

# KLEENE\*

## User guide

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PEG-based parser combinator

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**KLEENE** is a parser combinator based on Parsing Expression Grammars (PEG), that places a particular focus on **accessibility**, **modularity**, **quality of error messages**, and **unit testing**. Parsers generated by **KLEENE** can be modified on the fly or extended with new rules, have built-in well-formatted error reporting, and are easy to test.

**KLEENE** is **not** focused on performance above all else, in part because PEGs interpreted by recursive descent are known to exhibit exponential-time worst-case parsing. If the parsing work you need is very time-sensitive, consider using a more specialized library or a non-native parser (consult [Section VII.1](#) for a few alternatives).

### Contributions

If you have ideas for improvements, or if you encounter a bug, you are encouraged to contribute to **KLEENE** by submitting a [bug report](#), [feature request](#), or [pull request](#). This includes submitting test cases.

### Versions

- [dev](#)
- [0.1.0 \(latest\)](#)

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# Part I

## Quick start

### I.1 Skeleton

At minimum, using `KLEENE` takes the following form:

```
#import "@preview/kleene:0.1.0"

#let grammar = {
    // kleene.prelude contains all the operators, which we usually
    // don't want to have polluting the global namespace.
    import kleene.prelude: *

    kleene.grammar(
        // define the rules here
        main: {
            ...
        },
        ...
    )
}

// If the grammar includes any unit tests, this will evaluate them.
#kleene.test(grammar)

// This is how to invoke the parser with <main> as the entry point.
#let (ok, ans) = kleene.parse(grammar, <main>, "...")
```

For example, here is a very simple grammar that will simply look for the string "foo":

```
#let grammar = kleene.grammar(
    // This defines a rule <main>
    main: {
        // Each `pat` gives one possible form of the match, here the
        // literal string "main"
        pat("foo")
    }
)

// In case of success, the result is a pair (true, value)
#let (ok, ans) = kleene.parse(grammar, <main>, "foo")
```

```
#assert(ok)
#ans

// In case of failure, the result is a pair (false, error-message)
#let (ok, ans) = kleene.parse(grammar, <main>, "bar")
#assert(not ok)
#ans
```

foo

**Parsing error:** The input does not match the expected format.  
 1 | bar  
 ^ Can't match string "foo"  
 While trying to parse: <main>.

## I.2 Simple examples

### I.2.1 Decimal integers

To start with an easy example, let's write a parser of integers in base 10. We take the opportunity to demonstrate the use of `#kleene.test` to run the inline unit tests declared by `#prelude.yy` and `#prelude.nn`, as well as `#prelude.rw` to transform the parsed result post-matching.

```
#let grammar = kleene.grammar(
  digit: {
    pat(`[0-9]`)
  },
  digits: {
    // Using the <label> notation you can recursively refer to other rules
    pat(iter(<digit>))
    // `rw`, standing for "rewrite" applies a post-parsing transformation
    // to the data. By default, `iter` produces an array.
    rw(ds => ds.join())
  },
  int: {
    pat(<digits>)
    rw(ds => int(ds))
    // The command `yy` adds positive examples
    yy(`42`, `4096`)
    // The command `nn` adds negative examples
    nn(`42b`, ``)
  },
)
```

int		examples
42		42
4096		4096
int		counterexamples
42b		<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <p>1   42b      ~  ^ Surplus characters        Valid &lt;int&gt;</p> <p>Hint: halted due to the following:</p> <p>1   42b      ^ Regex '[0-9]' does not match</p> <p>While trying to parse: &lt;int&gt; → &lt;digits&gt; → &lt;digit&gt;.</p>
∅		<p><b>Parsing error:</b> The input does not match the expected format.</p> <p>1   ∅      ^ Regex '[0-9]' does not match</p> <p>While trying to parse: &lt;int&gt; → &lt;digits&gt; → &lt;digit&gt;.</p>

## I.2.2 Integers

KLEENE can backtrack, and the backtracking points are indicated by the operator `#prelude.fork`. Several possible sub-patterns can be given, and they will be explored sequentially until a match. This lets you define a rule as the union of other rules. To illustrate this, we add hexadecimal numbers to our parser.

```
#let grammar = kleene.grammar(
  decdigit: pat(`[0-9]`),
  hexdigit: {
    // `fork` introduces a backtracking point
    pat(fork(`[a-f]`, `[A-F]`))
    // multiple `pat` invocations also implicitly induce a `fork`
    pat(<decdigit>)
  },
  decint: {
    pat(iter(<decdigit>))
    rw(ds => int(ds.join()))
  },
  hexint: {
    // If some part of the input is matched but not used,
    // such as here the prefix "0x", we indicate this with a `drop`
    // and it will be removed before the transformation is applied.
    pat(drop("0x"), iter(<hexdigit>))
    rw(ds => ds.flatten().join())
  },
  value: {
```

```

pat(<hexint>)
rw(i => (hex: i)) // a `rw` applies to all the `pat` that come before
pat(<decint>)
rw(i => (int: i))
yy(`^42`, `0xfae`)
},
value-bad: {
    // Note that the order of rules can be significant.
    // Here, a <hexint> has as prefix a <decint> (0),
    // so putting them in the wrong order will cause problems because
    // the parser will think it has a successful <decint> match and then
    // stop before the end.
    pat(fork(<decint>, <hexint>))
    nn(`0xfae`)
},
)

