#MOJO PROGRAMMING

FROM PYTHONIC SYNTAX TO SYSTEMS-LEVEL PERFORMANCE

A COMPLETE GUIDE TO THE MOJO LANGUAGE FOR HIGH-PERFORMANCE COMPUTING AND AI DEVELOPMENT

BUILD FASTER.
SCALE BIGGER.
PERFORM BETTER.
WITH MOJO.

PYTHONIC SYNTAX | SYSTEMS-LEVEL PERFORMANCE | CPU & GPU PROGRAMMING | OPTIMIZE & PROFILE | DEBUG & MAINTAIN

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Mojo Programming: From Pythonic Syntax to Systems-Level Performance

A Complete Guide to the Mojo Language for High-Performance Computing and AI Development

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A Complete Guide to the Mojo Language for High-Performance Computing and AI Development

This book takes you from installing Mojo and writing your first program to designing, implementing, debugging, profiling, optimizing, and maintaining sophisticated high-performance software. Whether you are a Python developer seeking systems-level performance, a C/C++/Rust programmer looking for a more approachable syntax, or someone exploring GPU and heterogeneous computing, this guide provides the technical depth, practical examples, and architectural insight you need to master Mojo in production environments.

Introduction: The Case for Mojo

Why Another Language? The Performance Wall in AI and Systems

In 2023, researchers at Oak Ridge National Laboratory published a study showing that Mojo GPU kernels could achieve 87 percent of CUDA performance on NVIDIA H100 hardware while maintaining code readability comparable to Python. That result was not an anomaly. It was the realization of a design goal that has driven systems programming for decades: can we have both developer productivity and raw performance without choosing one over the other?

For years, the answer in the AI and high-performance computing communities was essentially no. You wrote your research and prototypes in Python because it was fast to write, readable, and had an unmatched ecosystem of libraries. When performance became a bottleneck, you rewrote hot paths in C, C++, CUDA, or Rust. This two-tier approach created friction: duplicated logic, context switching between languages, deployment complexity, and a gap between what researchers could prototype and what engineers could ship.

Mojo exists to close that gap. It is not a micro-optimization of Python or a fork with better compilation. It is a new language built from scratch on the MLIR compiler infrastructure, designed to target CPUs, GPUs, TPUs, and custom ASICs with a single source. Its creator, Chris Lattner, previously architected LLVM and Swift, bringing deep experience in balancing developer ergonomics with systems-level control.

The fundamental insight behind Mojo is that Python's performance problems are not inherent to its syntax. They stem from dynamic typing, garbage collection, runtime interpretation, and the inability to reason about memory layout or execution paths at compile time. Remove those constraints while keeping the familiar indentation-based syntax and straightforward readability, and you get something different: a language that looks like Python but behaves like a modern systems programming language.

Mojo at a Glance: Python Syntax Meets Systems Power

Mojo 1.0, released in August 2026 as part of Modular's 26.5 release cycle, represents the first production-stable version of the language after three years of development. It is fully open source under the Apache License 2.0 with LLVM exceptions. The language combines several design influences into a coherent whole:

- Python-like syntax and indentation-based block structure
- Static type checking and inference at compile time
- Ownership and borrowing semantics inspired by Rust, simplified for practical use
- Traits for polymorphism instead of inheritance hierarchies
- Compile-time metaprogramming using the same language as runtime code
- Built-in SIMD vectorization primitives
- GPU kernel programming in the same language used for CPU code
- Foreign function interface for C libraries
- Bidirectional interoperability with Python via the unmodified CPython runtime

When you write a Mojo program, it is compiled to native machine code targeting your specific hardware. There is no interpreter overhead, no garbage collector pauses, and no hidden allocations slowing down hot paths. The compiler uses MLIR's multi-level intermediate representation to apply aggressive optimizations across CPU architectures and GPU backends, including NVIDIA CUDA, AMD HIP, and Apple Metal.

