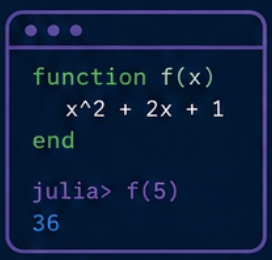
MASTERING JULIA PROGRAMMING

FROM FIRST PROGRAM TO PRODUCTION SYSTEMS



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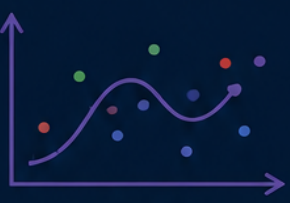

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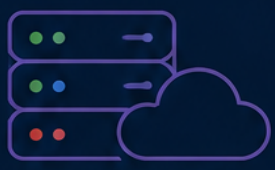

PRODUCTION READY

FOR DATA SCIENTISTS, ENGINEERS, RESEARCHERS & DEVELOPERS

ALEKSANDR IVANOV

Mastering Julia Programming

From First Program to Production Systems

Steve Publications

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From First Program to Production Systems

This book takes you from complete beginner to expert-level proficiency in Julia, one of the most powerful and elegant programming languages for technical computing. Through clear explanations, comprehensive examples, and real-world projects, you will learn not only how to write Julia code but also why the language is designed the way it is and how to leverage its unique features for maximum performance and productivity. Whether you are a data scientist, researcher, engineer, or software developer, this book gives you everything needed to use Julia confidently in both research and production environments.

Introduction: Why Julia?

The Two-Language Problem

For decades, technical computing has been trapped in what researchers call the two-language problem. Scientists and engineers prototype their algorithms in high-level languages like Python or R because these languages are expressive, interactive, and have rich ecosystems of libraries. But once the prototype works, they must rewrite critical parts in C, C++, or Fortran to achieve acceptable performance. This split workflow is expensive, error-prone, and frustrating. It forces teams to maintain two codebases, hire two kinds of developers, and accept that their most important algorithms live in a language far removed from the one used to discover them.

Consider a typical research workflow. A computational biologist develops a simulation model in Python, iterating quickly with Jupyter notebooks and NumPy arrays. The prototype runs fine on small datasets, but when scaled to production, performance becomes unacceptable. The team then rewrites the core loops in C++, creating a foreign function interface to call from Python. This process might take weeks or months, and subtle bugs often creep in during translation. Meanwhile, the original researcher who understands the algorithm best may lack the systems programming skills needed for the rewrite.

Julia was created to eliminate this problem entirely.

Julia in One Minute

Julia is a high-level, high-performance programming language designed specifically for numerical and scientific computing. It combines the ease of use and expressiveness of languages like Python with the raw speed of compiled languages like C and Fortran. This combination is not an accident or a compromise. It is the result of deliberate design choices made by a team of researchers who understood both computer science and computational science.

The core innovation behind Julia is multiple dispatch. Unlike most programming languages that select which function implementation to call based on a single argument type, Julia chooses methods based on the types of all arguments. This simple idea has profound consequences for both performance and code organization. It enables the compiler to generate highly optimized machine code for specific type combinations while keeping the source code generic and readable.

Julia uses a just-in-time compiler that translates code to native machine instructions via LLVM, the same infrastructure used by Clang, Rust, and Swift. This compilation happens automatically when you run your code, so there is no separate build step required for interactive work. The result is that well-written Julia code runs at speeds comparable to hand-optimized C while maintaining the productivity of an interpreted language.

As of this writing, Julia has been downloaded over 100 million times, has more than 1,000 contributors, and hosts over 12,000 packages in its official registry. It is used in fields ranging from computational physics and climate modeling to quantitative finance and machine learning. Major organizations including NASA, the European Space Agency, Bloomberg, and several national laboratories rely on Julia for production systems.

Who Should Use Julia

Julia is an excellent choice if any of the following describe your work:

- You perform numerical computations, simulations, or scientific calculations that are too slow in Python or R
- You need to prototype quickly but also deploy to production without rewriting code
- You work with large datasets or high-performance computing clusters
- You want a single language for both data analysis and application development
- You are frustrated by the performance limitations of interpreted languages

Julia is particularly well-suited for domains where mathematical thinking and computational efficiency matter equally. If your work involves linear algebra, differential equations, optimization, statistical modeling, or machine

learning, Julia will feel natural. Its syntax borrows from mathematics more than from traditional programming, making it intuitive for people with quantitative backgrounds.

