

An Evaluation of the current State of web server development in Rust and Java *

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Abstract

This paper aims to evaluate the current state of web server development in Rust and Java. In doing so, it will cover the basics of web server development in both languages, the tools and libraries available, and the advantages and disadvantages of using each language for web server development. Furthermore it will include a comparison of the two languages in terms of performance, ease of use, and other factors that are important for web server development.

*This document references v0.5.0 of the GitHub Repository

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1 Introduction

Web server development is an important aspect of modern software development as they are used to host websites, web applications, and other online services. One of the most popular languages for this is Java and the Spring framework. Java is a mature and widely used programming language that is known for its performance, scalability, and reliability. However, in recent years, Rust has emerged as a promising alternative to Java for web server development as seen at Discord [2], Cloudflare[1], and other companies. Rust is in stark contrast to Java, is a systems programming language that is designed for performance, safety, and concurrency. This paper aims to evaluate the current state of web server development in Rust and Java, and to provide an overview of the tools, libraries, and best practices for web server development in both languages.

1.1 An Overview of Spring Boot

Spring Boot is a popular Java framework for building web applications and microservices used by companies like Deutsche Bahn[3], Udemy [5] and many others[4]. Built on top of the Spring framework, Spring Boot provides a set of tools and libraries that make it easy to build web applications and microservices in Java. It finds wide adoption in the industry due to its ease of use, maintainability and scalability, as well as the vast amount of libraries and tools available for it.

1.2 An Overview of Actix Web

Actix is a Rust framework for building backend services in rust and the one currently one of the most actively developed frameworks, within the Rust ecosystem. It provides provides a very similar feature set to Spring Boot making it a suitable candidate for comparison.

1.3 Other Used Technologies

In addition to the frameworks mentioned above, I will use the following technologies to build the web server:

- RustRover An IDE by JetBrains that provides support for Rust development.
- IntelliJ IDEA Ultimate An IDE by JetBrains that provides support for Java development.
- VS Code A Text editor by microsoft used in this project for writing the LaTeX document.
- PostgreSQL A popular open-source relational database management system that is widely used in the industry.
- Docker A platform for building, shipping, and running applications in containers.
- Compose A tool for defining and running multi-container Docker applications.
- JWT A standard for creating JSON-based access tokens that are used for authentication and authorization.
- Swagger A tool for designing, building, and documenting APIs.
- JUnit A popular testing framework for Java.
- Postman A tool for testing APIs.
- K6 A tool for load testing web applications.
- DBeaver A database management tool.
- Talend API Tester A tool for testing APIs.

2 Specifications for the web server

In order to evaluate the current state of web server development in Rust and Java, I will build a simple web server in both languages using the previously mentioned frameworks. The web server will feature a REST api that allows users to create channels, add messages to channels, and retrieve messages from said channels. In addition, the web server will feature a websocket endpoint that allows users to subscribe to channels and receive messages in real-time. Authentication will be handled using JWT tokens and a profile endpoint to authenticate users and retrieve their information.

2.1 REST API

The REST API will feature the following endpoints:

Channel endpoints:

- **Create Channel** POST /api/v1/channels
Creates a new channel with the given name.
- **Get Channel** GET /api/v1/channels/{id}
Retrieves the channel with the given id.
- **Get All Channels** GET /api/v1/channels
Retrieves all channels.
- **Change Channel** PUT /api/v1/channels/{id}
Changes the name of the channel with the given id.
- **Delete Channel** DELETE /api/v1/channels/{id}
Deletes the channel with the given id.

Message endpoints:

- **Add Message** POST /api/v1/channels/{id}/messages
Adds a new message to the channel with the given id.
- **Get Message** GET /api/v1/channels/{id}/messages/{id}
Retrieves the message with the given id from the channel with the given id.
- **Get All Messages** GET /api/v1/channels/{id}/messages
Retrieves all messages from the channel with the given id.

- **Change Message** PUT /api/v1/channels/{id}/messages/{id}
Changes the content of the message with the given id from the channel with the given id.
- **Delete Message** DELETE /api/v1/channels/{id}/messages/{id}
Deletes the message with the given id from the channel with the given id.

