

MODENA E REGGIO EMILIA



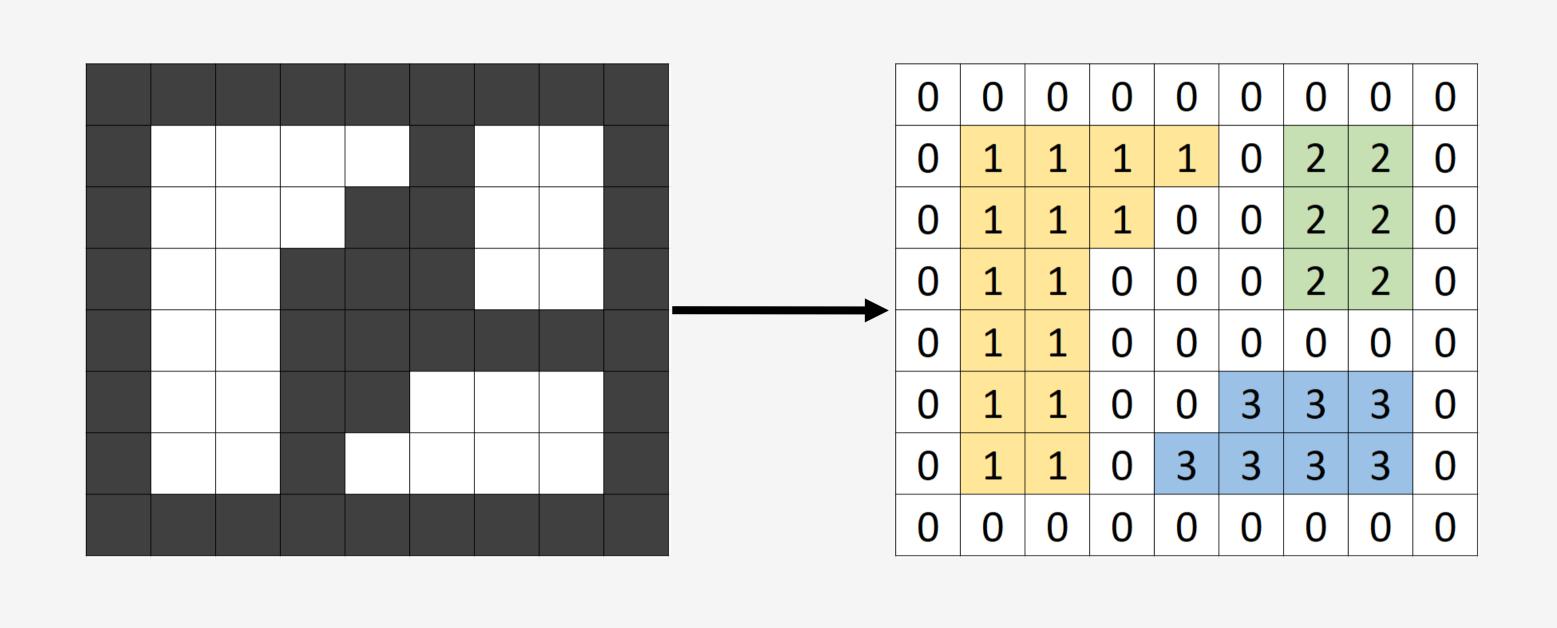
A Heuristic-Based Decision Tree for Connected Components Labeling of 3D Volumes

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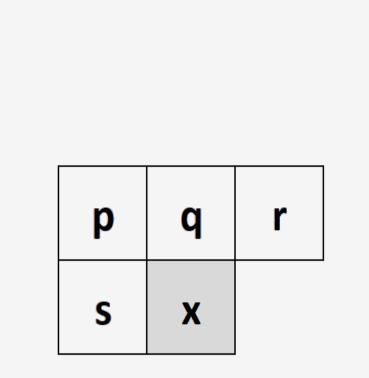
Connected Components Labeling (CCL)

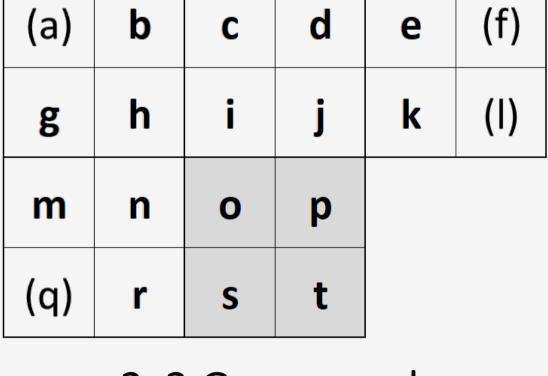
- Find all connected, foreground pixel regions within a binary image
- Each pixel region, or connected component, receives a unique label
- Fundamental for image segmentation and object recognition
- CCL should be as fast as possible

