Suffix tree construction with minimized branching

MASTER'S THESIS

Peter Bašista

Charles University in Prague
Faculty of Mathematics and Physics

Supervisor: RNDr. Tomáš Dvořák, CSc.
Reviewer: Mgr. Rudolf Kadlec

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Suffix tree

A tree-like data structure for performing fast search-like operations on strings.

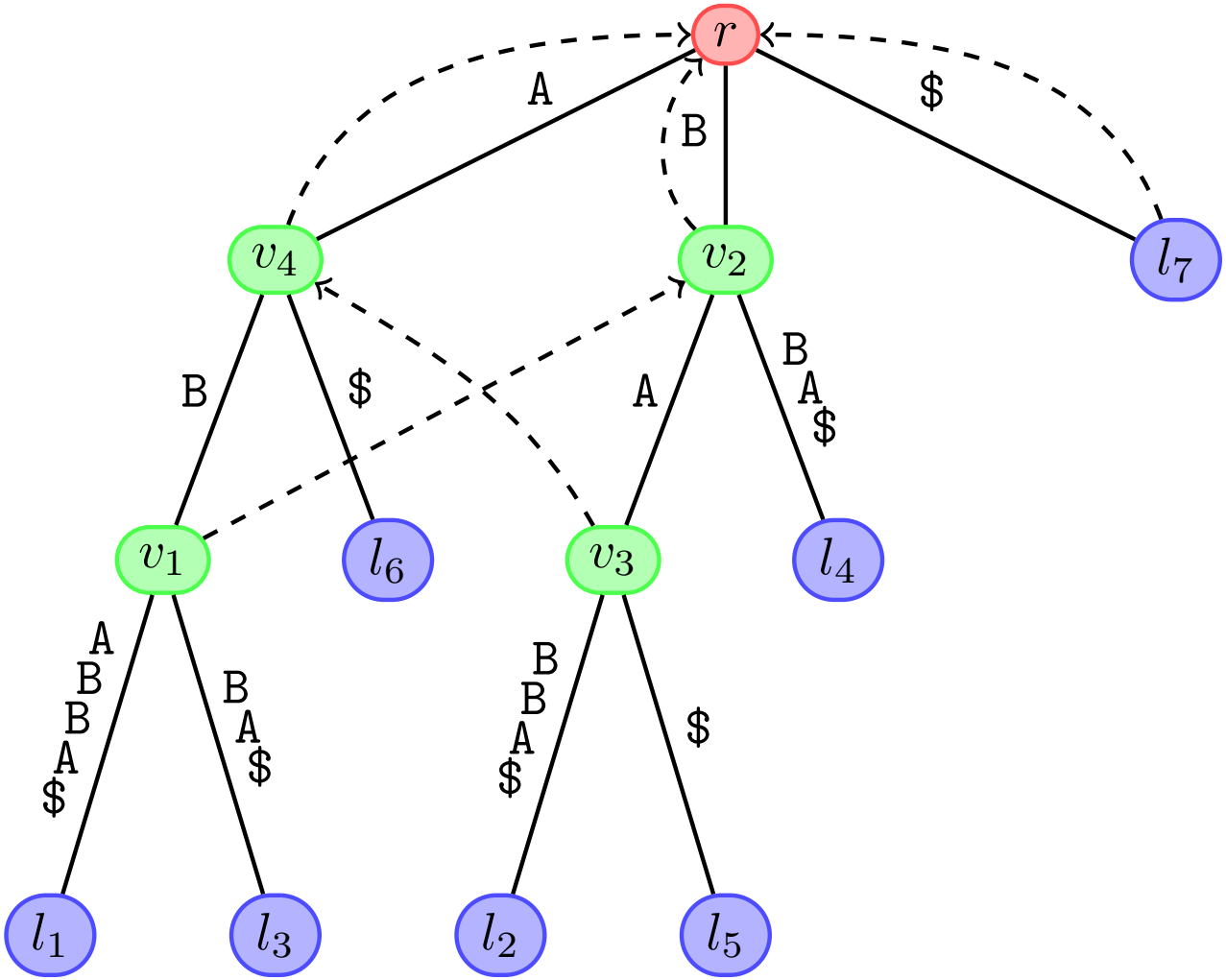
Properties

- Search for a pattern occurrence in $\mathcal{O}(|pattern|)$ time.
- Most implementations require 20–36 bytes per each input character in the worst case.

