Implementation and experimental study of GLL algorithm with Neo4j graph database

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Introduction

- Graph data model
  - Basic entities — graph vertices
  - Relationships between entities are graph edges
- Graph databases
  - The most popular is Neo4j
  - Only regular queries are partially supported
- Context-free constraints
  - Strictly more expressive than the regular one
  - Widely used in bioinformatics, RDF file analysis, static code analysis

Context-free path querying problems

All-paths CFPQ problem and reachability CFPQ problem

Let be:

- *Context-free grammar* $\mathbb{G} = \langle N, \Sigma, P, S \rangle$
- *Directed graph* $\mathbb{D} = \langle V, E, T \rangle$
- *Set of start vertices* $V_S \subseteq V$ *and set of final vertices* $V_F \subseteq V$

All-paths problem:

- *Find all paths* $\pi = (e_1, \cdots, e_{n-1}, e_n),\ e_k = (v_{k-1}, t_k, v_k)$ *in graph* $\mathbb{D}$*, such as* $l(\pi) = t_1 t_2 \cdots t_n \in L(\mathbb{G})$ *and* $v_0 \in V_S,\ v_n \in V_F$

Reachability problem:

- *Find all pairs* $\{(v_0, v_n) \mid \text{exists a path } \pi = (e_1, \cdots, e_{n-1}, e_n),\ e_k = (v_{k-1}, t_k, v_k) \text{ in } \mathbb{D},\ v_0 \in V_S,\ v_n \in V_F,\ l(\pi) = t_1 t_2 \cdots t_n \in L(\mathbb{G})\}$

Motivation

- The problem of poor performance of CFPQ algorithms was formulated by Jochem Kuijpers as a result of an attempt to extend Neo4j[1]
- Later, the matrix-based CFPQ algorithm showed high performance on real-world data

[1] An Experimental Study of Context-Free Path Query Evaluation Methods / Jochem Kuijpers, George Fletcher, Nikolay Yakovets, Tobias Lindaaker / SSDBM '19

Goal and tasks

The aim of this work is to improve existing CFPQ algorithm for the Neo4j graph database[2] and evaluate it
Tasks:

- To make initial experiments and analysis of existing algorithm to identify performance problems
- To refactor the code of the current implementation of the GLL-based CFPQ algorithm in order to identifying and eliminate performance problems of the current implementation of the algorithm
- To provide an ability to obtain information about both reachability CFPQ problem in a graph and all paths CFPQ problem
- To evaluate the resulting algorithm on real-world graphs and to compare it with an existing one

[2] Algoruthm implementation: `https://github.com/JetBrains-Research/GLL4Graph/tree/8be59e6b314a1bfa646b119f751b3f28ad34ac64`

Overview

Generalized LL algorithm (GLL)

- Supports the entire class of context-free languages
- To reconstruct the paths, the Shared Packed Parse Forest (SPPF) is used

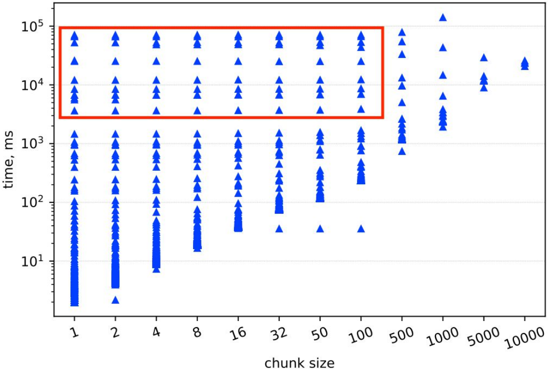
Proposed solution

- Based on GLL algorithm implementation in Iguana[3] project made at CWI Amsterdam in 2016
- Neo4j graph database is used as a graph storage
- The solution was integrated with Neo4j using Native Java API

