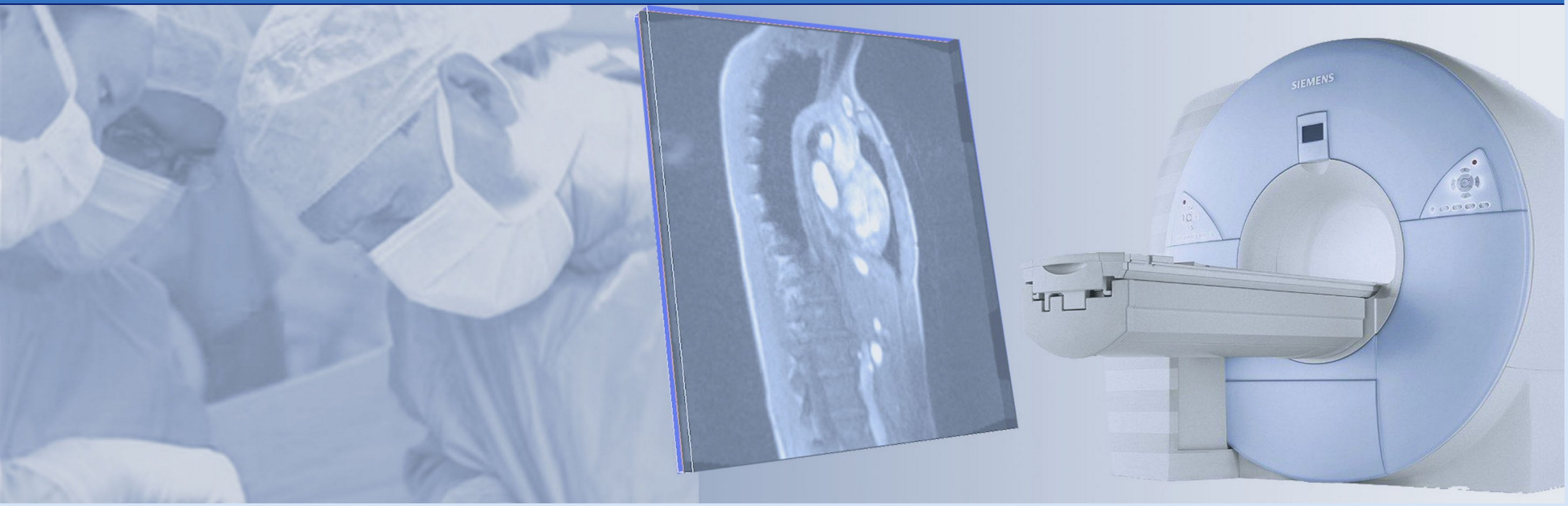
# Tutorial computer- and robot-assisted surgery

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NATIONALES CENTRUM
FÜR TUMORERKRANKUNGEN
PARTNERSTANDORT DRESDEN
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getragen von:
Deutsches Krebsforschungszentrum
Universitätsklinikum Carl Gustav Carus Dresden
Medizinische Fakultät Carl Gustav Carus, TU Dresden
Helmholtz-Zentrum Dresden-Rossendorf

Sebastian Bodenstedt
Translational Surgical Oncology

# Questions from the lecture?

# Reminder: Convolution & Filters

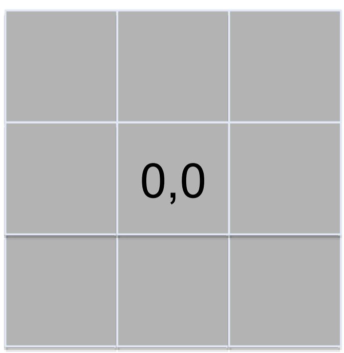
# Local Operation in 2D

- Input: Image matrix g(x,y)
- Filter: Filter matrix h(2r+1, 2r+1)
- Output: Image matrix G'(x,y)
- Image filtering is a convolution with filter matrix/mask:

