Syntactic Analysis with Menhir

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Agenda

- Examples of hand-coded parsers
- Brief tutorial on menhir

References

- Menhir homepage
- Menhir reference manual
- Parsing with OCamllex and Menhir

Syntactic analysis 1 (parsing)

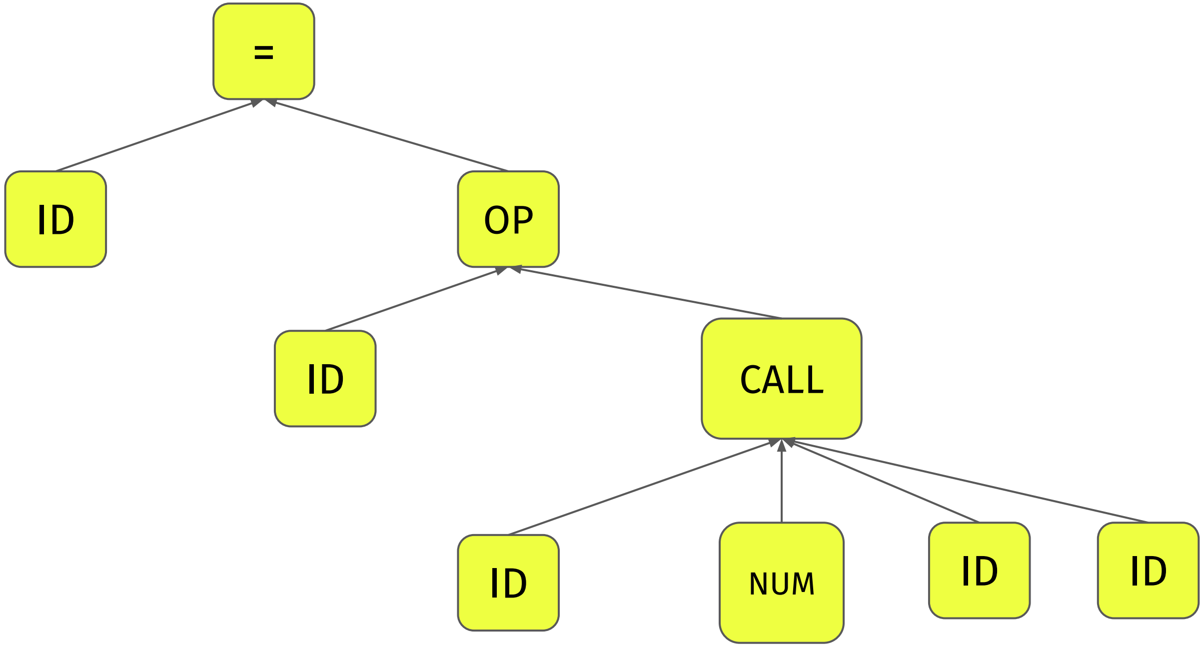
Translate a stream of tokens to a intermediate representation

```
result _ =_ i_*_bar (0, _42, _q);
```

ID	EQ	ID	TIMES	ID	LPAREN	INT	COMMA
INT	COMMA	ID	RPAREN	SEMICOL			

Syntactic analysis 2 (parsing)

Translate a stream of tokens to a intermediate representation



Symbol	Info
result	local, INT
i	local, INT
bar	global, FUNC
q	local, INT

Syntactic analysis (parsing)

Goals:

- Verify that program are well written
- Build a structured representation of the code (AST) that can easily manipulated from the rest of the compiler

Describing syntax:

- Syntax rules are usually specified by context-free grammars

Implementing parsers

Two approaches:

- Use parser generators, e.g., bison, flex, etc.

