Fast, Flexible, and Declarative Construction of Abstract Syntax Trees with PEGs

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Abstract: We address a declarative construction of abstract syntax trees with Parsing Expression Grammars. AST operators (constructor, connector, and tagging) are newly defined to specify flexible AST constructions. A new challenge coming with PEGs is the consistency management of ASTs in backtracking and packrat parsing. We make the transaction AST machine in order to perform AST operations in the context of the speculative parsing of PEGs. All the consistency control is automated by the analysis of AST operators. The proposed approach is implemented in the Nez parser, written in Java. The performance study shows that the transactional AST machine requires 25\% approximately more time in CSV, XML, and C grammars.

Keywords: parsing expression grammars, packrat parsing, AST construction, and parser generators

1. Introduction

A parser generator is a standard method for implementing parsers in practical compilers and many other software engineering tools. The developers formalize a language specification with a declarative grammar such as LR(\(k\)), LL(\(k\)), GLR, or PEGs \cite{4}, and then generate a parser from the formalized specification. However, in reality, many generated parsers are not solely derived from a formal specification. Rather, most parsers are generated with a combination of embedded code, called semantic actions.

The use of semantic actions has been a long tradition in many parser generators since the invention of yacc \cite{11}. One particular reason is that a formal grammar itself is still insufficient for several necessary aspects of practical parser generation. The construction of Abstract Syntax Trees (ASTs) is one of the such insufficient aspect of a formal grammar. Usually, the grammar developers write semantic actions to construct their intended form of ASTs. However, the semantic action approach lacks the declarative property of a formal grammar and reduces the reusability of grammars, especially across programming languages.

The purpose of this paper is to present a declarative extension of PEGs for the flexible construction of ASTs. The “declarative” extension stands for no semantic actions that are written in a general-purpose programming language. The reason we focus on PEGs is that they are closed under composition (notably, intersection and completion); this property offers better opportunities to reuse grammars.

We have designed AST operators that use an annotation style in parsing expressions, but allow for a flexible transformation of ASTs from a sequence of parsed strings. The structures that we can transform include a nested tree, a flattened list, and left/right-associative pairs. Due to a special left-folding operator, the grammar developers can construct a tree representation for binary operators that keep their associativity correct.

We have addressed how to implement AST operators in the context of PEG’s speculation parsing. The transactional AST machine is an machine abstraction of AST operations, in which the intermediate state of ASTs while parsing is controlled at each fragment of mutation. The AST machine produces the resulting ASTs in either the full lazy evaluation way (such as in function programming) or the speculation way at any point of parsing expressions. Either ways, the produced AST is always consistent against backtracking. Synchronous memoization is presented as the integration of the AST machine with packrat parsing, in which the immutability of memoized results is ensured.

Recently, the use of parser generators has been extensively accepted for protocol parsers and text-data parsers \cite{2, 13}. Parser performance, including the time cost of data extraction (i.e., AST construction in the parser terminology), is an integral factor in tool selection \cite{15, 19}. We have tested the Nez parser, which is implemented with the AST machine with the synchronous memoization. We demonstrate that the transactional AST machine approximately requires approximately 25\% more time in major grammars such as CSV, XML, and C.

This paper proceeds as follows. Section 2 states the problem with AST constructions in PEGs. Section 3 presents our extended notations for AST construction. Section 4 presents the transactional AST machine that makes AST construction consistent with backtracking. Section 5 presents the integration of packrat parsing with the transactional AST machine. Section 6 presents the performance study. Section 7 reviews related work. Section 8 concludes the paper. Our developed tools are open and available at http://nez-peg.github.io/.

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2. Problem Statement

2.1 Semantic Actions

PEGs, like other formal grammars, only provide syntactic recognition capability. This means that the parsed result is just a Boolean value indicating whether an input is matched or not. To obtain detailed parsed results such as ASTs, the grammar developers need additional specifications to describe how to transform parsed results.

**Semantic actions** are most commonly used in today’s parser generators in order to program AST constructions with a fragment of embedded code in a grammar. Figure 1 shows an example of a semantic action written in Java, a host language of Rats! [6]. The embedded code \{ . . . \} is a semantic action, combined with a generated parser at the parser generation time and invoked at the parsing time.

