LEARNING COMMON LISP

A COMPLETE GUIDE TO COMMON LISP PROGRAMMING FROM FIRST PRINCIPLES TO ADVANCED METAPROGRAMMING

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Learning Common Lisp

A Complete Guide to Common Lisp Programming from First Principles to Advanced Metaprogramming

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Contents

A Complete Guide to Common Lisp Programming from First Principles to Advanced Metaprogramming

This book takes you from your first S-expression to advanced metaprogramming techniques, covering the full breadth of Common Lisp. You will learn not only how to write Lisp code but why Lisp works the way it does: its design philosophy, its historical roots, and the practical engineering principles that make it one of the most powerful programming languages ever created. Every concept is explained with complete, working code examples built on SBCL, the leading open-source Common Lisp implementation. Whether you are a curious programmer exploring functional and symbolic programming for the first time or an experienced engineer seeking to master macros, CLOS, and Lisp's legendary condition system, this book provides a systematic path from beginner to advanced practitioner.

Introduction: Why Lisp Still Matters

In 1958, a young researcher at MIT named John McCarthy sat down to design a programming language for artificial intelligence. He did not have modern compilers, garbage collectors, or even structured programming paradigms to draw upon. What he produced was something that would turn out to be one of the most influential ideas in the history of software: a language whose code and data shared the same structure, a language that could rewrite itself while it ran, a language where the boundary between program and programmer blurred into something far more flexible than anything before or since.

That language was Lisp. Sixty-eight years later, Lisp is still here, and for reasons that have nothing to do with nostalgia or academic curiosity.

You may have heard the jokes. Edsger W. Dijkstra once wrote that "Lisp has jokingly been called 'the most intelligent way to misuse a computer'. I think that description a great compliment" [1]. You may have been told that Lisp is an esoteric curiosity, a language of parentheses and philosophy, beautiful but impractical, the programming equivalent of a museum piece. These opinions are not wrong, exactly, but they are incomplete in ways that matter.

The truth is simpler and more interesting: Lisp is an engineering tool of extraordinary power, built around ideas that other languages have been trying to approximate for decades. When Python introduced list comprehensions and decorators, it was reaching for Lisp-like expressiveness. When Ruby added blocks and metaprogramming, it was borrowing from Lisp's philosophy. When JavaScript popularized closures and first-class functions, it was implementing concepts that Lisp had used since the 1960s [2]. Even the read-eval-print loop, now standard in Jupyter notebooks and REPL-driven development across dozens of languages, originated in Lisp.

This book is about Common Lisp specifically, the most comprehensive and widely used general-purpose Lisp dialect, standardized by ANSI in 1994 as INCITS 226-1994 [3]. It is not the only Lisp, but it is the one that best embodies Lisp's full potential: a complete, industrial-strength language with a powerful object system, sophisticated error handling, rich macro facilities, and native compilation to machine code. Implementations like SBCL (Steel Bank Common

Lisp) produce executables whose performance rivals C and C++, while offering an interactive development experience unmatched by most statically typed languages [4].

What You Will Learn

This book is structured as a journey from first principles to advanced mastery. It assumes you know how to program in at least one other language, but it does not assume any prior exposure to Lisp or functional programming. Every concept is introduced clearly and built upon systematically.

The early chapters establish your foundation: how to read and write Lisp code, the data structures that form the language's backbone, functions and control flow, and the recursive thinking that makes Lisp programming elegant rather than awkward. You will learn to use the REPL not as a toy but as a serious development environment, editing code interactively and watching it take shape in real time.

The middle chapters tackle Lisp's signature features. You will learn to write macros, Lisp's most distinctive and powerful capability, which let you extend the language itself to create domain-specific syntax tailored to your problems. You will master CLOS, the Common Lisp Object System, whose multiple dispatch and metaobject protocol offer capabilities that single-dispatch languages like Java and C++ cannot match. You will understand Lisp's condition system, arguably the best error-handling model in any mainstream language, which separates the detection of exceptional situations from their handling and allows recovery without stack unwinding.