  They take as input a description of grammar (LR(1), LALR(1)) and code to run when a sentence is recognised

- Hand-coded parsers

  You need to implement all the details for recognize a sentence according to a rule of the grammar

Hand-coded parsers

Typically, they are top-down recursive recognizer that consist of

- An handle to the lexer to obtain the next token
- A function for each non-terminal symbol implementing the right-handside of the rule and the actions to build the intermediate representation
- A parsing function is usually a big switch on the current token (or some lookahead tokens)

Hand-coded parsers: examples

Toy compilers:

- Lox language from the book Crafting Interpreters

  See Parser.java

- Subset of Pascal language from the book Writing Compilers and Interpreters

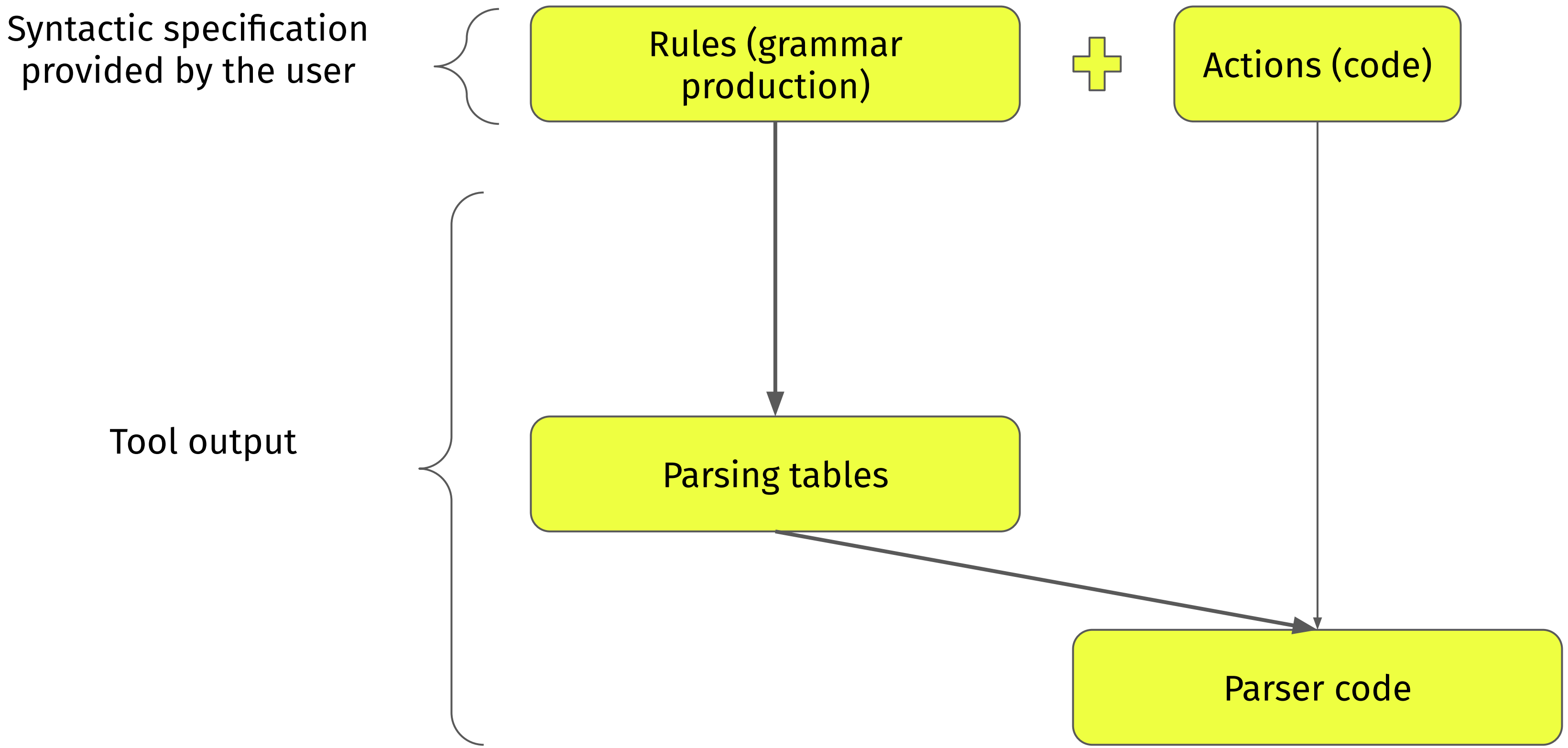
  See code of Chapter 5 package Frontend

Hand-coded parsers: examples

Real world compilers:

- Golang, see parser.go
- Rust, see librustc_parse/lib.rs
- Python (CPython implementation), see Parser/parser.c
- Clang, see Parser/Parser.h and Parser/Parser.cpp
- Many others, e.g., Solidity, V8, Scala, ...

