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UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

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How does Connected Components Labeling with Decision Trees perform on GPUs?

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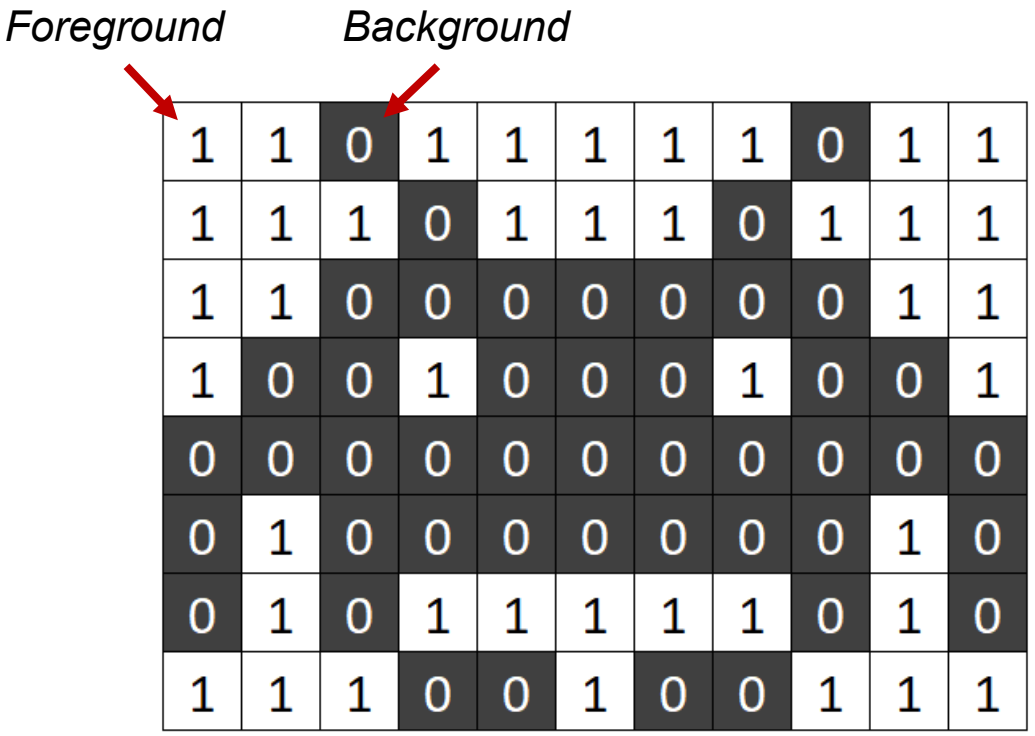
Connected Components Labeling (CCL)

- Extracts connected components (objects) from a binary image.
- All pixels of the same object are given the same label.



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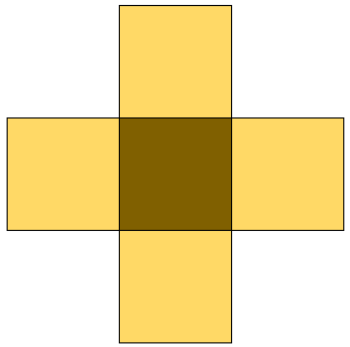
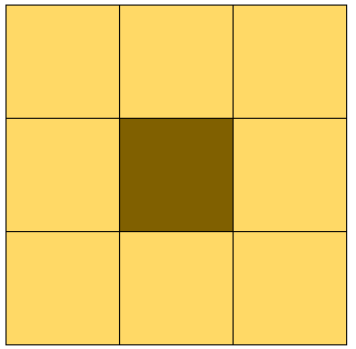
Optimizing CCL Algorithms

- CCL has an exact solution.
- Computational complexity is proven to be O(N).
- Optimization can be achieved in different ways:
  1. Designing algorithms to reduce the average number of memory accesses and to take advantage of instruction cache;
  2. Using hardware acceleration.



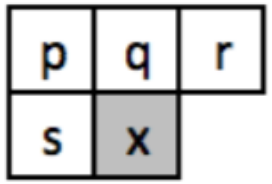
4-connectivity



8-connectivity

CPU-Based Algorithms

- Traditionally, on sequential machines a two-scan algorithm is employed:
  1. *First scan,* scans the input assigning provisional labels to the output and storing equivalences in the Union-Find data structure.
  2. *Flattening*, establishes the definitive labels.
  3. *Second scan*, updates the output replacing provisional with final labels.
- The second scan can be avoided when only statistics about the objects are required.



