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How to Structure a Large-Scale Rust Application Without Losing Your Mind

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Harishsingh Following

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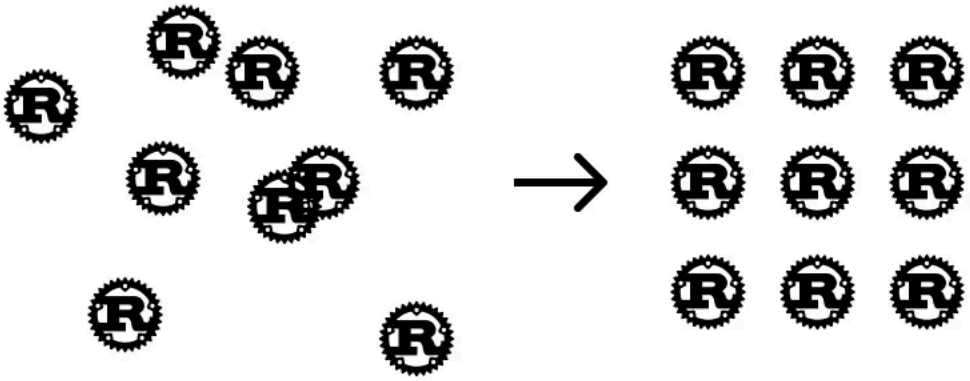
Rust gives you safety, performance, and control — but when your codebase starts to scale beyond a few thousand lines, you'll quickly face a different kind of complexity: **code organization**.

Whether you're building a service-oriented backend, a CLI tool, or a systems-level application, knowing how to **modularize**, **abstract**, and **scale** a Rust codebase is essential.

This post walks through real-world architecture techniques, crate layouts, and idiomatic patterns that help keep large Rust apps clean and maintainable.



Why Structure Matters in Rust

Unlike many dynamic or GC-based languages, Rust:

- **Forces early decisions** about ownership, lifetimes, and dependencies.
- Encourages a **functional-declarative style** that requires planning abstractions.
- Has **no inheritance**, but offers composition through traits, enums, and modules.

Without a good structure, your project can become a maze of `mod.rs`, cyclic imports, and monolithic logic.

Starting with a Strong Foundation

Let's begin with a base architecture for a large-scale Rust backend:

```
/my_app
├── Cargo.toml
└── src
```

```
    ├── main.rs               --> Entry point
    ├── lib.rs                --> App-wide exports and setup
    ├── config/               --> Config parsing and validation
    ├── api/                  --> HTTP handlers or CLI commands
    ├── services/             --> Business logic
    ├── domain/               --> Core types, enums, interfaces
    ├── db/                   --> Persistence layer (Postgres, Redis etc.)
    ├── errors/               --> Shared error types
    ├── utils/                --> Generic helpers
```

This layout follows the **Layered Architecture** pattern:

- Domain is at the center (pure logic)
- Services apply domain logic
- API and DB layers handle transport and storage

`main.rs` and `lib.rs`: Keeping the Entrypoint Clean

```rust
fn main() -> Result<(), Box<dyn std::error::Error>> {
    my_app::run()
}
```

In `lib.rs`, we wire everything together:

```rust
pub mod config;
pub mod api;
pub mod services;
pub mod db;
pub mod errors;

pub fn run() -> Result<(), Box<dyn std::error::Error>> {
    let cfg = config::load()?;
    let db_pool = db::init(&cfg.db)?;
    api::start_server(cfg, db_pool)
}
```

This separation lets you:

- Test `run()` without launching a binary
- Share `lib.rs` in integration tests or benchmarks

Config Module (with Serde and Envs)

```rust
// src/config/mod.rs
use serde::Deserialize;

#[derive(Debug, Deserialize)]
pub struct Config {
    pub db: Database,
    pub server: Server,
}
#[derive(Debug, Deserialize)]
pub struct Database {
    pub url: String,
}
#[derive(Debug, Deserialize)]
pub struct Server {
    pub port: u16,
}
pub fn load() -> Result<Config, config::ConfigError> {
    let cfg = config::Config::builder()
```

```
        .add_source(config::File::with_name("config/default"))
        .add_source(config::Environment::with_prefix("APP"))
        .build()?;
    cfg.try_deserialize()
}
```

Use `APP_DB__URL=postgres://...` to override nested values via env.

