)
- TypeError: Wrong type (e.g., `"text" + 5`)
- KeyError: Dictionary key not found
- IndexError: List index out of range
- FileNotFoundError: File doesn't exist
- ZeroDivisionError: Division by zero
- AttributeError: Attribute doesn't exist
- ImportError: Module not found
- RuntimeError: Generic runtime error

## 35.8 Custom Exceptions

```

1 class InsufficientFundsError(Exception):
2     """Raised when withdrawal exceeds balance."""
3     pass
4
5 class BankAccount:
6     """Bank account with custom exceptions."""
7
8     def __init__(self, balance=0):
9         self.balance = balance
10
11     def withdraw(self, amount):
12         """Withdraw money, raise exception if insufficient funds."""
13         if amount > self.balance:

```

```

14         raise InsufficientFundsError(
15             f"Cannot withdraw {amount}, balance is {self.balance}"
16         )
17         self.balance -= amount
18
19 # Usage
20 account = BankAccount(100)
21
22 try:
23     account.withdraw(150)
24 except InsufficientFundsError as e:
25     print(f"Transaction failed: {e}")

```

Listing 186: Creating custom exception classes

**Complete Reference:** <https://docs.python.org/3/library/exceptions.html>

## 36 Python Conventions and Best Practices

Following Python conventions ensures code is readable, maintainable, and Pythonic.

### 36.1 Naming Conventions

#### Variables and Functions:

```

1 # Variables: lowercase with underscores
2 user_name = "Alice"
3 total_count = 42
4 max_value = 100
5
6 # Functions: lowercase with underscores
7 def calculate_average(numbers):
8     return sum(numbers) / len(numbers)
9
10 def get_user_input():
11     return input("Enter value: ")

```

Listing 187: Variable and function naming

#### Constants:

```

1 # Constants: UPPERCASE with underscores
2 PI = 3.14159265359
3 MAX_CONNECTIONS = 100
4 DEFAULT_TIMEOUT = 30

```

Listing 188: Constant naming

#### Classes:

```

1 # Classes: CapitalizedWords (PascalCase)
2 class BankAccount:
3     pass
4
5 class UserProfile:

```

```

6     pass
7
8 class HTTPConnection:
9     pass

```

Listing 189: Class naming

#### Private/Internal:

```

1 class MyClass:
2     def __init__(self):
3         self._internal = "semi-private"    # Single underscore
4         self.__private = "name mangled"    # Double underscore
5
6     def _internal_method(self):
7         """Internal method, not part of public API."""
8         pass

```

Listing 190: Private naming convention

## 36.2 Important Naming Conventions

#### Standard Parameter Names:

- `self`: First parameter of instance methods
- `cls`: First parameter of class methods
- `args`: Variable positional arguments
- `kwargs`: Variable keyword arguments

```

1 class Example:
2     def instance_method(self, value):
3         """self refers to instance."""
4         pass
5
6     @classmethod
7     def class_method(cls, value):
8         """cls refers to class."""
9         pass
10
11     def flexible_method(self, *args, **kwargs):
12         """Accept variable arguments."""
13         pass

```

Listing 191: Standard parameter naming

## 36.3 The Zen of Python

Python's design philosophy, accessible via `import this`:

```

1 import this
2 # Output:
3 # Beautiful is better than ugly.
4 # Explicit is better than implicit.
5 # Simple is better than complex.
6 # Complex is better than complicated.
7 # Flat is better than nested.
8 # Sparse is better than dense.

```

```

9 # Readability counts.
10 # Special cases aren't special enough to break the rules.
11 # Although practicality beats purity.
12 # Errors should never pass silently.
13 # Unless explicitly silenced.
14 # In the face of ambiguity, refuse the temptation to guess.
15 # There should be one-- and preferably only one --obvious way to do it
16 # .
17 # Although that way may not be obvious at first unless you're Dutch.
18 # Now is better than never.
19 # Although never is often better than *right* now.
20 # If the implementation is hard to explain, it's a bad idea.
21 # If the implementation is easy to explain, it may be a good idea.
22 # Namespaces are one honking great idea -- let's do more of those!

