Introducing Rustemo: A LR/GLR Parser Generator for Rust

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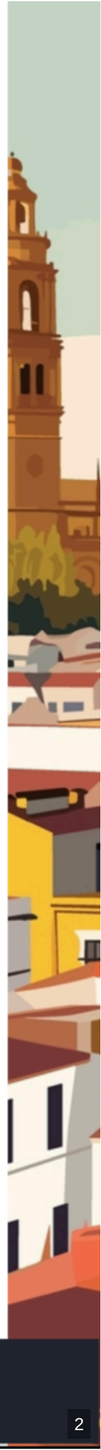
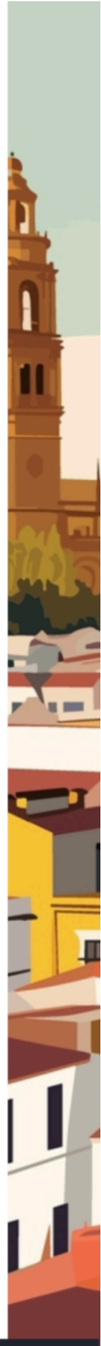
https://langdevcon.org/

Agenda

1. Introduction
2. Live demo - arithmetic expressions
3. Conclusion

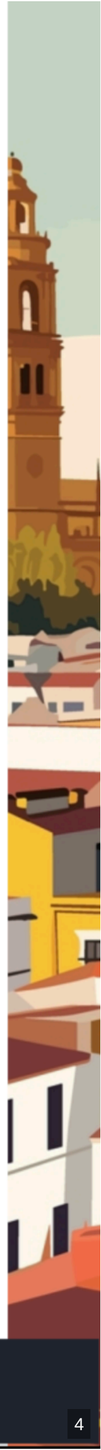


Introduction

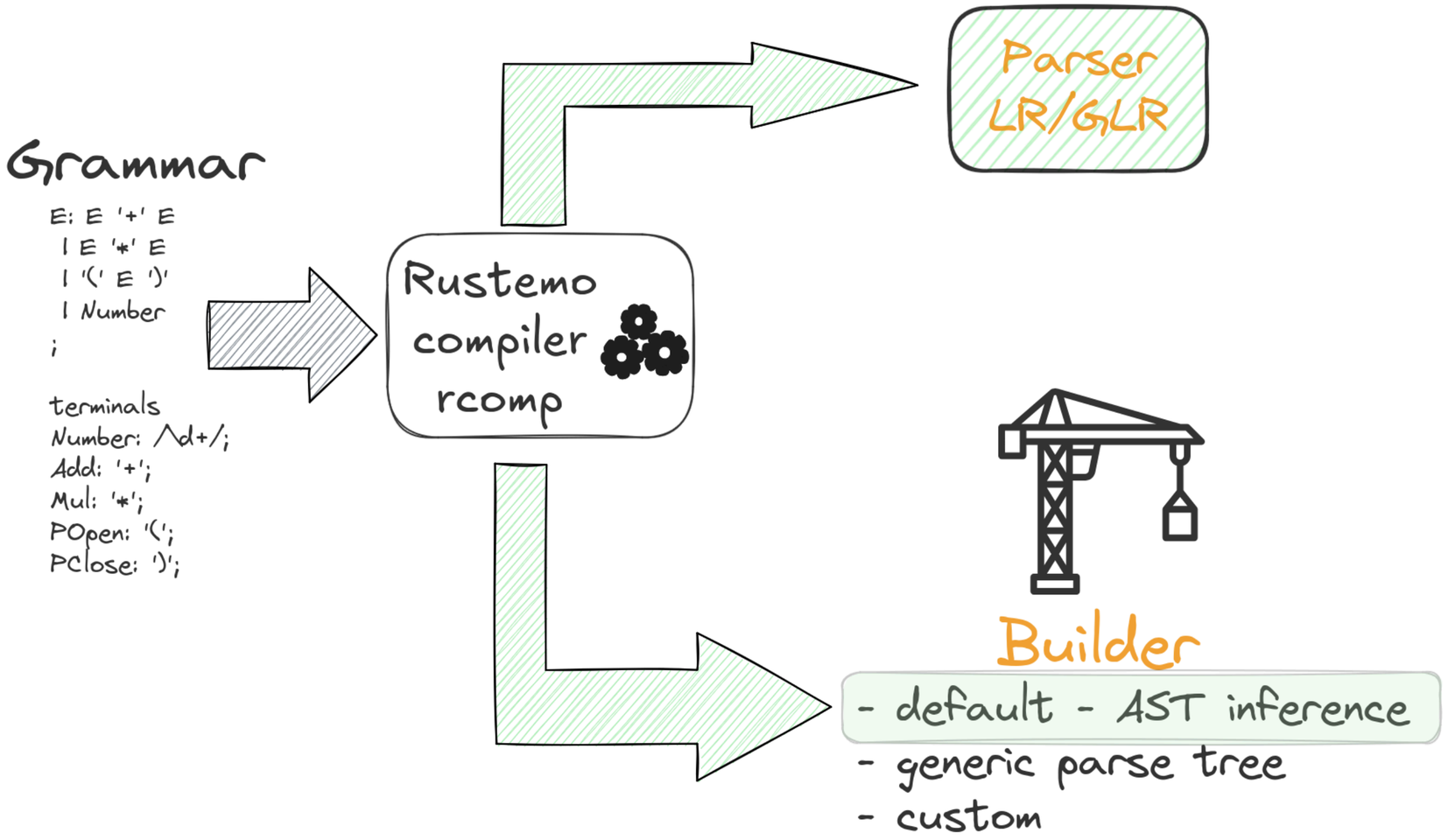


Introduction

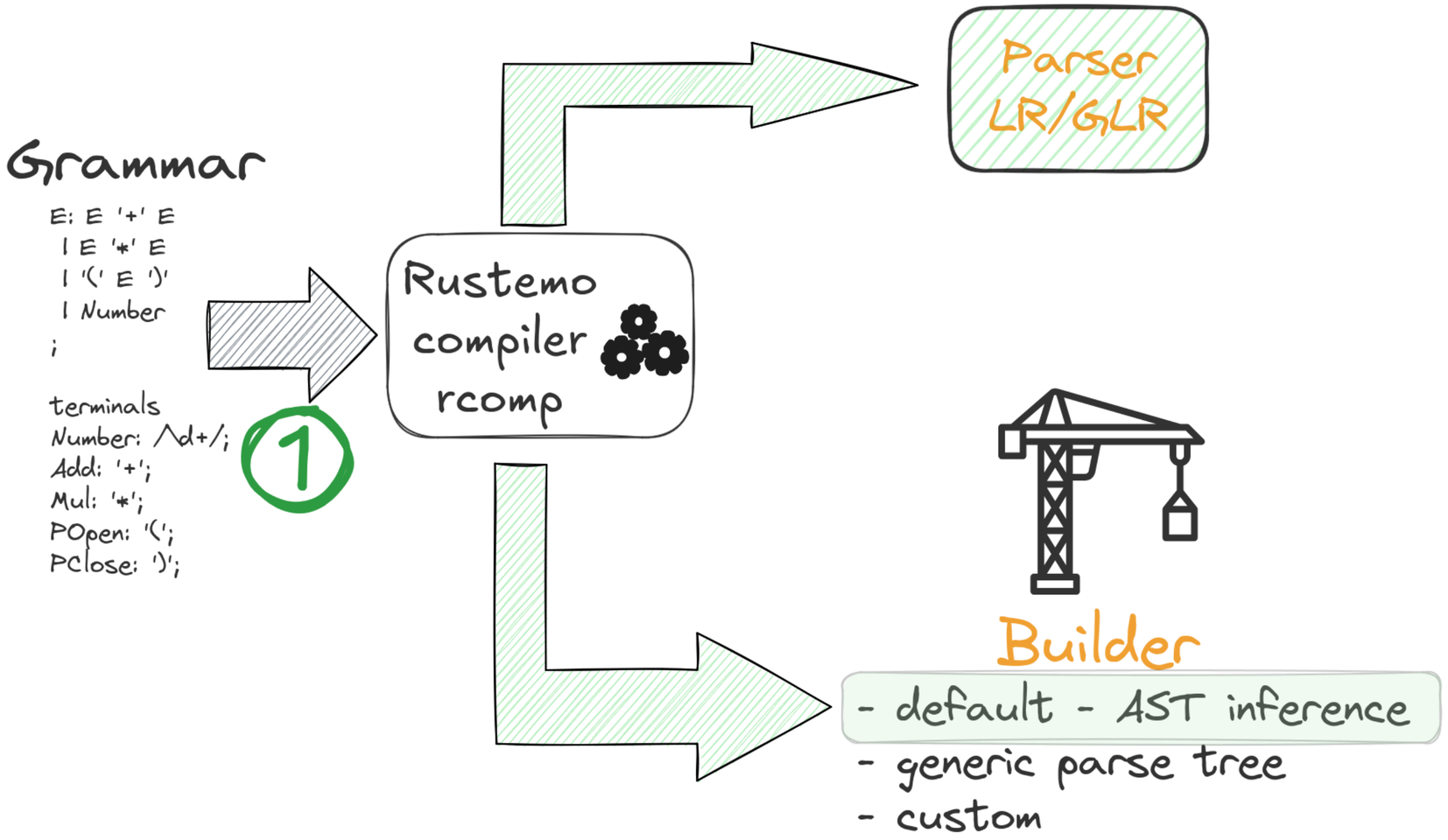
- An old-school LALR(1) parser generator (a.k.a. compiler-compiler) … with a modern twist - context aware lexing, GLR, flexible lexers/builders.
- Project started in November 2021
- Bootstrapping done in August 2022
- Generalized LR - Elizabeth Scott, Adrian Johnstone, Right Nulled GLR Parsers, 2006.
- Name: serbian word “растемо” pronounced as “rustemo” means “we grow”



