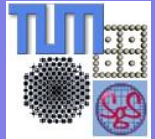
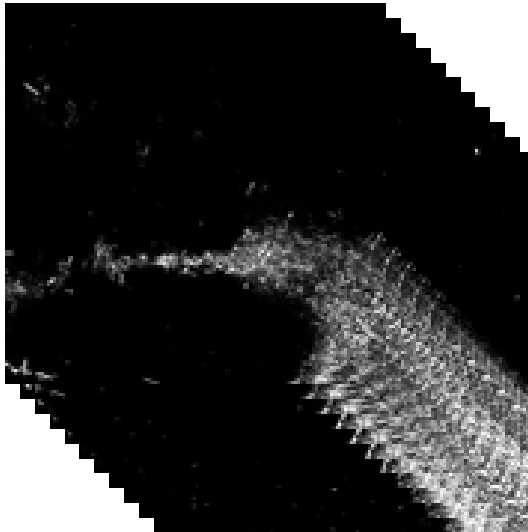


1. Interpreting the Results: Visualization 1

- visual/graphical/optical representation of large sets of data:
- data from experiments or measurements: satellite images, tomography in medicine, microscopy,...



Interpreting the ...

Interpreting the ...

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Methods of Image ...

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Methods of Image ...

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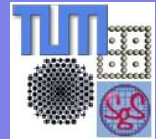
Visualizing Simulation ...

Visualizing Simulation ...

Component Hierarchy ...

Animation

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- data from simulations:
 - with resolution of space (and time): fluid mechanics, structural mechanics, quantum physics,...
 - without spatial resolution: vehicle dynamics, optimal control,...

0	1.141593e-02	0.000000e+00	1.985922e+00	8.541845e-01
0	1.141593e-02	0.000000e+00	2.084930e+00	8.575218e-01
1	0.000000e+00	0.000000e+00	1.000000e+00	8.593123e-01
0	0.000000e+00	0.000000e+00	1.878251e+00	8.619047e-01
0	1.734730e-02	0.000000e+00	1.965122e+00	8.634277e-01
0	2.241145e-02	0.000000e+00	1.989369e+00	8.644168e-01
0	1.473289e-02	0.000000e+00	2.046312e+00	8.652736e-01
1	0.000000e+00	0.000000e+00	1.000000e+00	8.657679e-01
0	0.000000e+00	0.000000e+00	1.820761e+00	8.674645e-01
0	1.716014e-02	0.000000e+00	1.893302e+00	8.681865e-01
0	2.220719e-02	0.000000e+00	1.924957e+00	8.682992e-01
0	1.508390e-02	0.000000e+00	1.980685e+00	8.677363e-01
1	0.000000e+00	0.000000e+00	1.000000e+00	8.659386e-01
1	0.000000e+00	0.000000e+00	1.000000e+00	8.650681e-01
0	0.000000e+00	0.000000e+00	1.844165e+00	8.652823e-01
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0	1.258916e-02	0.000000e+00	1.767734e+00	8.631065e-01

...

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Methods of Image ...

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Visualizing Simulation ...

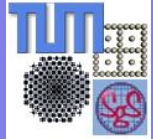
Component Hierarchy ...

Animation

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2. Interpreting the Results: Visualization 2

- Visualization is often the only chance to tackle a fast interpretation.
- Methods stem from
 - image processing,
 - computer graphics,
 - virtual and augmented reality,
 - ...



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Methods of Image ...

Methods of Image ...

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Visualizing Simulation ...

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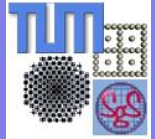
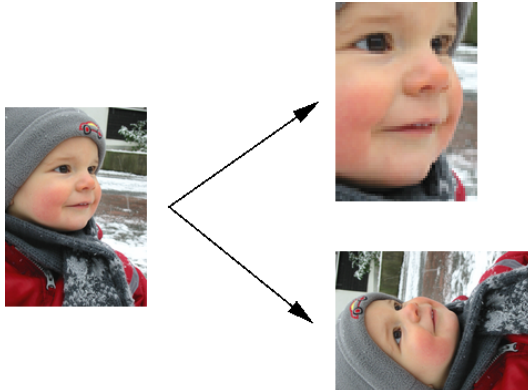
Component Hierarchy ...

