Parser-Combinators for Contex-Free Path Querying

Smolina
Saint Petersburg State University
St. Petersburg, Russia
trovato@corporation.com

Ekaterina Verbitskaia
Saint Petersburg State University
St. Petersburg, Russia
webmaster@marysville-ohio.com

Ilya Kirillov
Saint Petersburg State University
St. Petersburg, Russia
larst@affiliation.org

Semyon Grigorev
Saint Petersburg State University
St. Petersburg, Russia
semen.grigorev@jetbrains.com

ABSTRACT

Transparent intergration of domain-specific languages for graph-structured data access into general-purpose programming languages is an importatn for data-centric application development simplification. It is necessary to provide safety too (static errors checking, type chacking, etc) One of type of navigational queryes is a contex-free path queryes which stands more and more popular Context-free path querying reuquired in some areas, theoretical research, but no languages (cfSPARQL) Grammars cpecification languages — combinators. We propose to use parser combinators technique to implement context-free path qurying We demonstrate library and show that it is applicable for realistic problems.

Abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, Abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, Abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, Abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract, abstract,

CCS CONCEPTS

• **Information systems → Graph-based database models**; **Query languages for non-relational engines**; • **Software and its engineering** → *Functional languages*; • **Theory of computation** → *Grammars and context-free languages*;

KEYWORDS

Graph data bases, Language-constrained path problem, Context-Free path querying, Parser Combinators, Domain Specific Language, Generalized LL, GLL, Neo4J, Scala

ACM Reference Format:
Smolina, Ekaterina Verbitskaia, Ilya Kirillov, and Semyon Grigorev. 2018. Parser-Combinators for Contex-Free Path Querying. In *Proceedings of Joint International Workshop on Graph Data Management Experiences & Systems (GRADES) and Network Data Analytics (NDA) 2018 (GRADES-NDA'18).* ACM, New York, NY, USA, Article 4, 4 pages. https://doi.org/10.475/123_4

GRADES-NDA'18, June 2018, Houston, Texas USA

ACM ISBN 123-4567-24-567/08/06…$15.00
https://doi.org/10.475/123_4

1 INTRODUCTION

When you develop a data-centric application, you want to use general purpose programming language and have an transparent and native access to data sources. The naiv approach, named string-embedded DSLs, which means that you have a driver which can execute a string with query and return (posibly untiped) result have some serious problems. First of all, it is necessary to use special DSL which may require additional knolages from developer. Moreover, string-embedded languahe is a source of errors and vulnerabilities which static detection is very hard [4].

Applications which use graph structured data is also have such problem. There is a number of special languages for graph traversing/querying, such as SPARQL [15], Cypher [1], Gremlin [19]. It is necessary to integrate these languages into gp programming languge. , data access, languages integration for graph-structured data (or graph DB) access.

These leeds to creation such special techniques as Object Relationship Mapping (ORM) or Language Integrated Query (LINQ) which uses not only for relational data bases manipulation, but for graph DB too.

One of type of navigation queries is a language-constarined path querying [**?**]. Many of languages allow users to specify regular constraints, but some tasca requerd more powerfull – context-free constarints. For example, classical same generation query is not a regular, also CFL reacability can be used for static code analysis. Not only reachability information, but strucure of results: for debugging and futher processing. Structural representation of result: not only reachability, but paths; debuggibg [9]; understanding.

Theoretical research, but no languages for applications develoer Some different formulation of the similar problems: Language-constrained path querying and language reachability. Language-constrained path querying, Yannakakis [22]. Hellings [7, 8], RDF [23], etc [2, 3, 14, 18, 21]

Integration with general purpose programming languages is a classical problem [4]. Languge integration problem: special DSLs for SQL, ORM, Linq. Transperent integration inpo gp programming language: static correctness, typing, composability Similar to problem with SQL : correctnes, type safety, etc. Special DSL vs

[1]Cypher languge web page: https://neo4j.com/developer/cypher-query-language/. Access date: 16.01.2018

Combinators (LINQ [5, 13], etc) cfSparql — separated language Special graph query languages. SPARQL [15], cypher [2], gremlin [19] String-embedded DSLs.

One of the natural way to specify any language is specify its formal grammar. In practice of development programming languages processors there are two classical approach to do specify the grammar. One of them is by using special DSL for grammar specification. The classical alternative way is a parer combinator technique which.