An obvious problem with semantic actions is that the grammar definition depends tightly on the host language of the generated parser. This results in a loss of opportunity for reuse in many potential parser applications such as IDEs and other software engineering tools since the developers often need to write another grammar from scratch.

2.2 Consistency Problem

The PEGs’ flexibility come from the speculation parsing strategy. Typically, backtracking requires us to control the consistency management by means such as discarding some part of the constructed ASTs; otherwise, the ASTs may contain unnecessary subtrees that are constructed by backtracked expressions. In Fig. 1, for example, it is undecided whether a Node object becomes a part of the final ASTs. The developer adds the Action constructor for consistency when backtracking. This problem is not new for PEGs but is common for semantic actions being executed in speculative parsers such as Refs. [17] and [10]. However, the consistency still relies largely on the developer’s management of semantic actions.

Another consistency problem arises in packrat parsing [3], a popular and standard technique for avoiding PEGs’ potential exponential time cost. Roughly, packrat parsing uses memoization for nonterminal calls, represented by \( (N, P) \rightarrow R \), where \( N \) is a set of nonterminals in a grammar, \( P \) is a parsing position over an input stream, and \( R \) is a set of intermediate parsed results. As a part of the additional parsed results, we need to represent an intermediate state for ASTs, constructed at each nonterminal. More importantly, all memoized results have to be immutable in packrat parsing. Accordingly, we need to analysis the immutability of ASTs from the static property of grammars with semantic actions.

2.3 Parsing Performance and Machine Abstraction

Recently, the applications of formal grammars have been expanded from programming languages to protocol parsers and data analysis [13], [15], [19]. Parsing performance becomes a significant factor in parser tool selection. In this light, semantic actions written in functional languages would provide a very consistent solution to the AST construction but not to our option.

One of the research goals of the Nez parser generator is high-performance parsing for “Big Data” analysis. In the context of text-data parsing, the AST construction roughly corresponds to data extraction and transformation tasks. For the sake of enabling dynamic grammar loading, the Nez parser generates not only parser source code but also byte-compiled code for the specialized parsing runtime. The machine abstraction is demanded for the AST construction instead of local variables and recursive calls in a recursive decent parsing.

3. Extending AST Construction

3.1 ASTs

An AST is a tree representation of the abstract structure of parse results. The tree is “abstract” in the sense that it contains no unnecessary information such as white spaces and grouping parentheses. Figure 2 shows an example of ASTs that are parsed from an if-condition-then expression. Each node has a tag, prefixed by #, to identify the meaning of the tagged node. A parsed substring is denoted by a single quotation ‘ ’. For readability, we omit any parsed substrings in non-leaf nodes.

For convenience, we introduce a textual notation of ASTs, which is exactly equivalent to the pictorial notation. Here is a textual version of Fig. 2:

```java
#If
#GreaterThan[#Variable['a'] #Variable['b']]
#Return[#Variable['a']]
#Return[#Variable['b']]
```

To be precise, the syntax of the textual notation of ASTs, denoted \( T \), is defined inductively:

\[
T ::= #t[T] \mid #t[\ldots] \mid TT
\]

where \( #t \) is a tag to identify the meaning of \( T \) and a parsed substring written by \( \ldots \). A whitespace concatenates two or more

```
 constant Action<Node> LogicalAndExpressionTail = "&&":Symbol right:BitwiseOpExpression { 
  yyValue = new Action<Node>(); 
  public Node run(Node left) { 
    Node e = GNode.create("Expr", left, right); 
    e.setLocation(location(yyStart)); 
    return e; 
  } 
};
```

Fig. 1 Example of AST constructions in Rats!.

Input: \( \text{if}(a > b)\ \text{return}\ a; \ \text{else} \ (\ \text{return}\ b;) \)

Fig. 2 Pictorial notation of ASTs.
nodes as a sequence. In this paper, we assume that the parsed result always starts with a non-sequence form of \#T[7].

Note that our AST definition is a minimalist; we drop any labeling for subnodes, like if(cond, then, else). While the labeling may be convenient when accessing subnodes, the sequence preserves the order of subnodes, providing sufficient semantics to distinguish them.

