# Two More Strategies to Speed Up Connected Components Labeling Algorithms

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## Problem Statement

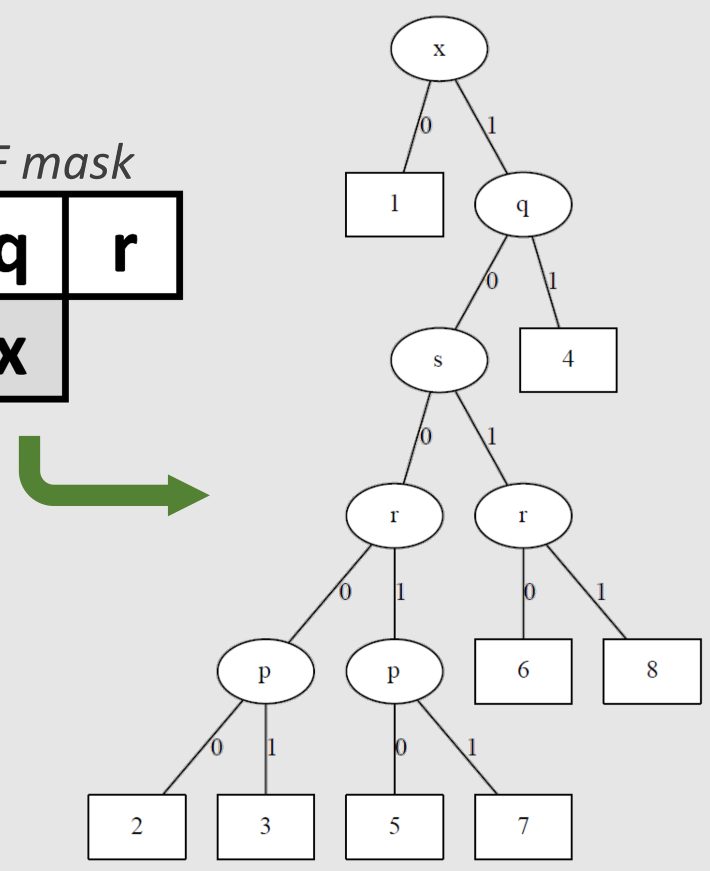
The problem of labeling the connected components (CCL) of a binary image is well-defined and it is a fundamental task in image processing and computer vision applications. Most of recent proposals exploit a scan mask to perform CCL and focus on performance optimization making use of optimal decision trees that allow a reduction of memory accesses.

***Goals:***

1) **Improve the speed of CCL taking into account image patterns occurrences and altering optimal decision trees;**
2) **Speed up CCL operations using parallelization.**

