Rust Workshop

Day 1

Why Rust?

✅ performance
✅ safety
✅ correctness
✅ productivity
✅ portability

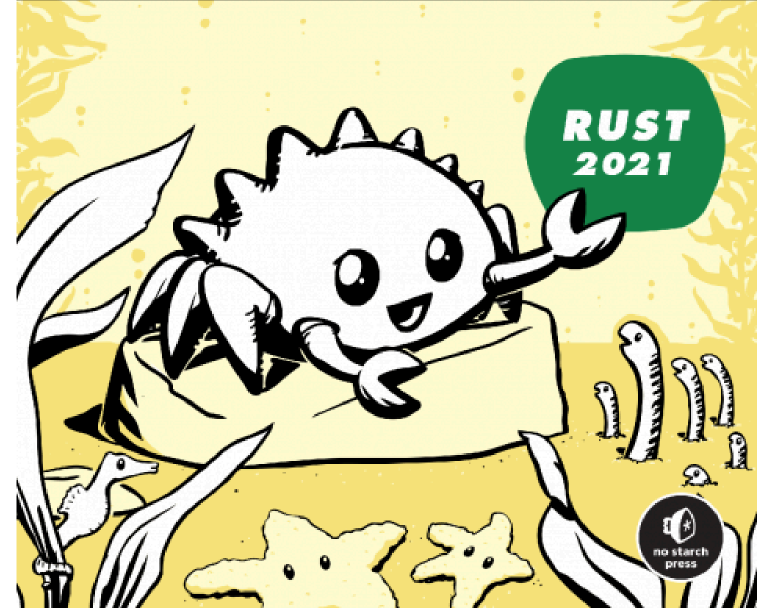
Program

Day 1	Language Basics 1	common programming concepts & ownership
Day 2	Language Basics 2	structs, enums, modules, collections, error handling
Day 3	Advanced Features 1	generics, traits, lifetimes, closures, iterators
Day 4	Advanced Features 2	smart pointers, dynamic dispatch, async programming
Day 5	The Rust Ecosystem	libraries, documentation, patterns, CI/CD, project start
Day 6	Projects 🚀	CLI tools, web APIs, python modules, LED matrix

SECOND EDITION

THE RUST PROGRAMMING LANGUAGE

STEVE KLABNIK *and* CAROL NICHOLS,
with CONTRIBUTIONS *from* THE RUST COMMUNITY

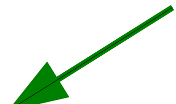


About these slides

Although they aren't meant as reference material...
Both the interactive version and PDF exports are available at:

senekor.github.io/rust-workshop

Using the interactive slides:
Hover over the bottom-left corner for controls.



Language Basics 1

book chapters 3 & 4

common programming concepts

ownership

```rust
fn main() {
    println!("Hello, world!");
}
```

Variables

book chapter 3.1

Variable Declaration

```
1  let x = 5;
2
3  let x: i32 = 5;
```

Variable Declaration

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1  let x = 5;
2
3  let x: i32 = 5;
```

Mutability

```
1  let x = 5;
2  x = 6; // error: cannot assign twice to immutable variable `x`
3
4  let mut x = 5;
5  x = 6; // ✅
```

Mutability

```rust
let x = 5;
x = 6; // error: cannot assign twice to immutable variable `x`

let mut x = 5;
x = 6; // ✅
```

Globals

```
1  // "copy-pasted" everywhere (like C's #define)
2  const THREE_HOURS_IN_SECONDS: u32 = 60 * 60 * 3;
3
4  // placed in static memory (text or data segment)
5  static EMBEDDED_TEXT_FILE: &str = include_str!("path/to/some/file.txt");
```

Globals

```rust
// "copy-pasted" everywhere (like C's #define)
const THREE_HOURS_IN_SECONDS: u32 = 60 * 60 * 3;

// placed in static memory (text or data segment)
static EMBEDDED_TEXT_FILE: &str = include_str!("path/to/some/file.txt");
```

Scope

```
let x = 5;
{
    let y = 6;
    // x and y available
}
// only x available
```

Shadowing

```
1  let x: i32 = 5;
2  {
3      let x = 6;
4      // x == 6
5  }
6  // x == 5
7  let x: &str = "five";
```

Shadowing