Implementing Parser Automatically

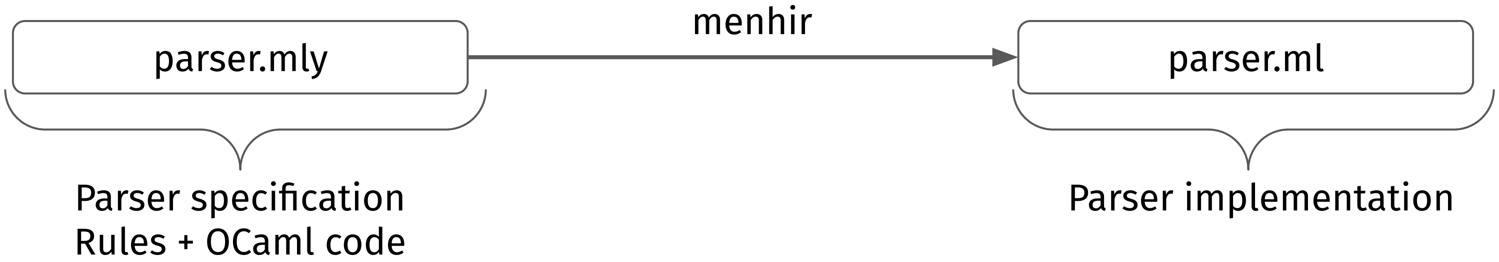


Generated scanners: examples

Real world compilers:

- OCaml, see parsing/parser.mly
- Haskell, see GHC/Parser.y
- FSharp, see fsharp/pars.fsy

Constructing Parsers with menhir



- You need to install it via
  $ opam install menhir
- The generated file is compiled and linked with the application
  $ ocamlbuild -use-menhir app.byte
- The parser is available through a specific function representing the start symbol of the grammar taking in input a function for scanning

Menhir grammar specification

```
%{
    Header              (* Ocaml code copied in the generated file: optional; *)
%}

    Declarations        (* Tokens, start symbol, associativity: mandatory *)

%%

    Grammar rules       (* grammar production + code *)

%%

    Trailer             (* Ocaml code copied in the generated file: optional; *)
```

Token declaration

Tokens are the terminal symbols and we need to declare them

A token declaration takes the form

%token [<OCaml type t>] uid [qid]

And defines the identifier uid as terminal symbol in the grammar specification and as data constructors of the token type

If an OCaml type t is present, then uid carries a semantic value of type t

If a quoted identifier qid is present, then it can work as an alias for the terminal symbol uid throughout the grammar specification

Start symbol declaration

A declaration of the form

%start [<OCaml type t>] lid

declares the non-terminal symbol lid to be the start symbol

The name lid becomes the name of a function that can be used to invoke the parser

The type specifies what the parser returns

Type declaration

A declaration of the form

%type <OCaml type t> lid

specifies the non-terminal symbol lid has type t

It is mandatory to specify a type for the start symbol, optional for other non-terminals

Priority and associativity declaration

A declaration of the form

%noassoc uid

%left uid

%right uid

specifies a priority level and an associativity to the symbols uid

The priority is assigned implicitly following the order of declaration (from lower to higher priority)

uid can be a token or a dummy symbol used to associate a priority to a rule (see later)

Rule syntax (1)

The syntax for rules is

```
nonterminal :
   id1=symbol ... idn=symbol   [%prec symbol]  { semantic-action: ocaml code }
 | ...
;
```

Where

- symbol is a terminal or non-terminal
- idi are names used to access the semantic value in the ocaml code (it is also possible use the yacc notation with $i to access the value of the i-symbol)

Rule syntax (2)

The syntax for rules is

nonterminal :
  id1=symbol … idn=symbol [%prec symbol] { semantic-action: ocaml code }
 | …
;

Where

- %prec directive override the default precedence and associativity of the rule with the precedence and associativity of the given symbol
- The precedence level assigned to each production is the level assigned to the rightmost terminal symbol that appears in it

A first example

The idea:

a small calculator that reads arithmetic expressions from the standard input, evaluates them and outputs their values on the standard output