[3] Repository of Iguana project: `https://github.com/iguana-parser/iguana`

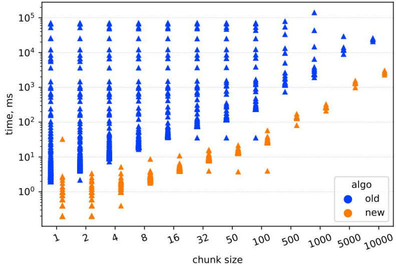
Initial experiments

An unexpected deterioration in the behavior of the resulting solution was revealed in the multiple-source scenario

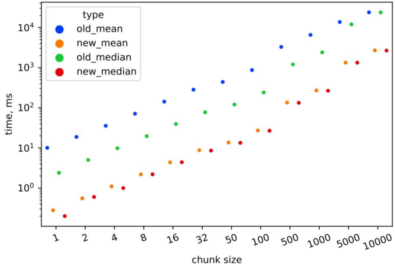


Grammar G_2 and Enzyme

- The modification of the way to get vertices from Neo4j graph database
- The optimization of transition between vertices while graph traversal
- The optimization of procedure for getting edge labels
- The change of result data representation



Query time

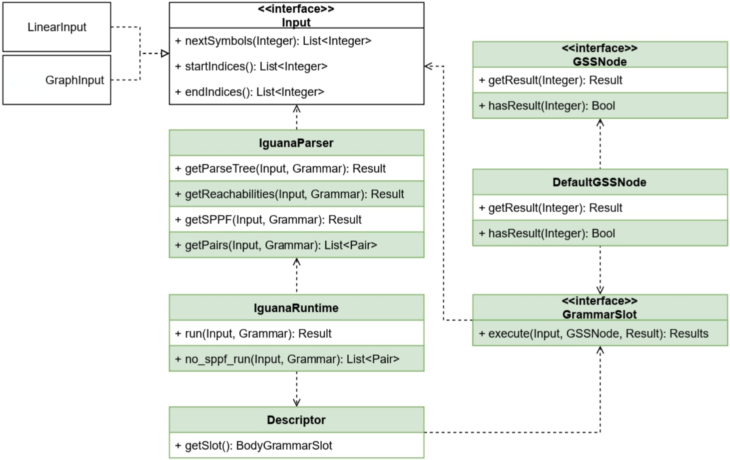


Median and mean time

Grammar G_2 and Enzyme

Extension to solve the reachability problem

The ability to switch between the SPPF construction and reachability facts calculation was provided



Architecture of the proposed solution

Experimental study setup

Data

- **RDF Graphs**
  - *Grammars*

$$S \to \overline{subClassOf}\ \ S\ subClassOf \mid \overline{type}\ \ S\ type \mid \overline{subClassOf}\ \ subClassOf \mid \overline{type}\ type \quad (G_1)$$

$$S \to \overline{subClassOf}\ \ S\ subClassOf \mid subClassOf \quad (G_2)$$

$$S \to broaderTransitive\ \ S\ \overline{broaderTransitive} \mid broaderTransitive\ \ \overline{broaderTransitive} \quad (Geo)$$

- **Program analysis graphs**
  - *Grammar*

$$\begin{aligned} M &\to \overline{d}\ \ V\ \ d \\ V &\to (M?\ \overline{a})^*\ \ M?\ (a\ \ M?)^* \end{aligned} \quad (PointsTo)$$

All pairs results for graphs related to **RDF analysis**

Graphs considered

Graphs	$\|V\|$	$\|E\|$	#subClassOf	#type	#broaderTransitive
Core	1 323	2 752	178	0.	0
Pathways	6 238	12 363	3 117	3 118	0
Go hierarchy	45 007	490 109	490 109	0	0
Enzyme	48 815	86 543	8 163	14 989	8 156
Eclass	239 111	360 248	90 962	72 517	0
Geospecies	450 609	2 201 532	0	89 065	20 867
Go	582 929	1 437 437	94 514	226 481	0
Taxonomy	5 728 398	14 922 125	2 112 637	2 508 635	0