That said, Julia is not a silver bullet. If you are building a simple web application with no numerical component, or if your team already has deep expertise in another language, the switching cost may not be justified. Julia shines brightest when computational performance and mathematical expressiveness are both important requirements.

How This Book Is Organized

This book is structured to take you on a complete journey from beginner to expert. Each chapter builds on previous material while remaining useful as a standalone reference. Here is how the book progresses:

The first part establishes foundations. You will learn Julia syntax, data types, control flow, functions, and collections through clear explanations and working examples. By the end of these chapters, you will be comfortable writing Julia programs for everyday tasks.

The second part explores Julia's distinctive features. Multiple dispatch, parametric types, metaprogramming, and macros are what make Julia different from other languages. These chapters explain not only how these features work but also why they were designed this way and how to use them effectively in real projects.

The third part covers advanced topics for serious practitioners. Performance optimization, concurrency, parallel computing, GPU programming, and distributed systems are essential for building production-quality applications that handle large-scale workloads.

The fourth part focuses on domain-specific applications. Scientific computing, data analysis, machine learning, and visualization are where Julia has made its strongest impact. You will learn the key libraries and patterns used by professionals in these fields.

The final part addresses software engineering concerns. Package development, testing, documentation, interoperability with other languages, and production deployment are what separate hobbyist code from systems that matter.

Throughout the book, you will find complete, working code examples that demonstrate real concepts rather than artificial snippets. Every example has been tested against Julia 1.12 and reflects current best practices in the community.

Installing Julia and Setting Up Your Environment

The recommended way to install Julia is using juliaup, the official version manager. Run the installer from the Julia website, which will set up Julia on your system and make it easy to switch between versions as needed. After installation, verify everything works by running `julia` in your terminal. You should see the REPL prompt appear with version information.

For interactive work, you have several options:

- The built-in REPL is powerful and supports multiple modes including package management, help lookup, and shell commands
- Jupyter notebooks integrate seamlessly via IJulia for familiar notebook workflows
- VS Code with the Julia extension provides excellent editing, debugging, and plotting support
- Pluto.jl offers reactive notebooks designed specifically for Julia

For this book, all examples are written to work in any of these environments. The REPL is sufficient for learning, but you may prefer an editor or IDE for larger projects.

Now let us begin the journey.

Chapter 1: Getting Started with Julia

The Julia REPL and Interactive Workflow

The Julia REPL (Read-Eval-Print Loop) is your primary interface for learning and experimenting with the language. When you run `julia` from the command line, you enter an interactive session where you can type code and see results immediately. This immediate feedback loop is one of Julia's greatest strengths for exploration and debugging.

Start by launching Julia:

```
$ julia

               _
   _       _ _(_)_     |  Documentation: https://docs.julialang.org
  (_)     | (_) (_)    |
   _ _   _| |_  __ _   |  Type "?" for help, "]" for Pkg mode.
  | | | | | | |/ _` |  |
  | | |_| | | | (_| |  |  Version 1.12.6 (2025-10-08)
 _/ |\__'_|_|_|\__'_|  |
|__/                   |

julia>
```

The REPL has five modes of operation, each activated by a special key:

- **Julia mode** (default, `julia>`): Type and evaluate Julia expressions
- **Package mode** (`]`): Manage packages with commands like `add`, `remove`, `update`
- **Help mode** (`?`): Search documentation interactively
- **Shell mode** (`;`): Run shell commands without leaving Julia
- **Search mode** (activated within help): Fuzzy search through available names

Try a simple calculation:

```
julia> 2 + 3
5

julia> sqrt(144)
12.0
```

The REPL stores the result of each expression in the variable `ans`, making it easy to chain interactive computations:

```
julia> 10 * 5
50

julia> ans + 7
57
```

Several features make the REPL particularly useful for development:

- **Tab completion**: Press Tab to autocomplete variable names, function names, and module paths
- **History navigation**: Use up and down arrows to cycle through previous commands
- **Inline documentation**: Type `?` followed by a function name to see its documentation
- **Unicode input**: Type backslash + name + Tab for mathematical symbols (e.g., `\pi` becomes π)

The workflow of editing code in an external file and loading it into the REPL with `include("file.jl")` is common practice. Combined with packages like Revise.jl, which automatically reloads changed code, this creates a development loop that rivals the best interactive environments in any language.