The later chapters cover practical engineering concerns: organizing large projects with packages and ASDF build systems, optimizing performance with type declarations and profiling, writing concurrent programs with threads and synchronization primitives, building web applications, accessing databases, interfacing with C libraries, testing your code systematically, and deploying Lisp programs to production.

How to Use This Book

Read this book in order. Each chapter depends on concepts introduced earlier, and trying to jump ahead will leave gaps in your understanding that will

compound over time. However, once you have completed the core chapters (roughly through Chapter 9), you can treat the later material as a reference, dipping into specific topics as needed for your projects.

Every code example in this book is complete and runnable under SBCL, the implementation used throughout. You should type these examples yourself rather than copying them, because the act of writing Lisp code by hand builds the muscle memory and intuition you need to think fluently in the language. Use the REPL as you read: define functions, test expressions, break things, and fix them. Lisp rewards experimentation, and the REPL is your laboratory.

The book uses inline citations marked with numbers like this [5] to indicate sources for factual claims, historical details, and technical specifications. A full reference list appears at the end of the book.

The Lisp Mindset

Before we begin, there is one thing you should understand about learning Lisp that distinguishes it from most other languages: Lisp will change how you think about programming. Not because it is mysterious or magical, but because it forces you to confront questions that other languages hide from you. What is the difference between code and data? When should transformation happen at compile time versus run time? How do you organize a system so that it can grow and adapt without becoming brittle?

Other languages give you opinions about these questions, often baked into their syntax and semantics in ways you cannot easily see or change. Lisp shows you the machinery and hands you the tools to build your own opinions. That is both its power and its responsibility: with Lisp, you are not just a user of a language but a participant in its ongoing evolution, even within your own programs.

If that sounds intimidating, do not worry. The path from confusion to clarity is straightforward, and every step along the way is rewarding. Let us begin.

Chapter 1: The Lisp Way of Thinking

A Language That Thought Differently

To understand Lisp, you need to understand the problem it was trying to solve. In the late 1950s, programming meant writing in languages like Fortran and Assembly, designed for numerical computation on batch-processing mainframes. These languages treated programs as static sequences of instructions operating on fixed data structures. If you wanted to manipulate symbolic expressions, parse text, or reason about logic, you had to contort these tools into shapes they were never meant to hold [6].

John McCarthy, a mathematician and computer scientist at MIT, was working on artificial intelligence research and needed a language that could represent and manipulate symbolic structures naturally. He realized that the lambda calculus of Alonzo Church, developed in the 1930s as a formal system for defining computable functions, provided an elegant theoretical foundation. But McCarthy wanted more than theory: he wanted a practical programming language built on these ideas [7].

The result was LISP, short for "LISt Processor," first described in McCarthy's 1960 paper "Recursive Functions of Symbolic Expressions and Their Computation by Machine, Part I" [8]. The name reflected Lisp's central data structure: the linked list. But Lisp was much more than a language for processing lists. It introduced concepts that were revolutionary at the time and remain influential today:

- **Tree data structures** as a natural way to represent hierarchical information
- **Automatic garbage collection**, so programmers did not need to manage memory manually
- **Dynamic typing**, allowing variables to hold values of any type
- **First-class functions**, treating functions as values that can be passed around and returned
- **The read-eval-print loop (REPL)**, enabling interactive development

- **Homoiconicity**, the property that code is represented as data structures within the language itself

Lisp was first implemented in 1960 by Steve Russell on an IBM 704 computer, with contributions from McCarthy and others [9]. It quickly became the dominant language for artificial intelligence research, powering systems from expert systems to natural language processing. Over the decades, Lisp evolved into many dialects: MacLisp at MIT, Interlisp at Xerox PARC, Scheme at Carnegie Mellon and elsewhere. Each dialect refined different aspects of the language, but all shared the core ideas McCarthy had established.

In 1984, Guy Steele published "Common Lisp: The Language," an attempt to unify these dialects into a single comprehensive specification [10]. This effort culminated in 1994 when the ANSI X3J13 committee approved the Common Lisp standard, ANSI INCITS 226-1994 [3].