```

value		examples
42		(int: 42)
0xfae		(hex: "fae")

value-bad		counterexamples
0xfae		<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <pre> 1   0xfae ~ ^^^ Surplus characters   Valid &lt;value-bad&gt; Hint: halted due to the following: 1   0xfae ^ Regex '[0-9]' does not match While trying to parse: &lt;value-bad&gt; → &lt;decint&gt; → &lt;decdigit&gt;. </pre>

# Part II

## Operators

### II.1 Constants

#### II.1.1 EOF

`eof()` matches the end of the stream and returns `none`.

```
#let grammar = kleene.grammar(
  main: {
    pat.eof()
    yy(` `)
    nn(`x`)
  },
)
```

main		examples
∅	█	( )

main		counterexamples
x	█	<p>Parsing error: The input does not match the expected format. 1   x ^ Expected end of stream While trying to parse: &lt;main&gt;.</p>

#### II.1.2 Str

`str("...")` matches the literal string `"..."` and returns the match. Any `str` is implicitly cast to `str`.

```
#let grammar = kleene.grammar(
  main: {
    pat("foo")
    yy(`foo`)
    nn(`bar`)
  },
)
```

main		examples
foo	█	foo

main		counterexamples
bar	green	<p><b>Parsing error:</b> The input does not match the expected format.</p> <pre>1   bar     ^ Can't match string "foo"</pre> <p>While trying to parse: &lt;main&gt;.</p>

## II.1.3 Regex

`regex("...")`, with `"..."` the same string you would pass to the standard function `std.regex`, matches a regular expression. Any raw text (i.e., wrapped in `'...'``) is implicitly cast to regex.

```
#let grammar = kleene.grammar(
  main: {
    pat(`[a-zA-Z]+`)
    yy(`Word`)
    nn(`w0rd`)
  }
)
```

main		examples
Word	green	Word
main		counterexamples
w0rd	green	<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <pre>1   w0rd     ~ ^^ Surplus characters       Valid &lt;main&gt;</pre> <p>Hint: halted due to the following:</p> <pre>1   w0rd     ^ No longer part of the regex match '[a-zA-Z]+'</pre> <p>While trying to parse: &lt;main&gt;.</p>

## II.1.4 Label

`label("lab")` recursively matches the rule named `lab`, which must be defined in the same grammar. Any `label` is implicitly cast to label.

```
#let grammar = kleene.grammar(
  sub: pat("foo"),
  main: {
    pat(<sub>)
    yy(`foo`)
  }
)
```

```
},
)
```

main		examples
foo		foo

## II.2 Sequencing and branching

### II.2.1 Seq

`seq(pattern1, pattern2, ...)` matches the successive patterns `pattern1, pattern2, ...` one after the other. Any `array` is implicitly cast to a `seq`. Furthermore most other operators (`iter`, `star`, `maybe`, `drop`, `rewrite`, ...) are variadic and accept multiple arguments that are understood as a `seq`.

An **explicit** call to `seq` will always return an array, even if it has only one element. Implicit calls however, such as those induced by variadic `pat`, `iter`, ... may for convenience return a single element rather than a singleton array. In both cases the array returned by `seq` is pre-filtered to exclude elements that are `none` (either `eof()` matches, or those that were dropped as explained in [Section II.4](#)).

```
#let grammar = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => int(ds))
  },
  pair: {
    pat("(", <int>, ",", <int>, ")")
    yy(`(42,64)`)
    nn(`(42,`)
  },
)
```

pair		examples
(42,64)		("(", 42, ",", 64, ")")

pair		counterexamples
(42,		<b>Parsing error:</b> The input does not match the expected format. 1   (42, ^ Regex '[0-9]+' does not match While trying to parse: <pair> → <int>.

## II.2.2 Fork

`fork(pattern1, pattern2, ...)` is the standard dual of `seq`, returning the first of pattern, pattern2, ... that has a successful match.

fork always returns the **first match** in the order provided, rather than the longest match. As such fork does not commute.

fork is the only operator that may return objects of different types. It is recommended that you insert the appropriate `rw` calls to be able to identify the provenance of the result.

```
#let grammar = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    // The rewrites will help us identify the provenance of the match
    rw(ds => (int: int(ds)))
  },
  float: {
    pat(`[0-9]+`, ".", `[0-9]+`)
    rw(ds => (float: float(ds.flatten().join())))
  },
  number: {
    pat(fork(<float>, <int>))
    yy(`42`, `12.1`)
  },
  // Beware: when a rule is a valid prefix of another,
  // swapping them in the `fork` may lead to failures.
  number-bad: {
    pat(fork(<int>, <float>))
    nn(`12.1`)
  }
)
```

number		examples
42		(int: 42)
12.1		(float: 12.1)

number-bad		counterexamples
12.1		<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <pre>1   12.1 ~~ ^__ Surplus characters   Valid &lt;number-bad&gt; Hint: halted due to the following: 1   12.1 ^ No longer part of the regex match '[0-9]+'</pre> <p>While trying to parse: &lt;number-bad&gt; → &lt;int&gt;.</p>

## II.3 Repetitions

### II.3.1 Maybe

`maybe(pattern)` returns either a match of pattern or a unit `()`, i.e. 0 or 1 matches of another pattern. If `maybe` is given multiple parameters, they will be wrapped in a seq. It is equivalent to `?` in regular expressions.

