# Regionen in Binärbildern

## Industrielle Bildverarbeitung, Vorlesung No. 9[1]

M. O. Franz

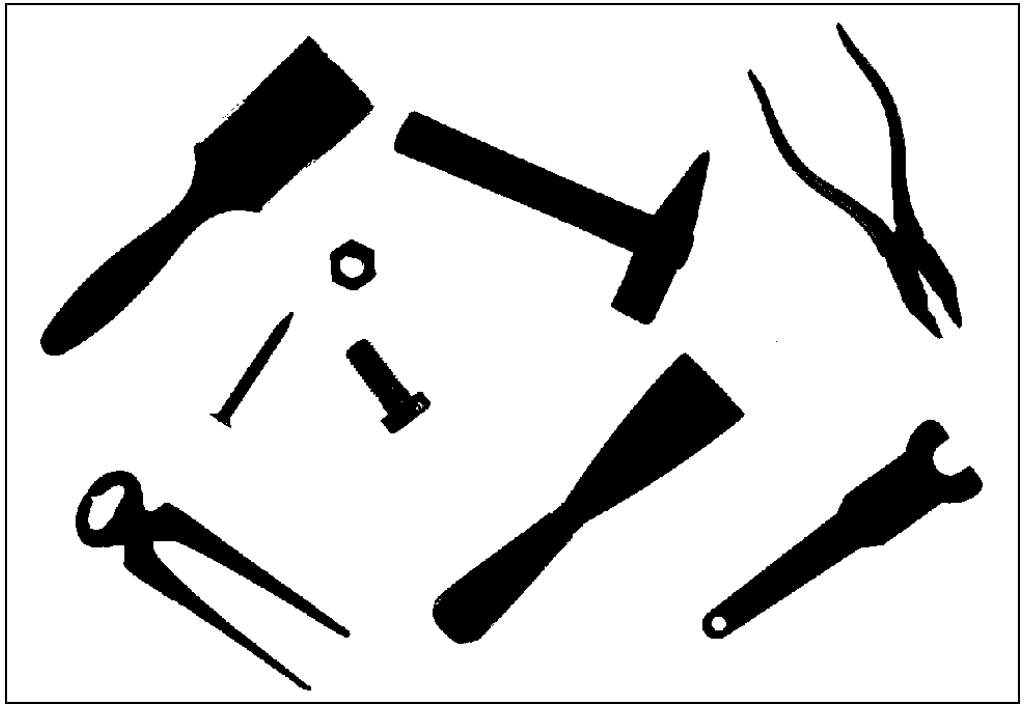
05.12.2007

[1] falls nicht anders vermerkt, sind die Abbildungen entnommen aus Burger & Burge, 2005.

# Übersicht

# Übersicht

# Regionen in Binärbildern



Aufgaben:

- Auffinden von verbundenen Regionen gleicher Pixelfarbe
- Extraktion von Konturen
- Repräsentation der Bildregionen
- Beschreibung der Regionen durch geeignete Kennzahlen

# Auffinden von Bildregionen

Regionenmarkierung (*region labeling* oder *coloring*):

- Bestimmung der Anzahl der Regionen im Bild
- Bestimmung der Position der Regionen im Bild
- Bestimmung der Zugehörigkeit der einzelnen Pixel zu den Bildregionen

Vorher festzulegen: Art der Nachbarschaft (4er oder 8er) $\Rightarrow$ führt zu unterschiedlichen Regionen.

Ergebnis der Regionenmarkierung:

$$I(u,v) = \begin{cases} 0 & \text{Hintergrundpixel } (\textit{background}) \\ 1 & \text{Vordergrundpixel } (\textit{foreground}) \\ 2, 3, \ldots & \text{Regionenmarkierung } (\textit{label}) \end{cases}$$

# Regionenmarkierung durch *Flood Filling* (1)

```
1:  RegionLabeling(I)
        I: binary image (0 = background, 1 = foreground)
2:      Initialize m ← 2 (the value of the next label to be assigned).
3:      Iterate over all image coordinates ⟨u, v⟩.
4:          if I(u, v) = 1 then
5:              FloodFill(I, u, v, m)        ▷ use any of the 3 versions below
6:              m ← m + 1.
7:      return.
```

---

```
8:  FloodFill(I, u, v, label)                          ▷ Recursive Version
9:      if coordinate ⟨u, v⟩ is within image boundaries and I(u, v) = 1 then
10:         Set I(u, v) ← label
11:         FloodFill(I, u+1, v, label)
12:         FloodFill(I, u, v+1, label)
13:         FloodFill(I, u, v−1, label)
14:         FloodFill(I, u−1, v, label)
15:     return.
```

entspricht rekursiver Tiefensuche bei Graphenalgorithmen. Vorsicht: Erschöpfung des Stack-Speichers bei großen Regionen

# Regionenmarkierung durch *Flood Filling* (2)

```
16: FloodFill(I, u, v, label)                    ▷ Depth-First Version
17:     Create an empty stack S
18:     Put the seed coordinate ⟨u, v⟩ onto the stack: Push(S, ⟨u, v⟩)
19:     while S is not empty do
20:         Get the next coordinate from the top of the stack:
                ⟨x, y⟩ ← Pop(S)
21:         if coordinate (x, y) is within image boundaries and I(x, y) = 1
                then
22:             Set I(x, y) ← label
23:             Push(S, ⟨x+1, y⟩)
24:             Push(S, ⟨x, y+1⟩)
25:             Push(S, ⟨x, y−1⟩)
26:             Push(S, ⟨x−1, y⟩)
27:     return.
```

entspricht sequentieller Tiefensuche bei Graphenalgorithmen. Da der Stack im Heapspeicher angelegt wird, besteht prinzipiell keine Größenlimitierung.

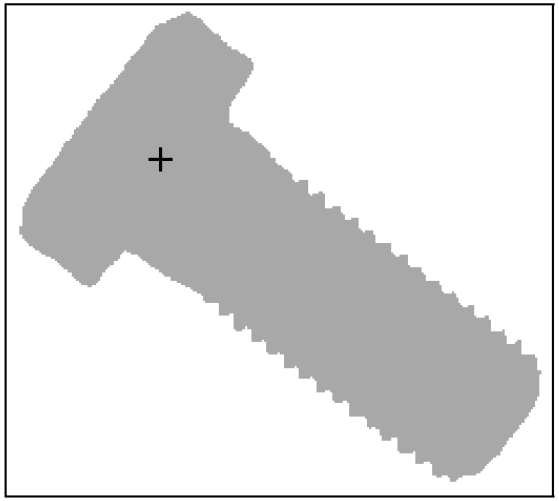
# Regionenmarkierung durch *Flood Filling* (3)

```
28: FloodFill(I, u, v, label)                    ▷ Breadth-First Version
29:     Create an empty queue Q
30:     Insert the seed coordinate ⟨u, v⟩ into the queue: Enqueue(Q, (u, v))
31:     while Q is not empty do
32:         Get the next coordinate from the front of the queue:
                ⟨x, y⟩ ← Dequeue(Q)
33:         if coordinate ⟨x, y⟩ is within image boundaries and I(x, y) = 1
                then
34:             Set I(x, y) ← label
35:             Enqueue(Q, ⟨x+1, y⟩)
36:             Enqueue(Q, ⟨x, y+1⟩)
37:             Enqueue(Q, ⟨x, y−1⟩)
38:             Enqueue(Q, ⟨x−1, y⟩)
39:     return.
```

entspricht sequentieller Breitensuche bei Graphenalgorithmen.
Ebenfalls keine Größenlimitierung, geringerer Speicherbedarf.