API Layer: Thin Controllers

```
// src/api/mod.rs
use axum::{routing::get, Router};
use crate::services::user::UserService;

pub fn start_server(cfg: crate::config::Config, db: sqlx::PgPool) -> Result<(), hyper::Error> {
    let user_service = UserService::new(db.clone());
    let app = Router::new()
        .route("/health", get(health))
        .route("/users/:id", get(move |id| get_user(id, user_service.clone())));
    axum::Server::bind(&([0, 0, 0, 0], cfg.server.port).into())
        .serve(app.into_make_service())
        .await?;
    Ok(())
}
async fn health() -> &'static str {
    "OK"
}
```

Each route delegates to a **service**, not directly to DB calls.

Domain Layer: Types and Traits

```
// src/domain/user.rs
#[derive(Debug, Clone)]
pub struct User {
    pub id: uuid::Uuid,
    pub email: String,
    pub is_active: bool,
}

pub trait UserRepo {
    fn find_by_id(&self, id: uuid::Uuid) -> Result<User, crate::errors::AppError>;
}
```

The domain layer defines **pure logic** and **contracts**, free from frameworks or database concerns.

Service Layer: Business Logic Lives Here

```
// src/services/user.rs
use crate::domain::user::{UserRepo, User};
use crate::errors::AppError;

#[derive(Clone)]
pub struct UserService<R: UserRepo> {
    repo: R,
}
impl<R: UserRepo> UserService<R> {
    pub fn new(repo: R) -> Self {
        Self { repo }
    }
    pub fn get_user(&self, id: uuid::Uuid) -> Result<User, AppError> {
        let user = self.repo.find_by_id(id)?;
        if !user.is_active {
            Err(AppError::InactiveUser)
        } else {
```

```
            Ok(user)
        }
    }
}
```

The service is generic over any `UserRepo`, making it easy to test.

Database Layer: The Adapter

```
// src/db/user_pg.rs
use crate::domain::user::{User, UserRepo};
use crate::errors::AppError;
use sqlx::PgPool;

pub struct PostgresUserRepo {
    pool: PgPool,
}
impl UserRepo for PostgresUserRepo {
    fn find_by_id(&self, id: uuid::Uuid) -> Result<User, AppError> {
        let rec = sqlx::query_as!(
            User,
            "SELECT id, email, is_active FROM users WHERE id = $1",
            id
        )
        .fetch_one(&self.pool)
        .await?;
        Ok(rec)
    }
}
```

If you later switch to Redis or mock the repo in tests, no service code changes.

Error Handling

Create your app-wide error types once:

```
// src/errors/mod.rs
#[derive(Debug)]
pub enum AppError {
    NotFound,
    InactiveUser,
    DbError(sqlx::Error),
}

impl From<sqlx::Error> for AppError {
    fn from(e: sqlx::Error) -> Self {
        AppError::DbError(e)
    }
}
```

Testing and Benchmarking

Use `#[cfg(test)]` modules inside each file for local tests:

```
#[cfg(test)]
mod tests {
use super::*;

struct MockRepo;
    impl UserRepo for MockRepo {
        fn find_by_id(&self, _: uuid::Uuid) -> Result<User, AppError> {
            Ok(User { id: uuid::Uuid::new_v4(), email: "test@example.com".into(), is_active: true })
        }
    }
    #[test]
    fn returns_user_if_active() {
        let service = UserService::new(MockRepo {});
```

```
        assert!(service.get_user(uuid::Uuid::new_v4()).is_ok());
    }
}
```

Benchmark Example

Using `criterion.rs`:

```
fn fibonacci(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fibonacci(n - 1) + fibonacci(n - 2),
    }
}

fn bench(c: &mut Criterion) {
    c.bench_function("fib 20", |b| b.iter(|| fibonacci(20)));
}
```

Dependency Management: Workspaces and Crates

If your project has multiple domains or shared libraries, split it into a **workspace**:

```
/project-root
├── Cargo.toml (workspace)
├── core/
│   └── Cargo.toml
├── web/
│   └── Cargo.toml
└── db/
    └── Cargo.toml
```

Workspace-level `Cargo.toml`:

```
[workspace]
members = ["core", "web", "db"]
```

This keeps domain logic, persistence, and delivery isolated.

