Index support for regular expression search

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Introduction

What are regular expressions?

Regular expressions are:

- powerful tool for text processing
- based on formal language theory
- expressing same class of "languages" as finite automata

Automata... didn't hear about it

So... automata

- Regular expression can be transformed into automaton.
- Moreover, such transformation is really used by regex engines

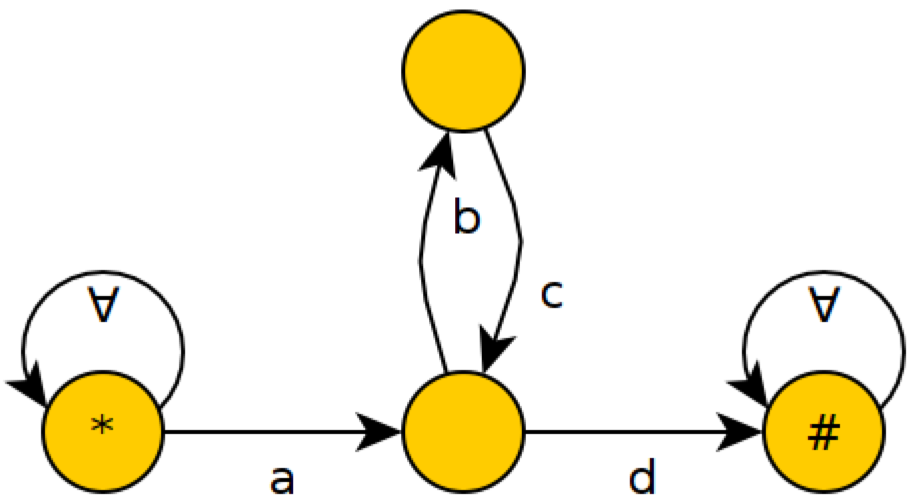
So... automata

- Automaton is a graph which vertices are “states” and which arcs are labeled by characters.
- Automaton “reads” string if you can type that string by a traversal from “initial” state to “final” state

Example

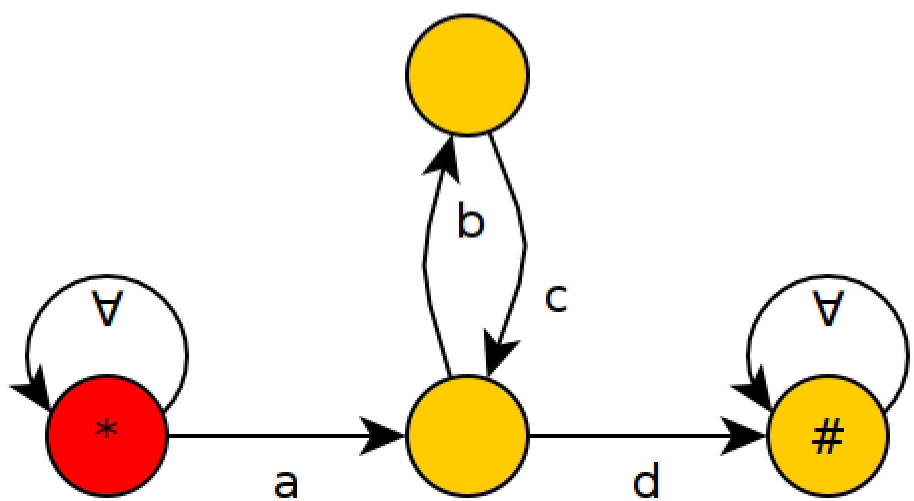
/a(bc)*d/

becomes



Example

xyzabcbcdxyz



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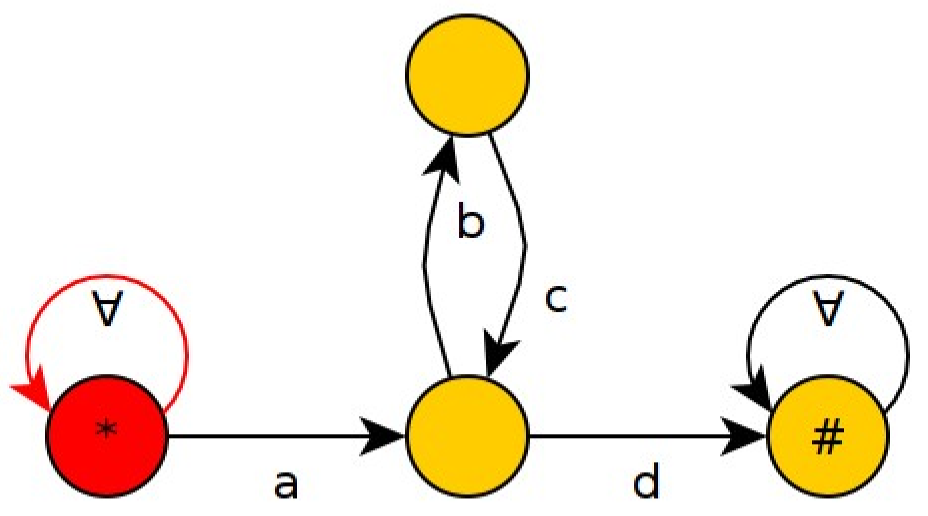

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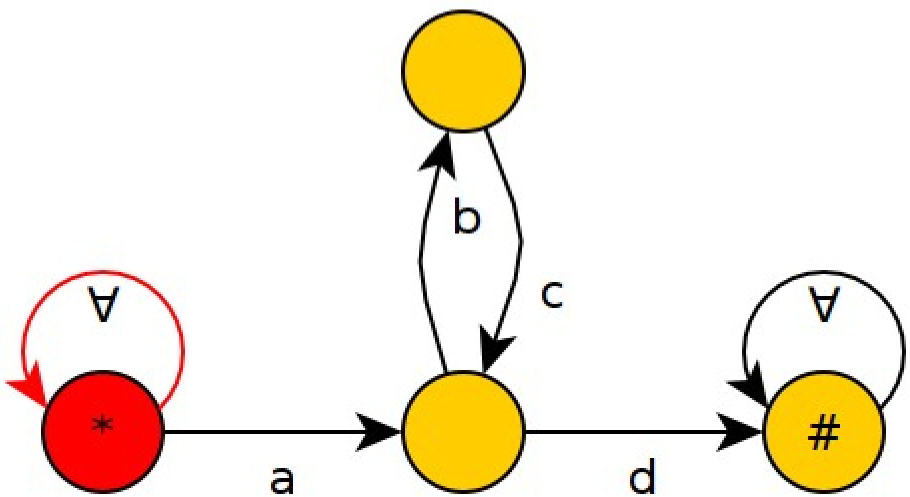

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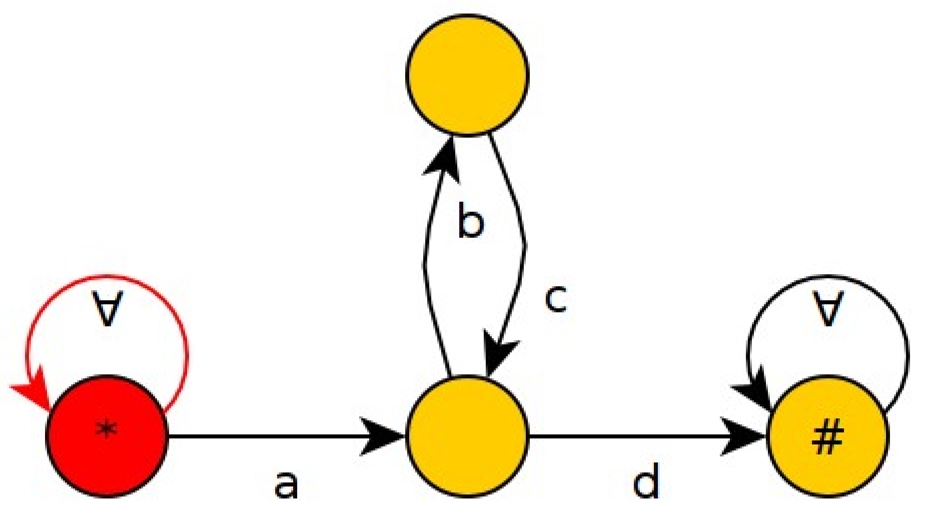

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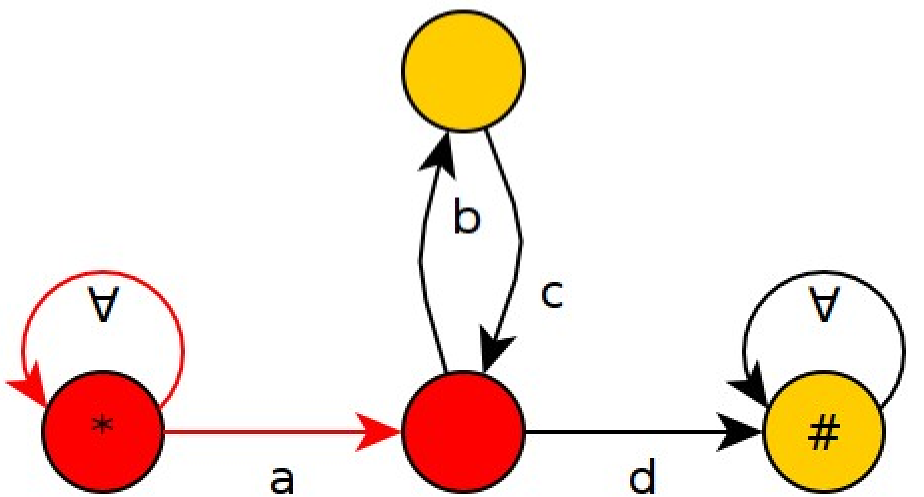

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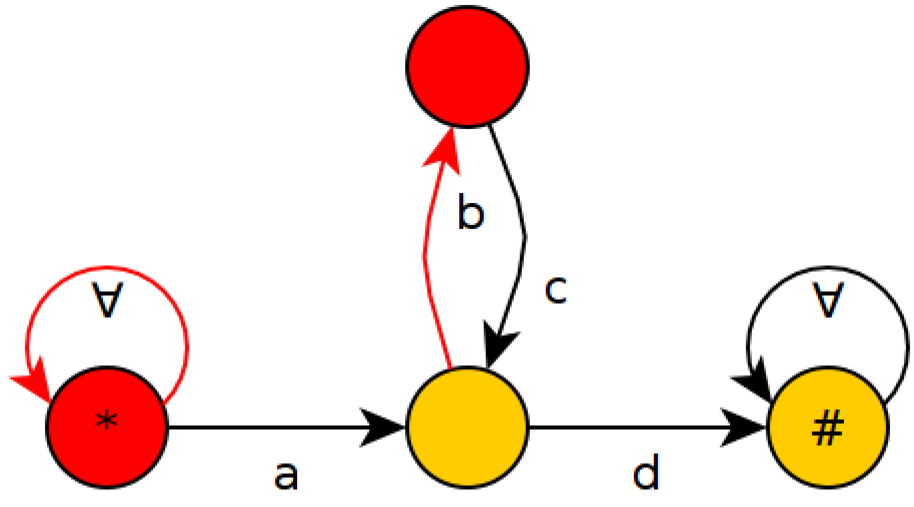
xyzabcbcdxyz



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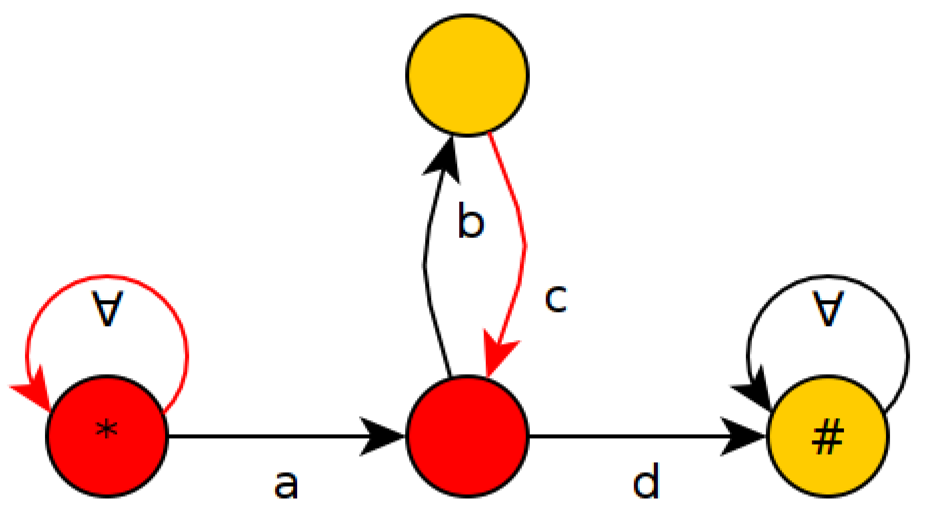
xyzabcbcdxyz