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3. Methods of Image Processing 1

- image: array of 2D/3D discrete greyscale/colour data
- **geometric processing:**
 - changes of shapes
 - depend on pixels' position, not on their values
 - examples: zooming, rotation,...



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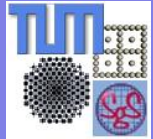
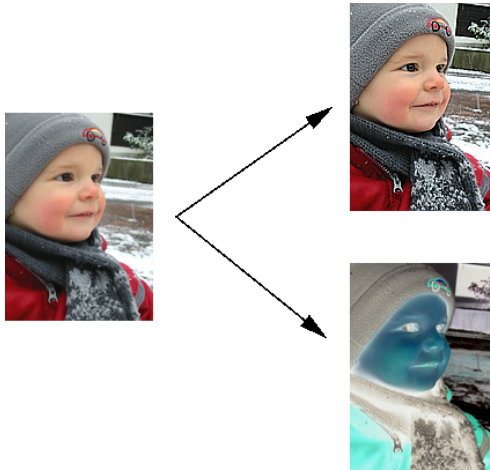
Visualizing Simulation ...

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Animation

4. Methods of Image Processing 2

- image: array of 2D/3D discrete greyscale/colour data
- **point-to-point processing:**
 - local changes of pixel values
 - depend on current values, but neither on geometry nor on neighbours' values
 - examples: addition of constants, contrast stretching, false colours, exponential transformations



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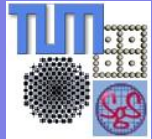
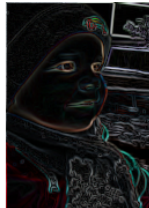
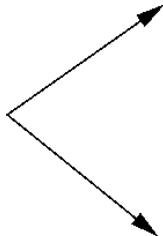
Visualizing Simulation ...

Component Hierarchy ...

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5. Methods of Image Processing 3

- image: array of 2D/3D discrete greyscale/colour data
- **local-to-point processing:**
 - local changes of pixels' values due to environment
 - examples: local weighted averaging (convolution, smoothing), local rank operators (median, sorting), segmentation (thresholds, filtering), edge detection, feature extraction, . . .



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Visualizing Simulation . . .

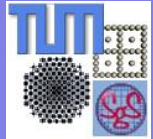
Component Hierarchy . . .

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6. Methods of Image Processing 4

- image: array of 2D/3D discrete greyscale/colour data
- **ensemble processing:**
 - comparison of different images of the same scene
 - examples: detection of motion (military), difference images (medicine, monitoring agricultural activities or vegetation)
- **domain processing:**
 - complicated modifications of pixel values due to both local and global information
 - examples: Fourier or cosine transform (JPEG), wavelet transform, tomography (CT, NMR,...)



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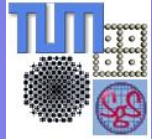
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7. Aspects of Computer Graphics 1

- visualization is based on methods from graphics:
 - crash simulation: representation of cars and the whole scene, perspective view, . . .
 - illumination for increasing realism
 - visualizing weather forecast (virtual flights): clouds, fog, . . .
 - virtual reality and augmented reality techniques



(movie)



Interpreting the . . .

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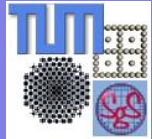
Component Hierarchy . . .

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8. Aspects of Computer Graphics 2

- geometric modelling:
 - representing 3D objects
- graphical representation / rendering:
 - perspective
 - illumination
 - shading
- stereoscopy (cf. VR)



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9. Simulation Data Resolved in Time & Space

- given: result (data set) of some numerical simulation

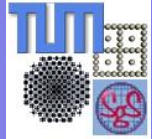
$$f : \mathbb{R}^d \supset \Omega \rightarrow \mathbb{R}^m, m \in \mathbb{N}$$

f: scalar or vector valued

- examples:

- $\vec{u}(x, y, (z))$ two-/three-dimensional velocities,
- $p(x, y, (z))$ pressure,
- $c(x, y, (z))$ solute concentration in a fluid,

- visualization clear for 2D,
but 3D?