Scan Mask

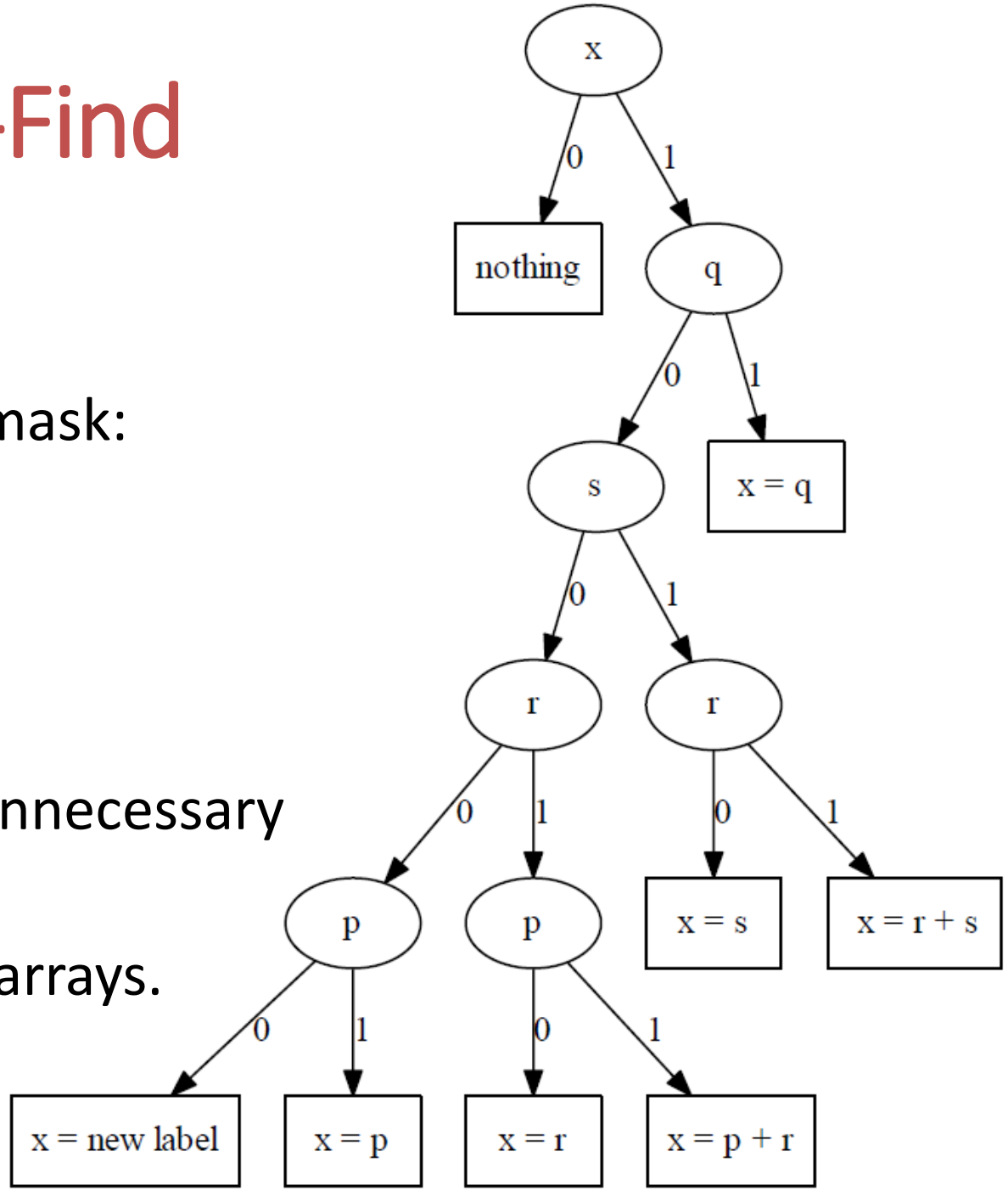
p	q	r								
s	x	0	1	1	1	1	1	0	1	1
1	1	1	0	1	1	1	0	1	1	1
1	1	0	0	0	0	0	0	0	1	1

Scan Array-Based Union-Find Algorithm (SAUF)

- It is based on the Rosenfeld scan-mask:

