Procedural Macros - Expand and Implement

In Todays Talk

YOU ...

1. ...learn about three gems in the Rust Ecosystem.

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1. ...learn about two gems in the Rust Ecosystem.
2. ...learn about `(Procedural) Macros` and how they make code **accessible** and **expressive**.

In Todays Talk

YOU ...

1. ...learn about two gems in the Rust Ecosystem.
2. ...learn about `(Procedural) Macros` and how they make code **accessible** and **expressive**.
3. ...write your first two Procedural Macros showing the concept of modern Macro Dev.
4. ...investigate how to parse in a more modular way.
5. ...get a lot of resources to dig deeper.

Who am I: Tim Janus!

- Studied Computer Science at TU Dortmund University.
- Started Learning Rust in 2021.
- Helping Clients as Rust Expert since 2023.
  - Performance and Security-critical Software Solutions.
  - Supporting Software Development Teams with Rust.
  - Instructor for Rust Workshops.
- The last 7 months: Worked with MM and YOU on the Rust Port for RediSearch.
- Meetup organizer, regular conference attendee, and broadly interested.

Chapter 1 - Gems in the Ecosystem

- Running Example `MyPoint`
- `Serde`
- `Clap`
- Compare Proc Macros with C Preprocessor Macros and C++ Templates.

Running Example - MyPoint

```rust
// missing often used derives: Hash, Eq, Ord
#[derive(Debug, Default, Clone, Copy, PartialEq, PartialOrd)]
pub struct MyPoint {
    x: f64,
    y: f64,
}
```

Before we dig deeper, explore the code...

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Before we dig deeper, explore the code...

... and open questions:

- Why are Hash, Eq and Ord Special?
- When not to derive?

Running Example - MyPoint

Why are Hash, Eq and Ord Special?

Many datatypes cannot easily derive them:

- `NaN` problem with floating point numbers

When not to derive?

Code Sizes matters

Gem No. 1 - Serde

By David Tolnay and many Contributors.

`Ser/De` - Easily add Serialization and Deserialization.

- Dervies Serialization and Deserialization Code.
- High Performance, no boilerplate.
- Many Formatters, e.g. json, protobuf, cbor, etc.

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```
use serde::{Deserialize, Serialize};

#[derive(Debug, Default, Clone, Copy, PartialEq, PartialOrd, Serialize,
Deserialize)]
pub struct MyPoint {
    #[serde(rename = "x")]
    value_x: f64,
    #[serde(rename = "y")]
    value_y: f64,
}

fn main() {
    let point = MyPoint { value_x: 1.0, value_y: 2.0 };
    let serialized = serde_json::to_string(&point).unwrap();
    println!("MyPoint JSON: {}", serialized);

    let json = r#"{"x":42.0,"y":42.0}"#;
    let deserialized: MyPoint = serde_json::from_str(&json).unwrap();
    println!("MyPoint in-memory: {:?}", deserialized);
}
```

Gem No. 2 - Clap

By Kevin B. Knapp and many Contributors.

- `Clap` - Expressive Command Line Parsing without Boilerplate.
- Builder API.
- Derive Macro API.
- User gets Polished CLI experience.
- Flexibility to port CLIs to Clap.

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```
Type 'help' for more information

> help
Available commands:
  add <x> <y>  - Add a new point with x and y coordinates
  list         - List all stored points
  quit         - Exit the application
  help         - Show this help message
> help add

Usage: mypoint add <X> <Y>

Arguments:
  <X>  X coordinate
  <Y>  Y coordinate

Options:
  -h, --help  Print help
```

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```
#[derive(Parser)]
#[command(name = "mypoint")]
#[command(about = "A CLI for managing MyPoint objects")]
struct Cli {
    #[command(subcommand)]
    command: Commands,
}

#[derive(Subcommand)]
enum Commands {
    /// Add a new point with x and y coordinates
    Add {
        /// X coordinate
        x: f64,
        /// Y coordinate
        y: f64,
    },
    /// List all points
    List,
    /// Quit the application
    Quit,
}
```

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Let's explore the code...

Compare C, C++ and Rust!

Category	C (Preprocessor Macros)	C++ (Templates)	Rust (Proc Macros)
When they run	Before compilation (preprocessor)	During compilation (template instantiation)	During compilation (syntax transformation)
What they see	Raw text / tokens	Types, templates, concepts	Token stream / AST-like structured syntax
Safety & Ergonomics	No type safety, brittle, unclear errors	Type-checked but complex errors	Type-checked after expansion, good tooling/errors

Chapter 2 - (Procedural) Macros, How?

1. Distinguish from Declarative Macros
2. What is a parser and an AST?
3. Definition: The three types of Macros.
4. Examples: The three types of Macros

Declarative Macros

Procedural Macros aren't declarative Macros (Pattern Matching).