Example

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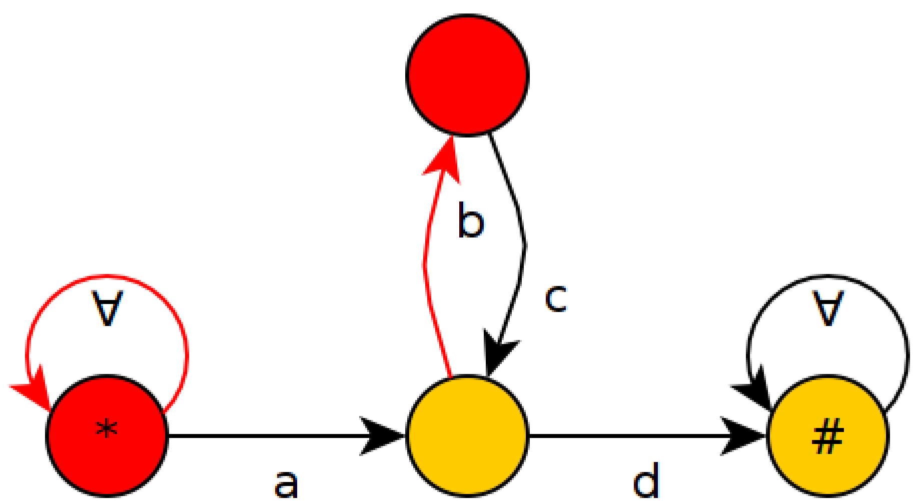

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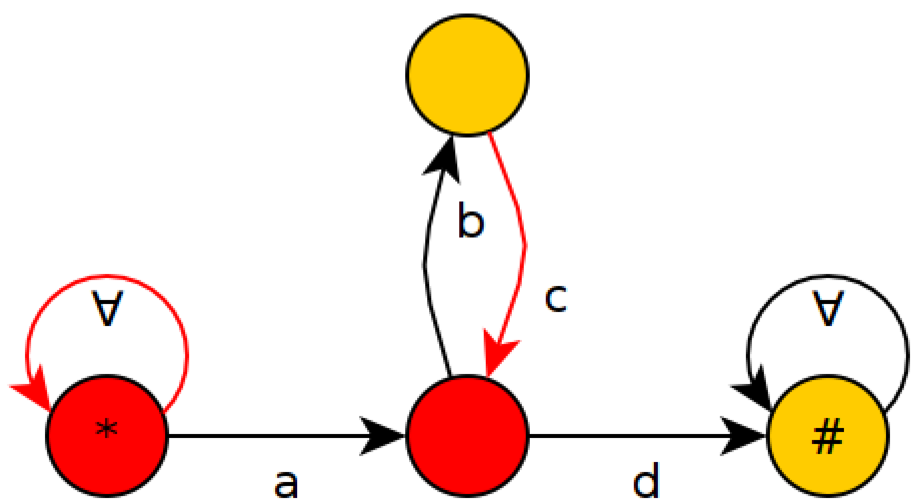
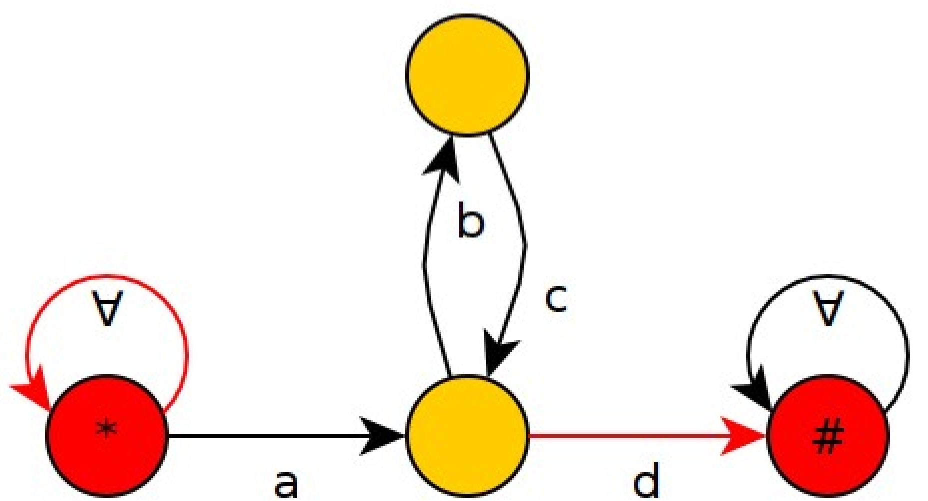


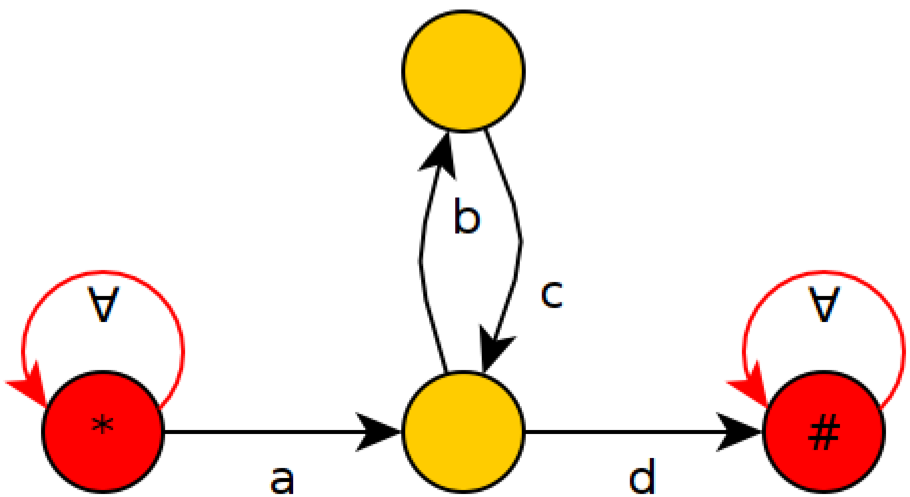
Example

xyzabcbcdxyz



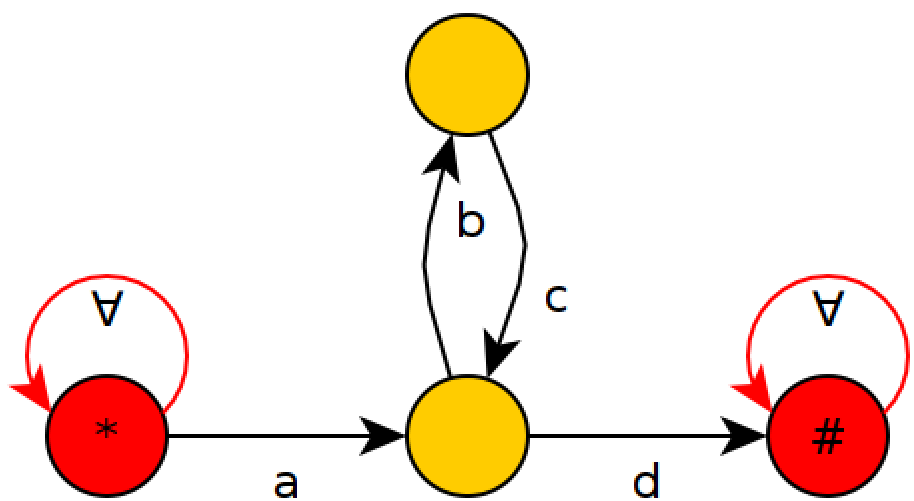
Example

xyzabcbcdxyz



Example

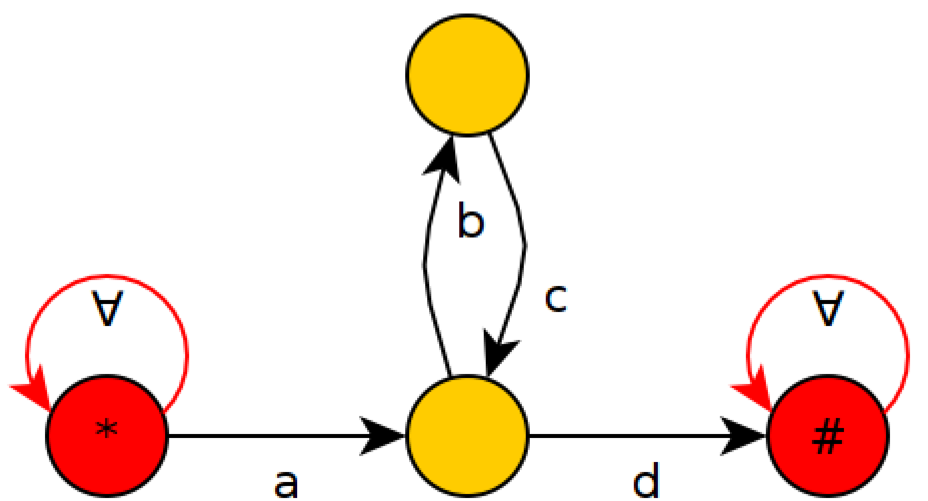
xyzabcbcdxyz



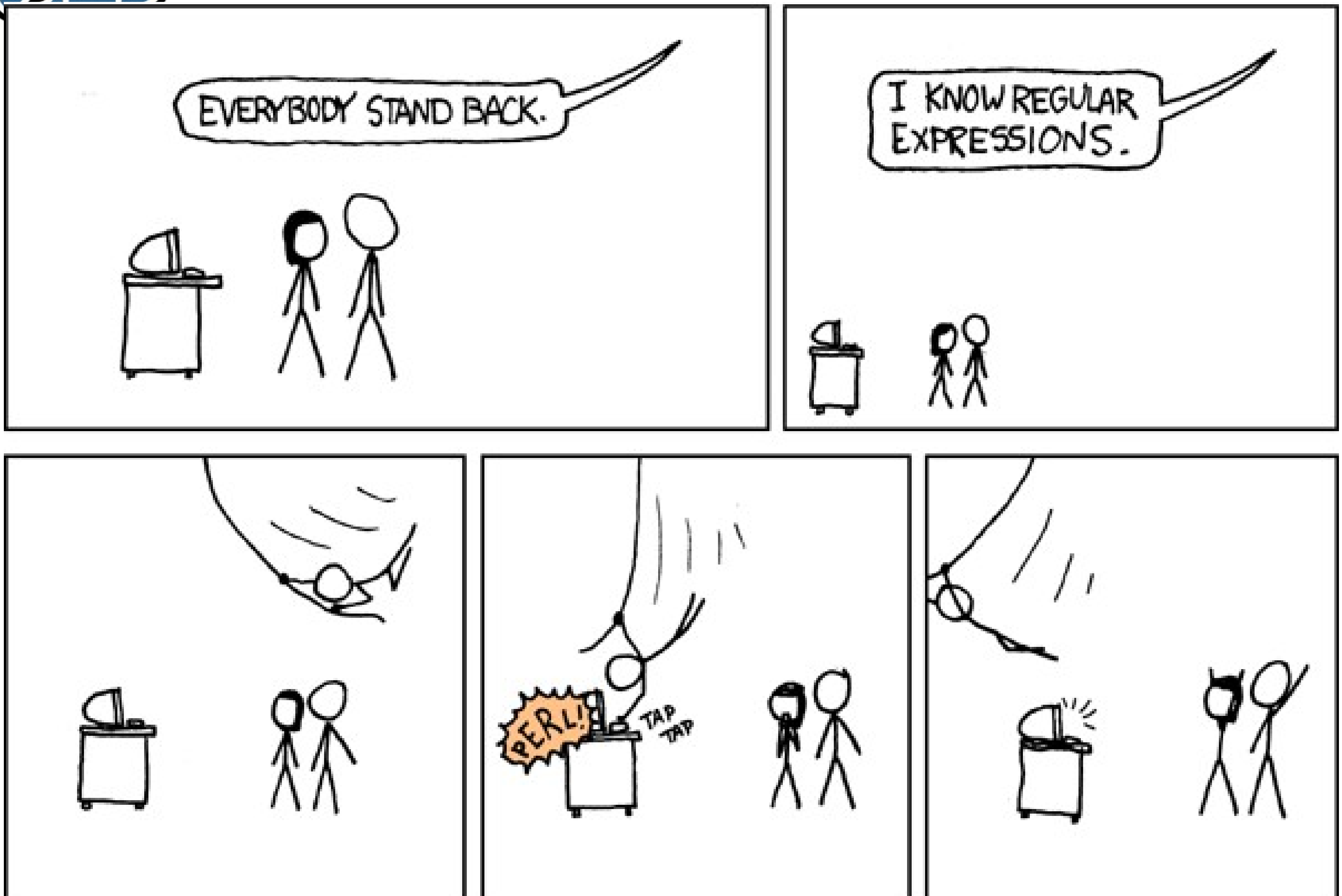
Example

xyzabcbcdxyz

Finish! Match!