Your First Julia Programs

Let us write a simple program that demonstrates several fundamental concepts. Create a file called `greet.jl`:

```
# greet.jl - A simple greeting program

function greet(name::String, times::Int)
    for i in 1:times
        println("Hello, ", name, "!")
    end
end

greet("World", 3)
```

Run it from the command line:

```
$ julia greet.jl
Hello, World!
Hello, World!
Hello, World!
```

This program introduces several concepts we will explore in depth: comments (lines starting with #), function definition, type annotations, loops, string concatenation, and the `println` function for output.

Julia programs can also be run interactively by loading them into the REPL:

```
julia> include("greet.jl")
Hello, World!
Hello, World!
Hello, World!

julia> greet("Julia", 2)
Hello, Julia!
Hello, Julia!
```

Once loaded, the function remains available in your session. This interactive development pattern is central to how Julia programmers work.

Variables and Assignment

Variables in Julia are names that refer to values. Assignment uses the = operator and does not print a result:

```
julia> x = 10
10

julia> y = 20
20

julia> z = x + y
30
```

Julia is dynamically typed, meaning you do not need to declare variable types explicitly. The type of a variable is determined by the value it holds:

```
julia> typeof(x)
Int64

julia> typeof(3.14)
Float64

julia> typeof("hello")
String
```

You can optionally annotate variable types using `::`. This is particularly useful for global variables, where it helps the compiler optimize code:

```
julia> count::Int = 5
5

julia> count = "not an integer"
ERROR: MethodError: Cannot convert an object of type String to an object of
↪  type Int
```

Type annotations on local variables are rarely needed because Julia's compiler infers types automatically. However, they can serve as documentation and catch errors early.

Julia supports multiple assignment, allowing you to assign several variables at once:

```
julia> a, b, c = 1, 2, 3
(1, 2, 3)

julia> a
1

julia> b
2
```

You can also swap values elegantly:

```
julia> x, y = 10, 20
(10, 20)

julia> x, y = y, x
(20, 10)
```

Variables in Julia follow lexical scoping rules. Variables defined inside functions are local to those functions and do not affect variables with the same name in outer scopes. This behavior differs from some other dynamically typed languages and is important for writing correct code.

Numbers and Numeric Types

Julia has a rich hierarchy of numeric types designed to handle all common numerical computing needs without sacrificing performance. Understanding these types is essential for writing efficient code.

Integers: Julia provides fixed-width integer types: `Int8`, `Int16`, `Int32`, `Int64`, and `Int128` (signed), plus their unsigned counterparts `UInt8`, `UInt16`, etc. The bare type `Int` is a platform-dependent alias for either `Int32` or `Int64`:

```
julia> typeof(42)
Int64

julia> typeof(Int)
Type{Int64}

julia> 0xff
255  # hexadecimal literal

julia> 0o77
63   # octal literal
```

For arbitrarily large integers, use `BigInt`:

```
julia> big(2)^100
1267650600228229401496703205376
```

Floating-point numbers: Julia follows IEEE 754 standards with `Float16`, `Float32` (single precision), and `Float64` (double precision). The type `Float` is an alias for `Float64`:

```
julia> typeof(3.14)
Float64

julia> typeof(1.0f0)
Float32

julia> 1.5e-10
1.5e-10  # scientific notation
```

Special floating-point values are available:

```
julia> Inf
Inf

julia> -Inf
-Infinity

julia> NaN
NaN
```

Complex numbers: Julia has native support for complex arithmetic:

```
julia> 3 + 4im
3 + 4im

julia> (3 + 4im) * (2 - im)
10 + 5im

julia> typeof(3 + 4im)
Complex{Int64}
```

Rational numbers: Exact rational arithmetic avoids floating-point rounding:

```
julia> 1//3
1//3

julia> 1//3 + 1//6
1//2
```

Julia's numeric types form a hierarchy rooted in the abstract type `Number`. Understanding this hierarchy matters because it enables generic code that works across different numeric types. For example, a function written for `Real` numbers will automatically work with integers, floats, rationals, and any future real number types without modification.

Type conversion is explicit in Julia. Use `convert` or type constructors:

```
julia> Int(3.7)
3

julia> Float64(5)
5.0

julia> convert(Float32, 3.14159)
3.14159f0
```

Strings and Characters

Julia's string handling is built around Unicode support from the ground up. The `String` type stores UTF-8 encoded text, and the `Char` type represents individual Unicode code points as 32-bit values.