In the case of a match, the result will be wrapped in a singleton array. This follows a design convention of `KLEENE` that a given operator should always return an object of the same type. It is further motivated by the observed usage of `maybe`, which is commonly to match one more optional element of an already repeating sequence: it is much easier to append to an array an optional element `elt` when it is presented as `(elt,)` or `()` than if it were as `elt` or `()`.

```
#let grammar = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => int(ds))
  },
  optional: {
    pat(maybe(<int>))
    yy(`42`, ``)
  }
)
```

optional		examples
42		(42,)
∅		()

### II.3.2 Iter

`iter(pattern)` matches one or more repetitions of pattern. If `iter` is given multiple parameters, they will be wrapped in a seq. It is equivalent to `+` in regular expressions.

The result of an `iter` is always an array, even if there is only one match.

```
#let grammar = kleene.grammar(
    digit: pat(`[0-9]`),
    int: {
        pat(iter(<digit>))
        rw(ds => int(ds.join()))
        yy(`^`420`)
        nn(``)
    }
)
```

int		examples
420		420

int		counterexamples
∅		<p><b>Parsing error:</b> The input does not match the expected format.            1   ∅            ^ Regex '[0-9]' does not match            While trying to parse: &lt;int&gt; → &lt;digit&gt;.</p>

`iter` is sophisticated enough to not get trapped in an infinite loop if you give a pattern that risks consuming no input. In that case it will stop after one iteration.

```
#let grammar = kleene.grammar(
    emp: {
        pat("[", star(""), "]")
        yy(`[]`)
    },
)
```

emp		examples
[]		("[", (""), "]")

### II.3.3 Star

`star(pattern)` matches arbitrarily many repetitions of pattern, including 0. If `star` is given multiple parameters, they will be wrapped in a `seq`. It is equivalent to `*` in regular expressions.

The result of a `star` is always an array, even if there is only one match.

```
#let grammar = kleene.grammar(
    whitespace: {
        pat(iterator(fork(" ", "\n", "\t")))
        rw(none)
    },
    comment: {
        pat("//", star(`[^`n]`), "\n")
        pat("/*", star(`[^*]`), "*/")
        rw(none)
    },
    irrelevant: {
        pat(star(fork(<whitespace>, <comment>)))
        rw(none)
        yy(```

        // a comment

        //
        /* another */

        ```)
    }
)
```

irrelevant		examples
<pre>uuu u// a comment u u//  uuu/* another */uu u uu</pre>		

## II.4 Ghost operators

These operators do not consume text or produce outputs, but they can manipulate how the parser behaves, transform data, and sometimes improve error messages.

### II.4.1 Drop

`drop(pattern)` matches pattern but does not include its outcome in the result. It can be useful to have less tuple unpacking in `rw`. If `drop` receives multiple patterns it will implicitly wrap them in a `seq`.

```
#let grammar = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => int(ds))
  },
  tuple: {
    pat(drop("()"), star(<int>, drop(", ")), maybe(<int>), drop("")))
    rw(l => l.flatten())
    yy(`()``, `(1,)``, `(1,2,3)``, `(1,2,3,)``)
  },
)
```

tuple		examples
( )		( )
(1, )		(1, )
(1,2,3)		(1, 2, 3)
(1,2,3,)		(1, 2, 3)

## II.4.2 Rewrite

`rewrite(fun)(pattern)` matches pattern then applies the transformation `fun`. This can also be achieved with a `rw`, but `rewrite` is inlined. If multiple patterns are provided, they are implicitly wrapped in a `seq`.

```
#let grammar = kleene.grammar(
  int: {
    pat(rewrite(ds => (int: int(ds))))(`[0-9]+`)
    yy(`42`)
  },
)
```

int		examples
42		(int: 42)

## II.4.3 Commit

`commit()`, also written `$$`, blocks backtracking. This can be very useful to improve both the performance of the parser and the quality of error messages.

Without `commit`, a grammar could look like this:

```
#let grammar = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => (int: int(ds)))
  },
  hex: {
    pat(drop("0x"), ` [0-9A-Fa-f]+`)
    rw(ds => (hex: ds))
  },
  val: {
    pat(fork(<hex>, <int>))
    yy(`42`, `0xFF`)
    nn(`0xZ`)
  },
)
```

val		examples
42		(int: 42)
0xFF		(hex: "FF")

val		counterexamples
0xZ		<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <p>1   0xZ    ~  ^ Surplus characters      Valid &lt;val&gt;</p> <p>Hint: halted due to the following:</p> <p>1   0xZ    ^ No longer part of the regex match '[0-9]+'</p> <p>While trying to parse: &lt;val&gt; → &lt;int&gt;.</p>

First we try to parse a `<hex>`, but this fails due to "z" so the `fork` goes to the second branch where we try to parse an `<int>`. This also fails, but for a different reason. The error message of `fork` takes the last failure, i.e. the one where we fail to parse an `<int>`.