p	q	r
s	x	

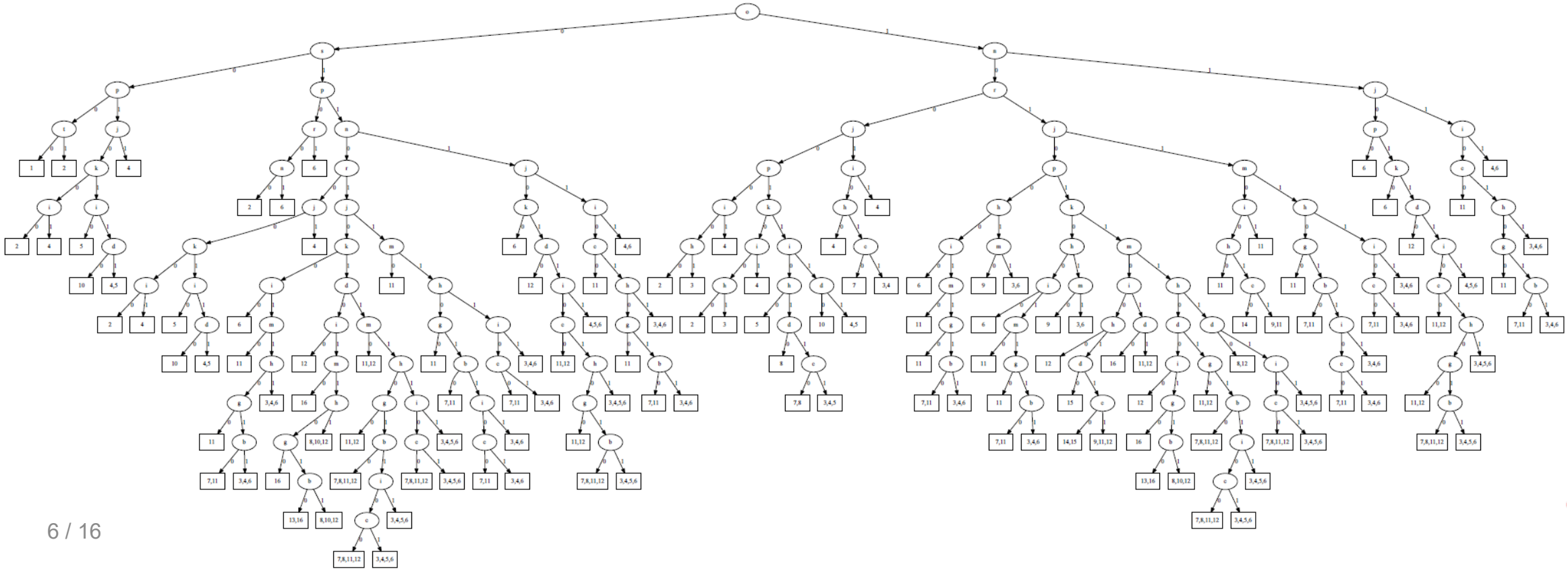
- Exploits a decision tree to avoid unnecessary read/write operations.
- Implements the Union-Find using arrays.



Block-Based with Decision Trees (BBDT)

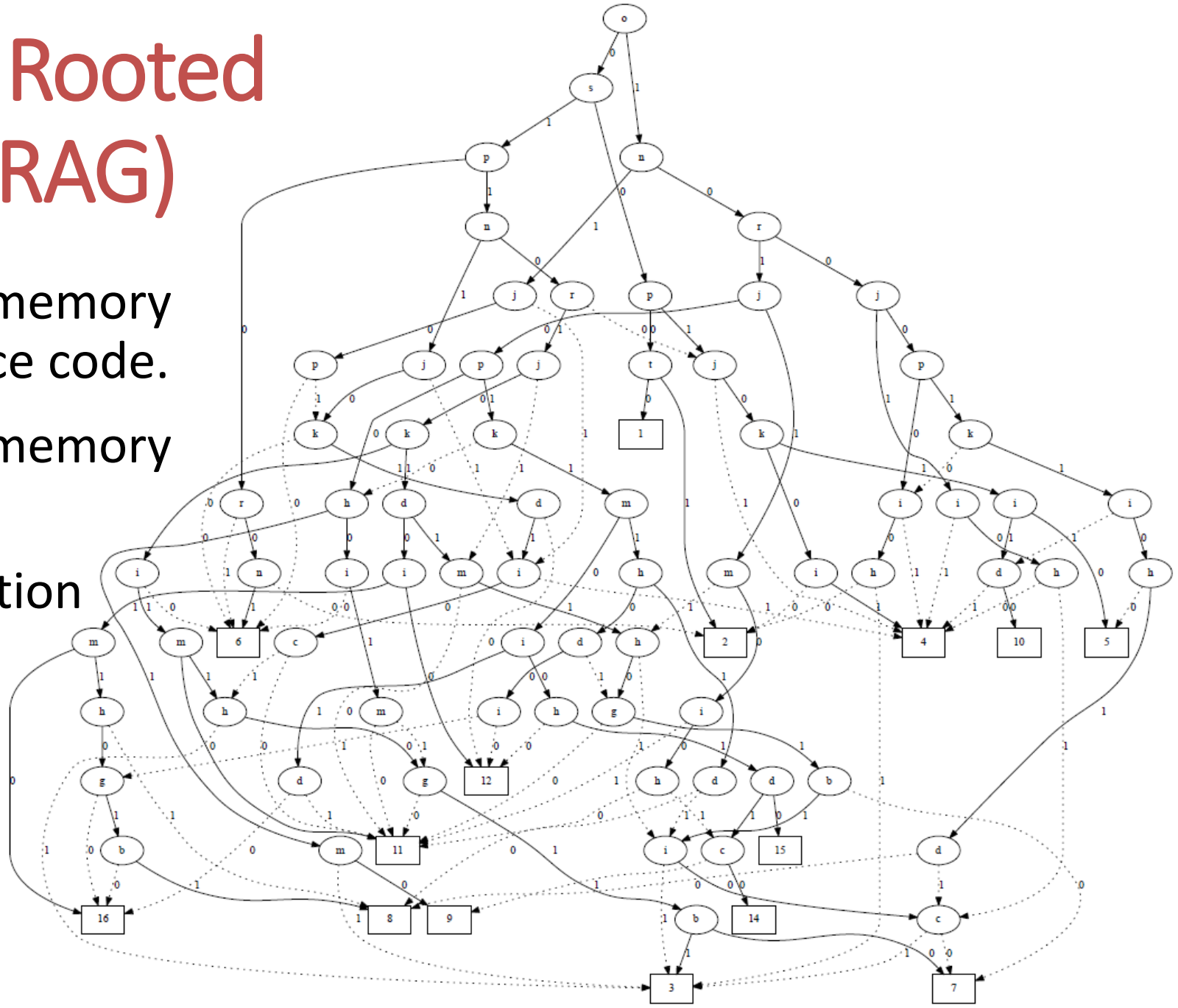
- Introduce the concept of 2x2 block mask.