2.2 Database Schema

The Implementations in both languages will feature the same PostgreSQL database, thus the database schema will be the same for both implementations.

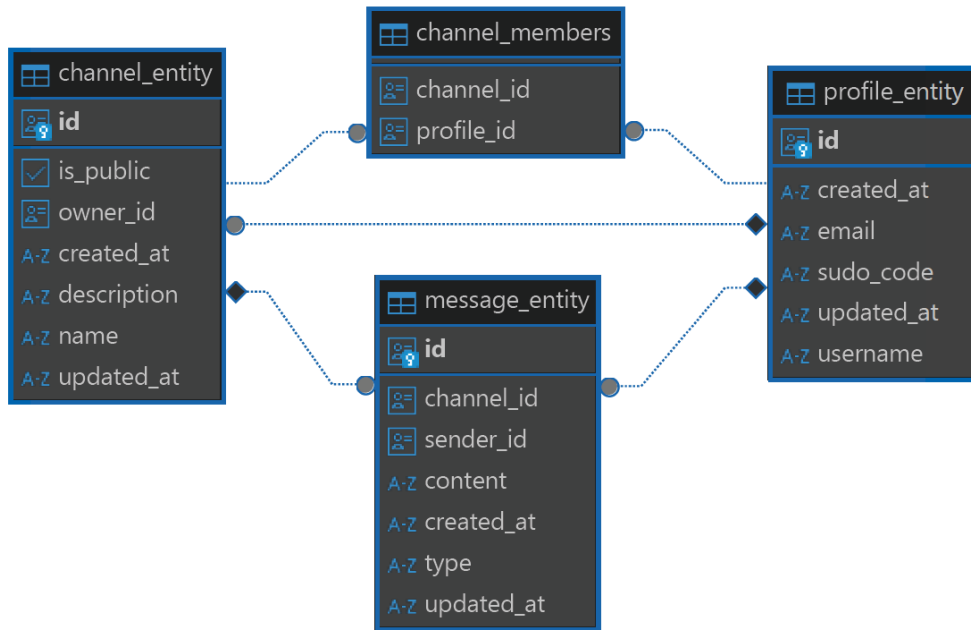


Figure 1: Database schema in DBeaver

It features a table for users, a table for channels, and a table for messages. The users table stores the username, email while the channels table stores the id of whoever created it, making him the **owner** of the channel. The messages table stores the content of the message, the id of the user who sent it, and the id of the channel it was sent to. All Tables also include columns for the creation and last update time of the row.

A note about creation

A worthy note about the creation of this database schema is that it was not created by hand. For both Rust and Java I took the help of ORMs (Object Relational Mapper) which automatically map structures from each language into SQL statements. Spring JPA, the ORM used in the Spring-Boot implementation, has the ability to automatically create relations between entities by using annotations.

```
@Entity
@Table(name = "channel_entity")
public class ChannelEntity {
    /* ... */
    @ManyToMany
    @JoinTable(
        name = "channel_members",
        joinColumns = @JoinColumn(name = "channel_id"),
        inverseJoinColumns = @JoinColumn(name = "profile_id")
    )
    private List<ProfileEntity> members;
    /* ... */
}
```

The **@ManyToMany** annotation denotes a traditional Many to Many relationship in a relational database, allowing me to let JPA do the heavy lifting of creating all necessary foreign keys and required Tables using the **@JoinTable** annotation. Further information about the workings of JPA can be found in the Java Implementation section.

2.3 Authentication

Authentication will be handled using JWT tokens. When a client signs up or signs in, they will receive a JWT token that they can use to authenticate themselves when making requests to the web server. The JWT token will be sent in the Authorization header of the HTTP request as a Bearer token. Both Server implementations will have to verify the token before sending new messages to the client.

3 Implementation in Java

3.1 Project Structure

```
backendspringboot
├── configuration
├── controller
├── data
│   ├── dto
│   ├── entities
│   ├── Mapper
│   ├── models
│   └── repositories
└── services
```

Pictured here is the Project structure for the Spring Boot implementation of the API. It is subdivided into the **configuration** folder which contains all descriptions for Spring Security, the **controller** folder which contains all rest controllers, which manage the incoming HTTP requests, A **data** folder with subfolders for all relevant data structures found within the API and **services** which perform all actions on the data using the repositories and basically glue together the controllers and the data.

