Improving Indexing of Text using the Ziv-Lempel Trie

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November 8, 2005

*Supported by the Portuguese Science and Technology Foundation through program POCTI and project POSI/EEI/10204/2001.

OVERVIEW:

Introduction

Modified LZIndex

Results

Future Work

Introduction:

PROBLEM (Exact Matching): find all occurrences of pattern string P in tree string T.

Suffix Tree are optimal index structures, solve the problem in $O(m + R)$ time and $O(u)$ space.

Classical compression algorithms can reduce the space requirements of index structures.

FM-index - Burrows-Wheeler transform, $O(m + R \log^{\epsilon} u)$ time, $5uH_k + O(u\frac{\log \log u + \sigma \log \sigma}{\log u})$ bits

LZ-index - LZ78 or LZW algorithm, $O(m^3 \log \sigma + (m + R) \log n)$ time, $4n \log_2 n(1 + o(1))$ bits

EXAMPLE:

0000111101100101000$

0000 1110 1001 1000

0001 1101 0010 000$

0011 1011 0101

0111 0110 1010

1111 1100 0100

Modified LZIndex:

LZ78 - parsing

0 0001111011001010000$

LZ78 - parsing

0 00 01111011100101000$

LZ78 - parsing

<u>0</u> <u>00</u> <u>01</u> 11101100101000$

LZ78 - parsing

0 00 01 1 1101100101000$

LZ78 - parsing

0 00 01 1 11 01100101000$

LZ78 - parsing

0 00 01 1 11 011 00101000$

LZ78 - parsing

0 00 01 1 11 011 001 01000$

LZ78 - parsing

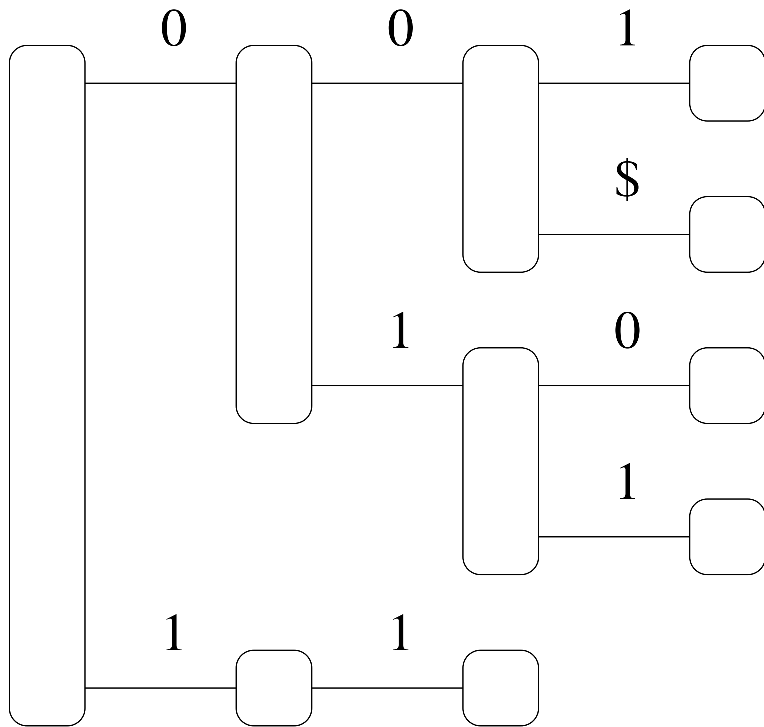
0 00 01 1 11 011 001 010 00$

LZ78 - parsing

0 00 01 1 11 011 001 010 00$

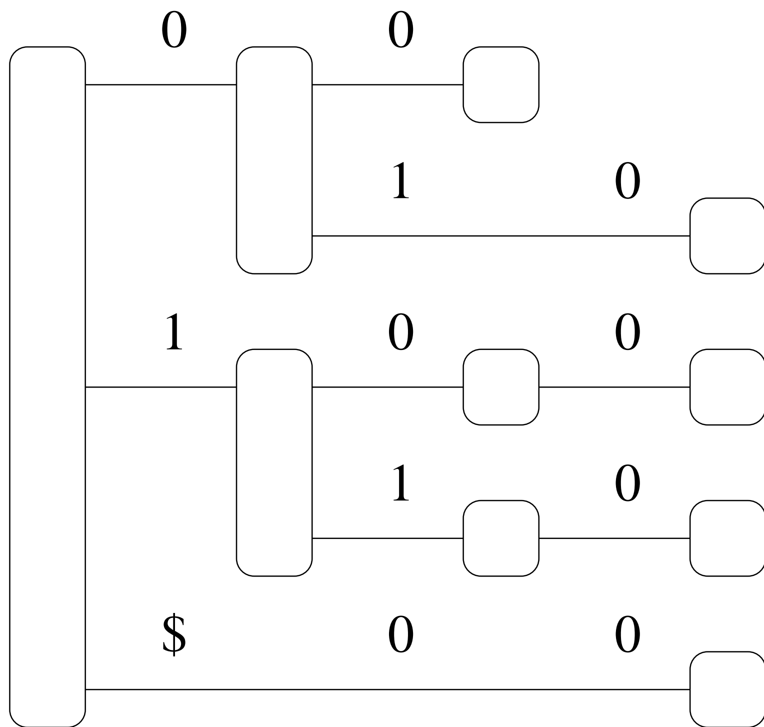
LZ78 - LZTrie

0 00 01 1 11 011 001 010 00$



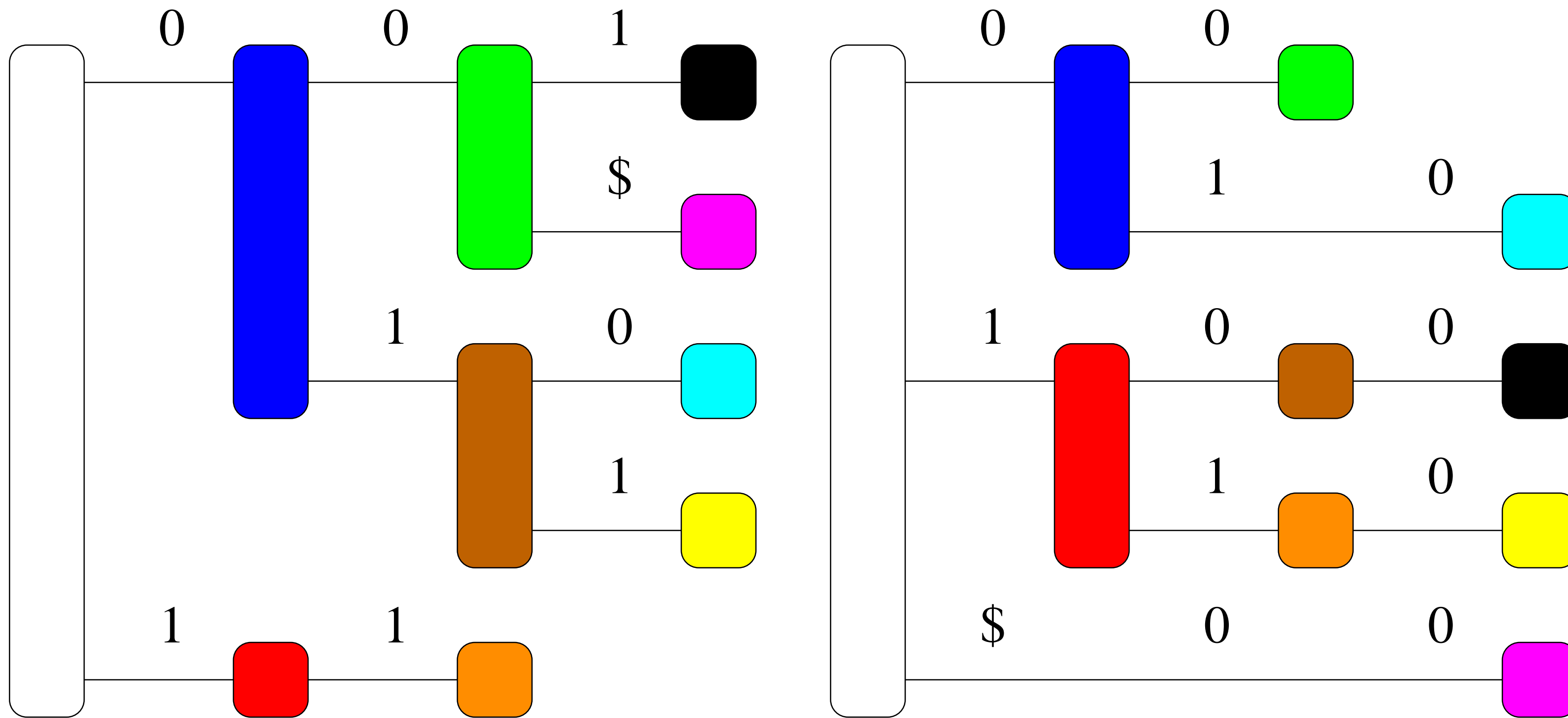
DEFINITION: The RevTrie is defined as the tree obtained from the reversed strings of the LZTrie.

0 00 01 1 11 011 001 010 00$



LZ78 - LZTrie and RevTrie (dual correspondence given by colors)

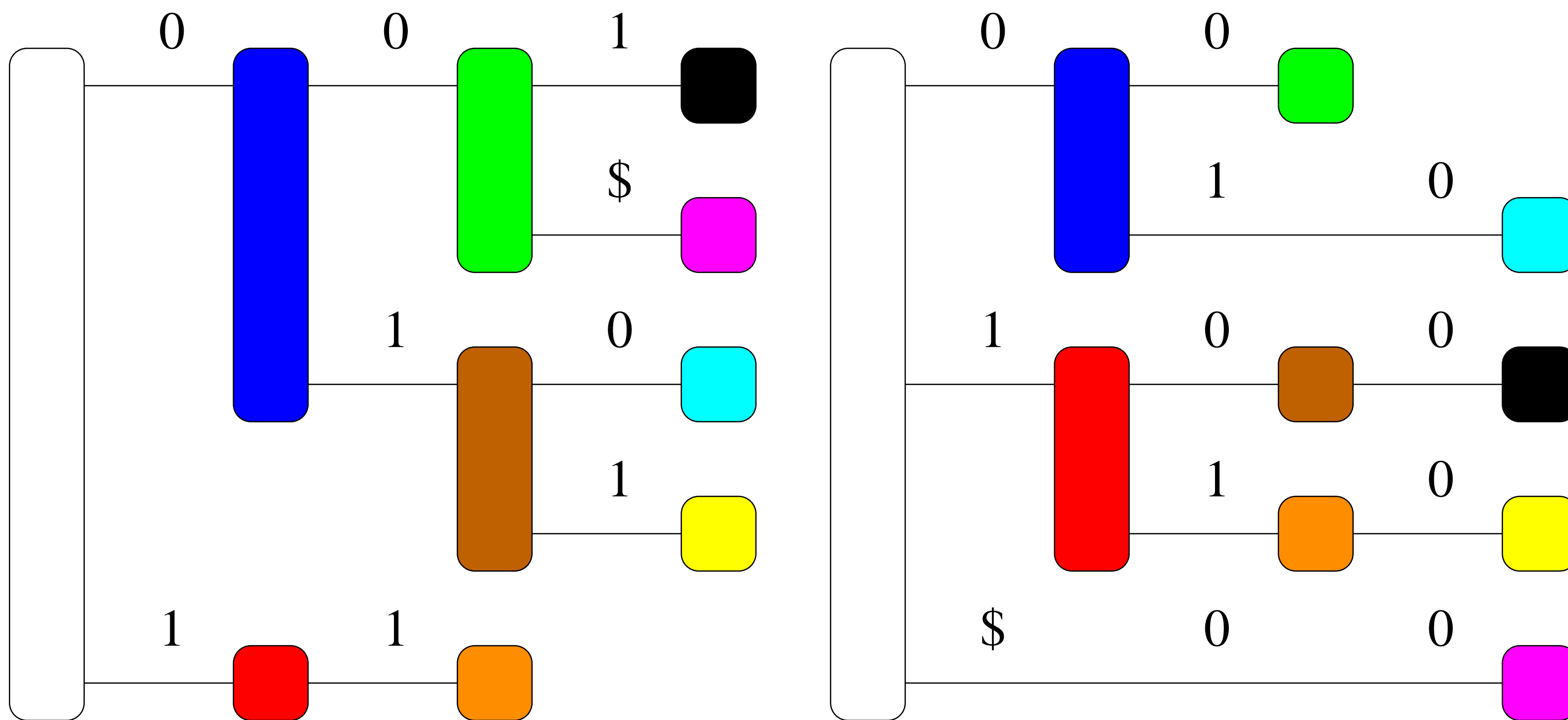
0 00 01 1 11 011 001 010 00$



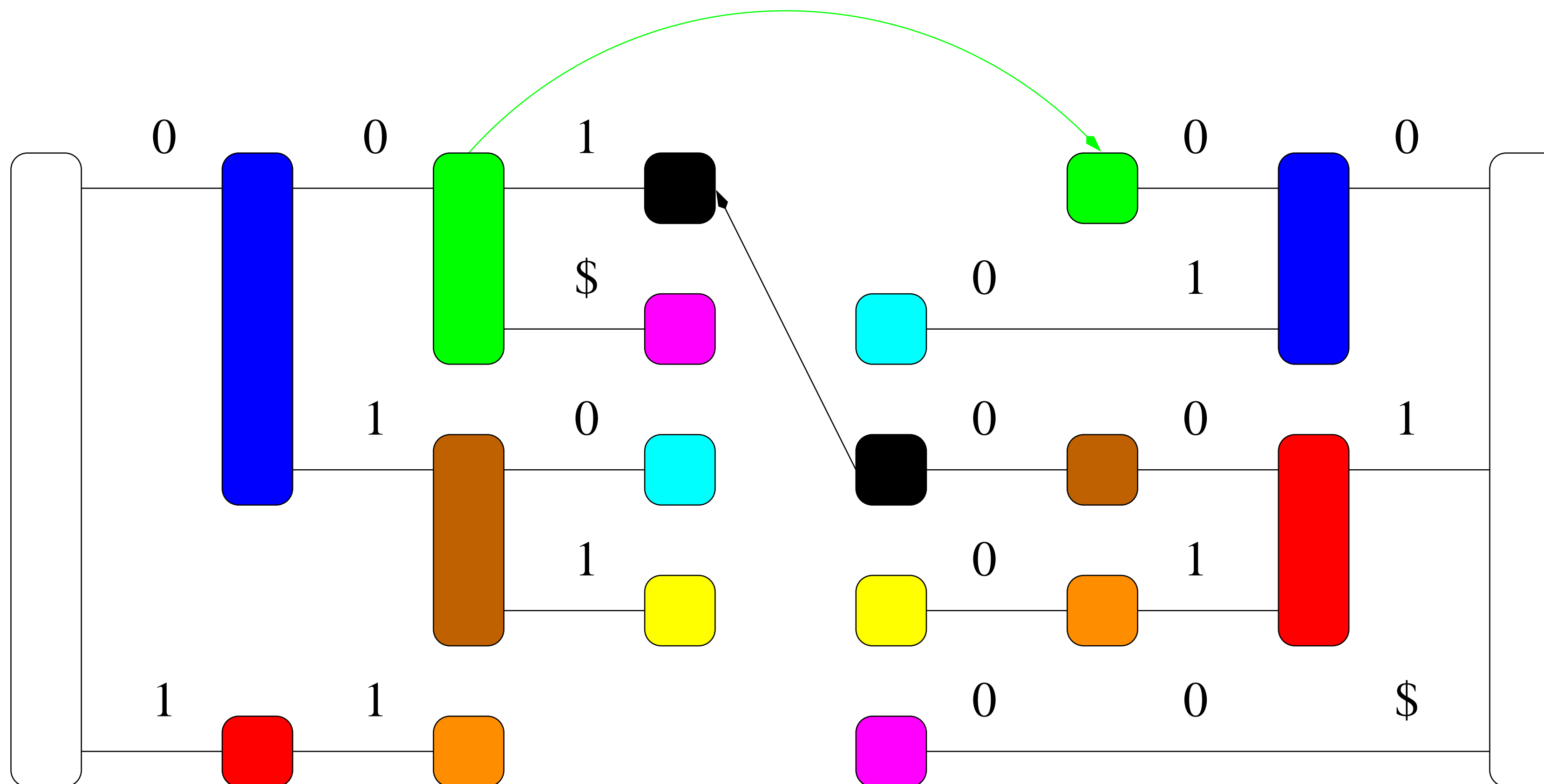
OBSERVATION:

The RevTrie is an implicit generalized suffix tree.

