RELIABLE BASH SCRIPTING

WRITING PORTABLE, SECURE, AND PRODUCTION-READY SHELL SCRIPTS ACROSS LINUX DISTRIBUTIONS

PORTABLE
Works across major Linux distributions

RELIABLE
Handles errors, edge cases, and unexpected situations

SECURE
Defends against common vulnerabilities and attacks

MAINTAINABLE
Write clear, testable, and maintainable scripts

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Reliable Bash Scripting

Writing Portable, Secure, and Production-Ready Shell Scripts Across Linux Distributions

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Contents

Writing Portable, Secure, and Production-Ready Shell Scripts Across Linux Distributions

A comprehensive guide to writing Bash scripts that work correctly the first time, run consistently across different Linux distributions, handle errors gracefully, resist common attacks, and remain maintainable for years. This book takes you from shell fundamentals through advanced patterns used by experienced system administrators, DevOps engineers, and SREs in production environments. Whether you are automating routine tasks, building CI/CD pipelines, managing infrastructure, or writing container entrypoints, the principles here will help you write scripts that do not fail unexpectedly.

Preface

This book was written for people who are tired of shell scripts that work on their machine but break in production. If you have ever spent an hour debugging a script only to discover it failed because of an unquoted variable, a missing error check, or a Bash feature that does not exist on the target system, this book is for you.

Who Should Read This Book

This book assumes you are comfortable using the command line and have written shell scripts before. You know how to use `echo`, `grep`, and basic redirection. You may have scripts running in production that you are nervous about touching. That is exactly the audience this book targets.

The material is organized to serve readers at different levels:

- **Experienced developers** new to shell scripting will find clear explanations of shell-specific quirks and gotchas that differ from mainstream programming languages.
- **System administrators and DevOps engineers** will find production-ready patterns for automation, monitoring, deployment, and container orchestration.
- **SREs and platform engineers** will find rigorous coverage of error handling, logging, concurrency, and reliability patterns that scripts in critical infrastructure require.

How This Book Is Structured

The book is divided into five parts plus three appendices:

Part I: Foundations (Chapters 1–5) covers the shell's execution model, variable handling, control flow, functions, and arrays. Understanding these

fundamentals is essential because most shell scripting bugs stem from misunderstanding how the shell parses and executes commands.

Part II: Reliability (Chapters 6–9) addresses process management, signals, error handling, and defensive scripting. These chapters teach you to write scripts that survive real-world chaos and clean up after themselves.

Part III: Quality Assurance (Chapters 10–11) covers debugging, static analysis, testing with Bats, and CI/CD integration. Scripts are code, and they deserve the same quality treatment as any other software.

Part IV: Portability, Security, and Performance (Chapters 12–17) dives into POSIX compatibility, distribution differences, security hardening, performance optimization, and concurrency patterns.

Part V: Production Applications (Chapters 18–19) presents practical patterns for DevOps, CI/CD pipelines, containers, and system administration tasks.

The three appendices provide quick-reference material: a Bash syntax cheat sheet, a library of reusable production patterns, and a POSIX versus Bash feature comparison matrix.

Conventions Used in This Book

Code examples use `#!/usr/bin/env bash` unless POSIX compatibility is explicitly required, in which case `#!/bin/sh` is used. All production-ready examples include `set -euo pipefail` and follow the security and error-handling practices described in the book.

Diagrams throughout the book use Mermaid.js syntax and can be rendered by any Markdown viewer that supports Mermaid, including GitHub, GitLab, VS Code with the Markdown Preview Mermaid extension, and many static site generators.

About the Author

This book is the product of years of writing, debugging, and maintaining shell scripts in production environments across multiple Linux distributions. The patterns and recommendations here are drawn from real-world experience

running automation at scale, combined with careful study of the Bash Reference Manual, POSIX specifications, and the collective wisdom of the shell scripting community.

Acknowledgments

The shell scripting ecosystem benefits from outstanding open-source tools and documentation. Special thanks to the ShellCheck project for making it easier to catch bugs before they reach production, the Bats Core team for providing a robust testing framework, and the GNU Bash maintainers for decades of careful development. The Advanced Bash-Scripting Guide at tldp.org and Greg's Wiki (mywiki.wooledge.org) have been invaluable resources for understanding shell behavior in depth.

Introduction: The Hidden Complexity of Shell Scripts

A Script That Broke Production

On a Tuesday morning at 3:14 AM, a backup script failed. Not dramatically, not with an error message anyone would notice. It simply stopped partway through, leaving the database in an inconsistent state and the nightly snapshots incomplete. By the time someone realized the backups were missing, six hours had passed. The root cause was three lines of Bash:

```
backup_dir=/backups/$(date +%Y-%m-%d)
mkdir $backup_dir
pg_dump mydb > $backup_dir/backup.sql
```

The script worked fine most nights. But on that particular morning, a system update had created a directory called `/backups/2025-01-14` that was owned by root. The `mkdir` command failed silently because there was no error handling, and the redirect in the next line wrote the backup to whatever `$backup_dir` expanded to, which happened to be an existing directory with different permissions. The dump file ended up truncated and unreadable.

This is not a contrived example. It is the kind of failure that happens regularly in production environments, because shell scripts are deceptively simple. They look like plain English instructions chained together. A person who has used the command line for a few weeks can write one. But writing a script that works reliably under all conditions, across different systems, over months or years of changes, requires understanding far more than basic syntax.