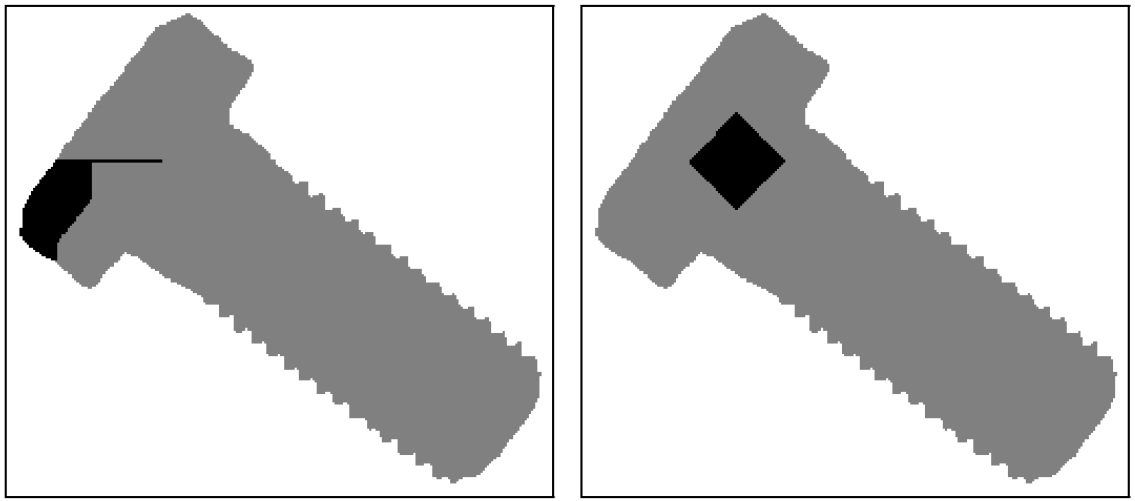
# Beispiel: *Flood Filling* (1)

(a)
Original



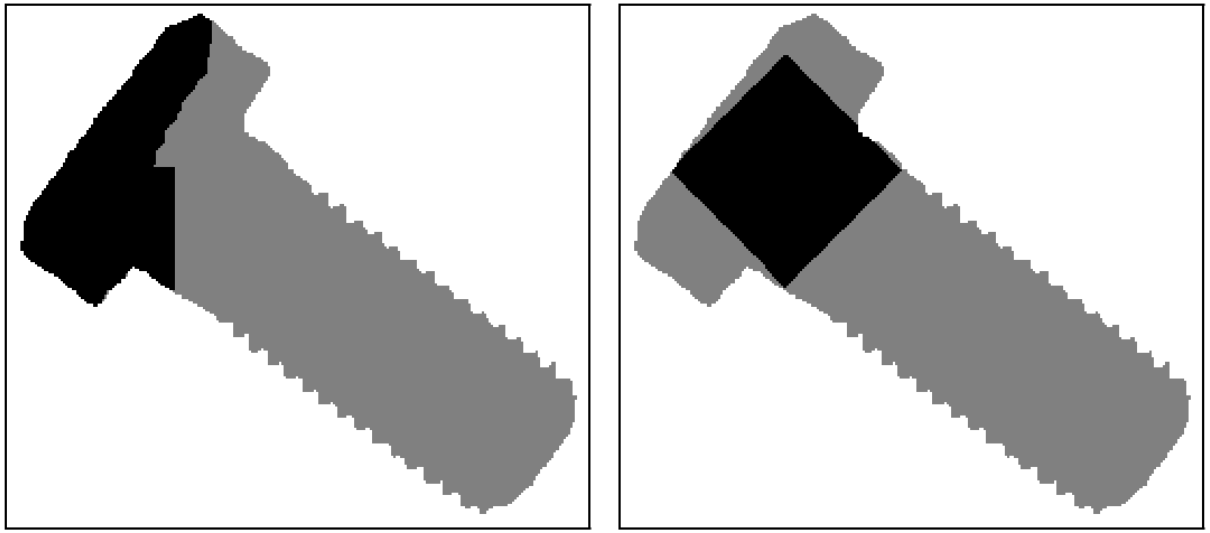
**depth-first** **breadth-first**

(b)
$K = 1.000$

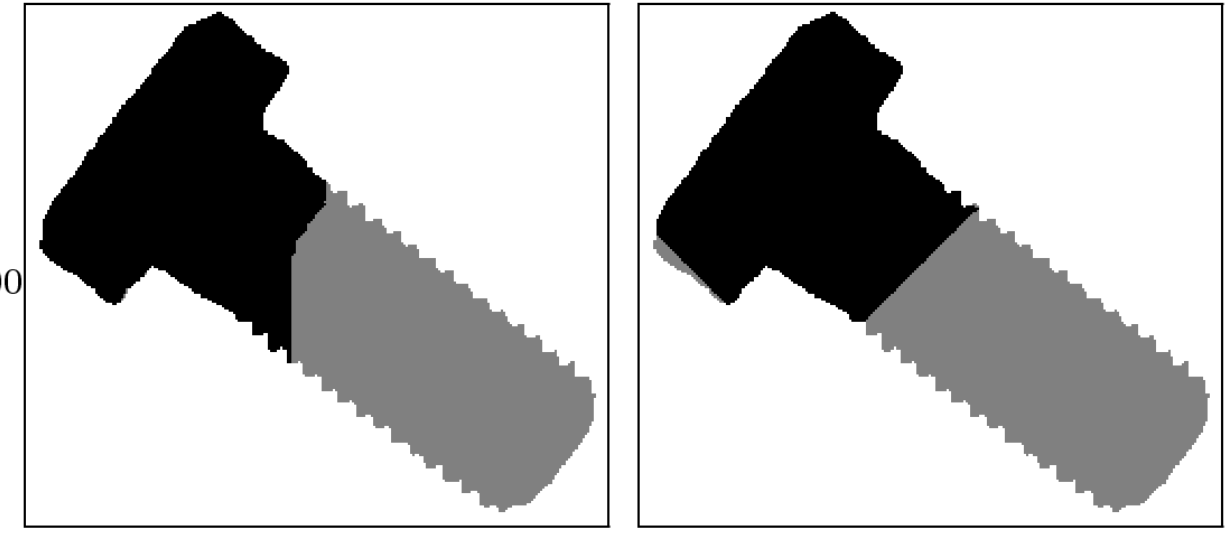


# Beispiel: *Flood Filling* (2)

(c)
$K = 5.000$



(d)
$K = 10.000$



# Sequentielle Regionenmarkierung

Verfahren läuft in 2 Schritten ab:

1. Schritt 1- Vorläufige Markierung: Beim ersten Durchlauf werden alle Labels aus der linken/oberen Nachbarschaft übernommen.

$$\mathcal{N}_4(u,v) = \begin{array}{|c|c|c|}\hline & N_2 & \\ \hline N_1 & \times & \\ \hline & & \\ \hline\end{array} \qquad \mathcal{N}_8(u,v) = \begin{array}{|c|c|c|}\hline N_2 & N_3 & N_4 \\ \hline N_1 & \times & \\ \hline & & \\ \hline\end{array}$$

   Gleichzeitig werden das Aufeinandertreffen von Regionen mit unterschiedlichen Labels (Kollisionen) gespeichert.