Create strings with double quotes:

```
julia> s = "Hello, Julia!"
"Hello, Julia!"

julia> typeof(s)
String
```

Characters use single quotes:

```
julia> c = 'A'
'A': ASCII/Unicode U+0041 (category Lu: Letter, uppercase)

julia> d = 'π'
'π': Unicode U+03C0 (category Lm: Mark, modifier)
```

Strings are immutable in Julia, meaning operations that appear to modify a string actually create new strings. This design choice enables optimizations and safe sharing of string data.

Concatenate strings with * or the `string()` function:

```
julia> "Hello" * ", " * "World"
"Hello, World"

julia> string("Age: ", 42, ", Status: ", "active")
"Age: 42, Status: active"
```

String interpolation embeds expressions directly in strings using $:

```
julia> name = "Alice"
"Alice"

julia> age = 30
30

julia> "$name is $age years old."
"Alice is 30 years old."
```

You can interpolate arbitrary expressions by wrapping them in parentheses:

```
julia> "The answer is $(2 * 21)."
"The answer is 42."
```

Julia supports several string literal formats:

- **Triple-quoted strings** (`"""..."""`) for multi-line text with flexible indentation
- **Raw strings** (`raw"..."`) that disable escape sequences and interpolation
- **Byte strings** (`b"..."`) for raw byte arrays
- **Version literals** (`v"1.2.3"`) for semantic versioning

Unicode support means Julia handles international text naturally:

```
julia> "□□□"
"□□□"

julia> length("café")
4
```

Note that `length` counts characters (code points), not bytes. For byte-level operations, use `ncodeunits`.

Basic Operators

Julia provides a comprehensive set of operators for arithmetic, comparison, and logical operations. Many mathematical symbols can be typed directly using Unicode input.

Arithmetic operators:

```
julia> 10 + 3    # addition
13

julia> 10 - 3    # subtraction
7

julia> 10 * 3    # multiplication
30

julia> 10 / 3    # division (always returns Float64)
3.3333333333333335

julia> 10 ÷ 3    # integer division (\div<Tab>)
3

julia> 10 % 3    # remainder
1

julia> 2 ^ 10    # exponentiation
1024
```

Comparison operators:

```
julia> 5 == 5    # equality
true

julia> 5 != 3    # inequality
true

julia> 5 > 3     # greater than
true

julia> 5 < 3     # less than
false

julia> 5 >= 5    # greater than or equal
true

julia> isapprox(1.0/3.0 * 3.0, 1.0)
true  # for floating-point comparison
```

Chained comparisons work naturally:

```
julia> 1 < 2 < 3
true

julia> 0 <= x <= 100
# evaluates as expected
```

Logical operators:

```
julia> true && false    # logical AND
false

julia> true || false    # logical OR
true

julia> !true            # logical NOT
false
```

The && and || operators short-circuit, meaning the right operand is not evaluated if the result is determined by the left operand. This behavior is useful for conditional execution:

```
julia> condition && do_something()
# do_something() only runs if condition is true
```

Bitwise operators:

```
julia> 0b1100 & 0b1010    # bitwise AND
0b1000

julia> 0b1100 | 0b1010    # bitwise OR
0b1110

julia> 0b1100 ⊻ 0b1010    # bitwise XOR (\xor<Tab>)
0b0110

julia> ~0b1100            # bitwise NOT
-13

julia> 0b1010 << 2        # left shift
0b101000

julia> 0b1010 >> 2        # right shift
0b10
```

Julia also supports augmented assignment operators like +=, -=, *=, /=, and others:

```
julia> x = 5
5

julia> x += 3
8

julia> x *= 2
16
```

Comments and Code Style

Comments in Julia start with # and extend to the end of the line:

```
# This is a single-line comment
x = 10  # inline comment
```

Block comments use `#= ... =#` and can be nested:

```
#=
This is a
multi-line comment
=#

y = 20
```

Docstrings are special comments that generate documentation. They come in two forms: one-line docstrings with """ and multi-line docstrings with """. Place them immediately before the definition they document:

```
"""
    square(x)

Return the square of x.
"""
function square(x)
    return x * x
end
```

Julia has an established style guide that reflects community conventions. Key recommendations include:

- Use 4 spaces for indentation (not tabs)
- Name modules and types with CamelCase (e.g., `MyModule`, `Point2D`)
- Name functions and variables with lowercase letters without underscores (e.g., `getvalue`, `mydata`)
- Append `!` to function names that modify their arguments in place (e.g., `sort!`, `push!`)
- Write code as functions rather than top-level scripts for better performance
- Prefer generic types over specific ones when writing library code
- Avoid unnecessary parentheses and abbreviations

Following these conventions makes your code more readable to other Julia developers and aligns with the broader ecosystem. The official style guide provides detailed guidance on naming, argument order, type design, and many other aspects of idiomatic Julia code.