```
let v = vec![1, 4, 7];
println!("{:?}", v);
```

- They are not distungishable for a caller from Procedural Function-like Macros.

Declarative Macros (Pattern Matching)

How are declarative Macros defined?

```
#[macro_export]
macro_rules! vec {
    () => (
        $crate::vec::Vec::new()
    );
    ($elem:expr; $n:expr) => (
        $crate::vec::from_elem($elem, $n)
    );
    ($($x:expr),+ $(,)?) => (
        <[_]>::into_vec(
            // Using the intrinsic produces a dramatic improvement in stack
usage for
            // unoptimized programs using this code path to construct large
Vecs.
            $crate::boxed::box_new([$($x),+])
        )
    );
}
```

- They are powerful, e.g. you can do a Lisp Parser
- They can help a lot with boilerplate!

What are Procedural Macros

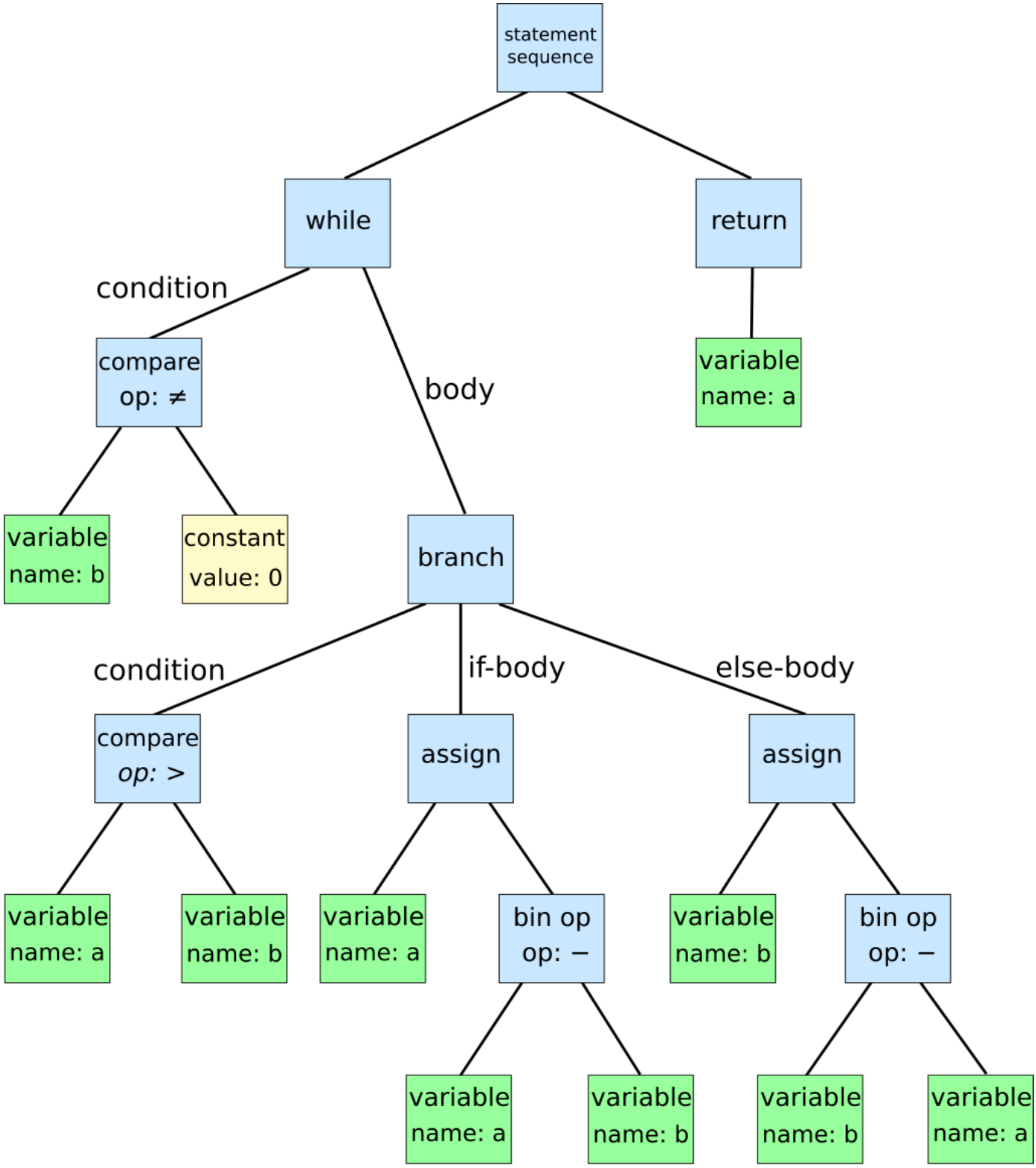
They are Parsers and Generators.

What's a Parser and how does it work on Rust Code?

Generates an AST (Abstract Syntax Tree) from Code or tokens.