Okay, now all of us know...



Regex based search

- PostgreSQL can regex based search :)
- It's only a sequential search for a while :(

Inverted indexes on q-grams

Q-grams?

Q-grams

- Q-gram is substring of length q which can be used as a signature of original string
- Widely used in various string processing tasks

Inverted index on q-grams

- Maintain association between q-gram and all the strings where it mentioned.
- pg_trgm has an implementation for q = 3

pg_trgm

1. "regular expressions",
2. "expressive speach",
3. "regular speaker"

=>

```
'  e': {1,2}
'  r': {1,3}
'  s': {2,3}
' ex': {1,2}
' re': {1,3}
' sp': {2,3}
'ach': {2}
'ake': {3}
'ar ': {1,3}
'ch ': {2}
'eac': {2}
'eak': {3}
'egu': {1,3}
'er ': {3}
'ess': {1,2}
'exp': {1,2}
'gul': {1,3}
'ion': {1}
'ive': {2}
'ker': {3}
'lar': {1,3}
'ns ': {1}
'ons': {1}
'pea': {2,3}
'pre': {1,2}
'reg': {1,3}
'res': {1,2}
'sio': {1}
'siv': {2}
'spe': {2,3}
'ssi': {1,2}
'ula': {1,3}
've ': {2}
'xpr': {1,2}
```

Q-grams frequencies

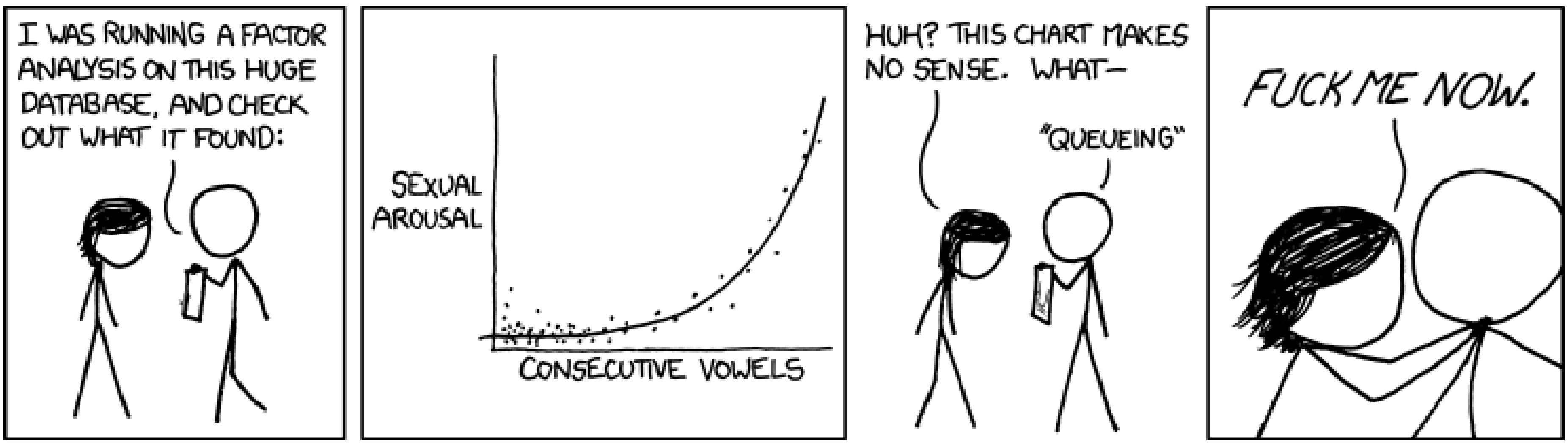
From 2.5M of DBLP paper titles

- 360K contain trigram “the”
- Only 1 contains trigram “zzz”

"Zzzzzzzzzzzzzzzzzzzzzzzzzz" chapter of the book "Formal Specification and Development in Z and B" by David Everett

Not all q-grams of fixed q are equally useful.

Q-grams are not equally useful



V-grams or multigrams

- Each q-gram can have specific q
- Selectivity of all q-grams are similar (and low enough)
- More effective index search!

V-grams or multigrams

Problems:

- Hard to maintain online
- ...

Patent trololo!

How to use it for regex search?

General idea

/[ab]cde/ => (acd OR bcd) AND cde

acd: {1,4,5}, bcd: {2,3,4}, cde:{2,4,6}

	acd	bcd	cde	(acd OR bcd) AND cde	recheck
1	t	f	f	f	
2	f	t	t	t	f
3	f	t	f	f	
4	t	t	t	t	t
5	t	f	f	f	
6	f	f	t	f	

General idea

/[ab]cde/ => (acd OR bcd) AND cde

How to do this in general case?

Existing approaches for q-gram extraction

Scholar paper

Junghoo Ch and Sridhar Rajagopalan, **A fast regular expression indexing engine**, Proceedings 18th International Conference on Data Engineering, 2002

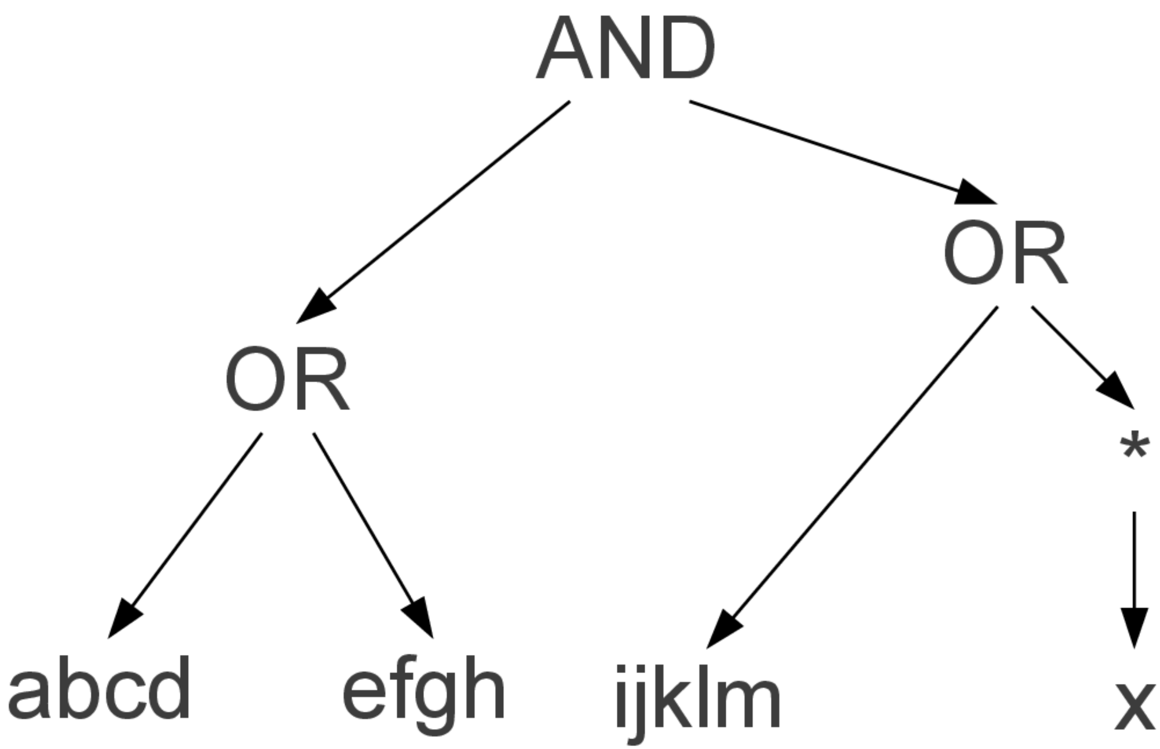
Still widely referenced as state of art work about indexing for regular expressions.

FREE method

- Extract tree of continuous string fraction from regex.
- Transform those continuous fractions to multigrams (q-grams with variable q).
- Use inverted index on multigrams for query evaluation