Today, Lisp is used in production systems around the world. The original Reddit was written in Common Lisp before migrating to Python [11]. Grammarly's core grammar engine is written in Common Lisp and processes over a thousand sentences per second in production [12]. At NASA's Jet Propulsion Laboratory, the Remote Agent autonomous control system for the Deep Space 1 spacecraft was written entirely in Common Lisp and won NASA's 1999 Software of the Year award [13]. Game developer Naughty Dog created GOAL (Game Oriented Assembly Lisp), a custom Lisp dialect built on Allegro Common Lisp, which powered over 98 percent of the codebase for the Jak and Daxter series on PlayStation 2 [14]. Financial firms use Lisp for trading algorithms and quantitative analysis, drawn by its speed and interactive development model. It may not be the most popular language by developer count, but among those who know it, Lisp is regarded with a kind of reverence that no other language commands.

Code as Data: The Fundamental Insight

The single most important idea in Lisp is homoiconicity, the property that code and data share the same representation. In most programming languages, there is a sharp distinction between code (written in some syntax, parsed into an abstract syntax tree by the compiler) and data (represented as values like numbers, strings, arrays). You can manipulate data easily within a program,

but manipulating code requires external tools: parsers, template engines, or reflection APIs.

In Lisp, this distinction collapses. Lisp programs are written as S-expressions (symbolic expressions), which are nested lists of symbols and values. These same S-expressions are also Lisp's primary data structure. A piece of Lisp code is literally a list that the Lisp evaluator knows how to interpret [15].

Consider this simple expression:

```
(+ 1 2 3)
```

To a human reader, this says "add one, two, and three." To the Lisp reader (the component that parses text into data structures), this becomes a list containing three elements: the symbol `+`, the number `1`, and the number `2`, and the number `3`. We can see this by preventing evaluation with a quote:

```
'(+ 1 2 3)
;; Returns: (+ 1 2 3) as a list, not evaluated
```

The quote character `'` tells Lisp to treat what follows as data rather than code. Without it, Lisp evaluates the expression and returns `6`. With it, you get the raw list structure. This is homoiconicity in action: the exact same structure that represents executable code also represents a manipulable data value.

Why does this matter? Because it means you can write programs that generate and transform other programs using the same tools you use to manipulate any other data. You can build lists, modify them, combine them, and then ask Lisp to evaluate the result as code. This capability is the foundation of Lisp's macro system, which we will explore in depth later, but even without macros, homoiconicity makes many tasks remarkably straightforward.

For example, suppose you want to generate a series of function calls at runtime based on some data:

```
;; Data-driven code generation
(defparameter *operations* '(+ - *))
(defparameter *values* '(10 3))

(loop for op in *operations*
      collect (list op (first *values*) (second *values*)))
;; Returns: ((+ 10 3) (- 10 3) (* 10 3))
```

We have constructed three S-expressions as data. We can now evaluate them:

```
(loop for expr in '( (+ 10 3) (- 10 3) (* 10 3) )
      collect (eval expr))
;; Returns: (13 7 30)
```

The `eval` function takes an S-expression and evaluates it as Lisp code. In most languages, calling `eval` is considered dangerous and should be avoided. In Lisp, it is a legitimate tool, though experienced programmers use it sparingly because macros provide a safer, compile-time alternative for most code-generation needs. The important point is that the capability exists naturally within the language design.

Installing Your First Lisp Environment

Before we write any real programs, you need a Lisp implementation installed. This book uses SBCL (Steel Bank Common Lisp) throughout, the leading open-source Common Lisp implementation. SBCL is fast, standards-compliant, actively maintained, and available on Linux, macOS, Windows, and many other platforms [16].

On Linux (Debian/Ubuntu):

```
sudo apt-get install sbcl
```

On macOS (using Homebrew):

```
brew install sbcl
```

On Windows: Download the binary distribution from https://www.sbcl.org/ and follow the installation instructions. Alternatively, use Roswell (https://www.roswell.com/), a Lisp version manager that simplifies installation across platforms.

Once installed, verify it works by running:

```
sbcl --version
```

You should see output like "SBCL 2.4.x" or similar, depending on your version.