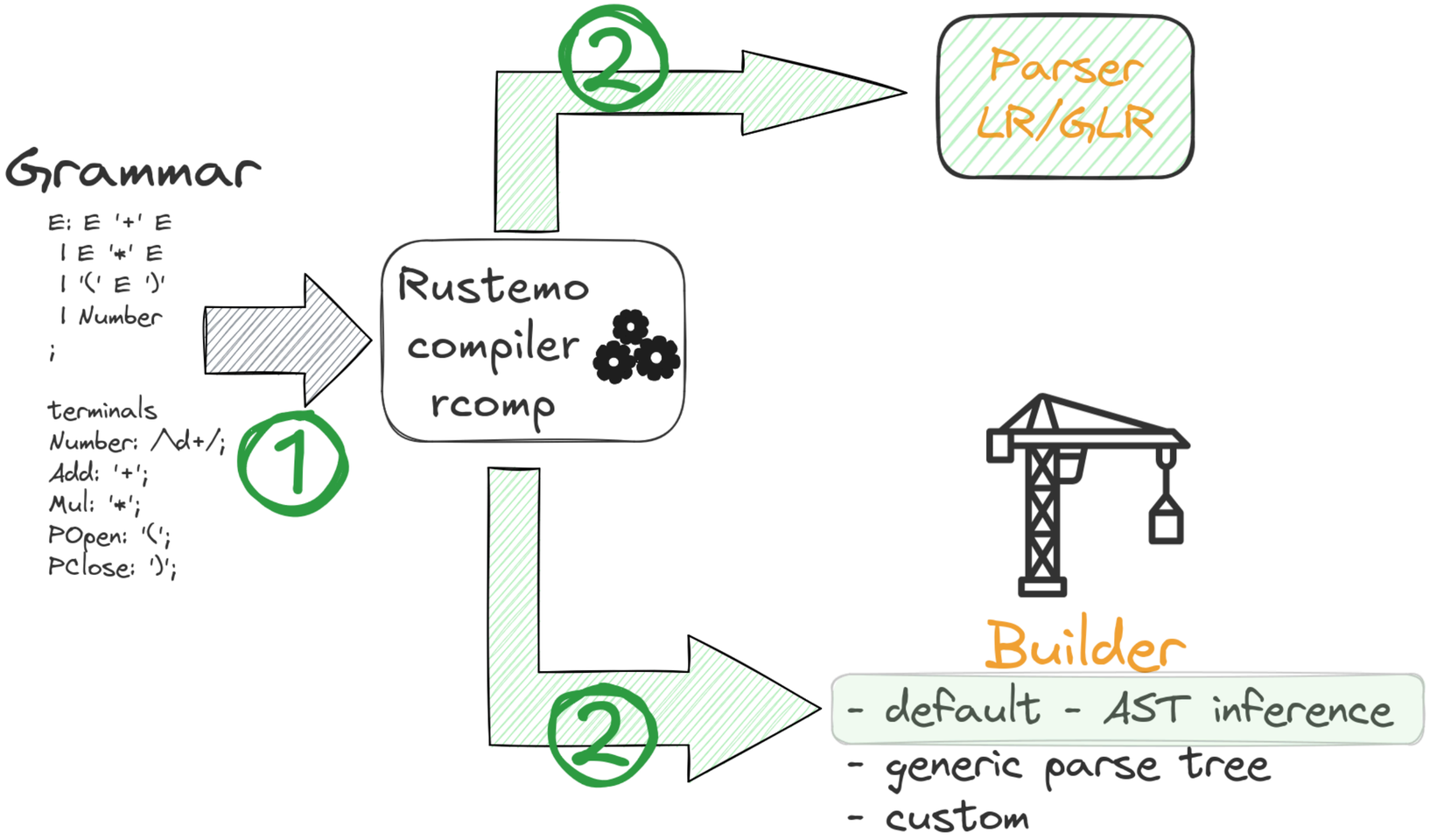
Rustemo compiler



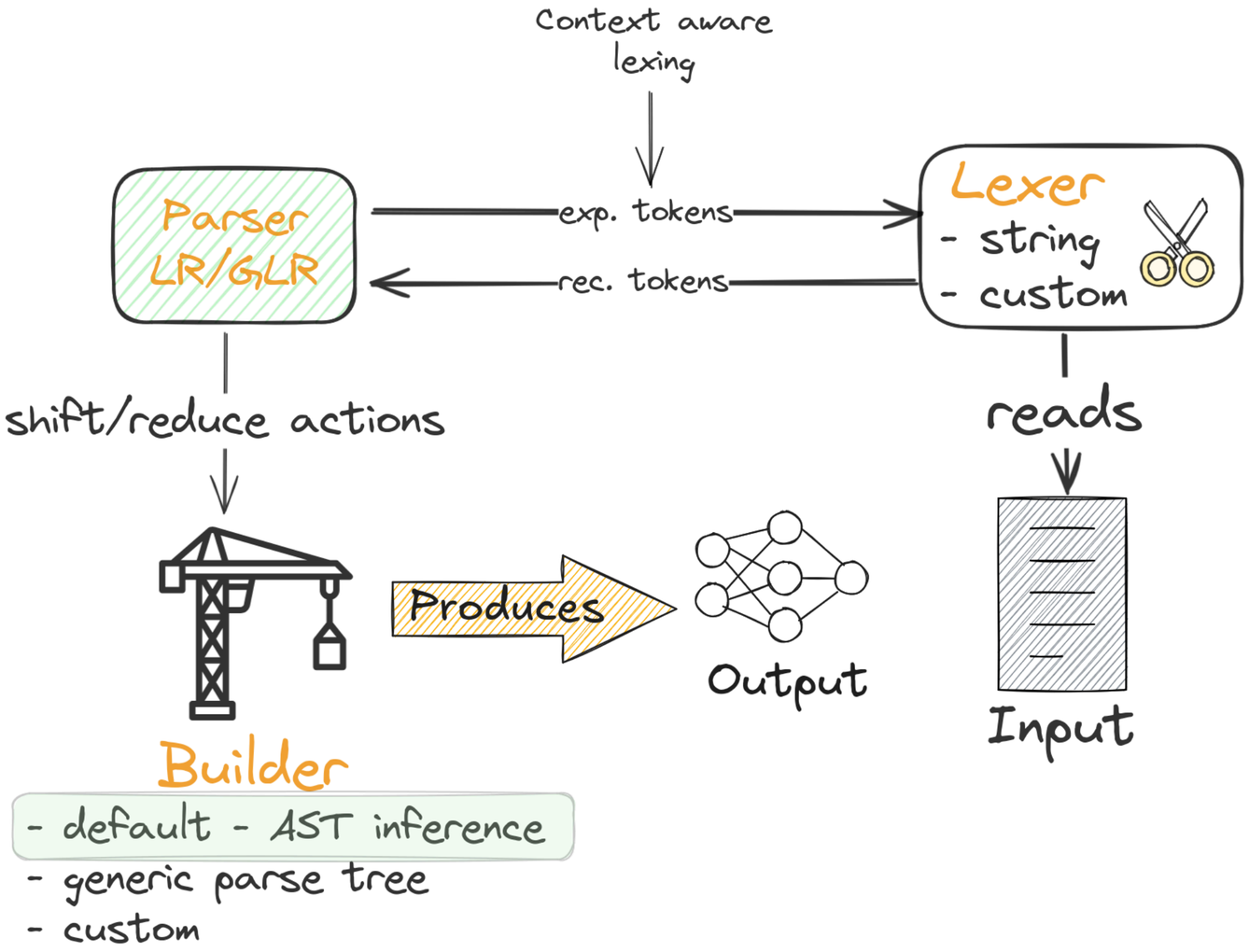
Rustemo compiler



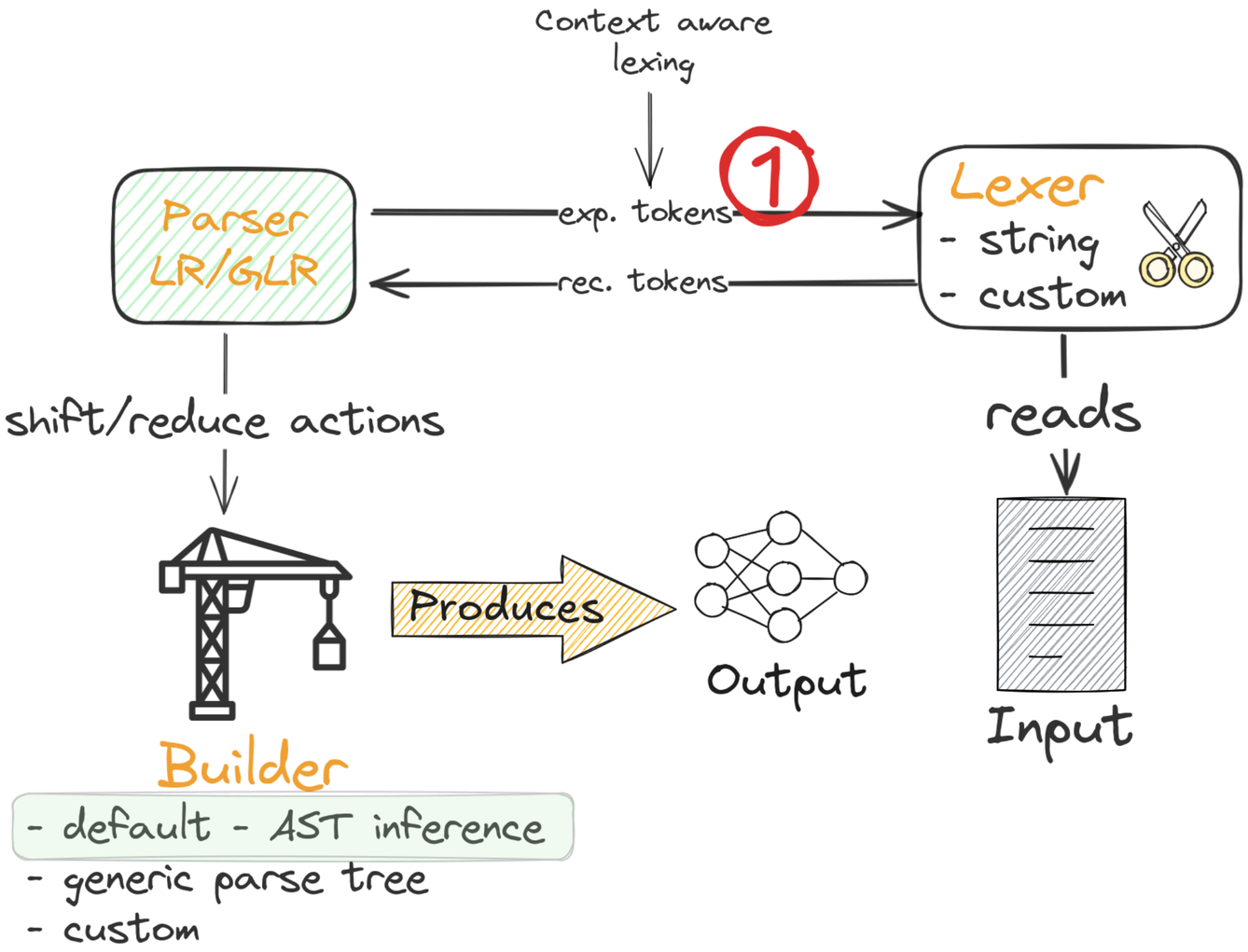
Rustemo compiler



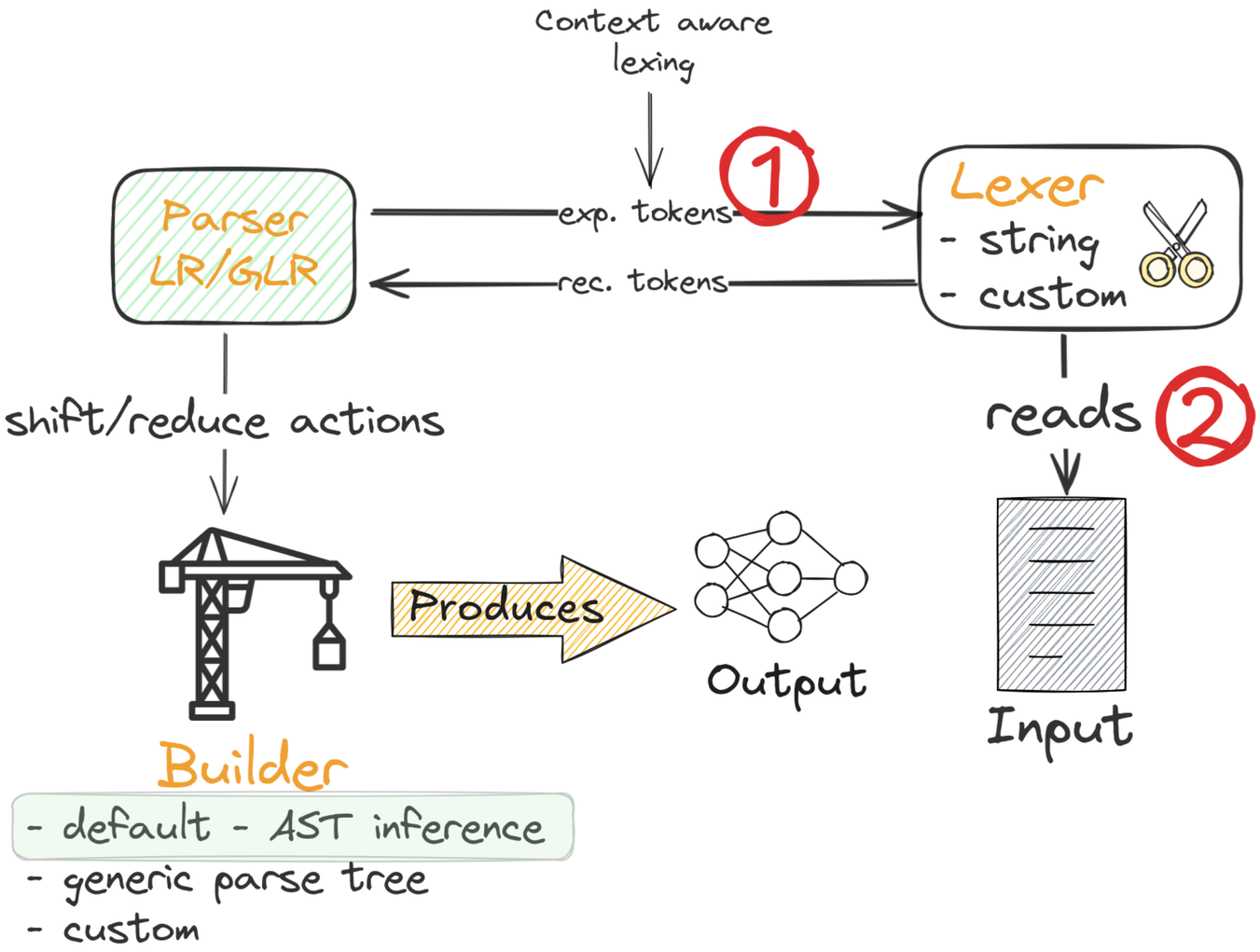
Parsing process overview



Parsing process overview

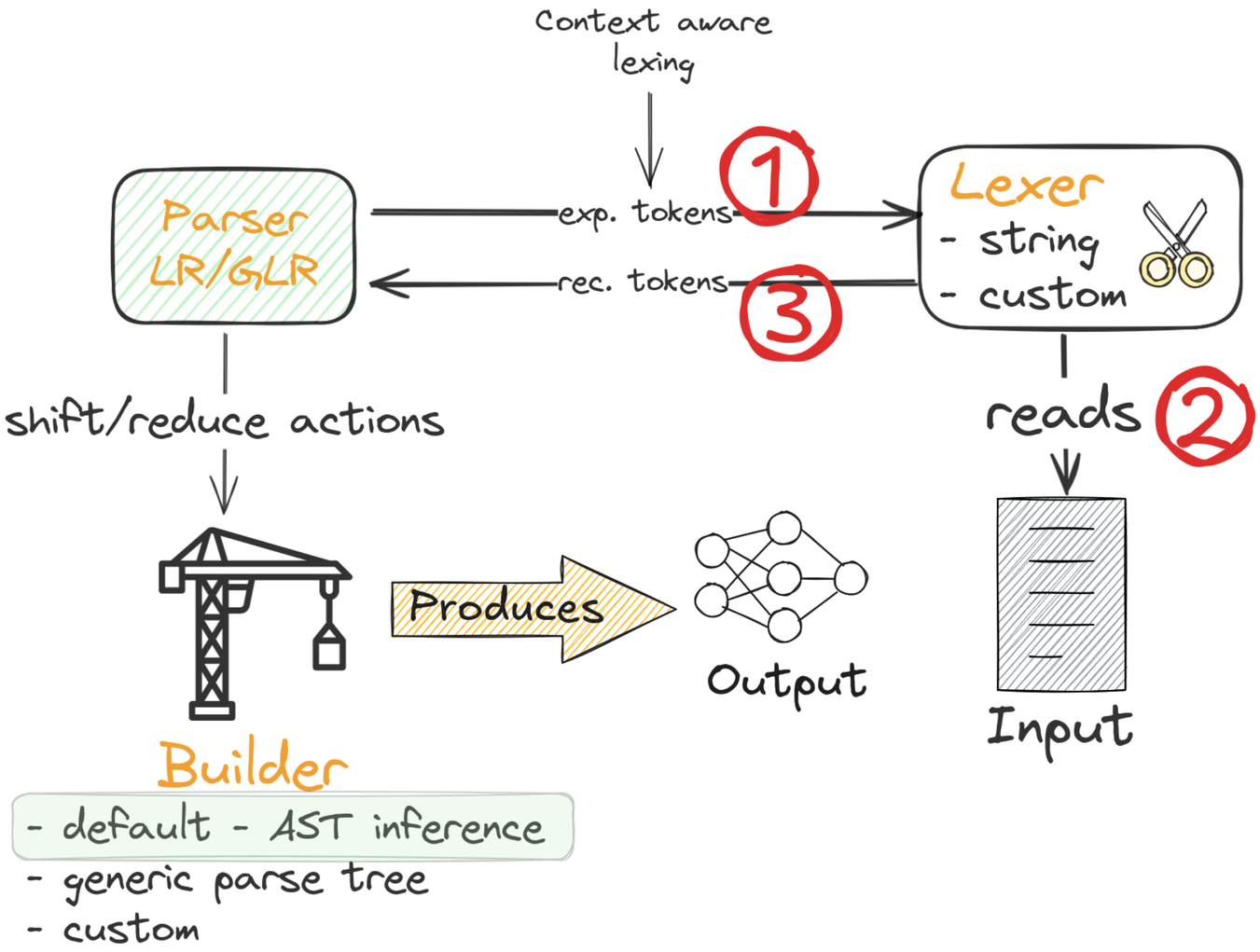


Parsing process overview



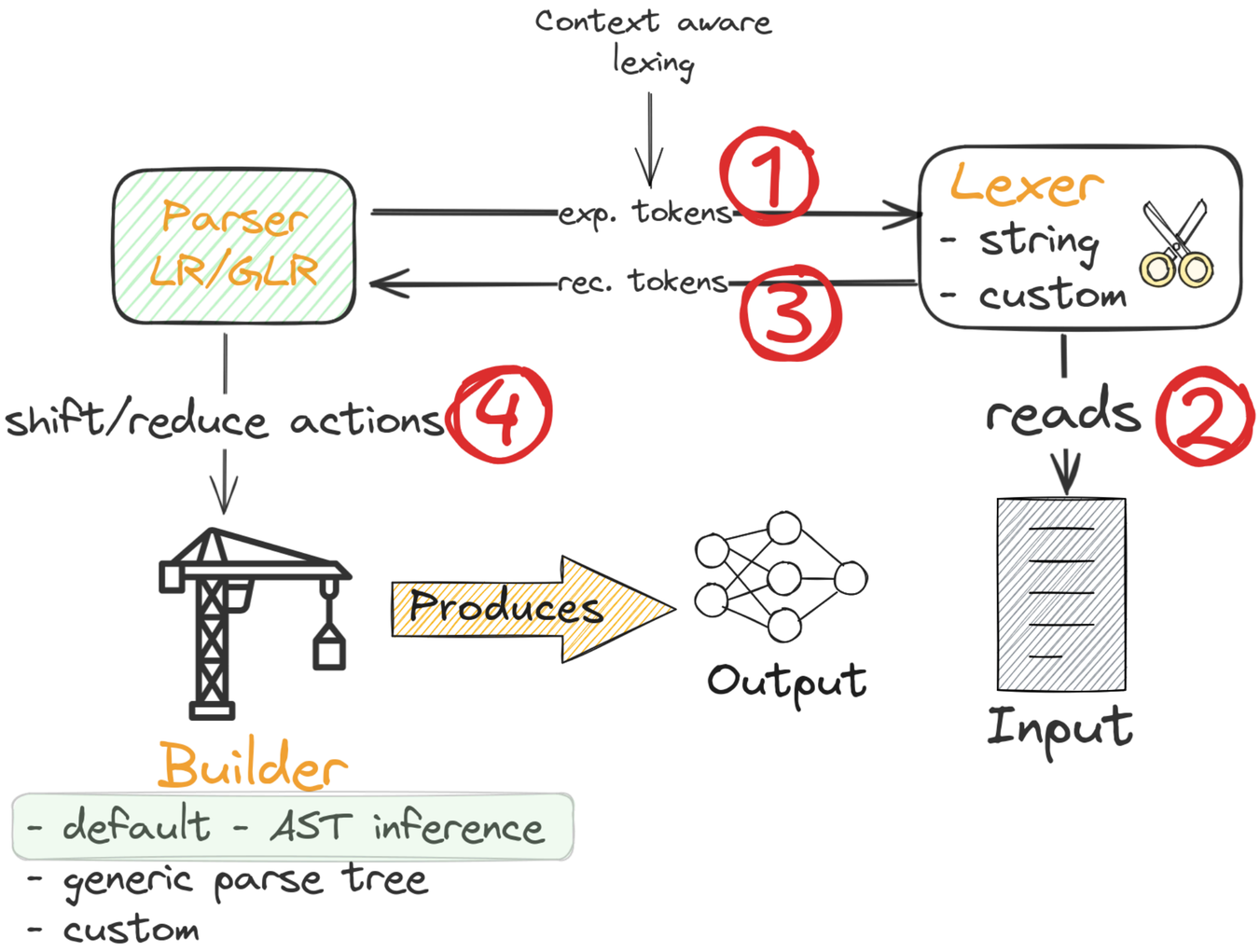
ProxyHands code: ZWQR

Parsing process overview

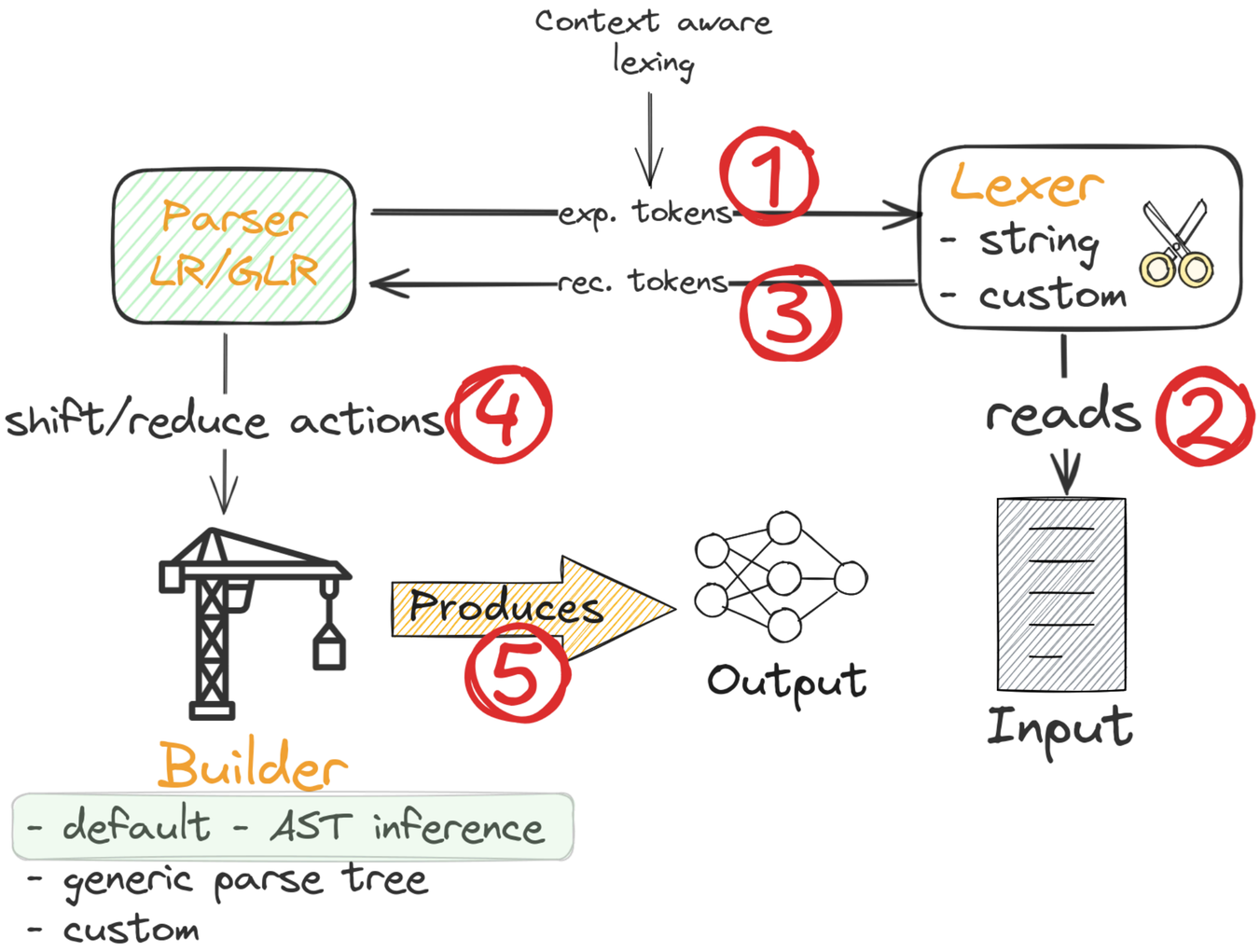


ProxyHands code: ZWQR

Parsing process overview

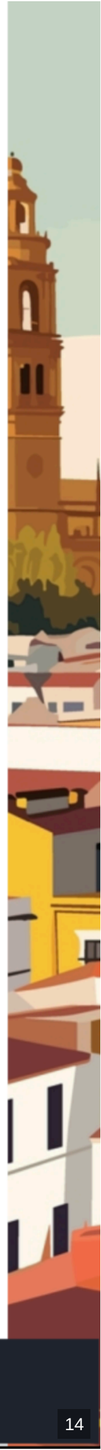


Parsing process overview



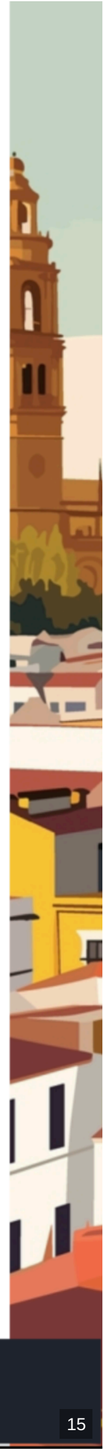
ProxyHands code: ZWQR

Live demo - arithmetic expressions

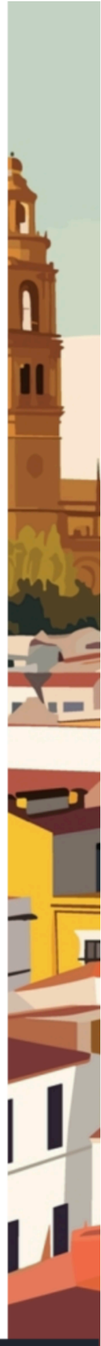


Demo repository

- GitHub repo
- Each step in this demo is a separate commit in the Git repo