Three files:

1. lexer.mll: a ocamllex lexer that tokenizes the input
2. parser.mly: the menhir parser
3. calc.ml: the main program that reads a line and invokes the parser

See the calc directory in the repository

A second example

The idea:

A version of the previous example that uses the alias mechanism for tokens

For example:

- %token PLUS "+"
- %token MINUS "-"
- %token TIMES "*"

See the calc-alias demo on the menhir repository

A third example

The idea:

A version of the previous example that build an abstract syntax tree for the arithmetic expression

See the calc-ast

Source File Position

ocamllex tracks the position of tokens associating a value of the type Lexing.position to each token

menhir extends that mechanism by associating a pair of positions to both terminal and non-terminal symbols

The position of a symbol is available inside the semantic action of a rule through a set of keywords

Position-related keywords

Pattern	Meaning
$startpos/$endpos	start/end position of the first/last symbol in the production's right-hand side, if there is one; end position of the most recently parsed symbol, otherwise
$startpos ($i | id) /$endpos($i | id)	start/end position of the symbol named $i or id
$startofs/$endofs/ $startofs ($i | id) /$endofs($i | id)	Similar to above, but return an offset instead that a value of type Lexing.position
$loc/$loc($i | id)	Stands for the pair ($startpos, $endpos) or ($startpos($i | id), $endpos($i/id))

Example 4

The idea:

An extension of the calc which builds an AST that stores also the position of each construct

See the calc-ast-pos

Splitting grammar specifications

Grammar specifications can be split in multiple files: it is sufficient invoke menhir with multiple file names

By default a non-terminal is not visible in other file as long as the non-terminal is declared as %public or it is the start symbol

Note that the definition of a %public non-terminal can be split across multiple file, they are joined together using the choice operator (|)

A typical example of modularity consists in placing all token declaration in one module, so as that they can be shared by different parser working on the same set of tokens

Example 5

An version of the calc example with one lexer and two parsers:

1. expressions in infix notation
2. expressions in postfix notation

The two parsers share a single set of tokens (see tokens.mly) and that share some productions (see common.mly)

See the [calc-two]()

Rules with parameters (1)

A rule can be parametrized over an arbitrary number of symbols

```
%public option(X):
  |           { None }
  | x = X     { Some x }
```

option(X) expands to either

- the empty string, producing the semantic value None, or
- to the string X, producing the semantic value Some x

Rules with parameters (2)

Consider to have

```
declarations:  { [] }
             | ds = declarations  option(COMMA)  d = declaration { d :: ds }
```

When option is instantiated, intuitively we have

```
optional_comma:
  |{ None }
  | x = COMMA { Some x }
declarations:
  | { [] }
  | ds = declarations optional_comma  d = declaration { d :: ds }
```

The Standard Library

Menhir provides a collection of commonly used definitions

Name	Recognize	Produces
option(X)	X | ε	A value of t option if X produces t
pair(X,Y)	X Y	A value of type t1 * t2 if X produce t1 and Y produces t2
separated_pair(X, sep, Y)	X sep Y	-
list(X)	X*	A value of type t list, if X produces t
nonempty_list(X)	X+	-
separated_list(sep,X)	X?(sep X)*	-
separated_nonempty_list(sep,X)	X (sep X)*	-

Example 6

An version of calc which reads multiple expressions on the same line separated by a comma: it returns a list of integers

See calc-multi

Mehnir APIs

When Menhir processes a grammar specification parser.mly, it produces:

- A module Parser module
- A file parser.ml and an interface parser.mli

The file parser.mli defines the API we can use to interact with the parser:

1. Monolithic API
2. Incremental API (when invoked with the --table flag)

Menhir Monolithic API

This API provides:

- The algebraic data type `token` that has a case for each token declared with the directive %token in the *.mly file
- An exception `Error` with no arguments raised when a syntactic error is detected
- The parsing function named after the start symbol of the grammar, whose type is

```
(Lexing.lexbuf -> token) -> Lexing.lexbuf -> t
```

where t is the type of values returned by the parser

Menhir Incremental API (--table option required)