3.2 Spring Boot

Rest APIs written in Spring boot use Java Classes with the **@RestController** annotation to handle incoming HTTP requests and route them to specific methods within the annotated controller class.

```
@RestController
@RequestMapping(CHANNEL_BASE_URL)
public class ChannelController {
    private final ChannelService channelService;
    @Autowired
    public ChannelController(ChannelService channelService) {
        this.channelService = channelService;
    }
    @GetMapping("/{id}")
    public ResponseEntity<Channel> getChannel(@PathVariable UUID id){
        return ResponseEntity.ok()
            .body(channelService.getChannel(id));
    }
    @PostMapping("")
    public ResponseEntity<Channel> createChannel() {
        var channel = channelService.createChannel(new UUID(0, 0));
        URI location = URI.create(CHANNEL_BASE_URL +
            channel.getId().toString());
        return ResponseEntity.created(location).body(channel);
    }
}
```

Figure 2: A shortened Example of a Controller in Springboot

In this case the **CHANNEL_BASE_URL** is set to **/api/v1/channels/** meaning, all requests starting with this specific string will be routed to this class and it's methods corresponding to how they are annotated. F.e. anything annotated **@GetMapping** will capture a GET request, while **@PostMapping** does the same for any POST requests that arrive at the specified path. These classes don't need to be specifically defined or initialized by the programmer, because of Java's ability to use Reflection. Spring can just look for the annotation and will automatically register it as a valid Controller.

3.3 Spring Data JPA

As the ORM of my choice, I have decided to use Spring JPA in this project as it gives me the lowest amount of code I have to write to get SQL statements to work and as explained in the Database paragraph it allows me to generate a schema from classes. A Feature, which other ORMs can lack. Data in Spring Data JPA is divided into **Entities** and **Repositories**. Repositories describe a collection of a specific type of Entity and can in their most basic form be written as a one liner. Repositories in Spring JPA allow writing SQL

```
public interface MessageEntityRepository
    extends JpaRepository<MessageEntity, UUID> {
    Collection<MessageEntity> findAllByChannelId(UUID channelId);
}
```

Figure 3: The Message Repository for the Message Entities

Statements purely but naming the method as shown in the example, where *findAllByChannelId* gets broken down into

SELECT FROM message_entity WHERE id = channelId

Entities

Entities in Springboot describe the objects in the Database and get mapped to a table. where the columns are described by the fields and properties of each object. Annotations help JPA to further define features and structure of each table. In my case, the Entities required in the Database are Channels, Messages and Profiles.

As is visible however, is that these entities are not directly relayed to the controllers by the services, that is because entities can be database specific and incorporate functionality that might break, when changing databases. That's why for each Object in the database Model and DTO (Data Transfer object) are created to decouple the controller logic from the underlying entities, which allows changing the Database without requiring changes to the controller logic.

Services

Services glue together the controller and their entities. Each controller is internally build as a Singleton class for for more efficient memory management. Each service allows for specific actions on entities and breaks those

down into their respective operations on the repositories. As an example here

```
@Service
public class ChannelService {
    /* ... */
    public Channel updateChannel(Channel channel) {
        var channelEntity = channelEntityRepository
            .findById(channel.getId())
            .orElse(null);
        if (channelEntity == null)
            throw new IllegalArgumentException("Channel not found");

        channelEntity.setDescription(channel.getDescription());
        channelEntity.setIsPublic(channel.getIsPublic());
        channelEntity.setName(channel.getName());
        channelEntity.setUpdatedAt(LocalDateTime.now().toString());

        var saved = channelEntityRepository.save(channelEntity);
        return ChannelMapper.ChannelEntityToChannel(saved);
    }
    /* ... */
}
```

Figure 4: Mapping the update action from one method to multiple repository methods

the Channel object gets new data by first fetching the current entity and it's values from the database and changing what is needed and allowed to change by the API. Afterwards the channel entity gets saved to the database and returned as it's model.