This does not mean Mojo is simply "faster Python." That framing misses what the language actually offers. Mojo is a distinct systems programming language that happens to use familiar syntax. It enforces memory safety through its ownership model rather than runtime checks. It requires explicit type annotations for struct fields and encourages static typing throughout. It provides direct control over memory layout, pointer arithmetic, and hardware-specific instructions when you need them. Python code does not automatically become Mojo code by changing the file extension, and expecting it to do so will lead to frustration.

What makes Mojo compelling is that once you understand its model, you can write code that is both readable and performant in a way that few other languages allow. You can prototype an algorithm at high level, then incrementally add type annotations, ownership semantics, SIMD operations, or GPU kernels without rewriting the logic from scratch. The same language serves for application logic, numerical kernels, device programming, and infrastructure code.

What This Book Will Teach You

This book is structured as a progressive learning path that also functions as a reference. It assumes you have some programming experience but does not assume familiarity with systems programming concepts like ownership, borrowing, or SIMD vectorization. Those topics are introduced gradually with concrete examples before appearing in optimized implementations.

The first section covers installation, tooling, and language fundamentals: variables, types, control flow, functions, modules, and the key differences between Mojo and Python that matter in practice. You will write complete programs from the beginning and build up a mental model of how Mojo handles memory, types, and execution.

The middle sections dive into the features that make Mojo distinctive: structs and traits as abstraction mechanisms, ownership and borrowing for memory safety, pointers and unsafe code for low-level control, generics and metaprogramming for compile-time optimization, and the standard library collections and utilities. Each concept is explained not just in terms of syntax but in terms of why it exists, what problems it solves, and when you should or should not use it.

The advanced sections cover performance-oriented programming: SIMD vectorization, multi-core parallelism, GPU kernel development, profiling, benchmarking, and optimization methodology. You will learn how to measure performance accurately, identify bottlenecks, and apply the right techniques without premature optimization. The book also covers interoperability with Python and C ecosystems, testing frameworks, debugging tools, error handling patterns, and considerations for building production systems.

Throughout, code examples are complete, realistic, and internally consistent with Mojo 1.0 syntax. Where functionality is experimental or on the

roadmap rather than stable in 1.0, it is clearly labeled so you can distinguish what works today from what may change.

How to Read This Book

If you are new to Mojo but experienced with Python, read the book sequentially from the beginning. The gradual introduction of concepts will help you internalize the differences between the two languages before they become important in complex code. Pay particular attention to chapters on ownership and memory management, as those represent the biggest conceptual shift.

If you come from C, C++, or Rust, you may want to skim the early fundamentals chapters and focus on chapters covering traits versus inheritance, Mojo's ownership model compared to Rust's borrow checker, metaprogramming patterns, GPU programming, and Python interop. The book frequently draws comparisons to these languages where they illuminate Mojo's design choices.

If you are primarily interested in a specific domain such as GPU programming or SIMD optimization, the relevant chapters provide enough context to understand the concepts independently. However, some foundational knowledge of types, structs, and ownership will be assumed in those sections.

The book targets Mojo 1.0.0 released in August 2026. While the core language design is stable, Mojo continues to evolve through nightly builds and future releases. Features marked as stable in the standard library follow semantic versioning and will not break source compatibility. Roadmap features such as pattern matching, async support, and richer dynamic reflection are discussed where relevant but clearly distinguished from what is available in the current release.

Code examples use .mojo file extensions and assume you have installed Mojo following the instructions in Chapter 1. All examples compile and run with Mojo 1.0 on supported platforms (Linux and macOS). Windows support is available through WSL at the time of writing, with native support planned for future releases.

Chapter 1: Getting Started with Mojo

Installing Mojo on Your System

Mojo is distributed as a package that bundles the compiler, standard library, language server, and debugging tools. As of version 1.0, installation options have matured significantly, supporting multiple package managers familiar to Python and systems developers. The official distribution supports Linux (Ubuntu 18.04 and later, CentOS 7+) and macOS (10.15+). At the time of writing, Windows requires WSL2 with Ubuntu; native Windows support is on the roadmap.