Diagram: Layered Ownership and Abstraction

```
       [ main.rs ]         --> Application entrypoint
            |
       [ lib.rs ]          --> Wire dependencies, start server
            |
+-----------------------+
|    Application Layer  |
|  (services, handlers) |
+-----------------------+
            |
+-----------------------+
|     Domain Layer      |
|  (types, traits, logic)|
+-----------------------+
            |
+-----------------------+
|  Infrastructure Layer |
| (DB, HTTP, Redis etc.)|
+-----------------------+
```

Closing Thoughts

Rust gives you the tools to write high-performance, safe systems — but with power comes complexity. If you're building something non-trivial:

- Keep your **domain pure and interface-driven**
- Push side effects and infra concerns **to the edges**
- Build around **traits, enums, and modules**, not inheritance
- Start small — but **structure like you're building big**

This structure has helped us scale codebases to **50k+ lines**, onboard new contributors quickly, and maintain rock-solid reliability in production.

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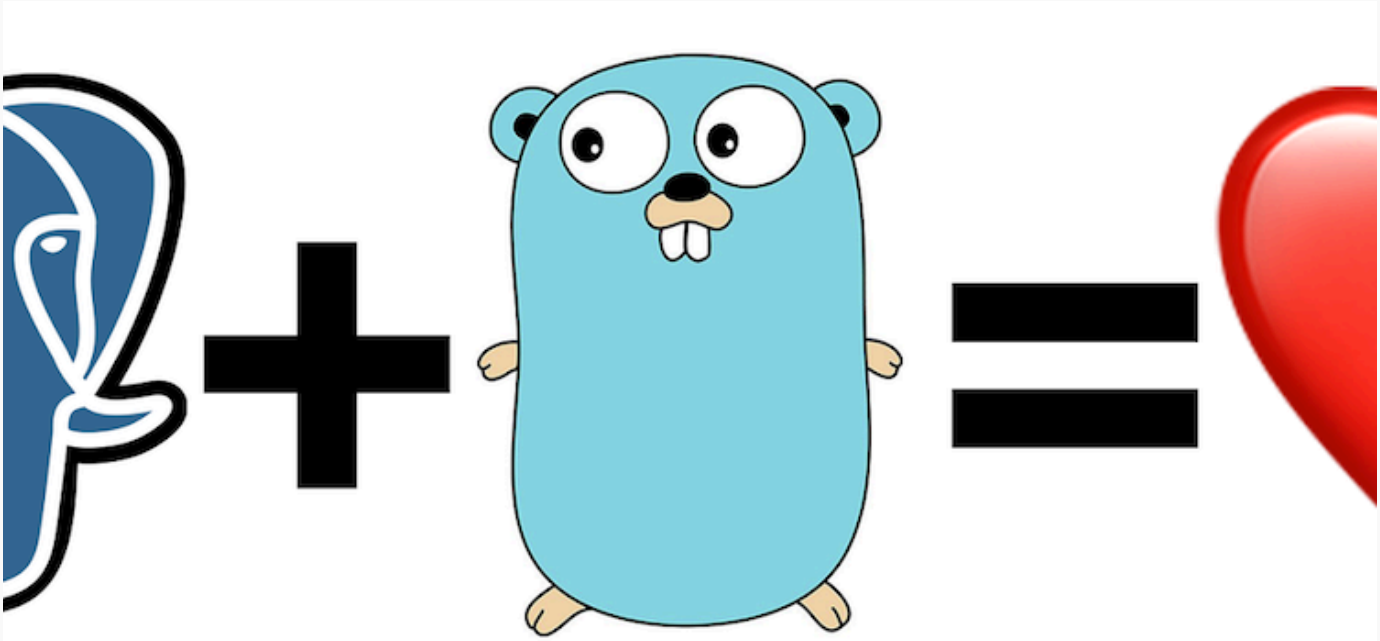

