Parsing techniques for graph analysis

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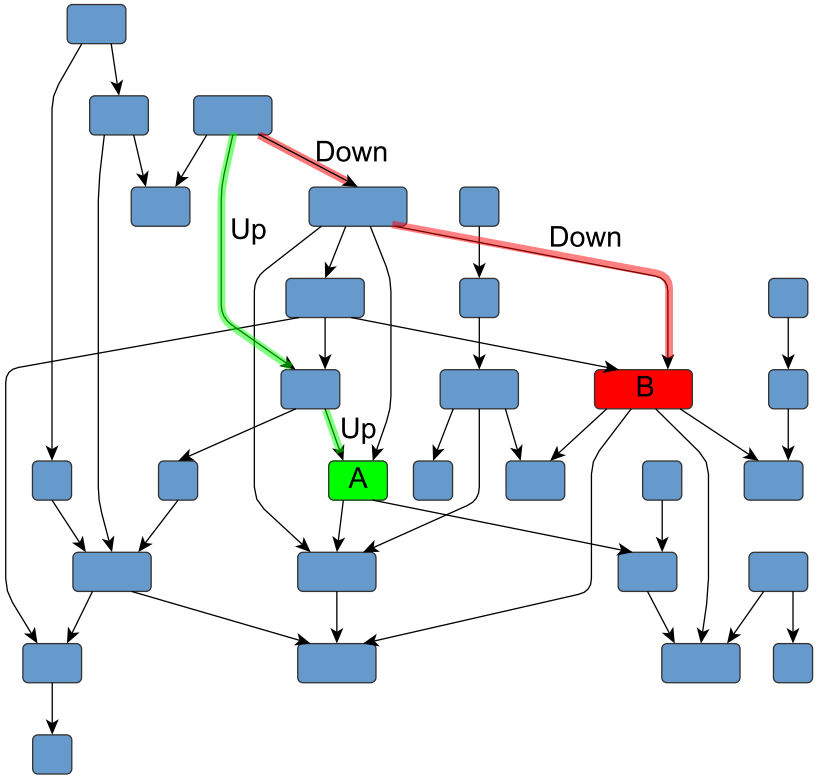
Language-constrained paths filtering



Navigation through a graph

- Are nodes A and B on the same level of hierarchy?
- Is there a path of form $\mathbf{Up}^n\,\mathbf{Down}^n$?
- Find all paths of form $\mathbf{Up}^n\,\mathbf{Down}^n$ which start from a node A.

- (How) Can this automaton generate phrases in some cpecific (context-free) languge?
- (How) Can this program produce some specific chain of calls?

Language-constrained paths filtering: more formal

- $\mathbb{G} = (\Sigma, N, P)$ — context-free grammar
- $G = (V, E, L)$ — directed graph
  - $v \xrightarrow{l} u \in E \subseteq V \times L \times V$
  - $L \subseteq \Sigma$
- $p = v_0 \xrightarrow{l_0} v_1 \xrightarrow{l_1} \cdots \xrightarrow{l_{n-2}} v_{n-1} \xrightarrow{l_{n-1}} v_n$ — path in G
- $\omega(p) = \omega(v_0 \xrightarrow{l_0} v_1 \xrightarrow{l_1} \cdots \xrightarrow{l_{n-2}} v_{n-1} \xrightarrow{l_{n-1}} v_n) = l_0 l_1 \cdots l_{n-1}$
- $R = \{p \mid \text{ exists } N_i \in N \text{ such that } \omega(p) \in L(\mathbb{G}, N_i)\}$

Applications

- Graph analysis
  - Graph database querying
  - Network graph analysis
- Code analysis
  - Static analysis CFL(linear conjunctive) reachability
    - alias analysis
    - points-to analysis
  - Dynamically generated strings analysis
  - Multiple input parsing
- ...

Existing solutions

- Do not use the power of advanced parsing techniques
  - Mostly based on CYK
    (Xiaowang Zhang, et al. “Context-free path queries on RDF graphs.”; Jelle Hellings. “Conjunctive context-free path queries.”)
  - Do not provide useful structural representation of result
- Impose restrictions on input
  - Problems with cycles in the input graph
    (Petteri Sevon, Lauri Eronen. “Subgraph queries by context-free grammars.”)

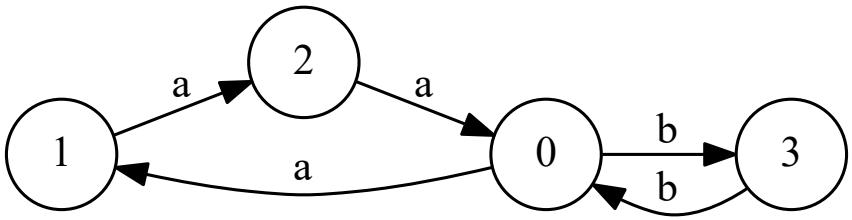
Open problems

- Effective algorithm development
- Result representation for debugging; further processing
- GPGPU utilization
- Processing of different types of grammars (ECFG, conjunctive, etc)

Bar-Hillel theorem

- Context-free languages are closed under intersection with regular languages
- Parsing algorithms are constructive proof of Bar-Hille theorem for one simple case . . .
- . . . so, classical parsing can be generalized for arbitrary regular language processing