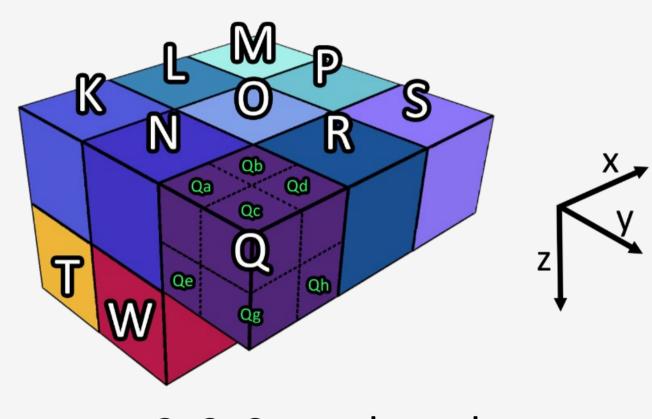


History of CCL Research

- Rosenfeld and Pfaltz invented two scans algorithms
- Wu et al. proposed Optimal Decision Trees (ODTs)
- Grana et al. proposed block-based mask
- What about 3D CCL?
 - Multiple possible block-based masks: 2x1x1, 2x2x1 and 2x2x2
 - Explosion in complexity makes the ODT generation infeasible
 - Existing 3D CCL algorithms do not employ block-based masks
 - Goal: generate a near-optimal tree with a heuristic strategy







Rosenfeld mask

2x2 Grana mask

2x2x2 voxel mask

Heuristics — Concept

- Shannon Entropy (information theory)
 - Given a set of events E, with P_i being the probability of an event $i \in P_i$ E, the entropy H_F is:

$$H_E = \sum_i -P_i \log P_i$$

Entropy describes the uncertainty of outcomes

- Decision Tree Learning
 - Recursively partition the dataset through entropy calculation
 - 1. Try *splitting* on every attribute
 - 2. Calculate Information Gain (IG) on subsets (IG measures average entropy reduction)
 - 3. Apply *split* with highest information gain

Entropy Partitioning Decision Tree (EPDT) for the Rosenfeld mask is nearoptimal

Node	Node Depth			p			\mathbf{q}			r			s			X	
		H(S)	H_0	H_1	IG	H_0	H_1	IG	H_0	H_1	IG	H_0	H_1	IG	H_0	H_1	\overline{IG}
1	0	2.2	2.0	1.4	0.5	2.3	1.5	0.3	1.9	2.1	0.2	2.1	2.1	0.1	0.0	2.4	1.0
2	1	2.4	2.0	0.8	1.0	2.5	1.0	0.7	1.8	2.3	0.4	2.2	2.2	0.2			
3	2	2.0				2.0	0.0	1.0	1.5	1.5	0.5	1.5	1.5	0.5			
4	2	0.8				1.0	0.0	0.3	0.0	1.0	0.3	0.8	0.8	0.0			
5	3	2.0							1.0	1.0	1.0	1.0	1.0	1.0			
6	3	1.0							0.0	0.0	1.0	1.0	1.0	0.0			
7	4	1.0										0.0	0.0	1.0			
8	4	1.0										0.0	0.0	1.0			

Applying Decision Tree Learning to 3D CCL

- New 3D EPDT CCL algorithms
- Varying block size and number of pixels

• EPDT_19c

- Block size 2x1x1
- Smallest 3D blockbased mask

Ka	Kb	La	Lb	Ma	Mb		Та	Tb	Ua	Ub	Va	Vb
Na	Nb	Oa	Ob	Pa	Pb		Wa	Wb	Ха	Xb		
Qa	Qb	Ra	Rb	Sa	Sb							

• **EPDT 22c**

- Block size 2x1x1
- Add borders pixels, for more efficient actions

Ka	Kb	La	Lb	Ma	Mb	Та	Tb	Ua	Ub	Va	Vb
Na	Nb	Oa	Ob	Ра	Pb	Wa	Wb	Ха	Xb		
Qa	Qb	Ra	Rb	Sa	Sb						