2. Schritt2 - Auflösung der Kollisionen: Zusammenhängende Regionen werden miteinander verschmolzen.

Häufig eingesetzt wegen moderatem Speicherbedarf, Verschmelzung der Regionen ist aber komplex.

# Sequentielle Regionenmarkierung: Schritt 1

1: SequentialLabeling($I$)
$I$: binary image ($0 = background$, $1 = foreground$)
2: Pass 1 – Assign Initial Labels:
3: Initialize $m \leftarrow 2$ (the value of the next label to be assigned).
4: Create an empty set $\mathcal{C}$ to hold the collisions: $\mathcal{C} \leftarrow \{\}$.
5: **for** $v \leftarrow 0 \ldots H{-}1$ **do** ▷ $H$ = height of image $I$
6: **for** $u \leftarrow 0 \ldots W{-}1$ **do** ▷ $W$ = width of image $I$
7: **if** $I(u,v) = 1$ **then** do one of:
8: **if** all neighbors are background pixels (all $n_i = 0$) **then**
9: $I(u,v) \leftarrow m$.
10: $m \leftarrow m + 1$.
11: **else if** exactly *one* of the neighbors has a label value $n_k > 1$ **then**
12: set $I(u,v) \leftarrow n_k$
13: **else if** *several* neighbors have label values $n_j > 1$ **then**
14: Select one of them as the new label:
$I(u,v) \leftarrow k \in \{n_j\}$.
15: **for** all other neighbors with label values $n_i > 1$ and $n_i \neq k$ **do**
16: register the pair $\langle n_i, k\rangle$ as a label collision:
$\mathcal{C} \leftarrow \mathcal{C} \cup \{\langle n_i, k\rangle\}$.

*Remark:* The image $I$ now contains label values $0, 2, \ldots m{-}1$.

# Beispiel: Vorläufige Markierung (1)

(a)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

0 Hintergrund

1 Vordergrund

(b) nur Hintergrundnachbarn

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

neues Label (2)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Beispiel: Vorläufige Markierung (2)

(c) genau 1 Nachbar-Label

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Nachbar-Label wird übernommen

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(d) 2 Nachbarn tragen versch. Labels

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 3 | 0 | 4 | 0 |
| 0 | 5 | 5 | 5 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

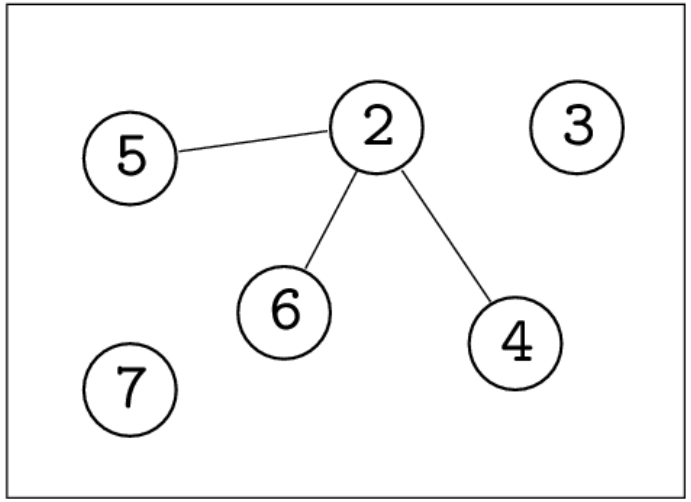
ein Label wird übernommen

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 3 | 0 | 4 | 0 |
| 0 | 5 | 5 | 5 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Beispiel: Vorläufige Markierung (3)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 3 | 0 | 4 | 0 |
| 0 | 5 | 5 | 5 | 2 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 4 | 0 |
| 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| 0 | 6 | 6 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 |
| 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 |
| 0 | 7 | 7 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(a)




(b)

# Sequentielle Regionenmarkierung: Schritt 2

17: PASS 2 – RESOLVE LABEL COLLISIONS:

18: Let $\mathcal{L} = \{2, 3, \ldots m{-}1\}$ be the set of preliminary region labels.

19: Create a partitioning of $\mathcal{L}$ as a *vector of sets*, one set for each label value: $\mathcal{R} \leftarrow [\mathcal{R}_2, \mathcal{R}_3, \ldots, \mathcal{R}_{m-1}] = [\{2\}, \{3\}, \{4\}, \ldots, \{m{-}1\}]$, so $\mathcal{R}_i = \{i\}$ for all $i \in \mathcal{L}$.

20: **for all** collisions $\langle a, b \rangle \in \mathcal{C}$ **do**

21: Find in $\mathcal{R}$ the sets $\mathcal{R}_a$, $\mathcal{R}_b$ containing the labels $a$, $b$, resp.:
$\mathcal{R}_a \leftarrow$ the set which currently contains label $a$
$\mathcal{R}_b \leftarrow$ the set which currently contains label $b$

22: **if** $\mathcal{R}_a \neq \mathcal{R}_b$ ($a$ and $b$ are contained in different sets) **then**

23: Merge sets $\mathcal{R}_a$ and $\mathcal{R}_b$ by moving all elements of $\mathcal{R}_b$ to $\mathcal{R}_a$:
$\mathcal{R}_a \leftarrow \mathcal{R}_a \cup \mathcal{R}_b$
$\mathcal{R}_b \leftarrow \{\}$

*Remark:* All equivalent label values (i.e., all labels of pixels in the same region) are now contained in the same sets within $\mathcal{R}$.

# Sequentielle Regionenmarkierung: Schritt 2

24: PASS 3: RELABEL THE IMAGE:

25: Iterate through all image pixels $(u, v)$:

26: **if** $I(u, v) > 1$ **then**

27: Find the set $\mathcal{R}_i$ in $\mathcal{R}$ which contains label $I(u, v)$.