```rust
let x: i32 = 5;
{
    let x = 6;
    // x == 6
}
// x == 5
let x: &str = "five";
```

Basic Types

book chapter 3.2

Integer Types

length	signed	unsigned
8-bit	`i8`	`u8`
16-bit	`i16`	`u16`
32-bit	`i32`	`u32`
64-bit	`i64`	`u64`
128-bit	`i128`	`u128`
arch	`isize`	`usize`

Number Literals

Decimal	`98_222`
Hex	`0xff`
Octal	`0o77`
Binary	`0b1111_0000`
ASCII Byte	`b'A'`
with type suffix	`57_i64`

Floating-point Types

IEEE-754

```
1  let x = 2.0; // default: 64-bit
2  let y: f32 = 3.0; // 32-bit
```

Booleans

```
1  let x = true;
2  let y: bool = false;
```

Characters

unicode, guaranteed 32-bit

```rust
// notice the single quotes
let x = 'a';
let y: char = '?';
let heart_eyed_cat = '😻';
```

Tuples

```rust
let tup: (i32, f64, u8) = (500, 6.4, 1);

let (x, y, z) = tup;
let a: i32 = tup.0;
```

Tuples

```
1  let tup: (i32, f64, u8) = (500, 6.4, 1);
2
3  let (x, y, z) = tup;
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Tuples

```
1   let tup: (i32, f64, u8) = (500, 6.4, 1);
2
3   let (x, y, z) = tup;
4   let a: i32 = tup.0;
```

The Empty Tuple

also known as the "unit"

```
1  let rusty_void: () = println!("printing doesn't return anything");
```

Arrays

size known at compile time

```
1  let a: [i32; 5] = [1, 2, 3, 4, 5];
2  let a = [3; 5]; // == [3, 3, 3, 3, 3]
3  let x = a[0];
```

Arrays

size known at compile time

```
1  let a: [i32; 5] = [1, 2, 3, 4, 5];
2  let a = [3; 5]; // == [3, 3, 3, 3, 3]
3  let x = a[0];
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Arrays

size known at compile time

```
1  let a: [i32; 5] = [1, 2, 3, 4, 5];
2  let a = [3; 5]; // == [3, 3, 3, 3, 3]
3  let x = a[0];
```

Functions

book chapter 3.3

Basic Function

```rust
fn main() {
    another_function();
}

fn another_function() {
    println!("Hello from another function!");
}
```

Parameters

```
1  fn print_labeled_measurement(value: i32, unit_label: char) {
2      println!("The measurement is: {}{}", value, unit_label);
3  }
4
5  fn main() {
6      print_labeled_measurement(5, 'h');
7  }
```

Expressions

A block is an expression where the last expression of the block becomes the value of the entire block.

```
let y = {
    let x = 3;
    x + 1  // <- note the lacking semicolon
};
// y == 4
```

Return Values

```rust
fn plus_one(x: i32) -> i32 {
    if x == i32::MAX {
        return i32::MAX; // no overflow
    }
    x + 1  // <- last expression of block
}
```

Interlude: Macros

General

Rust macros are a meta-programming feature like the C preprocessor.
Unlike in C, macros operate on *tokens* instead of text.

Rust macros use very specific syntax, so you can identify them easily.

"function-like" macros

```rust
let name = "Joe";
let age = 36;
println!("My friend {} is {} years old.", name, age);
```

These macros are identified by the exclamation mark.

The tokens within the parentheses are the inputs to the macro.
(string literal, comma, identifier, comma, identifier)

The output of the macro is the actual code
necessary to print the formatted string.

"attribute-like" macros

```rust
#[my_attribute_macro]
fn add(a: i32, b: i32) -> i32 {
    a + b
}
const PI: usize = 3 // close enough
```

These macros are identified by the `#[]` syntax.

The tokens of the item immediately after the macro are its input.
That includes the entire function definition of `add`,
but NOT the definition of `PI`.

`my_attribute_macro` might output additional code that's related to `add` or even modify the function itself.
However, it cannot generate code based on `PI`,
since it doesn't know about it.

Control Flow

book chapter 3.5

`if` Expressions

no parentheses around condition, curly brackets mandatory

```
1   let number = 3;
2
3   let size = if number < 5 {
4       "small"
5   } else if number < 10 {
6       "big"
7   } else {
8       "very big"
9   };
```

The variable `size` will hold one of the three strings.

`loop`

```rust
loop {
    println!("computer go brrr");

    if done() {
        break;
    } else {
        continue;
    }
}
```

`while` Loops

