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Two-Pass Connected Component Labeling (CCL) for Binary Image

Azriel Rosenfeld and John L. Pfaltz

Journal of ACM, 1966

Speaker: Shih-Shinh Huang

February 28, 2021

A. Rosenfeld and J. L. Pfaltz, "Sequential Operations in Digital Picture Processing", *Journal of the ACM vol. 13, pp. 471—494, Oct.* 1966.

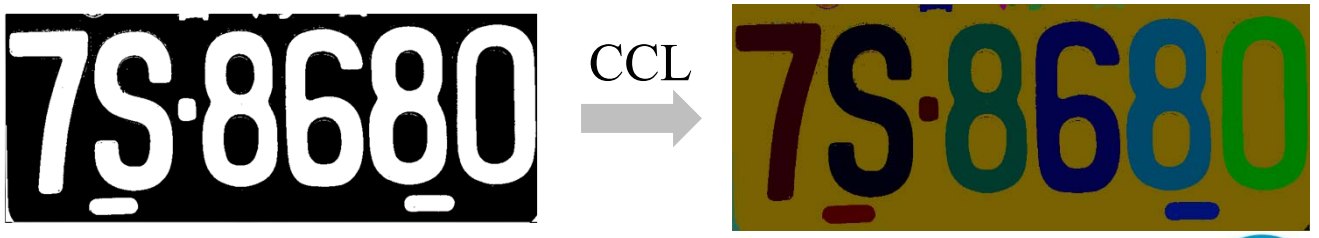
Outline

- Introduction
  - About CCL
  - Connectivity
  - Connected Component
- Two-Pass Labeling
  - Approach Overview
  - First Pass
  - Second Pass

Introduction

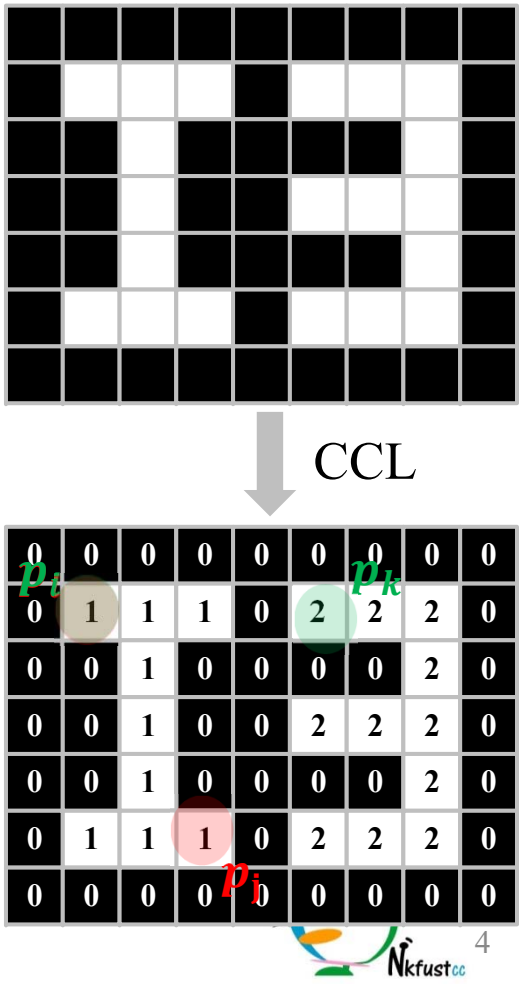
- About CCL
  - CCL is a fundamental operation in many image analysis applications.
    - group the connected points into a region
    - transform the unit to be processed from point to region

license plate recognition



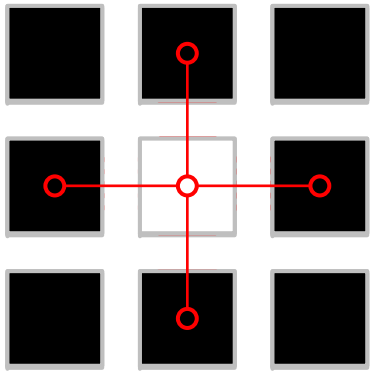
Introduction

- About CCL
  - The input to CCL is a binary image
    - 0: background points
    - 255: object points
  - The output of CCL is a label image
    - The label denotes the region identifier (0 stands for background region)
    - All connected points are with the same label.