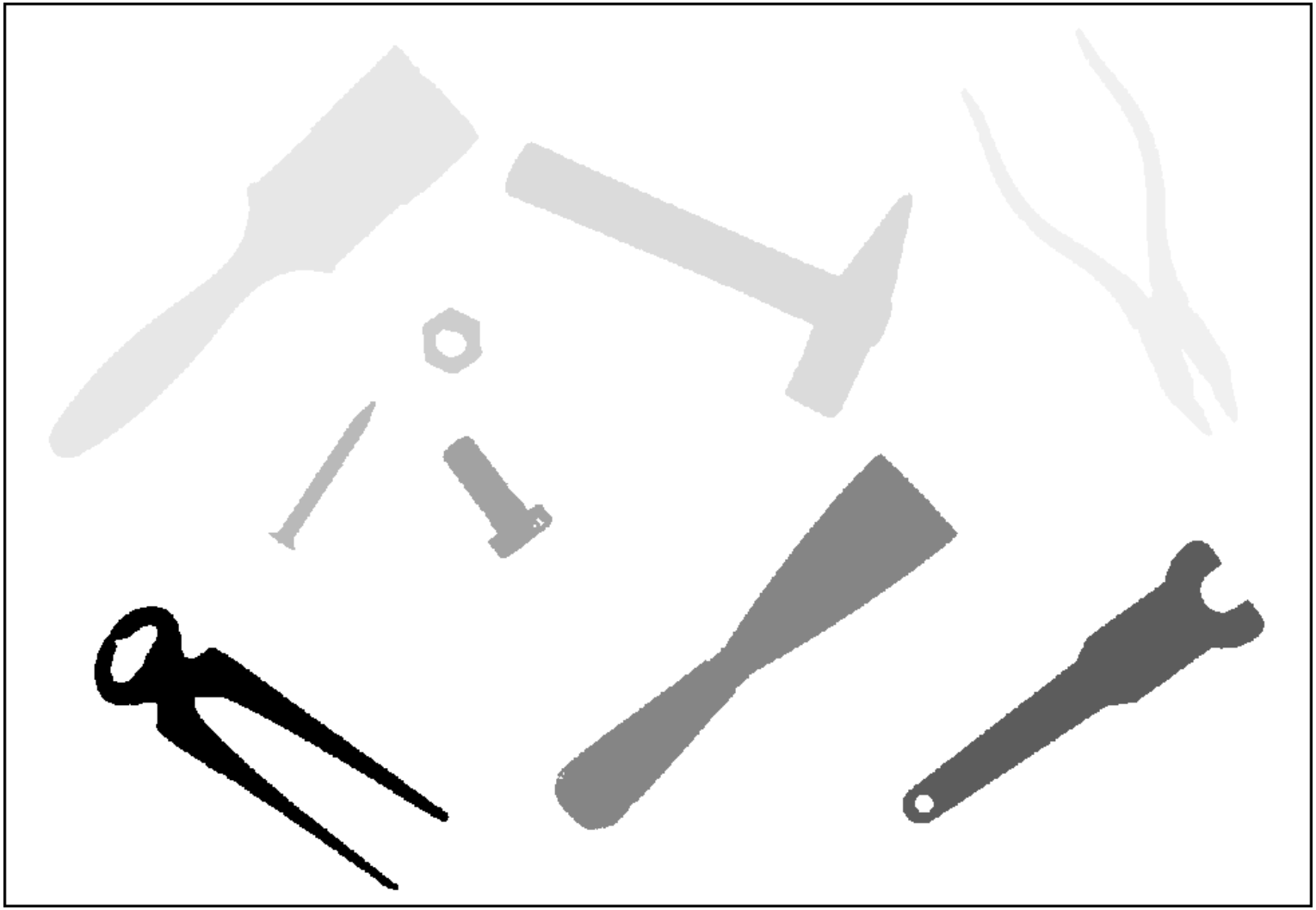
28: Choose one unique, representative element $k$ from the set $\mathcal{R}_i$ (e.g., the minimum value, $k \leftarrow \min(\mathcal{S})$).

29: Replace the image label: $I(u, v) \leftarrow k$.

30: **return** the labeled image $I$.

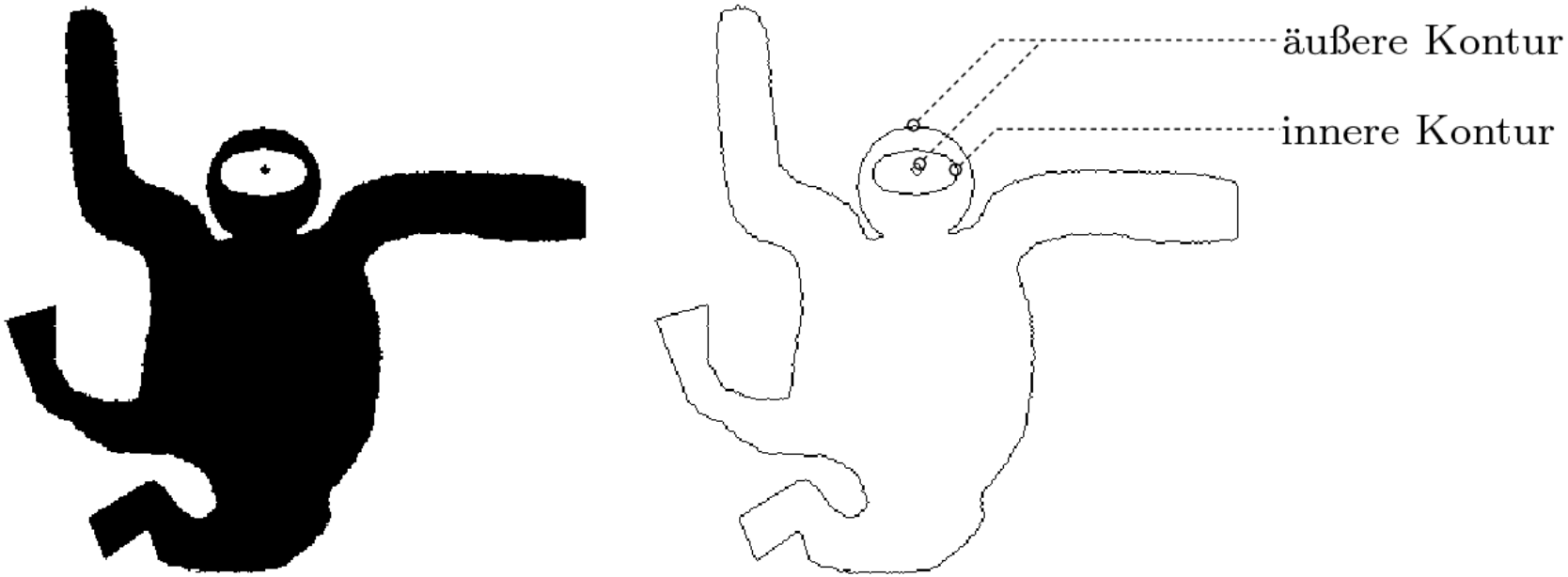
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 3 | 0 | 2 | 0 |
| 0 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 2 | 0 |
| 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 |
| 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 |
| 0 | 7 | 7 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Beispiel: fertige Regionenmarkierung