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



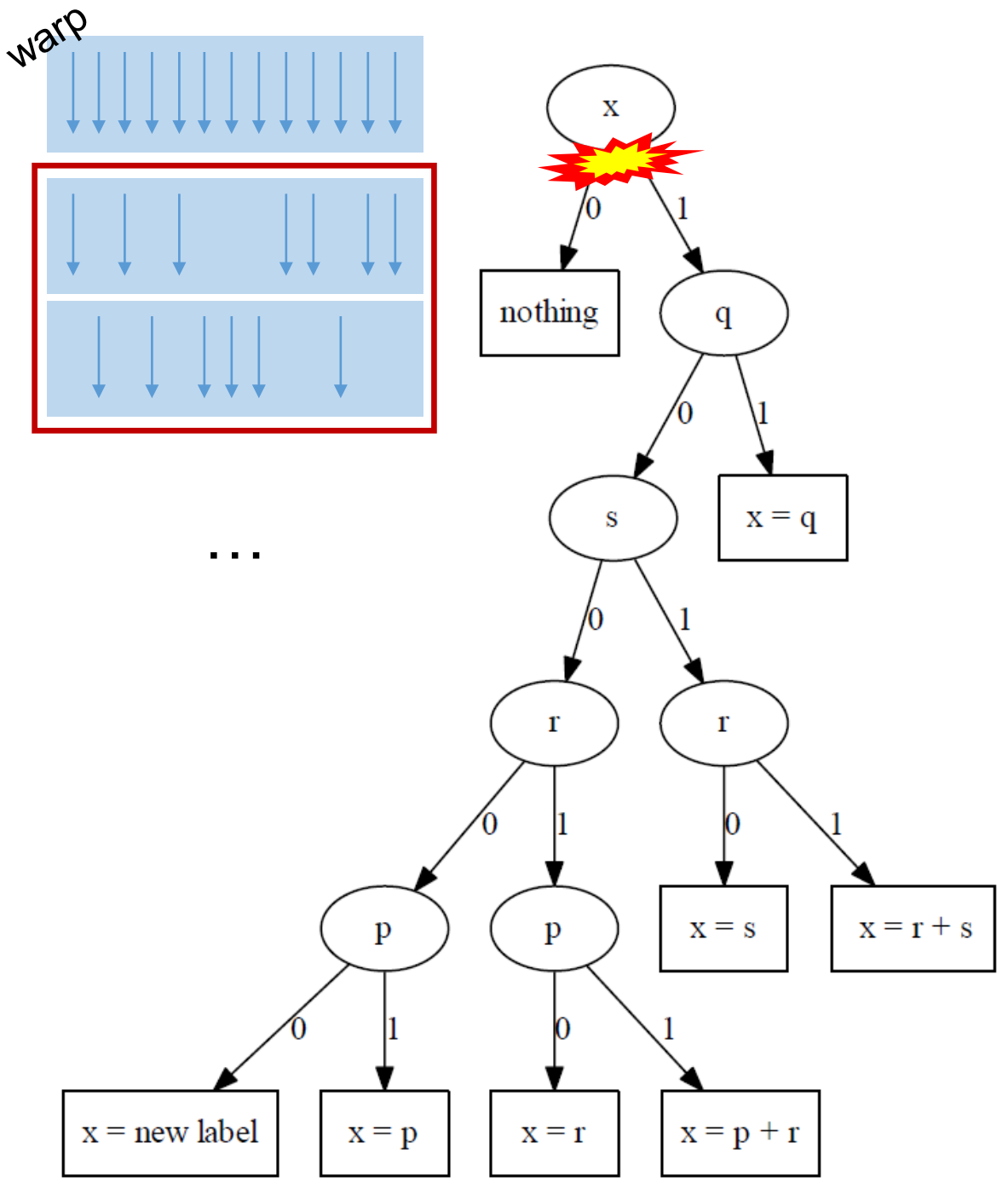
Tree to Directed Rooted Acyclic Graph (DRAG)

- Compresses the memory footprint of the source code.
- Does not impact on memory accesses.
- Increases the instruction cache hit rate.



Decision Trees on GPU

- A GPU uses the SIMT paradigm grouping threads into packets (warp).
- Branch divergence occurs when threads inside warps branch to different execution path.
- SIMT paradigm can group threads into warps flexibly *i.e.* can group threads supposed to truly execute the same instruction.