Some applications

- Bioinformatics
  - searching for patterns in DNA and protein sequences
- Finding repetitive text structures
- Pattern matching using wildcards or regular expressions

Example suffix tree on top of the text ABABBA$



Introduction

Suffix tree construction

- entirely in memory
- over a sliding window

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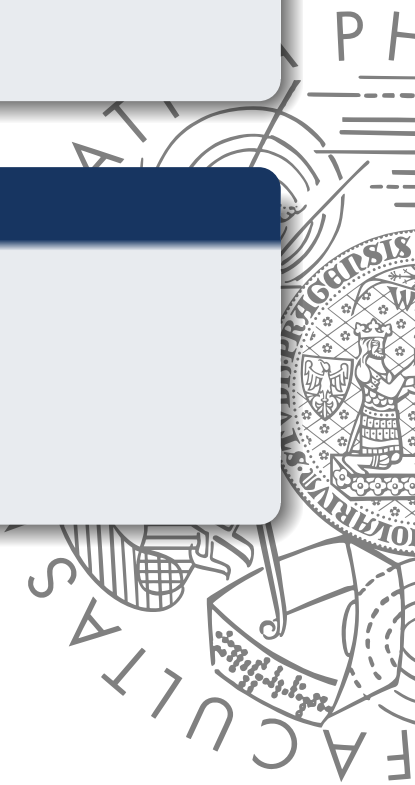
Goals

- theoretical analysis
- implementation
- experimental evaluation



Minimized branching

What is it?

An alternative method for suffix link simulation introduced by Senft and Dvořák, 2012.

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Suffix link simulation

- Top-down
- *Bottom-up*

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Applicable to the algorithms by

- McCreight (1976)
- Ukkonen (1992)

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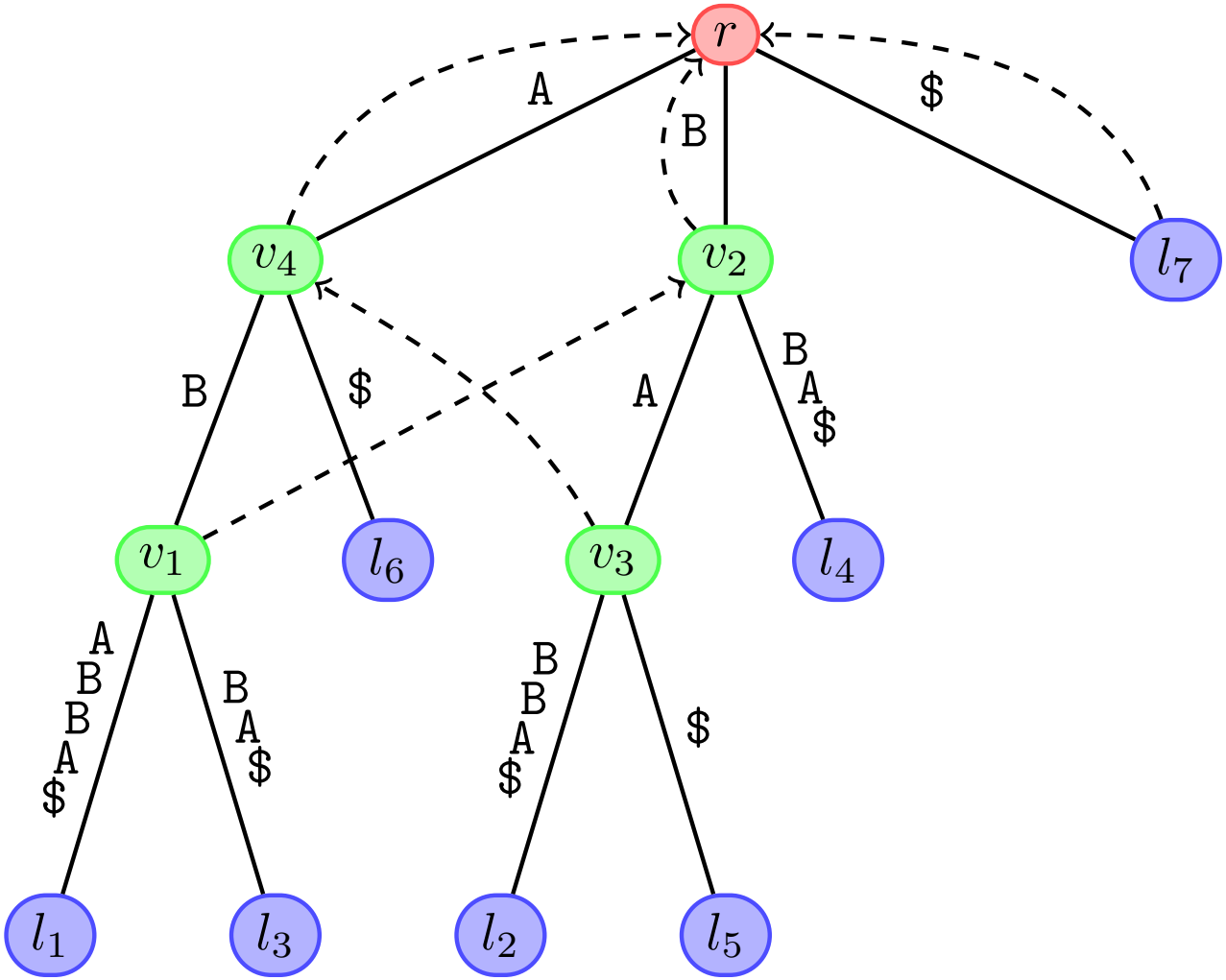