The recommended minimum system requirements are 8 GB of RAM and a modern CPU with SSE4.2 or later instruction sets. For GPU development, an NVIDIA GPU with compute capability 7.0+ (Volta architecture or newer) is recommended. The installation itself takes approximately 5 minutes depending on your network speed.

The primary installation methods are:

Using uv (recommended for most users)

uv is a fast Python package installer and project manager that provides a straightforward way to install Mojo:

```
# Install uv
curl -LsSf https://astral.sh/uv/install.sh | sh

# Install Mojo globally
uv pip install mojo

# Verify installation
mojo --version
```

For project-based workflows, you can initialize a new project and add Mojo as a dependency:

```
uv init hello-world && cd hello-world
uv add mojo
```

Using pixi (recommended for data science workflows)

pixi is a cross-platform package manager that works well with conda-style environments:

```
# Install pixi from https://pixi.sh/latest/
curl -fsSL https://pixi.sh/install.sh | bash

# Create a new project
pixi init hello-world && cd hello-world

# Add Mojo as a dependency
pixi add mojo

# Run Mojo through pixi
pixi run mojo --version
```

Using pip

Mojo can be installed directly via pip into an existing Python environment:

```
pip install mojo
mojo --version
```

This method bundles the compiler, LSP server, and debugger as part of the PyPI package. It works well if you already maintain a Python virtual environment for your projects.

Using conda

For users in the scientific computing ecosystem who rely on conda environments:

```
conda create -n mojo-env -c https://conda.modular.com/max/ -c conda-forge mojo
conda activate mojo-env
mojo --version
```

Nightly builds

If you want to experiment with features under development, nightly builds are available but come with no stability guarantees. They may have breaking changes or new bugs:

```
# Via uv
uv pip install --pre mojo --extra-index-url https://nightly.modular.com/simple/

# Via pixi
pixi init my-project && cd my-project
pixi add -c https://conda.modular.com/max-nightly/ mojo
```

Nightly builds are useful for contributing to the language or testing upcoming features, but production code should target stable releases.

Setting Up Your Development Environment

A good development environment makes learning and writing Mojo significantly more pleasant. The officially supported editor is Visual Studio Code with the Mojo extension, which provides syntax highlighting, code completion, inline error reporting, documentation tooltips, and integrated debugging.

Installing the VS Code extension

You can install the Mojo extension from:

- VS Code Marketplace: search for "Mojo" by modular-mojotools
- Open VSX Registry: available as an alternative distribution channel

Once installed, the extension automatically connects to the Mojo language server included with your installation. You will see inline errors and warnings as you type, function signature help when calling functions, and hover documentation for types and methods.

Configuring your workspace

For a typical Mojo project, create a directory structure like this:

```
my-project/
├── src/
│   ├── main.mojo
│   └── lib.mojo
├── tests/
│   └── test_lib.mojo
└── README.md
```

The `src/` directory holds your source code, and `tests/` contains test files. This is a conventional layout that works well with Mojo's module system.

AI coding assistant integration

If you use AI-assisted coding tools, Modular provides official skills packages that keep the models aligned with current Mojo syntax and best practices:

```
npx skills add modular/skills
```

These skills help ensure generated code uses correct argument conventions, trait constraints, and standard library APIs.

Running and Building Mojo Programs

Mojo provides two primary ways to execute code: interpreting (JIT compilation) for rapid development and building standalone executables for deployment. Both are handled through the `mojo` command-line interface.

Running with mojo run

The simplest way to execute a Mojo program is with `mojo run`:

```
mojo run hello.mojo
```

This command compiles the file just-in-time and executes it immediately. It is ideal for development because changes are reflected quickly without an explicit build step. The JIT compiler still applies optimizations, so performance during development is reasonable, though not identical to a fully optimized release build.