Consider instead an alternative that uses a commit point to block the backtracking once we've read the hexadecimal prefix "0x":

```
#let grammar = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => (int: int(ds)))
  },
  hex: {
    // Once we see "0x", we know it's supposed to be a hexadecimal number.
    pat(drop("0x"), $$, ` [0-9A-Fa-f]+`)
  },
)
```

```

    rw(ds => (hex: ds))
},
val: {
  pat(fork(<hex>, <int>))
  yy(`^42`, `0xFF`)
  nn(`0xZ`)
},
)

```

val		examples
42		(int: 42)
0xFF		(hex: "FF")

val		counterexamples
0xZ		<p><b>Parsing error:</b> The input does not match the expected format.  <code>1   0xZ</code>  <code>^ Regex '[0-9A-Fa-f]+' does not match</code>  While trying to parse: &lt;val&gt; → &lt;hex&gt;.</p>

The new error message much more accurately pinpoints the issue.

#### II.4.4 Try

`try(pattern)` is the inverse of `commit()`, restoring the ability to backtrack.

### II.5 Lookaheads

Lookaheads perform a match, but do not actually consume the input stream. This is only useful when the lookahead is followed by a pattern that actually does consume input, and the lookahead only serves as a guard.

As usual, lookaheads come with advantages and drawbacks depending on if you use them correctly. They might improve your error messages and reduce the amount of backtracking required,... or they might lead to worst-case exponential-time parsing.

#### II.5.1 Peek

`peek(pat)` introduces a positive lookahead: it will try to match `pat`, but even if it succeeds it will not consume any input. If multiple patterns are provided, they are implicitly cast to a `#prelude.seq`. For example here is an example where a lookahead determines if we parse a string as a key or as a value:

```

#let grammar = kleene.grammar(
  string: pat(drop("\\"), `[^"]*`, drop("\\")),

```

```

ident: pat(`[a-zA-Z][a-zA-Z0-9]*`),
named-arg: {
    pat(fork(<string>, <ident>), drop(` *: *`), <string>)
    rw((k,v), => (key: k, val: v))
    yy(`foo: "foo"`)
    yy(`"bar": "bar"`)
},
pos-arg: {
    pat(<string>)
    rw(v => (val: v))
    yy(`"baz"`)
},
arg: {
    // Read as: once we know that there is a ":" ahead,
    // we commit to parsing a <named-arg> without possibility
    // of backtracking anymore.
    pat(peek(`[^:]*:`), $$, <named-arg>)
    pat(<pos-arg>)
    yy(`foo: "foo"`, `"bar": "bar"`, `"baz"`)
    nn(`"foo":`, `foo:`)
},
arg-worse: {
    // Contrast the quality of the error message above
    // compared to if we omit the lookahead:
    pat(<named-arg>)
    pat(<pos-arg>)
    nn(`"foo":`, `foo:`)
},
)

```

named-arg		examples
foo: "foo"		(key: "foo", val: "foo")
"bar": "bar"		(key: "bar", val: "bar")

pos-arg		examples
"baz"		(val: "baz")

arg		examples
foo: "foo"		(key: "foo", val: "foo")
"bar": "bar"		(key: "bar", val: "bar")
"baz"		(val: "baz")

arg		counterexamples
"foo":	█	<p><b>Parsing error:</b> The input does not match the expected format.</p> <pre>1   "foo":       ^ Can't match string "n"</pre> <p>While trying to parse: &lt;arg&gt; → &lt;named-arg&gt; → &lt;string&gt;.</p>
foo:	█	<p><b>Parsing error:</b> The input does not match the expected format.</p> <pre>1   foo:       ^ Can't match string "n"</pre> <p>While trying to parse: &lt;arg&gt; → &lt;named-arg&gt; → &lt;string&gt;.</p>
arg-worse		counterexamples
"foo":	█	<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <pre>1   "foo":       ~~~~~  ^ Surplus characters                 Valid &lt;arg-worse&gt;</pre> <p>Hint: halted due to the following:</p> <pre>1   "foo":       ^ No longer part of the regex match '[^"]*' </pre> <p>While trying to parse: &lt;arg-worse&gt; → &lt;pos-arg&gt; → &lt;string&gt;.</p>
foo:	█	<p><b>Parsing error:</b> The input does not match the expected format.</p> <pre>1   foo:       ^ Can't match string "n"</pre> <p>While trying to parse: &lt;arg-worse&gt; → &lt;pos-arg&gt; → &lt;string&gt;.</p>

## II.5.2 Neg

Symmetrically `neg(pat)` will perform a negative lookahead, succeeding without consuming input when the inner pattern fails. If multiple patterns are provided, they are implicitly cast to a `#prelude.seq`.

```
#let grammar = kleene.grammar(
  int: {
    pat(neg("0x"), `'[0-9]`, $$, `'[0-9]*`)
    rw(ds => (int: int(ds.flatten().join())))
  },
  hex: {
    pat(drop("0x"), `'[0-9a-fA-F]+`)
    rw(hex => (hex: hex))
  },
  val: {
    pat(fork(<int>, <hex>))
    yy(`'42`, `'0`, `'0x31`)
    nn(`'0b1`)
  }
)
```

val		examples
42		(int: 42)
0		(int: 0)
0x31		(hex: "31")