  - Use diff to see what changed in each step
  - These slides are linked to relevant commits/steps - look for `step x` in titles.
- Prerequisite - Rust installed



Initial project

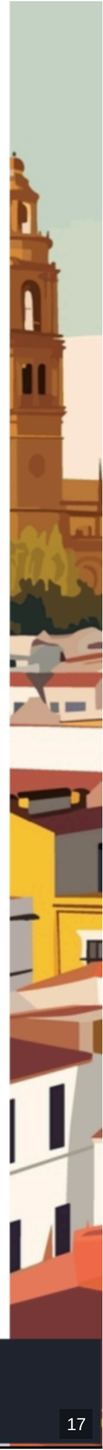


Create initial Rust project (step 1)

```
cargo new --bin arithmetic
```

Project layout is:

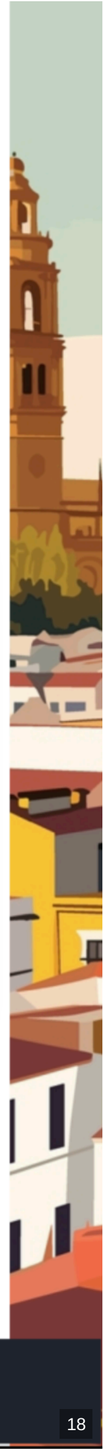
```
.
└── arithmetic
    ├── Cargo.toml
    └── src
        └── main.rs
```



Create expression grammar (step 2)

File `src/arithmetic.rustemo`

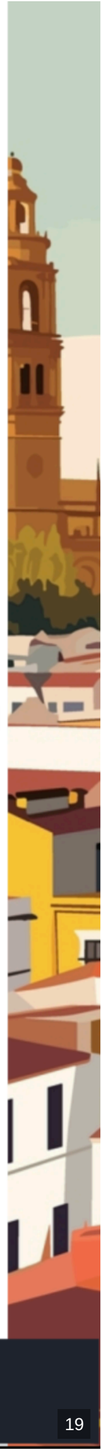
```
E: E '+' E
 | E '*' E
 | '(' E ')'
 | Number
;

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```



Install Rustemo compiler

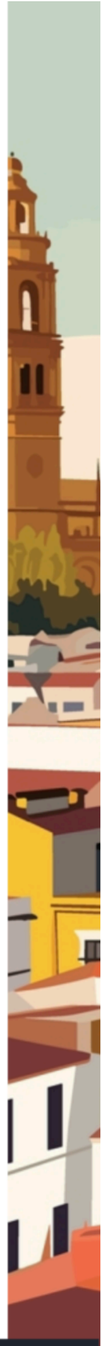
```
cargo install rustemo-compiler
```

After the installation completes the compiler (`rcomp` CLI tool) is available.



Try to compile the grammar