### 3.2 PEG Operators

A PEG is a collection of productions, mapping from nonterminals to expressions. To write productions, we use the following form:

\[ A = e \]

where \( A \) is the name of a nonterminal and \( e \) is a parsing expression to be evaluated. Parsing expressions are composed by PEG operators. AST operators are designed to create and mutate ASTs in the parsing context of PEGs. Table 1 shows a summary of the PEG/AST operators.

#### Table 1: PEG/AST operators.

| PEG   | Type   | Operate | Proc. | Description                      |
|-------|--------|---------|-------|----------------------------------|
| [ ]   | Primary| PEG     | 5     | Matches text                     |
| .     | Primary| PEG     | 5     | Any character                    |
| A     | Primary| PEG     | 5     | Non-terminal application         |
| #t    | Primary| AST     | 5     | Tagging                          |
| (e)   | Primary| PEG     | 5     | Grouping                         |
| $e$   | Primary| AST     | 5     | Constructor                      |
| $e$   | Primary| AST     | 5     | Connector                        |
| e?    | Unary suffix| PEG | 4     | Option                            |
| e*    | Unary suffix| PEG | 4     | Zero-or-more repetitions         |
| e+    | Unary suffix| PEG | 4     | One-or-more repetitions          |
| &e    | Unary prefix| PEG | 3     | And-predicate                    |
| !e    | Unary prefix| PEG | 3     | Negation                          |
| e1/e2| Binary  | PEG     | 2     | Sequencing                       |
| e1/e2| Binary  | PEG     | 1     | Prioritized Choice               |

PEG: PEG operators, AST: AST operators

#### Table 1: PEG/AST operators.

| Value    | Number    |
|----------|-----------|
| \{0-9\}+ | \#Int     |
| 12       | ["12"]   |

The major difference from the substring capturing in regular expressions is that we enhance the structural construction of nodes. To start, we introduce a global state reference, called the left node. The left node is implicit in notations but simply refers to an AST node that is constructed on the left hand of a parsing expression. To the left node, we define the following structural constructors:

- tagging, \#t — tagging the specified \#t to the left node;
- appending, \$e — appending an \$e’s constructed node to the left node;
- and

The tag \#t is introduced to identify the meaning of nodes. Grammar developers are allowed to define a set of tags that they want. The tagging operator is used to specify such a tag on the left node. Untagged nodes are \#tree and \#token as default tags for tree nodes and leaf nodes respectively.

### 3.3 AST Operators

The design of the AST operators was inspired by the substring capturing commonly used in extended regular expressions such as Perl and PCRE[7]. Instead of ( . . . ), we use \{ e \} to specify a substring that we want to capture as an AST node. Here are two expressions that capture the same substring 34 in an input 123456.
Left-recursive.

As the name implies, left-folding is chiefly used for the left-folding with a repetition (node. That is, creating a new node that contains the left node as the first child from the repetition. Left-folding is additionally defined as constructing a left-associative parse although the grammar contains left-recursion.

Note that is a known algorithm for eliminating any left-recursion from a grammar (as shown in Ref. [21]), this elimination does not ensure left-associativity. Left-recursion is a major restriction of PEG. Although there is a known algorithm for eliminating any left-recursion from a grammar (as shown in Ref. [21]), this elimination does not ensure the left associativity.

Left-folding is additionally defined as constructing a left-associative structure from the repetition. Left-folding ($e$) is creating a new node that contains the left node as the first child node. That is, $e_1($e2$)$ is equivalent to ($e_1$) $e_2$). Usually, we use the left-folding with a repetition ($e_1($e2$)$), or ($e_1($e2$)$) $e_1$). Note that $e_1($e2$)$ is equivalent to $A = ($e(A)$) / e_1$ although $A$ is left-recursive.

Figure 7 is the construction of left-associative pairs from A, B, C, D. As the name implies, left-folding is chiefly used for constructing left-associative binary operators. Figure 8 shows the basic mathematical operators with AST operators.