Examined methods of suffix tree construction

Algorithms

- McCreight's (1976)
- Ukkonen's (1992)
- Partition and Write Only Top Down — PWOTD (Tata, Hankins, Patel, 2004)

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Implementation techniques

- Simple Linked List (Kurtz, 1999)
- Simple Hash Table (Kurtz, 1999)
- Simple Linear Array (Tata, Hankins, Patel, 2004)

Experiments conducted

Implementations used

- implementation by Senft and Dvořák, 2012
- SLLI implementation by S. Kurtz, 1999
- PWOTD implementation by Tata, Hankins, Patel, 2004
- our own implementation

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Data used

- pseudorandom input files
- standard corpus files (Pizza & Chili and Lightweight corpus)
- special input files

Results

Description of the algorithms

- We have presented unified descriptions and definitions of every algorithm and its variation analyzed in this thesis.

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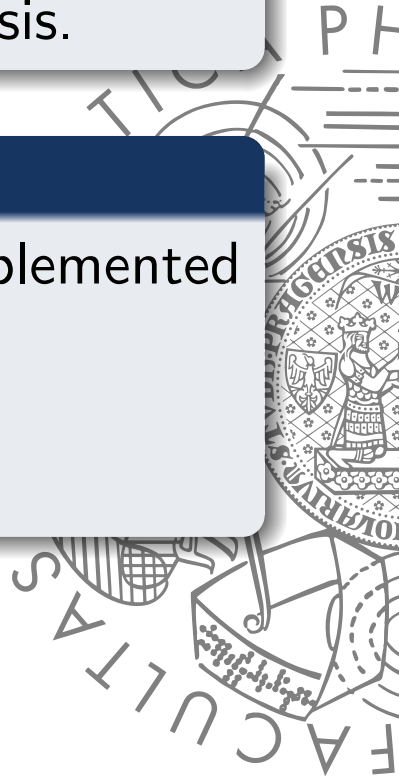
The implementation

- Every algorithm and implementation technique is implemented using similar level of detail and quality.
- Compilable on typical UNIX platforms.
  - tested on Linux and Mac OS X



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- McCreight's / Ukkonen's algorithms vs. PWOTD
  - PWOTD often computes the length of the lcp
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  - lower alphabet size $\Longrightarrow$ use linked lists
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- linked lists vs. hash table
  - lower alphabet size $\Longrightarrow$ use linked lists
  - higher alphabet size $\Longrightarrow$ use hash table
- percolating update vs. batch update
  - both methods have constant amortized time complexity
  - percolating update makes use of suffix tree traversal during the construction $\Longrightarrow$ its constant is smaller

Experimental results

McCreight's / Ukkonen's algorithms vs. PWOTD

- PWOTD is faster on pseudorandom files
- McCreight's / Ukkonen's algorithms are faster on corpus files
  - PWOTD is slow on files with large average lcp