$\$_1 0$ $\$_2 00$ $\$_3 01$ $\$_4 1$ $\$_5 11$ $\$_6 011$ $\$_7 001$ $\$_8 010$ $\$_9 00$

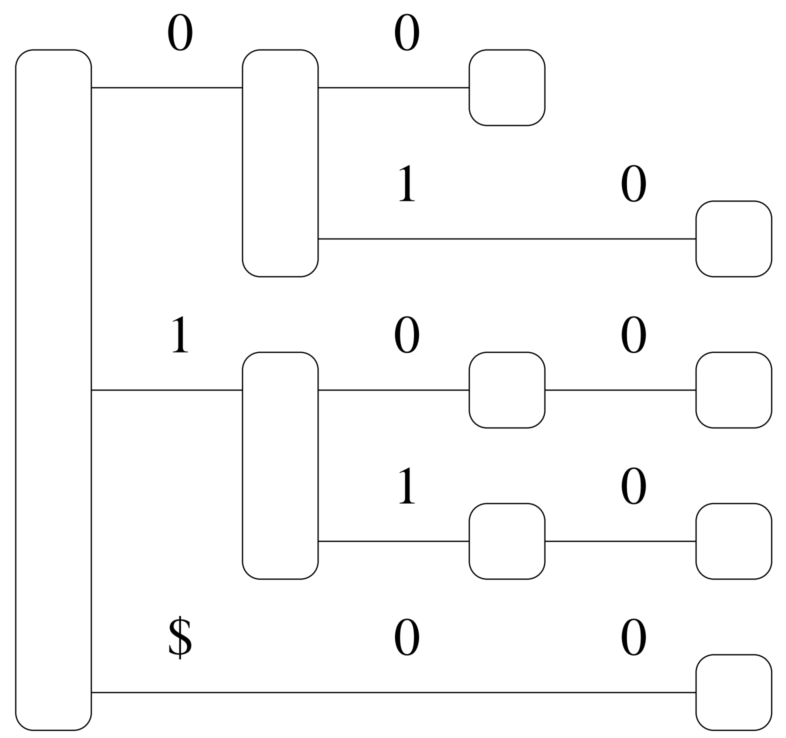


OBSERVATION: The duality between the LZTrie and the RevTrie can be used to compute suffix links.



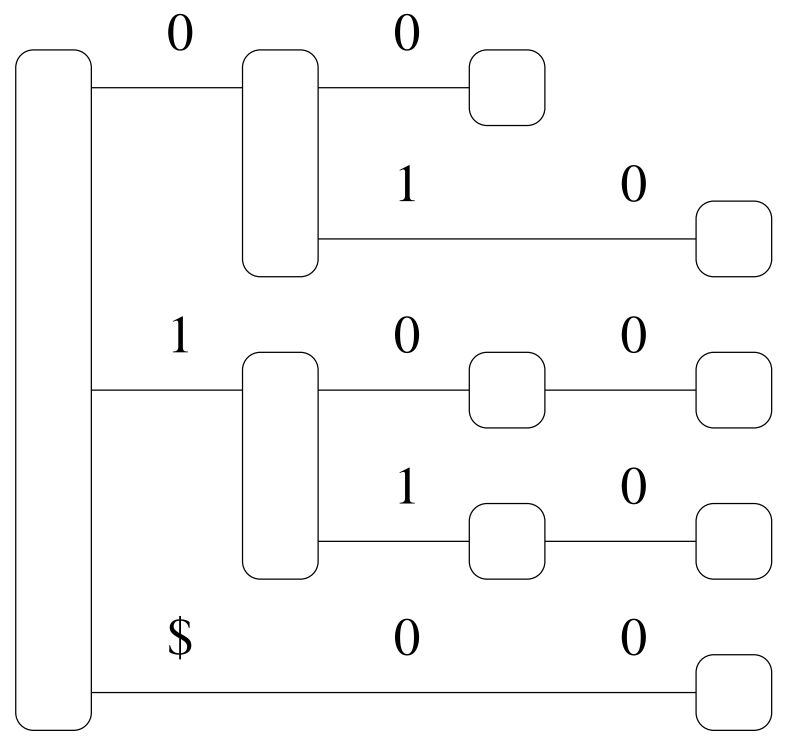
LZ78 - left maximal parsing

00001111011001010 <u>00$</u>



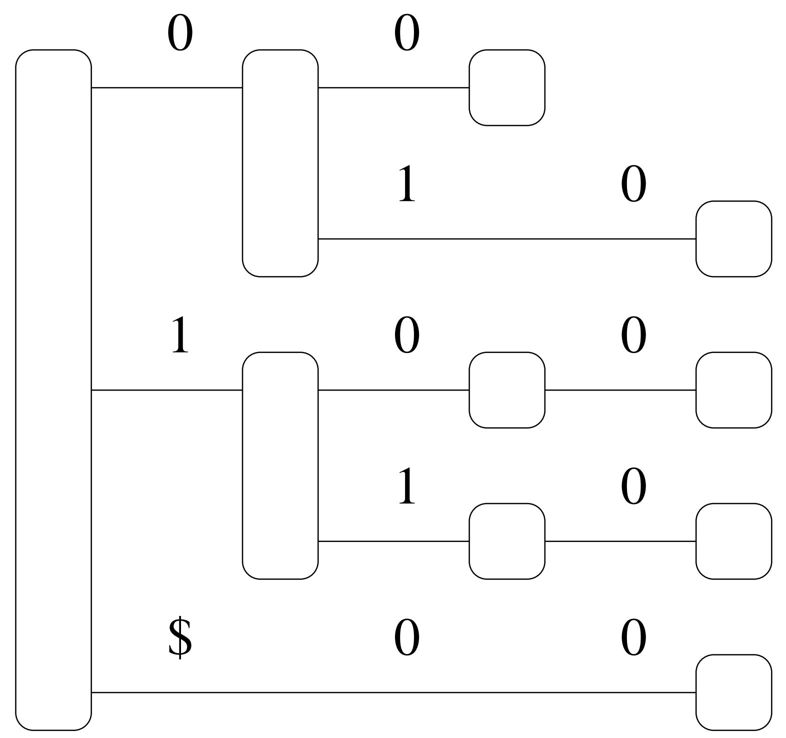
LZ78 - left maximal parsing

00001111011001 010 00$



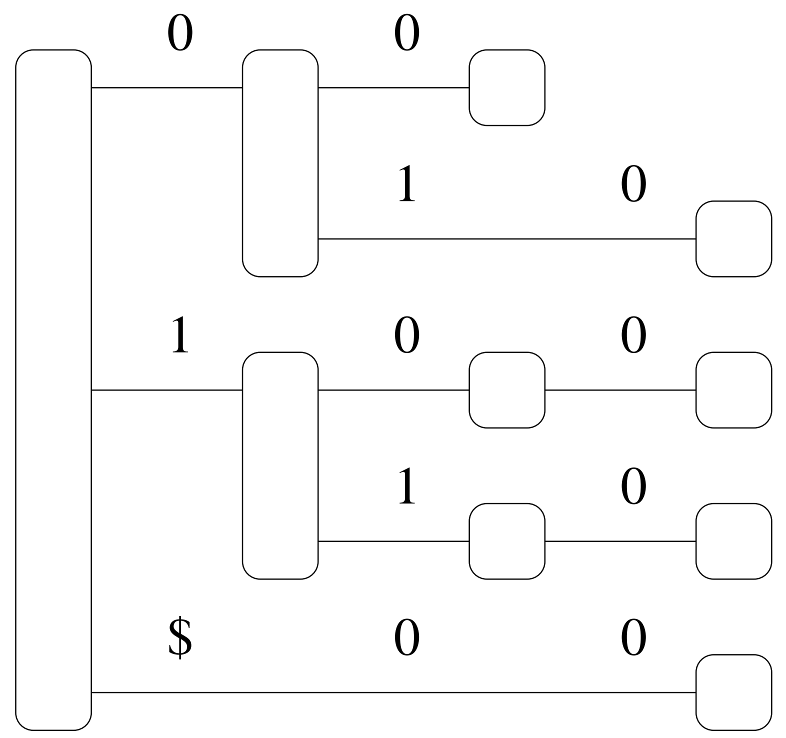
LZ78 - left maximal parsing

00001111011 <u>001</u> <u>010</u> <u>00$</u>



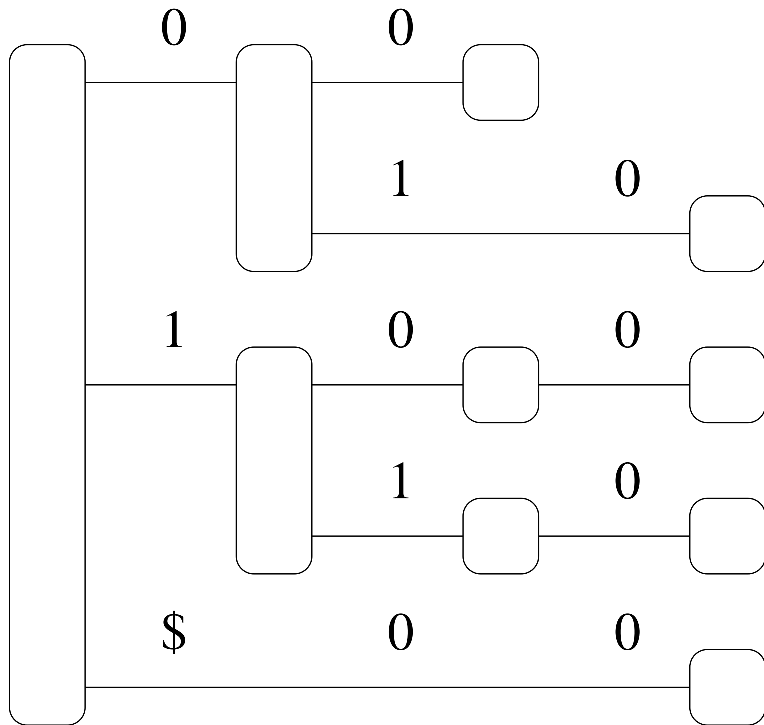
LZ78 - left maximal parsing

00001111 011 001 010 00$



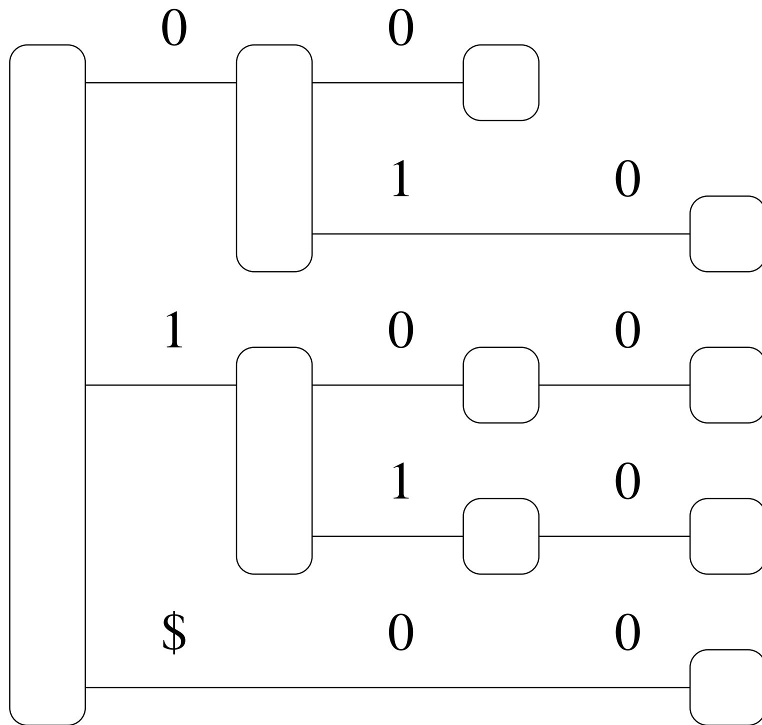
LZ78 - left maximal parsing

000011 11 011 001 010 00$



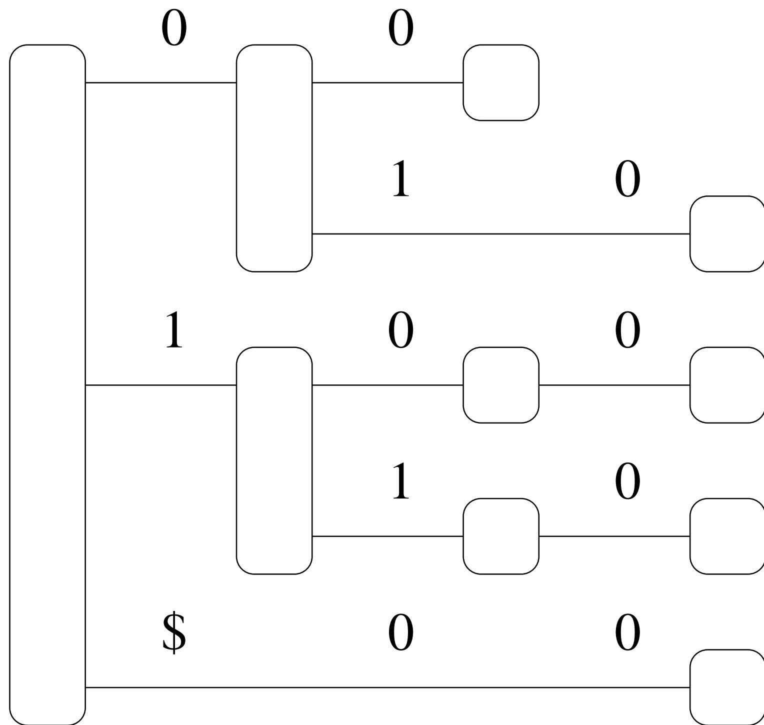
LZ78 - left maximal parsing

000 011 11 011 001 010 00$



LZ78 - left maximal parsing

0 <u>00</u> <u>011</u> <u>11</u> <u>011</u> <u>001</u> <u>010</u> <u>00$</u>

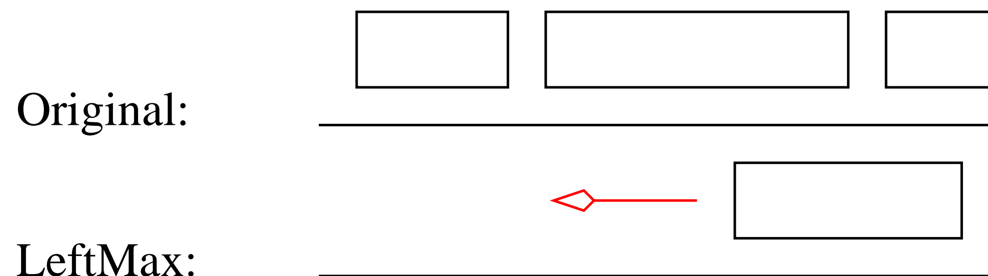


LZ78 - left maximal parsing

0 00 011 11 011 001 010 00$

Each node now stores a list of blocks.

Lemma: The LZ78 left maximal parsing has at most as many blocks as the LZ78 parsing.