```

Listing 192: The Zen of Python

## 36.4 PEP 8 Checklist

### Critical Rules:

1. Use 4 spaces per indentation level
2. NEVER use tabs
3. Maximum line length: 79 characters
4. Use blank lines to separate functions and classes
5. Use docstrings for all public modules, functions, classes, methods
6. Use spaces around operators and after commas
7. Name classes with CapitalizedWords
8. Name functions and variables with lowercase\_with\_underscores
9. Always use `self` for first method argument
10. Always use `cls` for first class method argument
11. Use UTF-8 encoding (default in Python 3)

## 36.5 Docstring Conventions - PEP 257

PEP 257: <https://www.python.org/dev/peps/pep-0257/>

```

1 def complex_function(arg1, arg2, option=None):
2     """Do something complex with arguments.
3
4     This is a more detailed explanation of what the function does.
5     It can span multiple paragraphs if needed.
6
7     Args:
8         arg1 (int): First argument description

```



```

9         arg2 (str): Second argument description
10        option (bool, optional): Optional parameter. Defaults to None.
11
12    Returns:
13        dict: Description of return value
14
15    Raises:
16        ValueError: If arg1 is negative
17        TypeError: If arg2 is not a string
18
19    Examples:
20        >>> complex_function(5, "test")
21        {'result': 'processed'}
22    """
23    if arg1 < 0:
24        raise ValueError("arg1 must be non-negative")
25    # Implementation...

```

Listing 193: Proper docstring formatting

## 36.6 Style Checking with pylint

**pylint** is a comprehensive code quality checker:

```

1 # Install
2 pip install pylint
3
4 # Check a file
5 pylint myfile.py
6
7 # Output includes:
8 # - Code style violations
9 # - Potential errors
10 # - Code smell detection
11 # - Complexity metrics
12 # - Overall score
13
14 # Generate config file
15 pylint --generate-rcfile > .pylintrc
16
17 # Disable specific warnings
18 # pylint: disable=line-too-long

```

Listing 194: Using pylint

## 36.7 Complementary Style Guides

Beyond PEP 8, organizations maintain their own guides:

### Google Python Style Guide:

- <https://google.github.io/styleguide/pyguide.html>
- Used across Google projects
- Extends PEP 8 with additional conventions

### NumPy Style Guide:

- <https://numpydoc.readthedocs.io/>

- Docstring conventions for scientific computing
- Used by NumPy, SciPy, and many scientific packages

## 37 Additional Resources and Further Learning

Python has extensive documentation and community resources for continued learning.

### 37.1 Official Python Documentation

#### Python Homepage:

- <https://www.python.org/>
- Downloads, news, community information

#### Python Tutorial:

- <https://docs.python.org/3/tutorial/index.html>
- Official beginner's guide
- Many examples in this document come from this tutorial
- Comprehensive introduction to Python concepts

#### Python Library Reference:

- <https://docs.python.org/3/library/index.html>
- Complete documentation for standard library
- Essential reference for built-in modules
- Includes usage examples

#### Python Language Reference:

- <https://docs.python.org/3/reference/index.html>
- Detailed language specification
- Explains how Python works internally
- For advanced users wanting deep understanding

### 37.2 Third-Party Packages

#### Python Package Index (PyPI):

- <https://pypi.org/>
- Over 500,000 packages
- Searchable repository
- Installation via pip

#### Key Scientific Packages:

- NumPy: <https://numpy.org/doc/>
- SciPy: <https://docs.scipy.org/>
- Matplotlib: <https://matplotlib.org/>
- pandas: <https://pandas.pydata.org/docs/>
- scikit-learn: <https://scikit-learn.org/>