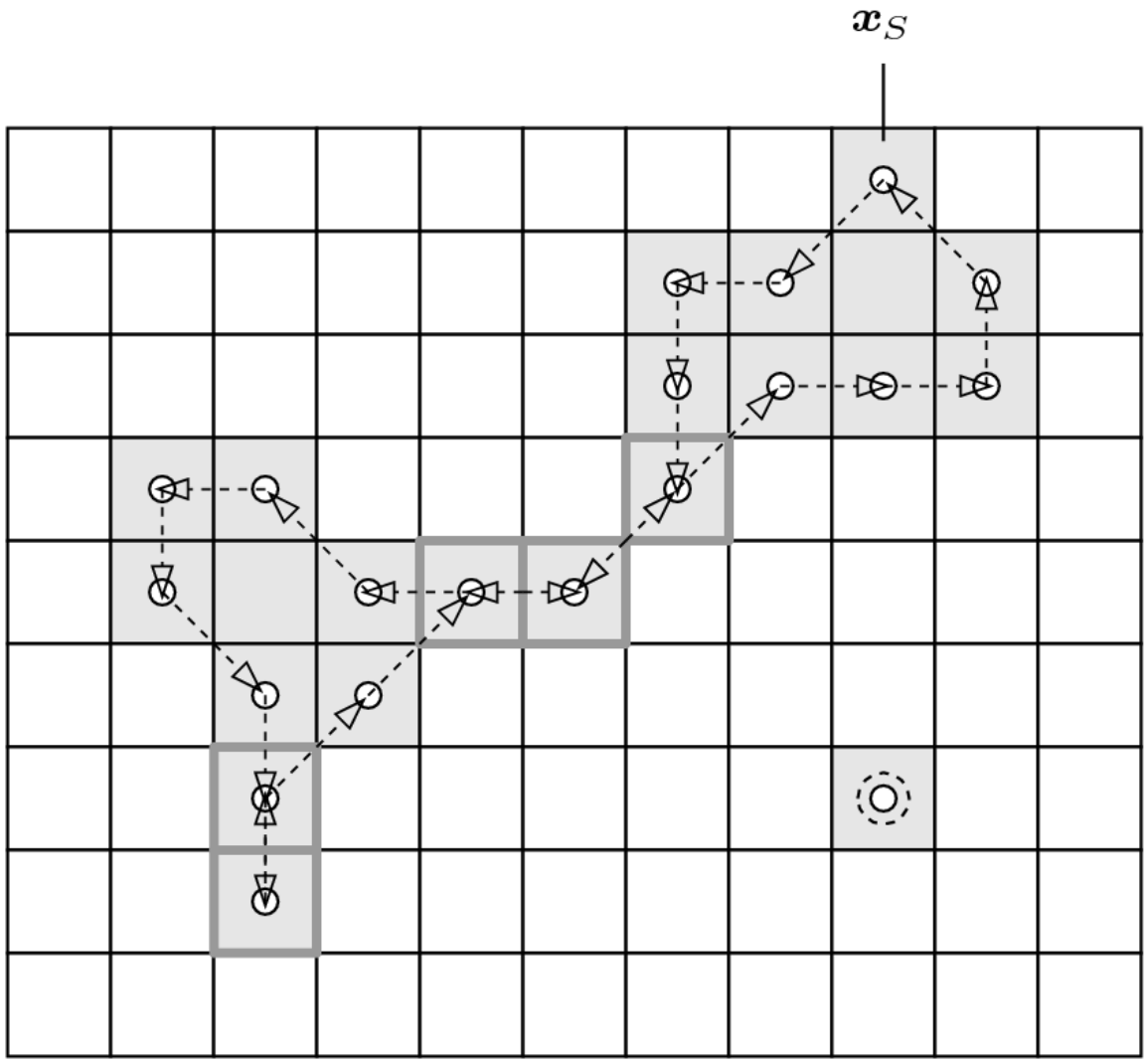


# Übersicht

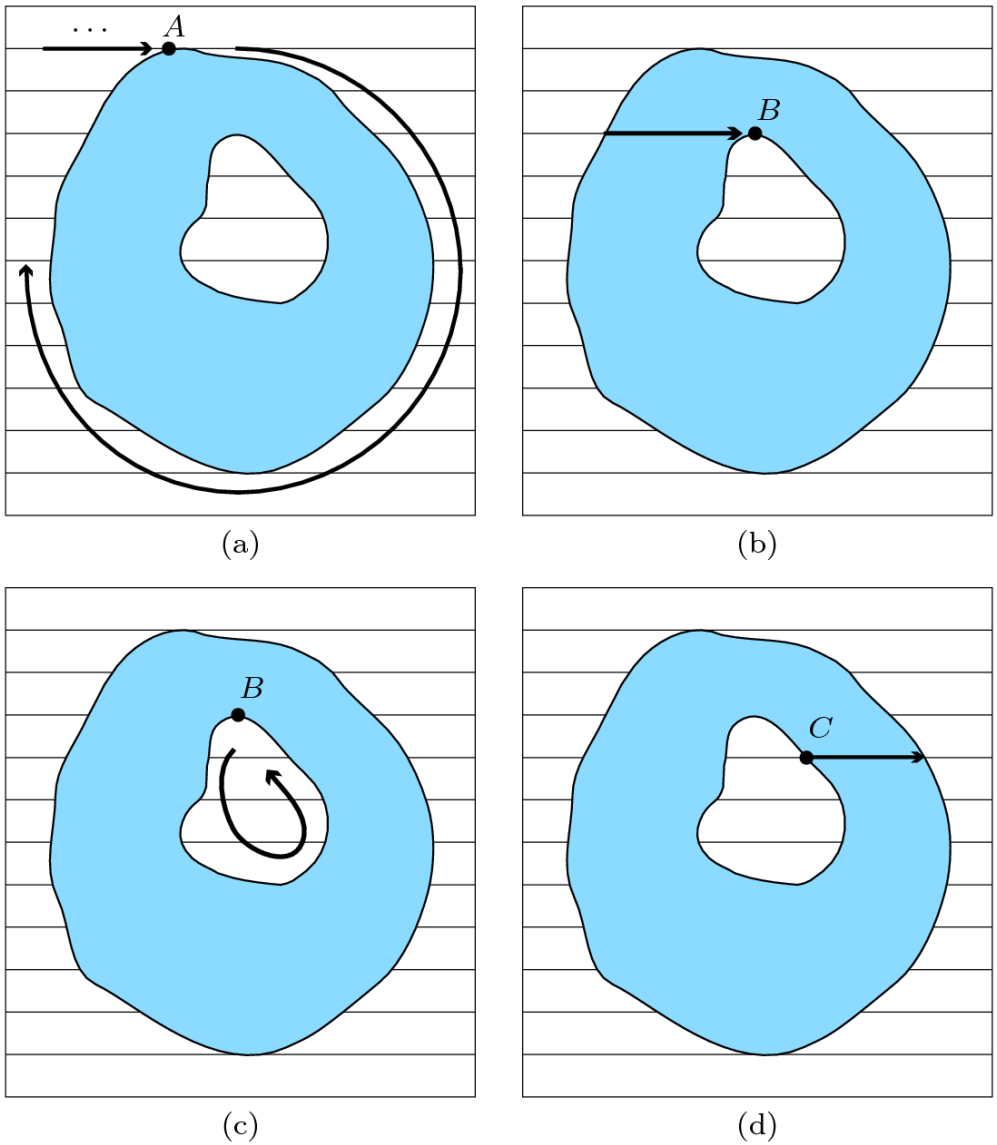
# Äußere und innere Konturen



# Repräsentation einer Kontur durch eine geordnete Folge von Pixelkoordinaten



# Kombinierte Regionenmarkierung und Konturfindung



# Algorithmus (1)

2: Create an empty set of contours: $\mathcal{C} \leftarrow \{\}$
3: Create a label map $LM$ of the same size as $I$ and initialize:
4: **for** all $(u, v)$ **do**
5: $LM(u, v) \leftarrow 0$ ▷ label map $LM$
6: $R \leftarrow 0$ ▷ region counter $R$
7: *Scan the image from left to right, top to bottom:*
8: **for** $v \leftarrow 0 \ldots N-1$ **do**
9: $L_c \leftarrow 0$ ▷ current label $L_c$
10: **for** $u \leftarrow 0 \ldots M-1$ **do**
11: **if** $I(u, v)$ is a *foreground* pixel **then**
12: **if** $(L_c \neq 0)$ **then** ▷ continue existing region
13: $LM(u, v) \leftarrow L$
14: **else**
15: $L_c \leftarrow LM(u, v)$
16: **if** $(L_c = 0)$ **then** ▷ hit new outer contour
17: $R \leftarrow R + 1$
18: $L_c \leftarrow R$
19: $\boldsymbol{x}_S \leftarrow (u, v)$
20: $C_{\text{outer}} \leftarrow \text{TraceContour}(\boldsymbol{x}_S, 0, L_c, I, LM)$
21: $\mathcal{C} \leftarrow \mathcal{C} \cup \{C_{\text{outer}}\}$ ▷ collect new contour
22: $LM(u, v) \leftarrow L_c$
23: **else** ▷ $I(u, v)$ is a background pixel
24: **if** $(L \neq 0)$ **then**
25: **if** $(LM(u, v) = 0)$ **then** ▷ hit new inner contour
26: $\boldsymbol{x}_S \leftarrow (u-1, v)$
27: $C_{\text{inner}} \leftarrow \text{TraceContour}(\boldsymbol{x}_S, 1, L_c, I, LM)$
28: $\mathcal{C} \leftarrow \mathcal{C} \cup \{C_{\text{inner}}\}$ ▷ collect new contour
29: $L \leftarrow 0$
30: **return** $(\mathcal{C}, LM)$. ▷ return the set of contours and the label map

# Algorithmus (2)

1: TRACECONTOUR($\boldsymbol{x}_S, d_S, L_C, I, LM$)
   $\boldsymbol{x}_S$: start position
   $d_S$: initial search direction