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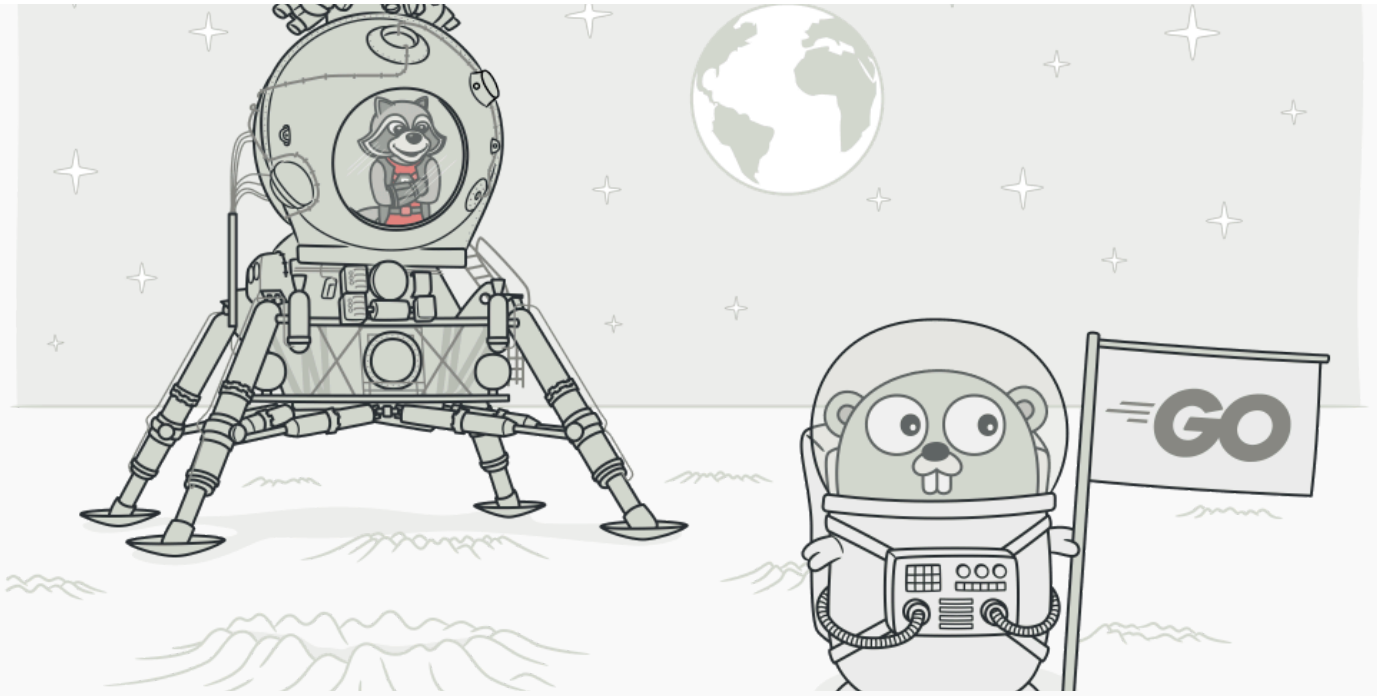