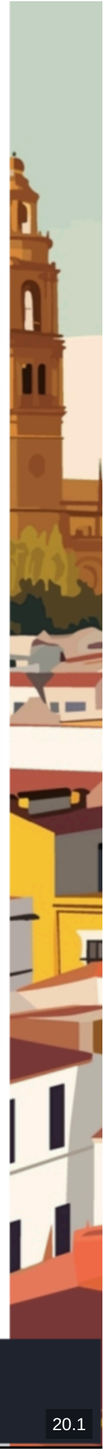
```
cd arithmetic/src/
rcomp arithmetic.rustemo
```



Try to compile the grammar

```
cd arithmetic/src/
rcomp arithmetic.rustemo
```

```
Generating parser for grammar "arithmetic.rustemo"
Terminals: 6
Non-terminals: 1
Productions: 4
States: 10

CONFLICTS:
In State 8:E
        1: E: E Add E .    {STOP, Add, Mul, PClose}
        1: E: E . Add E    {STOP, Add, Mul, PClose}
        2: E: E . Mul E    {STOP, Add, Mul, PClose}
When I saw E and see token Add ahead I can't decide should I shift or reduce by production:
E: E Add E

In State 8:E
        1: E: E Add E .    {STOP, Add, Mul, PClose}
        1: E: E . Add E    {STOP, Add, Mul, PClose}
        2: E: E . Mul E    {STOP, Add, Mul, PClose}
When I saw E and see token Mul ahead I can't decide should I shift or reduce by production:
E: E Add E
...

