Bring Graph Querying, Formal Language Theory, and Linear Algebra Together to Make It Better

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ABSTRACT

A clear and well-documented LaTeX document is presented as an article formatted for publication by ACM in a conference proceedings or journal publication. Based on the "acmart" document class, this article presents and explains many of the common variations, as well as many of the formatting elements an author may use in the preparation of the documentation of their work.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

KEYWORDS

Graph querying, formal language theory, formal language constrained path querying, education

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1 INTRODUCTION

Bridging the gap between fundamental disciplines and application is one of the important problems of education in software engineering. At the same time, real-world problems requires huge amount of preparatory work before the !!!

Data analysis involves broad range of !!! . Graph analysis. Application of fundamental ones. Motivation for students which focused on applied areas to study fundamental disciplines

Integration of formal language theory + HPC + linear algebra + graphs to show interconnection between different areas. How concepts and ideas from one area can be applied in another one with significant effect.

For engineers, so it is important to equip theory with practical tasks to !!!motivate!!!. Historically, programming languages and natural language processing form an area of formal languages theory application

In this work we describe our experience on such a course for third-year bachelor students. Software engineering. Structure of this work:

- Motivation: why we do exactly what we do and why we do it exactly such a way.
- Course structure: technical environment, Exercises and how they are related to !!!
- Discussion of !!!

2 MOTIVATION

We are aimed to create an applied course which allow students to touch !!!! !!! !!!

Why formal language constrained path querying. Formal languages is not only parsing.

Immediate and direct usage of theory to solve practical tasks: Closure properties. Languages intersection. Results representation — languages representation. Complexity analysis.

Parsing algorithms and new old problems: incremental parsing, parallel parsing. New context (amount of data to process, etc)

Linear algebra provides a suitable abstraction level. Optimizations !!! HPC, matrices, easy to abstract. One can easily replace one library with another without significant algorithm changes (but technical effort for different API-s). As a result, easy to apply for real-world data. Which also helps to solve a motivation problem (small synthetic tasks looks disconnected with real-world).

Selected algorithms can be expressed in terms of boolean matrices and vectors: easy to start. No need to create custom semirings. At the same time, native description of these algorithms requires custom semirings introduction. Conversion techniques. Weaker than semirings structure.

Relations with other areas such as graph theory, dynamic graph problems, algebra.

Touch open problems (truly subcubic CFPQ) and motivate to study them (and respective fundamentals eg fine-grained complexity).

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3 COURSE

While initially our course is a practical part of formal language theory course we think that it can be easily adopted to advanced part of data analysis course. So

Prerequirements: linear algebra basics, Python programming (intermediate level). Basic graph theory (can be introduced on the fly if required).

As advanced extension for formal language theory basics or as a part of formal language theory course. Or as an advanced part of data analysis course. Respect it, parts may be !!! more or less deep and detailed.

3.1 Environment

Automatization. Python programming language, PyFormLang[1] [1] for basis forma languages concepts: regular expressions, finite automata, context-free grammars, recursive automata, and operations over them (automata minimization, regular expression to finite automata conversion) , CFPQ-Data[2] as a collection of graphs and queries, sciPy[3] for sparse linear algebra, pyGrpahBlas[4] for advanced sparse linear algebra, pyCubool[5] [**?**], Google colab.

Testing (unit tests), code style guide checkers, automation using GitHUb actions.

3.2 Structure

The course is structured with respect to typical FL. Important aspects of formal language theory

(1) Introduction to formal languages, problem statement (FLPQ), different semantics (reachability, paths). Problems (infinite number of paths, representation of such a set, desidability for different languages classes). String to graph generalization. Applications (examples, differences in static code analysis). Differences with languages processing (grammar not fixed, input not fixed).
(2) Introduction to graphs and linear algebra. Matrices, edge-labelled graphs. With respect to initial level of students.
(3) Regular languages, queries. Closure properties, languages representations (regular expression, finite automata).
(4) Context-Free languages, queries. Closure properties. Language representations (grammars, RSMs).

3.3 Exercises

Focused on reachability problem.

(1) All-pairs RPQ, tensors. Basic FA intersection algorithm. (commutativity of Kronecker product)
(2) RPQ multiple-source BFS-based. Another algorithm for automata intersection. Different versions of multiple-source BFS problem (set-to-set, etc).
(3) RPQ evaluation and performance analysis. Different matrices formats etc. All-pairs vs multiple sources. Advanced: GPU or GraphBLAS. Easy switch.
(4) CFPQ Hellings. Pretty naive algorithm without LA. Baseline for comparison with other algorithms.
(5) CFPQ matrices (associativity and commutativity of operations), normal form for grammar.
(6) CFPQ tensors (unification of RPQ and CFPQ), RSF introduction.
(7) CFPQ evaluation and performance analysis. Different algorithms comparison. Advanced: GPU or GraphBLAS
(8) Query language design. Introduction of GQL and other real-world languages.
(9) Query language implementation

Can be splitted in subtasks or equipped with additional intros (for example, simple tasks aimed to introduce new library).

Outcomes FLPQ HPC

4 DISCUSSION

Motivation to study formal languages, refresh algebra, HPC.... Why matrices: pretty simple ideas and algorithms, rather than LR, hides implementation complexity, clear abstraction (it is easy to realize that one library of linear algebra operations can be replaced with another one). More over, students can do it yourself.

Also we want to highlight some drawbacks and weakness of our course. First is that non-linear-algebra-based algorithm for FLPQ (and parsing, respectively) are missed. Based on GLR, GLL. These algorithms are Powerful (can natively solve all-paths queries), but require special techniques that cannot be natively inferred from linear-algebra-based algorithms. Especially high-performance solution. Looks like advanced block.

Hides basics of some concepts. But it learns to use existing libraries that is a useful skill, and allows students to touch real-world problems and tasks.

Possible directions Multiple sources versions of algorithms for CFL-r (linear-algebra based). But it should be simplified first. A bit more concepts required. Non matrix based algorithms. Beyond context-free (MCFG). Desidability problems, so on. To build an advanced course on data analysis.

REFERENCES

[1] Julien Romero. 2021. Pyformlang: An Educational Library for Formal Language Manipulation. In *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education* (Virtual Event, USA) *(SIGCSE '21)*. Association for Computing Machinery, New York, NY, USA, 576–582. https://doi.org/10.1145/3408877.3432464

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