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AImage Lab

Fast Run-Based Connected Components Labeling for Bitonal Images

Paper ID 134

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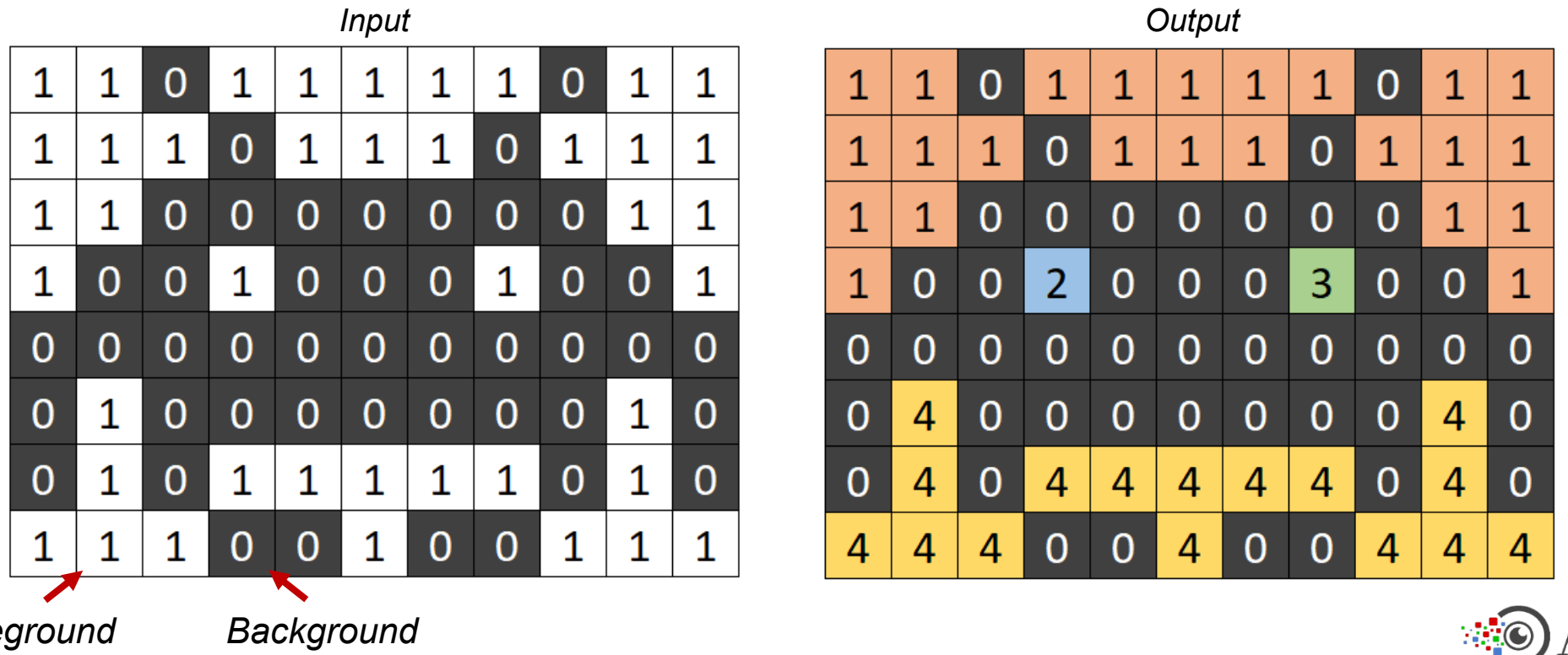
Connected Components Labeling

- Goal: **label objects** inside **binary** images
- Objects are identified as **connected components**
- Essential step of many **image processing pipelines**



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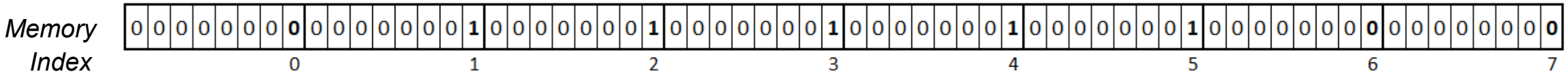
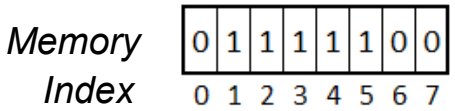
The *Bitonal Image* Format

- Binary input of CCL is usually stored with **one byte** per pixel



- The **bitonal** format, instead, only uses **a single bit** per pixel



- Bitonal images require **less memory**
- US and many other countries adopted the bitonal format as the **legally recognized standard** for **electronic check clearing**
- Aim of this work: design a fast CCL algorithm for **bitonal** images