  

val		counterexamples
0b1		<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <pre>1   0b1 ~ ^^ Surplus characters   Valid &lt;val&gt;</pre> <p>Hint: halted due to the following:</p> <pre>1   0b1 ^ No longer part of the regex match '[0-9]*'</pre> <p>While trying to parse: &lt;val&gt; → &lt;int&gt;.</p>

# Part III

## Unit tests

Many have already been included in previous examples, but to reiterate:

- `yy(input1, input2, ...)` declares as many **positive** unit tests as there are inputs, i.e. they should succeed.
- `nn(input1, input2, ...)` declares as many **negative** unit tests as there are inputs, i.e. they should fail.

### III.1 Post-parsing validation

In addition to checking that positive tests parse and negative tests do not, you may specify an additional validate parameter in the form of a function that will receive the input of the test and the parsed output. This function should return `none` if the result is valid, and anything else will cause the test to fail.

```
#let grammar = kleene.grammar(
    int: {
        pat(`[0-9]+`)
        rw(ds => (int: int(ds)))
    },
    hex: {
        pat(drop("0x"), `[0-9A-Fa-f]+`)
        rw(ds => (hex: ds))
    },
    val: {
        pat(fork(<hex>, <int>))
        yy(`0`)
        yy(`42`, `0xFF`, `0xZ`,
            validate: (_ ,ans) => if "int" not in ans [Integer expected])
    },
)
#kleene.test(grammar)
```

val		examples
0		(int: 0)
42		(int: 42)
0xFF	 	(hex: "FF") Validation failed: Integer expected

val		examples
0xZ		<p><b>Parsing error:</b> The parser did not consume the entire input.</p> <pre>1   0xZ ~ ^^ Surplus characters   Valid &lt;val&gt;</pre> <p>Hint: halted due to the following:</p> <pre>1   0xZ ^ No longer part of the regex match '[0-9]+'</pre> <p>While trying to parse: &lt;val&gt; → &lt;int&gt;.</p>
parsing		
4	3	1
validation		
3	1	1

A tally of all test outcomes is added to the bottom, showing from left to right

- the total number of tests
- positive tests that parse and negative tests that fail,
- positive tests that fail and negative tests that parse,
- number of tests that have a validate parameter, and of those:
  - how many passed validation,
  - how many were skipped due to an incorrect result in the parsing stage,
  - and how many failed validation,

# Part IV

## Modularity

The first way in which `KLEENE` is modular is that you can access any intermediate rules.

```
#let grammar = kleene.grammar(
    int: {
        pat(`[0-9]+`)
        rw(ds => (int: int(ds)))
    },
    hex: {
        pat(drop("0x"), ` [0-9A-Fa-f]+`)
        rw(ds => (hex: ds))
    },
    val: {
        pat(fork(<hex>, <int>))
    },
)

#kleene.parse(grammar, <int>, "42")

#kleene.parse(grammar, <hex>, "0xDEAD")
```

```
(true, (int: 42))
(true, (hex: "DEAD"))
```

This alone is not the focus of this section, however.

### IV.1 Extend

`kleene.extend(grammar1, grammar2)` produces a new grammar that has the combined rules of `grammar1` and `grammar2`, in the following manner:

- rules that exist in `grammar1` but not `grammar2` are left unchanged,
- so are rules that exist in `grammar2` but not `grammar1`,
- rules that exist in both are concatenated in a way that gives `grammar1` precedence,
- unit test sets are merged.

```
#let grammar1 = kleene.grammar(
    hex: {
        pat(drop("0x"), $$, ` [0-9A-Fa-f]+`)
        rw(ds => (hex: ds))
        yy(`0x42`)
    },
    val: {
```

```

    pat(<hex>)
    yy(`0x42`)
}
)

#let grammar2 = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => (int: int(ds)))
    yy(`42`)
  },
  val: {
    pat(<int>)
    yy(`42`)
  }
)

#let grammar = kleene.extend(grammar1, grammar2)

```

Extending a grammar in this way can cause negative tests to fail. You can use `kleene.strip(grammar, yy: false)` to remove only negative unit tests from the extended grammar, or `kleene.strip(grammar)` to remove all unit tests.

## IV.2 Patch

This operation is similar to `kleene.extend`, but rather than adding to the existing rules, `kleene.patch(grammar1, grammar2)` will keep only `grammar2`'s version of rules that exist in both. This includes removing all unit tests from the rules of `grammar1` that are also declared in `grammar2`.