What Makes a Shell Script Reliable

A reliable shell script is not merely one that runs without errors on your development machine. It must satisfy several criteria simultaneously:

Correctness. The script does exactly what it is supposed to do, with no unintended side effects. This means handling edge cases that rarely occur but will eventually happen in production, such as filenames with spaces, empty input files, or permission denied errors on specific paths.

Portability. The script runs correctly on all target systems without modification. Linux distributions differ in their default shell versions, available utilities, filesystem layouts, and system configurations. A script that works on Ubuntu may fail silently on Alpine Linux or behave differently on RHEL.

Security. The script does not introduce vulnerabilities, either through command injection, insecure temporary file handling, or improper privilege escalation. Production scripts often run as root or with elevated privileges, making security lapses especially dangerous.

Maintainability. Another person can read the script and understand what it does, why it does it that way, and how to modify it safely. This includes clear structure, meaningful variable names, appropriate comments, and adherence to consistent conventions.

Error handling. When things go wrong, the script fails fast with a clear indication of what happened, rather than continuing in a broken state or producing misleading output. It cleans up after itself, leaving no partial results or orphaned processes.

Performance. The script completes in reasonable time and does not waste system resources, especially when processing large datasets or running in loops that iterate thousands of times.

These criteria are not optional extras for scripts that happen to matter. They are requirements for any script that runs outside a personal sandbox. Yet many production scripts violate them routinely, because the shell language encourages quick-and-dirty solutions and provides few safeguards against common mistakes.

The Linux Distribution Landscape

Understanding the environment where your scripts will run is essential for writing portable code. The major Linux distributions differ in important ways:

Debian and Ubuntu ship with Bash as the default `/bin/sh` on many versions, though Debian has moved toward using Dash (a faster, more strictly

POSIX-compliant shell) as `/bin/sh`. Their package manager is `apt`, and they use systemd for service management.

Red Hat Enterprise Linux, AlmaLinux, and Rocky Linux all share similar tooling: Bash for scripting, `dnf` or `yum` for packages, and systemd for services. RHEL-based systems tend to ship slightly older but well-tested versions of tools.

Fedora serves as the upstream testing ground for RHEL features and often ships newer versions of Bash and core utilities. It is a useful reference for what will appear in enterprise distributions later.

Arch Linux follows a rolling release model, always providing the latest stable versions of software. Scripts written on Arch may use Bash features or utility options that are not available on more conservative distributions.

openSUSE offers both Tumbleweed (rolling) and Leap (stable) editions, uses `zypper` for package management, and historically offered choice between systemd, SysVinit, and OpenRC, though systemd is now the default.

Alpine Linux stands apart as a minimal distribution designed primarily for containers. Its default shell is BusyBox ash, not Bash. Many common utilities are BusyBox implementations with reduced feature sets. Scripts that assume Bash or GNU coreutils will fail on Alpine unless explicitly adapted.

These differences matter in practice. A script that uses `[[ ]]` conditionals, associative arrays, or process substitution will fail when run with Dash or BusyBox ash. A script that relies on GNU-specific options like `grep -P` may not work on systems using different implementations. Understanding these variations is not pedantry; it is the foundation of writing scripts that actually work where they need to.

How This Book Is Organized

This book proceeds from fundamentals to advanced topics in a sequence designed to build your understanding layer by layer:

The first section (Chapters 1 through 5) covers the shell's execution model and basic syntax. You will learn how Bash parses commands, expands variables, handles quoting, manages input and output, organizes code into functions, and structures data with arrays. Understanding these mechanisms is crucial

because many common bugs stem from misunderstanding what the shell actually does with your code.

The second section (Chapters 6 through 9) addresses reliability: process management, signals, error handling, and defensive scripting. You will learn to trap signals, ensure cleanup runs on exit, handle failures gracefully, and write scripts that survive real-world chaos.

The third section (Chapters 10 and 11) focuses on debugging and testing. You will learn Bash's built-in tracing options, how to use static analysis tools like ShellCheck, how to write automated tests with Bats, and how to integrate quality checks into CI pipelines.

The fourth section (Chapters 12 and 13) provides deep coverage of text-processing tools and portability. Chapter 12 introduces grep, sed, awk, find, xargs, and related utilities. Chapter 13 dives into advanced patterns for sed and awk, showing how to handle complex transformations efficiently. You will also learn how to write scripts that work correctly across different shells and environments.

The fifth section (Chapters 14 through 17) addresses distribution differences, security, performance optimization, and concurrency. You will learn the practical differences between major Linux distributions, how to protect scripts against injection attacks and privilege escalation, techniques for writing fast scripts, and patterns for parallel execution.

The final sections (Chapters 18 and 19) cover practical applications in DevOps, CI/CD, containers, and system administration, with production-ready examples you can adapt for your own environments.

The book concludes with three appendices: a Bash syntax cheat sheet, a library of common production patterns, and a POSIX versus Bash feature comparison matrix. Each chapter includes production-ready examples, comparison tables, and reference material you can consult when writing your own scripts.

This is not a book about memorizing commands. It is about understanding the shell deeply enough to write scripts that are correct by construction, that anticipate failure, and that remain maintainable as systems evolve around them. The code you write today will likely be run tomorrow, next month, and perhaps years from now, on systems you have not yet seen, by people who may not be you. Writing it well is not optional.