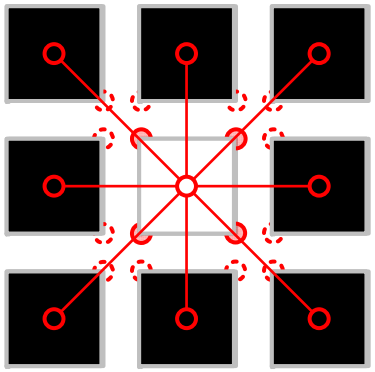


Introduction

- Connectivity
  - Adjacency: p_i and p_j are adjacent (neighbor) if their point squares share a common part
    - edge: 4-connectivity (N_4)
    - vertex: 8-connectivity (N_8)



4-connectivity (N_4)



8-connectivity (N_8)

Introduction

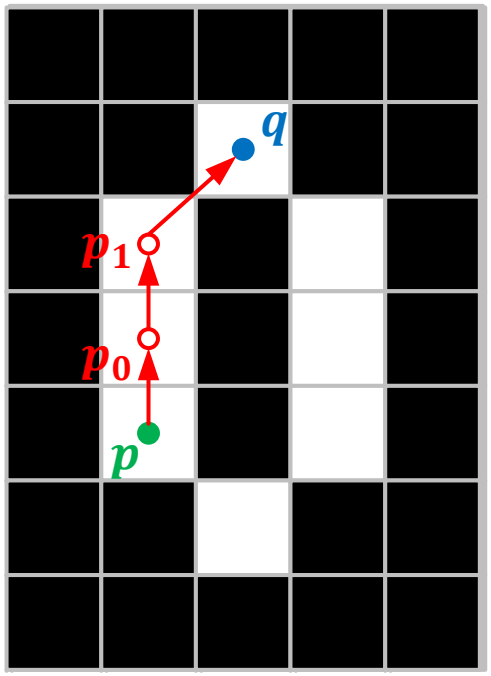
- Connectivity
  - Definition: two object points p and q are called connected if theres exist a path from p to q

$$\boldsymbol{p} \rightarrow p_0 \rightarrow p_1 \rightarrow p_2 \rightarrow \cdots \rightarrow p_n \rightarrow \boldsymbol{q}$$

    - $p_0, p_1, \ldots, p_n$ are all object points
    - $p_i \rightarrow p_j$ denotes p_i and p_j are adjacent

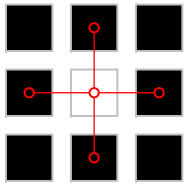
Introduction

- Connectivity



are the object points p and q connected ?

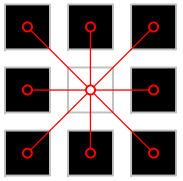
4-connectivity (N_4)



no path from p to q

➡ p and q are **not** connected

8-connectivity (N_8)