You can pass arguments to your program:

```
mojo run main.mojo arg1 arg2
```

These arguments become accessible through the `sys.argv` list from the standard library.

Building executables with mojo build

For production use or distribution, compile your code into a standalone executable:

```
mojo build main.mojo -o myprogram
./myprogram
```

The `build` command produces a native binary optimized for your target platform. This binary does not require Mojo to be installed on the target machine (though it may depend on shared libraries like libpython if you use Python interop).

Build options include:

- `-o <name>`: specify output file name
- `-g`: include debug symbols for debugging and profiling
- `-O0`, `-O1`, `-O2`, `-O3`: optimization levels (default is optimized)

For example, to build with debug information:

```
mojo build main.mojo -o myprogram -g -O0
```

Running tests

Mojo includes a built-in testing framework. Test files are regular Mojo programs that define test functions and use the `TestSuite` struct for discovery and execution. Run them like any other Mojo file:

```
mojo run tests/test_lib.mojo
```

The CLI also supports filtering tests with flags like `--only`, `--skip`, and `--skip-all`.

Your First Mojo Program: Beyond Hello World

Let us write a complete, non-trivial first program that demonstrates several core concepts while remaining accessible. We will build a simple temperature statistics calculator that reads values, computes basic statistics, and handles errors gracefully. This example introduces variables, types, functions, control flow, and error handling in one cohesive program.

Create a file called `temperature.mojo`:

```
"""
Temperature Statistics Calculator

A simple Mojo program that demonstrates:
- Variables and type annotations
- Functions with parameters
- Control flow (if/else, for loops)
- Error handling with try/except
- Basic mathematical operations
"""

def compute_average(temps: List[Int]) -> Float64:
    """Compute the average of a list of temperatures."""
    if len(temps) == 0:
        raise Error("Cannot compute average of empty list")

    var total = 0
    for t in temps:
        total += t

    return Float64(total) / Float64(len(temps))

def find_extremes(temps: List[Int]) -> Tuple[Int, Int]:
    """Find the minimum and maximum temperatures."""
    if len(temps) == 0:
        raise Error("Cannot find extremes of empty list")

    var min_temp = temps[0]
    var max_temp = temps[0]

    for t in temps:
        if t < min_temp:
            min_temp = t
        if t > max_temp:
            max_temp = t

    return (min_temp, max_temp)
```

```
38
39  def main():
40      """Main entry point: compute and display temperature statistics."""
41      # Sample temperature data in Celsius
42      var temps = List[Int]()
43      temps.append(22)
44      temps.append(19)
45      temps.append(25)
46      temps.append(18)
47      temps.append(30)
48
49      try:
50          var avg = compute_average(temps)
51          var (min_t, max_t) = find_extremes(temps)
52
53          print("Temperature Statistics:")
54          print(f"  Count: {len(temps)} readings")
55          print(f"  Average: {avg:.1f}°C")
56          print(f"  Minimum: {min_t}°C")
57          print(f"  Maximum: {max_t}°C")
58
59      except Error as e:
60          print(f"Error: {e}")
61
62  # Run the program
63  main()
```

Let us walk through this program section by section.

The docstring at the top uses triple quotes and documents what the file contains. This is idiomatic for both Python and Mojo.

The `compute_average` function takes a `List[Int]` as input and returns a `Float64`. Notice the explicit type annotations: `temps: List[Int]` specifies the parameter type, and `-> Float64` specifies the return type. Mojo is statically typed, so these annotations help the compiler catch errors early. The function checks for an empty list and raises an error if found, demonstrating basic error handling.

Inside the function, `var total = 0` declares a mutable variable initialized to zero. In Mojo, all variables must be declared with `var`. The type is inferred as `Int` from the initial value. The for loop iterates over each temperature and accumulates the sum. Finally, we cast both the total and the count to `Float64` before division to get a floating-point result rather than integer division.