Searching for pattern P

- Descend and Suffix Walk for P^R

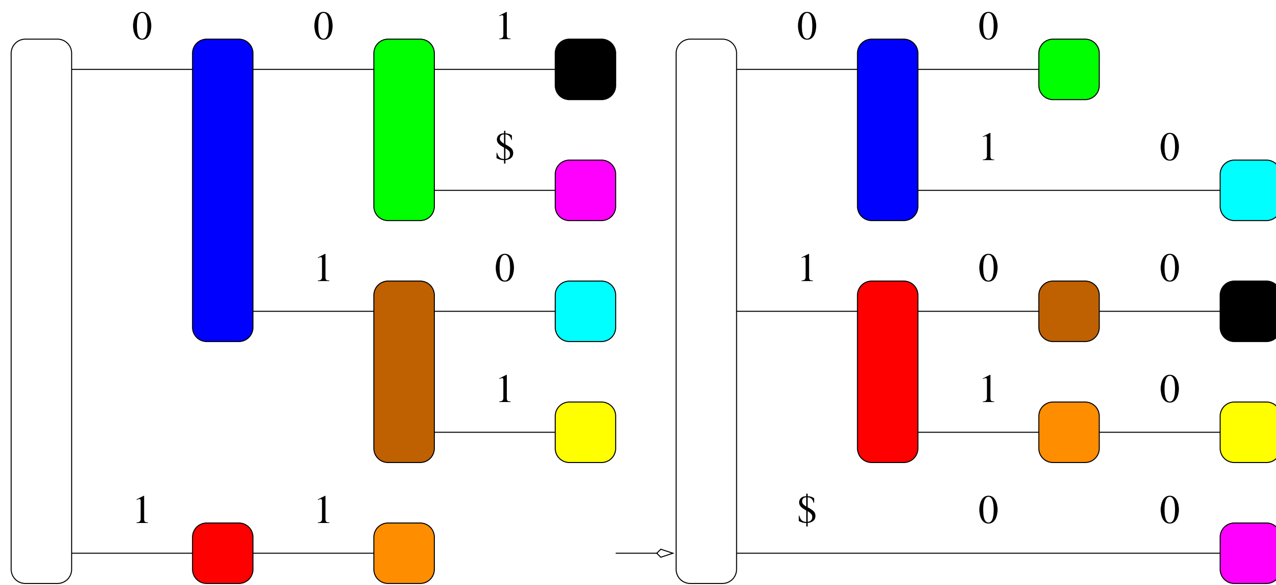
- Classify type of match

  one P is inside a block

  two P spans 2 blocks

  more than two P spans more than 2 blocks

```
1: procedure Descend_and_Suffix(P)
2:     point ← Root
3:     for i ← m, 0 do
4:         while NOT Descend_?(point, S[i]) do
5:             point ← Suffix_Link(point)
6:         end while
7:         point ← Descend(point, S[i])
8:     end for
9: end procedure
```