Chapter 1: The Bash Execution Model

Understanding how Bash actually works is the single most important step toward writing reliable scripts. Many shell scripting bugs are not caused by unfamiliar features but by subtle misunderstandings of the shell's parsing and execution behavior. This chapter explains the mechanics that govern every Bash script you will ever write.

How Bash Reads and Parses Input

When Bash encounters a command, it does not simply execute it as written. It goes through a series of processing stages that transform the raw text into something the system can run. Grasping this pipeline is essential because errors often occur at the transformation stage rather than during execution.

The process begins with reading. In an interactive shell, Bash reads a line from standard input after displaying a prompt. In a script, it reads lines sequentially from the file. Before any processing occurs, Bash performs lexical analysis: it breaks the input into tokens separated by metacharacters such as spaces, pipes (`|`), semicolons (`;`), and redirection operators (`<`, `>`).

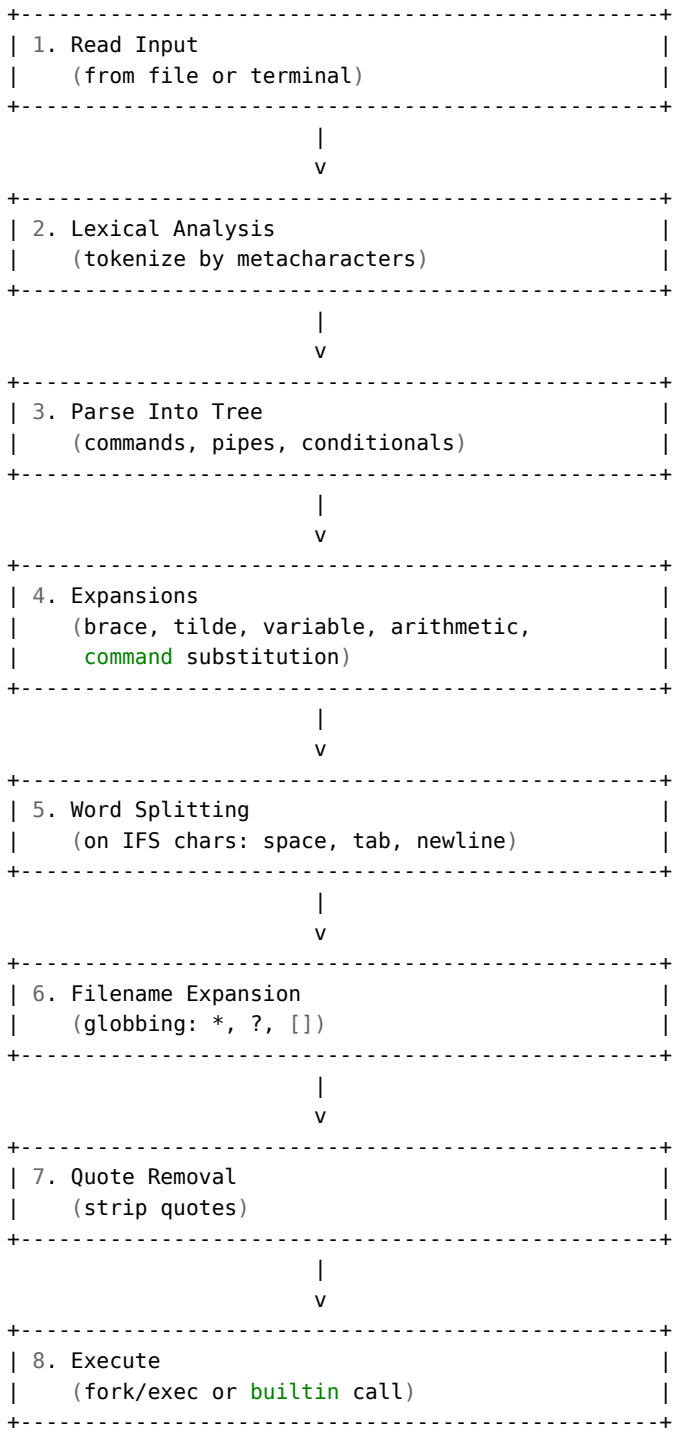
Consider this line:

```
1  echo hello world > output.txt
```

Bash tokenizes this into: `echo`, `hello`, `world`, `>`, `output.txt`. The metacharacter `>` is recognized as a redirection operator, not as part of a word. This tokenization happens before any variable expansion or other processing.

After tokenization, Bash builds a parse tree that represents the command structure. For pipelines, it creates nodes for each command connected by pipes. For conditional constructs like `if` and `while`, it creates branching structures. This parse tree is then processed through the expansion phases described below.

The entire process from raw text to execution can be visualized as a pipeline of transformations:



Each stage modifies the command representation before passing it to the next. Critically, quoting decisions made during the initial reading phase

influence which expansions occur and how splitting is applied later. This is why understanding where quotes appear in your source code matters so much.

One critical detail: Bash parses the entire command line before executing any part of it. This means that a syntax error anywhere on the line prevents the entire line from running, even if only a portion is malformed. It also means that variable values are not consulted during parsing; only the literal text matters at this stage. This distinction becomes important when using variables to construct dynamic commands.