```
while b != 0 {
    if a > b {
        a = a-b;
    } else {
        b = b-a;
    }
}
```

What is an AST?



Types of Procedural Macros

1. Function-like

Definition:

```
#[proc_macro]
pub fn foo(attr: TokenStream) -> TokenStream { ... }
```

Invocation:

```
foo!(Bar Baz Foo)
```

Types of Procedural Macros

2. Derive Macros

Definition:

```rust
#[proc_macro(derive(Bar))]
pub fn bar(body: TokenStream) -> TokenStream { ... }
```

Invocation:

```rust
#[derive(Bar)]
struct S;
```

Types of Procedural Macros

3. Attribute Macros

Defintion:

```rust
#[proc_macro_attribute]
pub fn baz(attr: TokenStream, item: TokenStream) -> TokenStream { ... }
```

Invocation:

```rust
#[baz(qux, quux)]
fn some_item() {}
```

Example - 1. Function-like Macros

Generates Rust-Code from the Macro Input. Looks like declarative Macro. Embeds JSON as DSL.

```
let john = json!({
    "name": "John Doe",
    "age": 43,
    "phones": [
        "+44 1234567",
        "+44 2345678"
    ]
});
```

Expands to:

```
let john = ::serde_json::Value::Object({
    let mut object = ::serde_json::Map::new();
    let _ = object
        .insert(("name").into(), ::serde_json::to_value(&"John Doe").unwrap());
    let _ = object.insert(("age").into(),
::serde_json::to_value(&43).unwrap());
    let _ = object
        .insert(
            ("phones").into(),
            ::serde_json::Value::Array(
                <[_]>::into_vec(
                    ::alloc::boxed::box_new([
                        ::serde_json::to_value(&"+44 1234567").unwrap(),
                        ::serde_json::to_value(&"+44 2345678").unwrap(),
                    ]),
                ),
            ),
        );
    object
});
```

Example - 2. Derive Macros

Generates Rust-Code from the definition of a type, e.g `struct` or `enum`.

```
#[derive(Debug)]
pub struct MyPoint {
    pub x: f64,
    pub y: f64,
}
```

Expands to

```
#[automatically_derived]
impl ::core::fmt::Debug for MyPoint {
    #[inline]
    fn fmt(&self, f: &mut ::core::fmt::Formatter) -> ::core::fmt::Result {
        ::core::fmt::Formatter::debug_struct_field2_finish(
            f,
            "MyPoint",
            "x",
            &self.x,
            "y",
            &&self.y,
        )
    }
}
```

Example - 3. Attribute Macros

```rust
#[tokio::main]
async fn main() {
    println!("hello world");
}
```

Expands to

```rust
fn main() {
    let body = async {
        {
            ::std::io::_print(format_args!("hello world\n"));
        };
    };
    #[allow(
        clippy::expect_used,
        clippy::diverging_sub_expression,
        clippy::needless_return,
        clippy::unwrap_in_result
    )]
    {
        return tokio::runtime::Builder::new_multi_thread()
            .enable_all()
            .build()
            .expect("Failed building the Runtime")
            .block_on(body);
    }
}
```

Chapter 3 - Drive your own Procedural Macros

- Tooling
- Easiest Macro: Greetings
- A derived Constructor
- Derive Validation Rules

Handy Tools for the Job

- Syn - is a parsing library for parsing a stream of Rust tokens
- Quote - provides the quote! macro for turning Rust syntax tree data structures into tokens of source code. (Introduces a a `proc_macro2` module, and you have to convert between `proc_macro2::TokenStream` and `proc_macro::TokenStream`)

`cargo expand` expands macros in source code, showing us what is really written.

Easiest Macro