   $L_C$: label for this contour
   $I$: image
   $LM$: label map
2: Create an empty contour $C$
3: $(\boldsymbol{x}_T, d) \leftarrow$ FINDNEXTNODE($\boldsymbol{x}_S, d_s, I, LM$)
4: APPEND($C, \boldsymbol{x}_T$) ▷ add $\boldsymbol{x}_T$ to contour $C$
5: $\boldsymbol{x}_p \leftarrow \boldsymbol{x}_S$ ▷ *previous* position $\boldsymbol{x}_p = (u_p, v_p)$
6: $\boldsymbol{x}_c \leftarrow \boldsymbol{x}_T$ ▷ *current* position $\boldsymbol{x}_c = (u_c, v_c)$
7: $done \leftarrow (\boldsymbol{x}_S = \boldsymbol{x}_T)$ ▷ isolated pixel?
8: **while** $(\neg done)$ **do**
9: $LM(u_c, v_c) \leftarrow L_C$
10: $(\boldsymbol{x}_n, d) \leftarrow$ FINDNEXTNODE($\boldsymbol{x}_c, (d+6) \bmod 8, I, LM$)
11: $\boldsymbol{x}_p \leftarrow \boldsymbol{x}_c$
12: $\boldsymbol{x}_c \leftarrow \boldsymbol{x}_n$
13: $done \leftarrow (\boldsymbol{x}_p = \boldsymbol{x}_S \wedge \boldsymbol{x}_c = \boldsymbol{x}_T)$ ▷ back at starting position?
14: **if** $(\neg done)$ **then**
15: APPEND($C, \boldsymbol{x}_n$) ▷ add point $\boldsymbol{x}_n$ to contour $C$
16: **return** $C$ . ▷ return this contour

# Algorithmus (3)

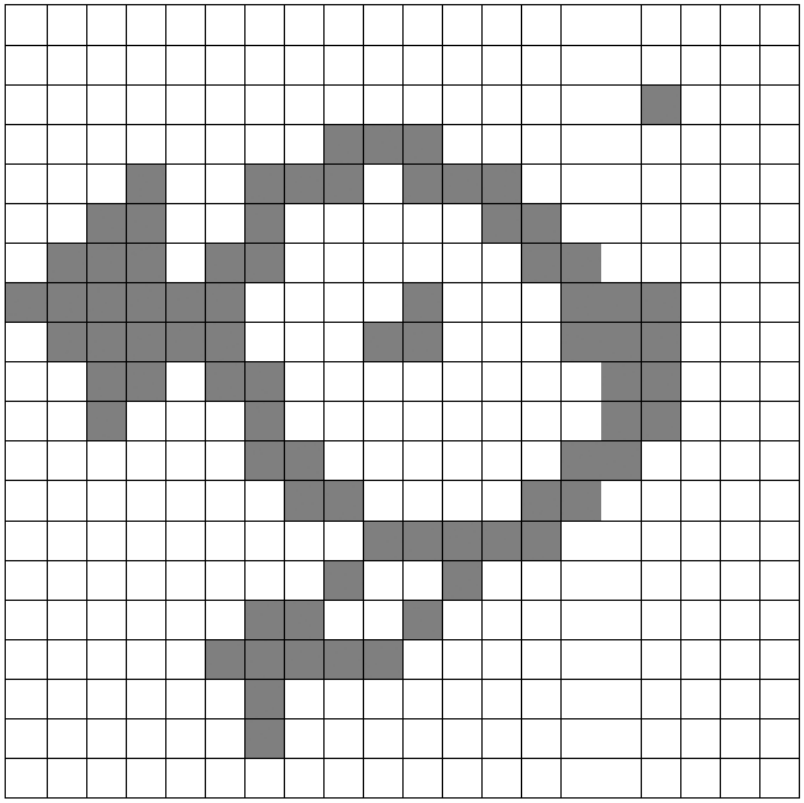
17: FindNextNode($\boldsymbol{x}_c, d, I, LM$)
$\boldsymbol{x}_c$: original position, $d$: search direction, $I$: image, $LM$: label map
18: **for** $i \leftarrow 0 \ldots 6$ **do** ▷ search in 7 directions
19: $\boldsymbol{x}' \leftarrow \boldsymbol{x}_c + \text{Delta}(d)$ ▷ $\boldsymbol{x}' = (u', v')$
20: **if** $I(u', v')$ is a *background* pixel **then**
21: $LM(u', v') \leftarrow -1$ ▷ mark background as *visited* $(-1)$
22: $d \leftarrow (d + 1) \bmod 8$
23: **else** ▷ found a non-background pixel at $\boldsymbol{x}'$
24: **return** $(\boldsymbol{x}', d)$
25: **return** $(\boldsymbol{x}_c, d)$ . ▷ found no next node, return start position

---

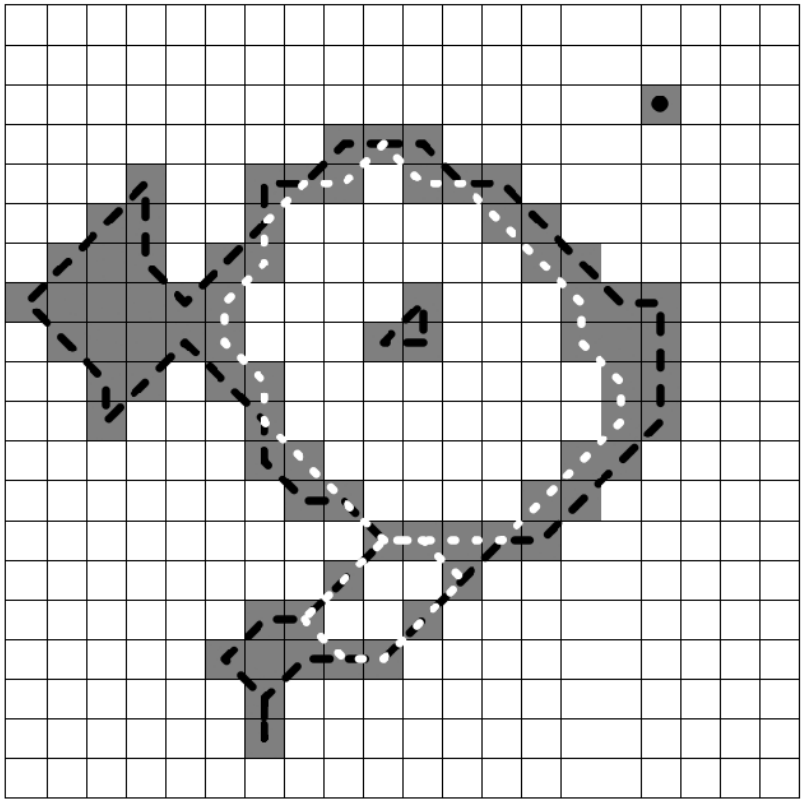
26: Delta($d$) = $(\Delta x, \Delta y)$, wobei