Run-Based CCL: Assign Provisional Labels

- Three possibilities for the **connections** of a **new run *r***:
  1. **No** connected upper runs → *r* gets a **new label**

0	0	0	0	0	0	0	0
0	1	1	1	1	1	0	0

  2. **One** connected upper run *s* → the label of *s* is **copied** to *r*

2	2	2	2	0	0	0	0
0	1	1	1	1	1	0	0

  3. **Multiple** connected upper runs → their provisional labels are made **equivalent**, and *r* gets the **representative of the equivalence class**

2	2	2	2	0	0	3	3
0	1	1	1	1	1	0	0

- Most **label equivalence solvers** are variations of **Union-Find**

Existing Run-Based Algorithm: RBTS

- Run-Based Two-Scan (RBTS), by He *et al.*[1]
- 1st scan:
  - Iterate on the input to **find runs**
  - **Assign provisional labels** to new runs
  - Check connectivity between runs and **solve label equivalences**
  - Store provisional labels **in the output**
- 2nd scan:
  - **Replace provisional labels with definitive labels** inside the output image

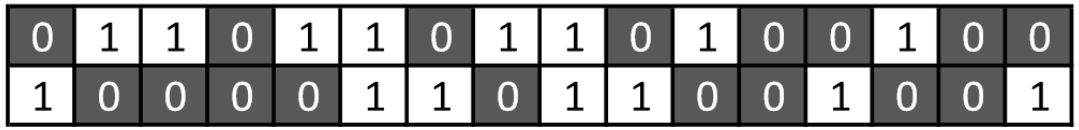
- First contribution of this work: **adapt RBTS to the bitonal format**

First Proposal: Bit-Run Two Scan (BRTS)

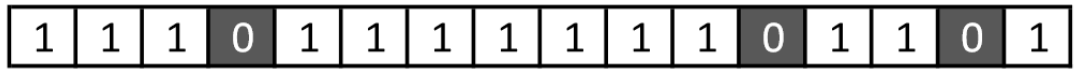
- Special **optimization of RBTS** for the **bitonal** (1-bit per pixel) format
- Change of BRTS (new) w.r.t. RBTS (He *et al.*, 2008*)*:
  - The input is **bitonal**
  - **Find First Set (FFS)** instructions
    - FFS gets the position of the **least significant 1** in a word
    - Useful to **efficiently retrieve start and end position** of runs
    - **Hardware** instruction on most systems → fast
  - Provisional labels are **only stored in run metadata**
    - The output is **only filled once**, during the second scan

Second Proposal: Bit-Merge-Run Scan

- Bit-Merge-Run Scan (**BMRS**) furtherly optimizes BRTS
- Every two consecutive rows are **merged with bitwise *OR***



(a)

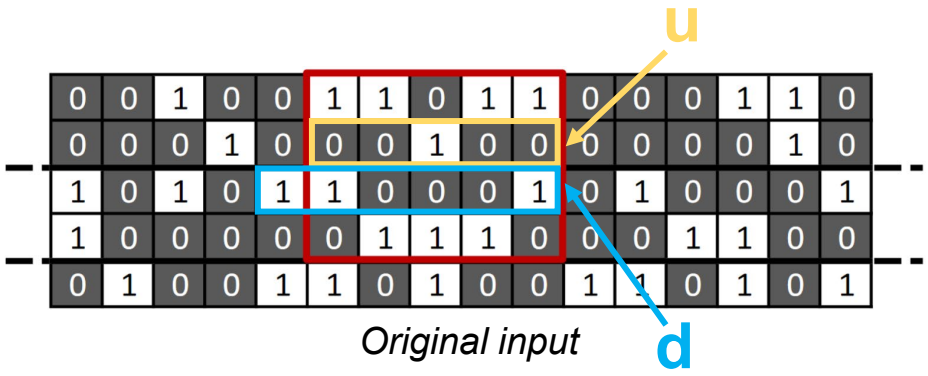


(b)

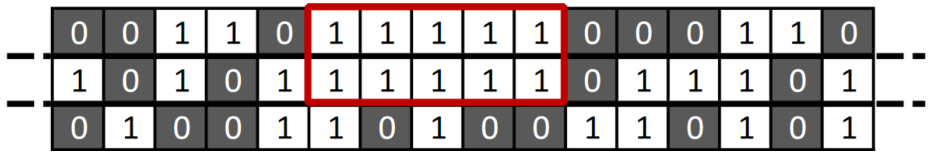
- Runs in the *merged rows* **correspond to CCs** in the input
- Connected Components are labeled on the merged rows

