Handmade or tool-built?

On the evolution of a parser generator written in D

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Motivation

Writing a parser by hand is easy …

… and boring !

Why not use a tool?

My goals for a parser generator

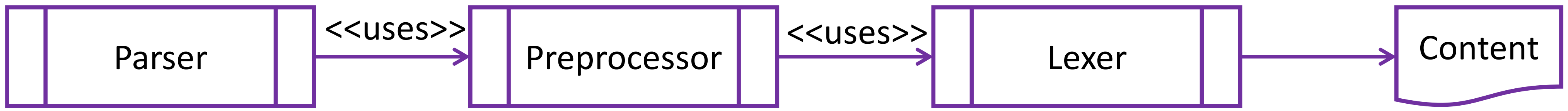
My tool should

- generate a parser body from a grammar description in EBNF
- allow the grammar to be augmented with code
- provide some error correction feature
- work standalone and should be CTFE-enabled

My tool should not

- generate a lexer
- have big runtime dependencies

Runtime architecture



- The lexer is a range (InputRange / ForwardRange)
- The (optional) preprocessor filters the range
- The parser does syntax analyzing on the range
- Only part of parser is generated

Interface to parser

- The generated code requires the following functions / properties

```
Token tok;

alias TokenKind = typeof(Token.kind);

void advance() { }

bool expect(TokenKind kind) { }

bool consume(TokenKind kind) { }
```

- TokenKind must be an enumeration
- Member names are derived from token names

- Interface is still under development!

Tools for parser generation

In the C/C++ world

- yacc and bison
- ANTLR
- Coco/R
- … and many more!

In the D world

- PEG
- ANTLR
- and now: LLtool

- PEG and ANTLR are excellent tools
- PEG has a different approach to parsing
- ANTLR comes with a huge runtime library

Example: simple expressions

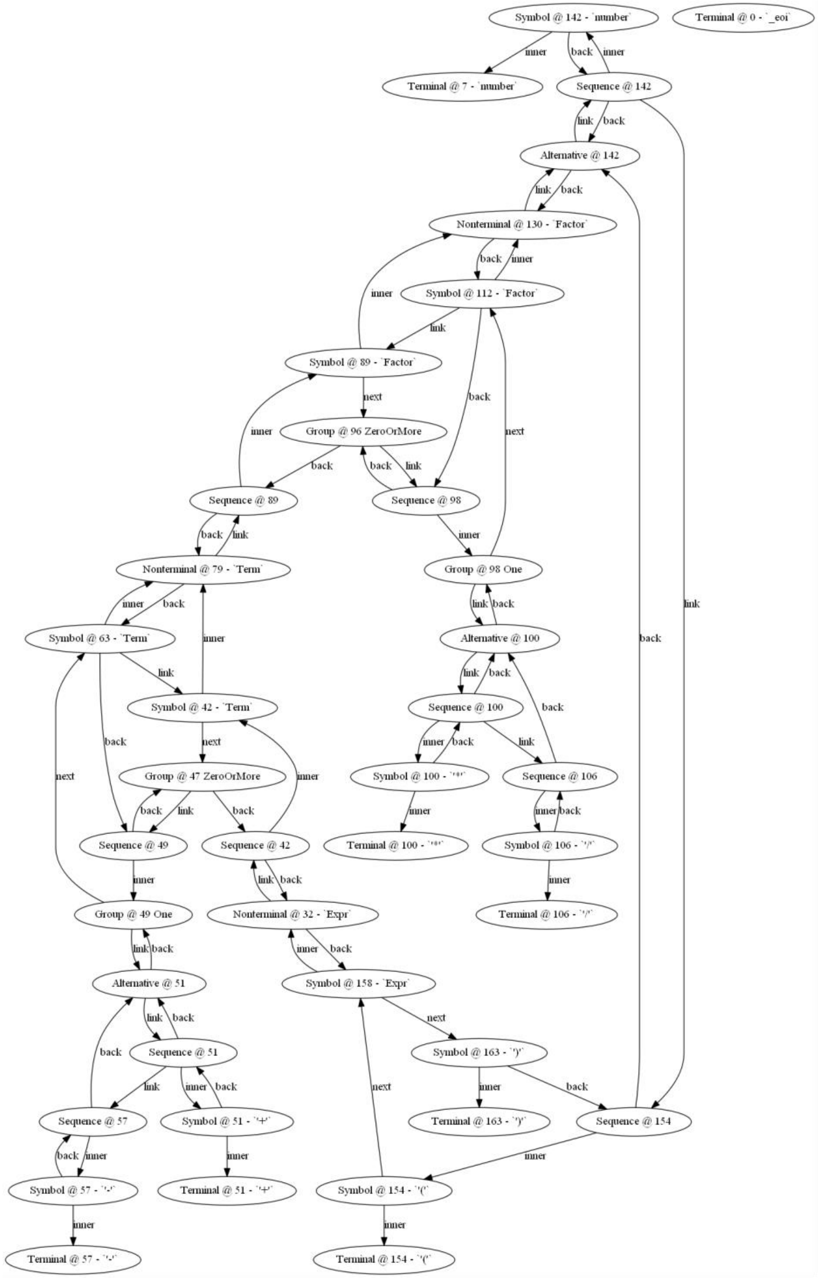
```
%token number
%start Expr
%%
Expr
  = Term ( ( "+" | "-" ) Term )*
  .

Term
  = Factor ( ( "*" | "/" ) Factor )*
  .

Factor
  = number
  | "(" Expr ")"
  .
```