```rust
#[derive(Debug, Greetings)]
pub struct MyPoint {
    pub x: f64,
    pub y: f64,
}

fn main() {
    let tmp = MyPoint { x: 1.0, y: 2.0 };
    tmp.greet();
}
```

Output:

```
Hello from MyPoint!
```

Greetings Implementation

```
#[proc_macro_derive(Greetings)]
pub fn derive_greetings(input: proc_macro::TokenStream) ->
proc_macro::TokenStream {
    let ast = parse_macro_input!(input as syn::DeriveInput);

    let name = &ast.ident;

    quote! {
        #[automatically_derived]
        impl #name {
            pub fn greet(&self) {
                println!("Hello from {}!", stringify!(#name))
            }
        }
    }.into()
}
```

We have to use a specialied crate, **let's look into the code...**

A Constructor

```
#[derive(Debug, Ctor)]
pub struct MyPoint {
    pub x: f64,
    pub y: f64,
}

fn main() {
    let tmp = MyPoint::ctor(1.0, 2.0);
}
```

Quote Iterators

For context:

```
  match &ast.data {
         syn::Data::Struct(data_struct) => {
     // ...
```

We generate iterators for later use:

```
 let params_in_sig = data_struct.fields.iter().map(|f| {
     let name = &f.ident;
     let ty = &f.ty;
     quote!(#name: #ty)
 });
```

Quote Variable Interpolation

Why are those Iterators useful?

Variable Interpolation with `#var`

- `#(#var)*` - no separators.
- `#(#var),*` - character, comma, before the asterisk is used as separator.
- `#(struct #var;)*` - Repetition can contain other tokens too.

Composite Quote for Constructor

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```
quote::quote! {
    #[automatically_derived]
    impl #type_name {
        pub fn ctor(#(#params_in_sig),*) -> Self {
            Self { #(#ctor_assignments),* }
        }
    }
}
```

Error handling - Basics

We use a `Result<TokenStream, syn::Error>` in the parsing code:

```
#[proc_macro_derive(Ctor)]
pub fn derive(input: proc_macro::TokenStream) -> proc_macro::TokenStream {
    let ast = parse_macro_input!(input as syn::DeriveInput);
    match ctor::derive_with_error_checks(&ast) {
        Ok(tokens) => tokens.into(),
        Err(err) => err.to_compile_error().into(),
    }
}
```

- The called code may use `syn::Error::new_spanned(token, msg)`.
- The token holds information on the error location.

Error handling - Example

```
fn check_right_type_struct(data_struct: &DataStruct) -> Result<(), syn::Error>
{
    match data_struct.fields {
        syn::Fields::Named(_) => { /* noop */}
        syn::Fields::Unnamed(_) => return Err(syn::Error::new_spanned(
            data_struct.struct_token,
            "Ctor cannot be derived for tuple structs, yet",
        )),
        syn::Fields::Unit =>
        return Err(syn::Error::new_spanned(
            data_struct.struct_token,
            "Ctor cannot be derived for unit structs, use Default instead",
        )),
    }
    Ok(())
}
```

Well, let's force them in the code...