*SAUF mask*

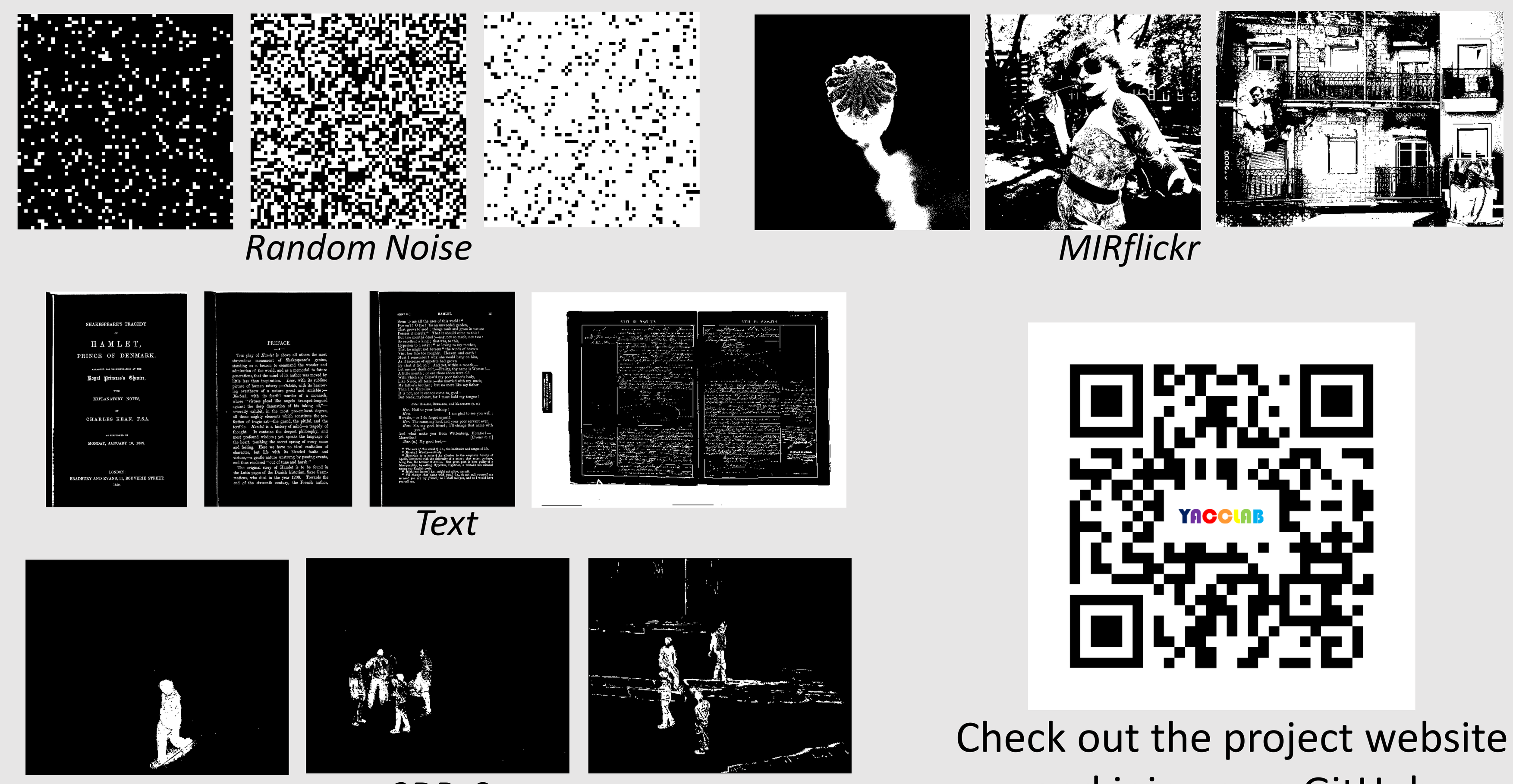
| p | q | r |
|---|---|---|
| s | x | |



## The Testing Framework

All reported results are conducted with YACCLAB: an open-source C++ framework for CCL performance evaluation which includes both synthetic and real images.