```rust
let mut countdown = 10;

while countdown != 0 {
    println!("{}!", countdown);

    countdown -= 1;
}

println!("LIFTOFF!!!");
```

`for` Loops

more details on day 3

```rust
let a = [10, 20, 30, 40, 50];

// `..` is the range operator
for i in 0..a.len() {
    let element = a[i];
    println!("the value is: {}", element);
}

for element in a {
    println!("the value is: {}", element);
}
```

Some Operators

some assignment variants exist (`+=`)

<table>
<tr><td>Comparison</td><td>`==` `!=` `<` `<=` `>` `>=`</td></tr>
<tr><td>Arithmetic</td><td>`+` `-` `*` `/` `%`</td></tr>
<tr><td>Boolean</td><td>`&&` `||` `!`</td></tr>
<tr><td>Bitwise</td><td>`&` `|` `^` `!` (no tilde!)</td></tr>
<tr><td>Range</td><td>`..` `..=` (integers and `char`)</td></tr>
</table>

Integer Conversions

`as` exists, it but has some footguns

```rust
// infallible
let x: i32 = 42_i16.into();

// fallible
let x: u32 = 42_i64.try_into().unwrap();
```

Ownership

book chapter 4.1

Memory Management

approach	properties	
manual	fast & predictable, but unsafe	✅❌
garbage-collection	slow & unpredictable, but safe	❌✅
ownership	fast, predictable, safe and expressive	✅✅✅

C and C++

a short history of manual memory management

Double free

```c
int *p = malloc(sizeof(int));
free(p);
free(p); // ⚠
```

Use after free

```c
int *p = malloc(sizeof(int));
free(p);
*p = 12; // ⚠
```

Implicit ownership in C

```c
some_t *foo(some_t *p);
```

- Is the function going to free the pointer, or do I have to?
- Does the function only read from the pointer or does it write to it?
- Can the return value alias the argument?
- Where is the documentation?
- Please let there be documentation…

C++

tools to express ownership

```
1  std::unique_ptr<some_t> foo(some_t const* p);
```

and destructors!

...but no compiler guarantees.

Rust

codify and enforce the rules of ownership

Ownership Rules

1. Every value has exactly one owner.
2. When the owner goes out of scope, the destructor is run.

Single Ownership

demo

```rust
fn main() {
    //                heap-allocated String
    //                vvvvvvvvvvvvvvvvvvvvv
    let first_owner = String::from("hello");

    let second_owner = first_owner;

    println!("{:?}, world!", first_owner);
    //                       ^^^^^^^^^^^
    //    ❌ error: borrow of moved value
}
```

Scope and Destructors

demo

```rust
// declaring a zero-sized struct
struct Foo;

// writing a custom destructor for demo-purposes
// (Rust-lingo: "implementing the Drop trait")
impl Drop for Foo {
    fn drop(&mut self) {
        println!("drop!")
    }
}

fn main() {
    let x = Foo;
    {
        let y = x; // What happens if you comment this line?
    } // y goes out of scope

    println!("Hello, world!");
} // x goes out of scope
```

Ownership and Functions

```rust
// recall: Foo's destructor prints "drop!"

fn main() {
    let x = Foo;
    take_foo(x);
    println!("Hello, world!");
}
fn take_foo(arg: Foo) {
    // empty function body
}
```

What's the output of this program?

Ownership is expressive

file handles, mutexes etc.
ownership applies to all kinds of resources

```rust
fn foo(m: &Mutex<i32>, random_choice: bool) -> Option<MutexGuard<i32>> {
    let guard: MutexGuard<i32> = m.lock().unwrap();

    if random_choice {
        Some(guard)
    } else {
        None
    }
}
```

Limitations

```rust
fn calculate_length(s: String) -> (String, usize) {
    let length = s.len(); // len() returns the length of a String
    (s, length)
}
fn main() {
    let s1 = String::from("hello");
    let (s2, len) = calculate_length(s1);
    println!("The length of '{}' is {}.", s2, len);
}
```

References and Borrowing

book chapter 4.2

What are references?

- basically, pointers with seat belts
- cannot be null
- guaranteed to point to valid memory

Syntax

```
1  let x = 42;
2  let r: &i32 = &x;
3  let y: i32 = *r;
```

Fixing the earlier example