Adapting Tree-Based Algorithms to GPUs …

First scan translates into two different kernels

Initialization

1	2	0	4	5	6	7	8	0	10	11
12	13	14	0	16	17	18	0	20	21	22
23	24	0	0	0	0	0	0	0	32	33
34	0	0	37	0	0	0	41	0	0	44
0	0	0	0	0	0	0	0	0	0	0
0	57	0	0	0	0	0	0	0	65	0
0	68	0	70	71	72	73	74	0	76	0
78	79	80	0	0	83	0	0	86	87	88

$L[id_x] = id_x$

Merge

1	1	0	4	4	4	4	4	0	10	10
~~1~~	~~1~~	14	0	16	17	18	0	20	21	22
23	24	0	0	0	0	0	0	0	32	33
34	0	0	37	0	0	0	41	0	0	44
0	0	0	0	0	0	0	0	0	0	0
0	57	0	0	0	0	0	0	0	65	0
0	68	0	70	71	72	73	74	0	76	0
78	79	80	0	0	83	0	0	86	87	88

$DecisionTree$

Adapting Tree-Based Algorithms to GPUs …

Flattening

Compression

1	1	0	1	1	1	1	1	0	1	1
1	1	1	0	1	1	1	0	1	1	1
1	1	0	0	0	0	0	0	0	1	1
1	0	0	37	0	0	0	41	0	0	1
0	0	0	0	0	0	0	0	0	0	0
0	57	0	0	0	0	0	0	0	57	0
0	57	0	57	57	57	57	57	0	57	0
57	57	57	0	0	57	0	0	57	57	57

$$L[id_x] = Find(L, id_x)$$

Second scan

Final Labeling

1	1	1	1	1	1
1	25	26	29	1	1
45	47	49	51	45	55
45	45	45	45	45	45

Block Labels into Pixels

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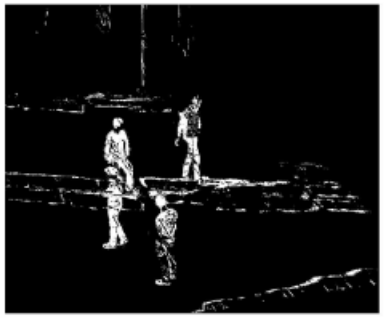
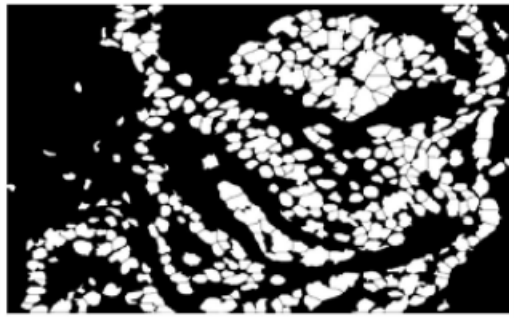
Comparative Evaluation

- We compared our proposals to state-of-the-art GPU algorithms.
- YACCLAB is employed:
  - Open source *C++* benchmarking system → github/prittt/YACCLAB;
  - Collection of real cases datasets;
  - Tests over diverse points of view;
- Our device is a Quadro K2200
  - CUDA capability 5.0;