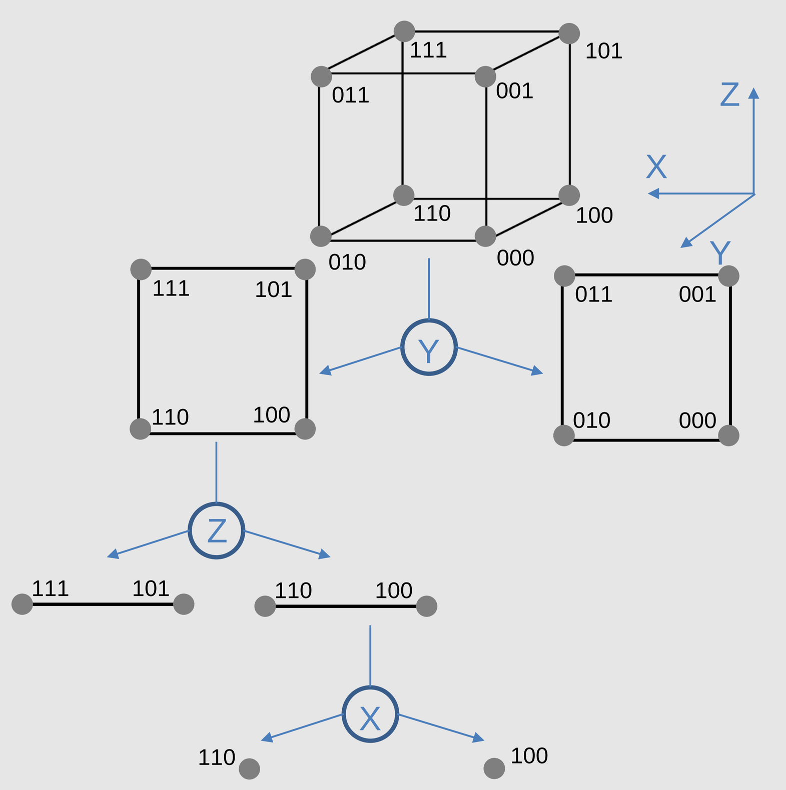
*The YACCLAB dataset*




Check out the project website and join us on GitHub

## Modeling of Decision Trees with Patterns Frequencies

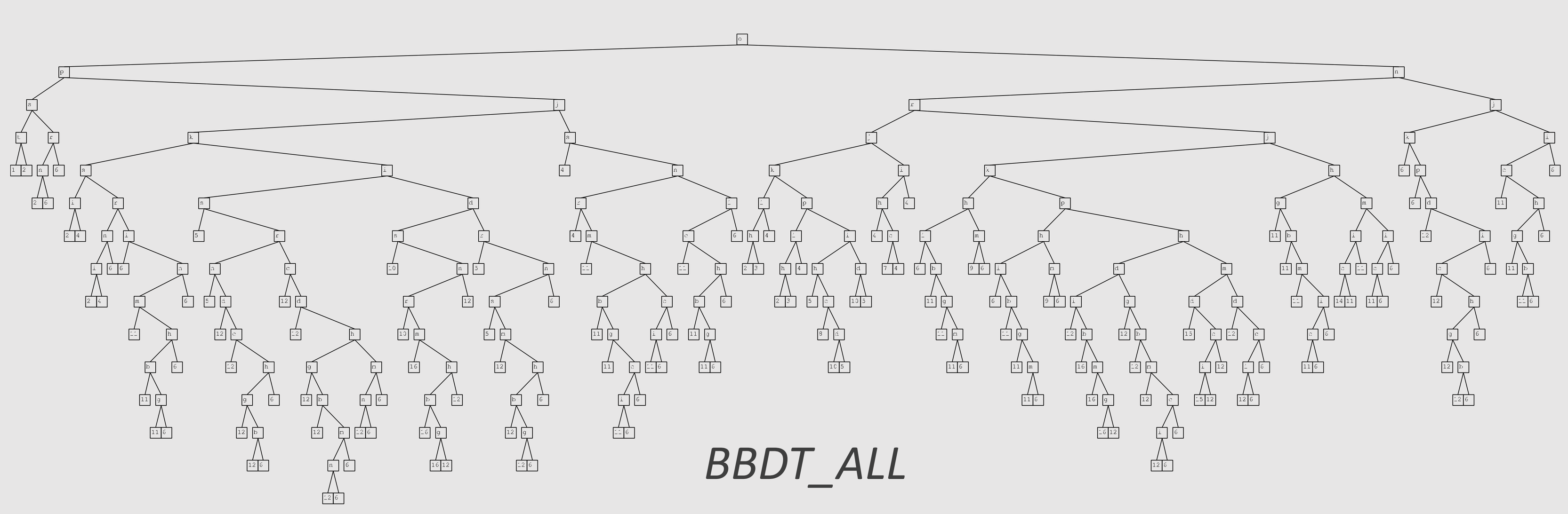
***Creation of an optimal decision tree***: if two branches lead to the same action, the condition from which they originate may be removed. This conversion can be geometrical interpreted as the partitioning of an $n$-dimensional hypercube where the vertexes correspond to the $2^n$ possible rules. Associating to each condition removal a unitary gain we can select the tree which maximizes the total gain and thus minimizes the number of memory accesses.