```rust
fn calculate_length(s: &String) -> usize {
    s.len()
    // s goes out of scope, but its destructor is not run.
}
fn main() {
    let s1 = String::from("hello");
    let len = calculate_length(&s1);
    println!("The length of '{}' is {}.", s1, len);
}
```

Mutable References

```
1  let mut x = 42;
2  let r = &mut x;
3  *r = 43;
```

Mutable References

demo

```rust
fn main() {
    let mut s = String::from("hello");

    change(&mut s);
}

fn change(some_string: &mut String) {
    some_string.push_str(", world");
}
```

Mutable references are exclusive

```rust
let mut x = 12;

let r1 = &mut x;
let r2 = &mut x; // error

*r1 = 13;
```

compiler says:

> cannot borrow `x` as mutable more than once at a time

Mutable references are exclusive

```
1   let mut x = 12;
2
3   let r1 = &mut x;
4   let r2 = &mut x; // error
5
6   *r1 = 13;
```

compiler says:

> cannot borrow `x` as mutable more than once at a time

Mutable references are exclusive

```rust
let mut x = 12;

let r1 = &mut x;
let r2 = &x;      // error

*r1 = 13;
```

compiler says:

> cannot borrow `x` as immutable because it is also borrowed as mutable

Dangling References

```
1  let r;
2  {
3      let s = String::from("hello");
4      r = &s;
5  }
6  println!("{}", r); // error
```

compiler says:

> `s` does not live long enough

Borrrowing Rules

1. At any given time, you can have either one mutable reference or any number of immutable references.
2. References must always be valid.

The Slice Type

book chapter 4.3

Slices in C ?

```c
void print_slice(int *start, size_t len) {
    for (size_t i = 0; i < len; i++) {
        printf("%d ", start[i]);
    }
}
void main() {
    int numbers[5] = {1, 2, 3, 4, 5};
    print_slice(numbers + 1, 3);  // 2 3 4
    print_slice(numbers + 3, 10); // ⚠
}
```

Start pointer and length are disconnected,
the compiler cannot reason about memory safety.
➔ buffer overflow

Rust Slices

```rust
fn print_int_list(list: &[i32]) {
    for elem in list {
        print!("{} ", elem);
    }
}
fn main() {
    let numbers: [i32; 5] = [1, 2, 3, 4, 5];
    print_int_list(&numbers[1..4]); // 2 3 4
    print_int_list(&numbers[3..13]); // panic: index out of range
}
```

Rust slices store their length alongside the start pointer.
The full length of a slice is guaranteed valid memory.
➔ no buffer overflow

The String Slice

```rust
let owned = String::from("Hello, world!");
let s: &str = &owned[3..9]; // "lo, wo"

// Range boundaries must be valid UTF-8 offsets!
let s: &str = &"😱"[1..];
```

computer says:

> byte index 1 is not a char boundary; it is inside '😱' (bytes 0...4) of 😱

Borrowing rules apply to slices

```rust
let mut owned = String::from("hello");
let s: &str = &owned[2..];
owned.pop(); // error: cannot borrow as mutable
println!("{}", s);
```

String Literals

```
1  let greeting: &str = "Hello, world!";
```

Off-Topic: Vectors

needed for exercises

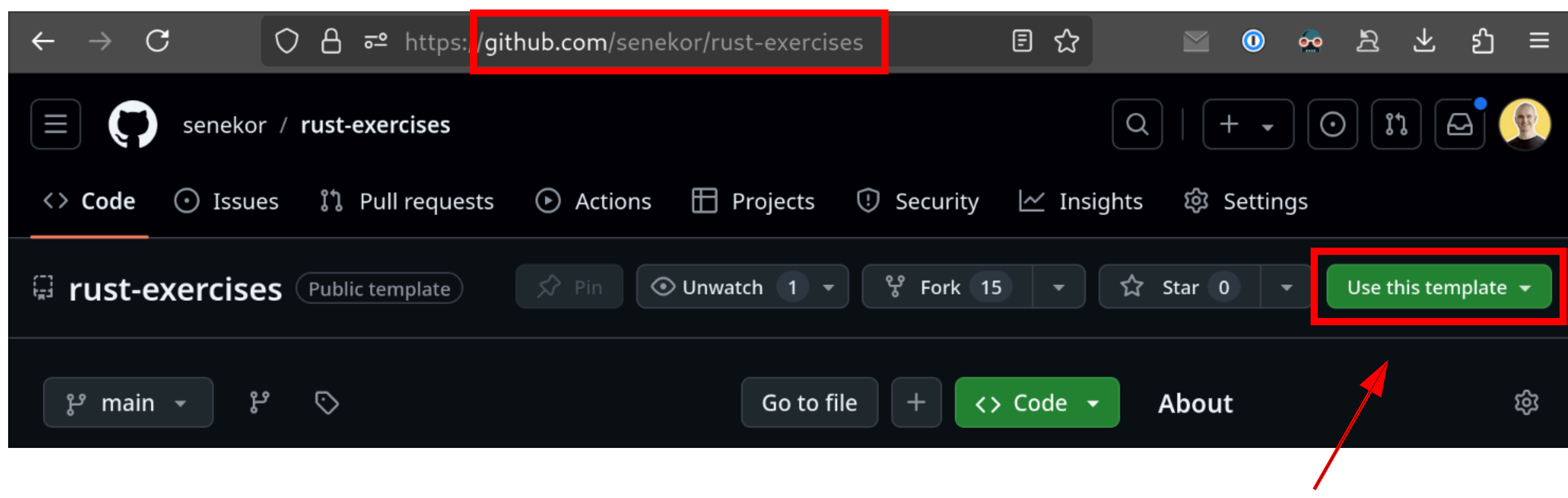
```rust
let v: Vec<f64> = Vec::new(); // create empty, elems of type f64