Va Vb

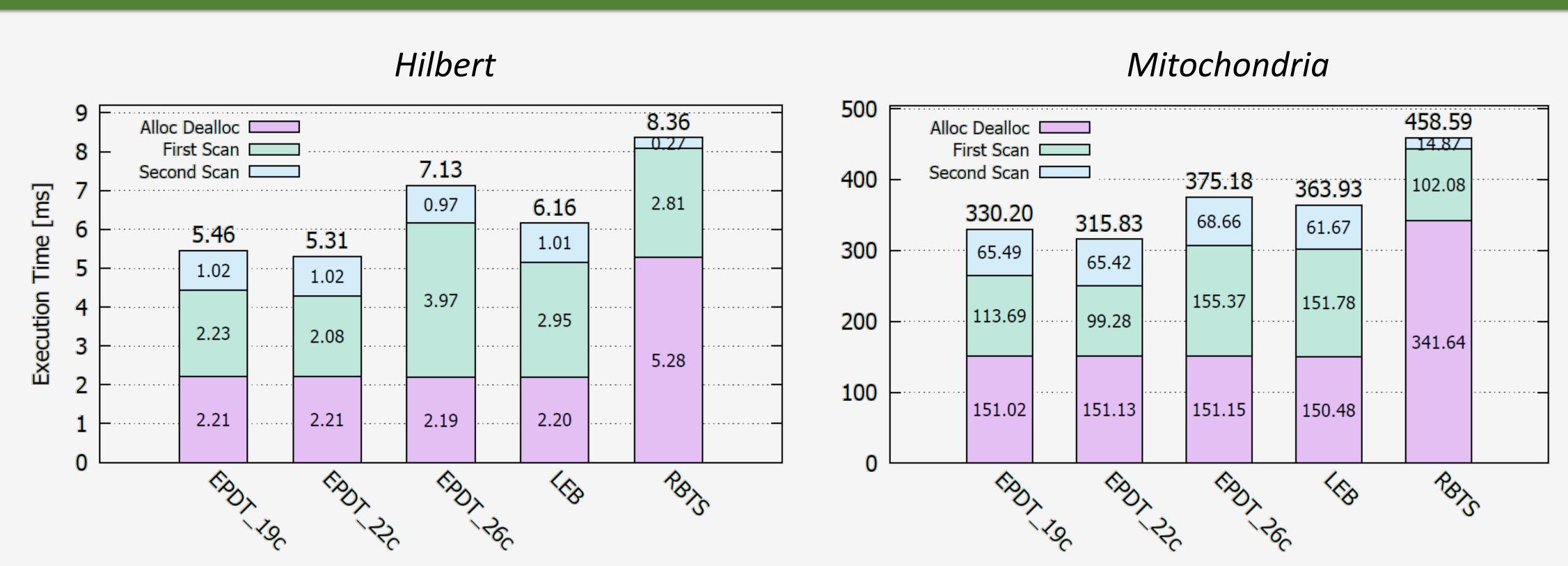
Vc Vd

EPDT 26c

- Block size 2x2x1
- Largest tree that compilers can handle

Ka	Kb	La	Lb	Ma	Mb	Та	Tb	Ua	Ub	
Kc	kd	Lc	Ld	Мс	Md	Tc	Td	Uc	Ud	
Na	Nb	Oa	Ob	Pa	Pb	Wa	Wb	Ха	Xb	
Nc	Nd	Oc	Od	Рс	Pd	Wc	Wd	Хс	Xd	
Qa	Qb	Ra	Rb	Pa	Pb					

Experimental Results



- EPDT algorithms improve the performance of the first scan by saving many memory accesses
- EPDT_26c has a very large decision tree -> bad impact on instruction cache
- EPDT 22c improves current state-of-the-art¹

50 – Alloc	Dealloc □						 50.09	•
Fir	rst Scan □ nd Scan □		_	44.10	_		3.84	
40				5.31				
	33.41	31.58				31.95	24.09	
30	6.18	6.18				4.06		
				29.69				
20	18.13	16.29				18.78		
10							 22.16	
	9.10	9.11		9.10		9.11		
0				J.20		J.11		
	(S)	⟨%⟩,	\	100	>	%	Por	Ċ
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OASIS

Average number of load/store operations on the OASIS dataset, expressed in millions.

Algorithm	Binary Image	Labels Image	Equivalences Vector	Total
LEB	11.461	27.182	9.851	48.494
EPDT_19c	14.917	17.760	1.169	33.846
EPDT_22c	14.057	17.753	1.145	32.955
EPDT_26c	13.695	13.145	0.728	27.568

¹L. He, Y. Chao, and K. Suzuki, "Two Efficient Label-Equivalence-Based Connected-Component Labeling Algorithms for 3-D Binary Images," IEEE Transactions on Image

Processing, vol. 20, no. 8, pp. 2122-2134, 2011.