Mapper

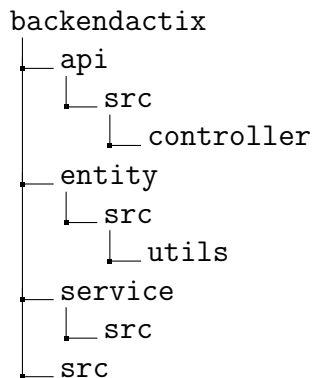
Mapper are very simple, they take in either an Entity or a model and map them to the corresponding other class. They are what keeps everything decoupled and implementation independent.

3.4 Dependencies

A list of all dependencies can be found here.

4 Implementation in Rust

4.1 Project Structure



Similar to Java, the project is broken down into different packages, or crates as they are called in Rust. In rust, this is done in order to manage dependencies better. F.E. the Services to not require Actix-Web, which means it does not need to rebuild all of Actix-Web whenever there are changes made to the services. Speeding up build times by a little bit. But just like in the spring boot implementation, it is once again divided up into the controllers, found in the api crate, the data, found in the entity crate, which was partly generated by SeaOrm, more on that later and the services glueing everything together.

4.2 Actix

Just like Spring, Actix features a System of routes by annotations (macros), however, due to the nature of Rust not featuring reflections, each route requires to at some point be manually registered to the server as a service, or by declaring it as a request endpoint and setting it's route and HTTP Request-type manually. In order to achieve this, Actix provides a configuration struct to register said services.

```
// found in api/src/lib.rs
fn init(cfg: &mut web::ServiceConfig) {
    controller::channel_controller::init(cfg);
    controller::message_controller::init(cfg);
}

// found in api/src/controller/channel_controller.rs
pub fn init (cfg: &mut web::ServiceConfig){
    cfg.service(create);
    cfg.service(get_all);
    cfg.service(get);
    cfg.service(put);
    cfg.service(delete);
}
```

Provided here is an example taken from the channel controller which gets all current channels in the database and returns them as a JSON object. The Service is talked to using the implementation methods on the ChannelService struct.

```
#[get("/api/v1/channels/")]
pub async fn get_all(state: web::Data<ApiState>) ->
    Result<HttpResponse, Error> {
    let conn = &state.conn;
    let result = ChannelService::get_all_channels(conn).await;

    if result.is_err() {
        return handle_error_internal(result.unwrap_err());
    }

    let json_result = serde_json::to_string(&result.unwrap());
    Ok(HttpResponse::Ok()
        .content_type(Content-Type::json())
        .body(json_result.expect("Failed to serialize")))
}
```

4.3 SeaOrm

The main Framework for modifying data in the Database is, at least for this project, SeaOrm, which is the closest framework I could find to replicate the behaviour of Spring JPA. It generates builds queries using the Sea-Query crate and allows for declaring SQL statements inside of Rust, rather than having to write them by hand. One thing it does not do, is build the Database from the provided Entities, but rather build the entities from an existing Database, which allowed me to use both the strength of spring JPA to create the Database, then SeaOrm to create the entities for the Rust implementation.

```
pub async fn get_all_channels(db: &DbConn) ->
    Result<Vec<channel_entity::Model>, DbErr>{
    channel_entity::Entity::find().all(db).await
}

pub async fn get_channel(db: &DbConn, id: Uuid) ->
    Result<Option<channel_entity::Model>, DbErr>{
    channel_entity::Entity::find_by_id(id).one(db).await
}
```

Entities

As mentioned before SeaORM allows the user to generate entities from an existing Database and also map their relations to one another directly into Rust structs and Implementations. One features of these generated structs is the provided structure to add code when a new entity is created and when an entity is deleted, this allows easy modification and preset values for f.e. the creation and update date.

```
impl ActiveModelBehavior for ActiveModel {
    fn new() -> Self {
        let current_date: DateTime<Utc> = SystemTime::now().into();
        Self {
            is_public : Set(false),
            id: Set(Uuid::new_v4()),
            owner_id : Set(
                Option::Some(
                    uuid!("00000000-0000-0000-0000-000000000000")
                ),
            ),
            created_at : Set(current_date.to_rfc3339()),
            description : Set("").to_owned(),
            name : Set("").to_owned(),
            updated_at : Set(current_date.to_rfc3339()),
            ..ActiveModelTrait::default()
        }
    }
}
```

4.4 Dependencies

A list of all dependencies can be found [here](#).