3.5 Operational Semantics

Finally, we define the operational semantics of AST operators in parsing expressions. To begin, we define several notations used in the semantics. Let $x, y, z \in \Sigma$ be a sequence of characters and $xy$ be a concatenation of $x$ and $y$. We write $T$ for a node of ASTs. $\#t[x]$ is a newly created node with a default tag $\#t$ and a substring $x$. $T[T']$ stands for adding a child $T'$ to the parent $T$. $T/#t$ stands for the replacement of the tag of $T$ with the specified $\#t$.

The semantics of $e$ is defined by a state transition $(xy, T) \xrightarrow{e} (y, T')$, which can be read: the expression $e$ parses the input stream $xy$ consumes $x$ and transforms the left node $T$ into $T'$. If $T = T'$ in the transition, then the node is not mutated.

Figure 9 is an abstract syntax of parsing expressions with the AST operators. Due to space constraints, we highlight core parsing expressions, which only contain $e$, $a$, $e_1$, $e_2$, $e_1/e_2$, and $\&$. Other expressions, including character class, option, repetition, and-predicate, can be rewritten by these core expressions [4]. Figure 10 shows the definition of the operational semantics of $e$. We write $\bullet$ for a special failure state. Any transitions to $\bullet$ suggests the backtracking to the alternative if one exists.

PEG operators and AST operators are orthogonal to each other. In other words, AST operators do not influence the operational semantics of PEG operators. On the contrary, AST operators only use a substring that is matched by an expression $e$.

4. Transactional AST Machine

A transactional AST machine is a state-based implementation to make the AST construction consistent with AST operators. All operations are recorded as instruction logs to be canceled when backtracking. In this section, we describe the transactional AST machine.
(x,T) \xrightarrow{a} (x,T)

\tau(e_1) = \begin{cases} 
\text{new} & \text{open}(\text{left}, p)
\tau(e) & \text{close}(\text{left}, p)
\end{cases}

\tau(\#) = \text{tag}(\text{left}, t)
\tau($$e$$) = \text{push}(\text{left})
\tau(e) = \text{link}(\text{left})
\text{left} \leftarrow \text{pop}
\tau(\$ e) = \text{push}(\text{left})
\text{left} \leftarrow \text{new}
\text{left} \leftarrow \text{swap}(\text{left})
\text{link}(\text{left}) \leftarrow \text{open}(\text{left}, p)
\tau(e) = \text{close}(\text{left}, p)
\tau(e) = p \leftarrow \text{parse}(e, p)

4.2 AST Construction with Backtracking

Backtracking requires the rollback handling of the instruction executions, since some executions could be unnecessary when backtracking. Suppose \{ # e_1 \} / e_2, for example. Before evaluating \( e_1 \), we need three AST instructions (\text{new}, \text{open}, and \text{tag}) to be executed. However, if the expression \( e_1 \) fails, these instructions are unnecessary before attempting alternatives \( e_2 \).

The transactional AST machine provides the lazy evaluation mechanism for the execution of AST instructions. The lazy evaluation means that we cannot perform any instructions until we reach a point where backtracking no longer occurs.

The lazy evaluation can be simply achieved by logging instructions in a stack-based buffer. Let \( i \) be a position of the latest stored instruction log on the buffer. The buffer is operated by the following transactional instructions:

- \text{log} \ (pushpop)_{\cdot} \text{swap} – log an AST instruction to the instruction buffer \( i \leftarrow i + 1 \);
- \text{save} – save \( i \) for the beginning of a transaction \( t \leftarrow i \);
- \text{commit}(t) – execute instruction logs stored between \( t \) and \( i \leftarrow i + 1 \), and then expire them; and
- \text{abort}(t) – expire the instruction logs stored between \( t \) and \( i \leftarrow i \).

In the above, we take an instruction form to represent the transactional operations. This is based on the implementation of a Nez interpreter-based parser. In practice, one could not necessarily implement these operations as instructions. Instead, the AST machine only provides APIs to control the \text{save}, \text{commit} and \text{abort} operations for the parser.

The \text{abort} operation is fully automated on a PEG parser. At the time of any failure occurrences, the parser aborts the transaction to the save point \( t \). The save points are exactly the same points where the parser saves a parser position (over the input) to attempt alternatives when backtracking. To be precise, the ↓ below indicating the save point for the transaction.