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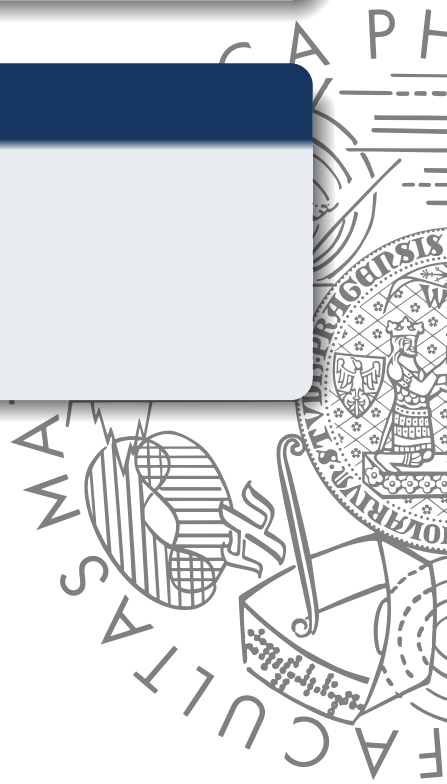
top-down vs. bottom-up suffix link simulation

- bottom-up method *usually* outperforms top-down
- suffix tree construction time is reduced by 5–10%
  - except for special, adversary strings



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percolating update vs. batch update

- percolating update is *almost* always faster
  - pseudorandom files: construction time is reduced by 5–10%
  - corpus files: the reduction is larger, typically around 15%

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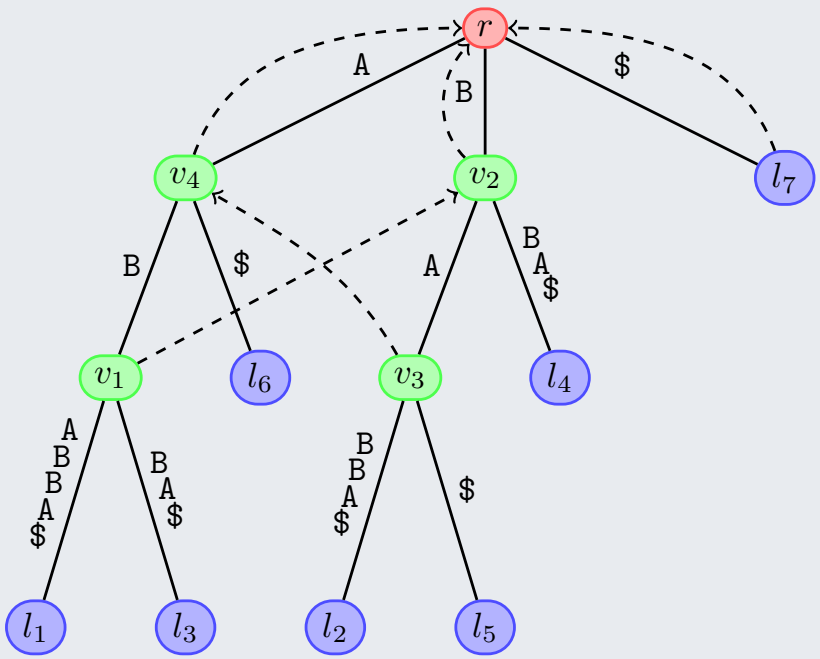
Suffix tree traversal log

Human readable suffix tree representation:

`P(number)[depth]--"label"(length)-->C(number)[depth]{suffix link}`

Suffix tree



DFS traversal log

```
Suffix tree traversal BEGIN
P(1)[0]--"a"(1)-->C(5)[1]{1}
P(5)[1]--"b"(1)-->C(2)[2]{3}
P(2)[2]--"abba$"(5)-->C(-1)[7]
P(2)[2]--"ba$"(3)-->C(-3)[5]
P(5)[1]--"$"(1)-->C(-6)[2]
P(1)[0]--"b"(1)-->C(3)[1]{1}
P(3)[1]--"a"(1)-->C(4)[2]{5}
P(4)[2]--"bba$"(4)-->C(-2)[6]
P(4)[2]--"$"(1)-->C(-5)[3]
P(3)[1]--"ba$"(3)-->C(-4)[4]
P(1)[0]--"$"(1)-->C(-7)[1]
Suffix tree traversal END
```

Repetitive structures

maximal pair

a pair of identical substrings impossible to extend in any direction

...GTTATTATTC...

maximal repeat

a substring whose occurrences form a maximal pair

...TACTGACGTTGTC...

supermaximal repeat

A maximal repeat which is not a substring of any other maximal repeat. In the text ACGGCCGTACGA:

- CG is a maximal repeat, but it is not supermaximal
- ACG is a supermaximal repeat