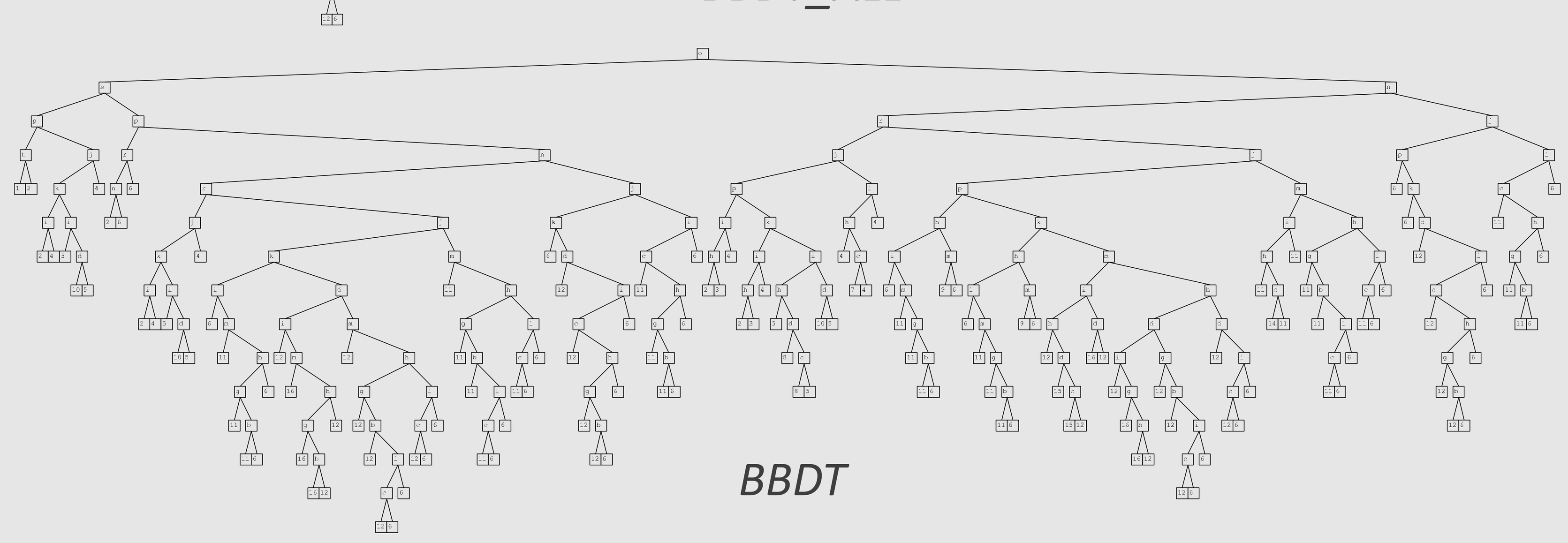

***Idea:*** We calculate the occurrence frequencies of all possible mask patterns in a reference dataset. Then, considering as gain of a condition removal the frequencies of associated patterns, it is possible to generate new optimal decision trees, further reducing the total number of memory accesses.

| a | b | c | d | e | f |
|---|---|---|---|---|---|
| g | h | i | j | k | l |
| m | n | o | p | | |
| q | r | s | t | | |