Chapter 2: Control Flow and Program Structure

Conditional Execution

Conditional statements let your program make decisions based on runtime values. Julia's conditional syntax is clean and familiar to programmers from most languages.

The basic `if-elseif-else` construct evaluates conditions in order and executes the first matching block:

```
function classify(x)
    if x < 0
        return "negative"
    elseif x == 0
        return "zero"
    else
        return "positive"
    end
end

classify(-5)   # returns "negative"
classify(0)    # returns "zero"
classify(10)   # returns "positive"
```

A few important details about conditionals in Julia:

- Any value can be used as a condition. Only `false` and `nothing` are falsy; everything else, including `0`, empty arrays, and empty strings, is truthy. This differs from Python and C.
- Blocks introduced by `if`, `elseif`, and `else` are "leaky" for variable scope. Variables defined inside any branch are visible outside the conditional, but they must be defined in all reachable branches to avoid errors.

The ternary operator provides a concise form for simple conditionals:

```
julia> x = 10
10

julia> x > 5 ? "greater" : "less or equal"
"greater"
```

Note the required spaces around `?` and `:` in Julia's ternary syntax. Without spaces, the parser interprets the symbols differently.

For complex conditions, consider extracting them into named functions or variables for readability:

```
function is_valid_user(user)
    has_email = !isempty(user.email)
    is_active = user.status == "active"
    meets_age = user.age >= 18

    if has_email && is_active && meets_age
        return true
    end
    return false
end
```

Julia also supports the `if` modifier for simple one-line conditionals:

```
println("x is positive") if x > 0
```

This form is useful but should be used sparingly to maintain readability.

Loops and Iteration

Julia provides two fundamental loop constructs: `while` loops for condition-based repetition and `for` loops for iterating over collections.

While loops continue executing as long as a condition remains true:

```
function countdown(n)
    while n > 0
        println(n)
        n -= 1
    end
    println("Liftoff!")
end

countdown(3)
# Output:
# 3
# 2
# 1
# Liftoff!
```

For loops iterate over elements of a collection, range, or any iterable object:

```
# Iterating over a range
for i in 1:5
    println(i)
end

# Iterating over an array
fruits = ["apple", "banana", "cherry"]
for fruit in fruits
    println("I like ", fruit)
end

# Iterating with enumerate for index and value
for (index, fruit) in enumerate(fruits)
    println("$index: $fruit")
end
```

Ranges are created with the `:` operator and support various patterns:

```
julia> 1:10          # from 1 to 10
1:10

julia> 10:-2:0       # from 10 down to 0, step -2
10:-2:0

julia> collect(1:5)  # convert range to array
[1, 2, 3, 4, 5]

julia> 1:0.5:3       # floating-point range
1.0:0.5:3.0
```

Nested loops iterate through multiple dimensions:

```
for i in 1:3
    for j in 1:3
        print(i * j, " ")
    end
    println()
end
# Output:
# 1 2 3
# 2 4 6
# 3 6 9
```

Loop control uses `break` to exit early and `continue` to skip to the next iteration:

```
function find_first_even(numbers)
    for n in numbers
        if n % 2 == 0
            return n
        end
    end
    return nothing
end

for i in 1:10
    if i % 3 == 0
        continue  # skip multiples of 3
    end
    println(i)
end
```

An important scoping detail: loop variables in `for` and `while` loops are local to the loop body when used in script files. This differs from the REPL, where

they may update global variables. To explicitly use an outer variable as a loop variable, use the `outer` keyword:

```
function demo_outer()
    i = 0
    for outer i in 1:5
        # uses the existing i rather than creating a new one
    end
    return i  # returns 5
end
```

Comprehensions and Generators

Comprehensions provide a concise syntax for constructing collections by transforming and filtering elements. They are often more readable and efficient than equivalent `for` loops.