The example below shows an application, where we have a grammar that parses lists of integers, and we patch it into a grammar that parses lists of booleans.

```

#let grammar1 = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => int(ds))
    yy(`42`)
  },
  comma: pat(drop(`*, *`)),
  elem: pat(<int>),
  list: {
    pat(drop("[", star(<elem>, <comma>), maybe(<elem>), drop("]")))
    rw(elts => elts.flatten())
    yy(`[], `[1], `[1,]`, `[1, 2, 3, 4]`)
  }
)

```

```
#let grammar2 = kleene.grammar(
  // <bool> is a new rule (be careful of accidental collisions)
  bool: {
    pat(fork("true", "false"))
    rw(e => ("true": true, "false": false).at(e))
    yy(`true`, `false`)
  },
  // <elem> will replace the original one
  elem: pat(<bool>),
  // We re-specify <list> but without a `pat`,
  // just to replace its unit tests that wouldn't work anymore.
  list: {
    yy(`[true, false, false]`)
  }
)

// In addition, `trim` removes rules that become unreachable.
#let grammar = kleene.trim(roots: <list>, kleene.patch(grammar1, grammar2))
```

bool		examples
true		true
false		false

list		examples
[true, false, false]		(true, false, false)

## IV.3 Freshening

To avoid collisions during `#kleene.extend` and `#kleene.patch`, you can use the `#kleene.freshen` operation.

```
#let grammar1 = kleene.grammar(
  int: {
    pat(`[0-9]+`)
    rw(ds => int(ds))
    yy(`42`)
  },
  comma: pat(drop(`*, *`)),
  elem: pat(<int>),
  list: {
    pat(drop("["), star(<elem>, <comma>), maybe(<elem>), drop("]"))
    rw(elts => elts.flatten())
    yy(`[]`, `[1]`, `[1,]`, `[1, 2, 3, 4]`)
  }
}
```

```

)
#let grammar2 = kleene.trim(roots: <list>, kleene.patch(grammar1,
kleene.grammar(
  // <bool> is a new rule (be careful of accidental collisions)
  bool: {
    pat(fork("true", "false"))
    rw(e => ("true": true, "false": false).at(e))
    yy(`true`, `false`)
  },
  // <elem> will replace the original one
  elem: pat(<bool>),
  // We re-specify <list> but without a `pat`,
  // just to replace its unit tests that wouldn't work anymore.
  list: {
    yy(`[true, false, false]`)
  }
)))
#let grammar = kleene.extend(
  kleene.freshen(grammar1, prefix: "int-", exclude: <int>),
  kleene.freshen(grammar2, prefix: "bool-", exclude: <bool>),
)

```

int		examples
42		42

int-list		examples
[]		()
[1]		(1,)
[1,]		(1,)
[1, 2, 3, 4]		(1, 2, 3, 4)

bool		examples
true		true
false		false

bool-list		examples
[true, false, false]		(true, false, false)

# Part V

## Advanced techniques

### V.1 Operator precedence

As is standard in PEGs, there is no notion of operator precedence. This can make it more challenging to parse e.g. arithmetic expressions, but there are standard tricks to escape this limitation. The usual way of having a form of precedence is simply to have multiple levels of expressions, as below:

```
#let grammar = kleene.grammar(
    whitespace: {
        pat(maybe(iterator(" ")))
        rw(None)
    },
    int: {
        pat(iterator(`[0-9]`))
        rw(ds => int(ds.join()))
    },
    atom: {
        pat(<int>)
        rw(i => i)
        pat(drop(`(`), <expr>, drop(`)`))
        rw((e,) => e)
        yy(`11`)
    },
    mul-expr: {
        pat(<atom>, iterator(<whitespace>, fork("*", "/"), <whitespace>, <atom>))
        rw(elts => (mul: elts.flatten()))
        pat(<atom>)
        rw(auto)
        yy(`42`, `11 * 12 * 4`)
    },
    add-expr: {
        pat(<mul-expr>, iterator(<whitespace>, fork("+", "-"), <whitespace>, <mul-expr>))
        rw(elts => (add: elts.flatten()))
        pat(<mul-expr>)
        rw(auto)
        yy(`1 + 1 * 2 - 1`)
    },
    expr: {
        pat(<add-expr>)
        yy(`1 + (1 + 1) * 2`)
    },
)
```

atom		examples
11		11

  

mul-expr		examples
42		42
11 * 12 * 4		(mul: (11, "*", 12, "*", 4))

  

add-expr		examples
1 + 1 * 2 - 1		(add: (1, "+", (mul: (1, "*", 2)), "-", 1))

  

expr		examples
1 + (1 + 1) * 2		(add: (1, "+", (mul: ((add: (1, "+", 1)), "*", 2))))

As a related limitation, PEG grammars are not suited to left-recursive rules (when the rule appears immediately at the left of itself without consuming any input). Prioritize using iteration instead.

# Part VI

## Public API

### VI.1 Toplevel definitions

Unless explicitly marked `private`, the functions in this module are available directly as `kleene.function(...)`.

#### VI.1.1 Parsing

```
#kleene.auto-cast          #kleene.parse
```

Private

`#kleene.auto-cast({pat}) → pattern`

Automatically reinterprets builtin types/values to operators.

— Argument —

`(pat)`

any

Pattern to interpret.

- `function` : native
- `str` : cast through `#prelude.str`
- `label` : cast through `#prelude.label`
- `array` : cast through `#prelude.seq`
- `$$` : shorthand for `#prelude.commit`
- `#raw` : cast through `#prelude.regex`

`#kleene.parse(({rules}, {pat}, {input}) → (bool, result))`

Initiate parsing. Returns a boolean and a result. The boolean indicates if the parsing is successful. It also determines the type of the result:

- whatever type is returned by the last rewriting function in the case of a success,
- content that can be directly displayed for an error message in the case of a failure.