The `find_extremes` function returns a tuple of two integers representing the minimum and maximum. Tuples in Mojo are fixed-size, heterogeneous

collections with value semantics. We initialize both extremes to the first element, then iterate through the rest updating as needed.

The `main` function is the program entry point. Every Mojo program must have a `def main()` function with no arguments. We create a list of temperatures using the standard library's `List` type, appending values one by one. The try-except block wraps our computation to catch any errors and print a friendly message rather than crashing.

The f-string syntax (`f" Average: {avg:.1f}°C"`) works similarly to Python, allowing inline expressions and format specifiers within strings.

To run this program:

```
mojo run temperature.mojo
```

Expected output:

```
Temperature Statistics:
  Count: 5 readings
  Average: 22.8°C
  Minimum: 18°C
  Maximum: 30°C
```

This first program demonstrates several key Mojo concepts that we will explore in depth throughout the book: static typing with type inference, functions with explicit signatures, ownership and borrowing (the list is borrowed immutably by default when passed to functions), error handling using try-except blocks, and standard library collections. In the next chapter, we will examine each of these fundamentals systematically.

Chapter Summary

In this chapter you installed Mojo on your system, set up a development environment with VS Code, learned how to run and build programs, and wrote your first complete Mojo application. You saw that Mojo uses Python-like syntax but requires explicit type annotations, variable declarations with `var`, and a `def main()` entry point. The next chapter will dive into the language fundamentals: variables, types, operators, expressions, and control flow, building the foundation for everything that follows.

Chapter 2: Language Fundamentals

Variables, Constants, and Mutability

In Mojo, every variable must be explicitly declared using the `var` keyword. This is one of the first noticeable differences from Python, where assignment alone creates a variable. The declaration syntax binds a name to typed storage that holds an owned value.

```
var count = 0          # Int (type inferred)
var name = "Alice"     # String (type inferred)
var rate: Float64 = 3.14  # Explicit type annotation
```

When you write `var x = 5`, three things happen: storage is allocated for a value of the appropriate type, the name `x` is bound to that storage, and the value `5` is placed into it. The type is determined at compile time and cannot change. Mojo variables are statically typed.

Type inference

Mojo infers types from initial values in most cases:

```
var a = 42           # Int
var b = 3.14         # Float64
var c = True         # Bool
var d = "hello"      # String
```

You can also provide explicit type annotations, which is useful for clarity or when the type cannot be inferred:

```
var x: Int32 = 100
var y: Float32 = 2.5
```

Explicit annotations are required for struct fields and highly recommended in function signatures for readability and documentation purposes.

Mutability

Variables declared with `var` are mutable by default. You can assign new values to them after declaration:

```
var counter = 0
counter = 1
counter = counter + 1
print(counter)  # prints 2
```

For compile-time constants, Mojo uses the `comptime` keyword (renamed from `alias` in recent versions):

```
comptime MAX_SIZE = 1024
comptime PI: Float64 = 3.141592653589793
```

Values declared with `comptime` are evaluated at compile time and become runtime constants. They cannot be reassigned, and the compiler uses them for optimizations like loop unrolling and array sizing. This is fundamentally different from Python's convention of using uppercase names to suggest immutability. In Mojo, `comptime` provides actual compile-time guarantees.

Scope and shadowing

Mojo uses lexical scoping with block-level scope. Variables are visible within the block where they are declared and any nested blocks:

```
def main():
    var outer = 10

    if True:
        var inner = 20
        print(inner)  # OK: inner is visible here

    # print(inner)   # Error: inner is not visible here

    print(outer)  # OK: outer is visible throughout main()
```

Inner scopes can shadow outer variables with the same name:

```
def main():
    var x = 100
    if True:
        var x = 200  # Shadows the outer x
        print(x)     # prints 200
    print(x)         # prints 100 (outer x, unaffected)
```

Shadowing is allowed but should be used sparingly to avoid confusion. The compiler will not warn about it.