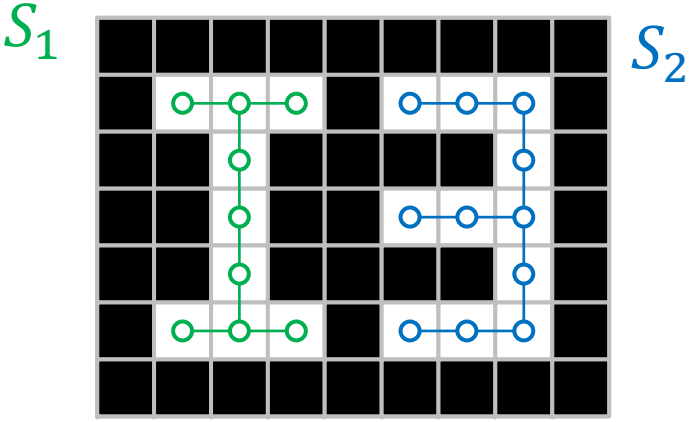


a path from p to q

➡ p and q are connected

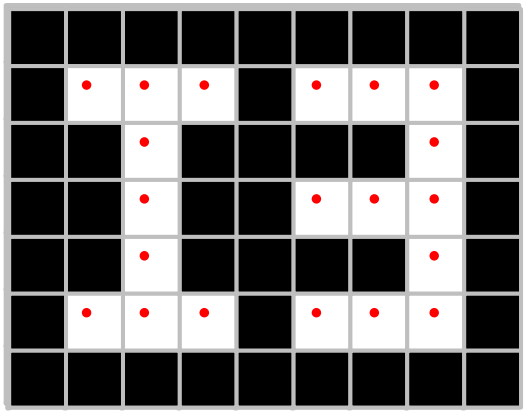
Introduction

- Connected Component
  - Definition: a maximum set S of object points that are connected of each other.
    - p and q are connected, and $p \in S$, $\Rightarrow q \in S$
    - $p \in S$ and $q \in S \Rightarrow$ p and q are connected



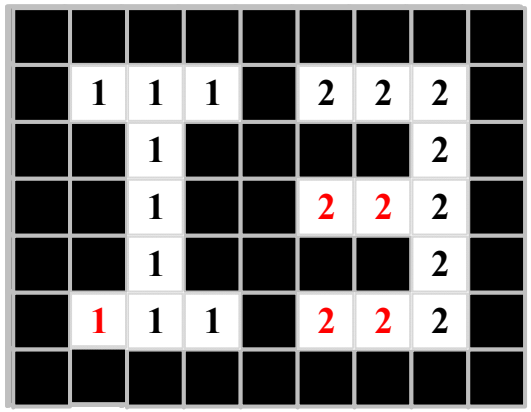
Two-Pass Labeling

- Approach Overview
  - scan the image for two times
    - go from left to right and top to bottom
    - only deal with the object points but skip the background points.



Two-Pass Labeling

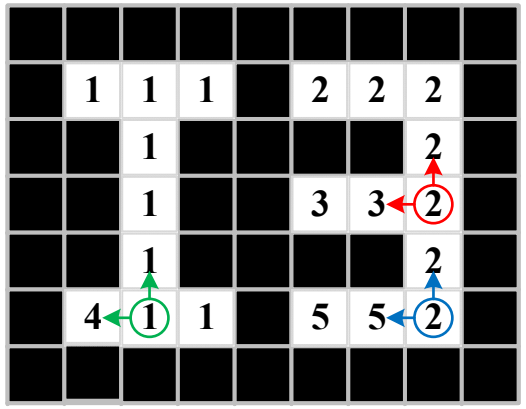
- Approach Overview
  - First Pass: assign temporary labels and record equivalence relations
  - Second Pass: resolve label equivalence and replace temporary labels.



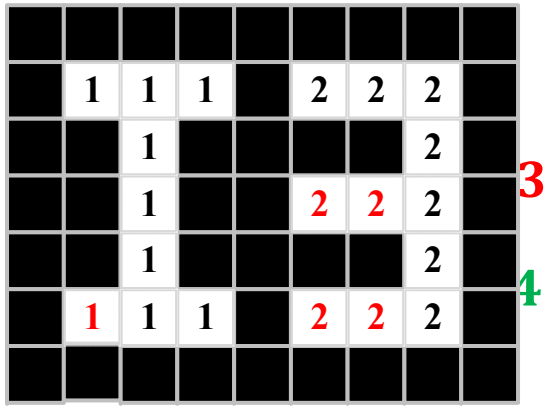
TwoPassCCL(*image*)

initialize ***label_map*** with the value 0

```
// first pass
for row=0  to  image.rows - 1
    for col=0  to  image.cols - 1
        if image[row, col] is not background
            ● assign temporary labels
            ● record equivalence relations
```