BMRS: Check *Merged Runs* Connections

- Merged runs can **seem connected** when they actually **are not**

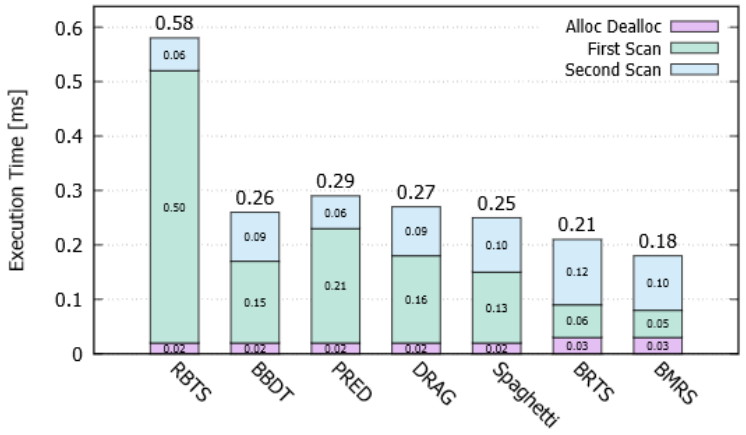


Original input

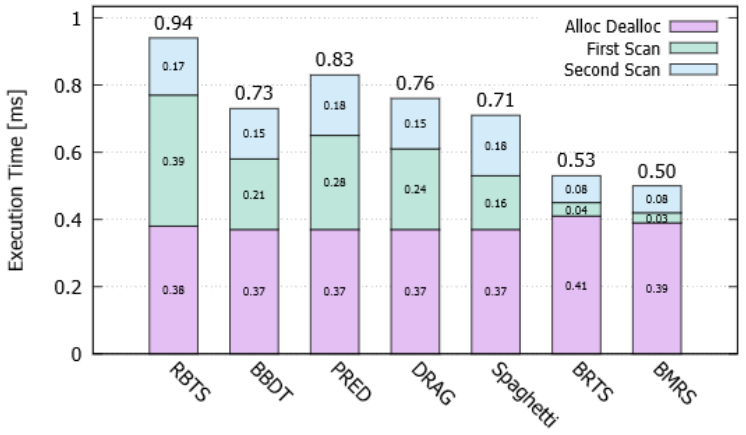

Merged runs

- The **original pixels must be checked**
- Be ***u*** and ***d*** the **border pixels** between two merged runs *R* and *S*:
  - *R* and *S* are connected iff **(*u* ∨ (*u* << 1)) ∧ (*d* ∨ (*d* << 1)) > 0**
- **Junction flags** pre-computed for each row pair

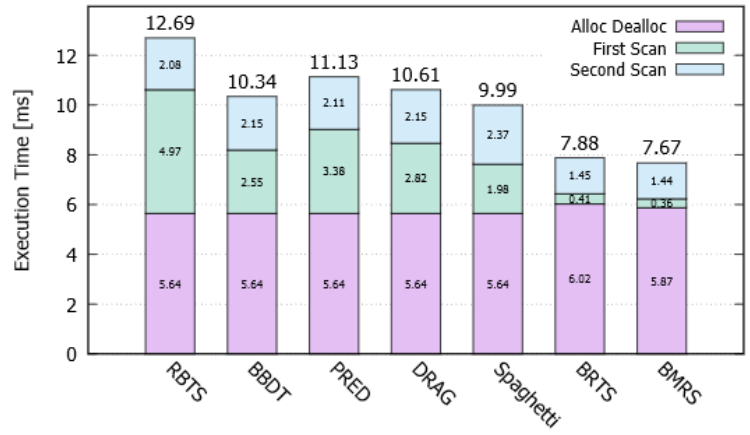
Experimental Results



(a) *Fingerprints*



(b) *3dpes*



(c) *Tobacco800*

- Comparison performed on *standard de-facto* benchmark YACCLAB[1]
- BRTS and BMRS **outperform** all competitors **on bitonal input** images
- Speedup of BMRS w.r.t. Spaghetti[2] (SoA) ranges from 1.34 to 1.60
- BMRS represents new state-of-the-art for CCL on bitonal images

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Thank You!

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