Reference bindings with ref

When working with collections or pointers, you may encounter references, which are aliases to values owned elsewhere. You can bind a reference to a stable name using the `ref` keyword:

```
var data = List[Int]()
data.append(10)
data.append(20)

var first_ref = ref data[0]
first_ref += 5  # Mutates data[0] through the reference

print(data[0])  # prints 15
```

The `ref` binding creates an alias that cannot be reassigned to point elsewhere, but the underlying value can be mutated (if the reference is mutable). This pattern is useful when you need stable access to a nested element.

Primitive Types and Type System Basics

Mojo's type system is nominal and static. Most types are defined by struct names in the standard library or your own code. The language provides a set of built-in primitive types that require no imports.

Integer types

The default integer type `Int` uses the system's native word size (64 bits on modern systems). For fixed-width integers, Mojo provides:

- Signed: `Int8`, `Int16`, `Int32`, `Int64`, `Int128`, `Int256`
- Unsigned: `UInt8`, `UInt16`, `UInt32`, `UInt64`, `UInt128`, `UInt256`

These are aliases to the SIMD type with a single element, but they behave like scalar integers in practice. Integer overflow wraps using two's complement arithmetic for signed types and wraps to zero for unsigned types. There is no automatic promotion or runtime overflow checking:

```
var x: Int8 = 127
x += 1
print(x)  # prints -128 (overflow wraps)
```

This behavior matches C/C++ and is intentional for performance. If you need overflow-safe arithmetic, you must implement it explicitly.

Floating-point types

Mojo supports IEEE 754-2008 floating-point formats:

- `Float16`: half precision (10 bits of mantissa)
- `Float32`: single precision (23 bits of mantissa)
- `Float64`: double precision (52 bits of mantissa)

For AI workloads, Mojo also provides specialized formats:

- `BFloat16`: brain floating point (8 bits exponent, 7 bits mantissa)
- `Float8_e5m2`, `Float8_e4m3fn`: 8-bit formats for quantized models
- `Float4_e2m1fn`: 4-bit format (GPU-only)

Floating-point literals default to `Float64`. Use suffixes or explicit casts for other types:

```
var a = 3.14        # Float64
var b: Float32 = 3.14  # Explicit type annotation
var c = Float32(3.14)  # Constructor cast
```

Due to rounding errors, never compare floating-point values for exact equality. Use `math.isclose()` instead:

```
from math import isclose

var x = 0.1 + 0.2
var y = 0.3

print(x == y)        # False (rounding error)
print(isclose(x, y)) # True
```

Boolean type

The `Bool` type has two values: `True` and `False`. Boolean negation uses the `not` operator:

```
var flag = True
flag = not flag  # False
```

Types implementing the `Boolable` trait can be used in boolean contexts. For example, an empty list evaluates as `False`, while a non-empty list evaluates as `True`:

```
var items = List[Int]()

if items:
    print("has items")
else:
    print("empty")  # This prints
```

String type

The `String` type stores UTF-8 encoded text and is mutable. String literals use double quotes or single quotes:

```
var greeting = "Hello, World!"
var name = 'Alice'
```

Raw strings disable escape sequences using the `r` prefix:

```
var path = r"C:\Users\Alice\Documents"
```

For accurate length calculation with Unicode text (including emoji and combining characters), use appropriate methods:

```
var s = "Hello 🌍"
print(s.byte_length())          # 12 (bytes in UTF-8)
print(s.count_codepoints())     # 7 (Unicode code points)
print(s.count_graphemes())      # 6 (visual characters)
```

NoneType

The `None` value represents the absence of a value. Its type is `NoneType`. Unlike Python, Mojo does not use `None` as a default return value for functions without explicit returns. Such functions return no value at all:

```
def log_message(msg: String):
    print(msg)
    # Returns nothing (no implicit None)
```

When you need to represent an optional value, use the `Optional` type from the standard library instead of `None`:

```
from collections import Optional

var maybe_value = Optional[Int](42)
var no_value = Optional[Int]()  # Empty optional

if maybe_value:
    print(maybe_value.value())  # prints 42
```

Numeric literals and compile-time precision

Integer and floating-point literals are arbitrary-precision at compile time. They materialize to finite types only when assigned to a variable or used in a runtime context:

```
comptime huge = 10_000_000_000_000_000_000  # OK at compile time
var x: Int64 = huge  # Materializes to Int64 (may overflow)
```

This design allows precise compile-time calculations while still requiring explicit choices about runtime representation.