The Development Environment: Emacs with SLIME or Sly

While you can use SBCL's built-in REPL directly from the command line, the Lisp community has developed sophisticated development environments that make Lisp programming extraordinarily productive. The traditional choice is Emacs paired with SLIME (Superior Lisp Interaction Mode for Emacs) or its modern successor Sly [17].

SLIME/Sly provides:

- Integrated REPL access
- Code completion and indentation
- Compilation with error navigation (jump directly to errors)
- Documentation lookup (describe any function with a keystroke)
- Disassembly viewing
- Thread management
- Package inspection

To set up SLIME with Quicklisp (the standard Lisp package manager), first install Quicklisp by running this in your Lisp REPL:

```
;; Download and install Quicklisp
(load (merge-pathnames "quicklisp/setup.lisp"
                       (user-homedir-pathname)))
(ql:add-to-init-file)
```

Then load SLIME from within SBCL:

```
(ql:quickload "slime")
(slime:start-swank-server :port 4005)
```

In Emacs, add to your configuration file (`.emacs` or `init.el`):

```
(load (expand-file-name "~/quicklisp/slime-helper.el"))
(setq inferior-lisp-program "sbcl")
(slime-setup '(slime-fancy))
```

Start SLIME with `M-x slime`, and you will have a fully integrated Lisp development environment.

If you prefer VS Code, the Lisp Extension by d12frosted provides reasonable support, though not as deep as SLIME. For now, even SBCL's command-line REPL is sufficient to follow along with this book, and we will use it for all examples.

Reading Your First S-Expression

Lisp syntax is famously minimal, which is both its greatest strength and the source of most beginner confusion. Let us walk through reading Lisp code carefully, because understanding how Lisp parses expressions is fundamental to everything else.

Atoms and Lists

Every piece of Lisp code is composed of atoms and lists:

- An **atom** is an indivisible unit: a number, a string, or a symbol.
- A **list** is a sequence of atoms or other lists, enclosed in parentheses.

Examples of atoms:

```
42              ; integer
3.14            ; floating-point number
"hello"         ; string
#\A             ; character
t               ; true (the symbol T)
nil             ; false and the empty list (the symbol NIL)
foo             ; symbol
+               ; symbol (also a function name)
```

Examples of lists:

```
()              ; empty list
(1 2 3)         ; list of three numbers
(foo bar baz)   ; list of three symbols
(+ 1 2)         ; list that, when evaluated, adds one and two
((1 2) (3 4))   ; nested lists
```

Symbols

Symbols are Lisp's most distinctive atom type. A symbol is essentially a name that can carry multiple pieces of information: its print name (what you type), its value (if it is bound as a variable), and its function definition (if it names a function). This separation of namespaces is why Common Lisp is called a "Lisp-2" [18].

```
(defparameter x 42)        ; bind the symbol X to value 42
x                          ; => 42 (accessing its value)

(defun x () "I am a function")  ; define X as a function
(x)                            ; => "I am a function" (calling it)
```

The symbol `x` simultaneously holds a numeric value and a function definition, because values and functions live in separate namespaces. This can seem confusing at first but becomes natural with practice.

Quoting

When you type an expression at the REPL, Lisp evaluates it. For numbers, this means returning the number itself. For symbols, this means looking up their value. For lists, Lisp treats the first element as a function name and the remaining elements as arguments:

```
(+ 1 2)      ; => 3
x            ; => 42 (if x is bound to 42)
```

But what if you want Lisp to treat an expression as data rather than evaluating it? You use **quote**:

```
(quote (+ 1 2))     ; => (+ 1 2) -- the list, unevaluated
'(+ 1 2)            ; => (+ 1 2) -- shorthand for quote
```

The single-quote character `'` is shorthand for `(quote ...)`. When you see `'something`, read it as "the literal something, do not evaluate it."

Quoting is essential throughout Lisp programming. You will use it to represent code as data, to match against symbols, and in countless other situations. Learn to recognize it immediately: whenever you see a single quote at the beginning of an expression, Lisp will return that expression exactly as written, without evaluating it.