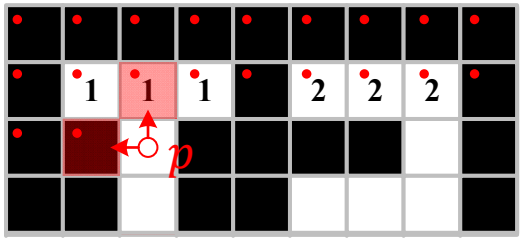

```
//second two
● resolve label equivalence
for row=0  to  image.rows - 1
    for col=0  to  image.cols - 1
        if image[row, col] is not background
            ● replace temporary labels
```



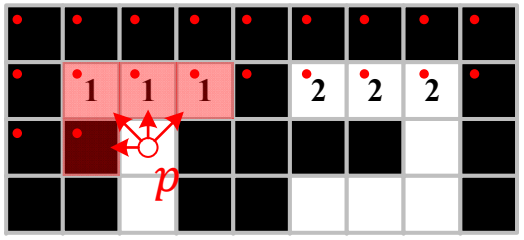
return ***label_map***

Two-Pass Labeling

- First Pass: assign temporary labels
  - Step 1: collect the labels in adjacent points of the object point p as $N(p)$



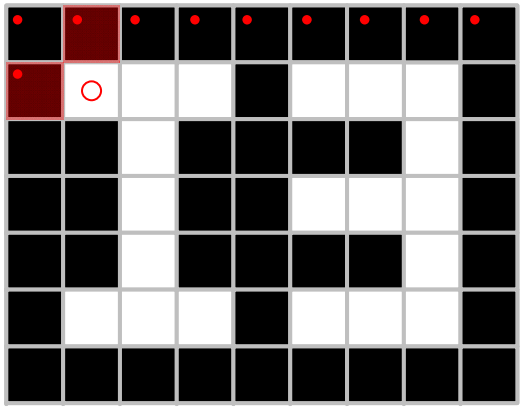
4-connectivity (N_4)



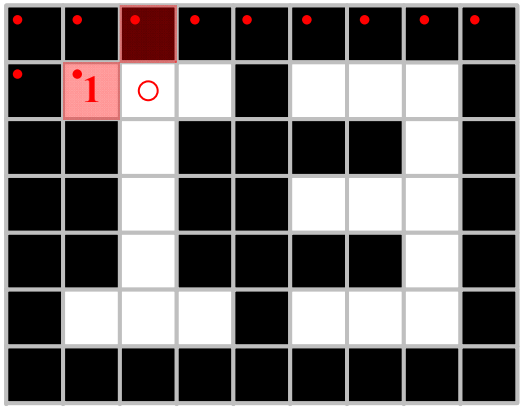
8-connectivity (N_8)

  - Step 2: assign a temporal label to p
    - $N(p) = \emptyset$: assign p a new label
    - $N(p) \neq \emptyset$: assign p a minimum in $N(p)$