Operators and Expressions

Mojo's operators are familiar to Python developers but with important differences reflecting its static typing and performance goals.

Arithmetic operators

Standard arithmetic works as expected: `+`, `-`, `*`, `/`, `%`, `//` (integer division), `**` (exponentiation):

```
var a = 10 + 5      # 15
var b = 17 % 5      # 2
var c = 17 // 5     # 3
var d = 2 ** 10     # 1024
```

Division with `/` always produces a floating-point result. Use `//` for integer division. Unlike Python, Mojo does not automatically promote types in mixed operations. Both operands must have compatible types:

```
var x: Int = 10
var y: Float64 = 3.0

# var z = x + y  # Error: type mismatch
var z = Float64(x) + y  # OK: explicit cast
```

Comparison operators

Comparison operators return `Bool`: `<`, `>`, `<=`, `>=`, `==`, `!=`:

```
var a = 10
var b = 20

print(a < b)   # True
print(a == b)  # False
```

Chained comparisons work as in Python:

```
var x = 15
print(10 < x < 20)  # True (equivalent to 10 < x and x < 20)
```

Logical operators

Use `and`, `or`, `not` for boolean logic:

```
var a = True
var b = False

print(a and b)  # False
print(a or b)   # True
print(not a)    # False
```

These operators short-circuit: in `a and b`, if `a` is `False`, `b` is not evaluated. In `a or b`, if `a` is `True`, `b` is not evaluated.

Bitwise operators

For low-level bit manipulation: `&` (AND), `|` (OR), `^` (XOR), `~` (NOT), `<<` (left shift), `>>` (right shift):

```
var x = 0b1100
var y = 0b1010

print(x & y)  # 8 (0b1000)
print(x | y)  # 14 (0b1110)
print(x ^ y)  # 6 (0b0110)
print(~x)     # -13 (two's complement)
print(x << 1) # 24 (0b11000)
```

Assignment operators

Compound assignment operators modify a variable in place: `+=`, `-=`, `*=`, `/=`, `%=`, `//=`, `**=`, `&=`, `|=`, `^=`, `<<=`, `>>=`:

```
var x = 10
x += 5    # x is now 15
x *= 2    # x is now 30
x >>= 1   # x is now 15
```

The transfer sigil (^)

Mojo introduces the `^` operator as a transfer sigil for moving ownership of values. When you apply `^` to a variable, you transfer ownership of its value and leave the original uninitialized:

```
var data = List[Int]()
data.append(1)
data.append(2)

var other = data^  # Transfer ownership to other
# data is now uninitialized : using it would be an error
print(len(other))  # prints 2
```

This operator is crucial for avoiding unnecessary copies of large or expensive-to-clone values. We will explore ownership transfer in depth in Chapter 5.

Expression statements and side effects

In Mojo, expressions can have side effects, but the language encourages separating computation from action. Function calls, assignments, and operations that modify state are statement-like even if they produce values:

```
var result = some_function()  # Expression with potential side effect
print(result)                 # Statement for output
```

Unlike Python, Mojo does not allow arbitrary expressions in places where statements are expected. This restriction helps the compiler optimize code more aggressively.

Control Flow: Conditionals and Loops

Mojo's control flow constructs use Python-like syntax but with stricter typing rules.