4 conflict(s). 4 Shift/Reduce and 0 Reduce/Reduce.
Error: Grammar is not deterministic. There are conflicts.
Parser(s) not generated.
```



Try to compile the grammar

```
cd arithmetic/src/
rcomp arithmetic.rustemo
```

```
Generating parser for grammar "arithmetic.rustemo"
Terminals: 6
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CONFLICTS:
In State 8:E
        1: E: E Add E .    {STOP, Add, Mul, PClose}
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E: E Add E

In State 8:E
        1: E: E Add E .    {STOP, Add, Mul, PClose}
        1: E: E . Add E    {STOP, Add, Mul, PClose}
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E: E Add E
...

4 conflict(s). 4 Shift/Reduce and 0 Reduce/Reduce.
Error: Grammar is not deterministic. There are conflicts.
Parser(s) not generated.
```
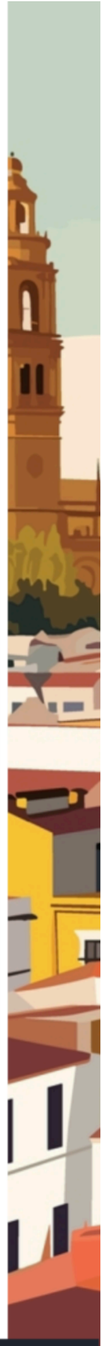
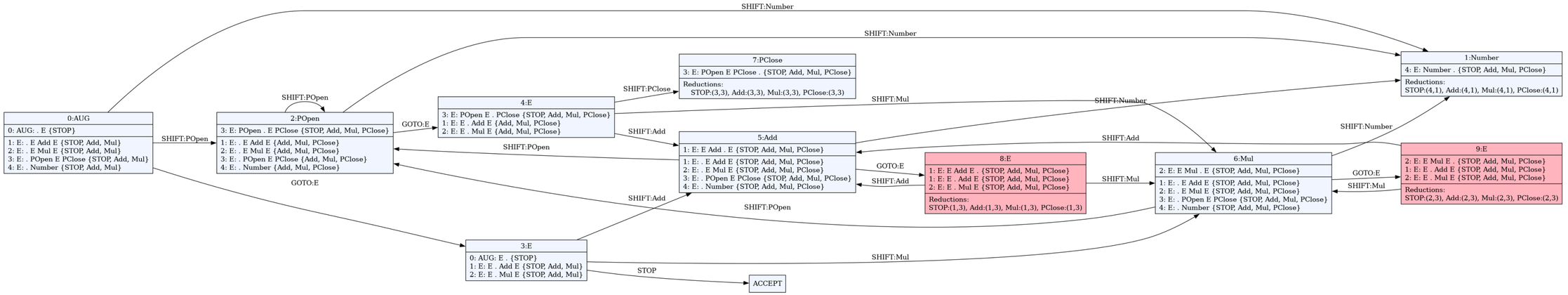

This grammar is ambiguous!



We can also visualize DFA for this grammar (step 3)

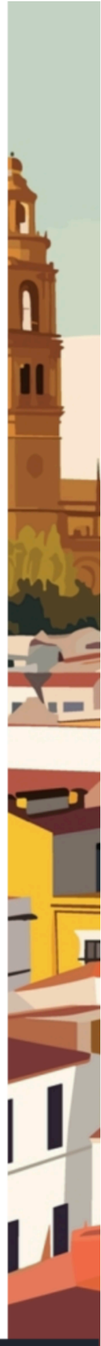
```
cd arithmetic/src
rcomp --dot arithmetic.rustemo
dot -Tpng -O arithmetic.dot
```

We get a PNG file with the DFA.



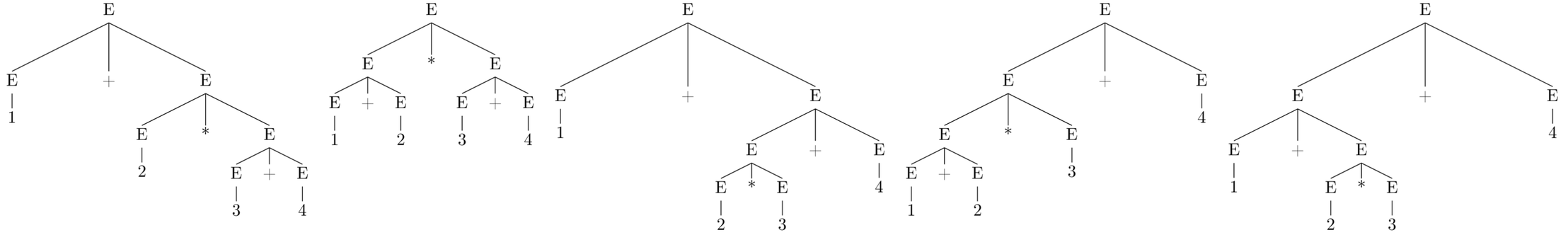
States colored red have conflicts.

Ambiguous grammars



What does it mean for a grammar to be ambiguous?

*1 + 2 * 3 + 4*



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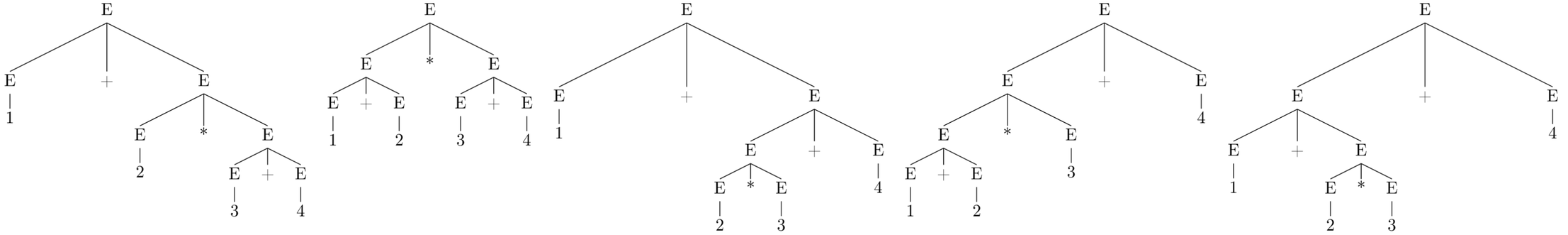
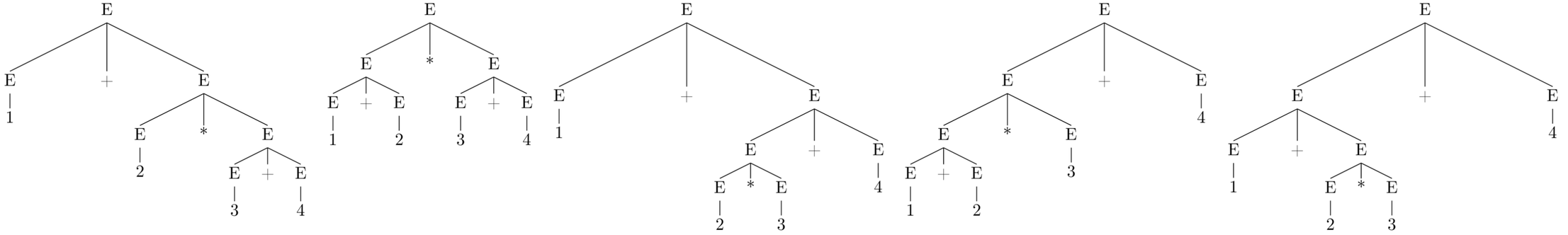
*1 + 2 * 3 + 4*



- The number of possible interpretation rise quickly with the addition of new operations.

What does it mean for a grammar to be ambiguous?

*1 + 2 * 3 + 4*

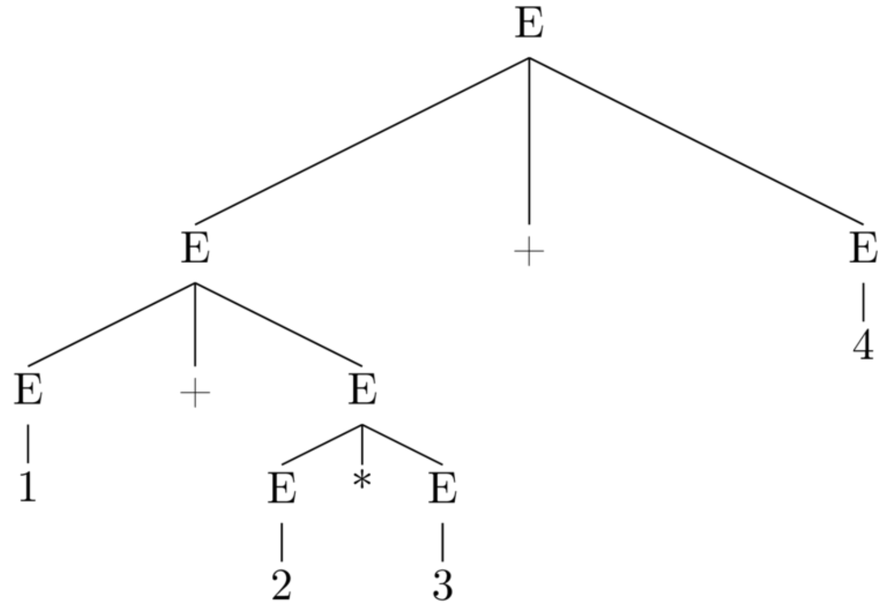


- The number of possible interpretation rise quickly with the addition of new operations.
- 1, 1, 2, 5, 14, 42, 132, 429, 1430, 4862, 16796, 58786, … - Catalan numbers

ProxyHands code: ZWQR

What does it mean for a grammar to be ambiguous?

*1 + 2 * 3 + 4*



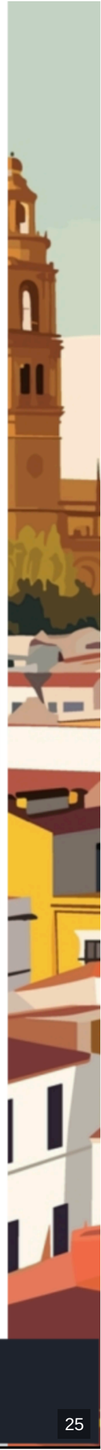
While the grammar is ambiguous, the language is not!

How to disambiguate?

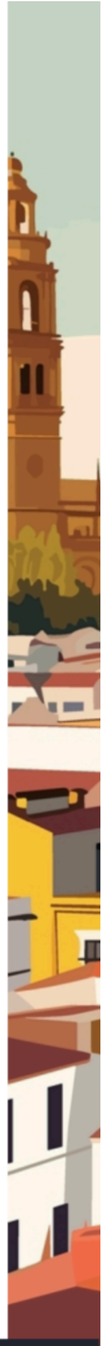
A classic approach - grammar rework by introducing intermediate rules:

```
AddExpr: MulExpr AddExprRest*;
AddExprRest: Add MulExpr;
MulExpr: AtomExpr MulExprRest*;
MulExprRest: Mul AtomExpr;
AtomExpr: Number | '(' AddExpr ')';

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```

We stay in the CFG realm, but this quickly leads to unmaintainable grammar + produced trees are not what the user expects.