5 Testing Methodology

As the main focus of this paper is to test performance, I will perform load testing to see, how much each implementation differs in performance. In doing so, i used help from the tool k6 developed by Grafana, which allows me to write my load tests in JavaScript and automatically get the results in a specified format. For this project, all results are written to a JSON file for later analysis. All tests were run on my private system with a Ryzen 7 3800x Prozessor, and 32 gigabytes of memory.

5.1 K6

As explained before for the main testing tool used for both implementations is k6, providing a platform independent system to test apis with. K6 works by leveraging the node.js runtime to create virtual users to send requests at the api specified by the user, or by using .env files.

5.2 Performance Testing

The performance test is ran multiple times and aggregated to a single result and for multiple virtual users. My numbers of choice ended up being 10, 30, 50 and 100 VUs in that order. Between every run, each instance was closed and restarted.

5.3 Load Testing

To facilitate efficient load testing, the k6 test suite is ran multiple times

5.4 Other Tests

Build times

Memory Usage

CPU Usage

6 Comparison

Coming into the comparison, I had a hypothesis. That rust would be faster at lighter workloads, while Java will excel at heavier workloads. In order to prove my hypothesis I ran my the channels test with first 1 users, then the messages test with 10, 30, 50 and 100 VUs in that order. In all following graphs Springboot will be represented in green, while Actix is purple.

6.1 Developer Experience

Coming from a Java background, I was more versed in the development of web servers in Springboot, but while saying that, once I got the hang of Actix the development experience was not very dissimilar, which was to be expected given that both, frameworks use an established pattern also found in frameworks like microsoft's Asp.NET for C# and Flask for Pyhthon. However, having the comforts of JPA and the ability to build Databases by

writing them in Java instead of pure SQL was definitely a big help in the development of this entire Project.

6.2 Performance

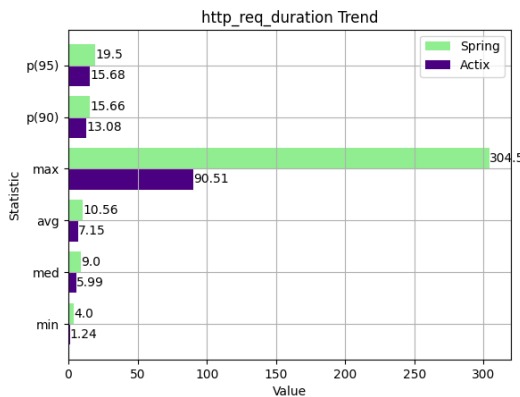


Figure 5: Message test with 10 VUs

As is expected of Rust, in this simple scenario, running 10 Virtual Users, it outperforms Spring by about 30% on average and even 70% a sizable achievement given that Springboot has about 6 Years more time to mature with it's 1.0 release coming 2014, while the first 1.0 release of Actix released in 2019, however, this isn't the be all end all.

Testing 100 VUs on both backends reveals, that Springboot, actually outperforms Actix on average as well as in the 90th and 95th percentile. If, compiled using opt-level 0. In rust, when building an application it is advised to build development builds with opt-level 0 which gives the fastest build times, but worse performance. When built with opt-level 3, the story changes.

