String Matching

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Given a string P (*the pattern*) and a longer string T (*the text*).
Find all occurrences of pattern P in text T.

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Example

- $P = aba$ and $T = bbabaxababay$.
- P occurs in T at positions 3, 7, and 9.
- Note: Occurrences may overlap!

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Terminology Confusion

- Substring: *aba* in *bbabaxababay*.
- Subsequence: *aba* in *bbabxaababay*.

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Literature

Dan Gusfield, *Algorithms on Strings, Trees, and Sequences*, New York, 1997

String Matching Algorithms

Classical comparison-based methods

- Naive Approach
- Boyer-Moore
- Knuth-Morris-Pratt (KMP)
- Rabin-Karp

Improvements result from preprocessing of the given pattern P.

Methods based on special data structures

- Data Structures: Suffix-Tries, Suffix-Trees, Suffix-Arrays.
- Improvements result from preprocessing of the given text T.
- Good for finding many different patterns in the text.

Naive Approach

Naive Approach

```
n = text.size();
m = pattern.size();

for s = 0 to n - m {
  if (pattern[1 .. m] = text[s+1 .. s+m]) {
    add_result(s);
  }
}
```

For $T = a^n$, $P = a^m$ and $m = n/2$ the worst case occurs, yielding a running time of $\Theta(n^2)$.

Boyer-Moore

Key Ideas

- Right-to-left scan.
- Bad character rule.
- The good suffix rule.

- Possible that some text characters are never compared.
- Preprocessing stage needed for efficient use of the bad character rule and good suffix rule.
- In practice one of the best known algorithms for string matching.
- Good explanation in *Dan Gusfield, Algorithms on strings trees and sequences*.

Boyer-Moore

Bad Character Rule

```
T: prstaqstubabvqxrst
                |
P:    qcabdaedab
```

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Boyer-Moore

The Good Suffix Rule

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Boyer-Moore

The Good Suffix Rule

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```

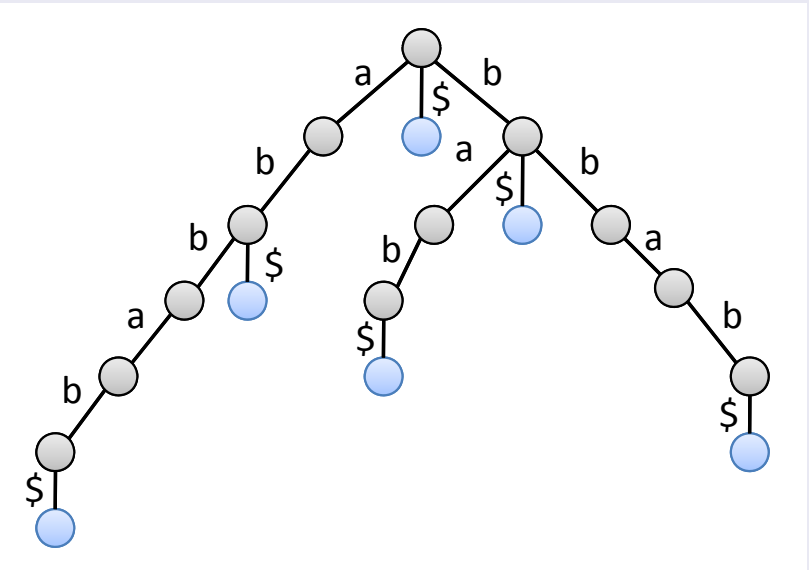
Suffix-Tries/Trees

General

- Representation of one (or many) string(s) in a tree-structure.
- Usually used for preprocessing the text not the pattern.
- Searching fast for any substring.

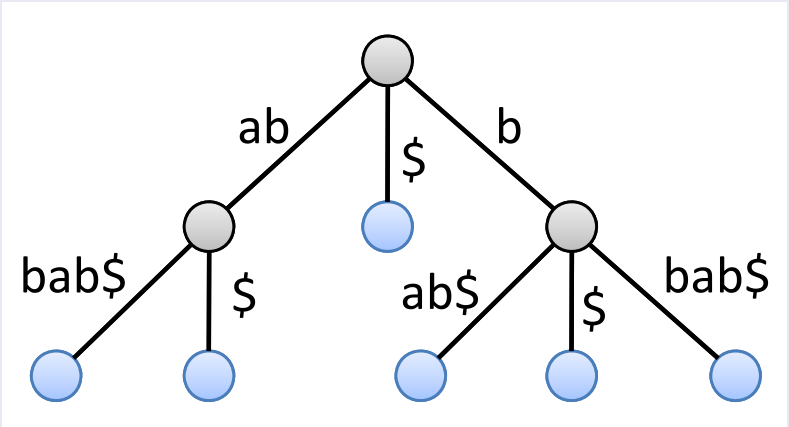
Suffix-Tries (from re*trie*val)

- Each leaf corresponds to a suffix of some string (contains the starting-position).
- Each edge corresponds to a character.
- Example trie for $T = abbab$:



Suffix-Trees

- Trie$\longrightarrow$Tree: One edge for paths without branches.
- There are efficient algorithms for constructing suffix trees, e.g. Ukkonen.



Suffix-Arrays

Suffix-Arrays

- Array of length $|T| = n$ listing the suffixes of T in ascending order.
- Search for each P ($|P| = m$) in $m \log n$ time.
- Simple construction in $\mathcal{O}(n^2 \log n)$.

Example for $T = abbab$

```
ab
abbab
b
bab
bbab
```