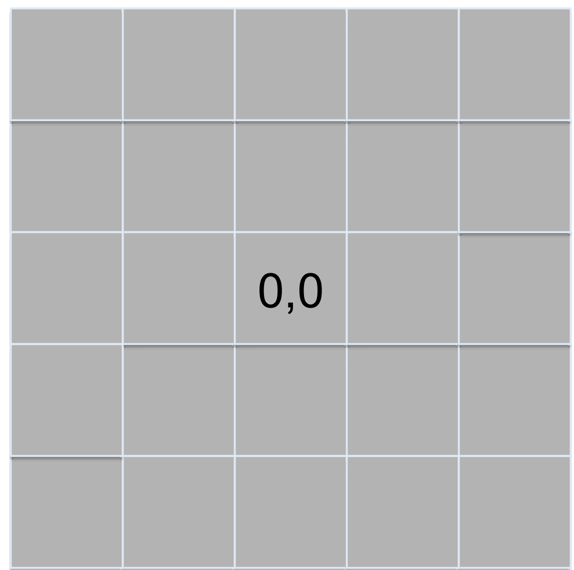
$$g'(x,y) = \sum_{u=-r}^{r} \sum_{v=-r}^{r} h(u,v)\, g(x+u, y+v)$$

# Local Operation in 2D: Masks

- Discretization of the filter function
- Each entry in the mask is assigned a weight h(i,j)
- Center point of the mask has coordinate (0,0)




r = 1




r = 2

# Example

Input

| | | | | |
|---|---|---|---|---|
| 0 | 2 | 2 | 2 | 0 |
| 1 | 10 | 2 | 10 | 1 |
| 2 | 2 | 20 | 2 | 2 |
| 1 | 10 | 5 | 10 | 1 |
| 0 | 2 | 10 | 2 | 1 |

Output

| | | | | |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

$\frac{1}{10}$

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

# Example

Input

| | | | | |
|---|---|---|---|---|
| 0 | 2 | 2 | 2 | 0 |
| 1 | 10 | 2 | 10 | 1 |
| 2 | 2 | 20 | 2 | 2 |
| 1 | 10 | 5 | 10 | 1 |
| 0 | 2 | 10 | 2 | 1 |

Output

| | | | | |
|---|---|---|---|---|
| ? | ? | ? | ? | ? |
| ? | **5.1** | **5.4** | **5.1** | ? |
| ? | **5.5** | **9.1** | **5.5** | ? |
| ? | **6.2** | **6.8** | **6.3** | ? |
| ? | ? | ? | ? | ? |

$\frac{1}{10}$

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

# Box filter

- Averages out extreme points
- Smoothing effect proportional to mask size
- Fast computation
- Can cause „smearing“
  => Edges are flattend

$$\frac{1}{9}\begin{bmatrix}1 & 1 & 1\\ 1 & 1 & 1\\ 1 & 1 & 1\end{bmatrix}$$

| | | | | |
|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 0 |
| 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 3 | 255 | 1 |
| 1 | 2 | 1 | 1 | 1 |
| 0 | 2 | 3 | 1 | 1 |

What will happen?

# Edge detector - Prewitt Filter

- Differences of pixel values are averaged with the same weight
- Prewitt-X filter enhances vertical, Prewitt-Y filter horizontal edges

$$P_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

$$P_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

# Sobel filter

- Gaussian-based weighting the difference of the pixel values to enhance edges
- Sobel-X filter enhances vertical, Sobel-Y Filter horizontal edges

$$S_x = \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix} * \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

$$S_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

# Laplace filter

- Edges are zero-crossings in the 2nd derivative
- Laplace-Operator:

$$\nabla^2 G(x, y) = \frac{\partial^2 G(x, y)}{\partial^2 x} + \frac{\partial^2 G(x, y)}{\partial^2 y}$$

$$LP = \begin{matrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{matrix}$$

- Orientation-independent edges enhancement
- Sensitive to noise (Pseudo-edges)