let mut v = vec![1, 2, 3]; // macro for "vector literals"

v.push(4);
assert_eq!(v.pop().unwrap(), 4); // `unwrap` because `pop` might return "nothing"
```

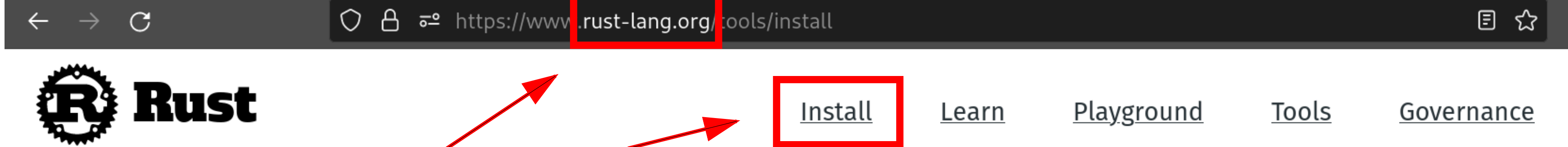
Practice

Ready your laptops!

I will quickly explain all the setup steps.

You'll receive step-by-step instructions in writing as well.


https://github.com/senekor/rust-exercises
senekor / rust-exercises
Code
Issues
Pull requests
Actions
Projects
Security
Insights
Settings
rust-exercises
Public template
Pin
Unwatch 1
Fork 15
Star 0
Use this template
main
Go to file
Code
About



Install Rust

Using rustup (Recommended)

It looks like you're running macOS, Linux, or another Unix-like OS. To download Rustup and install Rust, run the fo
terminal, then follow the on-screen instructions. See "Other Installation Methods" if you are on Windows.