The Expansion Order: A Critical Sequence

After parsing, Bash applies a series of expansions to each word in the command. The order is fixed and significant. Changing the order would change the meaning of many commands. According to the Bash Reference Manual, the expansion order is:

1. Brace expansion
2. Tilde expansion, parameter and variable expansion, arithmetic expansion, and command substitution (performed left to right)
3. Word splitting
4. Filename expansion (globbing)
5. Quote removal

Each stage transforms the text further. Understanding what happens at each stage explains why certain patterns work and others fail.

Brace expansion is purely textual and happens before anything else. It generates multiple strings from patterns like `{a,b,c}` or `{1..10}`. For example, `echo file{1,2,3}.txt` becomes `echo file1.txt file2.txt file3.txt`. Brace expansion does not involve variables or file system checks; it is simple pattern duplication.

Tilde expansion replaces ~ with the home directory of the current user (or a specified user when written as `~username`). This happens early so that paths like `~/documents/file.txt` are resolved before other processing.

Parameter and variable expansion replaces `$variable` or `${variable}` with the variable's value. This is where most dynamic behavior comes from. The expanded value is inserted literally into the command line at this point.

Arithmetic expansion, written as `$((expression))`, evaluates a mathematical expression and substitutes the result. For example, `$((5 + 3))` becomes `8`.

Command substitution, written as `$(command)` or with backticks, runs the specified command and substitutes its standard output into the command line. For example, `echo $(date +%Y)` might become `echo 2025`.

After these expansions complete, **word splitting** occurs. Bash splits each word at characters found in the IFS (Internal Field Separator) variable, which by default contains space, tab, and newline. This is why unquoted variables containing spaces cause problems: `files="a.txt b.txt"` followed by `rm $files` becomes `rm a.txt b.txt`, which works, but if the filenames themselves contain spaces, the splitting breaks them apart incorrectly.

Filename expansion, also called globbing, replaces patterns like `*.txt` or `[0-9]` with matching filenames from the current directory. If no files match, Bash behaves differently depending on shell options: by default, it leaves the pattern unchanged (which often causes a "file not found" error from the command being run).

Finally, **quote removal** strips the quotation marks that were used to control earlier expansion stages. The quotes themselves never appear in the final command; they only affect how expansions are applied.

This sequence explains a common source of confusion. Consider:

```
echo "hello world"
```

The double quotes prevent word splitting on the expanded result. Without them, `hello` and `world` would be separate arguments to echo. With them, they form a single argument. But the quotes do not prevent variable expansion inside them:

```
name=World
echo "Hello $name"
# Output: Hello World
```

Single quotes are stricter: nothing inside them is expanded at all.

```
name=World
echo 'Hello $name'
# Output: Hello $name
```

How quoting affects each expansion stage. The key insight is that quotes are processed at different stages:

1. During lexical analysis, Bash tracks which characters are inside quotes
2. During expansion phases (brace, tilde, variable, arithmetic, command substitution), quoted regions suppress certain expansions
3. Word splitting only applies to unquoted portions
4. Filename expansion only applies to unquoted portions
5. Quote removal happens last, stripping the quote marks themselves

This means:

- Double quotes suppress word splitting and filename expansion, but allow variable, arithmetic, and command substitution
- Single quotes suppress all expansions except their own handling (you cannot embed a single quote inside single quotes without ending the quoted section)
- Backslash escaping works differently inside single vs double quotes

Complex quoting interactions. Consider this line with mixed quoting:

```
var="hello world"
echo "$var" 'and' '$HOME'
# Output: hello world and $HOME
```

Bash treats each quoted segment separately:

- `"$var"` undergoes variable expansion, becomes “hello world”, no word splitting
- `'and'` is literal, no expansion
- `'$HOME'` is literal because single quotes prevent expansion

Now consider this more subtle case:

```
files=("a.txt" "b.txt")
echo "${files[@]}" *.log
```

Here `"${files[@]}"` expands to two separate quoted words: “a.txt” and “b.txt”. The `*.log` is unquoted, so it undergoes filename expansion. If the directory contains `c.log`, the final command is equivalent to:

```
echo a.txt b.txt c.log
```

The order matters for nested expansions. When you have command substitution inside variable expansion or vice versa, the innermost construct is processed first:

```
dir="/tmp"
file=$(echo "test")
echo "${dir}/${file}"
# Step 1: Command substitution $(echo "test") -> "test"
# Step 2: Variable expansion ${dir} -> "/tmp", ${file} -> "test"
# Result: /tmp/test
```

```
pattern="*.txt"
echo $(echo "$pattern")
# Step 1: Inside command substitution, $pattern expands to "*.txt"
# Step 2: Command substitution runs echo "*.txt", output is "*.txt"
# Step 3: The result is unquoted in the outer context, so filename expansion
↪  occurs
# Result: list of .txt files (if any exist)
```

This last example demonstrates why understanding the order is critical. The glob pattern survives the command substitution and then expands at the outer level because the command substitution result is unquoted.