- ↓$$e$$, ↓$$e$$, ↓$$e$$, ↓$$e$$
5. Packrat Parsing with ASTs

Packrat parsing [3] is an essential technique to avoid the potential exponential time cost of backtracking. This section describes the safe integration of the transactional AST machine with packrat parsing.

5.1 Laziness vs. Speculation

Packrat parsing [3] is a memoization version of the recursive decent parsing. Since all the intermediate parse results of nonterminal calls are memoized at each distinct position, we can avoid redundant calls, which lead to exponential time costs in the worst case. In the context of AST constructions, we additionally need to memoize the intermediate state of ASTs.

We consider two strategies: lazy-full and speculation. The lazy-full strategy involves memoizing instruction logs to take full advantage of lazy evaluation. The speculation strategy involves memoizing an AST node that is instantiated despite the fact that the instantiated node may eventually be unused and discarded. We choose the speculation strategy, after the following comparison of the pros and cons of both strategies.

The lazy-full strategy is natural and very compatible with the transactional AST machine. An obvious advantage is that we take full advantage of lazy evaluation of AST constructions. However, a disadvantage is also clear; we need to copy a large number of instruction logs to be memoized. Although the memoized logs can be reduced to a subsequence of logs that are only added by a given nonterminal, the size of the copy is roughly proportional to the size of input characters that the nonterminal has consumed. Since packrat parsing is based on the constant memoization cost in the size of the input, the memoized logs may invalidate the linear time guarantee.

The advantage of the speculation strategy is that the reduced overhead of the memoization. Note that the instantiation costs of ASTs are not an actual overhead since we need the instantiation at least once even in the lazy-full strategy. Due to memoization, we can avoid the repeated instantiation of the same nodes. As a result, the overheads are the unnecessary instantiation and discard costs for the sake of eventually unused nodes. However, we consider that a modern garbage collector is efficient enough to handle such memory iterations.

Another disadvantage is that we require the immutability analysis for the memoization point. To illustrate, we suppose that the production Symbol that overrides the tag of a Name-produced node.

Now we may commit the transaction at any point in parsing expressions. However indiscriminate commitments may result in the speculative AST instantiation if backtracking occurs. As discussed in the next section, the speculative instantiation is also consistent against backtracking, although no unused instantiation is ideal. It is still unknown whether a certain point of the parser context never backtracks. The simplest solution is to invoke the commit when the whole input is parsed. This gives us the benefit of a full lazy evaluation as in functional programming languages.

5.2 Synchronous Memoization

The memoization of an AST node is performed not at arbitrary nonterminals, but at a safe point where we ensure that the instantiated node is immutable. Let \( m \) be an identifier that uniquely represents such a memoization point. Let \( s \) be a starting point for the instantiation of the node for \( m \).

Synchronous memoization is a memoization that synchronizes with a transactional instantiation of an AST node. The following pseudo code illustrates the algorithm of the synchronous memoization of \( (s, m) \).

```plaintext
\( \tau(e) = \begin{cases} \text{push(left)} \\
left \leftarrow \text{lookup}(m) \\text{ifon}(left, L) \\
f \leftarrow \text{save()} \\
\tau(e) \\
left \leftarrow \text{commit}(f) \\
\text{memo}(w, left) \\
L \text{link}(m) \\
\text{pop}(left) \end{cases} \)
```

Following the speculation strategy, an AST node is instantiated after Name to be memoized. The same node can be memoized at Symbol, but it is mutated by a different tagging #Symbol. As a result, the lookup of the memoization table for Name is different, as we have memoized at at Name.

In general, it is not easy to analyze the mutable region of nodes in parsing expressions with semantic actions. Fortunately, AST operators have restricted semantics in terms of the mutation of nodes. In addition, there is no method to mutate to a child node of the left node. Accordingly, the mutable region is surrounding by \( S(e) \).

Before the instantiation of a node, we use Lookup(\( m \)) to find an already instantiated node from the memoization table. If found, we set it to the left node and never attempt any mutations for the set node. Otherwise, we start a transaction that instantiates a new node. During the transaction, the node mutations are all logged in the transactional AST machine. When backtracking occurs, the mutations are automatically aborted. If we reach at the \( m \) point, we commit the logged instructions by Commit(\( s, m \)) and then obtain an instantiated node. Memoize(\( m \)) is called to store the instantiated node in the memoization table.