Classical combinators are based on LL(k) and has restrictions: left-recursive grammars. GLL [20] can handle arbitrary context-free grammars, SPPF [16] There is a solution whish use GLL for CFPQ [6]

An idea to use combinators for graph traversing proposed in [11], but has some problems: cycles, left-recursive grammars Parser-combinators is one of classical approach for parsing!!!. Scala combinators for graph [11] — one of attempt to adopt combinators technique for graph processing. Only an idea of combinators using, but language class and restrictions are not discussed. Problems with cycles in graph. Ad-hoc solution. We propose a general solution. Problems with left-recursive grammars(???Should be checked)

Combinators for arbitrary grammars on GLL. Parser combinators library bsed on GLL — Meerkat [3] [10]. Can handle arbitrary context-free grammars Written in Scala

We show how to compose these ideas and get general solution for transparent integration of context-free constrained path querying language into general-purpose programming language.

We make the following contributions in this paper.

(1) We show that it is possible to create parser combinators for context-free path querying which supports both arbitrary contex-free grammars and arbitrary graphs and provide finite structural representation of query result.
(2) We provide the implementation of parser combinators library in Scala. This library provide integration with Neo4J graph data base. Source code available on GitHub:https://github.com/YaccConstructor/Meerkat.
(3) We perform an evaluation on realistic data. Also we compare performance of our library with other GLL-bsed CFPQ tool and with Trails library. As a result we conclude that our solution provide good expressivity and performance to be applied for real-world problems.

2 PARSER-COMBITATORS FOR PATH QUERYING

In this section we present our implementation of and describe some details.

Our implenemtation is based on Meerkat library. We need only some steps for generalization.

As far as linear input is a one of case of graph, it is possible to provide input abstraction which make possible to generalize combinators.

SPPF may be an arbitrary graph in opposite of linear input parsing.

Let we introduce an example. Graph. Grammar. In terms of combinators.

Interface for Neo4J bata base

Extensible solution

An architecture of the solution.

3 EVALUATION

In this section we present evalution of Meerkat grph querying library. We show its perfomance on a classical ontology graphs for in memory graph and for Neo4j database, show application on may-alias static code analysis problem, and compare with Trails [11] library for graph traversals.

All tests are perfomed on a machine running Fedora 27 with quad-core Intel Core i7 2.5 GHz CPU with 8 GB of memory.

3.1 Ontology querying

One of well-known graph querying problems is a queries for ontologies [1]. We use Meerkat to evaluate it on some popular ontologies presented as RDF files from paper [23]. We convert RDF files to a labeled directed graph like the following: for every RDF triple $(subject,\ predicate,\ object)$ we create two edges $(subject,\ predicate,\ object)$ and $(object,\ predicate^{-1},\ subject)$. On those graphs we apply two queries from the paper [6] which grammars are in Fig. 1, and Fig. 2

$$
\begin{aligned}
&S \to subClassOf^{-1}\ S\ subClassOf\\
&S \to type^{-1}\ S\ type\\
&S \to subClassOf^{-1}\ subClassOf\\
&S \to type^{-1}\ type
\end{aligned}
$$

Figure 1: Query 1 grammar

$$
\begin{aligned}
&S \to\ B\ subClassOf\\
&B \to subClassOf^{-1}\ B\ subClassOf\\
&B \to subClassOf^{-1}\ subClassOf
\end{aligned}
$$

Figure 2: Query 2 grammar

Meerkat represetaion of those queries in terms of parser combinators is similar to its EBNF form and presnted in Fig. 3 and Fig. 4

The queries applied in two following ways.

- Convert RDF files to a graph input for meerkat and then directly parse on query 1 and query 2
- Convert RDF files to a Neo4j database and then parse this database on given queries

Table 1 shows experimental results of those two aproaches over the testing RDF files where $number\ of\ results$ is a number of pairs of nodes $(v_1,\ v_2)$ such that exists S-path from v_1 to v_2.

[2]Cypher languge web page: https://neo4j.com/developer/cypher-query-language/. Access date: 16.01.2018
[3]Meerkat project repository: https://github.com/meerkat-parser/Meerkat. Access date: 16.01.2018

Ontology	#tripples	Query 1				Query 2			
		#results	In memory graph (ms)	DB query time (ms)	Trails (ms)	#results	In memory graph (ms)	DB query time (ms)	Trails (ms)
atom-primitive	425	15454	174	236	2849	122	49	56	453
biomedical-mesure-primitive	459	15156	328	398	3715	2871	36	52	60
foaf	631	4118	23	42	432	10	1	2	1
funding	1086	17634	151	175	367	1158	18	23	76
generations	273	2164	9	27	9	0	0	0	0
people_pets	640	9472	68	87	75	37	2	3	2
pizza	1980	56195	711	792	7764	1262	44	56	905
skos	252	810	4	29	6	1	0	1	0
travel	277	2499	23	93	34	63	2	2	1
univ-bench	293	2540	19	74	31	81	2	3	2
wine	1839	66572	578	736	3156	133	5	7	4

Table 1: Evaluation results for In Memory Graph and Graph DB

```
val S: Nonterminal = syn(
   "subclassof-1" ~~ S ~~ "subclassof" |
   "type-1" ~~ S ~~ "type" |
   "subclassof-1" ~~ "subclassof" |
   "type-1" ~~ "type")
```

Figure 3: Meerkat representation of Query 1

```
val S: Nonterminal = syn(
   "subclassof-1" ~~ S ~~ "subclassof" |
   "subclassof")
```

Figure 4: Meerkat representation of Query 2

The perfomance is about 2 times slower than in [6] and shows the same results. If compare the perfomance of in memory graph querying and database querying, the second one is slower in about $2 - 4$ times.