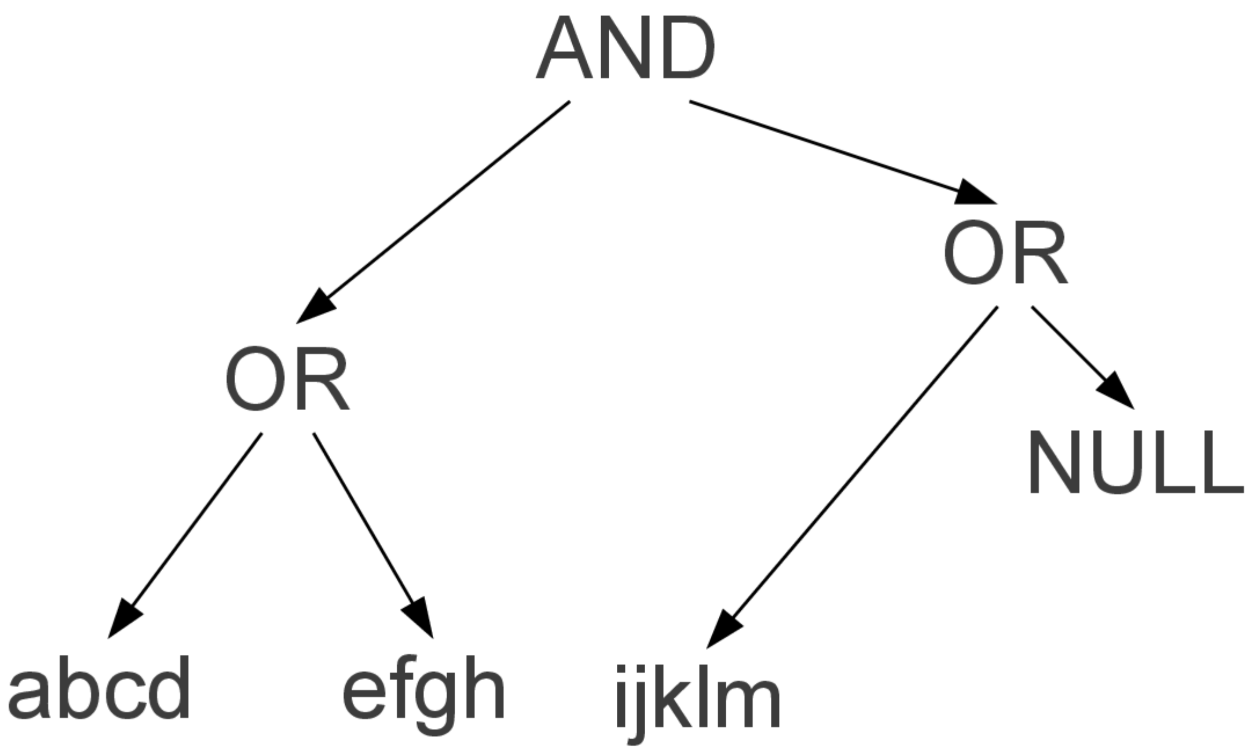
FREE method: example

Tree for /(abcd|efgh)(ijklm|x*)/



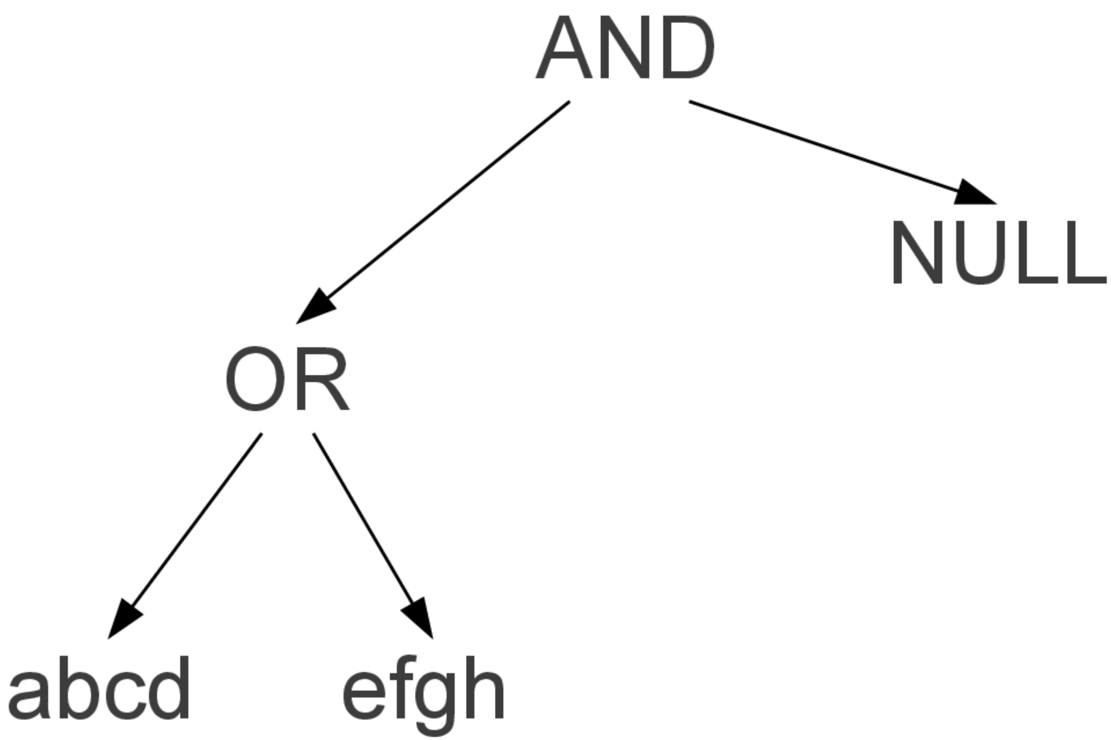
Scholar paper: example

Replace "*" nodes with NULL



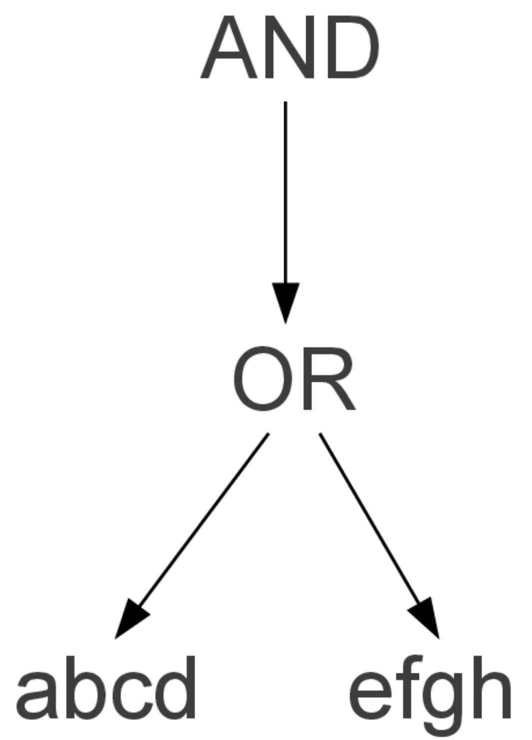
Scholar paper: example

NULL “eats” parent OR node



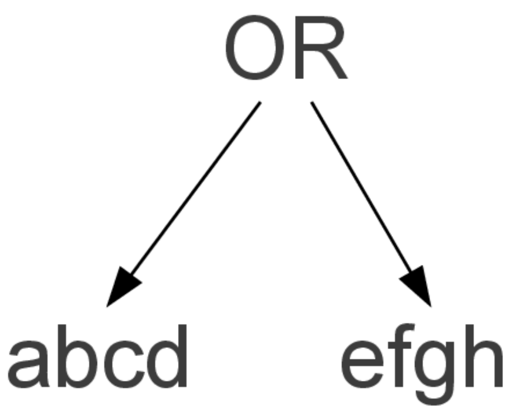
Scholar paper: example

AND node “eats” child NULL



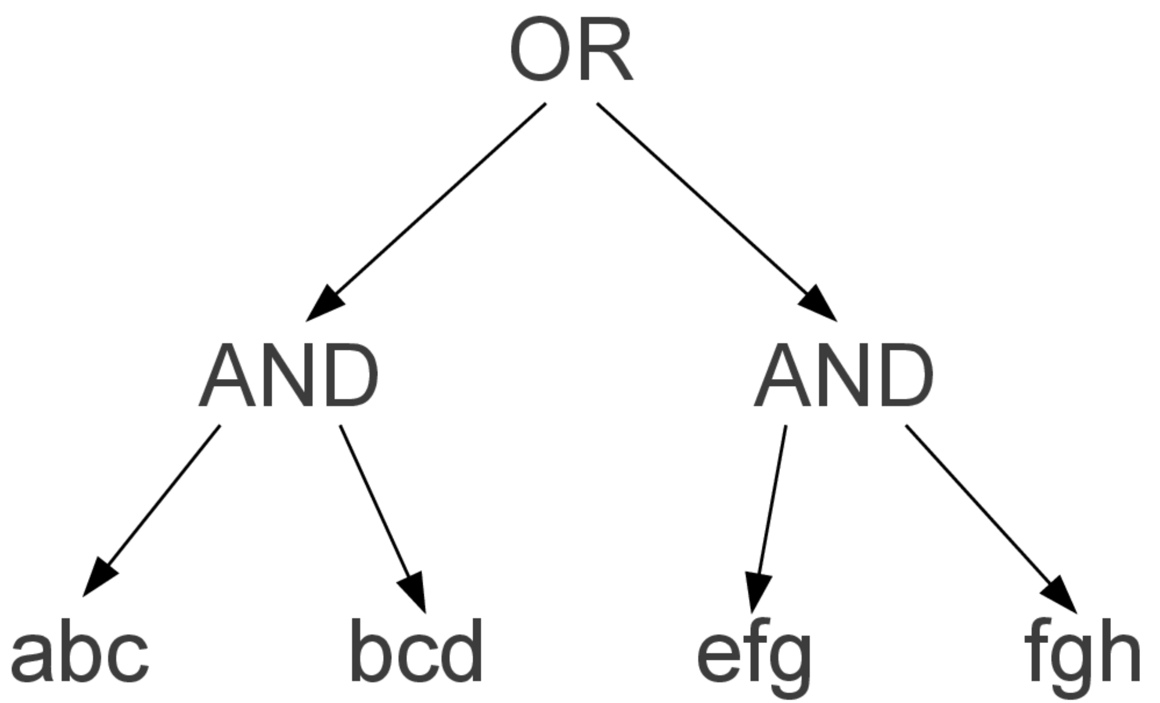
Scholar paper: example

Simplify a bit



Scholar paper: example

Expand continuous string fractions into trigrams



Google code search

- Was launched in 2006.
- Supports regex search.
- Google guys are smart. It can’t be a sequential scan.
- It also seemed to be something better than previous technique.
- We don’t know what... :(

We **didn’t** know what until…

- Google code search was closed in 2011 :(
- Russ Cox has published description of indexing technique in January 2012

http://swtch.com/~rsc/regexp/regexp4.html

- More than 5 years of intrigue!

Google code search method

- Get 5 characteristics about each part of regex: emptyable, exact, prefix, suffix, match.
- Recursively union them (with possible simplification)
- Use inverted index of trigrams for query evaluation (similar to pg_trgm)

Google code search method

Original regex: /a(bc)+d/

a: {exact: a}

bc: {exact: bc}

d: {exact: d}

(bc)+: {prefix:bc, suffix: bc}

a(bc)+: {prefix:abc, suffix:bc}

a(bc)+d: {prefix:abc, suffix:bcd}

Google code search method

/a(bc)+d/

↓

{prefix:abc, suffix:bcd}

↓

abc AND bcd

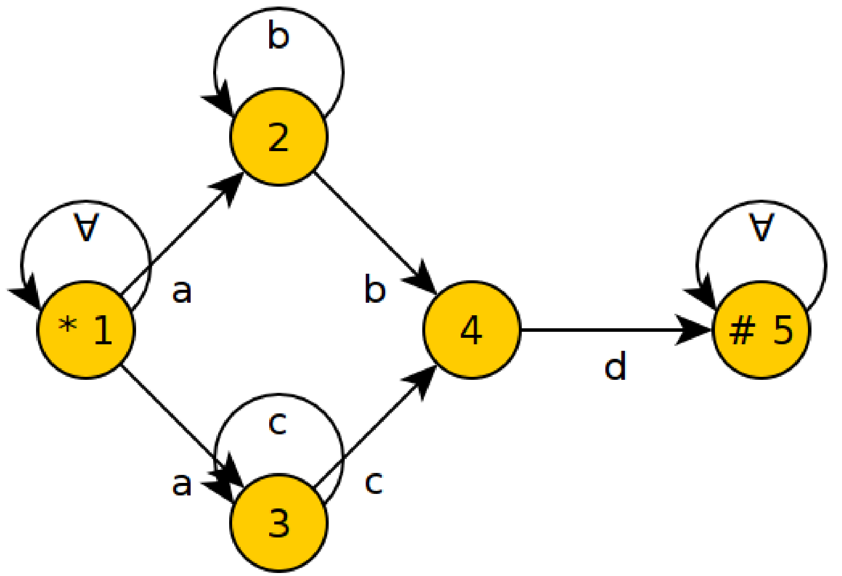
Proposed method

Proposed method

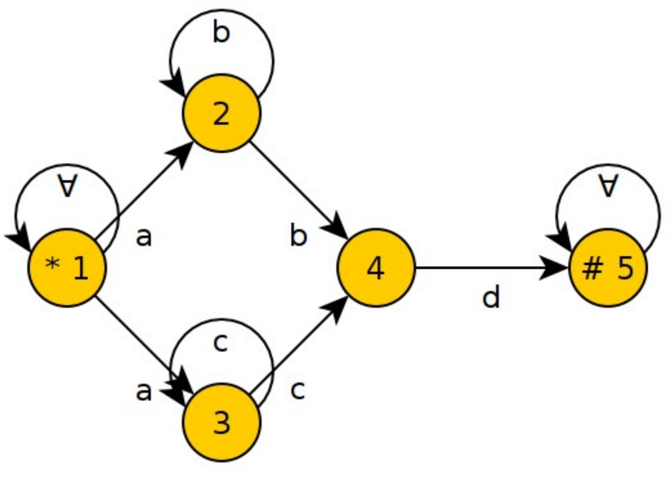
- Transform automaton into automaton like graph on trigrams
- Simplify that graph
- Use pg_trgm indexes