Brace expansion edge cases. Brace expansion is unique because it happens before all other expansions, including variable expansion. This means you cannot use variables inside brace expressions:

```
start=1
end=5
echo {$start..$end}
# Output: {1..5} (literally, no expansion)
```

To work around this, use `eval` (with caution) or a loop:

```
# Using eval (dangerous with untrusted input)
eval echo "{$start..$end}"
# Output: 1 2 3 4 5

# Safer: use a while loop
i=$start
while [[ $i -le $end ]]; do
    echo "$i"
    ((i++))
done
```

Tilde expansion quirks. Tilde expansion only occurs at the beginning of a word and only when unquoted:

```
echo ~          # /home/username
echo ~/docs     # /home/username/docs
echo "~"        # ~ (literal)
echo "a~"       # a~ (no expansion, tilde not at start)
echo ${HOME}/docs  # /home/username/docs
```

This behavior is intentional: the shell needs to recognize ~ as a special character only when it stands alone at the start of a word.

Word Splitting and Pathname Expansion

Word splitting and pathname expansion are two of the most common sources of bugs in shell scripts. Both happen automatically after variable expansion, unless you explicitly prevent them with quoting.

Word splitting occurs on unquoted text that contains IFS characters. The default IFS is space, tab, and newline. When Bash encounters an unquoted variable whose value contains these characters, it splits the value into separate words.

```
IFS=$' \t\n'  # Default
files="file1.txt file2.txt"
for f in $files; do
    echo "Processing: $f"
done
# Output:
# Processing: file1.txt
# Processing: file2.txt
```

This works when filenames have no spaces. But if a filename contains a space, the behavior breaks:

```
files="file1.txt my document.txt"
for f in $files; do
    echo "Processing: $f"
done
# Output:
# Processing: file1.txt
# Processing: my
# Processing: document.txt
```

The filename `my document.txt` is split into two separate words. The fix is to quote the variable expansion:

```
for f in "$files"; do
    echo "Processing: $f"
done
```

But this creates a different problem: the entire string becomes one argument, including the space between filenames. For handling multiple filenames safely, arrays are the correct solution:

```
files=("file1.txt" "my document.txt")
for f in "${files[@]}"; do
    echo "Processing: $f"
done
```

The `"${files[@]}"` syntax expands each array element as a separate, properly quoted word.

Pathname expansion (globbing) replaces patterns with matching filenames. The most common patterns are:

- *: matches any string of characters (including empty)
- ?: matches exactly one character
- [abc]: matches any character in the brackets
- [!abc] or [^abc]: matches any character not in the brackets

```
echo *.txt
# If the directory contains a.txt, b.txt, c.log:
# Output: a.txt b.txt
```

Globbing only applies to unquoted patterns. Quoting disables it:

```
echo "*.txt"
# Output: *.txt (literally)
```

A subtle issue arises when no files match the pattern. By default, Bash leaves the pattern unchanged:

```
# No .log files in directory
echo *.log
# Output: *.log
rm *.log
# Error: rm: cannot remove '*.log': No such file or directory
```

This behavior can be changed with `shopt -s nullglob`, which causes unmatched patterns to expand to nothing:

```
shopt -s nullglob
echo *.log
# Output: (nothing)
```

In scripts, always consider what happens when a glob matches zero files, many files, or files with unusual names. Using `find` instead of globs often provides more predictable behavior for complex file operations.

Advanced globbing options. Bash provides several shell options that modify globbing behavior:

```
# nullglob: unmatched patterns expand to nothing (empty)
shopt -s nullglob
echo *.nonexistent
# Output: (nothing, no error)

# failglob: unmatched patterns cause an error
shopt -s failglob
echo *.nonexistent
# Error: bash: no match: *.nonexistent

# dotglob: globs match files starting with .
shopt -s dotglob
echo .*
# Output: . .. .bashrc .profile (etc.)

# globstar: ** matches directories recursively
shopt -s globstar
echo **/*.txt
# Output: all .txt files in current and subdirectories

# nocaseglob: case-insensitive matching
shopt -s nocaseglob
echo *.TXT
# Matches both .txt and .TXT files
```

These options are powerful but should be set deliberately and unset afterward if they might affect other parts of the script:

```
# Save current settings, modify, restore
saved_nullglob=$(shopt -p nullglob)
shopt -s nullglob
# ... do work that benefits from nullglob ...
eval "$saved_nullglob"
```

The ARG_MAX limit. When a glob matches many files, Bash expands it into a long list of arguments. If the total length exceeds the system's ARG_MAX limit (typically 2MB on Linux), the command fails:

```
# If there are millions of files, this may fail
ls /var/log/*/*/*/*
# -bash: /usr/bin/ls: Argument list too long
```

Use `find` with `-exec` or `xargs` instead:

```
find /var/log -type f -print0 | xargs -0 ls -la
```

This approach processes files in batches that fit within ARG_MAX.

Subshells and Process Forking

Bash creates new processes in several situations, and understanding when this happens is crucial for writing correct scripts. Each new process is a separate instance of the shell with its own copy of variables, working directory, and file descriptors. Changes made in a subshell do not affect the parent shell.

Explicit subshells are created using parentheses:

```
( cd /tmp; pwd )
# Output: /tmp
pwd
# Output: (original directory)
```

The `cd` inside the parentheses runs in a subshell. When the subshell exits, the parent shell's working directory is unchanged.

Pipelines create subshells for each command in the pipe. This is a common source of confusion:

```
counter=0
echo -e "a\nb\nc" | while read line; do
    ((counter++))
done
echo "$counter"
# Output: 0
```

The `while` loop runs in a subshell created by the pipe. The variable `counter` is incremented inside that subshell, but the changes are lost when the subshell exits. The parent shell still sees `counter=0`.