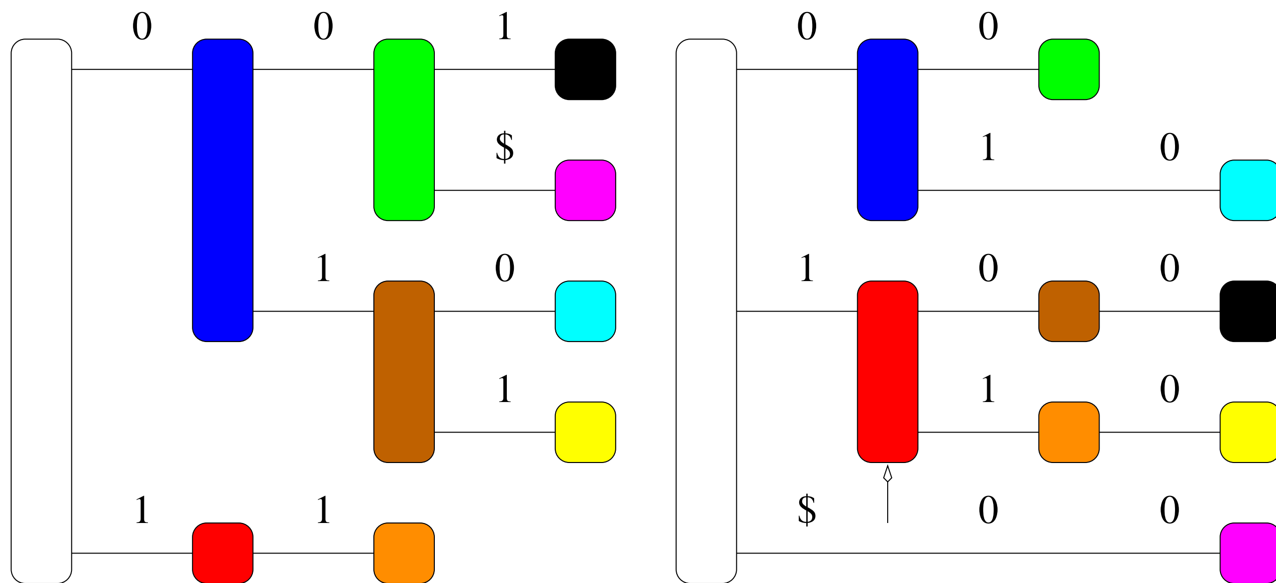


Pat # 0 0 1 1 1 1

Left

Left–Child

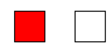
Right

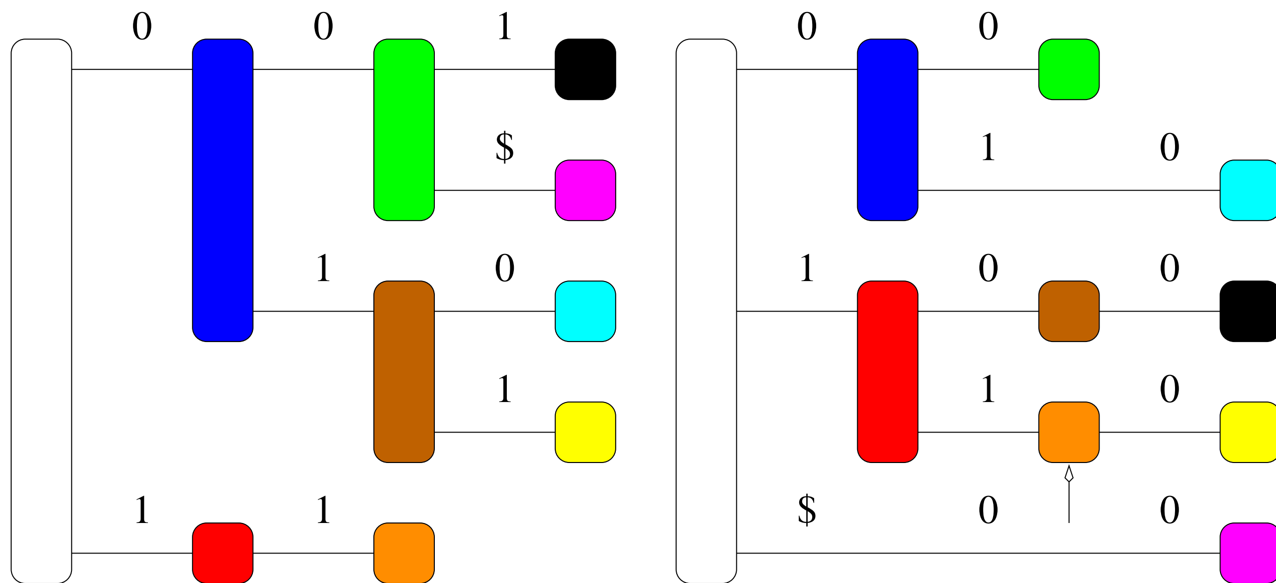


Pat # 0 0 1 1 1 1

Left

Left–Child

Right 

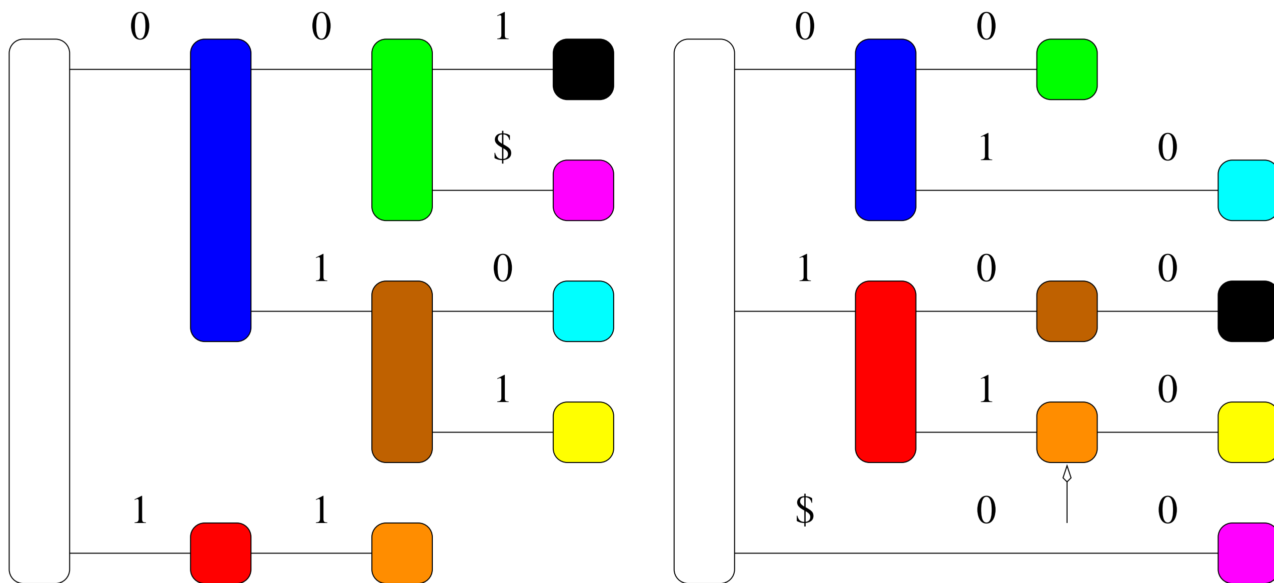


Pat # 0 0 1 1 1 1

Left

Left–Child

Right

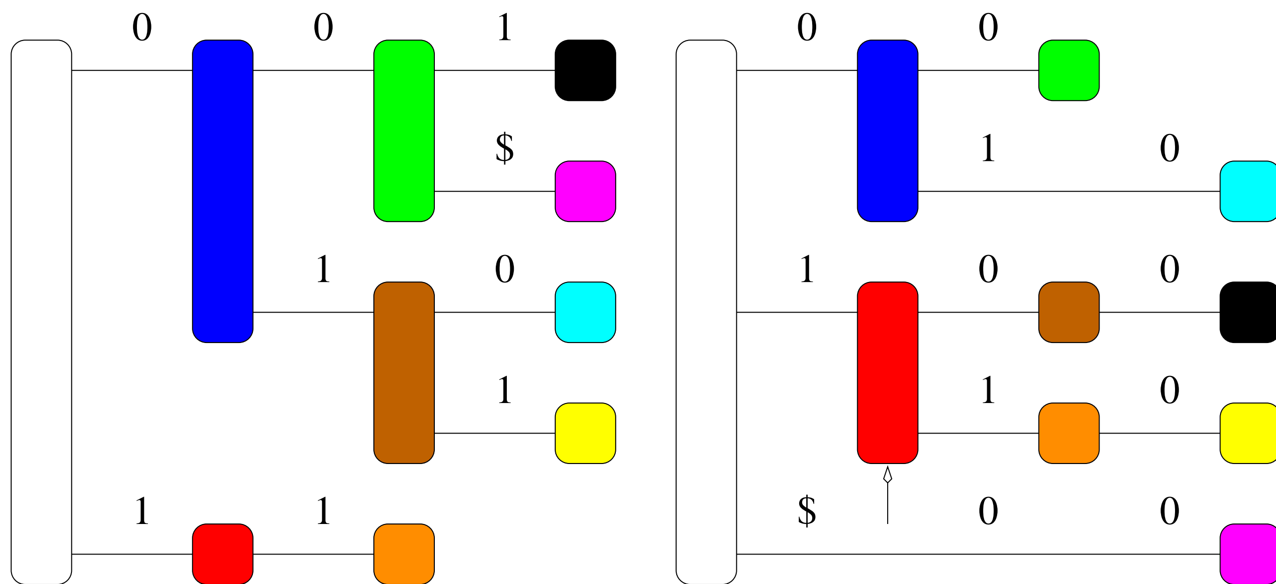


Pat # 0 0 1 1 1 1

Left

Left–Child

Right

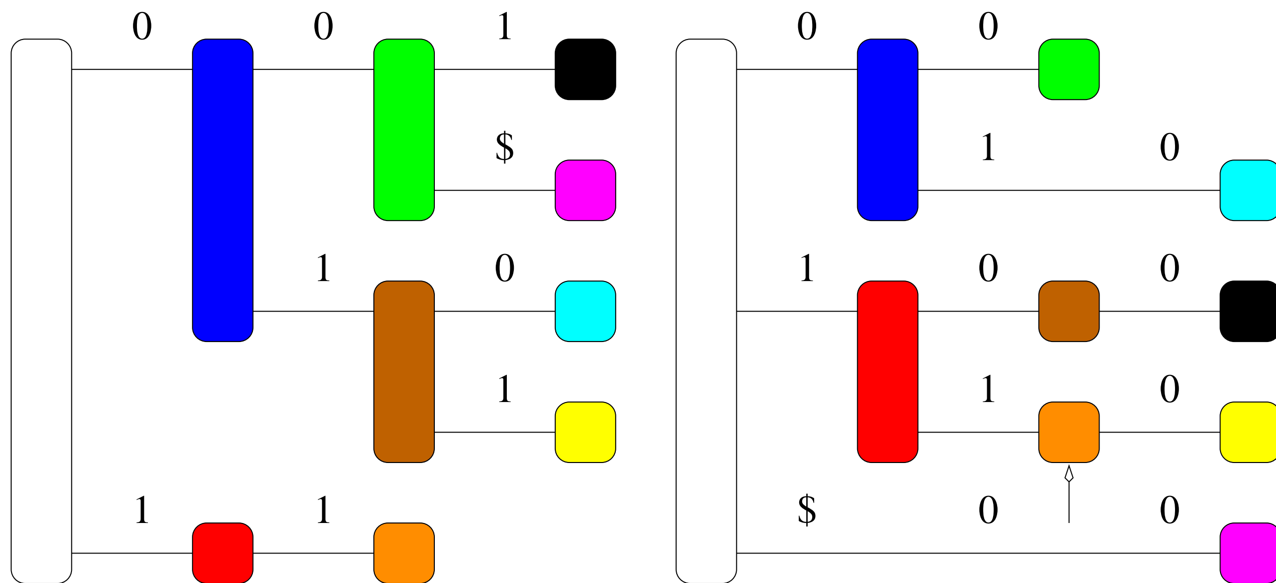


Pat # 0 0 1 1 1 1

Left

Left–Child

Right



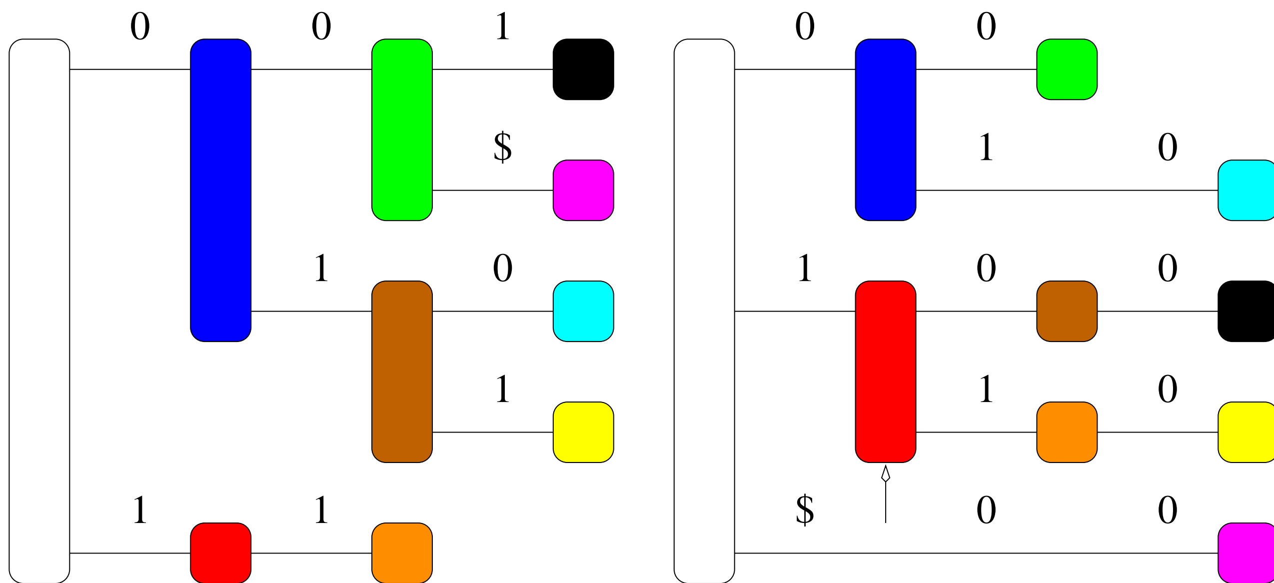
Pat # 0 0 1 1 1 1

Left

Left–Child

Right

Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

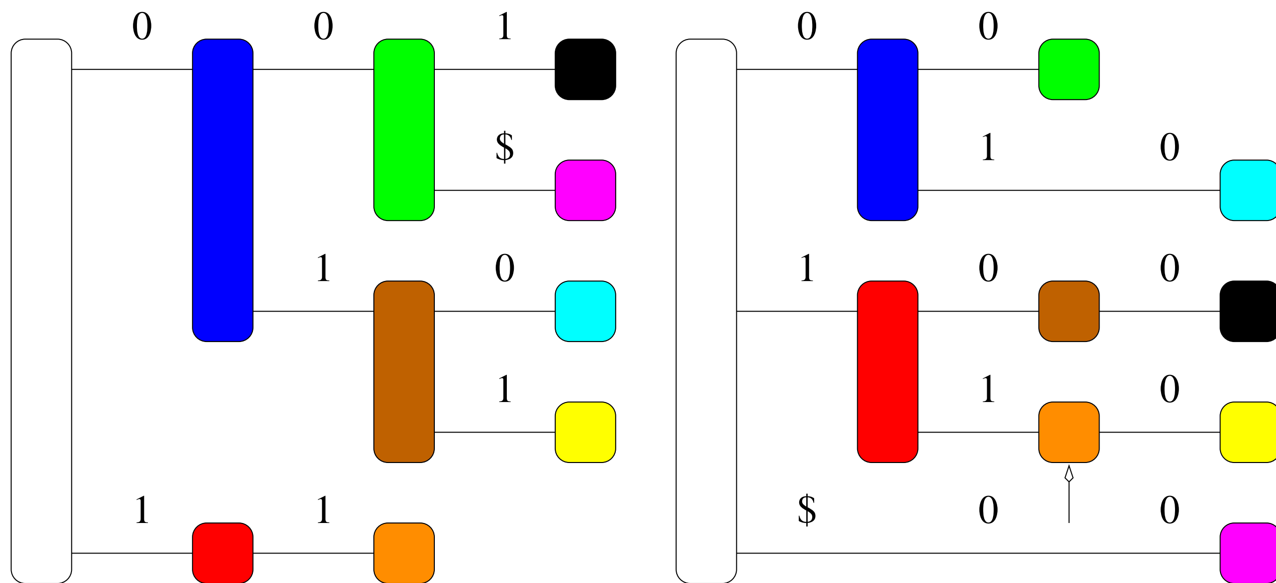


Pat # 0 0 1 1 1 1

Left

Left–Child

Right


0
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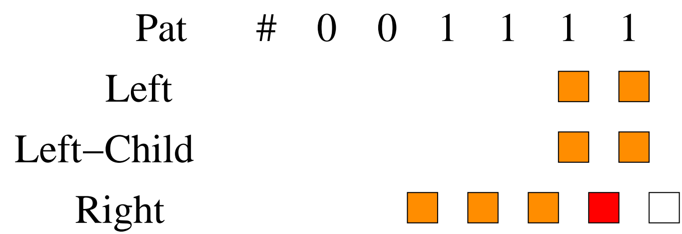
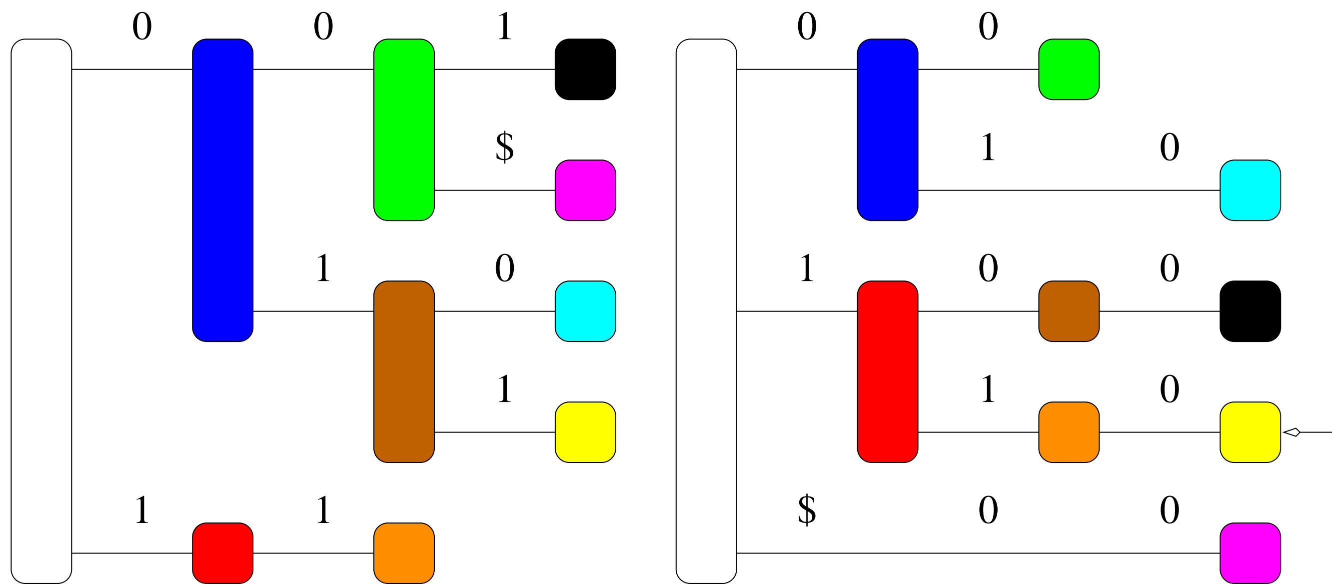
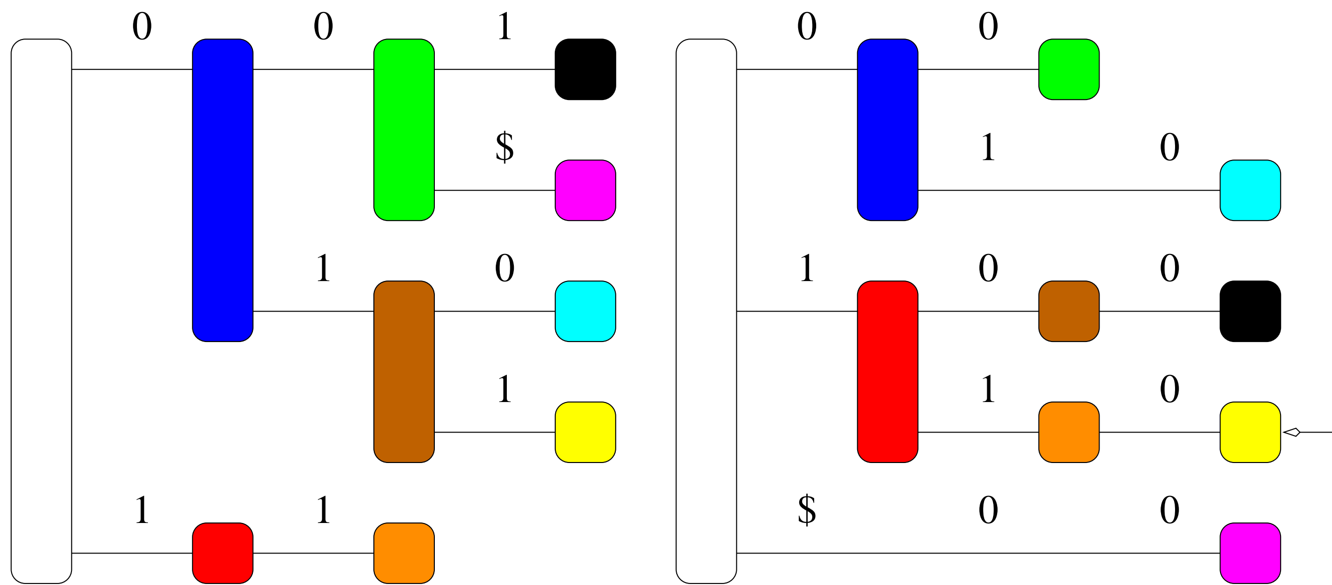
1
0
$
0
0