Video surveillance

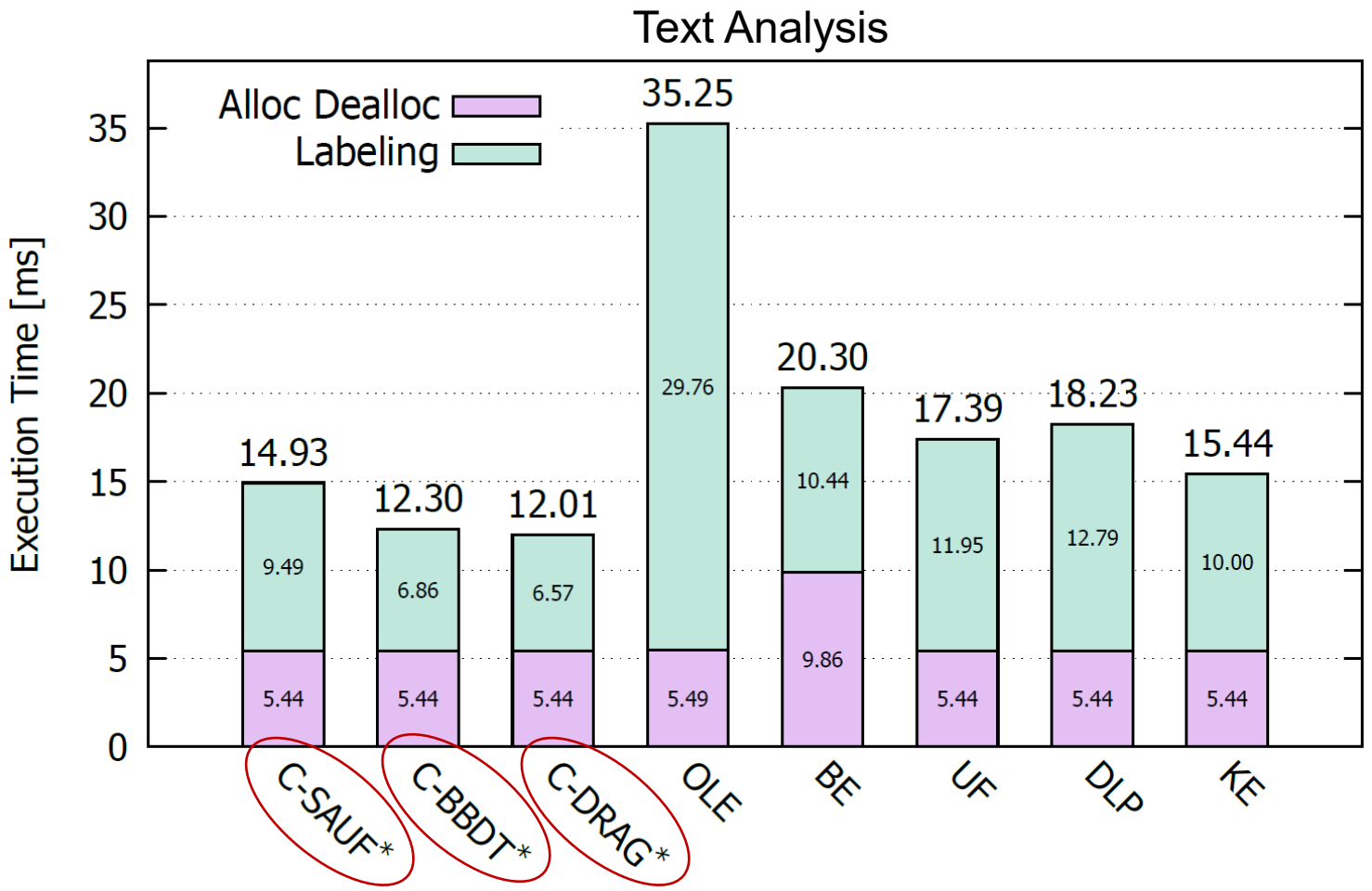

Fingerprints


Medical imaging


Natural

Text analysis

Average Execution Time



- Optimized Label Equivalence (OLE):
  - propagates minimum label
- Block Equivalence (BE):
  - same as OLE, but works on 2x2 blocks
  - needs more data structures
- Union Find (UF)
  - uses the *union-find* data structure
- Distanceless Label Propagation (DPL)
  - merges the UF and OLE strategies
- Komura Equivalence (KE):
  - changes the initialization kernel of the UF