Using GLR

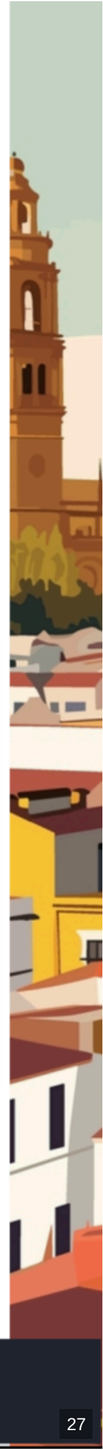


Ok, lets try GLR (step 4)

- GLR - Generalized LR - can accept any CFG, even ambiguous.
- Explores and returns all possible interpretations efficienly (polinomial time/space).

We'll just let the grammar be without any disambiguation.

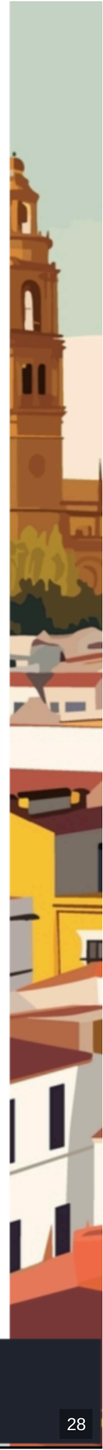
```
E: E '+' E
 | E '*' E
 | '(' E ')'
 | Number
;

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```



Now, lets compile the grammar to a GLR parser.

```
rcomp --parser-algo glr arithmetic.rustemo
```

```
Generating parser for grammar "arithmetic.rustemo"
Terminals: 6
Non-terminals: 1
Productions: 4
States: 10
Writing actions file "arithmetic_actions.rs"
Writing parser file "arithmetic.rs"
```



Add required dependencies (step 5)

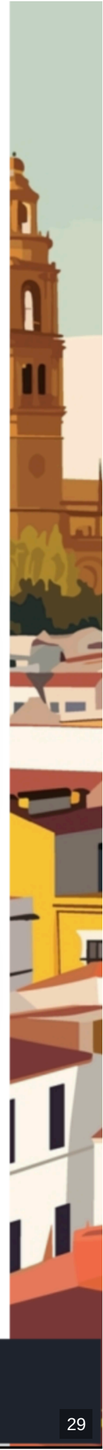
Generated parser depends on `rustemo` library. It is a runtime part of the Rustemo.

```
cargo add rustemo
```

```
    Updating crates.io index
      Adding rustemo v0.6.0 to dependencies
             Features:
             + glr
    Updating crates.io index
```

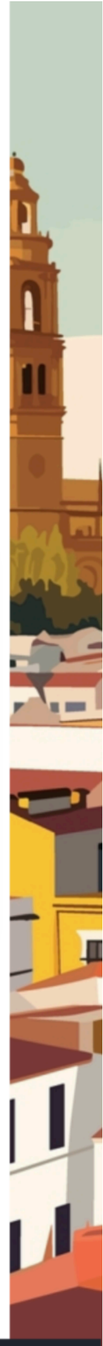
Generated code also uses `regex`, `once_cell` and `colored` libraries, so lets add those.

```
cargo add regex --no-default-features --features std,unicode-perl
cargo add once_cell colored
```



Now, your `Cargo.toml` should look like this:

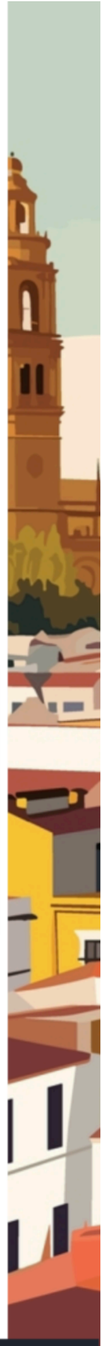
```toml
[package]
name = "arithmetic"
version = "0.1.0"
edition = "2021"

[dependencies]
colored = "2.1.0"
once_cell = "1.20.1"
regex = { version = "1.11.0", default-features = false, features = ["std", "unicode-perl"] }
rustemo = "0.6.1"
```



Update `main.rs`

Read expression from stdin.

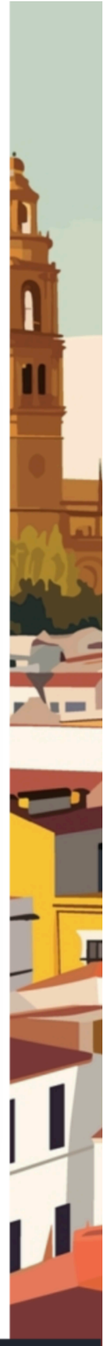
```rust
fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");
}
```



Update `main.rs`

Import generated parser modules and the parser type.

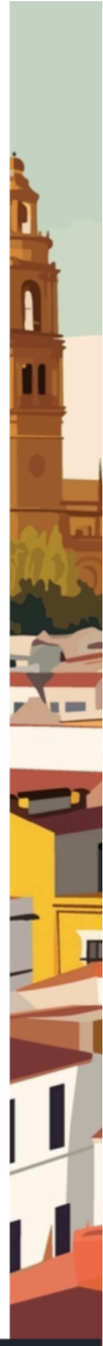
```rust
use rustemo::Parser;
use std::io;
// Use the generated parser
use crate::arithmetic::ArithmeticParser;

// Include generated modules
#[rustfmt::skip]
mod arithmetic;
#[allow(unused)]
#[rustfmt::skip]
mod arithmetic_actions;

fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");
}
```



Update `main.rs` (step 6)

Parse the input and process the forest.

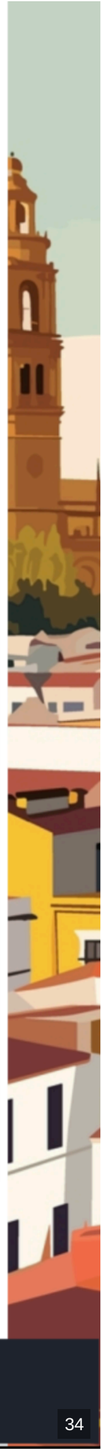
```rust
use rustemo::Parser;
use std::io;
// Use the generated parser
use crate::arithmetic::ArithmeticParser;

// Include generated modules
#[rustfmt::skip]
mod arithmetic;
#[allow(unused)]
#[rustfmt::skip]
mod arithmetic_actions;

fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");

    // Parse the line and get all results.
    let forest = ArithmeticParser::new().parse(&expression).unwrap();

    println!("Number of interpretations = {}", forest.solutions());

    for (tree_idx, tree) in forest.iter().enumerate() {
        println!("**** TREE {tree_idx}");
        println!("{tree:#?}");
    }
}
```



Run with:

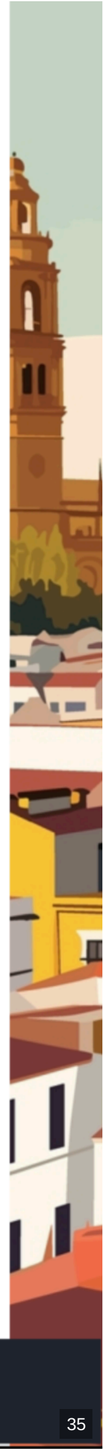
```
cargo run
```

```
Expression:
2 + 3 * 5
Number of interpretations = 2
**** TREE 0
[
    [
        [
            "2",
        ],
        "+",
        [
            "3",
        ],
    ],
    "*",
    [
        "5",
    ],
]
**** TREE 1
[
    [
        "2",
        ...
```



Improve default actions

- The builder can be changed. See builders section in the Rustemo book for more info.
- The default builder calls actions to create AST nodes where the types are auto-inferred from the grammar.
- Actions are generated Rust functions.

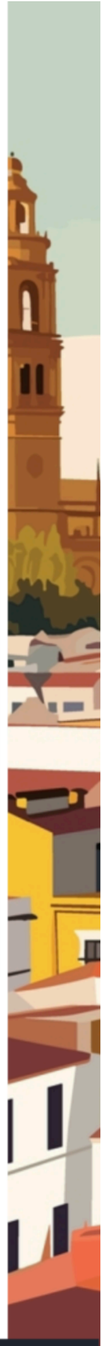


Improve default actions

File `arithmetic_actions.rs`

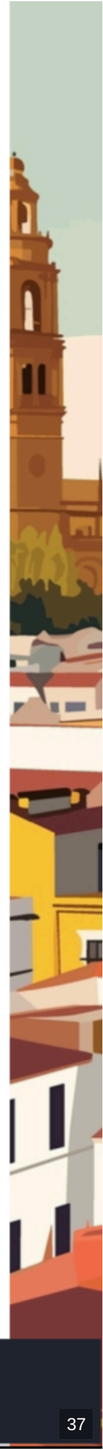
```
<snip>
pub type Number = String;
pub fn number(_ctx: &Ctx, token: Token) -> Number {
    token.value.into()
}
#[derive(Debug, Clone)]
pub struct EC1 {
    pub e_1: Box<E>,
    pub e_3: Box<E>,
}
<snip>
pub fn e_c1(_ctx: &Ctx, e_1: E, e_3: E) -> E {
    E::C1(EC1 {
        e_1: Box::new(e_1),
        e_3: Box::new(e_3),
    })
}
pub fn e_number(_ctx: &Ctx, number: Number) -> E {
    E::Number(number)
}
```

This just creates an AST. But, we would like actions to perform actual calculation. Let's do that!



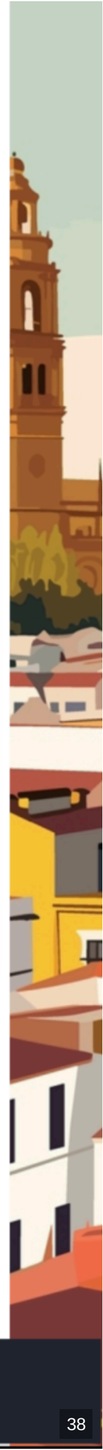
Improve actions - add nice production names

```
E: E '+' E {Add}
 | E '*' E {Mul}
 | '(' E ')' {Paren}
 | Number {Num}
;