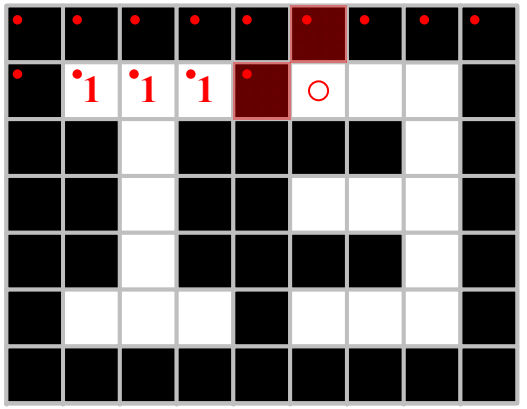
Two-Pass Labeling



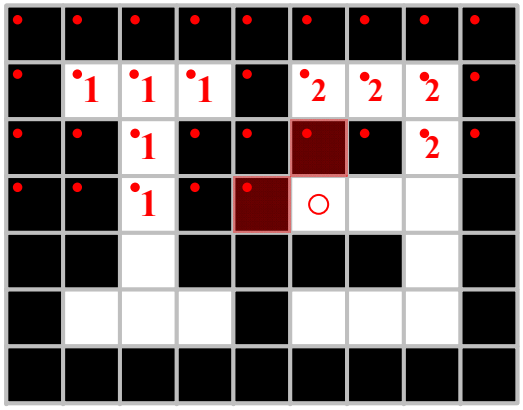
$N(p) = \emptyset$



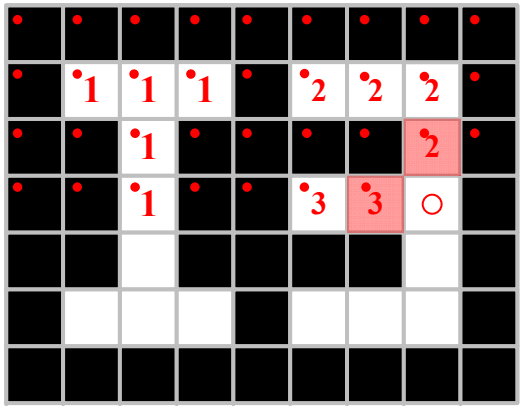
$N(p) = \{1\}$



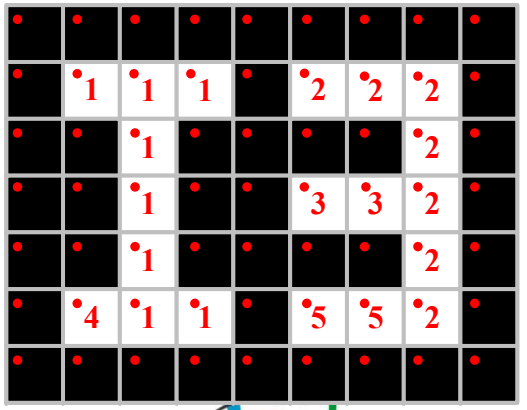
$N(p) = \emptyset$



$N(p) = \emptyset$

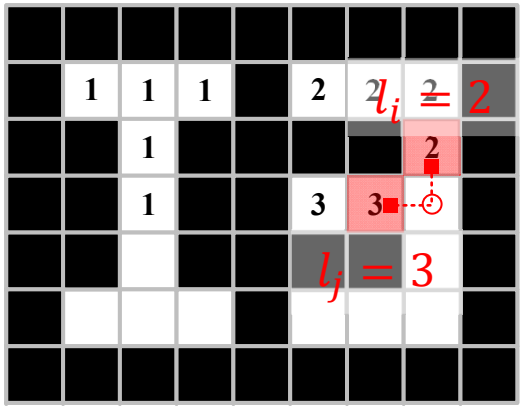


$N(p) = \{2,3\}$

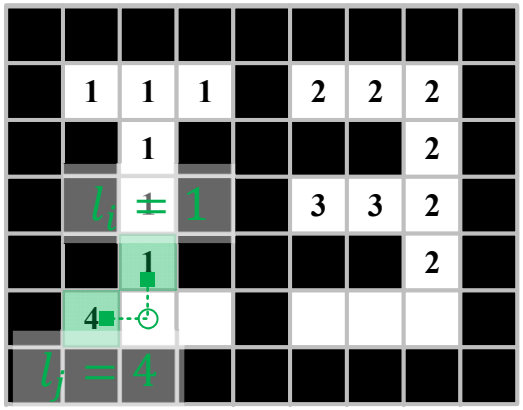


Two-Pass Labeling

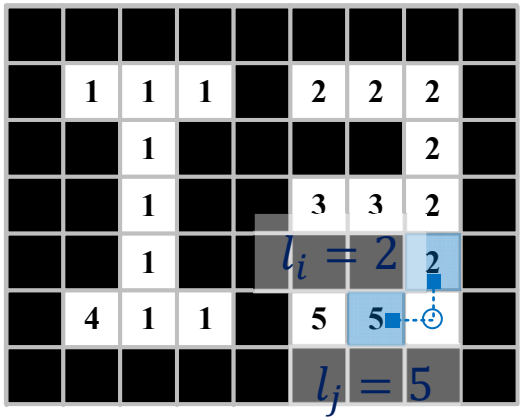
- First Pass: record equivalence relations
  - Condition: more than one label in $N(p)$
    - current point p connects different labels in $N(p)$
    - add equivalence relation $l_i \sim l_j$ for $l_i, l_j \in N(p)$