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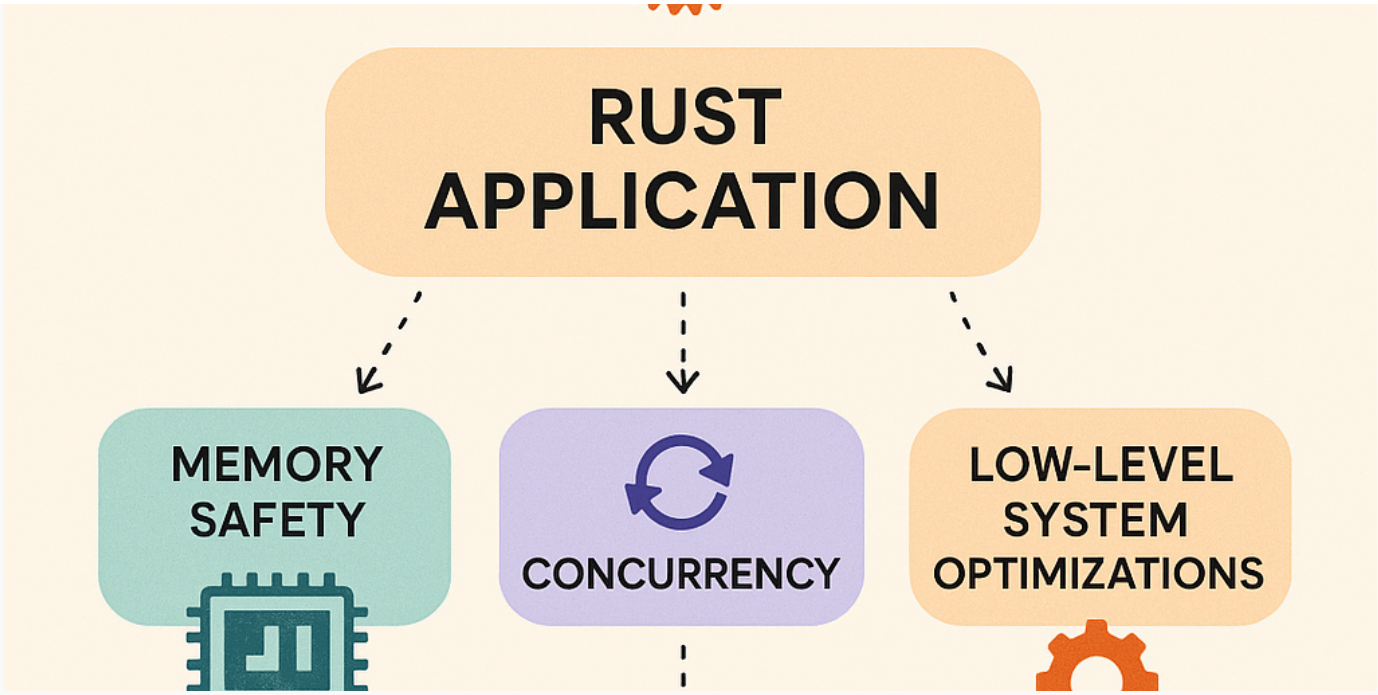

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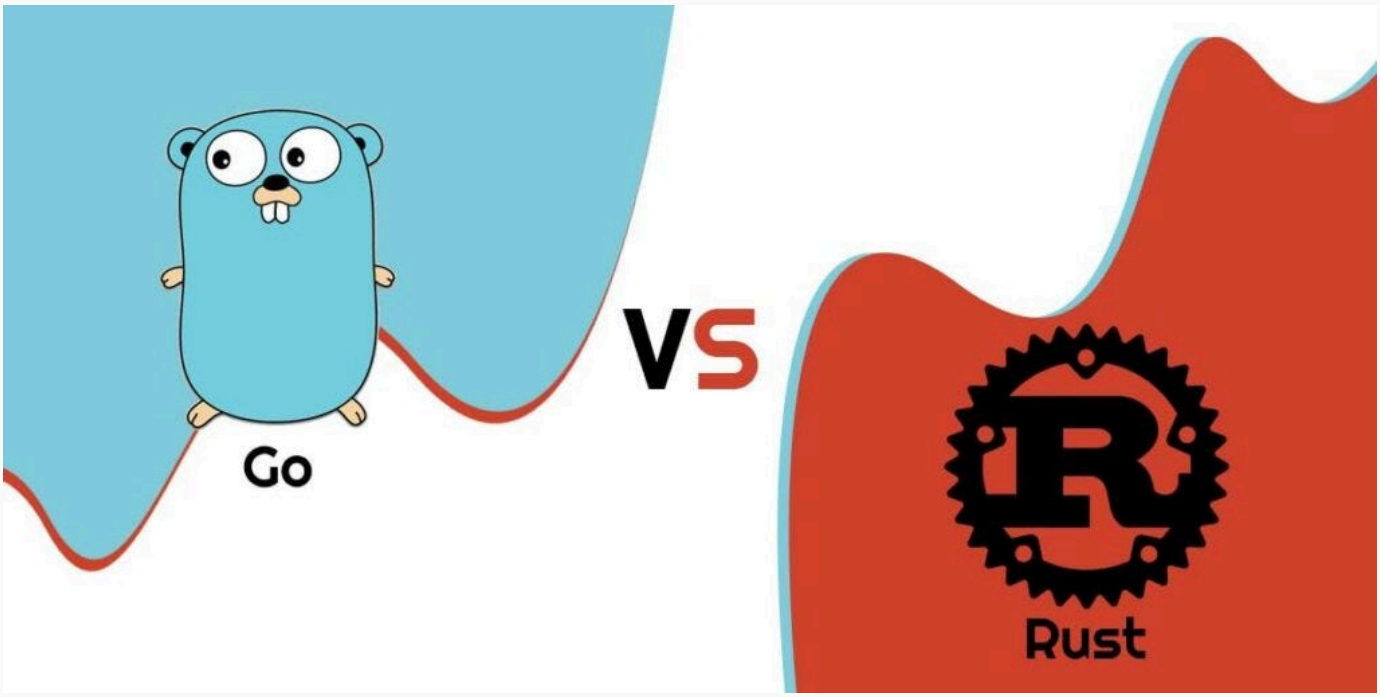