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```



Improve actions - add assignments

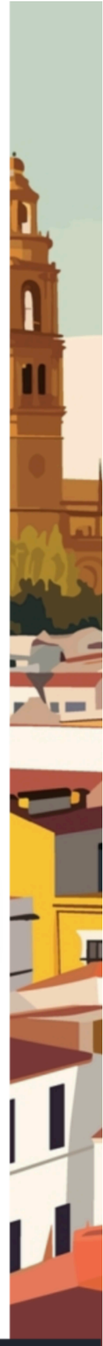
```
E: left=E '+' right=E {Add}
 | left=E '*' right=E {Mul}
 | '(' E ')' {Paren}
 | Number {Num}
;

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```



Improve actions - regenerate (step 7)

- Actions are regenerated on each `rcomp` run.
- Old content is preserved as we are able to manually tune actions and types.
- In this case we don’t have manual changes so we just delete `arithmentic_actions.rs` and run `rcomp` again.

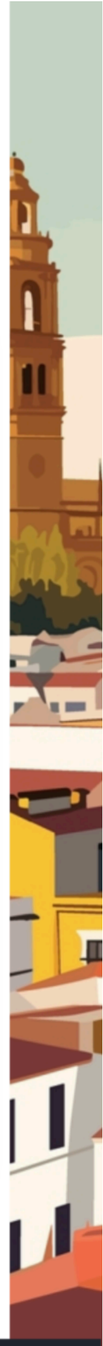
```
rm arithmetic_actions.rs
rcomp --parser-algo glr arithmentic.rustemo
```



Improve actions - improved

And, now our actions are more readable.

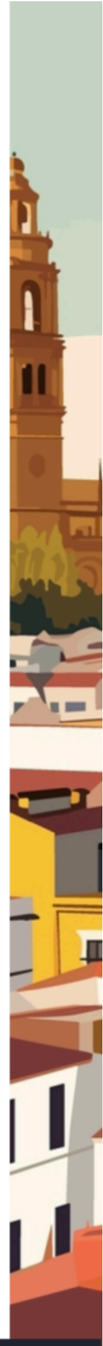
```rust
pub type Token<'i> = RustemoToken<'i, Input, TokenKind>;
pub type Number = String;
pub fn number(_ctx: &Ctx, token: Token) -> Number {
    token.value.into()
}
#[derive(Debug, Clone)]
pub struct Add {
    pub left: Box<E>,
    pub right: Box<E>,
}
#[derive(Debug, Clone)]
pub struct Mul {
    pub left: Box<E>,
    pub right: Box<E>,
}
#[derive(Debug, Clone)]
pub enum E {
    Add(Add),
    Mul(Mul),
    Paren(Box<E>),
    Num(Number),
}
```



Improve actions - improved

And, now our actions are more readable.

```rust
pub fn e_add(_ctx: &Ctx, left: E, right: E) -> E {
    E::Add(Add {
        left: Box::new(left),
        right: Box::new(right),
    })
}
pub fn e_mul(_ctx: &Ctx, left: E, right: E) -> E {
    E::Mul(Mul {
        left: Box::new(left),
        right: Box::new(right),
    })
}
pub fn e_paren(_ctx: &Ctx, e: E) -> E {
    E::Paren(Box::new(e))
}
pub fn e_num(_ctx: &Ctx, number: Number) -> E {
    E::Num(number)
}
```



Improve actions - calculate

We can now manually tune our actions to do calculations during the build. We don't want to build the tree, we want to get the result of the calculation.

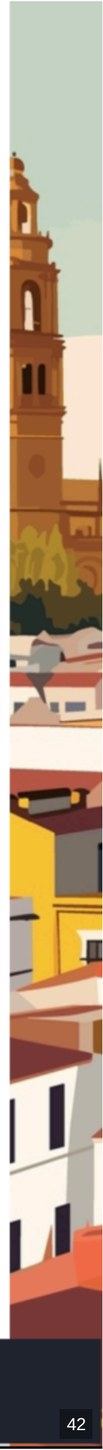
First, we change this:

```
pub type Number = String;
pub fn number(_ctx: &Ctx, token: Token) -> Number {
    token.value.into()
}
```

Into this:

```
pub type Number = i32;
pub fn number(_ctx: &Ctx, token: Token) -> Number {
    token.value.parse().unwrap()
}
```

to convert numbers from strings to integers.



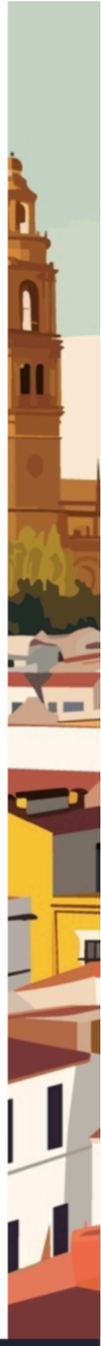
Improve actions - calculate

We replace all these types.

```rust
#[derive(Debug, Clone)]
pub struct Add {
    pub left: Box<E>,
    pub right: Box<E>,
}
#[derive(Debug, Clone)]
pub struct Mul {
    pub left: Box<E>,
    pub right: Box<E>,
}
#[derive(Debug, Clone)]
pub enum E {
    Add(Add),
    Mul(Mul),
    Paren(Box<E>),
    Num(Number),
}
```

With just:

```rust
pub type E = i32;
```

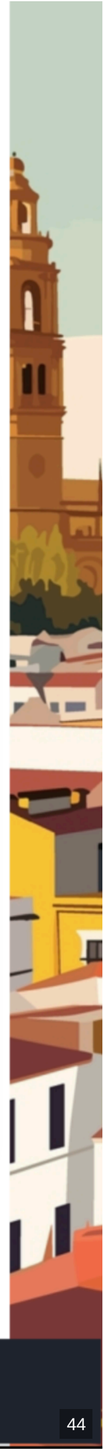


Improve actions - calculate

Now, we replace actions bodies with a proper calculations.

We replace this:

```
pub fn e_add(_ctx: &Ctx, left: E, right: E) -> E {
    E::Add(Add {
        left: Box::new(left),
        right: Box::new(right),
    })
}
pub fn e_mul(_ctx: &Ctx, left: E, right: E) -> E {
    E::Mul(Mul {
        left: Box::new(left),
        right: Box::new(right),
    })
}
pub fn e_paren(_ctx: &Ctx, e: E) -> E {
    E::Paren(Box::new(e))
}
pub fn e_num(_ctx: &Ctx, number: Number) -> E {
    E::Num(number)
}
```

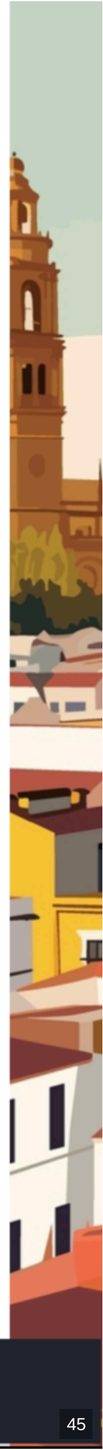


Improve actions - calculate (step 8)

Now, we replace actions bodies with a proper calculations.

With this:

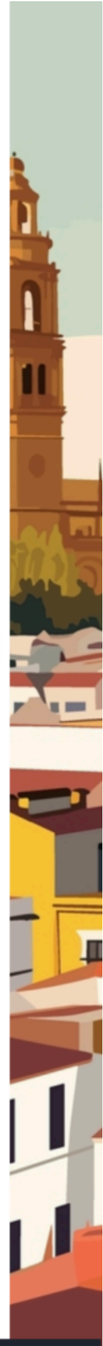
```
pub fn e_add(_ctx: &Ctx, left: E, right: E) -> E {
    left + right
}
pub fn e_mul(_ctx: &Ctx, left: E, right: E) -> E {
    left * right
}
pub fn e_paren(_ctx: &Ctx, e: E) -> E {
    e
}
pub fn e_num(_ctx: &Ctx, number: Number) -> E {
    number
}
```



Improve actions - run

Run it again:

```
cargo run
```

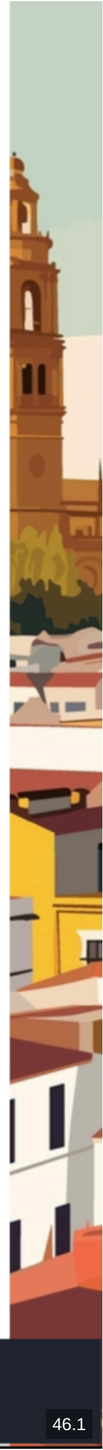


Improve actions - run

Run it again:

```
cargo run
```

- Nothing changed! Why?

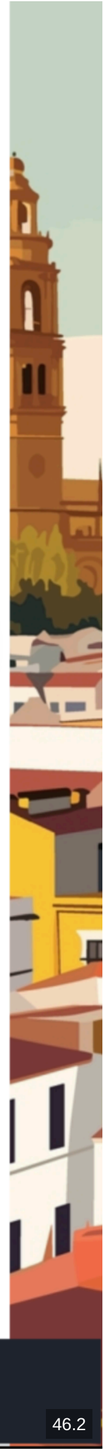


Improve actions - run

Run it again:

```
cargo run
```

- Nothing changed! Why?
- When using GLR, trees are not converted by builders automatically as it would impose a big overhead.

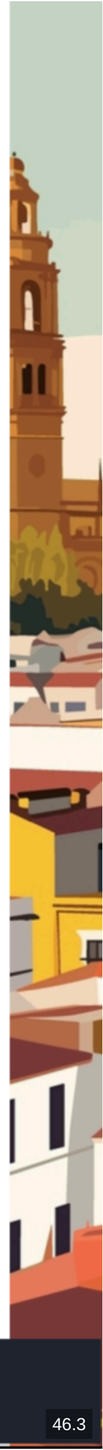


Improve actions - run

Run it again:

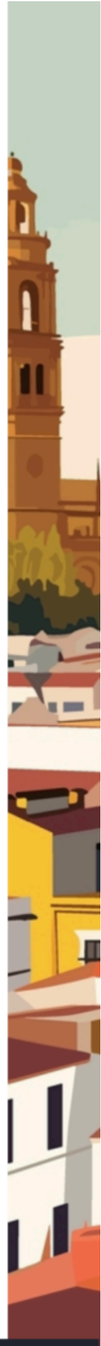
```
cargo run
```

- Nothing changed! Why?
- When using GLR, trees are not converted by builders automatically as it would impose a big overhead.
- We must call builder explicitly over trees extracted from the forest.



GLR - calculate over all trees

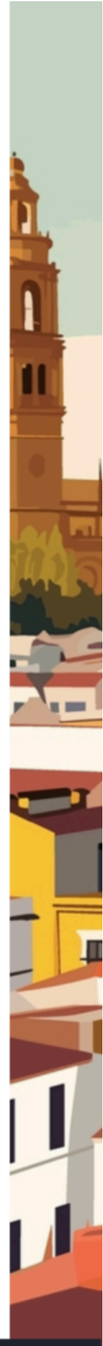
Change our `main.rs` to build all trees from the forest using our new calculation actions.



GLR - calculate over all trees

Change from this:

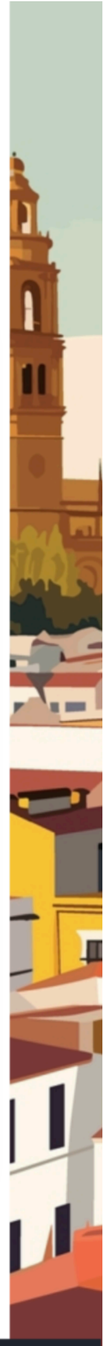
```rust
use rustemo::Parser;
use std::io;
// Use the generated parser
use crate::arithmetic::ArithmeticParser;