$N(p) = \{2,3\}$ **2~3**



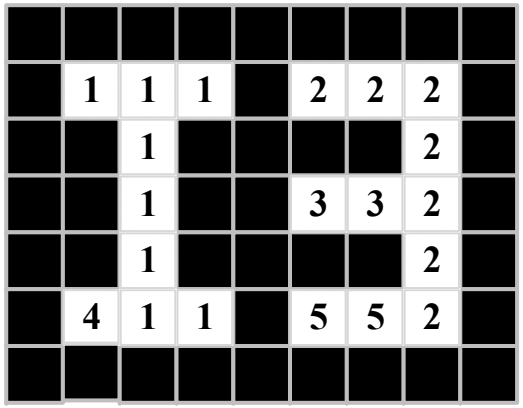
$N(p) = \{1,4\}$ **1~4**



$N(p) = \{2,5\}$ **2~5**

Two-Pass Labeling

- Second Pass: resolve label equivalence
  - Step 1: create single-integer-item sets
  - Step 2: process every equivalence pair $l_i \sim l_j$ to form equivalence classes



{2~3, 1~4, 2~5}

{1}, {2}, {3}, {4}, {5}

2~3 ➡ {1}, {2,3}, {4}, {5}

1~4 ➡ {1,4}, {2,3}, {5}

2~5 ➡ {1,4}, {2, 3, 5}

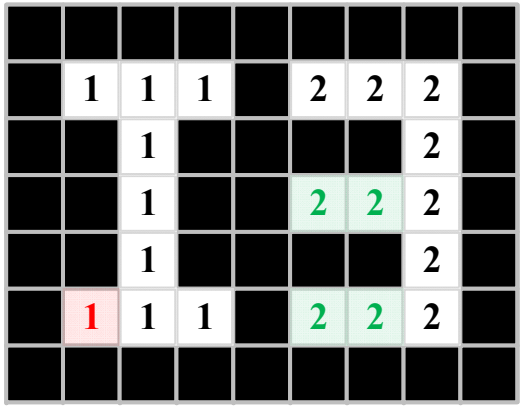
Two-Pass Labeling

- Second Pass: replace temporary labels
  - replace the label at p by the minimum of the set containing the label of p

$\{1,4\}, \{2,3,5\}$

$\{1,4\} \rightarrow 1$

$\{2,3,5\} \rightarrow 2$



TwoPassCCL(*image*)

initialize ***label_map*** with the value 0

```
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for row=0  to  image.rows - 1
    for col=0  to  image.cols - 1
        if image[row, col] is not background
            assign temporary labels
            record equivalence relations
//second two
resolve label equivalence
for row=0  to  image.rows - 1
    for col=0  to  image.cols - 1
        if image[row, col] is not background
            replace temporary labels
```

return ***label_map***

- N =collected labels in adjacency of point p (row, col)
- ***if*** $N = \emptyset$
  - assign a new label to p
- ***else***
  - assign minimum of N to p

- ***if*** $|N| > 1$
  - $l_i = \min(N)$
  - add equivalence relation $l_i \sim l_j$ for all $l_j \in N$

TwoPassCCL(*image*)

initialize ***label_map*** with the value 0

```
// first pass
for row=0  to  image.rows - 1
    for col=0  to  image.cols - 1
        if image[row, col] is not background
            assign temporary labels
            record equivalence relations

//second two
resolve label equivalence
for row=0  to  image.rows - 1
    for col=0  to  image.cols - 1
        if image[row, col] is not background
            replace temporary labels
```

return ***label_map***

- create single-integer-item sets, $\{1\},\{2\},\ldots\ldots$
- ***for*** each equivalence pair (l_i, l_j)
  - unify two sets that contains l_i and l_j, respectively.

- replace the label at p by the minimum of the set containing the label of p


thank you
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