| $d$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| $\Delta x$ | 1 | 1 | 0 | −1 | −1 | −1 | 0 | 1 |
| $\Delta y$ | 0 | 1 | 1 | 1 | 0 | −1 | −1 | −1 |

# Beispiel Konturverfolgung (1)

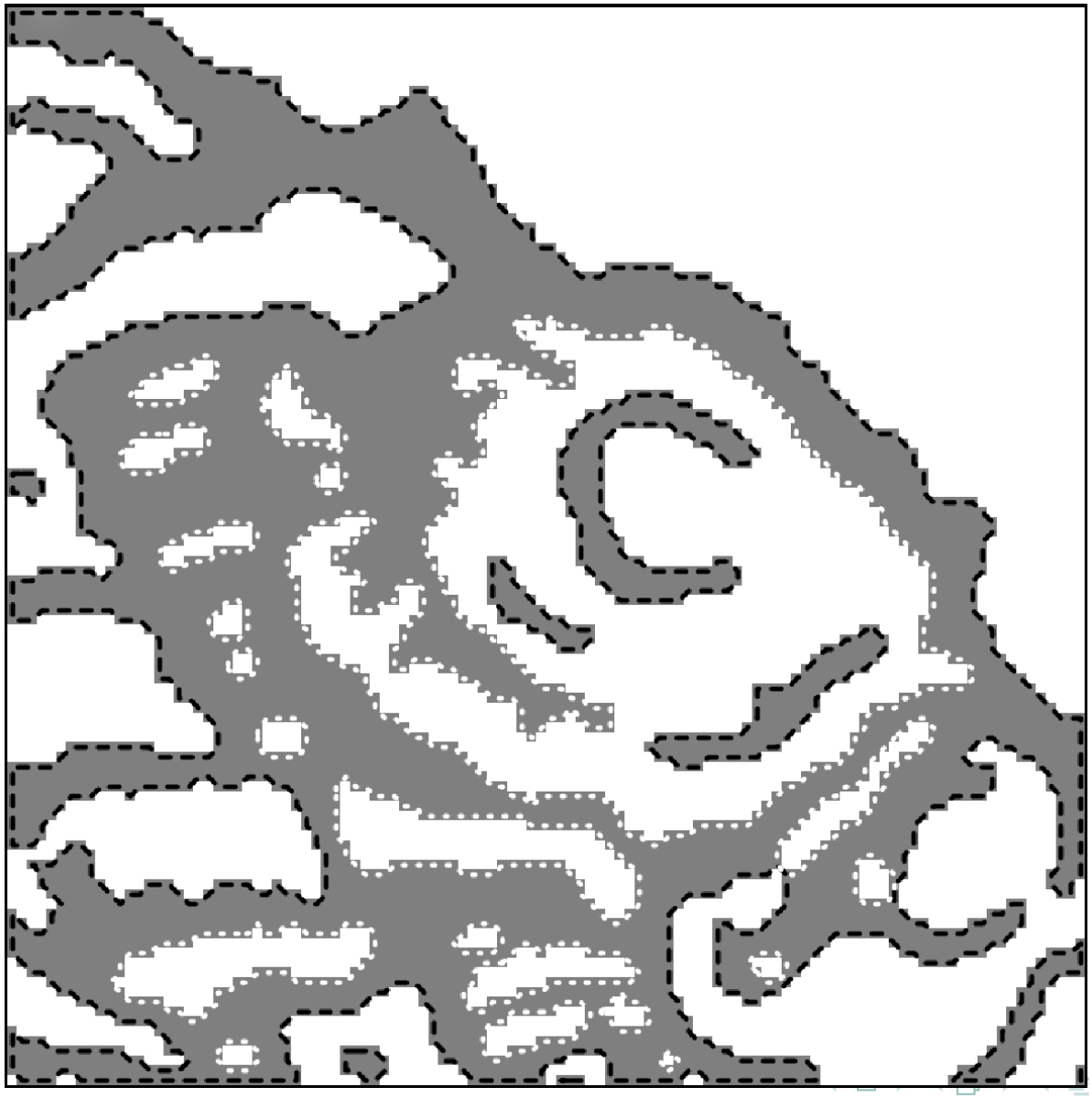


(a)



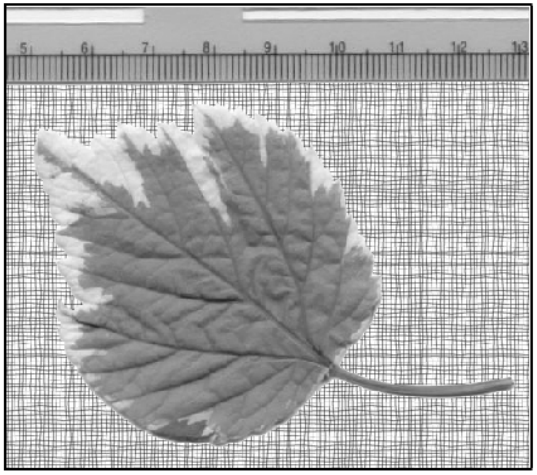
(b)

# Beispiel Konturverfolgung (2)

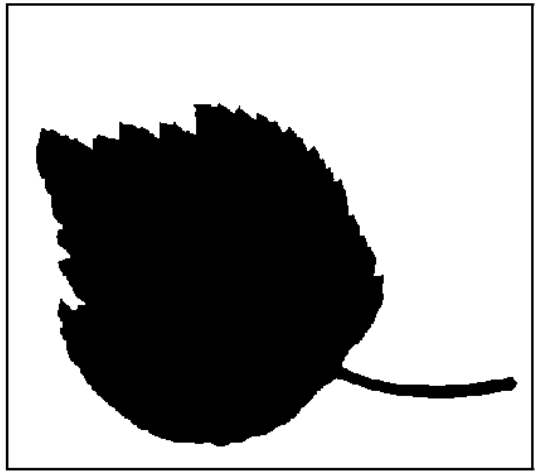


# Übersicht

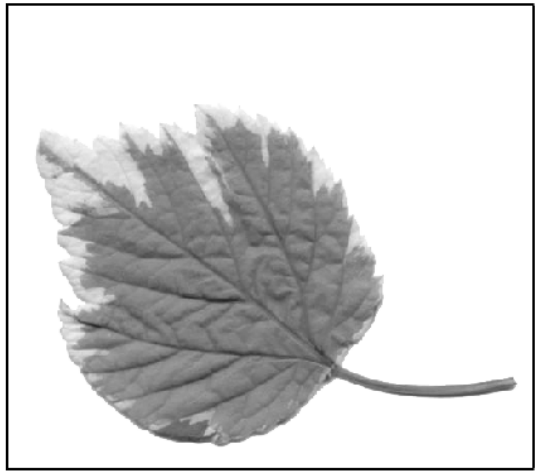
# Matrixrepräsentation und Lauflängencodierung