Pat # 0 0 1 1 1 1
Left
Left–Child
Right



Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

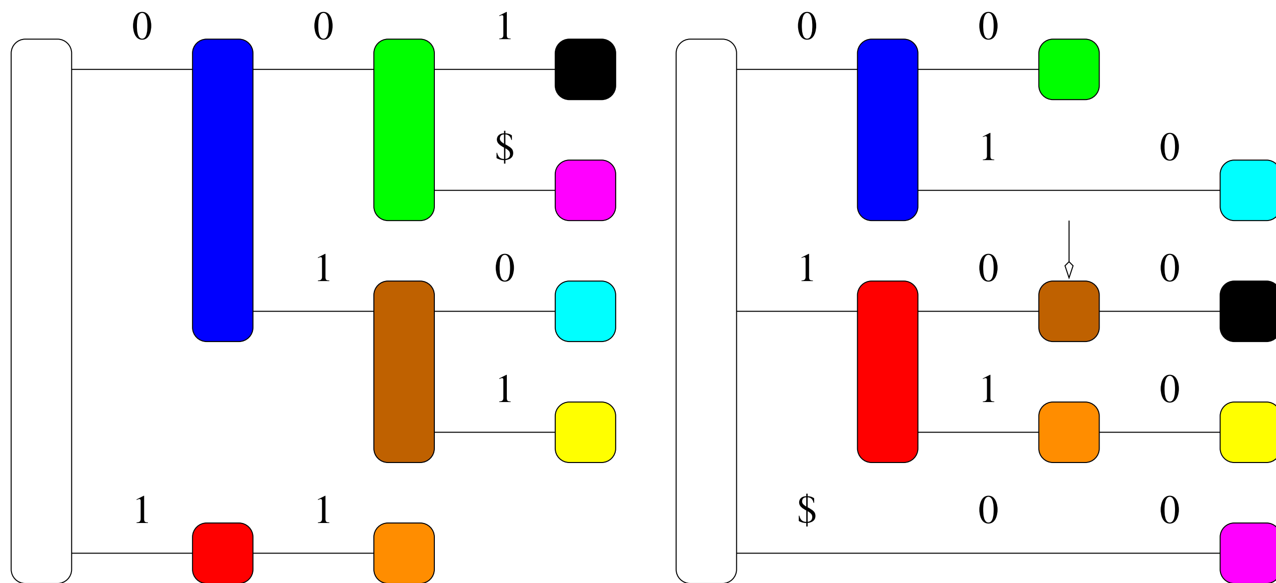


Pat # 0 0 1 1 1 1

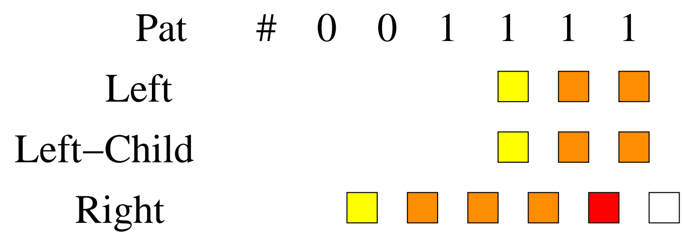
Left

Left–Child

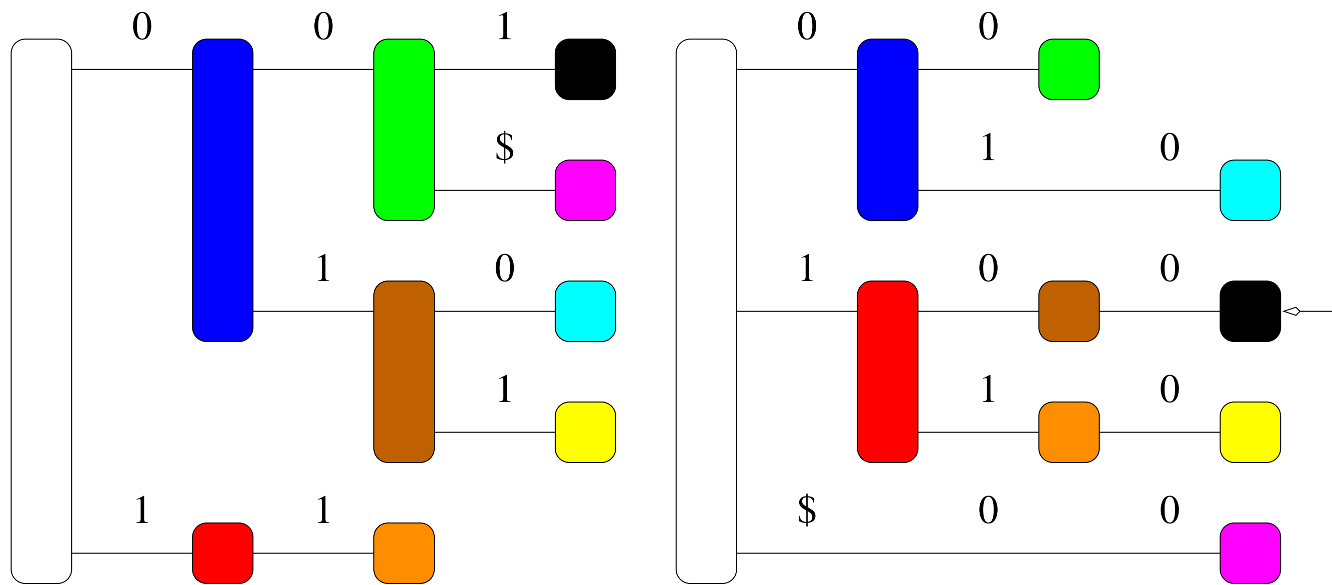
Right



0
0
1
$
1
0
1
1
1
0
0
1
0
1
0
0
1
0
$
0
0



Pat # 0 0 1 1 1 1
Left
Left–Child
Right

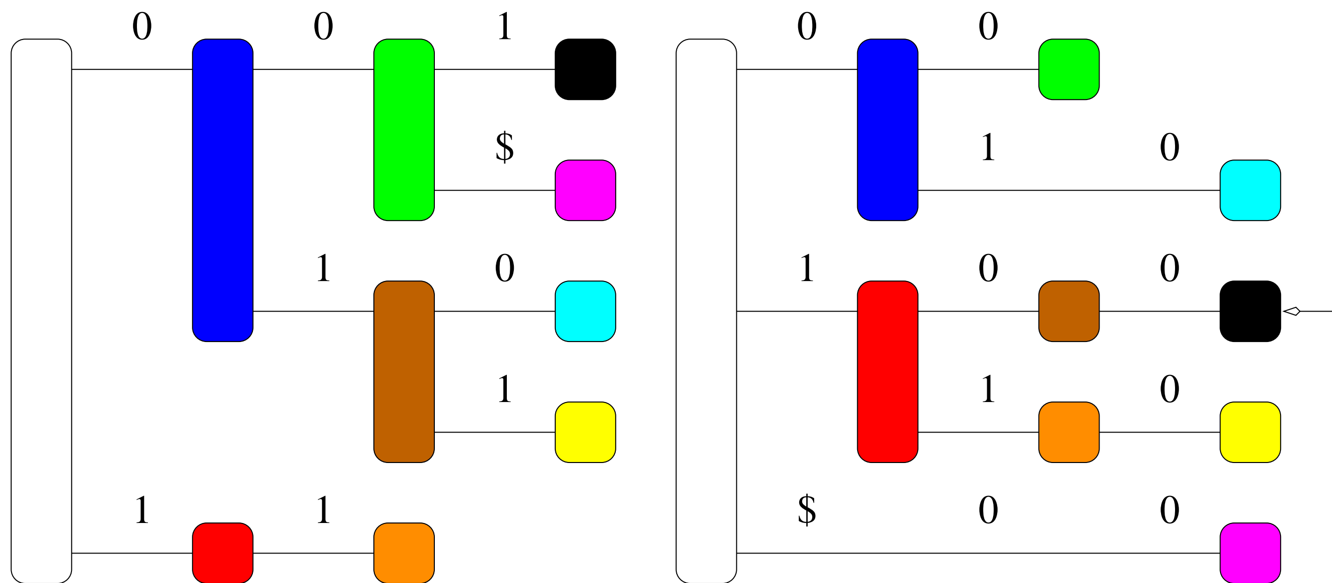


Pat # 0 0 1 1 1 1

Left

Left–Child

Right

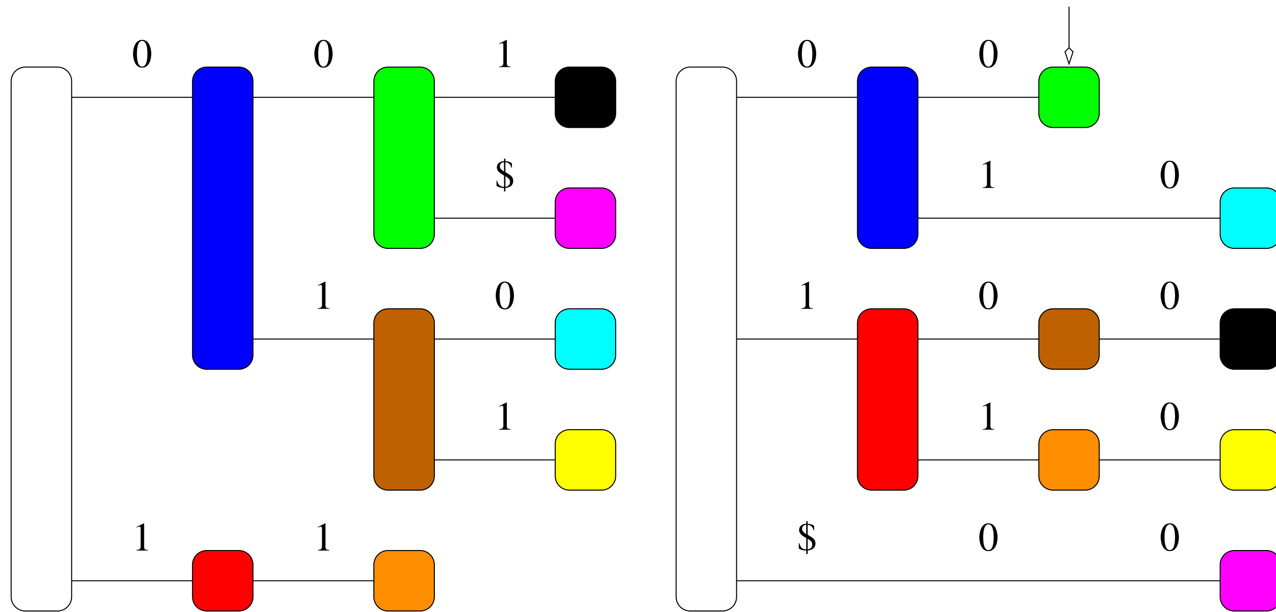


Pat # 0 0 1 1 1 1

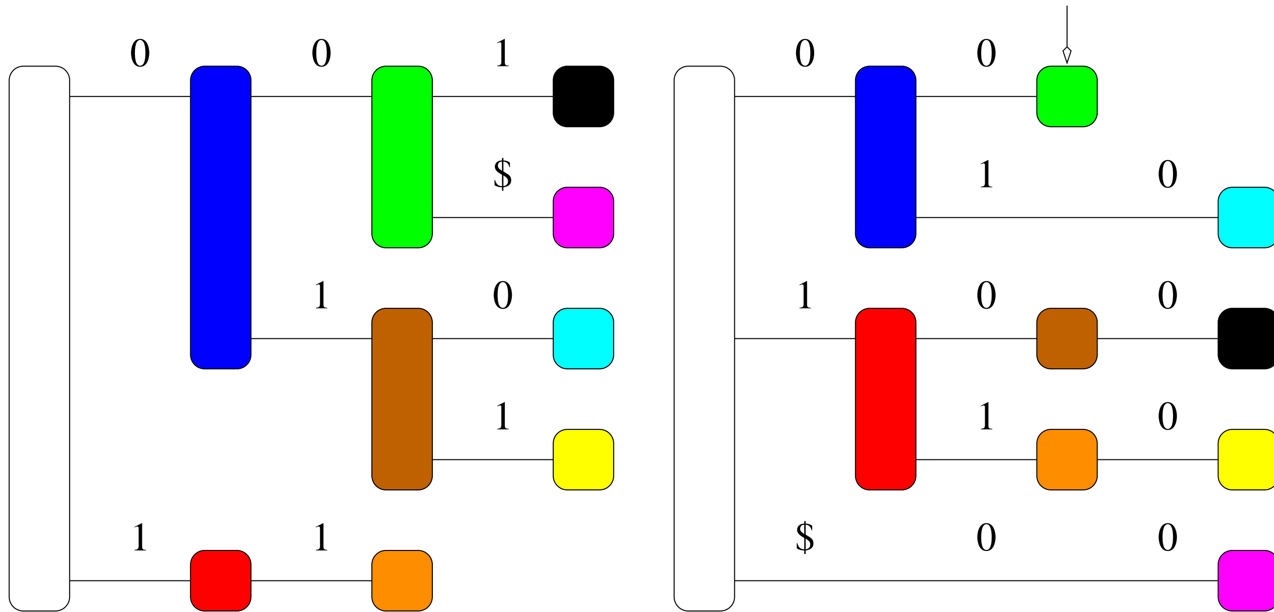
Left

Left–Child

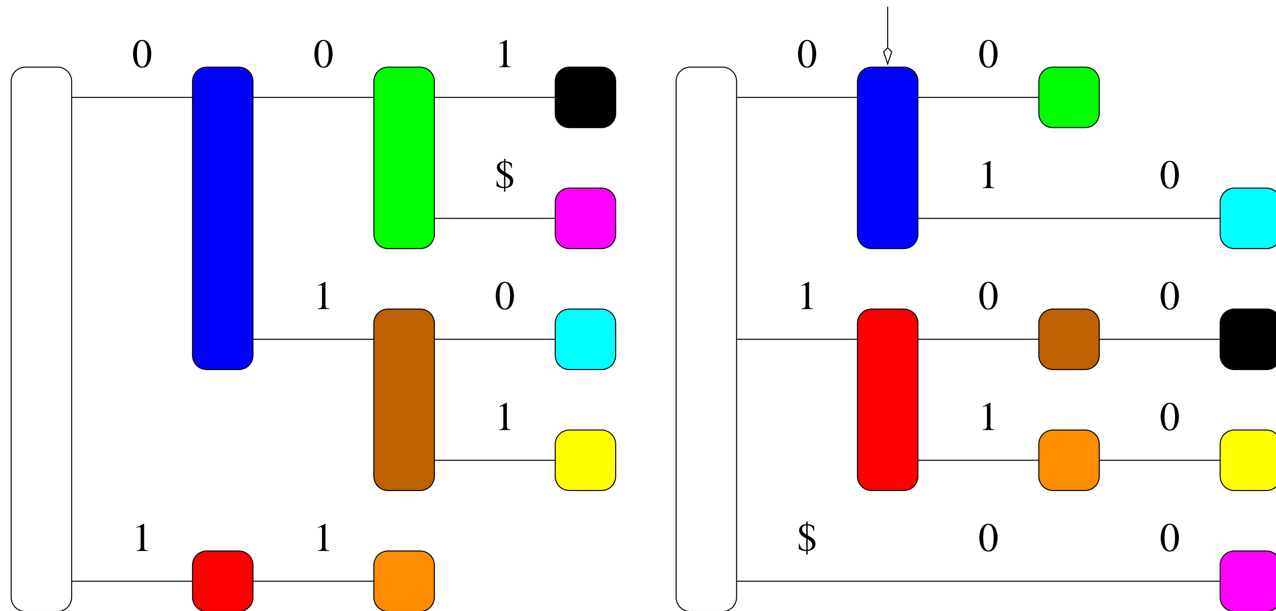
Right



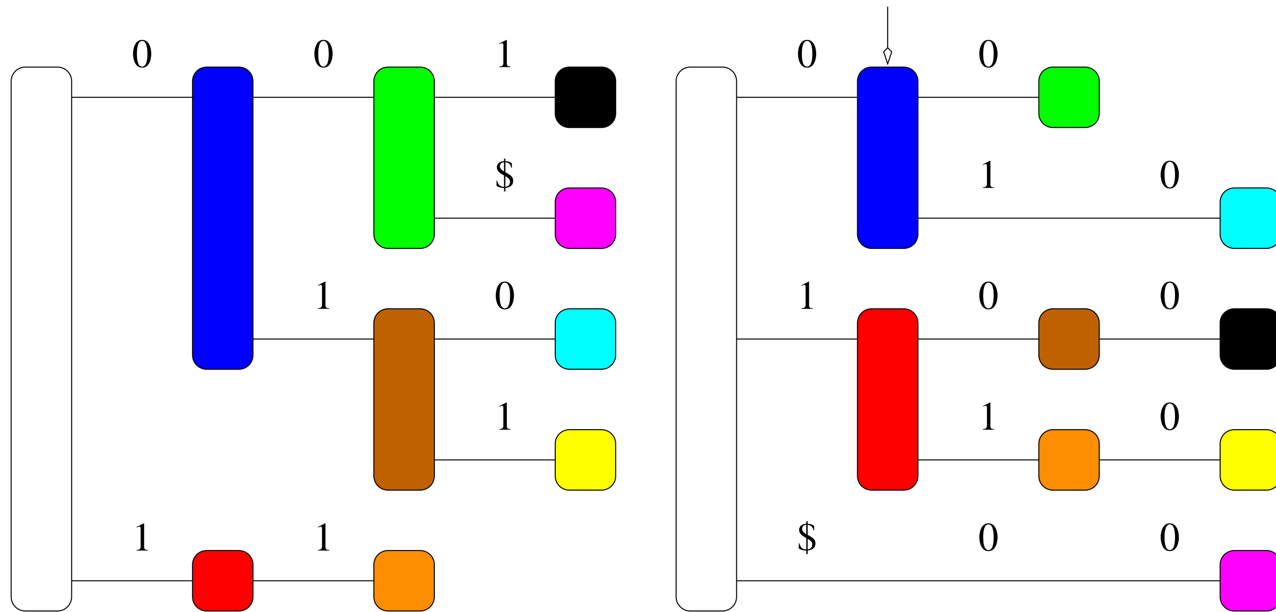
Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							



Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							



Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

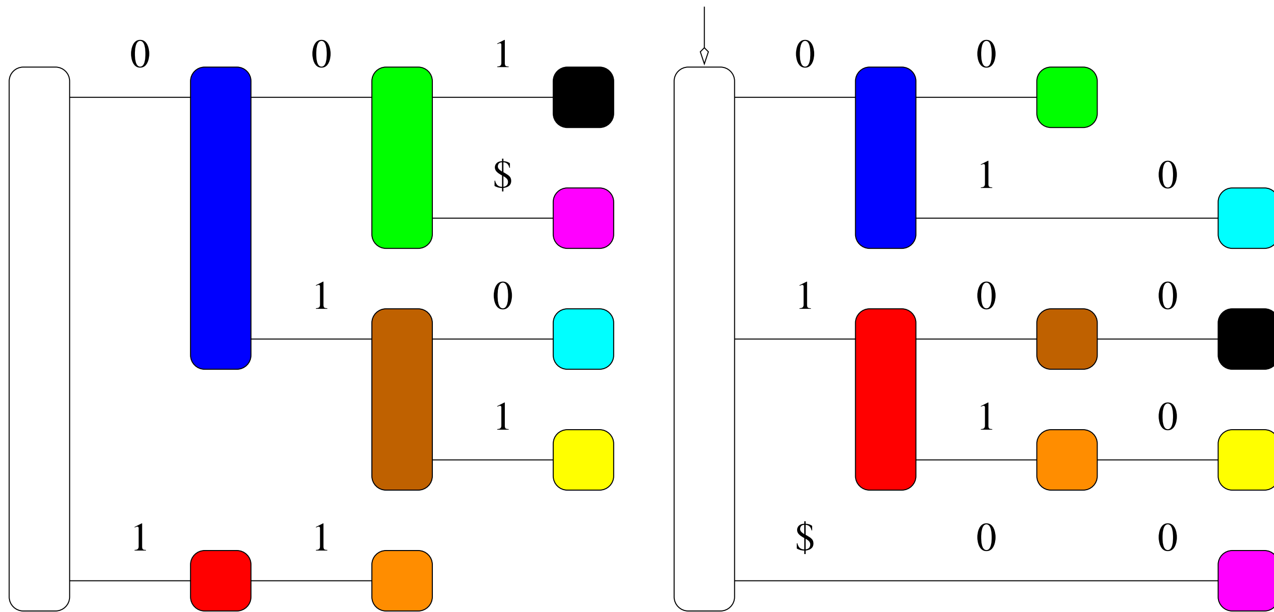


Pat # 0 0 1 1 1 1

Left

Left–Child

Right

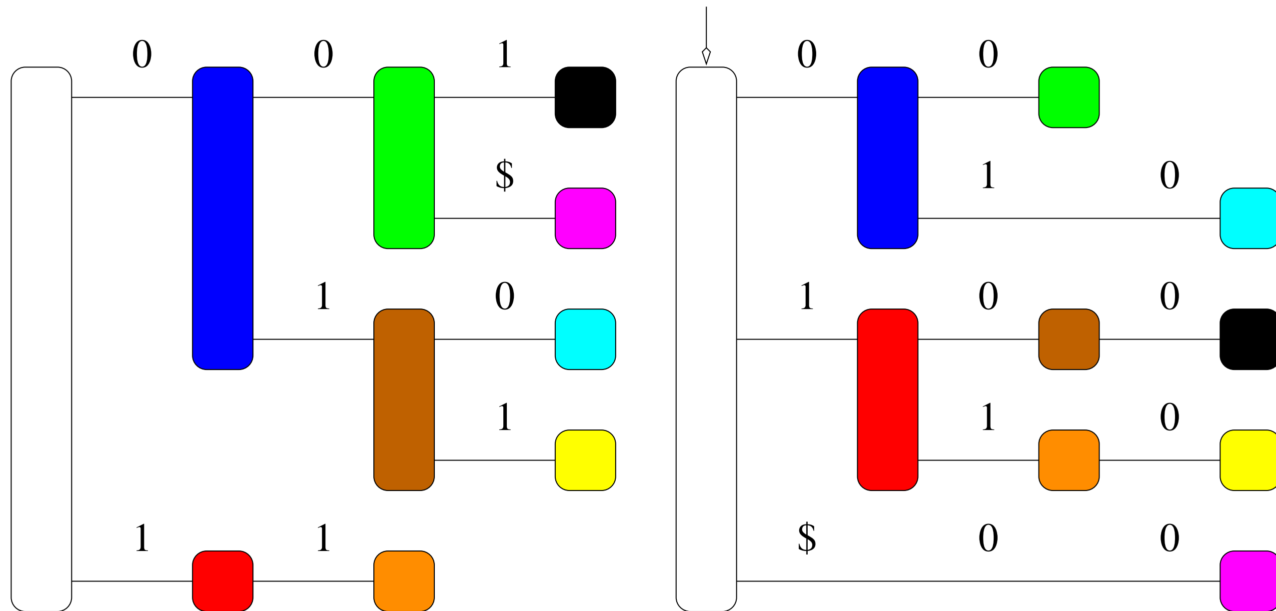


Pat # 0 0 1 1 1 1

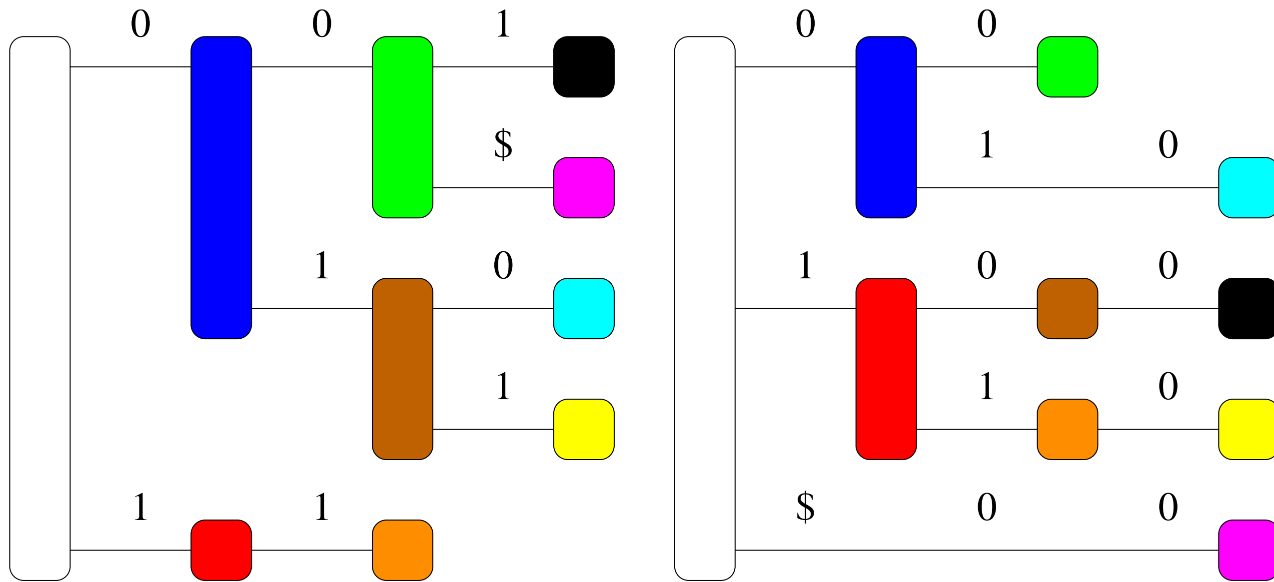
Left

Left–Child

Right

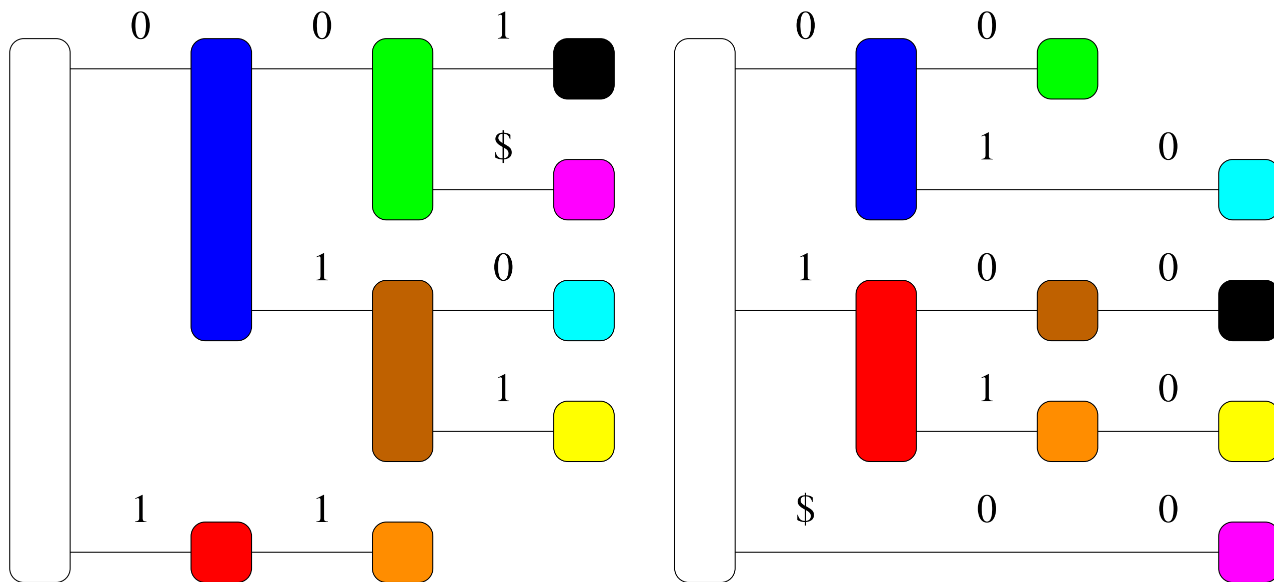


Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							



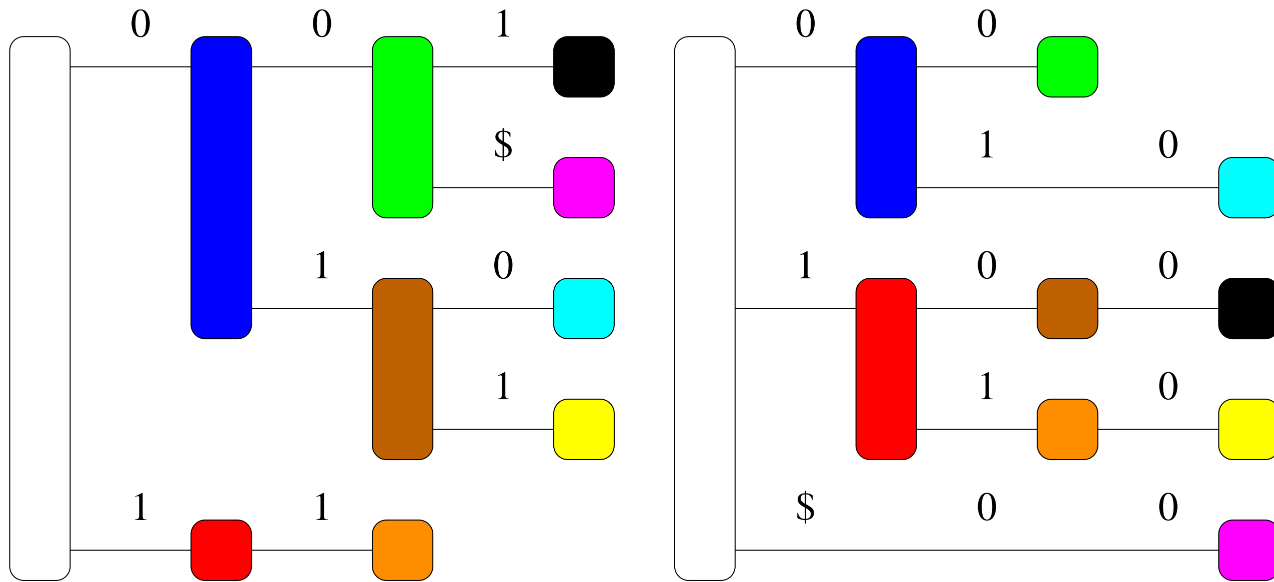
Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

Break the pattern in all the points until the condition of the while loop is true for the first time.