Figure 12 illustrates the synchronous memoization version of \( \tau(S(e)) \). The memoization point \( m \) is an unique number for every distinct subexpression \( e \), which is derived from the grammar.

symbol = { NAME #Name } 
Symbol = Name #Symbol

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analyze.

Note that nonterminal calls in general are not memoized in the synchronous memoization. However, this may reduce the number of memoization points and decrease the effect of packrat parsing. On the other hand, nonterminals involving no AST operations have no side effect for node constructions. In the Nez parser, we use such nonterminals for another available memoization point.

5.3 Garbage Collection

Another problem with the speculation strategy is how to discard unused nodes. Unused nodes inevitably occur since the instantiated nodes are temporarily stored on the $\log_{10}$ logs before their parent nodes are instantiated. (Note that the $\log_{10}$ logs can be always expired by backtracking). The memoization table on the other hand has to keep the expired nodes from the logs in order to avoid the reinstatiation of the same node.

The conventional packrat parsers keep all memoized results until the whole parser process ends [3]. This suggests that the heap consumption considerably increases when we add all intermediate AST nodes. Worse, it is impossible in general to determine the point at which a memoized node is no longer used [18].

One practical solution is the use of a sliding window to range the memoization table over the input position. In the sliding window, memoized nodes are expired if the parse moves forward in the window size. Our previous work [16] confirms both the linear time parsing and the constant memory consumption if the window size is large enough to cover the length of backtracking. The Nez parser uses the sliding window for memoization, and allows the garbage collector to collect expired nodes. This results in the reduced memory pressure.

6. Experimental Results

This section describes the results of our performance study on AST constructions on the Nez parser.

6.1 Parser Implementation

Nez is a PEG-based parser generator that has a language support for the AST operators. The Nez parser is written in Java, and integrated with enhanced packrat parsing with sliding window, presented in Ref. [16], and the transactional AST machine with synchronous memoization, described in Sections 4 and 5.

In this experiment, we run the Nez parser as an interpreter mode, although it can generate parser source code. The Nez interpreter is highly optimized with several techniques including grammar inlining, partial DFA-conversions, and superinstructions.

The test environment is Apple Mac Book Air, with 2 GHz Intel Core i7, 4 MB of L3 Cache, 8 GB of DDR3 RAM, on Mac OS X 10.8.5 and Oracle Java Development Kit version 1.8. All measurements represent the best result of five or more iterations over the same input.

6.2 Grammars and Datasets

The grammars we have investigated are selected from the same set [16] in such a way that we can examine the variety of backtracking activity. Data sets are chosen to demonstrate a typical parser behavior for the given grammar. We label the pair of tested grammar and dataset as follows.

- CSV – a simple grammar that involves no backtracking and many flattened AST nodes. The tested data come from an open data file offered by the JapanPost.
- XML – a typical grammar for data formats that involves low backtracking activity and many nested AST nodes. The tested data are obtained from the XMark benchmark project [23].
- C – a language grammar that involves moderate backtracking activity. The tested data are derived from Google NSS Cache project.
- JS – a language grammar that involves high backtracking activity and then shows an exponential time cost, as reported in Ref. [16]. The tested data are an uncompressed js object source file.

Table 2 shows a summary of grammars and datasets. The left side of the table indicates the static properties of grammars. The column labeled “Production” stands for the number of productions, and Column “Memo Points” stands for the number of memo points. The right side of the table indicates the statistics of internal parser behaviors when we parse the data sets. Column “Backtrack” stands for the backtrack activity, measured by the ratio of the total backtracking length by the input size. Column “Memo Effects” is measured by the hit ratio of memoized results. Column “Nodes” stands for the number of nodes that the final ASTs contain, and Column “Unused” stands for the number of eventually unused nodes.