(a)



(b)



(c)

Bitmap

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 1 | | | × | × | × | × | × | × | |
| 2 | | | | | | | | | |
| 3 | | | | | × | × | × | × | |
| 4 | | × | × | × | | × | × | × | |
| 5 | × | × | × | × | × | × | × | × | × |
| 6 | | | | | | | | | |

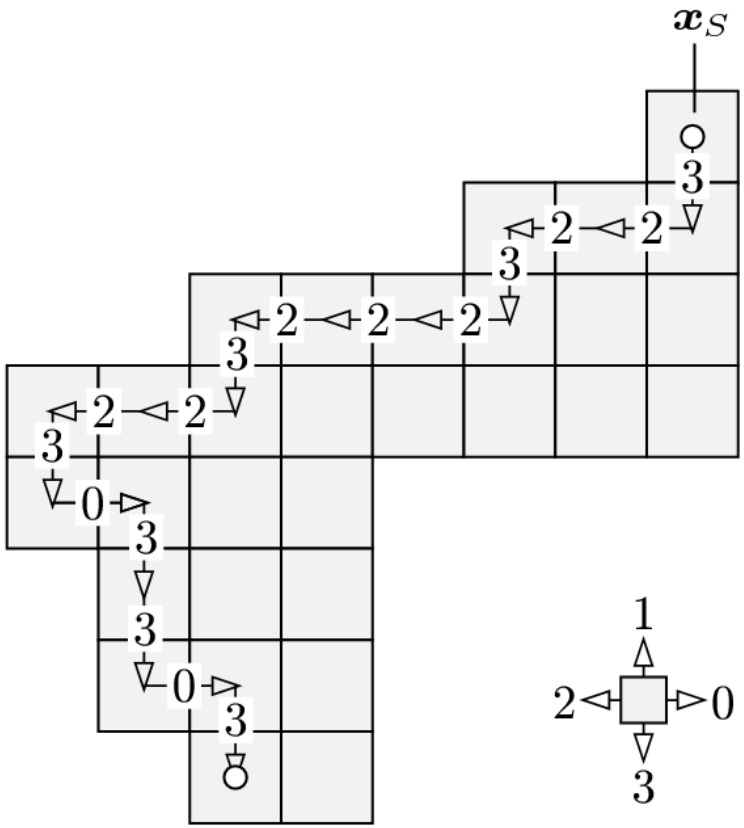
$\longrightarrow$

RLE

$\langle row, column, length \rangle$

$\langle 1, 2, 6 \rangle$
$\langle 3, 4, 4 \rangle$
$\langle 4, 1, 3 \rangle$
$\langle 4, 5, 3 \rangle$
$\langle 5, 0, 9 \rangle$

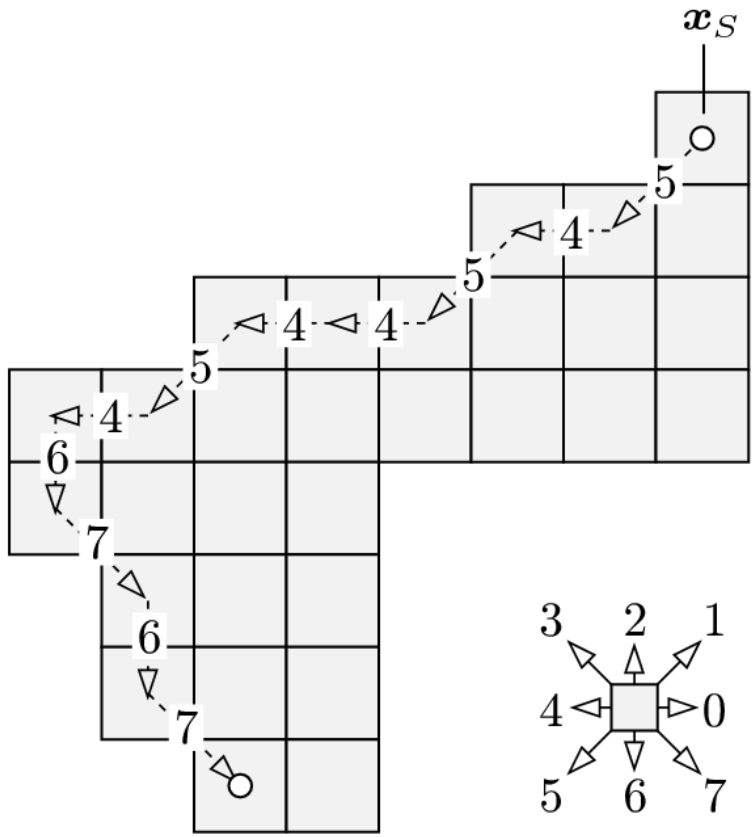
# Chain Codes




**4-Chain Code**

3223222322303303...111

$length = 28$




**8-Chain Code**

54544546767...222

$length = 18 + 5\sqrt{2} \approx 25$

# Differentielle Chain Codes

Problem: Vergleich zweier durch *Chain Codes* dargestellter Regionen ist schwierig, da

- abhängig vom Startpunkt
- Drehung um $90°$ führt zu völlig anderem *Chain Code*.

Umwandlung *absoluter* Chain Code $C = (c_0, c_1, \ldots, c_{M-1})$ in *differentiellen* Chain Code $C' = (c'_0, c'_1, \ldots, c'_{M-1})$:

$$c'_i = \begin{cases} (c_{i+1} - c_i) \bmod 8 & \text{für } 0 \leq i < M-1 \\ (c_0 - c_i) \bmod 8 & \text{für } i = M-1 \end{cases}$$

Voriges Beispiel:

$$C_{\mathcal{R}} = (5, 4, 5, 4, 4, 5, 4, 6, 7, 6, 7, \ldots 2, 2, 2)$$
$$C'_{\mathcal{R}} = (7, 1, 7, 0, 1, 7, 2, 1, 7, 1, 1, \ldots 0, 0, 3)$$

# Shape Numbers

Problem: Differentielle Chain Codes bleiben zwar bei Drehungen um $90°$ unverändert, aber sie hängen immer noch von Startpunkt ab.

Idee: Repräsentation als Zahlen zur Basis 4 oder 8 (Shape Numbers). Zyklisch vertauschen, z.B.

$$C' = (0, 1, 3, 2, \ldots, 9, 3, 7, 4) \quad C' \rightarrow 2 = (7, 4, 0, 1, \ldots, 0, 3)$$

und maximale Ähnlichkeit suchen.Aber:

- Drehungen um beliebige Winkel
- Skalierungen
- Verzerrungen
- Veränderung an Teilen

führen zu starken Abweichungen in dieser Repräsentation.

# Übersicht

# Eigenschaften binärer Bildregionen

Nächstes Mal....