Example

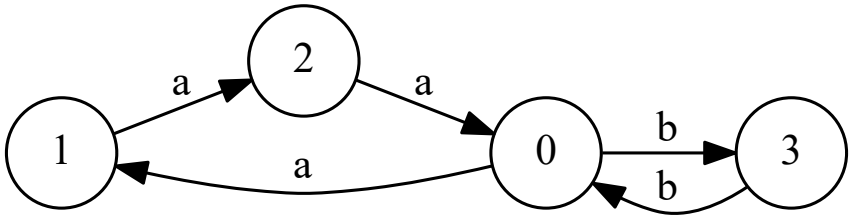


Input graph

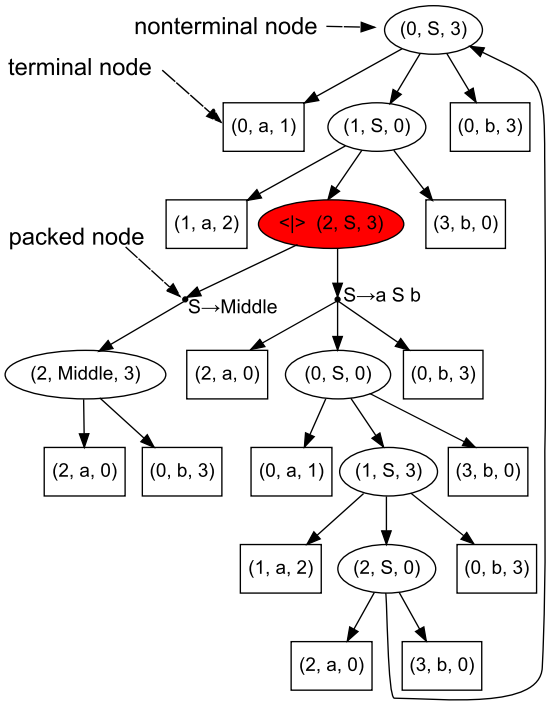
$$
\begin{aligned}
0: &\quad S \rightarrow a\ S\ b \\
1: &\quad S \rightarrow Middle \\
2: &\quad Middle \rightarrow a\ b
\end{aligned}
$$

Query: a grammar for the language $L = \{a^n b^n; n \geq 1\}$ with an additional marker for the middle of a path

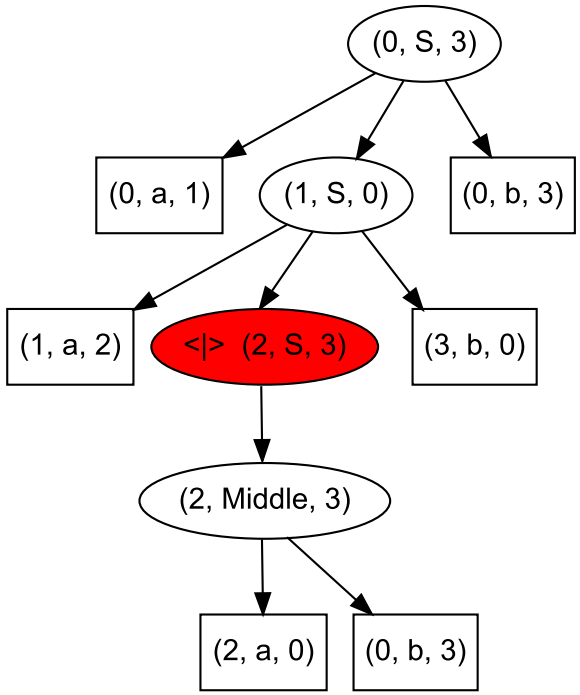
Example



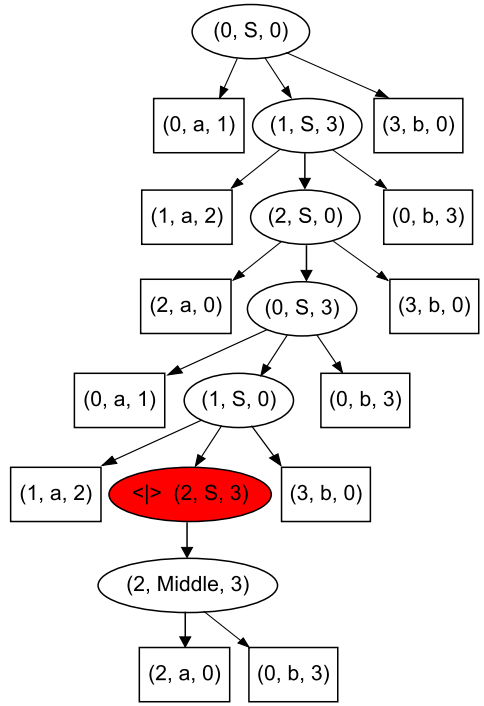
Input graph



Query result: SPPF



Tree for path from 0 to 3



Tree for path from 0 to 0

Our solutions

- Relaxed parsing of dynamically generated SQL-queries
  - Based on RNGLR parsing algorithm (Elizabeth Scott, Adrian Johnstone)
- Context-free path querying with structural representation of result
  - Based on GLL parsing algorithm (Elizabeth Scott, Adrian Johnstone)
- Combinators for context-free path querying
  - Based on the Meerkat: a general parser combinator library for Scala (Ali Afroozeh, Anastasia Izmaylova)
- Context-free path querying by matrix multiplication
  - Inspired by Leslie Valiant and Alexander Okhotin

Future work

- Other grammars and language classes intersection
  - Context-free grammars intersection: Mark-Jan Nederhof, "The language intersection problem for non-recursive context-free grammars"
  - Approximated intersection of regular and conjunctive/boolean languages
  - ...
- Mechanization in Coq
  - Bar-Hillel theorem
  - GLL-based algorithms
  - ...
- New areas for application

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