Special Forms vs Functions

In Lisp, most expressions are function calls: `(function-name arg1 arg2 ...)` evaluates each argument, then calls the function with those values. But some expressions are **special forms**, which control how their arguments are evaluated. Special forms break the normal evaluation rules, and they are essential for implementing control flow, variable binding, and macros.

Examples of special forms:

```
(if condition then-form [else-form])    ; conditional execution
(let ((x 1) (y 2)) (+ x y))            ; local variable binding
(defun name (params) body...)           ; function definition
(quote expression)                      ; prevent evaluation
```

In an `if` form, for example, Lisp evaluates only the condition and then either the `then-form` or the `else-form`, not all of them. If it evaluated all arguments first, you could not implement conditional logic. Special forms are how Lisp achieves this control.

Interactive Development: The REPL as Your Laboratory

The read-eval-print loop (REPL) is Lisp's signature development tool and one of the language's most powerful features. It is not a debugging aid or an

educational toy; it is a first-class development environment where serious Lisp programmers spend most of their time [4].

Start SBCL from your terminal:

```
sbcl
```

You will see output like this:

```
This is SBCL 2.4.8, an implementation of ANSI Common Lisp.
...
*
```

The asterisk * is the REPL prompt, waiting for your input. Type expressions and press Enter to evaluate them:

```
* (+ 1 2 3)
6

* (* 7 8)
56

* (format t "Hello, Lisp!~%")
Hello, Lisp!
NIL

* (defparameter *greeting* "Hello from the REPL")
*GREETING*

* *greeting*
"Hello from the REPL"
```

Notice several things:

1. Every expression you type is evaluated immediately, and the result is printed.
2. `format` writes to standard output (the `t` argument means "to terminal") and also returns a value (in this case, `NIL`, because its primary purpose was the side effect of printing).
3. `defparameter` defines a global variable and echoes back the symbol name as confirmation.

Defining Functions Interactively

```
* (defun square (x)
    "Return the square of X."
    (* x x))
SQUARE

* (square 5)
25

* (square (square 3))
81
```

You defined a function, documented it, and used it, all in seconds. Now suppose you realize you want to add input validation:

```
* (defun square (x)
    "Return the square of X. Signals an error if X is not a number."
    (if (numberp x)
        (* x x)
        (error "~S is not a number" x)))
SQUARE

* (square 7)
49

* (square "hello")
; ERROR: "hello" is not a number
```

The function was redefined instantly, without restarting the REPL or recompiling anything. This interactive cycle of define, test, refine is the core Lisp workflow, and it is dramatically faster than the edit-compile-run-debug cycle of most other languages. Peter Seibel describes this as maintaining psychological "flow": you stay engaged with your problem continuously, rather than being interrupted by tooling overhead [4].

Exploring the Language

The REPL is also your primary tool for learning and exploring. When you encounter a function you do not understand, ask Lisp about it:

```
* (describe 'mapcar)
MAPCAR
  [symbol]
Function: #<SYSTEM-FUNCTION MAPCAR>
Documentation:
  MAPCAR takes as arguments a function and one or more sequences, and returns
  a list of the results of calling the function with elements of each sequence.
NIL

* (apropos "sort")
SORT      [symbol]
STABLE-SORT  [symbol]
NIL
```

`describe` shows you documentation and type information. `apropos` searches for symbols matching a pattern. These are built into every Lisp implementation and should be among your most-used tools.

The REPL Workflow in Practice

Here is how an experienced Lisp programmer typically works:

1. Start with a REPL session and begin defining functions interactively, testing each one as you go.
2. When a function is stable, move it to a source file (`.lisp`).
3. Load the file into the REPL with `(load "myfile.lisp")` and continue developing.
4. Iterate: modify code in files, reload, test in REPL, repeat.
5. For larger projects, use ASDF (discussed in Chapter 9) to manage compilation and dependencies.

This workflow is not a compromise or a beginner-friendly crutch; it is the primary way professional Lisp code is developed. The ability to modify running systems, redefine functions on the fly, and experiment interactively makes Lisp uniquely suited for exploratory programming, rapid prototyping, and maintaining complex systems over long periods.

In the next chapter, we will dive deep into Lisp's data structures and syntax rules, building the foundation you need to write real programs.

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