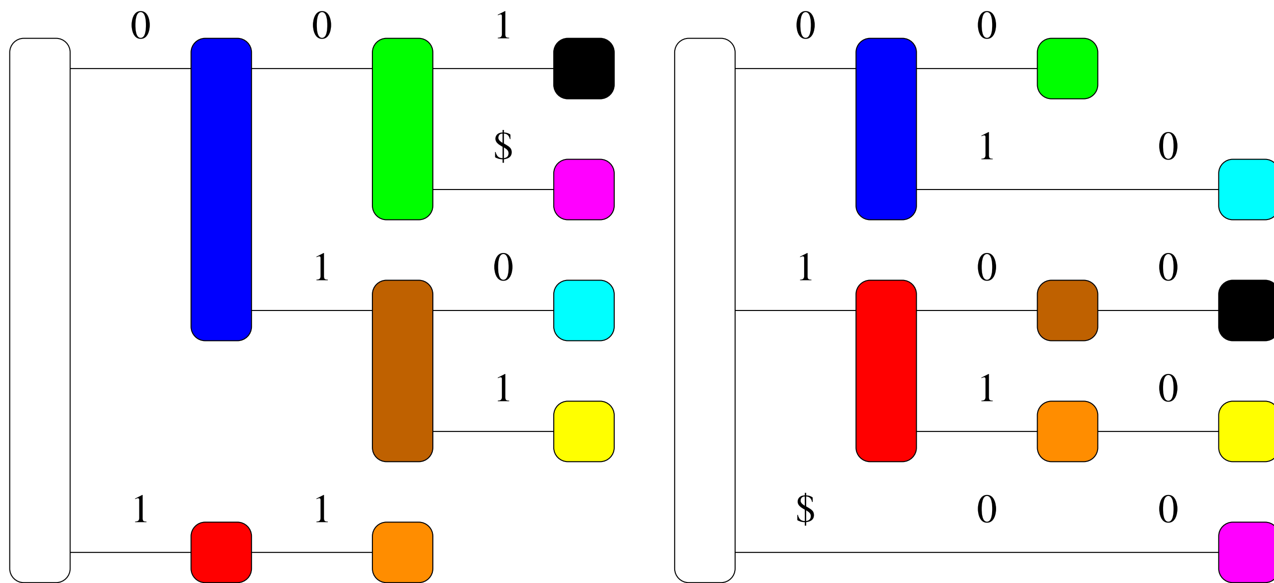
Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

For this point the only possible case is 1.
No occurrences of type 1 may exist since neither the Left nor the Left–Child overlap the hole pattern.



Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

From this point the only possible cases are 2 and >2
Since neither the Left nor the Left–child overlap the hole pattern it is not case 2.


0
0
1
$
1
0
1
1
1
0
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1
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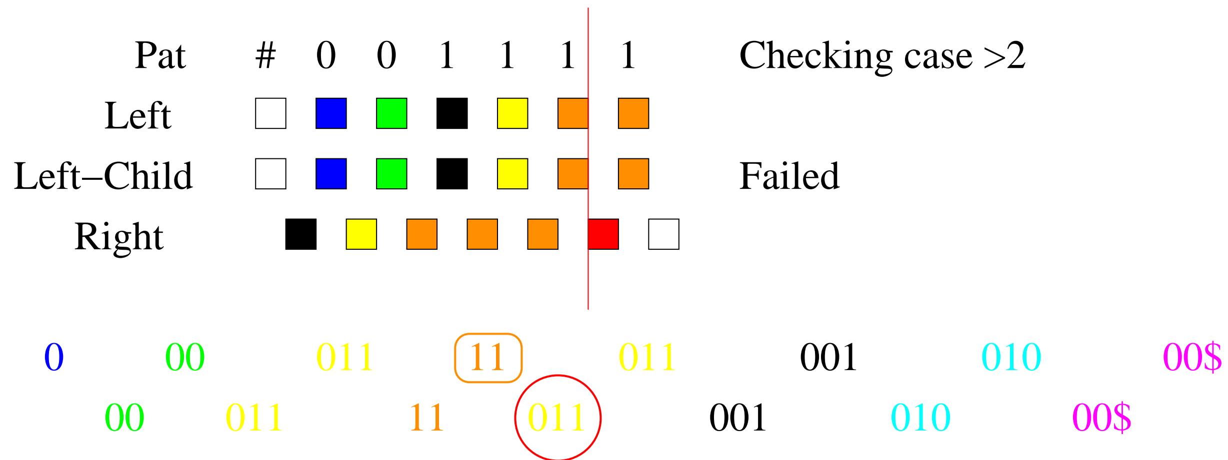
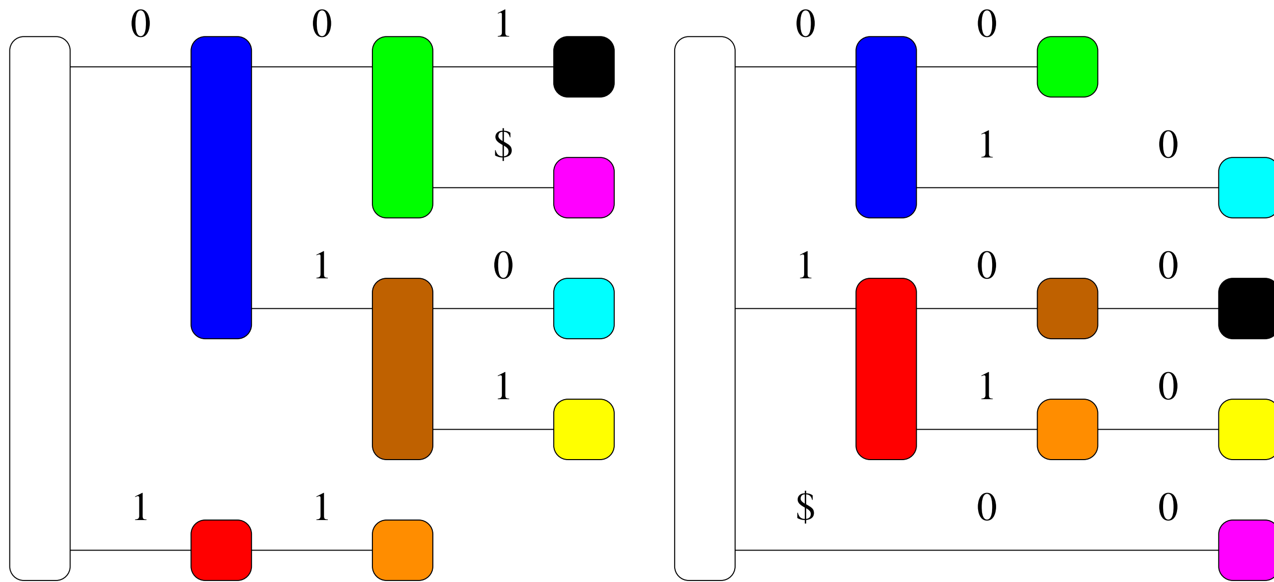
1
0
0
1
0
$
0
0

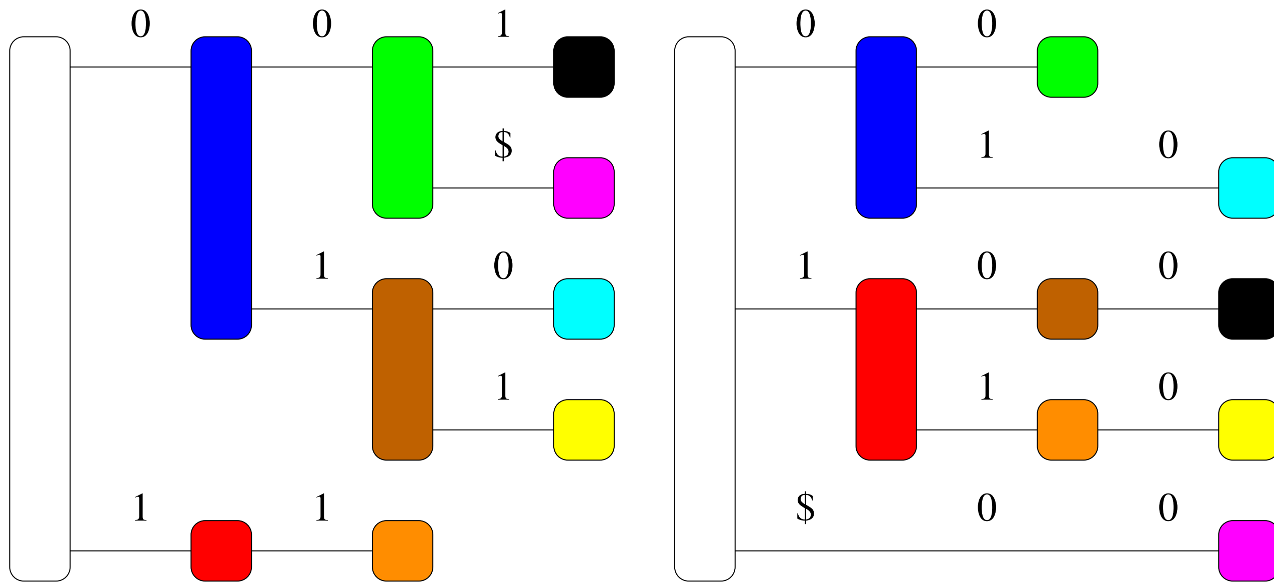

Pat
0 0 1 1 1 1
Checking case >2
Left
Left–Child
Failed
Right
0
00
011
11
011
001
010
00$
00
011
11
011
001
010
00$



Pat	#	0	0	1	1	1	1
Left							
Left–Child							
Right							

From this point the only possible cases are 2 and >2

Since neither the Left nor the Left–child overlap the hole pattern it is not case 2.