3.2 Static code analysis

Alias analysis is one of the fundamental static analysis problems [12]. Alias analysis checks may-alias relations between code expressions and can be formulated as a Context-Free language (CFL) reachability problem [17]. In that case program represeted as Program Expression Graph (PEG) [24]. Verticies in PEG are program expressions and edges are relations between them. In a case of analysisng C source code there is two kind of edges **D**-edge and **A**-edge.

- Pointer dereference edge (**D**-edge). For each pointer deference $*e$ there is a directed D-edge from e to $*e$.
- Pointer assignment edge (**A**-edge). For each assignment $*e_1 = e_2$ there is a directed A-edge from e_2 to $*e_1$

Also, for the sake of simplicity, there are edges labeled by $\overline{D}$ and $\overline{A}$ which corresponds to reversed D-edge and A-edge, respectively.

$$M \rightarrow \overline{D}\ V\ D$$
$$V \rightarrow (M?\ \overline{A})^*\ M?\ (A\ M?)^*$$

Figure 5: Context-Free grammar for the may-alias problem in syntax

Program	Code Size (KLOC)	Count of aliases		Time (ms)
		M aliases	V aliases	
wc-5.0	0.5K	0	174	350
pr-5.0	1.7K	13	1131	532
ls-5.0	2.8K	52	5682	436
bzip2-1.0.6	5.8K	9	813	834
gzip-1.8	31K	120	4567	1585

Table 2: Running may-alias queries on Meerkat on some C open-source projects

The grammar for may-alias problem from [24] presented in Fig. 5. It consists of two nonterminals **M** and **V**. It allows us to make two kind of queries for each of nonterminals **M** and **V**.

- **M** production shows that two l-value expression are memory aliases i.e. may stands for the same memory location.
- **V** shows that two expression are value aliases i.e. may evaluate to the same pointer value.

We made **M** and **V** queries on the code some open-source C projects. The results are presented on the Table 2

It may be usefull for tools development.

3.3 Comparison with Trails

Trails [11] is a Scala graph combinator library. It provides traversers for describing paths in graphs in terms of parser combinators and allows to get results as a stream (maybe infinite) of all possible paths described by composition of basic traversals. Trails as well as Meerkat support parsing in memory graphs, so we compare perfomance of Trails and Meerkat on the queries from subsection 3.1. Query 1 and Query 2 in terms of Trails are in Fig. 6 and Fig. 7.

Here queries made in same way as in Meerkat. S traversal returns pairs (*begin node*, *start node*) of S-path. Combine operators ~ and ~> in queries made in the way to get only last node from path.

```
val B = (out("type-1") ~> out("type")) |
   (out("subclassof-1") ~> B ~> out("subclassof")) |
   (out("type-1") ~> B ~> out("type")) |
   (out("subclassof-1") ~> out("subclassof"))
val S = V ~ B
```

Figure 6: Trails representation of Query 1

```
val B = out("subclassof") |
   (out("subclassof-1") ~> B ~> out("subclassof"))
val S = V ~ B
```

Figure 7: Trails representation of Query 2

The result of comparation are in table 1. Trails gives the same results as Meeerkat (column *results* in table 1) but slower than Meerkat.

4 CONCLUSION

We propose a native way to integrate language for language-constrained path querying into general purpose programming language. We implement it and show that our implementation can be applied for real problems. Arbitrary context-free grammars for querying.

Code is available on GitHub:

Future work is

Technical improvements: sppf as a set of paths, combinators for vertices information processing, etc

SPPF utilization for debugging and results processing

Attributed grammars processing to provide mechanim for semantics calcualtion, filtration, etc

REFERENCES

[1] Serge Abiteboul, Richard Hull, and Victor Vianu. 1995. Foundations of Databases. (1995).

[2] Pablo Barceló, Gaelle Fontaine, and Anthony Widjaja Lin. 2013. Expressive Path Queries on Graphs with Data. In *International Conference on Logic for Programming Artificial Intelligence and Reasoning*. Springer, 71–85.

[3] Chris Barrett, Riko Jacob, and Madhav Marathe. 2000. Formal-language-constrained path problems. *SIAM J. Comput.* 30, 3 (2000), 809–837.