*BBDT mask*



*BBDT_ALL*

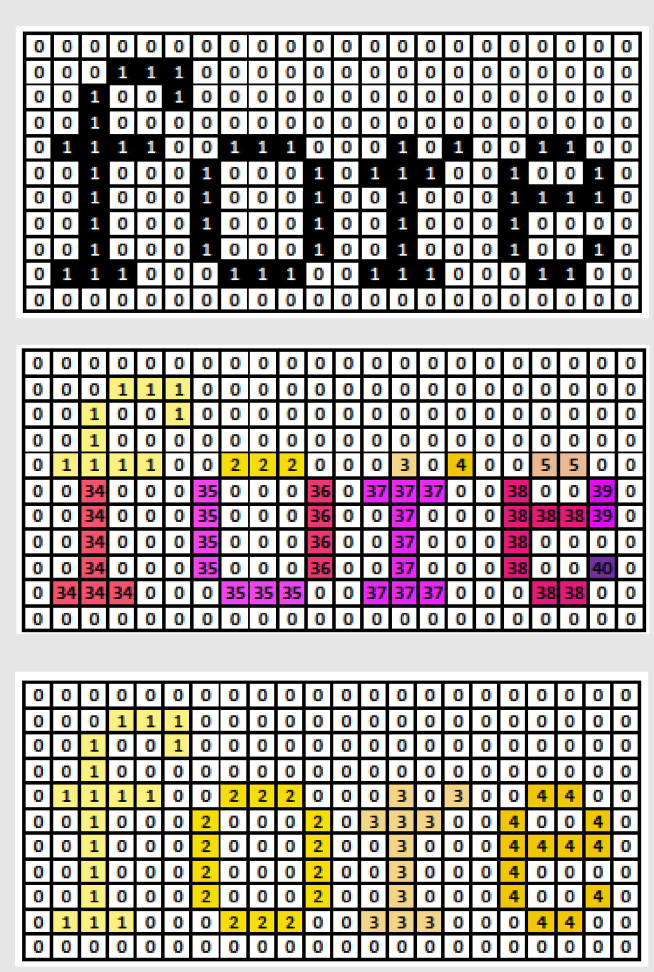


*BBDT*

| | BBDT | BBDT_ALL | BBDT_ONE |
|---|---|---|---|
| *3DPeS* | 0.678 | **0.621** | 0.645 |
| *Fingerprints* | 0.343 | 0.322 | **0.320** |
| *Hamlet* | 5.284 | **5.048** | 5.252 |
| *Medical* | 2.273 | **2.154** | 2.213 |
| *MIRflickr* | 0.450 | **0.414** | 0.424 |
| *Tobacco800* | 7.752 | **7.283** | 7.431 |

*Results in ms on Windows PC with Intel Core i5-6600 @ 3.30 GHz and Microsoft Visual Studio 2013 (lower is better).*

## Parallel Connected Components Labeling



***Idea:*** Improving the performance of existing algorithms employing parallelization.

Solution proposal:

- ✓ Divide image into stripes;
- ✓ Compute first scan on each stripe (in parallel);
- ✓ Merge border labels;

| p | q | r |
|---|---|---|
| | x | |

| p | - | q | - | r | - |
|---|---|---|---|---|---|
| - | - | - | - | - | - |
| | | x | - | | |
| | | - | - | | |

- ✓ Compute second scan (in parallel);

Results show that the speed up obtained with two threads on SAUF is ×1.5 in average and it increases up to ×4 on random dataset when 12 threads are involved. BBDT shows a greater speed up with low number of threads (i.e. ×1.7 with 2 threads, up to ×4.7 on random dataset with 8 threads)

| | SAUF | SAUF_2 | SAUF_4 | SAUF_8 | SAUF_12 | SAUF_16 | SAUF_24 |
|---|---|---|---|---|---|---|---|
| *3DPeS* | 1.817 | 1.258 | 1.013 | 0.886 | **0.845** | 0.972 | 0.969 |
| *Fingerprints* | 0.793 | 0.548 | 0.431 | 0.361 | **0.338** | 0.402 | 0.426 |
| *Hamlet* | 13.449 | 8.682 | 6.726 | 5.651 | **5.338** | 5.615 | 5.446 |
| *Medical* | 6.316 | 4.414 | 3.104 | 2.626 | **2.542** | 2.742 | 2.745 |
| *MIRflickr* | 1.053 | 0.770 | 0.608 | 0.544 | **0.543** | 0.618 | 0.657 |
| *Tobacco800* | 22.075 | 14.362 | 11.083 | 9.445 | **9.057** | 9.457 | 9.166 |
| *Random* | 31.525 | 19.554 | 11.956 | 8.695 | **7.795** | 9.144 | 8.605 |

| | BBDT | BBDT_2 | BBDT_4 | BBDT_8 | BBDT_12 | BBDT_16 | BBDT_24 |
|---|---|---|---|---|---|---|---|
| *3DPeS* | 1.274 | 0.794 | **0.609** | 0.720 | 0.812 | 0.918 | 1.002 |
| *Fingerprints* | 0.606 | 0.386 | 0.298 | **0.274** | 0.290 | 0.347 | 0.388 |
| *Hamlet* | 10.528 | 5.989 | **4.342** | 4.528 | 5.186 | 5.423 | 6.146 |
| *Medical* | 4.945 | 3.051 | **1.831** | 2.060 | 2.407 | 2.621 | 2.998 |
| *MIRflickr* | 0.790 | 0.520 | **0.393** | 0.438 | 0.479 | 0.559 | 0.622 |
| *Tobacco800* | 16.587 | 9.590 | **6.518** | 7.207 | 8.206 | 9.215 | 10.375 |
| *Random* | 25.106 | 13.177 | 7.084 | **5.375** | 6.004 | 7.567 | 8.387 |

*Average results in ms on a virtual Windows workstation with two Intel Xeon X5650 CPU @ 2.67GHz (6 physical cores and 12 logical processors per socket) and Microsoft Visual Studio 2013 (lower is better).*