# Overview Filters

$$\text{Box} = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$S_x = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

$$S_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

$$P_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

$$\text{LP} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

$$P_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

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# Median filter

| | | |
|---|---|---|
| 2 | 4 | 3 |
| 5 | 9 | 2 |
| 7 | 2 | 4 |

2,4,3,5,9,2,7,2,4

2,2,2,3,4,4,5,7,9

9 replaced with 4

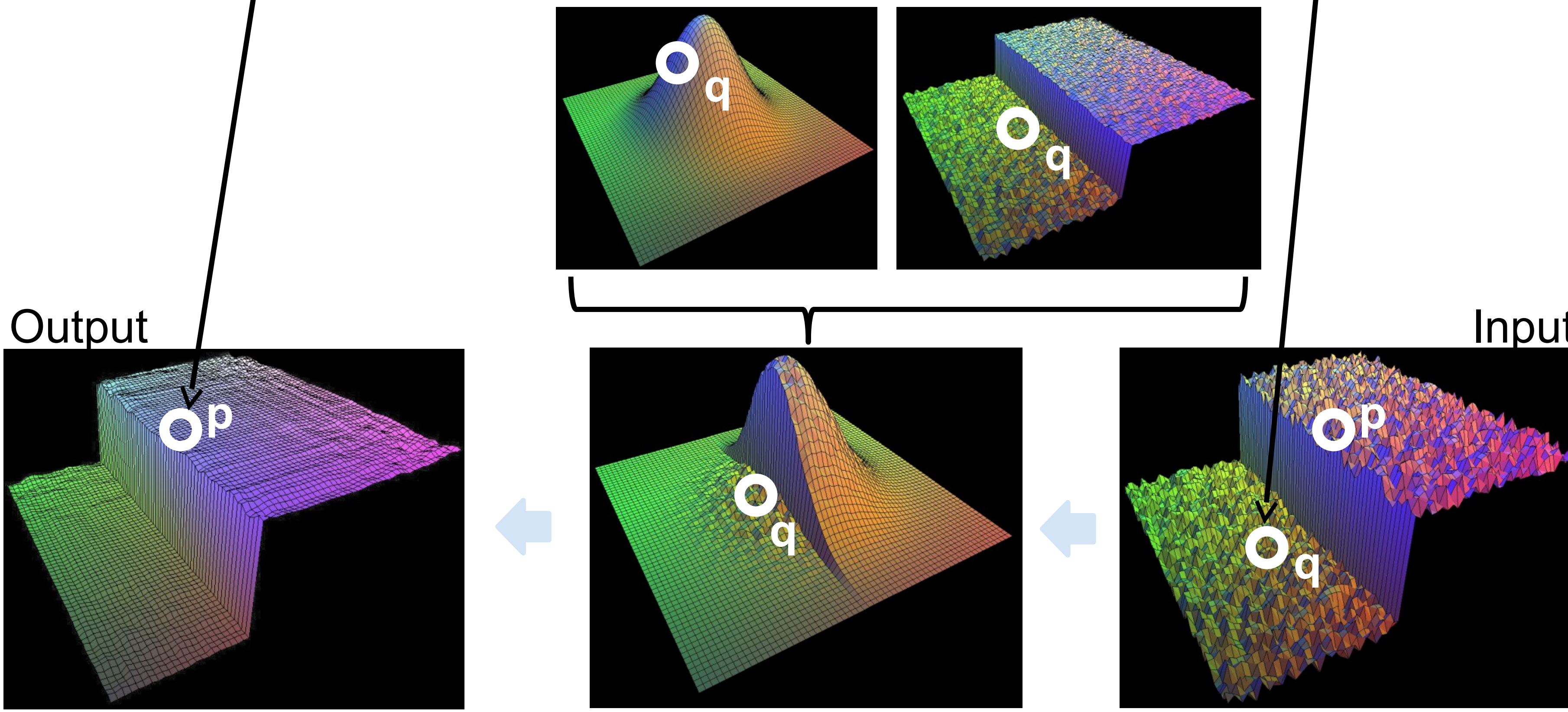
- Center pixel is assigned the median of the grayscale values of the local neighborhood
- Robust against outliers
- Sharpness barely suffers
  Edges are mostly conserved
- Smoothing effect is less