Results

Graphs	G_1		G_2		Geo	
	time (sec)	#answer	time (sec)	#answer	time (sec)	#answer
Core	0,02	204	0,01	214	–	–
Pathways	0,07	884	0,04	3117	–	–
Go hierarchy	3,68	588 976	5,4	738 937	–	–
Enzyme	0,22	396	0,17	8163	5,7	14 267 542
Eclass	1,5	90 994	0,98	96 163	–	–
Geospecies	2,87	85	2,65	0	145,8	226 669 749
Go	5,56	640 316	4,2	659 501	–	–
Taxonomy	45,47	151 706	36,07	2 112 637	–	–

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All pairs results for graphs related to **static code analysis**

Graphs considered

Graphs	$\|V\|$	$\|E\|$	#a	#d
Apache	1 721 418	1 510 411	362 799	1 147 612
Block	3 423 234	2 951 393	669 238	2 282 155
Net	4 039 470	3 500 141	807 162	2 692 979
Postgre	5 203 419	4 678 543	1 209 597	3 468 946
Init	2 446 224	2 112 809	481 994	1 630 815
Drivers	4 273 803	3 707 769	858 568	2 849 201
Kernel	11 254 434	9 484 213	1 981 258	7 502 955

Results

Graphs	*PointsTo*		
	GLL time (sec)	#answer	Matrix time (sec)
Apache	–	92 806 768	536,703
Block	113,01	53 514 095	123,88
Net	160,64	8 833 403	206,29
Postgre	–	90 661 446	969,89
Init	87,25	3 783 769	45,84
Drivers	371,18	18 825 025	279,39
Kernel	614,05	16 747 731	378,05

All pairs results for graphs related to **static code analysis**

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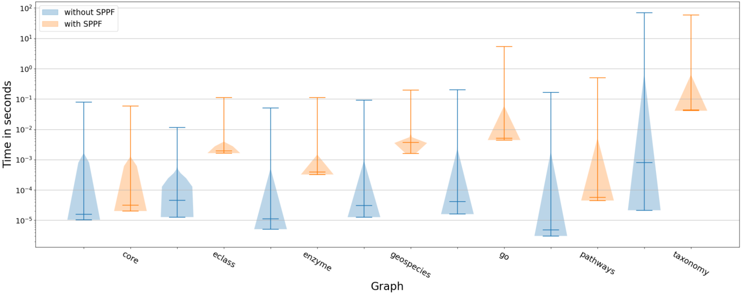
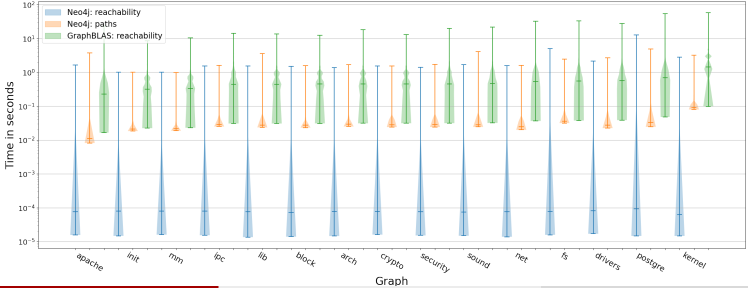
Single-source results





Results

- There were made initial experiments and analysis which confirmed performance problems
- The performance problems in the implementation of the GLL-based CFPQ algorithm were eliminated
- The implementation of GLL-based CFPQ algorithm was extended with ability to solve the reachability CFPQ problem
- The resulting algorithm implementation was evaluated on two sets of real-world graphs: a number of graphs related to RDF analysis and a number of graph related to static code analysis problem for both the *all pairs* and the *multiple sources* scenarios. The evaluation shows that the proposed algorithm is more than 45 times faster than the previous solution for Neo4j