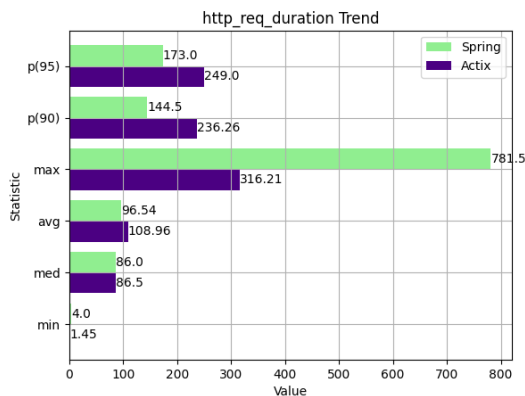


Figure 6: Message test with 100 VUs using opt-level 0

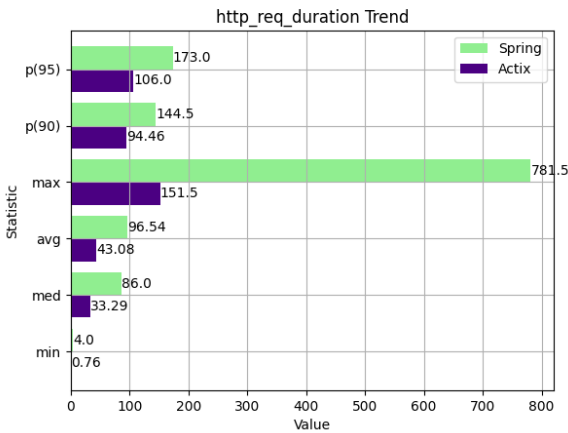


Figure 7: Message test with 100 VUs using opt-level 3

Rust still comes out ahead and beats Java by 50% on average and an 80% decrease in maximum request times.

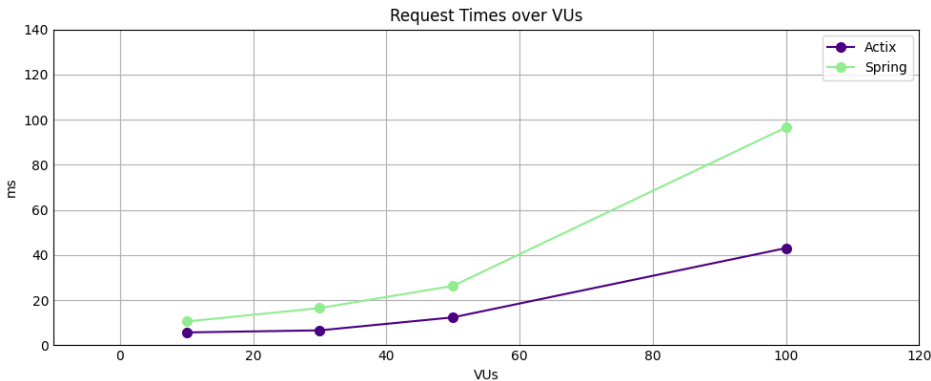


Figure 8: Average request times over multiple vu configurations

To better visualize The differences in Performance over VUs I have provided another graph directly comparing their performance.

6.3 Resource Intensity

Build Time

- Actix (opt-level 0): 52.85s
- Actix (opt-level 3): 1m 27s
- Springboot: 22.876s

From these numbers, we can conclude that Rust takes a significantly longer time to build, than Java. This comes down to the nature of both Languages. Java, running inside the JVM does not need to recompile all of it's dependencies but rather can just use them, without rebuilding, while Rust rebuilds every single dependency from source.

File Size

- Actix (opt-level 0): 18 Mb
- Actix (opt-level 3): 9.7 Mb
- Springboot: 60 Mb

Ignoring the fact that Java also requires the Java Runtime to function, adding another 200 Mb to the required file size, Rust also comes out ahead in file size by being significantly smaller, while bundling everything into a singular binary.

Memory Usage

- Actix (opt-level 3): 9.7 Mb
- Springboot: 60 Mb

7 Conclusion

Rust being marketed as the new big thing certainly shows. With a near seamless transition in workflow from Java to Rust and a significant increase in performance it does bring truth to the notion, that Rust is the future.

Closing words

Noteworthy of these tests is that it only covers a small portion of features of both the Java, as well as the Rust ecosystem, as well as only one framework for each language other frameworks, such as Rocket.rs may be faster than Actix. Furthermore it only covers the standard system of relational databases, when alternatives, such as Document oriented databases like MongoDB and Google's Firebase exist. Further investigation is needed in this field as well as covering multiple use cases such as implementing a web server on an embedded system such as an ESP32, which java does not run on.

But once again, Rust rains supreme.