— Argument —

`{rules}`

grammar

Typically constructed by `#kleene.grammar`.

— Argument —

`(pat)`

label

Indicates the entry point for the parsing.

— Argument —

`(input)`

str

Input data to parse.

## VI.1.2 Grammar builders

#kleene.extend	#kleene.grammar	#kleene.strip
#kleene.freshen	#kleene.patch	

**#kleene.extend({base}, ..(ext)) → grammar**

Edits a grammar by adding new rules and new cases to existing rules.

See: [Section IV.1](#).

Argument —

{base}

grammar

Base grammar, takes precedence on rules that are defined by both.

Argument —

..(ext)

grammar

New rules and cases.

**#kleene.freshen({grammar}, {prefix}: "\_", {exclude}: ()) → grammar**

Adds a prefix to some rules of a grammar. Useful before #kleene.patch or #kleene.extend to avoid collisions.

Argument —

{grammar}

grammar

Base grammar.

Argument —

{prefix}: "\_"

str

This prefix will be added to all rules.

Argument —

{exclude}: ()

label | array | function

Rules that match this selector will not receive the prefix. What this means depends on the type of exclude:

- `label` : the exact rule specified,
- `function` : rules whose label returns `true` via this function,
- `array` : union of all the individual interpretations.

**#kleene.grammar(..{rules}) → grammar**

Constructs a new grammar from its rules.

Argument —

..(rules)

rule

List of named rules, as constructed by #prelude.pat and its related functions.

## #kleene.patch({base}, ..(ext)) → grammar

Edits a grammar by substituting old rules for new ones.

See: [Section IV.2](#).

— Argument —

{base}

grammar

Base grammar.

— Argument —

..(ext)

grammar

Patch, replaces rules already defined by base.

## #kleene.strip({base}, {yy}: true, {nn}: true) → grammar

Removes unit tests from a grammar. Particularly useful when patching a grammar to remove those that would no longer pass.

— Argument —

{base}

grammar

Base grammar.

— Argument —

{yy}: true

bool

Whether to remove positive tests.

— Argument —

{nn}: true

bool

Whether to remove negative tests.

**VI.1.3 Running tests**

#kleene.show-invisible      #kleene.test

Private

## #kleene.show-invisible({line}, {preserve-linebreaks}: false, {dim-color}: black.lighten(70%), {mode}: "special") → content

Transforms a string to show invisible characters (spaces, linebreaks, tabs). Returns the resulting text as a #raw block.

— Argument —

{line}

str

Input text to transform.

— Argument —

{preserve-linebreaks}: false

bool

By default, linebreaks ("\\n") are replaced by a substitute character. If this option is enabled, the formatted text will still have the original linebreaks in addition to the marker.

Argument –

`(dim-color): black.lighten(70%)`

color

Which color the special characters should be shown as.

Argument –

`(mode): "special"`

str

Determines the substitution dictionary to use.

- "special": \\n and \\t.
- "unicode": \\, \\>, \\\_\\, \\ø denote respectively linebreak, tab, space, eof.

`#kleene.test({grammar}, {select}: auto, {total}: true) → content`

Runs the unit tests attached to a grammar. See `#prelude.yy` and `#prelude.nn` for details. Runs all positive and negative tests, and formats them in a table.

Argument –

`(grammar)`

grammar

The grammar to test, as constructed by `#kleene.grammar`.

Argument –

`(select): auto`

auto | array | function

Pass an array or a function to filter a subset of the tests.

Argument –

`(total): true`

bool

Whether to display the final tally of passed/failed tests.

## VI.2 Pattern combinators

<code>#prelude.commit</code>	<code>#prelude.label</code>	<code>#prelude.rewrite</code>
<code>#prelude.drop</code>	<code>#prelude.maybe</code>	<code>#prelude.seq</code>
<code>#prelude.eof</code>	<code>#prelude.neg</code>	<code>#prelude.star</code>
<code>#prelude.fork</code>	<code>#prelude.peek</code>	<code>#prelude.str</code>
<code>#prelude.iter</code>	<code>#prelude.regex</code>	<code>#prelude.try</code>

`#prelude.commit → pattern`

Inserts a non-backtracking point. Returns `#none`.

See: [Section II.4.3](#).

`#prelude.drop(..{pats}) → pattern`

Matches an arbitrary pattern, but returns `#none`.

See: [Section II.4.1.](#)

— Argument —

`..(pats)`

`pattern`

Implicitly cast to a `#prelude.seq`.

#### `#prelude.eof` → `pattern`

Matches the end of the stream. Returns `#none`.

See: [Section II.1.1.](#)

#### `#prelude.fork(..(pats))` → `pattern`

Branching choice between multiple possible subpatterns. Returns the first match.

See: [Section II.2.2.](#)

— Argument —

`..(pats)`

`pattern`

List of ordered patterns between which a choice is made.

#### `#prelude.iter(..(pats))` → `pattern`

Matches 1 or more instances of the inner pattern. Returns an `array`.

See: [Section II.3.2.](#)

— Argument —

`..(pats)`

`pattern`

List of patterns, implicitly cast to a `#prelude.seq`.