New:

| | | |
|---|---|---|
| 2 | 4 | 3 |
| 5 | 4 | 2 |
| 7 | 2 | 4 |

# Bilateral filter

$$\underbrace{I_{new}(p)} = \frac{1}{W_p}\sum_{q\in N} \underbrace{G_{\sigma_s}(\|p-q\|)}\;\underbrace{G_{\sigma_r}(|I_p - I_q|)}\;\underbrace{I_q}$$

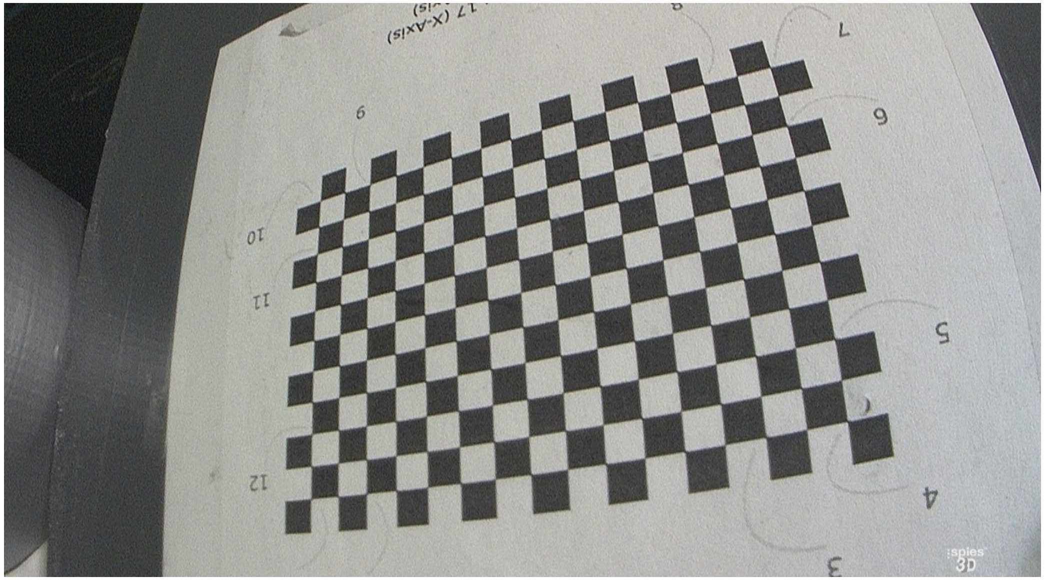



Source: Durand et al.: „Fast bilateral filtering for the display of high-dynamic-range images”

# Introduction: Camera-calibration and 3D-Reconstruction in OpenCV

# Calibration after Zhang

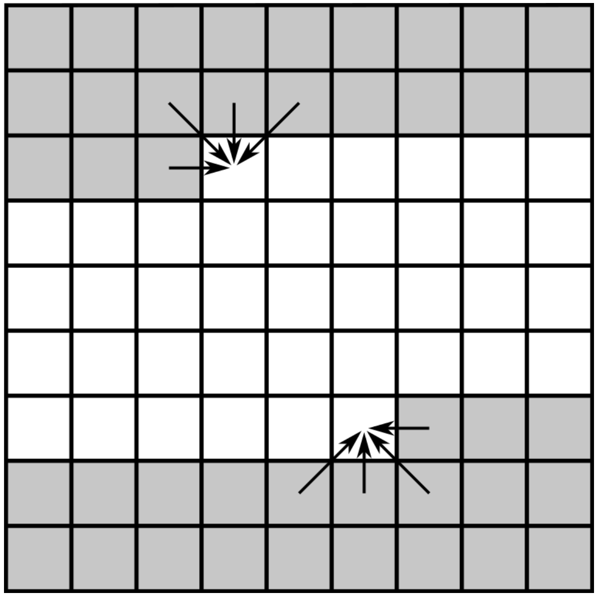
- Calibration with chessboard pattern with known geometry
  - Multiple snapshots from different angles required
  - Each snapshot provides a homography
    - Transformation between 2 planes, accounting for perspective distortion
  - Multiple homographies → System of equations for calculating camera parameters