To fix this, use process substitution instead of a pipe:

```
counter=0
while read line; do
    ((counter++))
done < <(echo -e "a\nb\nc")
echo "$counter"
# Output: 3
```

Process substitution `<(...)` runs the command inside in a subshell, but the `while` loop runs in the current shell, so variable changes persist.

Command substitution also creates a subshell:

```
result=$(some_command)
```

The `some_command` runs in a subshell, and its standard output is captured into `result`. Any variables set inside the command substitution are not visible outside it.

Forking cost. Each subshell requires a fork operation, which creates a new process. On modern Linux systems with copy-on-write memory, forking a single process is fast (typically under 1 millisecond). However, in loops that iterate thousands or tens of thousands of times, the cumulative cost becomes significant. A loop that forks a subprocess on each iteration can be an order of magnitude slower than one using built-in shell features.

For performance-critical scripts, minimize unnecessary subshells:

- Use `while read` with input redirection instead of piping into a loop
- Prefer built-in commands over external utilities when possible
- Use parameter expansion for string manipulation instead of calling sed or awk in a loop

Interactive vs Non-Interactive Mode Differences

Bash behaves differently depending on whether it is running interactively (reading from a terminal with a user typing commands) or non-interactively (running a script). Many scripts fail in production because they assume interactive behavior that does not occur when run automatically.

Key differences:

Startup files. Interactive login shells read `/etc/profile` and then `~/.bash_profile`, `~/.bash_login`, or `~/.profile`. Interactive non-login shells read `~/.bashrc`. Non-interactive scripts read the file specified by the `BASH_ENV` environment variable, if set. This means that aliases, functions, and variables defined in `.bashrc` are not available in scripts unless explicitly sourced.

Job control. Interactive shells enable job control by default, allowing you to suspend processes with Ctrl+Z and manage background jobs. Non-interactive shells disable job control. Attempting job control operations in a script without a controlling terminal will fail.

History. Command history is maintained only in interactive shells. Scripts do not have access to history expansion (`!` syntax) unless explicitly enabled.

Prompt display. Interactive shells display prompts (PS1, PS2). Non-interactive shells do not. If a script accidentally enters interactive mode (for example, by calling `read` without input), it will hang waiting for user input that never comes.

Signal handling. Interactive shells ignore SIGINT (Ctrl+C) when reading a command line to allow you to edit the current line. Non-interactive scripts terminate immediately on SIGINT unless a trap is set.

To check whether Bash is running interactively, test the `-i` option:

```
if [[ $- == *i* ]]; then
    echo "Running interactively"
else
    echo "Running non-interactively (script)"
fi
```

For scripts, always assume non-interactive behavior. Do not rely on aliases from `.bashrc`, do not expect history to be available, and do not write code that requires user input unless you explicitly design for it.

Chapter 2: Variables, Quoting, and Safe Syntax

Variables and quoting form the foundation of every Bash script. Misunderstanding how variables are stored, expanded, and quoted is responsible for more bugs than any other single factor. This chapter covers everything you need to know to use variables correctly and avoid the quoting pitfalls that trip up experienced developers.

Variable Assignment and Naming Conventions

Bash variables are untyped strings. There is no distinction between numbers, text, or other types; everything is stored as a sequence of characters until it is used in a context that requires interpretation.

Assignment syntax. Assign values with = and no spaces around the equals sign:

```
name="John Doe"
count=42
path="/usr/local/bin"
```

Spaces around = cause errors because Bash interprets them as command separators:

```
name = "John Doe"
# Error: name: command not found
```

No dollar sign on assignment. The $ prefix is used only when reading a variable's value, not when setting it:

```
$incorrect="bad"    # Syntax error
correct="good"      # Correct
echo "$correct"     # Output: good
```

Naming rules. Variable names must start with a letter or underscore, followed by letters, digits, or underscores. They are case-sensitive. By convention in shell scripts:

- UPPERCASE names are reserved for environment variables and system-defined variables (PATH, HOME, USER, etc.)
- lowercase or mixed_case names are used for script-local variables
- This convention prevents accidental overwriting of important system variables

```
# Good practice
output_dir="/var/log/myapp"
max_retries=3
TEMP_FILE=$(mktemp)

# Avoid: might conflict with environment
PATH="/custom/path"    # Overwrites the system PATH
USER="admin"           # Confuses scripts checking $USER
```

Variable scope. By default, Bash variables exist only in the current shell. Child processes (subshells, executed commands) inherit a copy of exported variables but cannot modify the parent's variables.

The `export` builtin makes a variable available to child processes:

```
API_KEY="secret123"
export API_KEY
./child_script.sh    # Can read $API_KEY
```

Inside functions, the `local` keyword restricts a variable to that function's scope:

```
process_file() {
    local input="$1"
    local result
    result=$(cat "$input")
    echo "$result"
}
# $input and $result are not accessible outside this function
```

Always use `local` for variables inside functions. Global variables create hidden dependencies between functions and make scripts harder to reason about.

The Three Types of Quotes

Bash provides three quoting mechanisms, each with different behavior. Using the wrong type is a frequent source of bugs.