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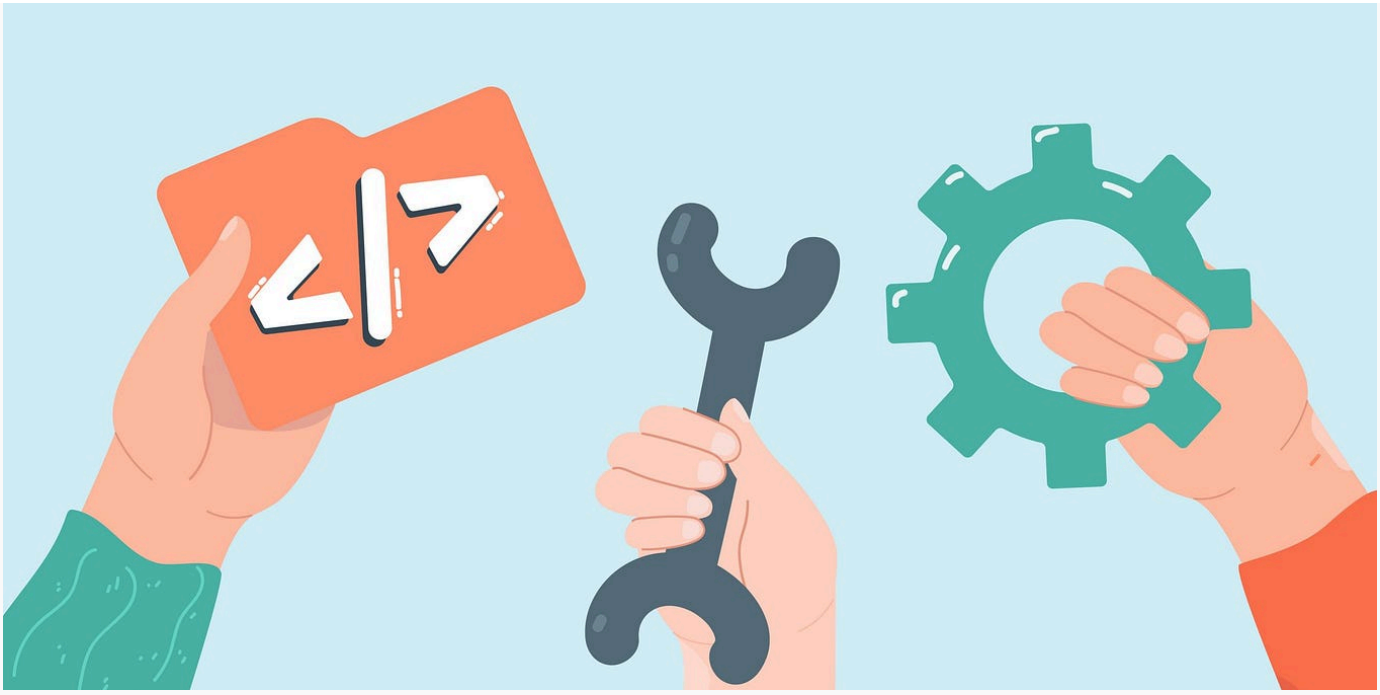

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