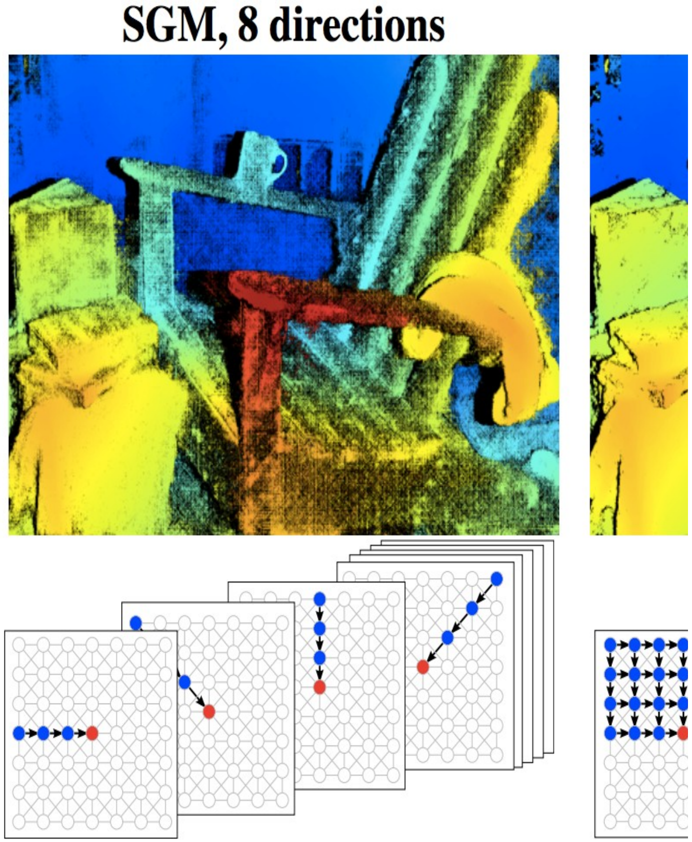


Zhang, Zhengyou. "A flexible new technique for camera calibration."
IEEE Transactions on pattern analysis and machine intelligence 22.11 (2000): 1330-1334.

# Semi-global block matching

- Method for stereo matching/correspondence analysis
- Search for correspondences within a block

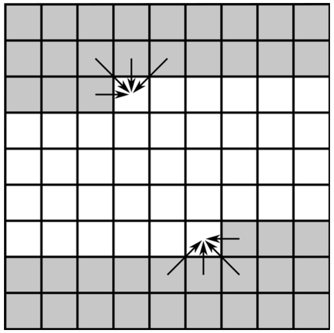






Hirschmuller, H., 2007. Stereo processing by semiglobal matching and mutual information. IEEE Transactions on pattern analysis and machine intelligence, 30(2), pp.328-341

# Semi-global block matching



- Compute for each pixel *p* and disparity value *d* cost function *S(p, d)*:

$$S(p,d) = \sum_r L_r(p,d)$$

- $L_r(p,d)$: Cost of reaching pixel *p* with disparity value *d* from direction *r*:

$$L_r(p,d) = D(p,d) + \min\left\{L_r(p-r,d), L_r(p-r,d-1)+P_1, L_r(p-r,d+1)+P_1, \min_i L_r(p-r,i)+P_2\right\} - \min_k L_r(p-r,k)$$

- Important: Distance term *D(p, d)* and smoothness regularization term $R(d_p, d_q)$:
  - Distance term can be cross-correlation, hamming distance, mutual information, …
  - Regularization term assures that neighboring pixels have similar disparities

$$R(d_p,d_q) = \begin{cases} 0 & d_p = d_q \\ P_1 & |d_p - d_q| = 1 \\ P_2 & |d_p - d_q| > 1 \end{cases}$$

Hirschmuller, H., 2007. Stereo processing by semiglobal matching and mutual information. IEEE Transactions on pattern analysis and machine intelligence, 30(2), pp.328-341

# Any questions?