Double quotes ("). Double quotes preserve most literal characters while allowing variable expansion, command substitution, and arithmetic expansion. They prevent word splitting and globbing on the expanded result.

```
name="World"
echo "Hello $name"
# Output: Hello World

files=("a.txt" "b.txt")
echo "${files[@]}"        # Unquoted: subject to word splitting and globbing
echo "${files[@]}"        # With spaces in filenames, this breaks
echo "${files[@]}"        # Double-quoted: each element is a separate word
```

Double quotes are the default choice for protecting variable values. Almost every variable expansion in a script should be double-quoted.

Single quotes ('). Single quotes preserve everything literally. No expansions of any kind occur inside single quotes. To include a single quote inside a single-quoted string, you must end the quote, add an escaped quote, and start a new quoted section:

```
echo 'No expansion here: $HOME is literal'
# Output: No expansion here: $HOME is literal

echo 'It'\''s working'
# Output: It's working
```

Use single quotes for strings that contain no variables and should never be interpreted. This includes regular expressions passed to grep or sed, where shell interpretation would interfere with the pattern:

```
grep -E '[0-9]{3}-[0-9]{4}' file.txt    # Single quotes protect the braces
sed 's/old/new/g' file.txt              # Single quotes protect the slashes
```

Backticks (`). Backticks perform command substitution, capturing the standard output of a command:

```
today=`date +%Y-%m-%d`
echo "Today is $today"
```

Backticks are considered legacy syntax. The preferred form uses `$(...)`:

```
today=$(date +%Y-%m-%d)
```

Reasons to prefer `$()`:

- Nesting is straightforward: `$(echo $(pwd))` vs the difficult `echo `pwd``
- Quotes and special characters inside are easier to manage
- The syntax clearly distinguishes command substitution from other constructs

Modern scripts should never use backticks. Use `$()` exclusively.

Backslash escaping. A backslash before any character preserves that character literally, preventing its special meaning:

```
echo "Price: \$100"
# Output: Price: $100

echo "Line with a tab:\there"
# Output: Line with a tab:  here
```

Inside single quotes, backslashes are literal except before another single quote or another backslash. Inside double quotes, backslashes only escape $, `, ", \, and newline.

Parameter Expansion and Default Values

Bash provides powerful parameter expansion features beyond simple variable substitution. These are essential for writing robust scripts that handle missing values, validate input, and manipulate strings.

Basic forms:

```
${var}        # Same as $var, but allows unambiguous boundaries
echo "${var}_suffix"    # Without braces: echo "$var_suffix" would be wrong
```

Always use `${var}` when the variable name is followed by characters that could be part of a valid name. This prevents ambiguity and makes code more readable.

Default values:

```
${var:-default}      # Use default if var is unset or empty
${var-default}       # Use default only if var is unset (not if empty)
${var:=default}      # Set var to default if unset or empty, then use it
${var=default}       # Set var to default only if unset, then use it
```

These are invaluable for providing sensible defaults:

```
#!/usr/bin/env bash
set -euo pipefail

output_dir="${OUTPUT_DIR:-/var/log/myapp}"
log_level="${LOG_LEVEL:-info}"
max_connections="${MAX_CONN:=100}"    # Also sets the variable for later use
```

Error on empty:

```
${var:?error message}     # Exit with error if var is unset or empty
${var?error message}      # Exit with error only if var is unset
```

Use this pattern for required parameters:

```
#!/usr/bin/env bash
set -euo pipefail

target="${1:?Usage: $0 <target_host>}"
port="${PORT:-8080}"
```

String manipulation:

Bash can manipulate strings without calling external commands, which is both faster and more portable.

Remove shortest match from front:

```
filename="/path/to/file.txt"
basename="${filename##*/}"      # file.txt (# removes longest match from front)
extension="${filename##*.}"     # txt
name="${filename%.*}"           # /path/to/file (% removes shortest from end)
```

Substring extraction:

```
text="Hello, World!"
echo "${text:7:5}"    # Output: World (start at position 7, length 5)
echo "${text: -5}"    # Output: World! (last 5 characters, note the space
↪  before -)
```

Case modification (Bash 4+):

```
name="hello world"
echo "${name^}"       # Hello world (capitalize first letter)
echo "${name^^}"      # HELLO WORLD (uppercase all)
echo "${name,}"       # hello world (lowercase first letter)
echo "${name,,}"      # hello world (lowercase all)
```

Pattern replacement:

```
url="http://example.com/path"
https_url="${url/http/https}"        # Replace first occurrence
all_https="${url//http/https}"       # Replace all occurrences
no_scheme="${url#*://}"              # Remove scheme: example.com/path
```

Using these built-in expansions instead of calling sed, awk, or cut for simple string operations makes scripts faster and more readable.

Special Parameters: Positional, IFS, PATH, and More

Bash provides several special parameters with fixed names that control shell behavior or provide information about the current execution context.

Positional parameters. When a script is invoked with arguments, they are available as `$1`, `$2`, etc.:

```
#!/usr/bin/env bash
# Invoked as: ./script.sh arg1 arg2 arg3
echo "First argument: $1"
echo "Second argument: $2"
```

Related special parameters:

- `$0`: The script's name (or command used to invoke it)
- `$@`: All positional parameters, each as a separate word. Always quote it: `"$@"`
- `$*`: All positional parameters joined into a single string separated by the first character of IFS. Rarely useful; prefer `"$@"`
- `$#`: The number of positional parameters

The distinction between `"$@"` and `"$*"` is critical. `"$@"` preserves each argument as a separate word:

```
#!/usr/bin/env bash
for arg in "$@"; do
    echo "Argument: [$arg]"
done
# Invoked as: ./script.sh "hello world" foo bar
# Output:
# Argument: [hello world]
# Argument: [foo]
# Argument: [bar]
```

Using `"$*"` would join them into one argument with spaces.