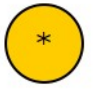
Transformation example

/a(b+|c+)d/



Transformation example





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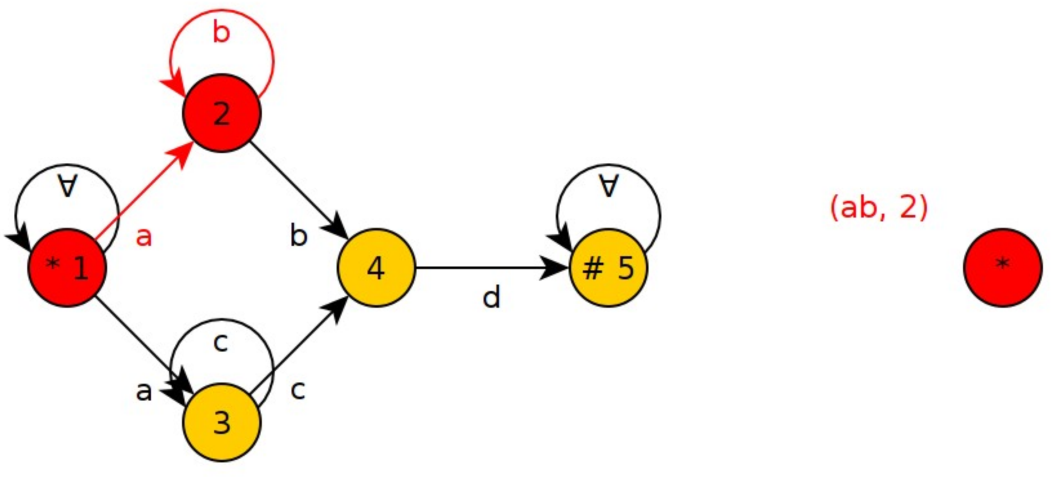
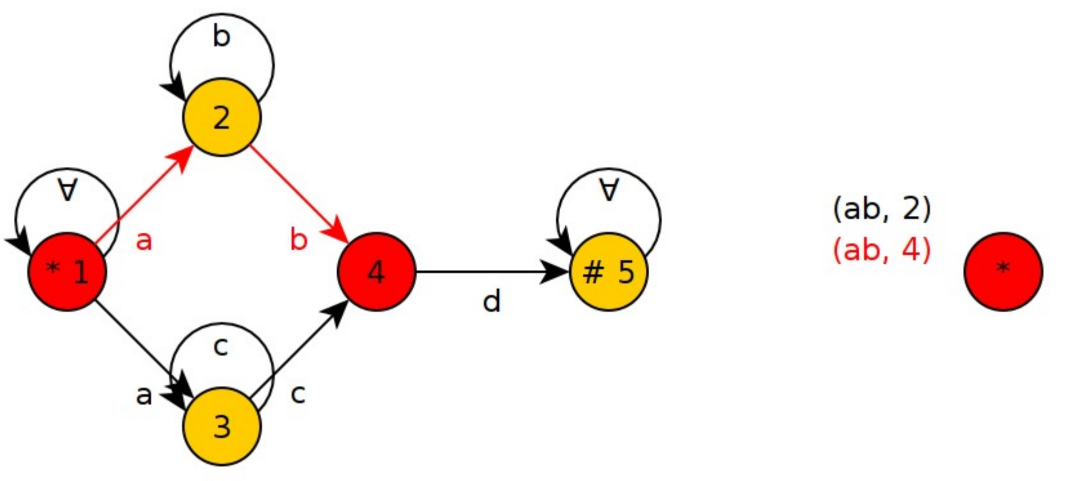
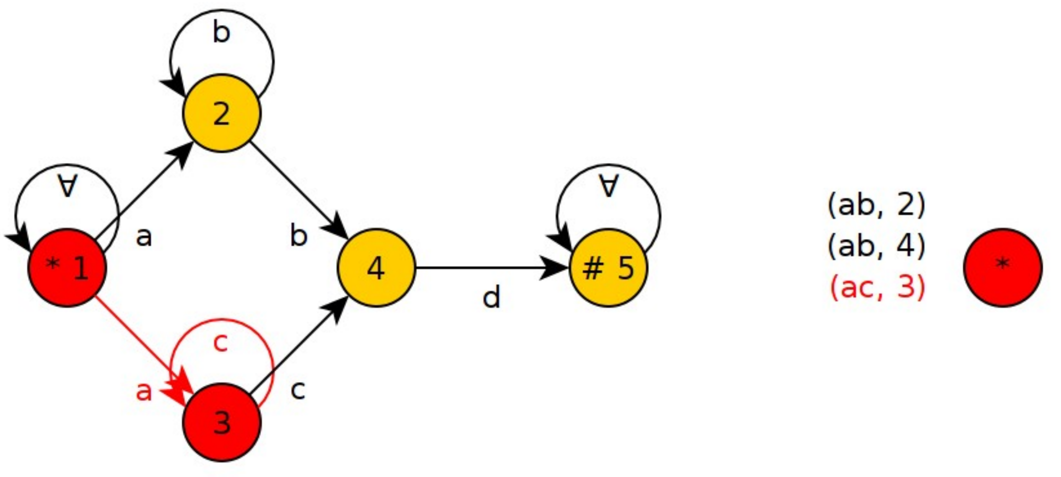


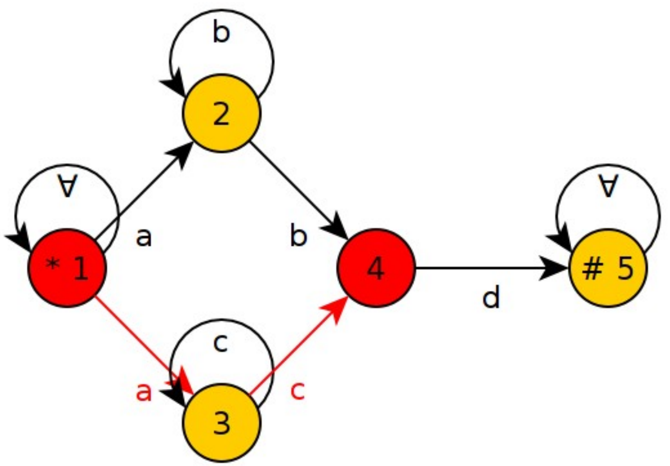
Transformation example



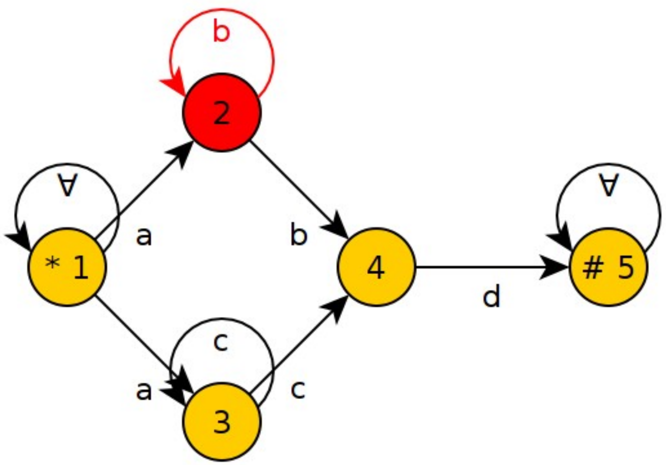
Transformation example

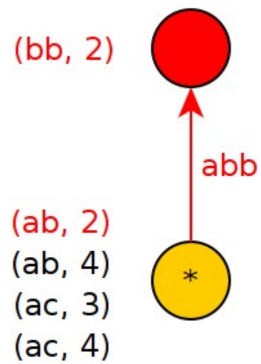


Transformation example

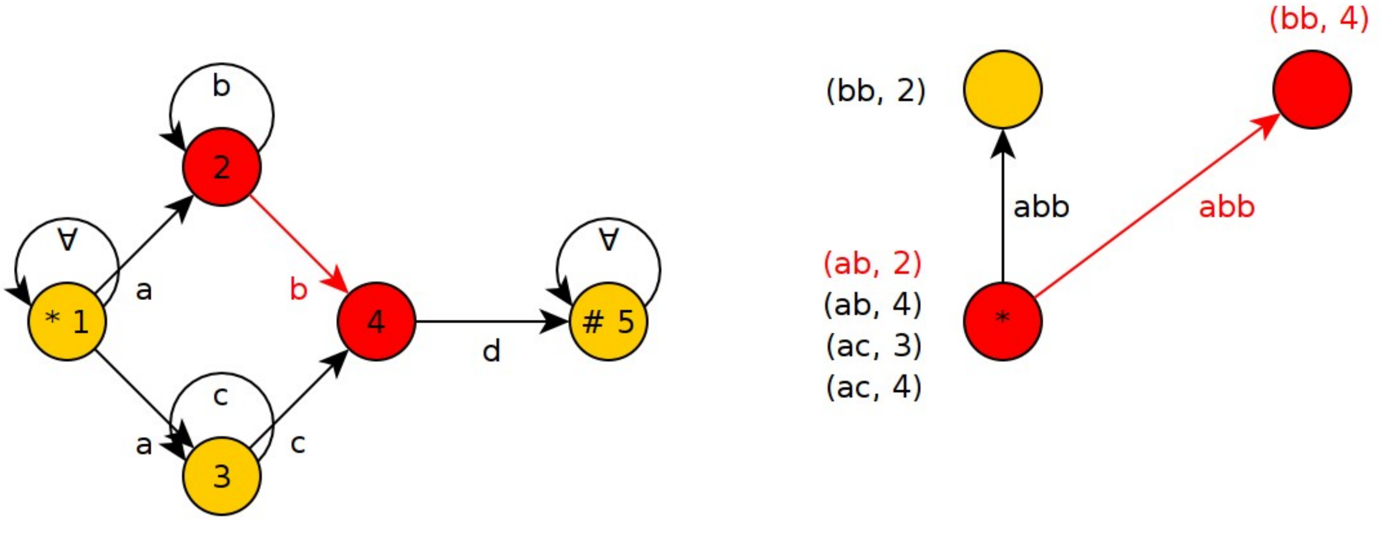


Transformation example





Transformation example



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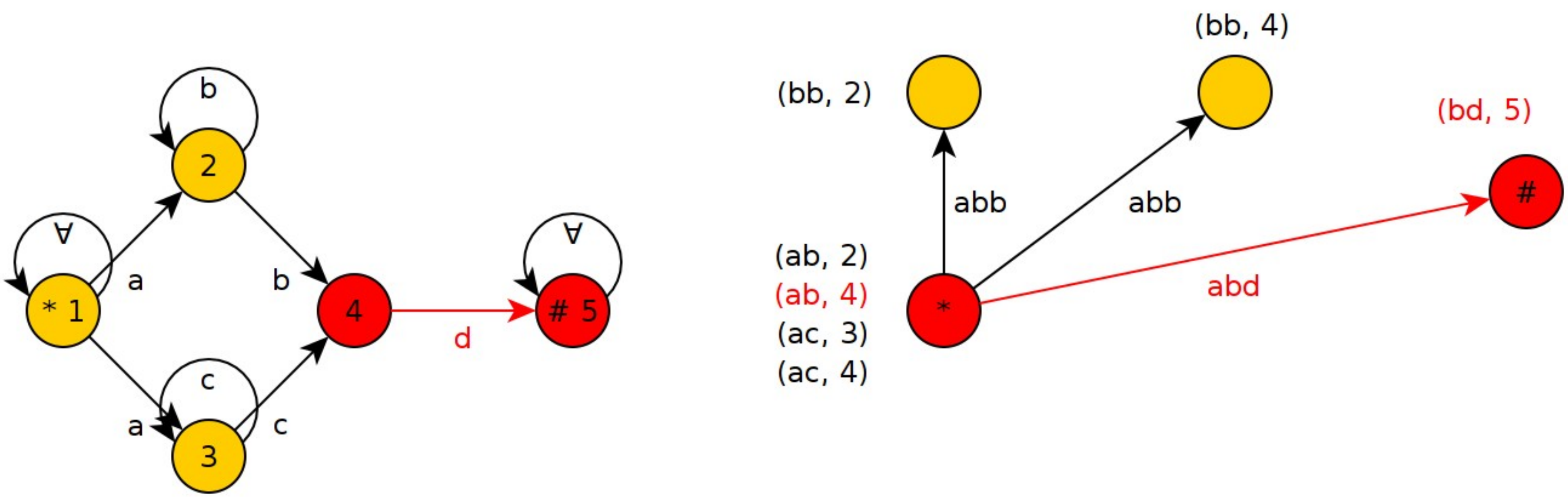

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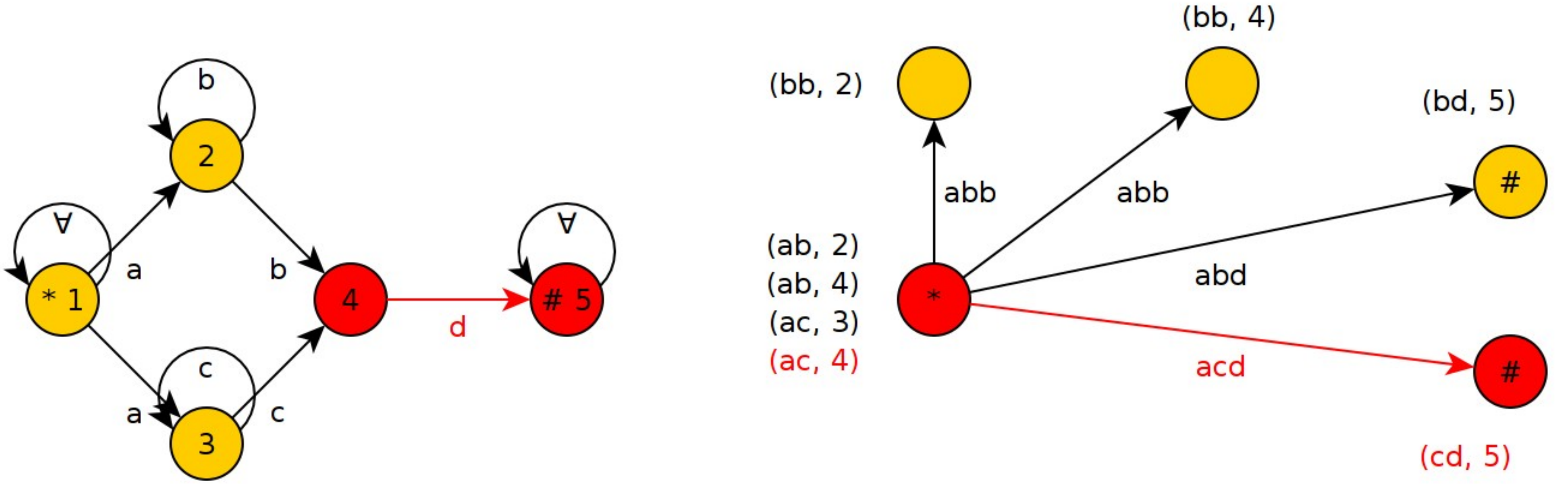