The Use-Case: A distillation column

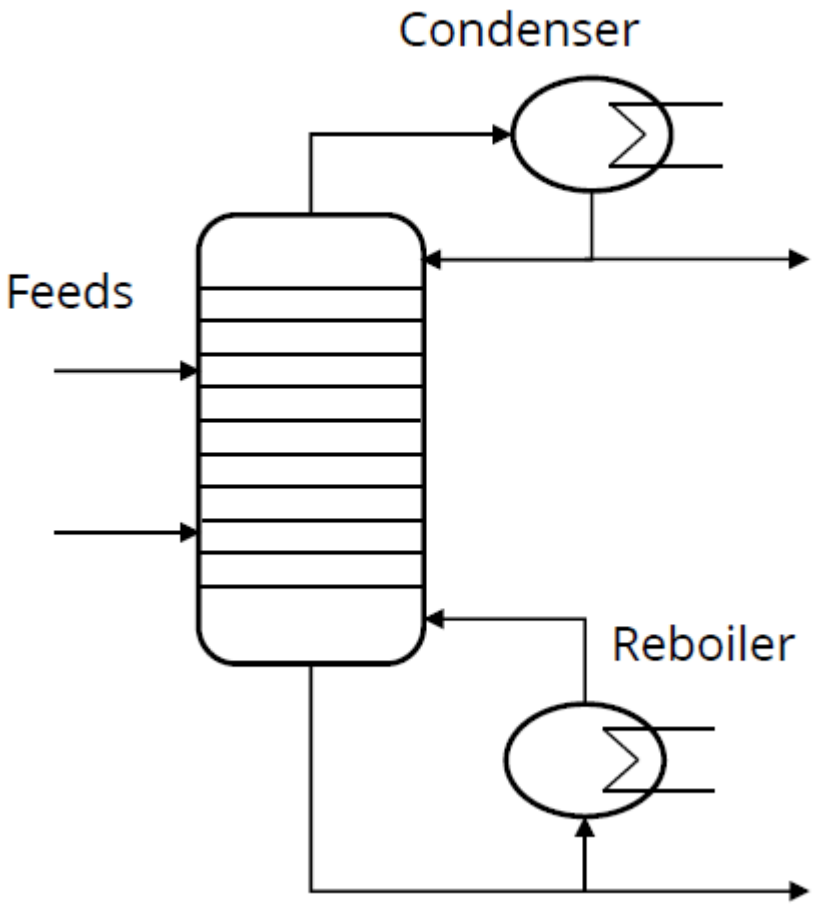
- EngCon - My old learning project for Procedural Macros

```rust
#[derive(Debug, Clone, Default, Copy, PartialEq, Validatable)]
pub struct DistillationColumn {
    #[validate_value(x >= 3)]
    pub trays: i32,

    #[validate_value(x < trays, x >= 1)]
    pub feed_place: i32,

    #[validate_value(x > 0.0)]
    pub reflux_ratio: f32,

    #[validate_value(x > 0.0, x < 1.0)]
    pub distiliate_to_feed_ratio: f32,
}
```



The Parser Trait

```rust
pub trait Parse: Sized {
    // Required method
    fn parse(input: ParseStream<'_>) -> Result<Self>;
}
```

Parsing interface implemented by all types that can be parsed in a default way from a token stream.

The Parser Trait Impl

```
pub trait Parse: Sized {
    // Required method
    fn parse(input: ParseStream<'_>) -> Result<Self>;
}


impl Parse for ValidationRule {
    fn parse(input: syn::parse::ParseStream) -> syn::Result<Self> {
        let mut candidate = ValidationRule {
            left: input.parse()?,
            cmp_op: input.parse()?,
            rigth: input.parse()?,
            right_is_field_on_self: false,
        };
        // ...
        if !matches!(
            candidate.cmp_op,
            syn::BinOp::Ge(_) | syn::BinOp::Gt(_) | syn::BinOp::Le(_) |
syn::BinOp::Lt(_)
        ) {
            // operator must be `<`, `<=`, `>=` or `>`
            return Err(syn::Error::new_spanned(
                candidate.cmp_op,
                "Only <, <=, >= and > are supported operators",
            ));
        }
        // ...
        Ok((candidate))
    }
}
```

Many Parser Traits Impls

- impl Parse for BinOp
- impl Parse for CapturedParam
- impl Parse for Expr
- impl Parse for FnArg
- impl Parse for ForeignItem
- impl Parse for GenericArgument
- impl Parse for GenericParam
- impl Parse for ImplItem
- impl Parse for Item
- impl Parse for Lit
- impl Parse for Member
- impl Parse for Meta
- impl Parse for PointerMutability
- impl Parse for RangeLimits
- impl Parse for ReturnType
- ...

Several hundred types

Further Sources

- A more depth Intro - Ciara gave a talk and it's already on YouTube.
- David Tolnays Workshop - A project-based workshop to learn Procedural Macros.

Learning begins the moment you stop watching and start building.

Thank - You!

It was a pleasure working with all of you! I l've learned a lot and truly enjoyed contributing to this project.

Let's stay in touch - and best of success for what comes next!

All that said

I'm happy to answer your questions...