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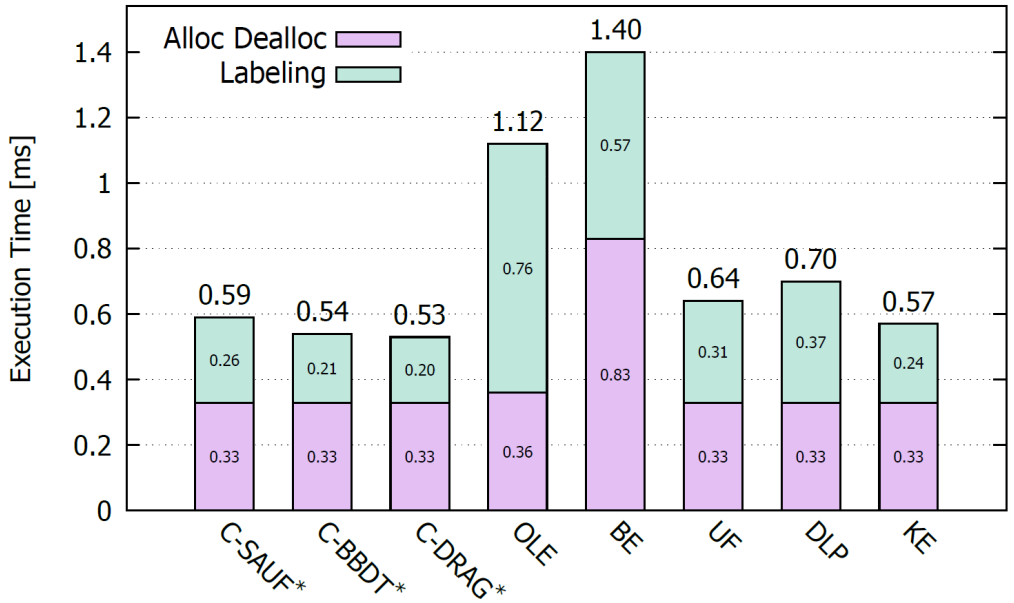
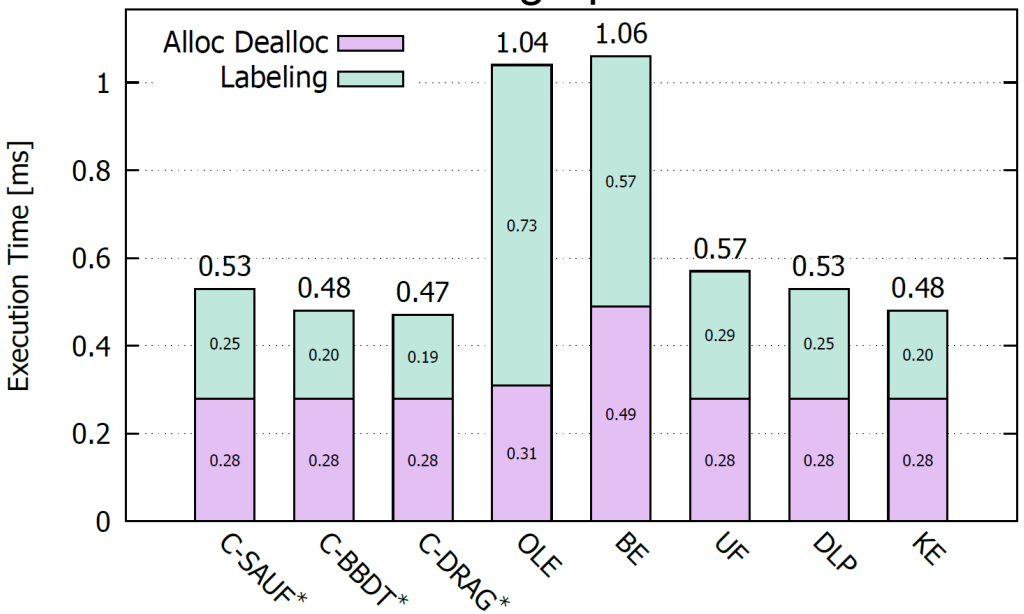
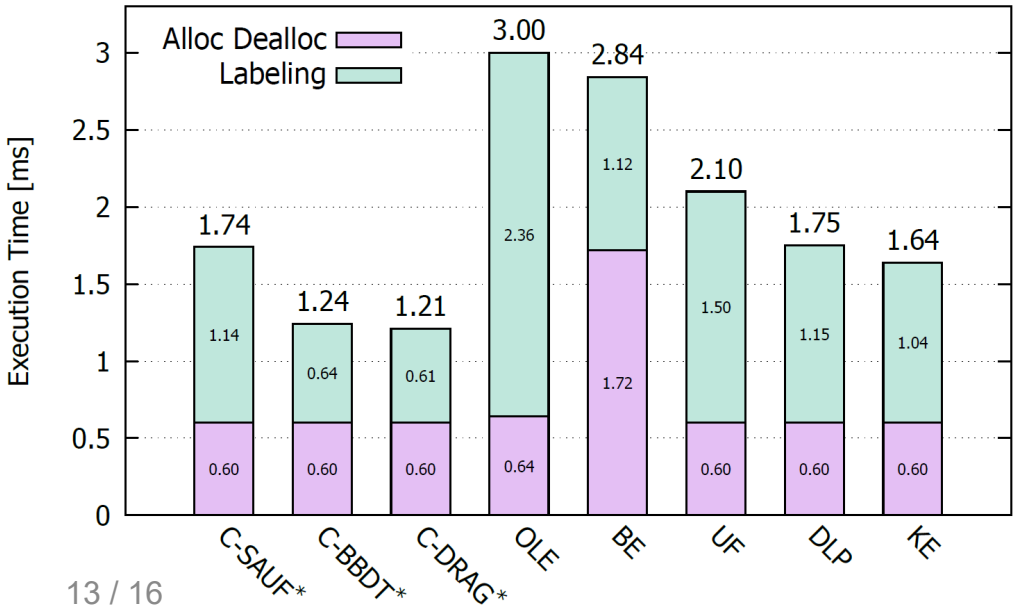
Video Surveillance



