Generalized LL parsing for context-free constrained path search problem

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Path querying is an actual problem in bioinformatic, graph databases, ... One of specific problem is formal languages path problem [?] which meens that paths constraints formulated as $G = (N, \Sigma, P)$ and $M = (V, E, L)$ where V — vertices set, $L \subseteq \Sigma$ — edges labels set, $E \subseteq V \times L \times V$. Let $tag(e = (v_1, l, v_2), e \in E) = l$. Let $\oplus$ — concatenation operation. Query may be specified as context-free grammar: path $p = e_0, \ldots, e_n$, $\omega = tage_0 \oplus \cdots \oplus tage_n$, $\omega \in L(G)$.

As an example let we want to find all path with form $A^n B^n$ where $n \geq 1$: $\{AB; AABB; AAABBB; \ldots\}$. This constraint can not be specified with regular language as far as $L = \{a^n b^n; n \geq 1\}$ is not regular but context free. Required language can be specified by grammar G presrnted in picture **??**. Here s and $middle$ are nonterminals and A and B are terminals and we meens that edges of input graph tagged by them.

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s: A s B | middle
middle: A B
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Figure 1: Grammar G for language $L = \{a^n b^n; n \geq 1\}$

We propose a context-free language constrained path problem solution which allow to find all paths and construct implicit representation of result.

Our solution is based on generalized LL (GLL) [?] parsing algorithm which allow to process arbitrary context-free grammars. Complexity is $O(n^3)$ in worst case and linear for unumbigues grammars, that better then complexity of CYK and Erly which used as base in other solutions. Input is set of start vertices, set of final vertices, grammar, graph. Output — finite data structure which contains all paths As far as we can specify sets of start and final vertices, our solution can find all paths in graph, all paths from specified vertice, all paths between specified vertices.

All-path semantic — SPPF constructed by algorithm contains all paths matched with specified constraints. Let we introduce the next example. Grammar G is a query and we want to find all paths in graph M (presented in picture **??**) matched this query. SPPF for grammar $G = (N, \Sigma, P)$ and graph $M = (V, E, L); L \subseteq \Sigma$ is presented in picture **??**.

We use next markers for nodes.

- Node with rectangle shape labeled with $(T(v_0, v_1))$ is terminal node. Each terminal node corresponds with edge in the input graph: for each node with label $(T(v_0, v_1))$ there is $e \in E : e = (v_0, T, v_1)$. Duplication of terminal nodes is only for figure simplification.
- Node with oval shape labeled with $(nt(v_0, v_1))$ is nonterminal node. This node meens that there is at least one path p from vertice v_0 to vertice v_1 in input graph M such that $nt \Rightarrow^*_G p$. All paths matched this condition can be extracted by subgraph traversal.
- Filled node with oval shape labeled with $(nt <|> (v_0, v_1))$ is nonterminal node where v_0 v_1
- Node with dot shape is used for representation of derivation varians. Subghraph with root in one such node is one variant of derivation.

Extensions allow to check whether path from u to v exists and extract it. Path extraction is SPPF traversal. For example ....

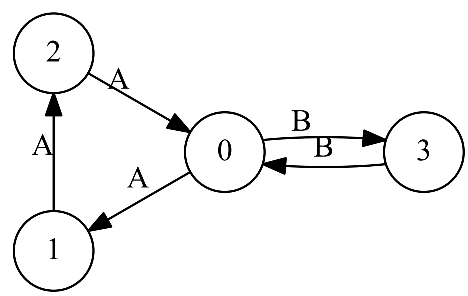

Figure 2: Input graph M

SPPF contains infinite set of paths (cycles in SPPF). Also its represent a structure of pats: 'middle' of any path in example above can be found simply by finding corresponded nonterminal *middle* in SPPF. It may be useful not only for results understanding and processing but also for query debugging especially for complex queries.

1. REFERENCES

[1] Miller, J. A., Ramaswamy, L., Kochut, K. J., & Fard, A. (2015, June). Research Directions for Big Data Graph Analytics. In 2015 IEEE International Congress on Big Data (pp. 785–794). IEEE.
[2] Scott, E., & Johnstone, A. (2010). GLL parsing. Electronic Notes in Theoretical Computer Science, 253(7), 177–189.
[3] Hellings, J. (2014). Conjunctive context-free path queries.

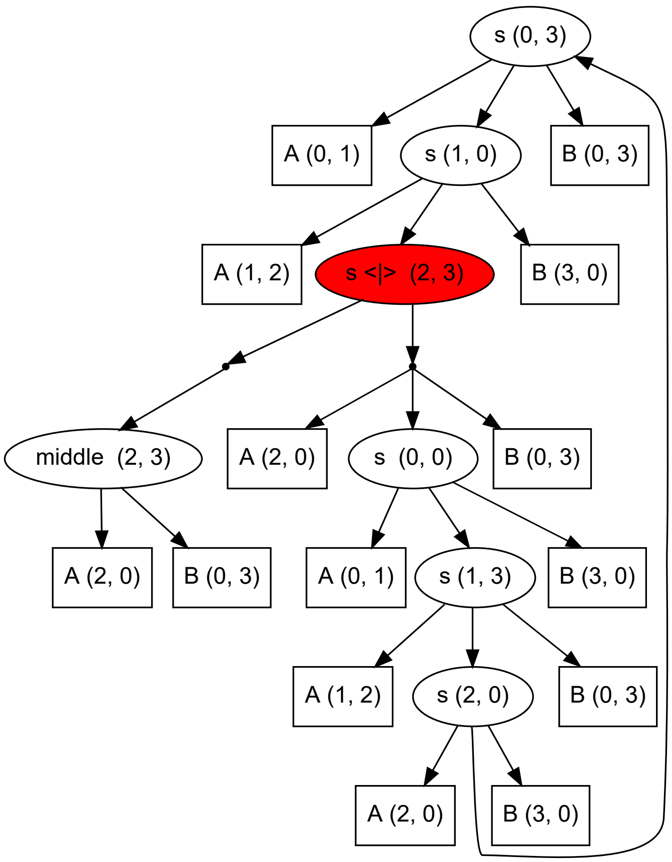

Figure 3: Result SPPF for input graph M(pic. ??) and query G(pic. ??)

[4] Hellings, J. (2015). Querying for Paths in Graphs using Context-Free Path Queries. arXiv preprint arXiv:1502.02242.