// Include generated modules
#[rustfmt::skip]
mod arithmetic;
#[allow(unused)]
#[rustfmt::skip]
mod arithmetic_actions;

fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");

    // Parse the line and get all results.
    let forest = ArithmeticParser::new().parse(&expression).unwrap();

    println!("Number of interpretations = {}", forest.solutions());

    for (tree_idx, tree) in forest.iter().enumerate() {
        println!("**** TREE {tree_idx}");
        println!("{tree:#?}");
    }
}
```



GLR - calculate over all trees

To this:

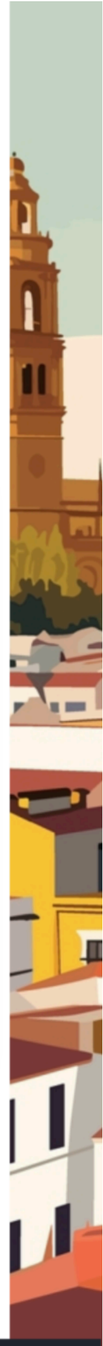
```rust
use rustemo::Parser;
use std::io;
// Use the generated parser and builder
use crate::arithmetic::{ArithmeticParser, DefaultBuilder};

// Include generated modules
#[rustfmt::skip]
mod arithmetic;
#[allow(unused)]
#[rustfmt::skip]
mod arithmetic_actions;

fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");

    // Parse the line and get all results.
    let forest = ArithmeticParser::new().parse(&expression).unwrap();

    println!("Number of interpretations = {}", forest.solutions());

    // Evaluate each tree from the forest
    let results = forest
        .into_iter()
        .map(|tree| {
            let mut builder = DefaultBuilder::new();
            tree.build(&mut builder)
        })
        .collect::<Vec<_>>();

    println!("{results:?}");
}
```



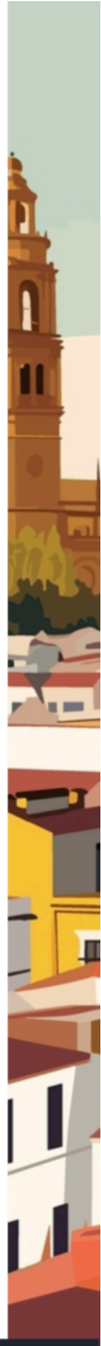
GLR - calculate over all trees (step 9)

To this:

```
23      // Parse the line and get all results.
24      let forest = ArithmeticParser::new().parse(&expression).unwrap();
25
26      println!("Number of interpretations = {}", forest.solutions());
27
28      // Evaluate each tree from the forest
29      let results = forest
30          .into_iter()
31          .map(|tree| {
32              let mut builder = DefaultBuilder::new();
33              tree.build(&mut builder)
34          })
35          .collect::<Vec<_>>();
36
37      println!("{results:?}");
```



Declarative disambiguation

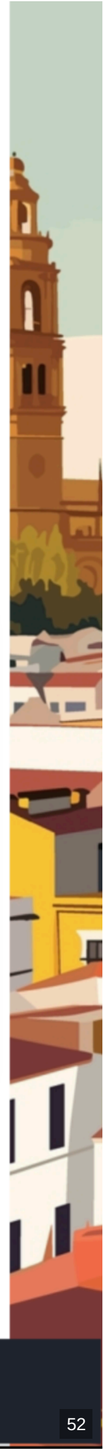


ProxyHands code: ZWQR

Rustemo - declarative disambiguation

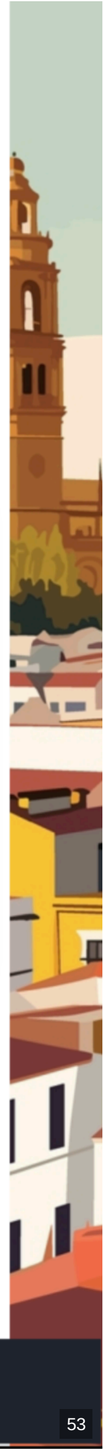
But, this language is not ambiguous. We have priorities and associativities. Let's disambiguate by using Rustemo declarative disambiguation so we can use LR instead of GLR.

```
E: left=E '+' right=E {Add}
 | left=E '*' right=E {Mul}
 | '(' E ')' {Paren}
 | Number {Num}
;

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```



Rustemo - declarative disambiguation

```
E: left=E '+' right=E {Add, 1, left}
 | left=E '*' right=E {Mul, 2, left}
 | '(' E ')' {Paren}
 | Number {Num}
;

terminals
Number: /\d+/;
Add: '+';
Mul: '*';
POpen: '(';
PClose: ')';
```

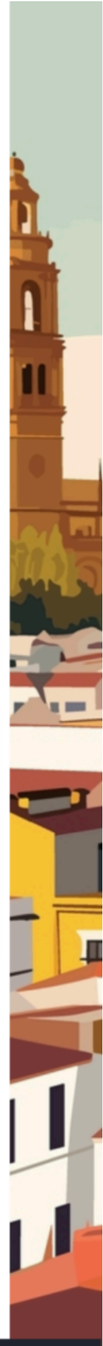


Regenerate the parser

Now, we can use LR.

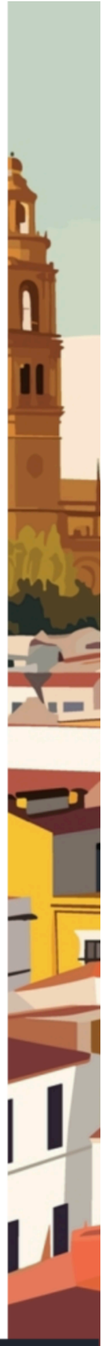
```
rcomp arithmetic.rustemo
```

```
Generating parser for grammar "arithmetic.rustemo"
Terminals: 6
Non-terminals: 1
Productions: 4
States: 10
Writing actions file "arithmetic_actions.rs"
Writing parser file "arithmetic.rs"
```



Fix `main.rs` for LR

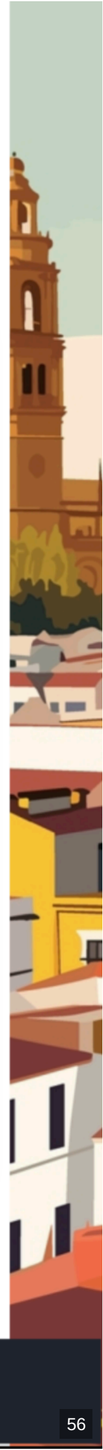
Now, we don’t get a forest from the LR parser but the result of the default builder evaluation.
Let’s fix that.



Fix `main.rs` for LR

We change `main.rs` from this:

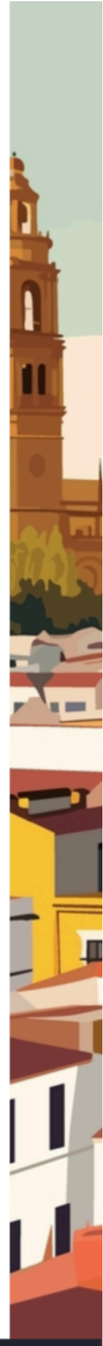
```rust
use rustemo::Parser;
use std::io;
// Use the generated parser and builder
use crate::arithmetic::{ArithmeticParser, DefaultBuilder};

// Include generated modules
#[rustfmt::skip]
mod arithmetic;
#[allow(unused)]
#[rustfmt::skip]
mod arithmetic_actions;

fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");

    // Parse the line and get all results.
    let forest = ArithmeticParser::new().parse(&expression).unwrap();

    println!("Number of interpretations = {}", forest.solutions());

    // Evaluate each tree from the forest
    let results = forest
        .into_iter()
        .map(|tree| {
            let mut builder = DefaultBuilder::new();
            tree.build(&mut builder)
        })
        .collect::<Vec<_>>();

    println!("{results:?}");
}
```



Fix `main.rs` for LR (step 10)

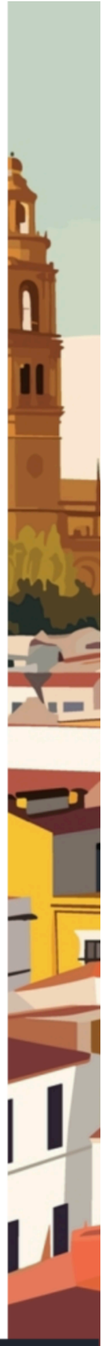
To this:

```rust
use rustemo::Parser;
use std::io;
// Use the generated parser
use crate::arithmetic::ArithmeticParser;

// Include generated modules
#[rustfmt::skip]
mod arithmetic;
#[allow(unused)]
#[rustfmt::skip]
mod arithmetic_actions;

fn main() {
    let mut expression = String::new();

    // Read the line from the input
    println!("Expression:");
    io::stdin()
        .read_line(&mut expression)
        .expect("Failed to read line.");

    // Parse the line and get the result.
    let result = ArithmeticParser::new().parse(&expression).unwrap();

    println!("Result = {result}");
}
```



Conclusion

- Learn more
  - Rustemo GitHub repo
  - The Rustemo Book
  - Rustemo integration/features tests
- Possible further directions
  - Grammars modularization, rule inheritance/macros etc.
  - Additional disambiguation filters (static & dynamic)
  - Error recovery
  - Incremental parsing
  - Tooling for working with Rustemo grammars (e.g. LSP server, plugins for popular editors).
- Rustemo is FLOSS and open for contributions!



Thanks!

Q&A

ZWQR

ProxyHands

LangDev CON 2024

Seville 17-19 October, 2024

https://langdevcon.org/