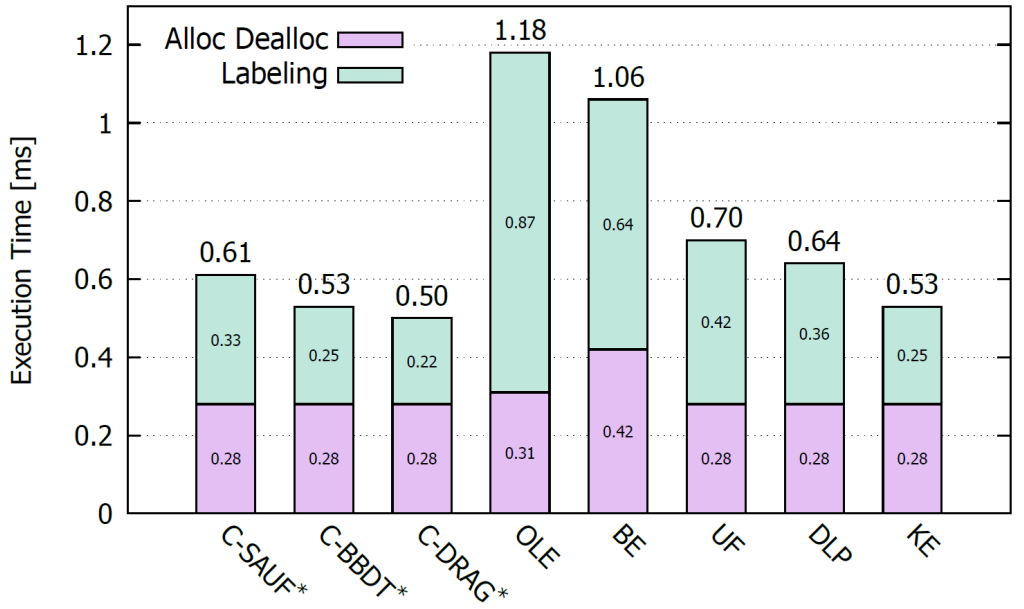
Fingerprints



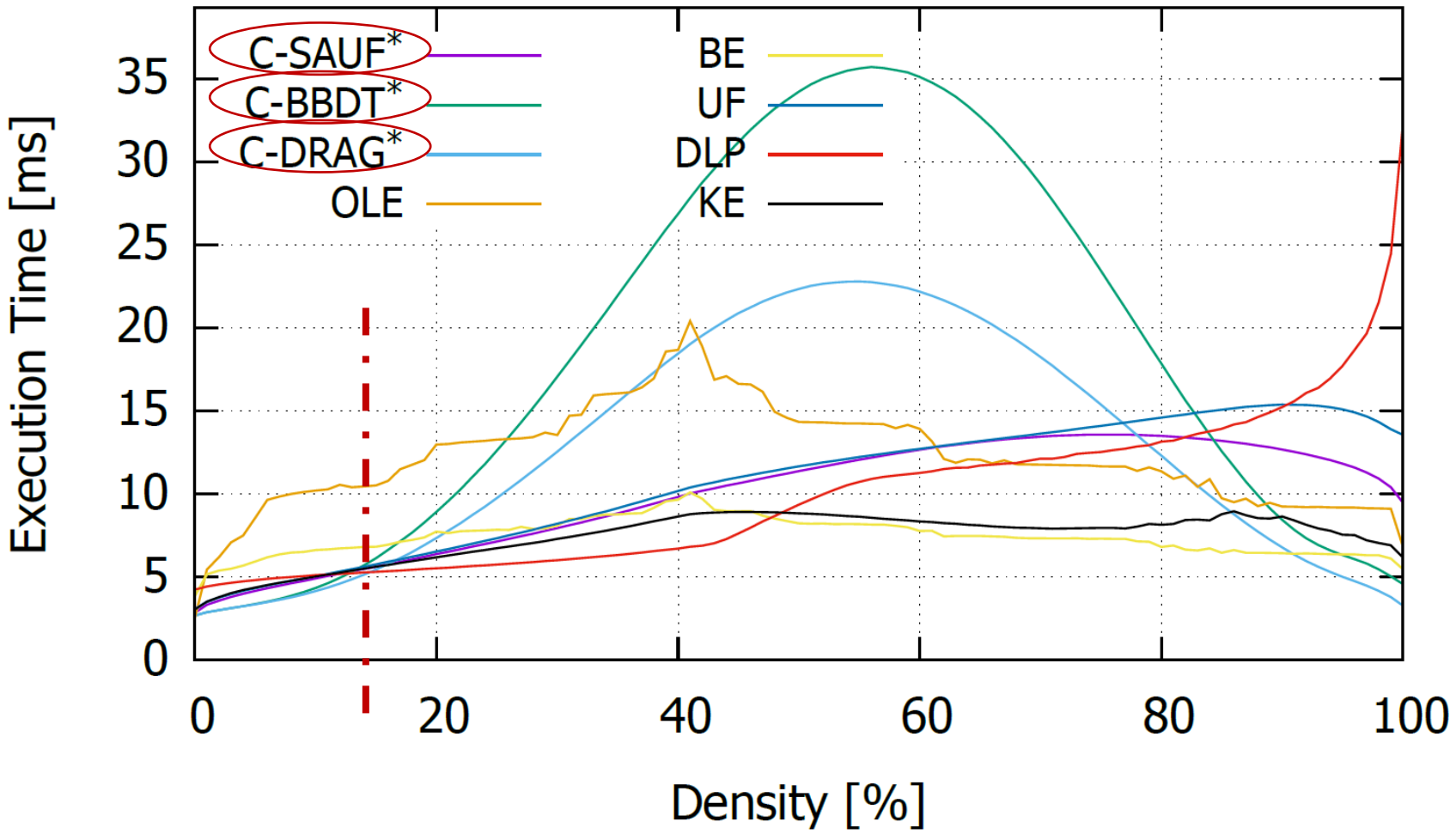
Medical



Natural



Density



- Random images of 2048x2048 size with increasing density
- Tree-based solutions have the best performance when density is below ~18%
- Most real cases images are there!

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Conclusion Remarks

- How does Connected Components Labeling with Decision Trees perform on GPUs?
  - Better than state-of-the-art approaches.
- "*It is a capital mistake to theorize before one has data*"

SHERLOCK HOLMES

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Thank you!

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