Internal data structure

- Grammar is stored as graph
- Graph elements are of type **`Node`**
- Graph can be visualized with dot (specify **`–d`** on command line)



Internal data structure - attributes

inner: Pointer to content of sequence/ alternative/group

link: Arbitrary list e.g. list of nonterminal occurrences

Node

```
NodeType type;
Cardinality card;
string name;
bool derivesEpsilon;
bool isProductive;
bool isReachable;
TerminalSet firstSet;
TerminalSet followSet;
…
```

next: Pointer to next node in sequence

back: Pointer to parent node
Only used if last node in sequence

Myth #1: generated parsers are slow

From Oberon-2 grammar

```
Statement = ...
 | "IF" Expr "THEN" StatementSeq
   "END"
 | ...
 .
```

Generated D code

```
else if (tok.kind == TokenKind.KW_IF) {
    advance();
    parseExpr();
    consume(TokenKind.KW_THEN);
    parseStatementSeq();
    consume(TokenKind.KW_END);
}
```

The generated code reflects the grammar. No performance penalty added.

Myth #2: Generators are not flexible enough

From the LLtool grammar:

```
rule
  = (. Node node; .)
    nonterminal<node>
    "="
    rhs<node.link>
    (. node.link.back = node; .)
    "."
  .
```

The generated D code:

```
void parseRule() {
    Node node;
    parseNonterminal(node);
    consume(TokenKind.Equal);
    parseRhs(node.link);
    node.link.back = node;
    consume(TokenKind.Period);
}
```

- Add `(. code .)` in any places
- Pass `< parameters >` as needed

Myth #3: Bad error messages

- A hand-generated error message from the Oberon-2 lexer:

```
        v := 1A;
             ^^
Error: 22,13: Found hex constant without trailing H
```

- Error message based on parser-provided information:

```
    PROCEDURE (l : List) Get*   : Integer;
                                ^
Error: 25,31: Expected ; but found :
```

- Can we do better? A human can spot that **()** is missing…

LL what?

- Recursive descent parsers belong to the LL(1) class

- This acronym means:
  - L – the input is read from **l**eft to right
  - L – the **l**eftmost nonterminal is expanded first
  - 1 – **one** token look-ahead is used

- For most programming languages there is no LL(1) grammar

What are LL(1) conflicts?

- The parser uses the current state (= program counter) and the next token to decide about next move
- A conflict occurs if there is more than one possibility for next move
- Example from Oberon-2 grammar:

```
DeclSeq
  = … ProcDecl ";" | ForwardDecl ";" … .

ProcDecl
  = "PROCEDURE" (Receiver)? IdentDef … .

ForwardDecl
  = "PROCEDURE" "^" (Receiver)? IdentDef … .
```

State: in DeclSeq
Next token: "PROCEDURE"

Call ProcDecl or ForwardDecl?