### 37.3 Recommended Learning Path

#### For Beginners:

1. Start with official Python tutorial
2. Practice with simple programs
3. Learn one module at a time from standard library
4. Read and understand others' code
5. Contribute to open source projects

**For Scientific Computing:**

1. Master Python fundamentals
2. Learn NumPy thoroughly
3. Explore SciPy for specific needs
4. Master Matplotlib for visualization
5. Learn pandas for data analysis
6. Explore domain-specific packages

## 37.4 Community Resources

**Online Communities:**

- Stack Overflow: <https://stackoverflow.com/questions/tagged/python>
- Reddit: <https://www.reddit.com/r/Python/>
- Python Discord servers
- Local Python user groups

**Learning Platforms:**

- Real Python: <https://realpython.com/>
- Python Tutor (visualizes code execution): <https://pythontutor.com/>
- Codecademy, Coursera, edX courses

**Books:**

- "Python Crash Course" by Eric Matthes
- "Fluent Python" by Luciano Ramalho
- "Effective Python" by Brett Slatkin
- "Python Cookbook" by David Beazley

## 38 Summary and Conclusion

This comprehensive guide has covered the fundamental concepts of Python programming, from basic syntax to advanced object-oriented programming features.

## 38.1 Key Concepts Covered

### Language Fundamentals:

- Interpreted execution model
- Dynamic typing system
- Python 2 vs Python 3
- Installation across platforms

### Basic Syntax:

- Data types: integers, floats, strings, booleans, complex numbers
- Operators and expressions
- Comments and documentation
- Indentation-based structure

### Data Structures:

- Lists: mutable sequences
- Tuples: immutable sequences
- Dictionaries: key-value mappings
- Sets: unordered unique collections
- List and dictionary comprehensions

### Control Flow:

- Conditional statements (if-elif-else)
- Loops (while, for)
- Loop control (break, continue)
- Chained comparisons

### Functions:

- Function definition and calling
- Parameters: positional, keyword, default, variable-length
- Return values
- Lambda functions
- First-class functions

### Object-Oriented Programming:

- Class definition and instantiation
- Instance and class variables
- Methods and properties
- Inheritance and super()
- Magic methods
- Decorators

### Advanced Topics:

- Pass by assignment
- Mutability vs immutability
- Shallow and deep copying
- Module system
- Exception handling
- File I/O
- String formatting

### Best Practices:

- PEP 8 style guide

- Docstring conventions
- Code organization
- Use of tools (formatters, linters)

## 38.2 Python's Philosophy

Python emphasizes:

- **Readability:** Code should be easy to read and understand
- **Simplicity:** Simple solutions are preferred over complex ones
- **Explicitness:** Explicit is better than implicit
- **Practicality:** Pragmatism over purity
- **Community:** Strong emphasis on conventions and consistency

## 38.3 Next Steps

To continue your Python journey:

1. **Practice regularly:** Write code every day
2. **Read others' code:** Learn from open source projects
3. **Build projects:** Apply concepts to real problems
4. **Contribute:** Join open source communities
5. **Specialize:** Dive deep into areas of interest (web, data science, ML, etc.)
6. **Stay updated:** Follow Python Enhancement Proposals (PEPs)
7. **Use the documentation:** Make the official docs your primary reference

## 38.4 Final Thoughts

Python is a powerful, versatile language that has become indispensable in scientific computing, data analysis, web development, automation, and many other domains. Its clear syntax, extensive libraries, and supportive community make it an excellent choice for both beginners and experienced programmers. The key to mastering Python is consistent practice and engagement with the community. Start with small programs, gradually tackle more complex projects, and don't hesitate to consult the excellent documentation and community resources available.

Remember: Python's strength lies not just in its syntax, but in its philosophy of writing clear, readable code that others (including your future self) can understand and maintain. Follow the conventions, embrace the Zen of Python, and you'll find yourself writing not just functional code, but truly Pythonic code. Happy coding!