Pat # 0 0 1 1 1 1

Checking case >2

Left

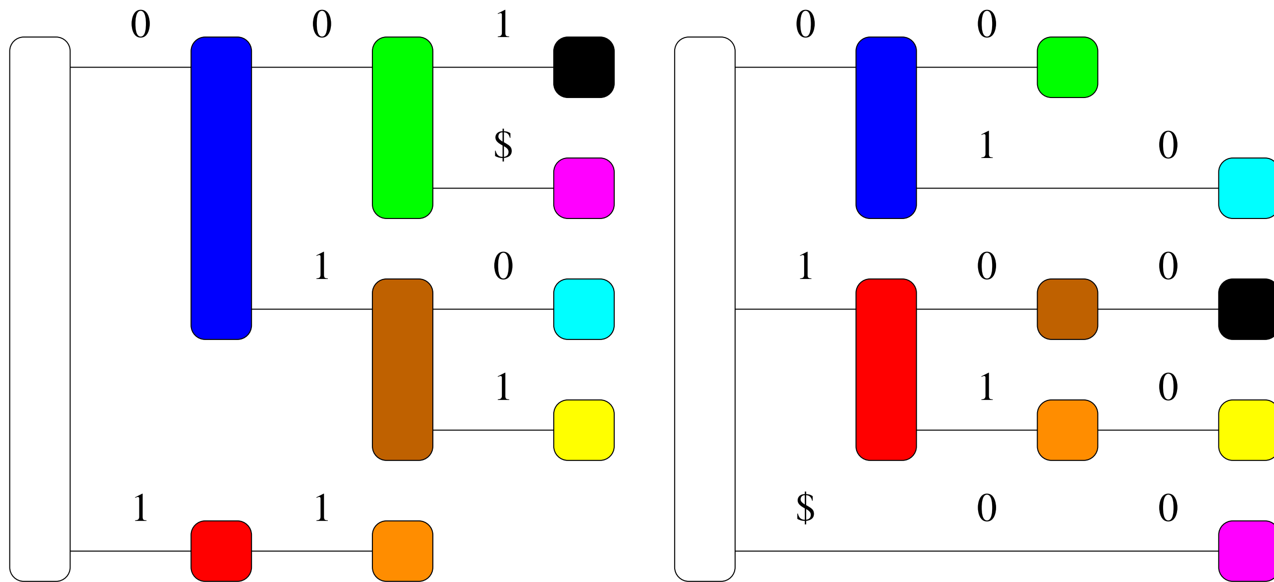
Left–Child

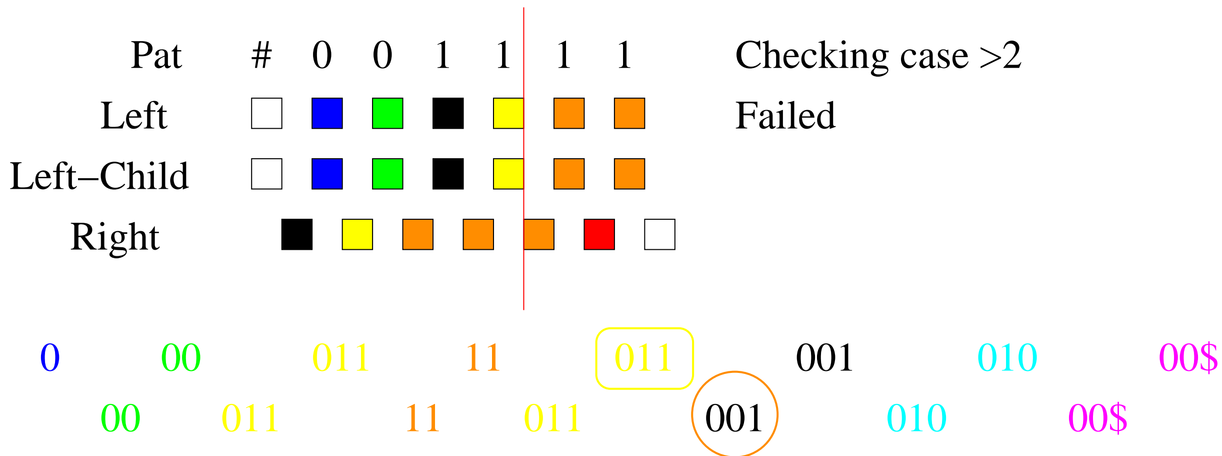
Found

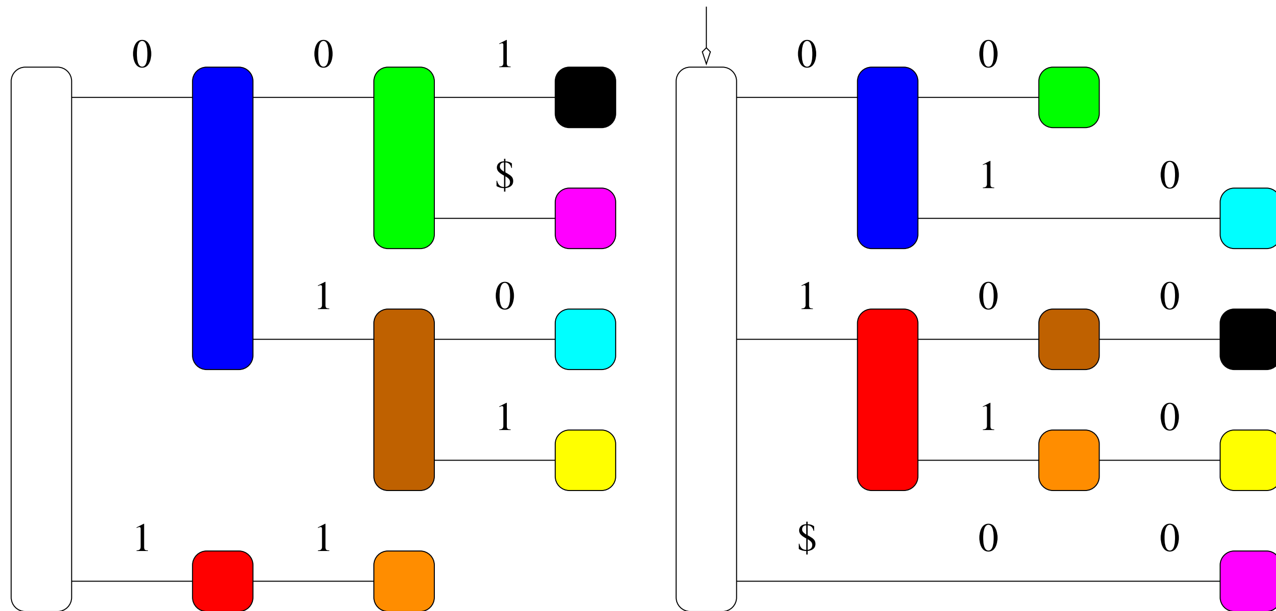
Right

0 00 011 11 011 001 010 00$

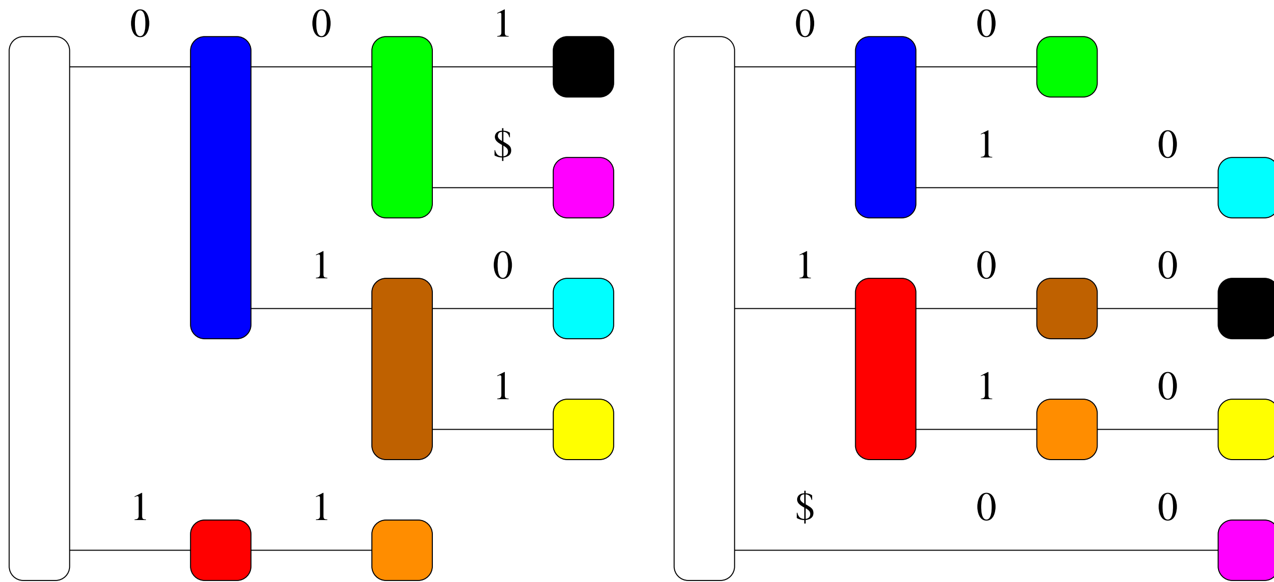
00 011 11 011 001 010 00$


0
0
1
$
1
0
1
1
1
0
0
1
0
1
0
0
1
0
$
0
0


Pat # 0 0 1 1 1 1
Left
Left–Child
Right
Checking case >2
Failed
0 00 011 11 011 001 010 00$
00 011 11 011 001 010 00$



Pat	#	1	1	0	0
Left					
Left–Child					
Right					



Pat # 1 1 0 0

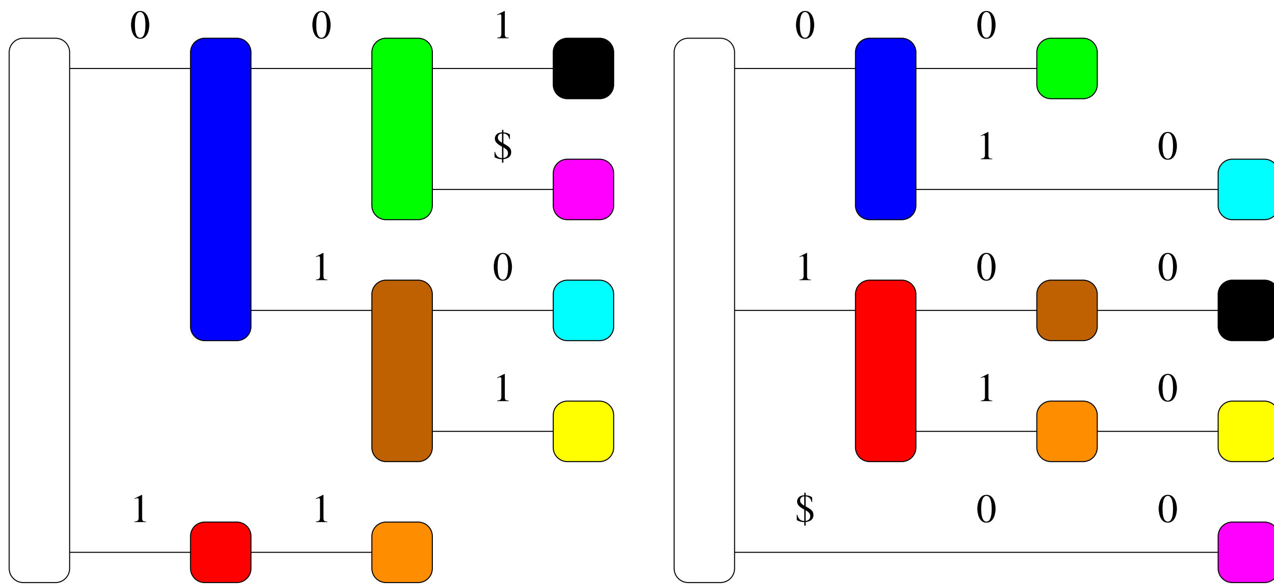
Left

Left–Child

Right

Breaking points.

Skiping points that fail.



Pat # 1 1 0 0

Left

Left–Child

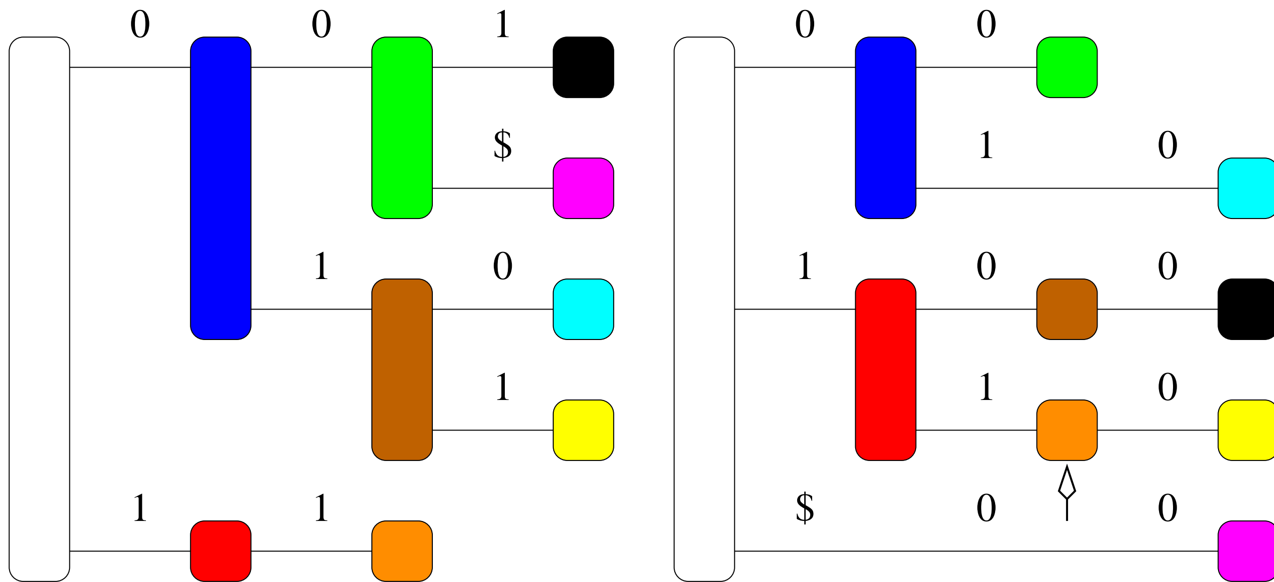
Right

Either perform a dfs on the LZtrie from the green node or a dfs on the RevTrie from the orange node.

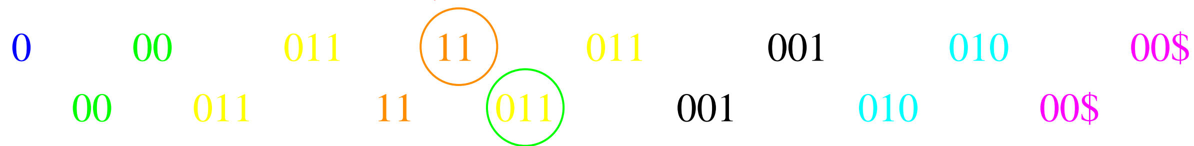
Since the subtree of the orange node is smaller we choose the RevTrie.

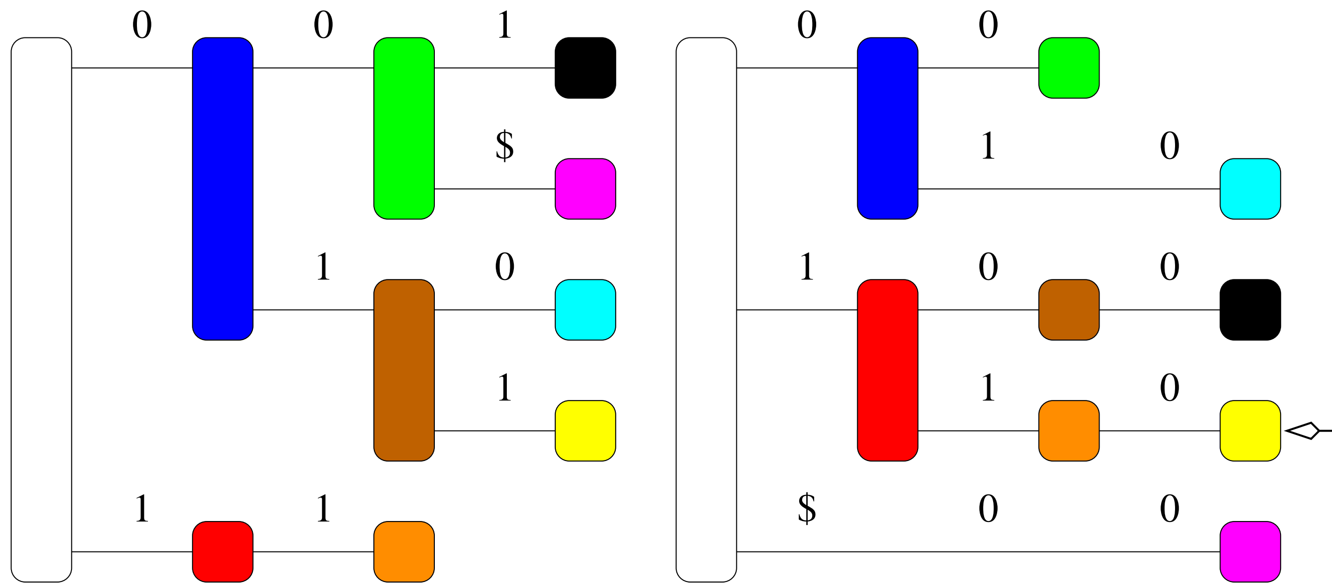
0 00 011 11 011 001 010 00$

00 011 11 011 001 010 00$

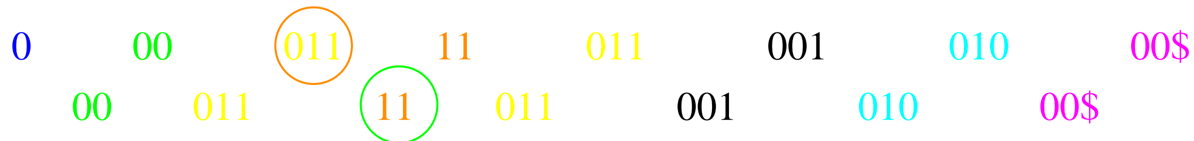


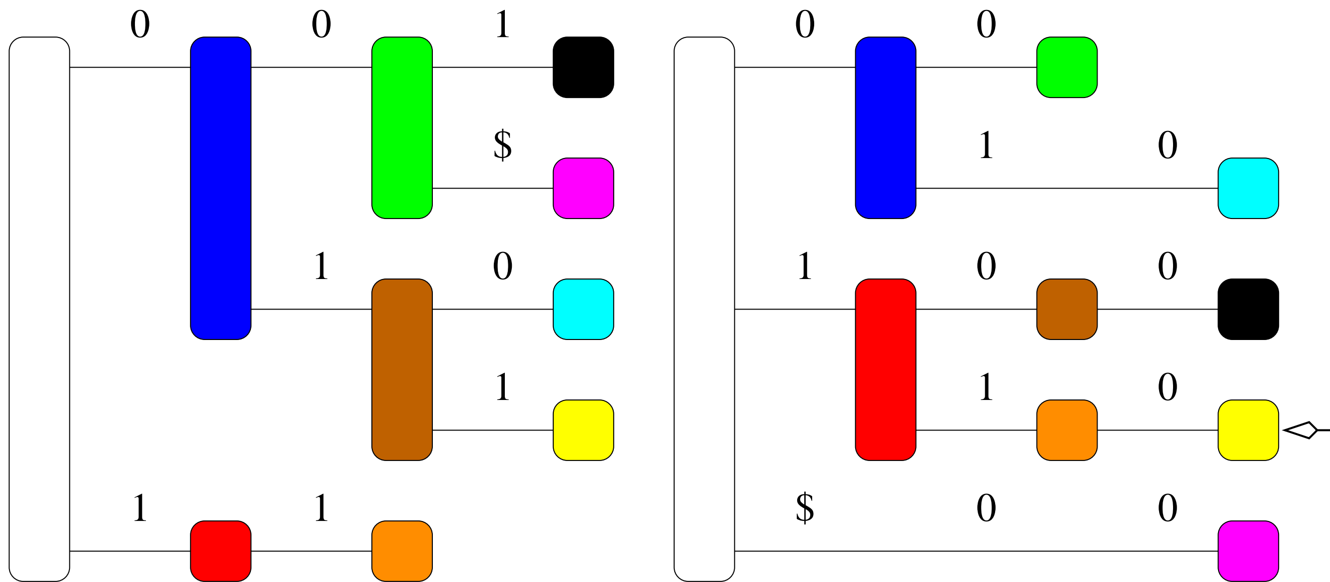
Pat	#	1	1	0	0	
Left						Failed
Left–Child						
Right						