```
curl --proto '=https' --tlsv1.2 -sSf https://sh.rustup.rs | sh
```

Batteries included

component	purpose	example
rustup	toolchain manager	`rustup update`
cargo	package manager	`cargo add my-fav-library`
rustc	compiler	`cargo run` , `cargo build`
rustdoc	documentation generator	`cargo doc --open`
rustfmt	formatter	`cargo fmt`
clippy	linter	`cargo clippy`
rust-analyzer	LSP implementation	N/A

Ensure you have a linker

System	install command
Debian-based	`sudo apt install gcc`
MacOS	`xcode-select --install`

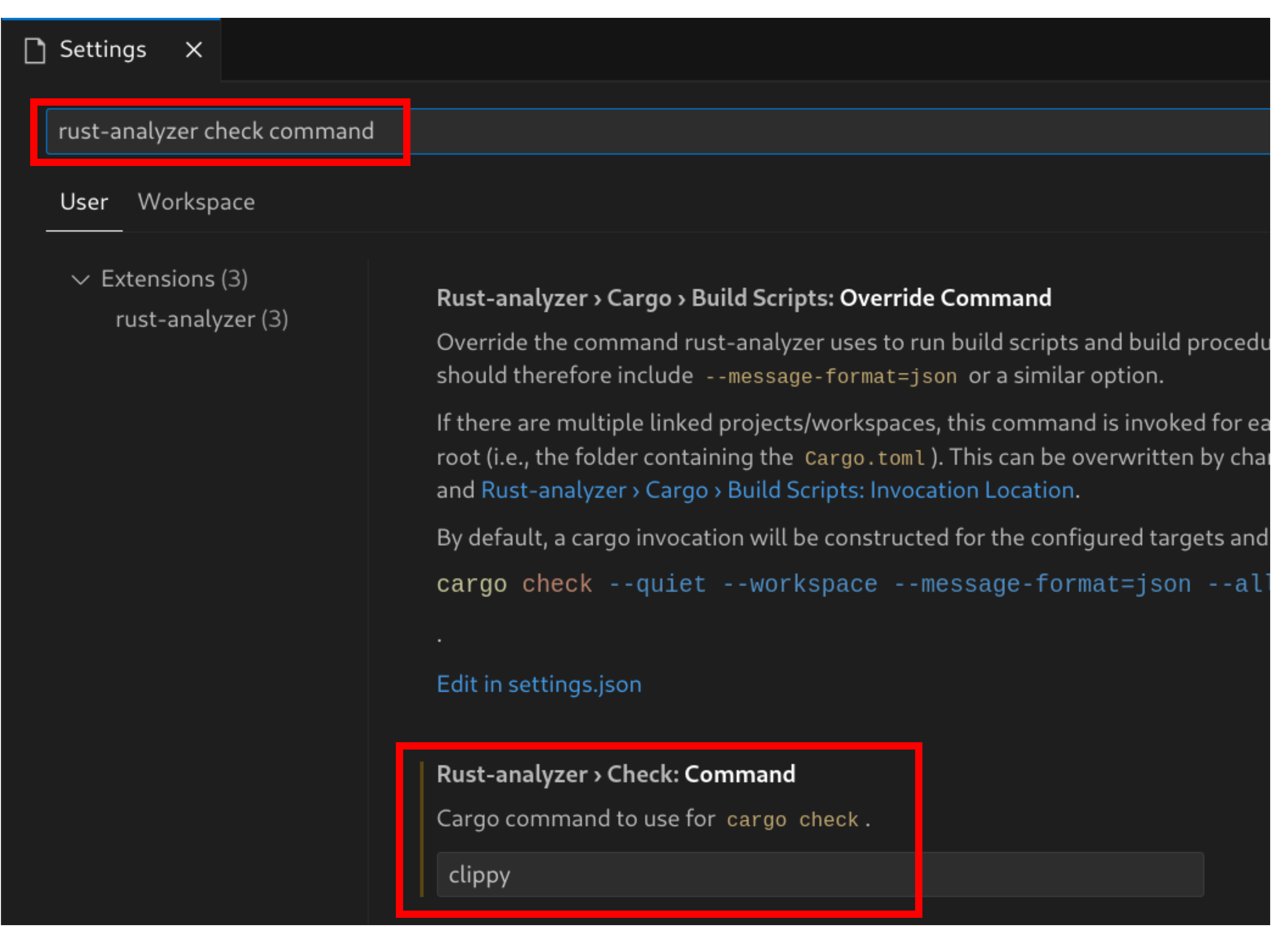
Initialize, compile and run a Rust project

```
$ cargo new hello
    Creating binary (application) `hello` package

$ cd hello
$ ls --tree
.
├── Cargo.toml
└── src
    └── main.rs

$ cargo run
Hello, world!
```

Visual Studio Code Extensions

recommendations cover:

- syntax-highlighting
- autocomplete
- diagnostics
- debugging
- `toml` syntax-highlighting


Settings
rust-analyzer check command
User
Workspace
Extensions (3)
rust-analyzer (3)
Rust-analyzer › Cargo › Build Scripts: Override Command
Override the command rust-analyzer uses to run build scripts and build procedu
should therefore include --message-format=json or a similar option.
If there are multiple linked projects/workspaces, this command is invoked for ea
root (i.e., the folder containing the Cargo.toml). This can be overwritten by cha
and Rust-analyzer › Cargo › Build Scripts: Invocation Location.
By default, a cargo invocation will be constructed for the configured targets and
cargo check --quiet --workspace --message-format=json --al
Edit in settings.json
Rust-analyzer › Check: Command
Cargo command to use for cargo check .
clippy

Practice 🧑‍💻

github.com/senekor/rust-exercises

`rust-exercises/day_1/README.md`