[4] Tevfik Bultan, Fang Yu, Muath Alkhalaf, and Abdulbaki Aydin. 2018. String Analysis for Software Verification and Security. (2018).

[5] James Cheney, Sam Lindley, and Philip Wadler. 2013. A Practical Theory of Language-integrated Query. *SIGPLAN Not.* 48, 9 (Sept. 2013), 403–416. https://doi.org/10.1145/2544174.2500586

[6] Semyon Grigorev and Anastasiya Ragozina. 2017. Context-free Path Querying with Structural Representation of Result. In *Proceedings of the 13th Central & Eastern European Software Engineering Conference in Russia (CEE-SECR '17)*. ACM, New York, NY, USA, Article 10, 7 pages. https://doi.org/10.1145/3166094.3166104

[7] Jelle Hellings. 2014. Conjunctive context-free path queries. (2014).

[8] Jelle Hellings. 2015. Path Results for Context-free Grammar Queries on Graphs. *CoRR* abs/1502.02242 (2015). http://arxiv.org/abs/1502.02242

[9] Piotr Hofman and Wim Martens. 2015. Separability by short subsequences and subwords. In *LIPIcs-Leibniz International Proceedings in Informatics*, Vol. 31. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik.

[10] Anastasia Izmaylova, Ali Afroozeh, and Tijs van der Storm. 2016. Practical, General Parser Combinators. In *Proceedings of the 2016 ACM SIGPLAN Workshop on Partial Evaluation and Program Manipulation (PEPM '16)*. ACM, New York, NY, USA, 1–12. https://doi.org/10.1145/2847538.2847539

[11] Daniel Kröni and Raphael Schweizer. 2013. Parsing Graphs: Applying Parser Combinators to Graph Traversals. In *Proceedings of the 4th Workshop on Scala (SCALA '13)*. ACM, New York, NY, USA, Article 7, 4 pages. https://doi.org/10.1145/2489837.2489844

[12] Thomas J. Marlowe, William G. Landi, Barbara G. Ryder, Jong-Deok Choi, Michael G. Burke, and Paul Carini. 1993. Pointer-induced Aliasing: A Clarification. *SIGPLAN Not.* 28, 9 (Sept. 1993), 67–70. https://doi.org/10.1145/165364.165387

[13] Erik Meijer, Brian Beckman, and Gavin Bierman. 2006. LINQ: Reconciling Object, Relations and XML in the .NET Framework. In *Proceedings of the 2006 ACM SIGMOD International Conference on Management of Data (SIGMOD '06)*. ACM, New York, NY, USA, 706–706. https://doi.org/10.1145/1142473.1142552

[14] A. Mendelzon and P. Wood. 1995. Finding Regular Simple Paths in Graph Databases. *SIAM J. Computing* 24, 6 (1995), 1235–1258.

[15] Eric Prud, Andy Seaborne, et al. 2006. SPARQL query language for RDF. (2006).

[16] Joan Gerard Rekers. 1992. *Parser generation for interactive environments*. Ph.D. Dissertation. Universiteit van Amsterdam.

[17] Thomas Reps. 1997. Program Analysis via Graph Reachability. In *Proceedings of the 1997 International Symposium on Logic Programming (ILPS '97)*. MIT Press, Cambridge, MA, USA, 5–19. http://dl.acm.org/citation.cfm?id=271338.271343

[18] Juan L Reutter, Miguel Romero, and Moshe Y Vardi. 2015. Regular queries on graph databases. *Theory of Computing Systems* (2015), 1–53.

[19] Marko A Rodriguez. 2015. The gremlin graph traversal machine and language (invited talk). In *Proceedings of the 15th Symposium on Database Programming Languages*. ACM, 1–10.

[20] Elizabeth Scott and Adrian Johnstone. 2010. GLL parsing. *Electronic Notes in Theoretical Computer Science* 253, 7 (2010), 177–189.

[21] Petteri Sevon and Lauri Eronen. 2008. Subgraph queries by context-free grammars. *Journal of Integrative Bioinformatics* 5, 2 (2008), 100.

[22] Mihalis Yannakakis. 1990. Graph-theoretic methods in database theory. In *Proceedings of the ninth ACM SIGACT-SIGMOD-SIGART symposium on Principles of database systems*. ACM, 230–242.

[23] Xiaowang Zhang, Zhiyong Feng, Xin Wang, Guozheng Rao, and Wenrui Wu. 2016. Context-free path queries on RDF graphs. In *International Semantic Web Conference*. Springer, 632–648.

[24] Xin Zheng and Radu Rugina. 2008. Demand-driven Alias Analysis for C. In *Proceedings of the 35th Annual ACM SIGPLAN-SIGACT Symposium on Principles of Programming Languages (POPL '08)*. ACM, New York, NY, USA, 197–208. https://doi.org/10.1145/1328438.1328464