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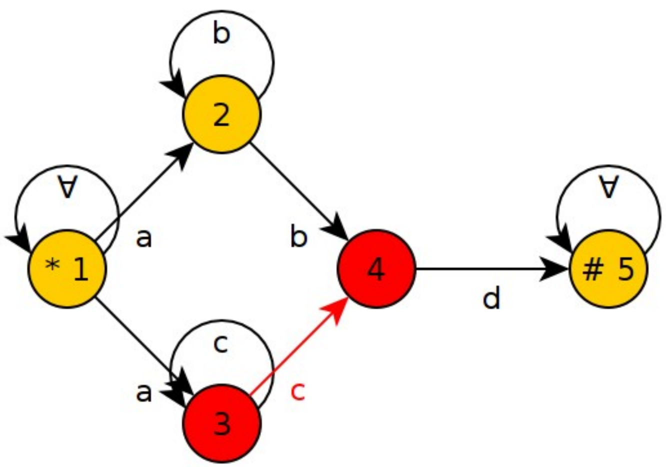

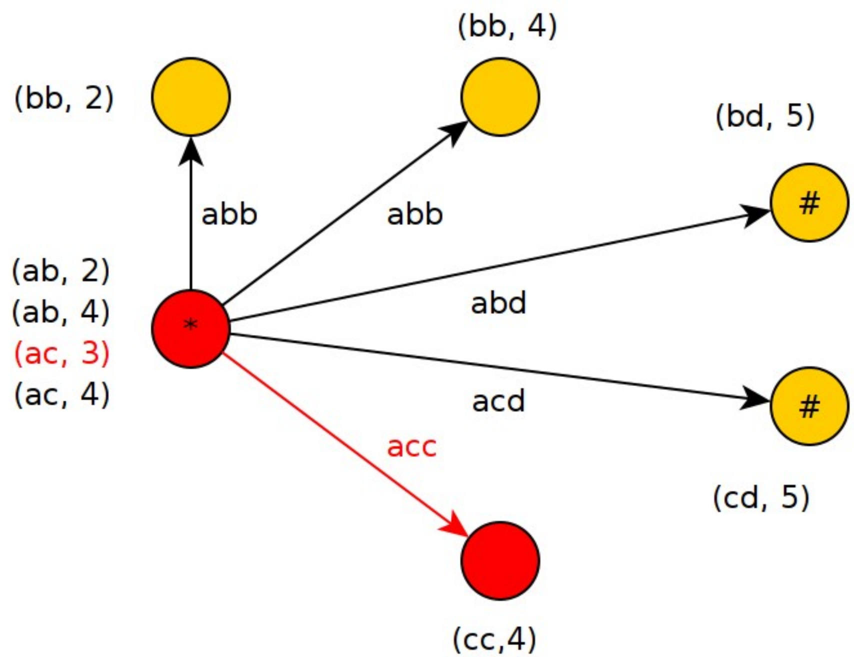

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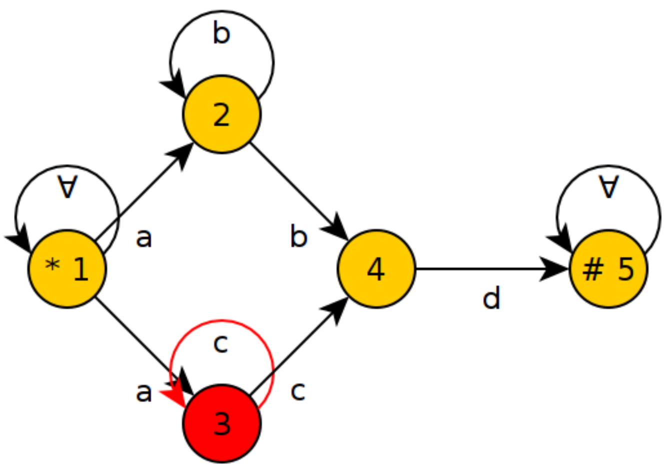

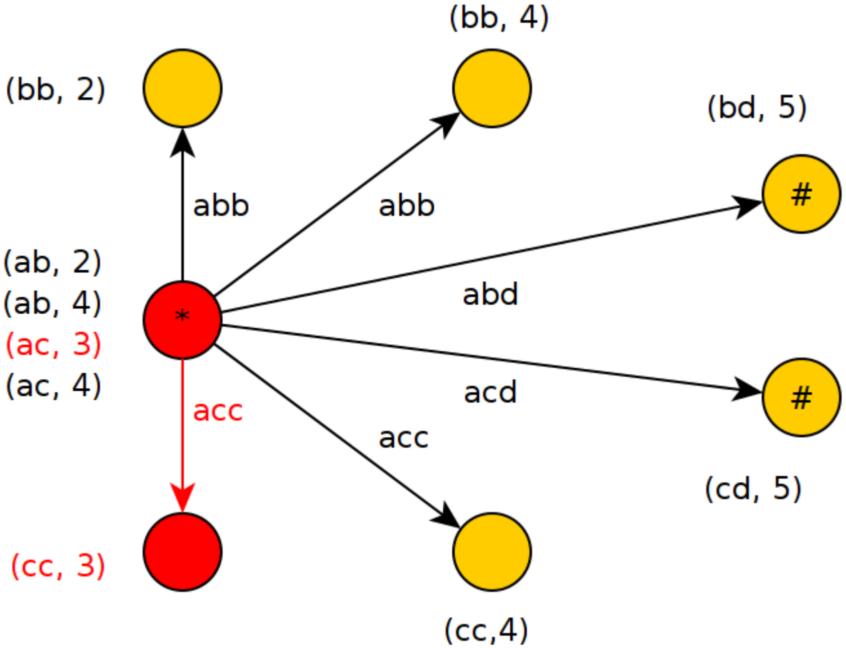

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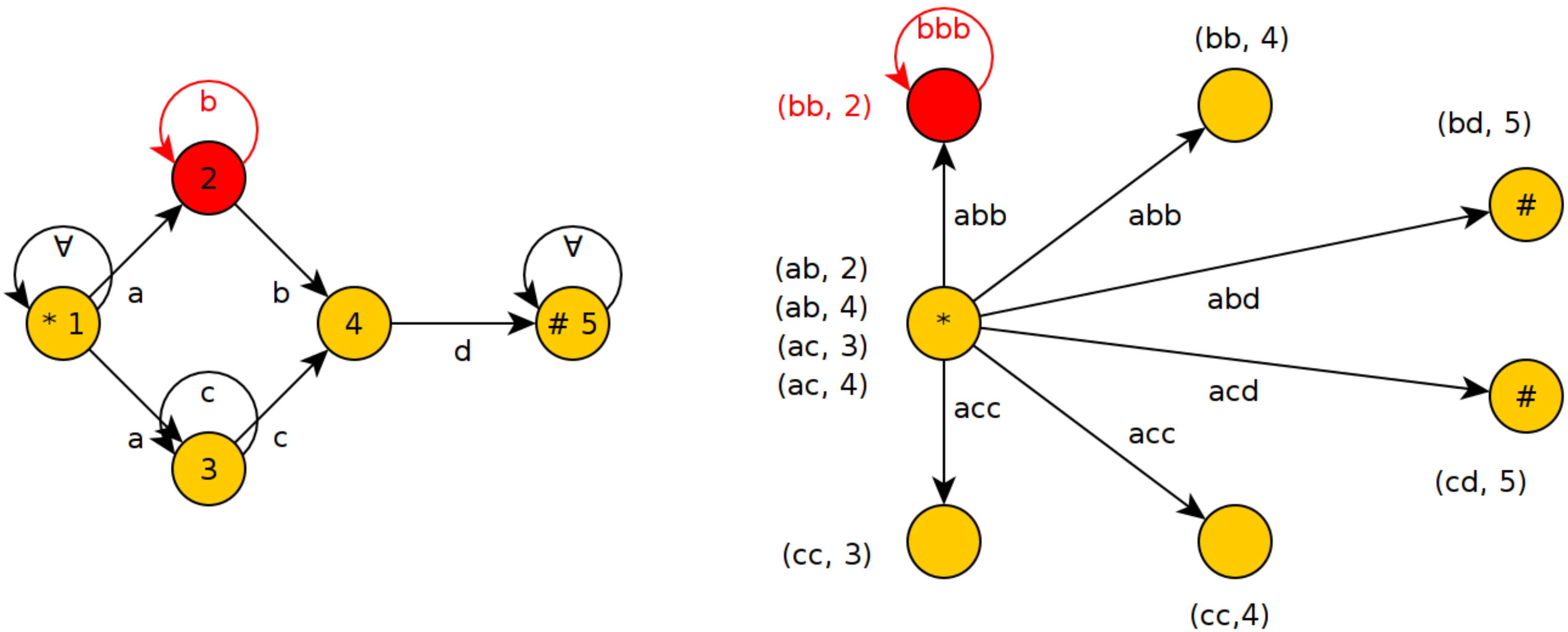
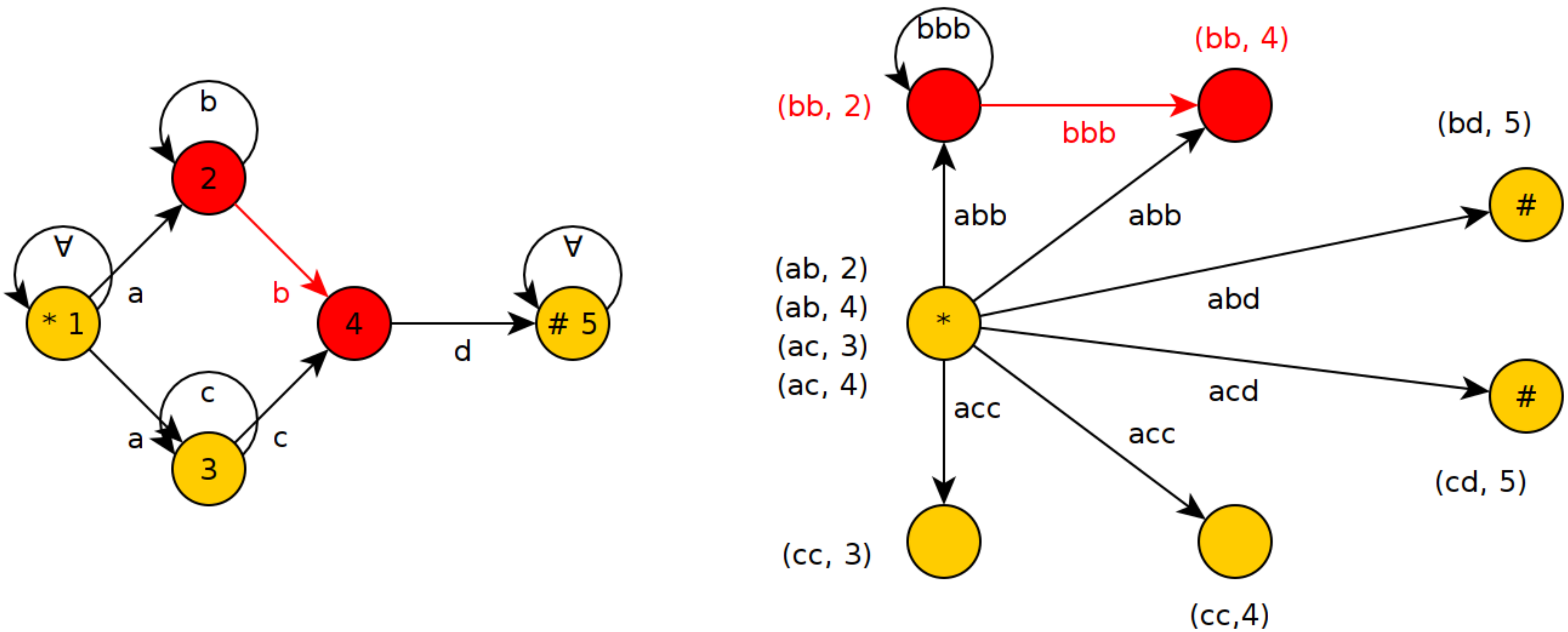
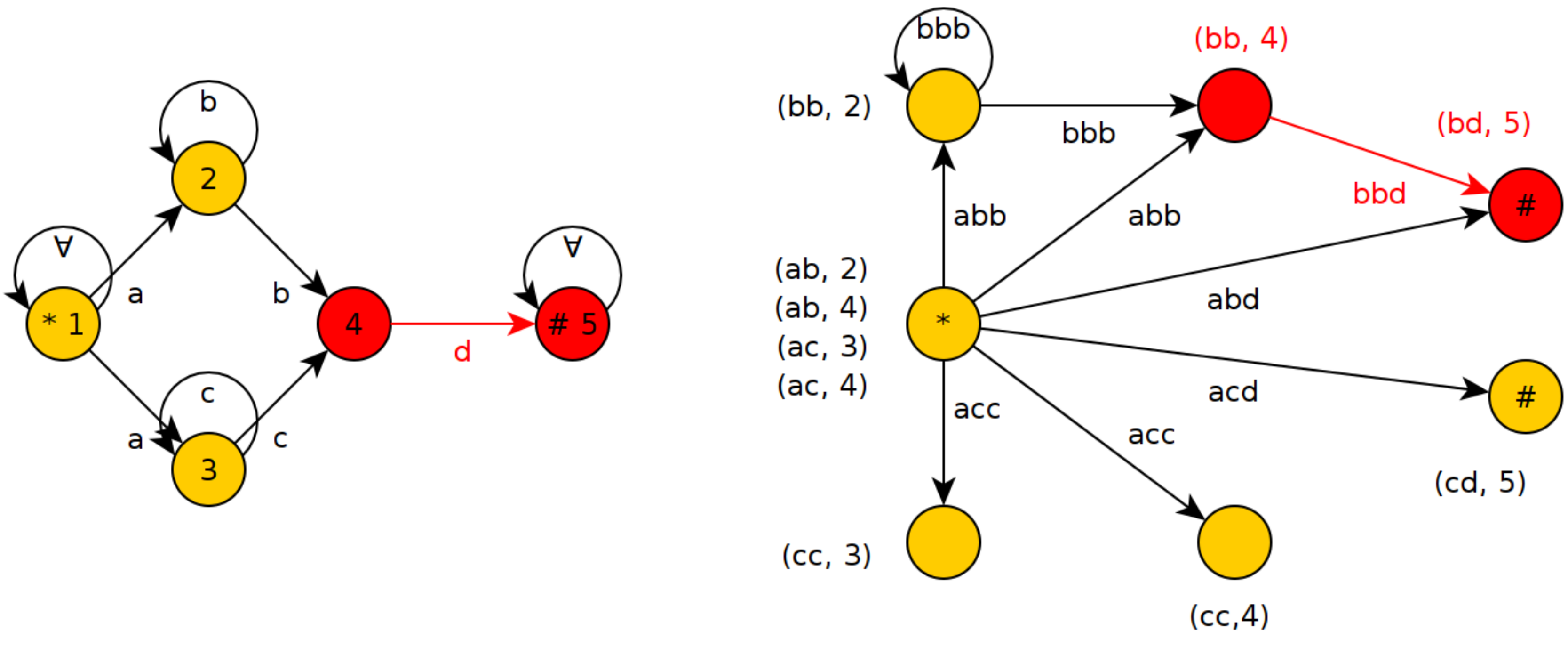