Array comprehensions create arrays using bracket notation:

```
# Squares of numbers 1 through 5
squares = [x^2 for x in 1:5]
# [1, 4, 9, 16, 25]

# Filtering: even numbers only
evens = [x for x in 1:20 if x % 2 == 0]
# [2, 4, 6, 8, 10, 12, 14, 16, 18, 20]

# Multiple dimensions
matrix = [i * j for i in 1:3, j in 1:3]
# 3×3 Matrix{Int64}:
#  1  2  3
#  2  4  6
#  3  6  9
```

The comma-separated form creates multidimensional arrays where the first index varies slowest (column-major order, matching Julia's array storage).

Set and dictionary comprehensions work similarly:

```
# Set comprehension
unique_letters = Set(c for c in "hello")
# Set(['h', 'e', 'l', 'o'])

# Dictionary comprehension
squares_dict = Dict(x => x^2 for x in 1:5)
# Dict{Int64, Int64} with 5 entries
```

Generators are lazy versions of comprehensions that produce values on demand rather than building an entire collection upfront. They use parentheses instead of brackets:

```
# Generator expression
gen = (x^2 for x in 1:1_000_000)

# Can be consumed once
sum(gen)  # sums all squares without storing them
```

Generators are memory-efficient for large datasets and work seamlessly with functions like `sum`, `map`, and `reduce`:

```
# Sum of even numbers from 1 to 1000
sum(x for x in 1:1000 if x % 2 == 0)
# 250500
```

Comprehensions and generators support nested iteration and multiple conditions:

```
# Nested with filtering
pairs = [(i, j) for i in 1:3 for j in 1:3 if i != j]
# [(1, 2), (1, 3), (2, 1), (2, 3), (3, 1), (3, 2)]
```

When deciding between a loop and a comprehension, consider readability and intent. Use comprehensions when you are building a collection from existing data. Use explicit loops when the logic is complex or involves side effects.

Short-Circuit Evaluation

Short-circuit evaluation allows conditional execution without full `if` statements. The operators && (and) and || (or) evaluate their right operand only when necessary.

With &&, the right side runs only if the left side is true:

```
function log_and_run(msg, action)
    println(msg)
    return action()
end

should_run = true
should_run && log_and_run("Running task", () -> println("Done"))
# Output: Running task, Done
```

With ||, the right side runs only if the left side is false:

```
value = nothing
fallback = 42
result = value || fallback
# result is 42 because nothing is falsy
```

Short-circuiting is commonly used for guard conditions and default values:

```
function safe_divide(a, b)
    b == 0 && return NaN
    return a / b
end

file_exists(path) || error("File not found: $path")
```

The && and || operators also chain naturally:

```
a && b && c   # runs b only if a is true, runs c only if both a and b are true
x || y || z   # returns first truthy value among x, y, z
```

Be careful with short-circuiting in performance-critical code. While convenient, heavily chained conditions can become harder to read and debug than explicit `if` statements. Use them for simple guards and defaults, but prefer structured conditionals for complex logic.

Control Flow Best Practices

Writing clear control flow requires balancing conciseness with readability. Here are guidelines that reflect Julia community norms:

- Prefer early returns to reduce nesting depth. Instead of deeply nested conditionals, check failure conditions first and return immediately.
- Use comprehensions for simple transformations and filters. They express intent more clearly than equivalent loops.
- Avoid complex boolean expressions. Extract conditions into named variables when they become hard to read.
- Be explicit about falsy values. Remember that only `false` and `nothing` are falsy in Julia, not `0` or empty collections.
- Structure loops for clarity. Use descriptive variable names and keep loop bodies focused on a single responsibility.
- Consider functional alternatives. Functions like `map`, `filter`, and `reduce` often express transformations more clearly than manual loops.

Here is an example applying these principles:

```
# Instead of this nested version:
function process_users(users)
    result = []
    for user in users
        if user.active
            if user.age >= 18
                if !isempty(user.email)
                    push!(result, uppercase(user.name))
                end
            end
        end
    end
    return result
end

# Prefer this version with early returns:
function process_users(users)
    result = String[]
    for user in users
        !user.active && continue
        user.age < 18 && continue
        isempty(user.email) && continue
        push!(result, uppercase(user.name))
    end
    return result
end

# Or even more concisely with a comprehension:
function process_users(users)
    [uppercase(u.name) for u in users
```

```
    if u.active && u.age >= 18 && !isempty(u.email)]
end
```

Each version is correct, but the last two are clearer about intent and easier to maintain. As you gain experience with Julia, you will develop an instinct for choosing the right structure for each situation.

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