Pat	#	1	1	0	0	
Left						Failed
Left–Child						
Right						





Pat	#	1	1	0	0

Left

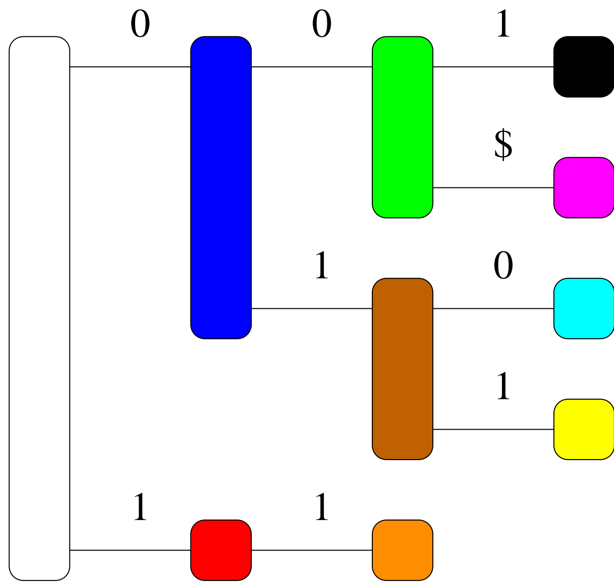
Left–Child

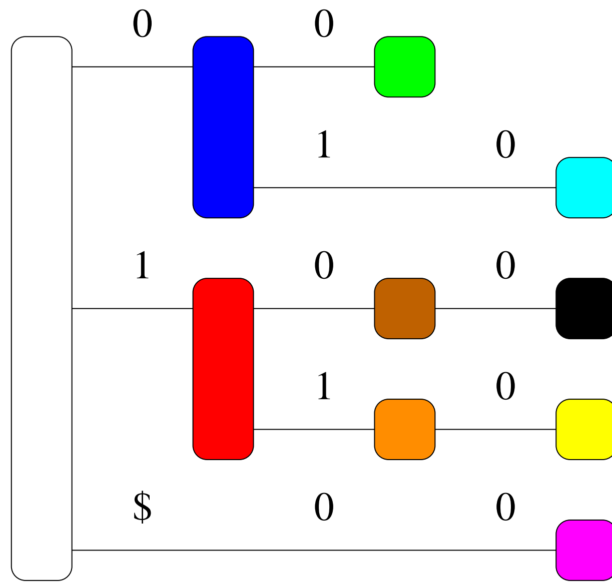
Right

Found

0 00 011 11 011 001 010 00$

00 011 11 011 001 010 00$





Pat # 0 1

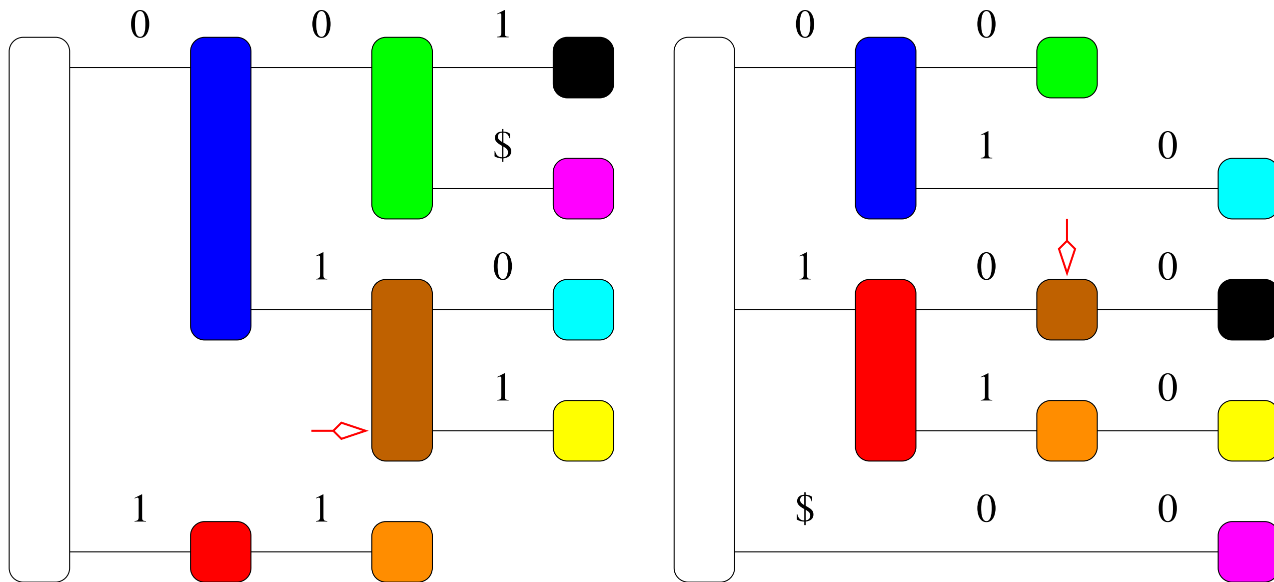
Left

Left–Child

Right

Searching only for type 1 occurrences
of this pattern

Perform a dfs search on the RevTrie that
for each visited node starts a dfs on the dual
node of the LZTrie.



Pat # 0 1

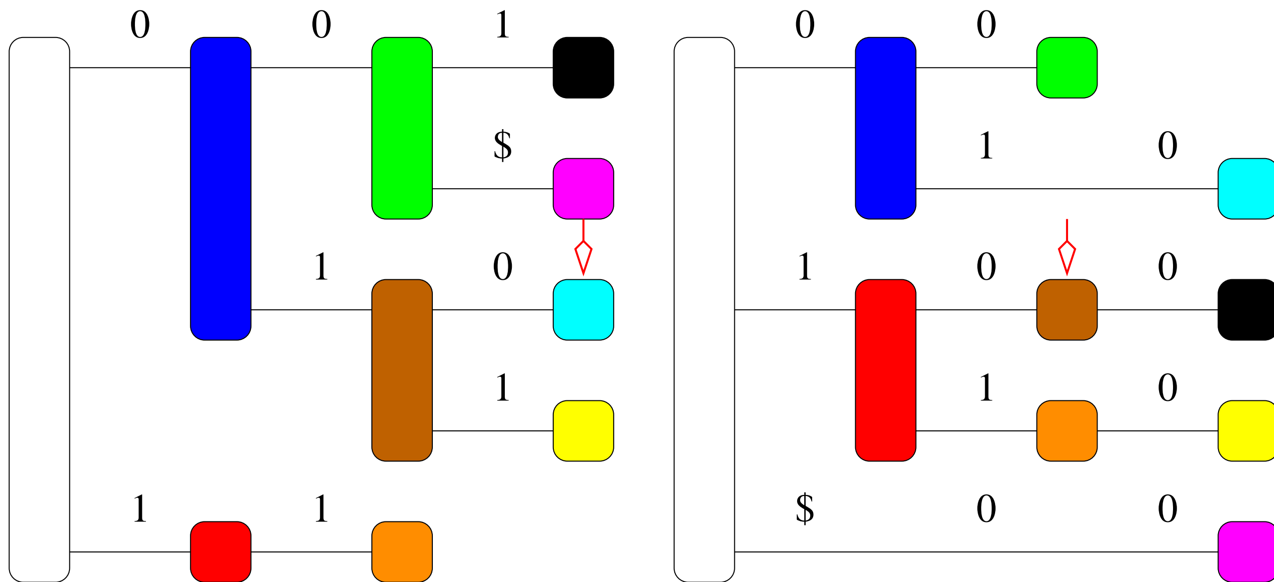
Left

Left–Child

Right

0 00 011 11 011 001 010 00$

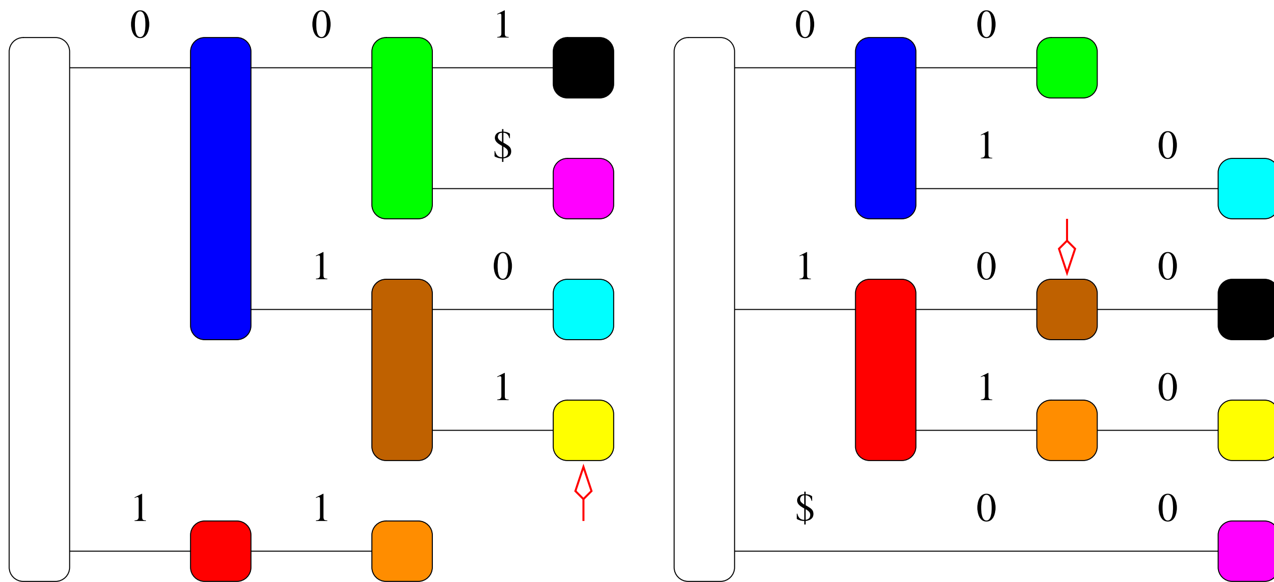
00 011 11 011 001 010 00$



Pat	#	0	1
Left			
Left–Child			
Right			

0 00 011 11 011 001 010 00$

00 011 11 011 001 010 00$



Pat # 0 1

Left

Left–Child

Right

0 00 011 11 011 001 010 00$

00 011 11 011 001 010 00$

0 0 1
$
1 0
1
1 1

0 0
1 0
1 0 0
1 0
$ 0 0

Pat # 0 1
Left
Left–Child
Right

0 00 011 11 011 001 010 00$
00 011 11 011 001 010 00$

Control the growth of the LZTrie by keeping counters at the internal nodes.

Typical maximum value 2.

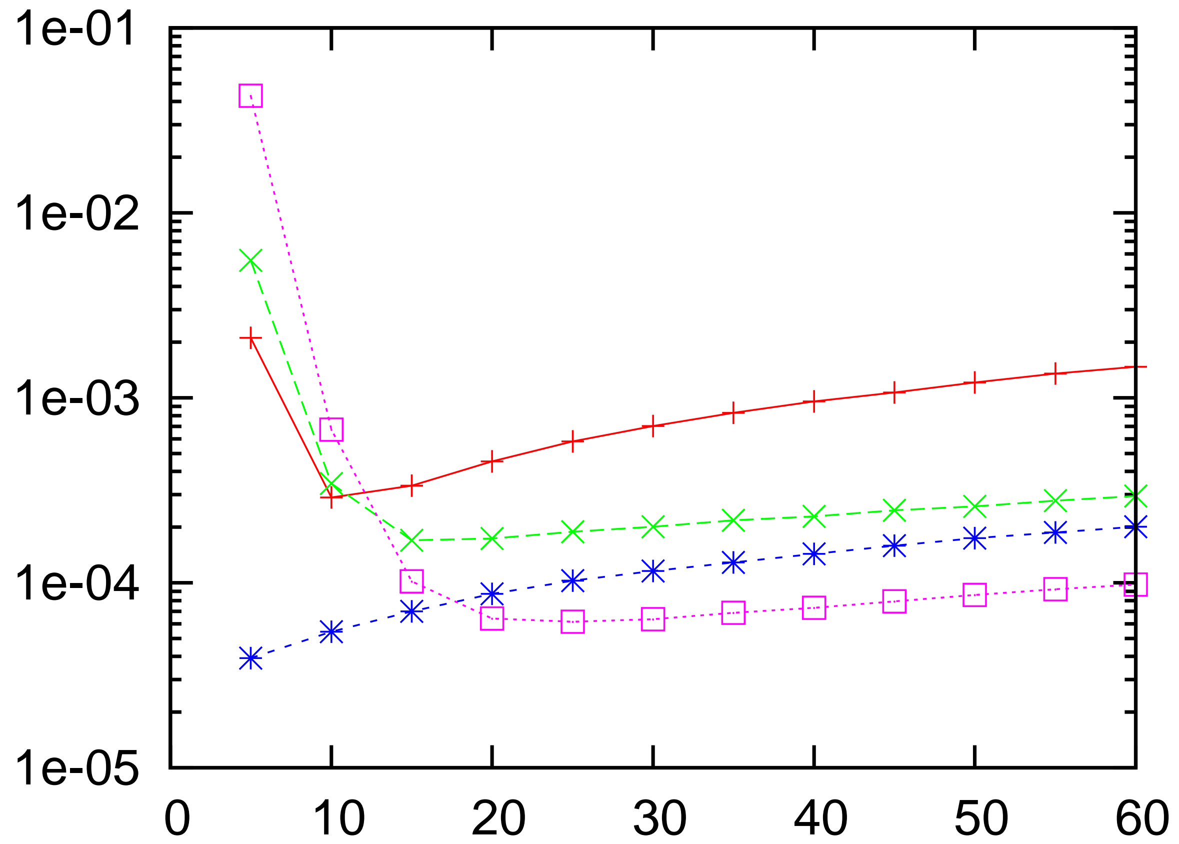
Results:

Processed Newgroups. Main Memory space.

20ng-train-all-terms.txt	16 291 Kbytes
LZIndex	26 607 Kbytes
Modified - 0	47 244 Kbytes
Modified - 2	34 605 Kbytes

Approx. +30%.

Results: Report positions. Time in seconds.



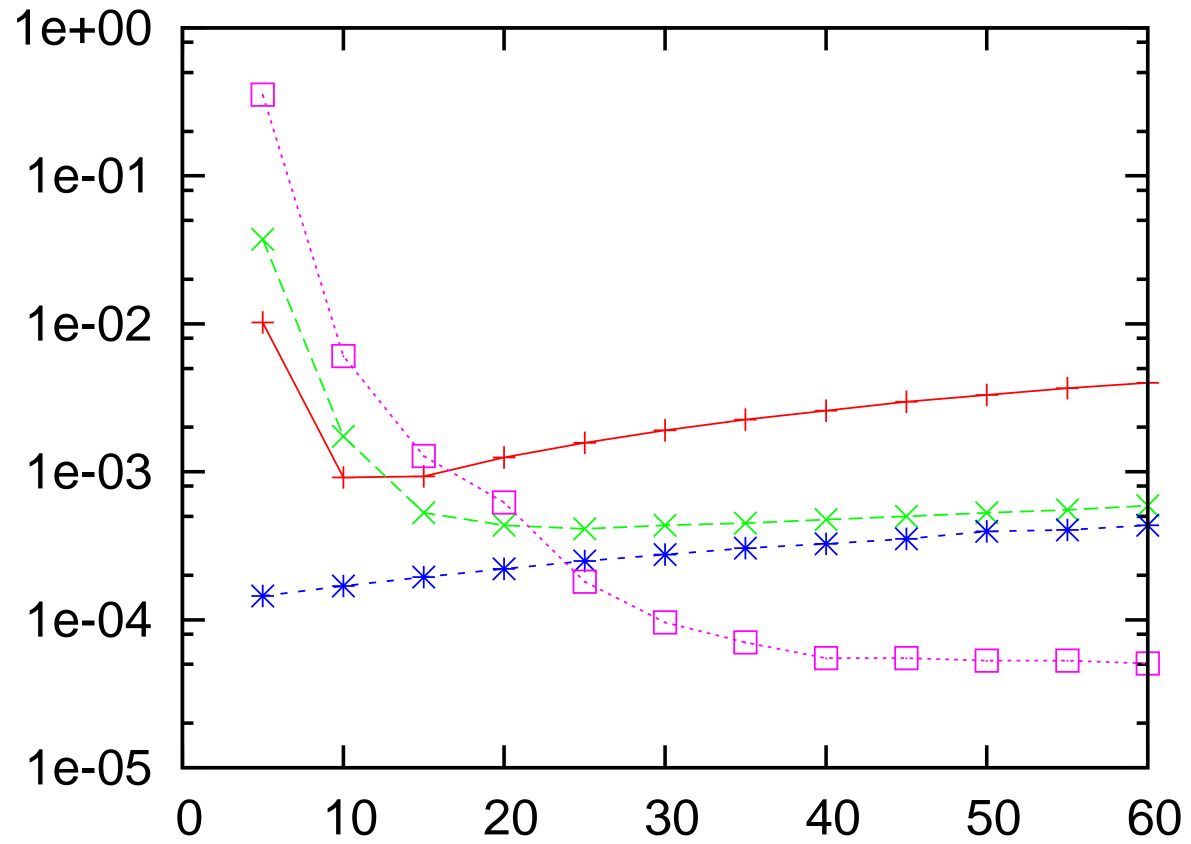
Results:

Gutenberg Project. Main Memory Space.

txt	96 413 Kbytes
LZIndex	155 660 Kbytes
Modified - 2	205 224 Kbytes

Approx. +32%

Results: Report positions. Time in seconds.



Conclusions:

3 main ideas:

- The RevTrie is an implit generalized suffix tree

- The text should be left maximal parsed to improve search times

- Controling the groth of the LZTrie

Future Work:

Re-implement the tree data structures.

Store information relative to both trees in one location elemi-nating duality links.

Store this nodes in bfs time of the revtrie.

pros: Allows to branch in $\log |\Sigma| +$ cache locality.

cons: Uses more space.

Future Work:

Implement lazy Descend and Suffix Walk.

All the queries in the example matched.

Future Work:

Further testing

Acknowledgements:

Professor Gonzalo Navarro for LZ-index code,

Luís Coelho,

Thanks

Questions ?