If-elif-else

Conditional execution uses `if`, `elif`, and `else`:

```
def classify_temperature(temp: Int):
    if temp < 0:
        print("Freezing")
    elif temp < 15:
        print("Cold")
    elif temp < 25:
        print("Moderate")
    elif temp < 35:
        print("Warm")
    else:
        print("Hot")
```

Indentation defines blocks, just like Python. The condition must evaluate to a boolean or a type implementing the `Boolable` trait.

For loops

The `for` loop iterates over iterable collections:

```
var numbers = List[Int]()
numbers.append(1)
numbers.append(2)
numbers.append(3)

for n in numbers:
    print(n * 2)
```

You can use `range()` for numeric iteration:

```
for i in range(5):
    print(i)  # prints 0, 1, 2, 3, 4

for i in range(2, 8, 2):
    print(i)  # prints 2, 4, 6
```

For loops in Mojo can also iterate with ownership transfer using the `var` keyword and `^` sigil:

```
var items = List[String]()
items.append("first")
items.append("second")

for var item in items^:
    # item owns each string, no copies made
    print(item)
# items is now consumed (moved)
```

While loops

The `while` loop repeats as long as a condition holds:

```
var counter = 0
while counter < 5:
    print(counter)
    counter += 1
```

Break and continue

Use `break` to exit a loop early and `continue` to skip to the next iteration:

```
for i in range(10):
    if i == 3:
        continue  # Skip 3
    if i == 7:
        break     # Stop at 7
    print(i)      # prints 0, 1, 2, 4, 5, 6
```

Match statement (roadmap feature)

As of Mojo 1.0, pattern matching with a `match` statement is not yet available but is on the roadmap for future releases. Use `if-elif-else` chains or enumerated types with conditional checks as alternatives.

Mojo vs Python: Key Differences in the Basics

Understanding how Mojo differs from Python at the foundational level prevents many early mistakes. Here are the critical distinctions:

Explicit variable declaration

Python:

```
x = 10
name = "Alice"
```

Mojo:

```
var x = 10
var name = "Alice"
```

Every variable in Mojo requires `var`. There is no implicit declaration through assignment.

Static typing

Python variables can change type at runtime. Mojo variables have a fixed type determined at compile time:

```
var x = 10      # Int
# x = "hello"   # Error: cannot assign String to Int variable
```

This constraint enables the compiler to generate efficient machine code and catch errors before execution.

No dynamic attribute access

Python allows adding attributes to objects at runtime:

```
obj = object()
obj.new_attr = 42  # Works in Python
```

Mojo structs have fixed fields defined at compile time. You cannot add fields dynamically, and accessing a non-existent field is a compile-time error.

No implicit type coercion

Python automatically converts between types in many contexts:

```
result = 5 + 3.0  # 8.0 (Int promoted to Float)
```

Mojo requires explicit conversions:

```
var a: Int = 5
var b: Float64 = 3.0
# var result = a + b  # Error
var result = Float64(a) + b  # OK
```

No global mutable state by default

While Mojo allows module-level variables, the language design encourages encapsulating state within structs and passing it explicitly through function arguments. This makes code easier to reason about and parallelize.

Entry point requirement

Python scripts execute top-to-bottom when run directly. Mojo requires a `def main()` function as the program entry point:

```
# This code does NOT run automatically
print("This won't print")

def main():
    print("This prints")  # Entry point
```

These differences may feel restrictive initially if you are accustomed to Python's flexibility. However, they are precisely what enable Mojo's performance characteristics and memory safety guarantees. As you progress through the book, you will see how these constraints lead to more predictable, optimizable code without sacrificing readability.

Chapter Summary

This chapter established the foundational building blocks of Mojo: variables declared with `var`, compile-time constants with `comptime`, static typing with inference, primitive types including integers, floats, booleans, and strings, operators familiar from Python but with stricter type rules, control flow using if-elif-else, for loops, and while loops, and the key philosophical differences between Mojo and Python.

In the next chapter, we will explore how to organize code into functions, handle parameters and return values with Mojo's argument conventions, structure modules and packages, and manage imports. These are the essential skills for writing anything beyond a single-file program.

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