In this API (in Incremental module) the user needs to drive the parser

- The parser does not have access to a lexer, the user is responsible to feed it with tokens
- The user has access to the intermediate states of the parser and attach functionalities
- The parsing function named after the start symbol of the grammar, whose type is

position -> t MenhirInterpreter.checkpoint

Checkpoints

A checkpoint represent an intermediate or final state of the parser

```
type 'a checkpoint = private
  | InputNeeded of 'a env                         (* The parser needs more tokens *)
  | Shifting of 'a env * 'a env * bool            (* The parser is a shift transition *)
  | AboutToReduce of 'a env * production          (* The parser is a reduce step *)
  | HandlingError of 'a env                       (* The parser detect an error *)
  | Accepted of 'a       (* The input is accepted: a value of type ‘a is returned *)
  | Rejected             (* The input is rejected *)
```

‘a env represents the current state of the stack of the automaton

Driving the parser (1)

To drive the parser with the incremental API you have to

- provide a token supplier, a function that delivers a new token every time is invoked

```
type supplier = unit -> token * position * position
```

- Call the functions
  - offer to feed the parser with a new token when in a InputNeeded checkpoint
  - resume to allow the parser to continue when in a AboutToReduce or HandlingError checkpoints

Driving the parser (2)

To implement the monolithic API on top of the incremental:

- Call the parsing function to obtain the first checkpoint
- Repeatedly call the offer and resume functions until a final checkpoint is obtained
  - If it is Accepted(v), return v
  - If it is Rejected, throws an exception
- If an error occurs during the parsing throw an exception

See the functions lexer_lexbuf_to_supplier, loop and loop_handle in the documentation.

Example 7

An version of calc which uses the intermediate API

It shows two functions loop in calc.ml that drives the parser

1. The first one only uses offer and resume
2. The second one uses the library function loop_handle

See the [calc-incremental]()

Example 8

A parser for Json

- Json.ml: the definition of the Json abstract syntax tree (we distinguish between integers and floats)
- parser.mly & lexer.mll: the parser and lexer (the parser returns a json values one by one)
- No support for unicode

To compile:

```
$ ocamlbuild -use-menhir -use-ocamlfind -package ppx_deriving.std main.byte
```

Other features

- An interpreter mode that allows reading a sentence from the standard input, parsing it and printing on the standard output the result: this is useful for debugging a grammar

```
$ menhir --interpret --interpret-show-cst demos/calc/parser.mly
```

- A declarative approach for error reporting that builds and displays a diagnostic message based on the state of the automaton
- Detection of explanation of conflicts in the grammar: using the --explain flag it generates a file with the log the conflicts

See documentation for details

Conclusions

- Examples of handwritten parsers
- Tutorial on main features of menhir
- Some examples of parsers

References

- Menhir homepage
- Menhir reference manual
- Parsing with OCamllex and Menhir

Examples of parsers generators in other languages

Name	Parsing Algorithm	Languages
Bison	GLR/LARL	C/C++/Java
JavaCup	LALR	Java
JavaCC	LL(1)	Java
CocoR	LL(k)	Java/C#/C++/F#/Swift/...
FSYacc	LR/LALR	F#
Antlr4	ALL(k)	Java/C#/C++/Python/Go/....

For further examples see
https://en.wikipedia.org/wiki/Comparison_of_parser_generators

Parser combinators

An approach typically used in functional languages for defining recursive descent parsers

The underlying idea is that a parser is a function that takes a string as input and returns some structure as output

A parser combinator is a high-order function that accepts some parsers as input and returns a new parser as output

Some examples of parser combinators

Name	Languages
FParsec	F#
Angstrom	OCaml
Parjs	Javascript
Scala Parser Combinators	Scala
Parsec	Haskell
Combine	Rust
...	

Parsing Expression Grammars (PEG)

It is a special kind of formal grammar, similar to CFG where the choice operator | is ordered: the choice operator selects the first match that succeeds ignoring the others

The packrat parsing algorithm is a sort of recursive descent parser that exploits memoization to ensures that each parsing function is invoked once at a given input position

Some examples of PEG parser

Name	Languages
pappy	Haskell
Parboiled2	Scala/Java
Peg.js	Javascript
PEG	Go
PEGTL	C++
…	