#### `#prelude.label((lab))` → `pattern`

Recursively invokes another rule.

See: [Section II.1.4.](#)

— Argument —

`(lab)`

`str`

Label of a rule defined elsewhere in the grammar.

#### `#prelude.maybe(..(pats))` → `pattern`

Matches 0 or 1 instances of the inner pattern. Returns an `array`, either empty or singleton.

See: [Section II.3.1.](#)

— Argument —

`..(pats)`

`pattern`

Implicitly cast to a `#prelude.seq`.

### `#prelude.neg(..{pats}) → pattern`

Negative lookahead: checks that a pattern does not match. Returns `#none` and does not consume the input.

See: [Section II.5.2](#)

Argument —

`..{pats}`

`pattern`

Inner patterns that should not match. Auto-cast to a `#prelude.seq`.

### `#prelude.peek(..{pats}) → pattern`

Positive lookahead: matches a pattern without consuming the input. Returns `#none`.

See: [Section II.5.1](#).

Argument —

`..{pats}`

`pattern`

Inner patterns that should match. Auto-cast to a `#prelude.seq`.

### `#prelude.regex({re})`

Uses a regular expression to more efficiently match a string. Returns `str`.

See: [Section II.1.3](#).

Argument —

`{re}`

`str`

String representing a regular expression using the syntax of the `standard library`

### `#prelude.rewrite({fun}) → function(..pattern) => pattern`

Curried so that common rewriting patterns can be conveniently written as stand-alone functions. The type of the return value is that of the function. If multiple patterns are given, they are implicitly cast to a `#prelude.seq`.

See: [Section II.4.2](#).

Argument —

`{fun}`

`none` | `auto` | `function`

Pattern to rewrite with.

- `#none`: the value is dropped,
- `#auto`: identity transformation,
- `function` : applies the given function.

### `#prelude.seq(..{pats}), {array}: true → pattern`

Matches a sequence of patterns in order. Returns an `array`, except for possible optimizations where an implicit invocation matches only one element.

See: [Section II.2.1](#).

Argument  
`..(pats)` `array(pattern)`  
 Patterns that need to be matched in order.

Argument  
`{array}: true` `bool`  
 If true, forces the result to be an array even if it is of size 1.

### `#prelude.star(..(pats)) → pattern`

Matches 0 or more instances of the inner pattern. Returns an `array`.

See: [Section II.3.3](#).

Argument  
`..(pats)` `pattern`  
 List of patterns, implicitly cast to a `#prelude.seq`.

### `#prelude.str({string}) → pattern`

Matches a string literal. Returns a `str`.

See: [Section II.1.2](#).

Argument  
`{string}` `str`  
 Any string to match as-is.

### `#prelude.try(..(pats))`

Cancels out a `#prelude.commit` to re-enable backtracking. Returns the inner match.

See: [Section II.4.4](#)

Argument  
`..(pats)` `pattern`  
 Implicitly cast to a `#prelude.seq`.

## VI.3 Rule definition

<code>#prelude.nn</code>	<code>#prelude.rw</code>
<code>#prelude.pat</code>	<code>#prelude.yy</code>

### `#prelude.nn(..(tests), {validate}: auto) → rule`

Declares one or more negative unit tests. They must produce a parsing error and pass validation. See [Section III](#) for details.

Argument —

`..{tests}`

raw

Inputs passed to the parser.

Argument —

`{validate}: auto`

function | auto

Additional checks to run on the output. If a function, it will be given two arguments: the input and the error message.

#### `#prelude.pat(..{pats}) → rule`

Adds one case to the rule. Multiple invocations are globally taken as a `#prelude.fork`.

Argument —

`..{pats}`

pattern

Pattern that the rule matches. If there are multiple, they are cast to a `#prelude.seq`.

#### `#prelude.rw({fun}) → rule`

Adds a rewrite to all preceding `#prelude.pat` that do not already have one. See [Section II.4.2](#) for more information.

Argument —

`{fun}`

function | auto | none

Rewriting a function. Uses the same convention as [Section II.4.2](#), where `#auto` is the identity (also the default), and `#none` removes the matched value entirely.

#### `#prelude.yy(..{tests}, {validate}: auto) → rule`

Declares one or more positive unit tests. They must parse correctly and pass validation. See [Section III](#) for details.

Argument —

`..{tests}`

raw

Inputs passed to the parser.

Argument —

`{validate}: auto`

function | auto

Additional checks to run on the output. If a function, it will be given two arguments: the input and the parsed output.

# Part VII

## About

### VII.1 Alternatives

- [JIEXI](#) was recently released, employing a completely different approach compared to [KLEENE](#) in both implementation and philosophy: [JIEXI](#) is based on shift-reduce automata and uses an external tool via WASM. This will result in a completely different tradeoff in terms of performance, quality of error messages, customizability, etc.
- [KLEENE](#) is general-purpose, but if the language you want to read already has a dedicated parser you will likely get much better results with a specialized tool, of which [many already exist](#).
- Writing a [plugin](#) is not strictly speaking a native solution, but if you're willing to write the parser in Rust you will be able to import it into Typst.

### VII.2 Dependencies

[KLEENE](#) itself has no dependencies.

This manual is built using [MANTYS](#) and [TIDY](#).