8 Sources

- Rust Edu
- The Rust Programming Language
- Rust Standard Library
- Cargo Guide
- Rust by Example
- Rustdoc
- Actix
- DBeaver
- SeaOrm Actix Example

Whole bibliography

- [1] Cloudflare. *Open sourcing Pingora: our Rust framework for building programmable network services*. URL: <https://blog.cloudflare.com/pingora-open-source> (visited on 08/14/2024).
- [2] Discord. *Why Discord is switching from Go to Rust*. URL: <https://discord.com/blog/why-discord-is-switching-from-go-to-rust> (visited on 08/14/2024).
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- [4] Stackshare. *Spring Boot*. URL: <https://stackshare.io/spring-boot> (visited on 08/14/2024).
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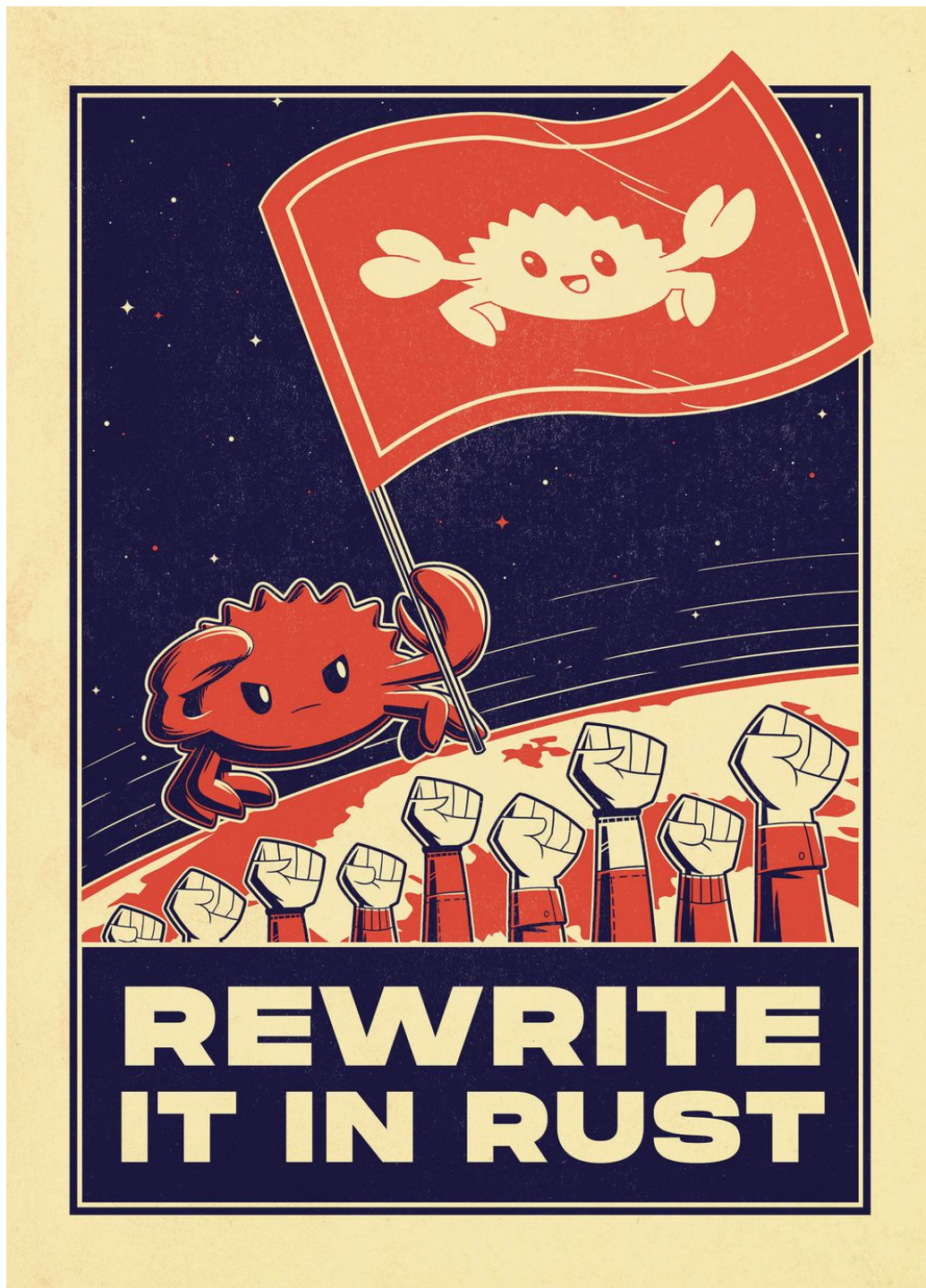


Figure 9: <https://fission.codes/rewrite-in-rust/>