6.3 Performance Study

Now we will turn to the performance study. Figure 13 shows the parsing time in each dataset. The data point labeled “Recognition” stands for parsing time without AST construction, and “R+Allocation” stands for a cumulative time of “Recognition” and a simple instantiation time of AST nodes. The instantiation time is estimated by the elapsing time of the duplication of ASTs, whose size are the same as constructed in “AST Construction”. It takes roughly 3 milliseconds to instantiate every 10,000
nodes. The differential time between “R+Allocation” and “AST Construction” implies a pure overhead of the transactional AST machine. We confirm that the transactional AST machine raises the time costs by 26%, 16%, 25% and 59% to the “R+Allocation” time in CSV, XML, C, and JS. The reason why the JS dataset shows the larger time cost may be the minor degradation of packet-parsing, which is indicated by the increased backtracking activity in Table 2.

Table 3 shows a performance comparison of other PEG-based parser generators. We have chosen Rats! and PEG.js since they notably produce notably efficient parsers and are accepted in several third-party projects. Rats! runs on Java8 as well as Nez, while PEG.js tested in the node.js environment including a V8-based JIT-compiler. To highlight the time cost of the underlying AST construction, we show the time difference between the “AST Construction” time and the “Recognition” time in millisecond.

The experiment indicates that Rats! is weak at parsing CSV and XML that contains many AST nodes. PEG.js shows good performance in total but is weak at parsing JavaScript that involves many backtracking. While the strength/weakness characteristic varies in datasets, Nez indicates the lowest time costs in all datasets. We confirm that the transactional AST machine achieves fast AST construction in contexts of PEG parsing.

8. Conclusion

This paper presented a declarative extension of PEGs for flexible AST constructions in such a way that AST can be transformed into nested trees, flattened lists, and left/right-associative pairs. The transactional AST machine is modeled to allow for the consistent AST construction with backtracking. In addition, the synchronous memoization is presented, integrating the packrat parsing to avoid potential exponential time costs. A transactional AST machine with the synchronous memoization is implemented in the Nez parser written in Java. We have demonstrated that the Nez parser requires a 25% higher time cost for AST construction in most cases. In future work, we will investigate a more complex tree transformation with macro expansions while parsing.

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References

[1] Bravenboer, M., Kalleberg, K.T., Vermaas, R. and Visser, E.: StrategiesXT 0.17. A Language and Toolset for Program Transformation, Sci. Comput. Program., Vol.72, No.1-2, pp.52–70 (online), DOI: 10.1016/j.scico.2007.11.003 (2008).
[2] Fisher, K. and Walker, D.: The PADS Project: An Overview, Proceedings of the 14th International Conference on Database Theory, ICDT ’11, New York, NY, USA, pp.11–17, ACM (online), DOI: 10.1145/1938551.1938556 (2011).
[3] Ford, B.: Packrat Parsing:: Simple, Powerful, Lazy, Linear Time, Functional Pearl, Proceedings of the Seventh ACM SIGPLAN International Conference on Functional Programming, ICFP ’02, New York, NY, USA, pp.36–47, ACM (online), DOI: 10.1145/581478.581483 (2002).
[4] Ford, B.: Parsing Expression Grammars: A Recognition-based Syntactic Foundation, Proceedings of the 31st ACM SIGPLAN-SIGACT Symposium on Principles of Programming Languages, POPL ’04, New York, NY, USA, pp.111–122, ACM (online), DOI: 10.1145/964001.964011 (2004).
[5] Gray, R.W., Levi, S.P., Hearing, V.P., Sloane, A.M. and Waite, W.M.: Eli: A Complete, Flexible Compiler Construction System, Comm. ACM, Vol.35, No.2, pp.121–130 (online), DOI: 10.1145/129630.129637 (1992).
[6] Grimm, R.: Better Extensibility Through Modular Syntax, Proceedings of the 2006 ACM SIGPLAN Conference on Programming Language Design and Implementation, PLDI ’06, New York, NY, USA, pp.38–51, ACM (online), DOI: 10.1145/1133981.1133987 (2006).
[7] Hazel, P.: PCRE · Perl Compatible Regular Expressions, available from (http://www.pcre.org).
[8] Hill, O.: Language Development with Waxeye (2014), available from (http://waxeye.org/manual.html).
[9] Ierusalimschy, R.: A Text Pattern-matching Tool Based on Parsing Expression Grammars, Softw. Pract. Exper., Vol.39, No.3, pp.221–258 (online), DOI: 10.1002/spe.v39.3 (2009).
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