More LL(1) conflicts

- Left recursion also creates LL(1) conflicts

```
StatementList = StatementList Statement | .
Statement = … ";" .
```

- Defines a list of statements, separated by ;
- Can you spot the problem?

```
void parseStatementList() {
    if (tok.kind.among(/* List of tokens */)) {
        parseStatementList();
        parseStatement();
    }
    /* … */
}
```

LL(1) conflict resolution: Grammar rewriting

- Rewrite grammar
  E.g. rewrite the statement list

```
StatementList = StatementList Statement | .
Statement = … ";" .
```

as

```
StatementList = ( Statement )* .
```

- In some cases result can be difficult to understand

LL(1) conflict resolution: Adding resolvers

- Add custom code to guide decision at runtime
- Syntax is **`%if (. bool expression .)`**
- Only allowed where LL(1) conflict occurs
- Can use additional information; e.g.

```
Qualident = ( %if (. isModule() .) ident ".“ )? ident.
```

uses a symbol table lookup in the D function:

```
bool isModule() {
    return tok.val in modules;
}
```

Handling of grammar variants

- Language families often have a lot of syntax in common
  - C and C++
  - PIM4 and ISO version of Modula-2
- It is desirable to build one parser for one language family
- Is this possible with a parser generator?

Grammar variants: the token trick

- A lot of rules is triggered by special keywords
  - E.g. **`class`** is a keyword in C++ but not in C

- Use the following approach
  - The lexer recognizes only identifiers
  - The preprocessor maps keyword identifiers to keyword tokens, based on language family
  - The parser does not see keyword token and does not handle this case

Grammar variants: the variant selector

- The token trick does not always help
  - E.g. there is no special keyword

- I am working on a special feature: the variant selector

- Idea: mark variant specific element

```
DefinitionModule = ("GENERIC“)?!generic "DEFINTIION" "MODULE" identifier ";" .
```

- Requires bool property **`generic`** in the parser

The variant selector looks cool, but …

- It makes elements “invisible”
  - Can introduce non-reachable rules – an error today

- Can unintentionally make elements optional

```
DefinitionModule
  = "DEFINTIION" "MODULE" identifier ";“
  | ("GENERIC" "DEFINTIION" "MODULE" identifier ";“)!generic
  .
```

- Requires more thought!

More ideas

- Add a look-ahead heuristic for resolvers
- From Oberon-2 grammar

```
Import = ( ident ":=" )? ident .
```

- LL(1) conflict because **`ident`** is start and successor of (   )?
- Resolver is based on one more token look-ahead

```
bool isAlias() { return lexer.save.moveFront.kind == TokenKind.ColonEqual; }
```

- Can be generated automatically … but it is tricky (ANTLR does it)

Even more ideas

- Create LRtool – a parser generator for SLR(1)/LALR(1) grammars
- Output as recursive ascent-descent parser (no parsing tables!)
  - Either via data flow analysis or extended left-corner parsing
- Needs much more investigation

Feedback welcome!

- Clone the source from https://github.com/redstar/LLtool
- Create an issue at https://github.com/redstar/LLtool/issues
- Write me an e-mail

Thank you!

Backup

Syntax of input file

```
%token identifier, code
%token argument, string
%start lltool
%%
lltool = ( header )? ( rule )+ .

header = ( "%start" identifier
         | "%token" tokenlist
         | "%eoi" identifier )* "%%" .

tokenlist = tokendecl ("," tokendecl )* .

tokendecl = (identifier | string)
            ( "=" identifier )? .
```

```
rule = nonterminal "=" rhs "." .

nonterminal = identifier ( argument )? .

rhs = sequence ( "|" sequence )* .

sequence = ( group
           | identifier ( argument )?
           | string | code
           | "%if" code )* .

group = "(" rhs ( ")“
                | ")?“
                | ")*“
                | ")+" ) .
```