Shift. The `shift` builtin removes positional parameters from the front, shifting remaining ones down:

```
#!/usr/bin/env bash
set -euo pipefail

verbose=false
while [[ $# -gt 0 ]]; do
    case "$1" in
        -v|--verbose)
            verbose=true
            shift
            ;;
        -*)
            echo "Unknown option: $1" >&2
            exit 1
            ;;
        *)
            break
            ;;
    esac
done

target="${1:-}"
echo "Verbose: $verbose, Target: $target"
```

IFS (Internal Field Separator). IFS controls word splitting. The default value is space, tab, and newline. Changing IFS affects how unquoted expansions are split:

```
IFS=',' read -r a b c <<< "one,two,three"
echo "$a"    # one
echo "$b"    # two
echo "$c"    # three
```

Be careful when modifying IFS globally. It affects all subsequent word splitting in the script. Use a subshell or local scope to limit changes:

```
# Safe: change IFS only within this block
(
    IFS=$'\n'
    while read -r line; do
        echo "Line: $line"
    done < file.txt
)
```

PATH. The PATH variable is a colon-separated list of directories where Bash searches for executable commands. When you type a command name without a path, Bash looks through each directory in PATH until it finds a matching executable.

```
echo "$PATH"
# Typical output: /usr/local/bin:/usr/bin:/bin:/usr/local/sbin:/usr/sbin:/sbin
```

Modifying PATH in scripts should be done carefully. Prepend directories rather than appending to control priority:

```
export PATH="/opt/custom/bin:$PATH"    # Custom tools take precedence
```

Other important special parameters:

- `$$`: Process ID of the current shell
- `$!`: Process ID of the most recent background command
- `$?`: Exit status of the most recently executed foreground command
- `$-`: Current shell options (useful for checking interactive mode)
- `${BASH_VERSION}`: Version of the running Bash instance
- `${RANDOM}`: A random integer between 0 and 32767

Common Quoting Pitfalls and How to Avoid Them

Even experienced developers make quoting mistakes. Here are the most common patterns and how to fix them.

Pitfall 1: Unquoted variables in conditionals.

```
# WRONG
if [ $var = "value" ]; then    # If var is empty: syntax error
fi

# CORRECT
if [[ "$var" == "value" ]]; then
fi

# Also correct with single brackets
if [ "$var" = "value" ]; then
fi
```

When `$var` is empty and unquoted, `[ $var = "value" ]` becomes `[ = "value" ]`, which is a syntax error. Always quote variables in conditionals.

Pitfall 2: Quoting the wrong thing in loops.

```
# WRONG: globs are quoted, so they never expand
for f in "*.txt"; do
    echo "$f"
done
# Output: *.txt (literally, if no files match)

# CORRECT: glob is unquoted, filenames are quoted in the body
for f in *.txt; do
    echo "Processing: $f"
done
```

Pitfall 3: Command substitution with trailing newlines.

Command substitution strips trailing newlines from output. This can cause issues when preserving exact output matters:

```
content=$(cat file.txt)
# Trailing newlines from file.txt are lost
echo "$content" > output.txt
# output.txt may differ from file.txt if it had trailing newlines
```

Use `cp` instead of cat-echo for copying files. If you must use command substitution and preserve newlines, add a sentinel character:

```
content="$(cat file.txt; echo x)"
content="${content%x}"    # Remove the sentinel
```

Pitfall 4: Nested quotes.

```
# WRONG: inner double quotes end the outer string prematurely
echo "Hello "World""

# CORRECT: use single quotes inside double quotes, or escape
echo "Hello \"World\""
echo "Hello 'World'"
```

Pitfall 5: Forgetting to quote "$@".

```
# WRONG: arguments are joined and re-split
run_command() {
    echo "$*"
}

# CORRECT: each argument is preserved separately
run_command() {
    echo "$@"
}
```

The golden rule of quoting in Bash: always quote variable expansions unless you have a specific reason not to. The only common legitimate reasons to leave variables unquoted are:

- Intentional word splitting (rare; arrays are usually better)
- Glob patterns that must be expanded
- Arithmetic expressions where `$((var))` works without quotes
- Passing options that contain no spaces or special characters

When in doubt, quote it. The consequences of under-quoting are far more severe than the occasional inconvenience of over-quoting.

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Input/Output Redirection

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Arithmetic

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Special Variables

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Common set Options

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shopt Options

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Appendix B: Common Production Patterns Library

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Standard Script Skeleton

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Retry Pattern with Exponential Backoff

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Parallel Processing with Concurrency Limit

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Safe File Write (Atomic)

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Wait for Service with Timeout

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Parse Configuration File into Associative Array

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Send Alert via Webhook

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Disk Space Check

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Appendix C: POSIX vs. Bash Feature Comparison Matrix

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Core Language Features

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Quoting and Expansion

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Control Flow

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Input/Output

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Functions and Scope

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Special Variables

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Shell Options (shopt)

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Utilities and Commands

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References

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