Transformation example



Transformation example



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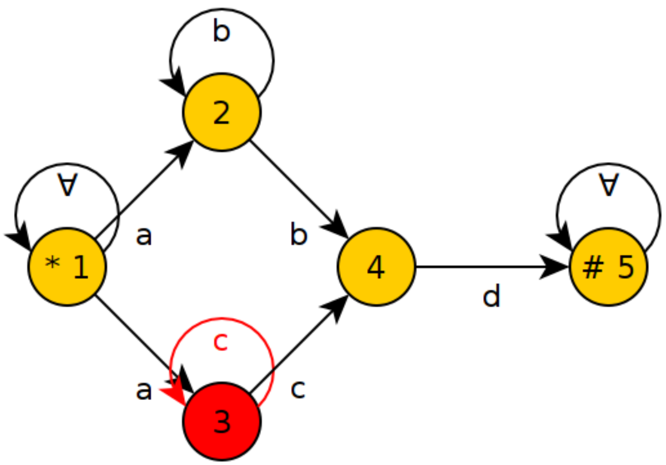

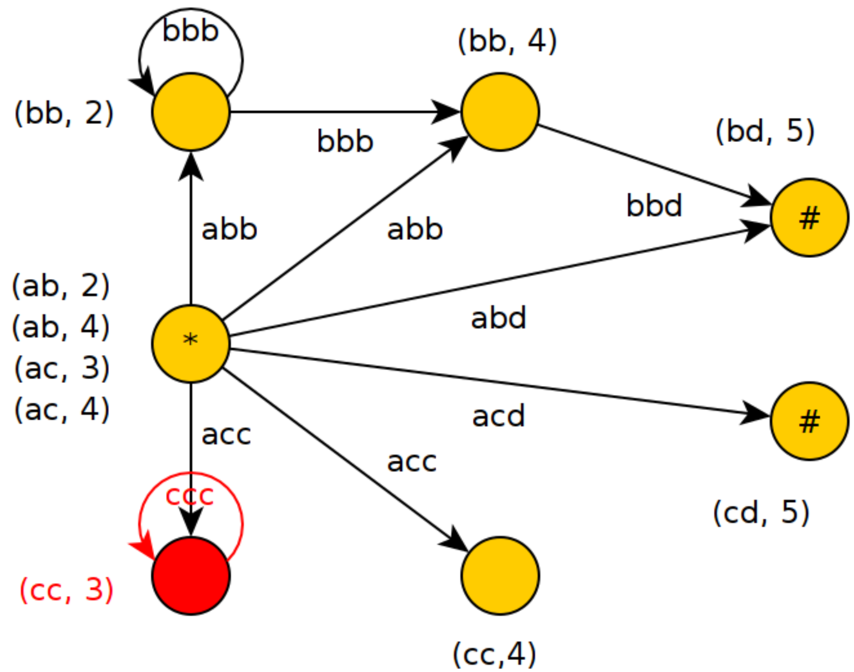

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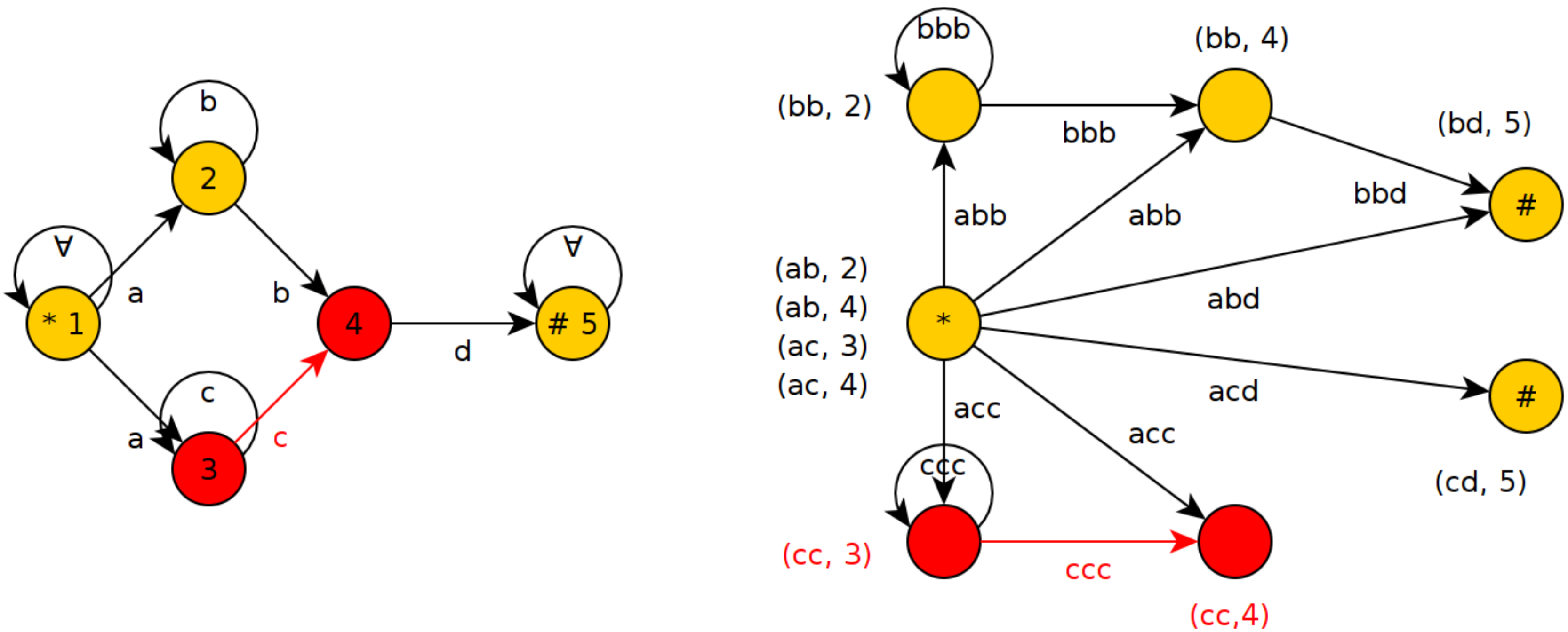

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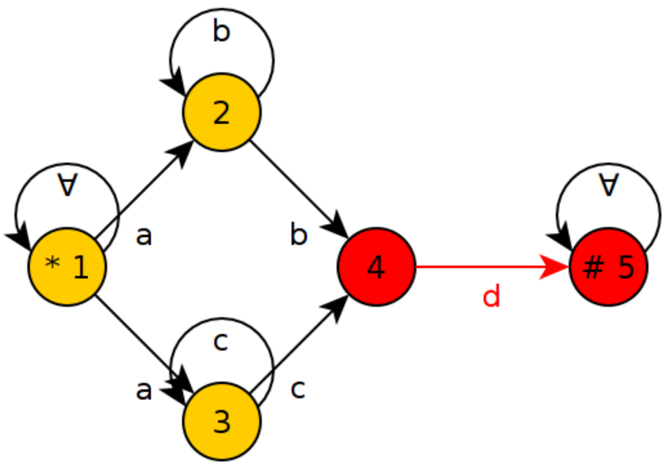
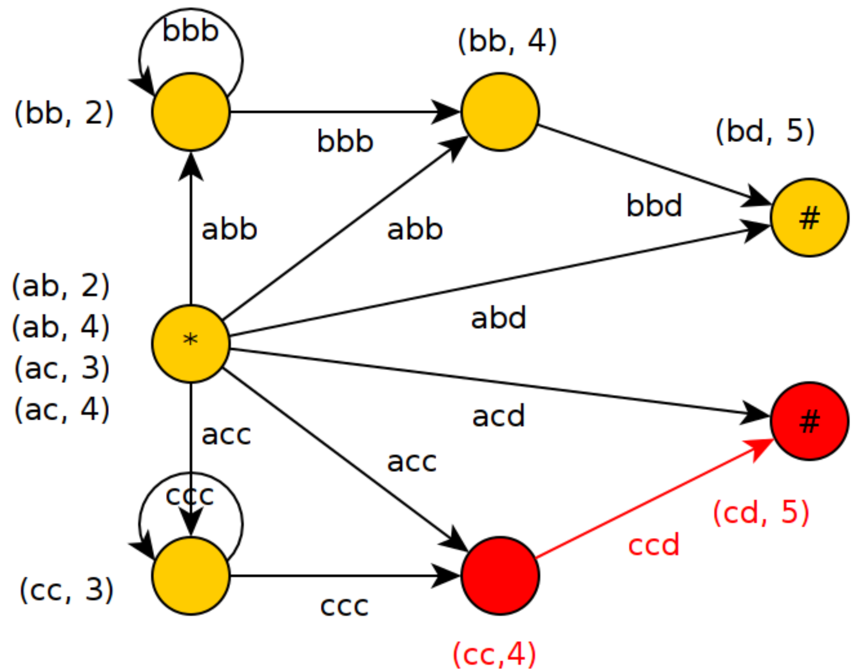
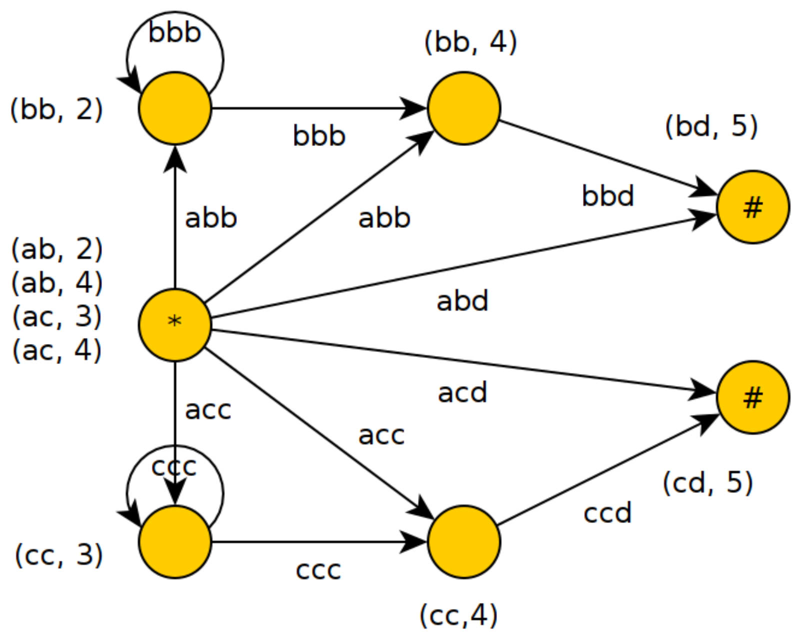
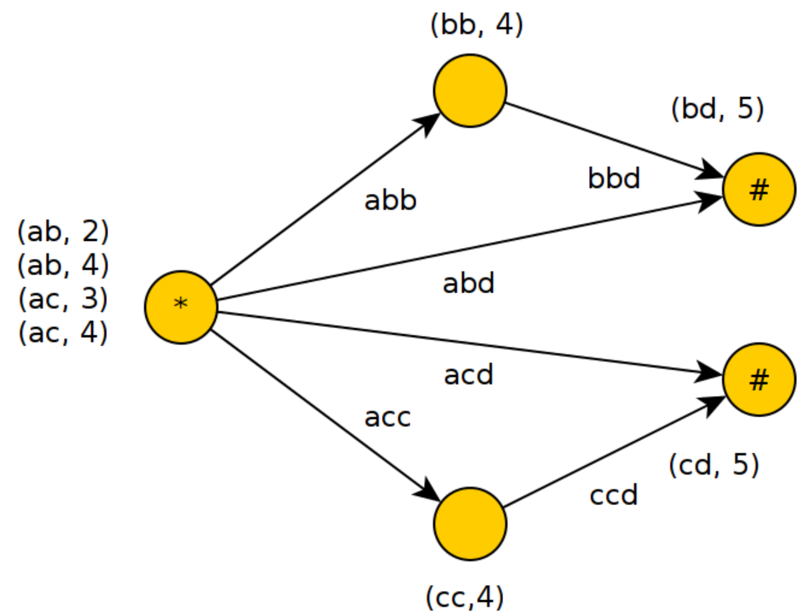




Transformation example

Result could be simplified





Transformation example

Implemented simplification technique:

collect path matrix.

abd	abb	bbd	acd	acc	ccd
1	0	0	0	0	0
0	1	1	0	0	0
0	0	0	1	0	0
0	0	0	0	1	1

Means: abd OR (abb AND bbd) OR acd OR (acc AND ccd)

Comparison on examples

Regex: /(abc|cba)def/

FREE: (abc OR cba) AND def

GSC:

def AND ((abc AND bcd AND cde) OR (ade AND bad AND cba))

My:

(abc AND bcd AND cde AND def) OR (ade AND bad AND cba AND def)

Comparison on examples

Regex: /abc+de/

FREE: nothing

GSC: abc AND cde

My:

(abc AND cde AND bcd) OR

(abc AND cde AND bcc AND ccd)

Comparison on examples

Regex: /(abc*)+de/

FREE: nothing

GSC: nothing

My:

(abd AND bde) OR

(abc AND bcd AND cde) OR

(abc AND bcc AND ccd AND cde)

Comparison on examples

Regex: /ab(cd)*ef/

FREE: nothing

GSC: nothing

My:

(abe AND bef) OR

(abc AND bde AND cde AND def)

Performance results

2.5 M DBLP paper titles of 47 avg. length

Regex	Index scan	Seq scan
/database.*(sql|query)/	773 ms	18653 ms
/postgres(ql)?/	268 ms	17574 ms
/plan+er/	253 ms	12885 ms
/(nucl|anino).*acid/	200 ms	20085 ms
/[aei](bc)+a/	2 ms	13195 ms

Help needed

Regular expressions and string collections from real-life tasks for proving effectiveness of proposed method.

New since PGCon 2012

- Have an optimization for making resulting graph smaller.
- Can use both graph and path matrix (which is simplier)
- Encoding problem is solved.

New patch will be posted soon.

GIN improvements

Summary of changes

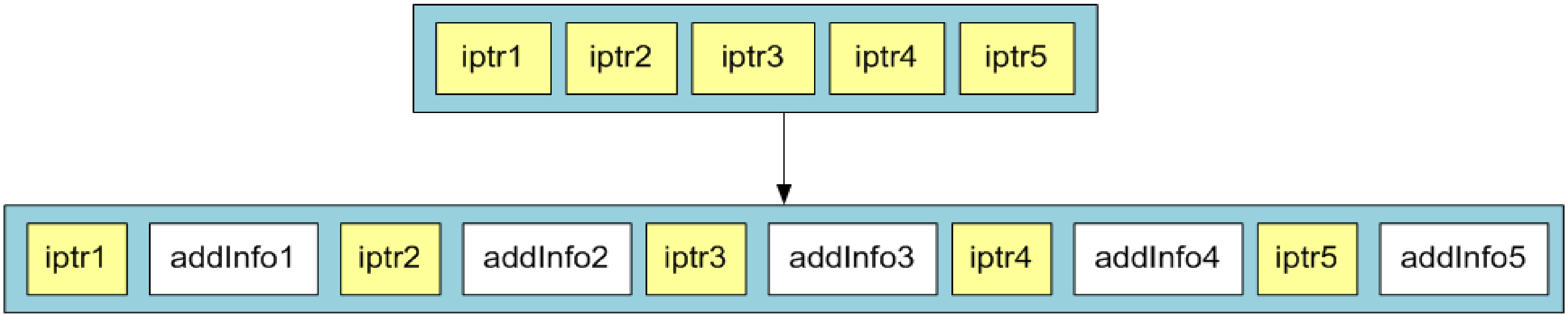
- Compressed storage with additional information
- Optimized search («frequent_entry & rare_entry» case)
- Return ordered results by index (ORDER BY optimization)

interface changes needs for all this stuff

Every GIN application can have a benefit

- Fulltext search: store word positions, get results in relevance order.
- Trigram indexes: store trigram positions, get results in similarity order.
- Array indexes: store array length, get results in similarity order.

Store additional infromation

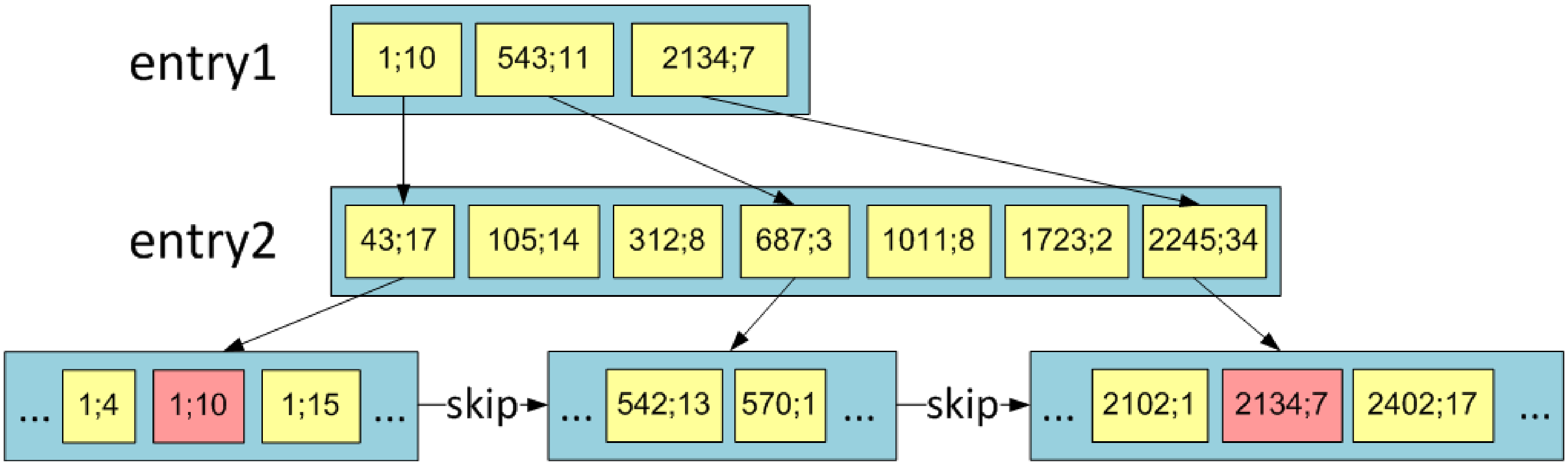


Use increments and variable byte encoding to keep index small

1034, 1036, 1038 (12 bytes) => 1034, 2, 2 (4 bytes)

Fast scan

entry1 && entry2

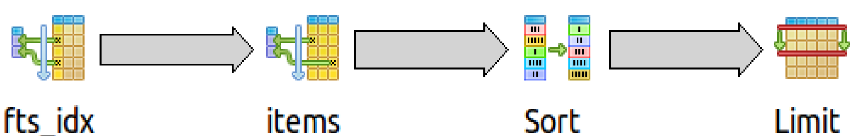


Visiting 3 pages instead of 7

ORDER BY using index

Before

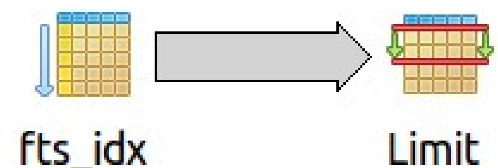
SELECT itemid, title
FROM items
WHERE fts @@ to_tsquery('english', 'query')
ORDER BY
ts_rank(fts, to_tsquery('english', 'query')) DESC
LIMIT 10;



Ranking and sorting are outside the fulltext index

After

SELECT itemid, title
FROM items
WHERE fts @@ to_tsquery('english', 'query')
ORDER BY
fts **><** to_tsquery('english', 'query')
LIMIT 10;



Index returns data ordered by rank. Ranking and sorting are inside.

368 ms vs 13 ms

Example: frequent entry (30%)

Before:

node type	count	sum of times	% of query
Bitmap Heap Scan	1	367.687 ms	94.6 %
Bitmap Index Scan	1	6.570 ms	1.7 %
Limit	1	0.001 ms	0.0 %
Sort	1	14.465 ms	3.7 %

388 ms

After:

node type	count	sum of times	% of query
Index Scan	1	13.346 ms	100.0 %
Limit	1	0.001 ms	0.0 %

13 ms

Example: rare entry (0.08%)

Before:

node type	count	sum of times	% of query
Bitmap Heap Scan	1	0.959 ms	93.4 %
Bitmap Index Scan	1	0.027 ms	2.6 %
Limit	1	0.001 ms	0.1 %
Sort	1	0.040 ms	3.9 %

1.1 ms

After:

node type	count	sum of times	% of query
Index Scan	1	0.052 ms	98.1 %
Limit	1	0.001 ms	1.9 %

0.07 ms

Example: frequent entry (30%) & rare entry (0.08%)

Before:

node type	count	sum of times	% of query
Bitmap Heap Scan	1	1.547 ms	23.0 %
Bitmap Index Scan	1	5.151 ms	76.7 %
Limit	1	0.000 ms	0.0 %
Sort	1	0.022 ms	0.3 %

6.7 ms

After:

node type	count	sum of times	% of query
Index Scan	1	0.998 ms	100.0 %
Limit	1	0.000 ms	0.0 %

1.0 ms

Thank you for attention!
Sponsors are welcome!