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10. Visualizing Simulation Data 1

- different techniques for the visualization of 3D data:

- lower-dimensional subdomains:

- * **(ortho-) slices:**

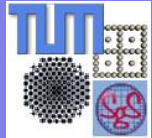
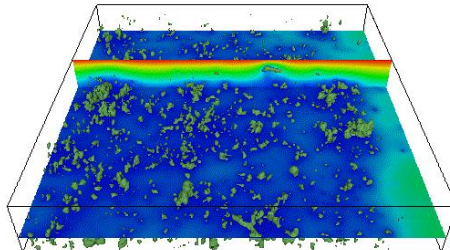
- the respective quantity is considered on some plane only (aligned with coordinate directions or not)

- * **isosurfaces:**

- surface on which the scalar f or one component of its components takes some prescribed value t :

$$I(c) = \{(x, y, z) \in \Omega : f(x, y, z) = c\}$$

- interactive creation or modification (change of c , change in time) require efficient algorithms (marching cubes, e.g.)



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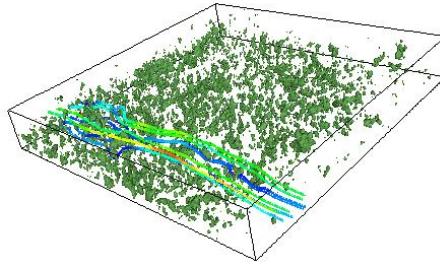
Animation

11. Visualizing Simulation Data 2

- visualization of 3D data (continued):
 - lower-dimensional subdomains (continued):

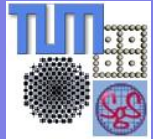
- * **streamlines:**

- for the visualization of vector fields ($m > 1$);
- curves with tangent always parallel to local vectors of the given vector field (velocities in CFD, e.g.)



- * **particle tracing:**

- for the visualization of time-dependent vector fields;
- introduce a virtual particle somewhere and follow its path through the domain according to the vector field



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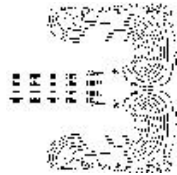
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12. Visualizing Simulation Data 3

- visualization of 3D data (continued):
 - lower-dimensional subdomains (continued):

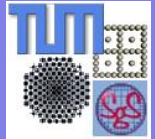
- * **streaklines:**

- for time-dependent vector fields, too;
- introduce a sequence of virtual particles somewhere and catch their positions at some point of time



(movie)

- * In the stationary case, all three methods lead to the same lines!
- * furthermore: **streakbands**, **streaktubes** (allow to visualize additional quantities as well as rotation, e.g.)
- * widespread: combinations of the above methods



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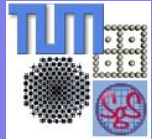
Component Hierarchy ...

Animation

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13. Visualizing Simulation Data 4

- visualization of 3D data (continued):
 - colours: use hue or intensity for expressing a scalar quantity
 - * use intuition: red/blue for temperature
 - * also possible: different colours for different quantities (temperature and concentration, e.g.; limit: about 5)
 - * Take care of scale!
 - use of graphical primitives:
 - * arrows, balls,...
 - * parameters: colour, size, distance (for speed)
 - use of textures:
 - * for indicating material or other characteristics (type of soil)
 - use of legends and annotations:
 - * very important: which scenario, which quantities, which scale
 - * images without legends may be pretty, but not useful



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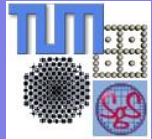
Component Hierarchy ...

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14. Component Hierarchy of AVS/Express

- examples of commercial visualization tools:
 - AVS/Express
 - Explorer
- internal representation of data (hopefully able to profit from data structures used for the computations):
- example AVS:
 - component hierarchy (tree structure)
 - **field**: highest component, whole information
 - **mesh**: geometric description
 - * **grid**: position of grid points
 - * **cells**: neighbourhood relations, connectivity (edges, faces, elements, . . .)
 - **data**: data of the grid (values of f), node data and cell data



Interpreting the . . .

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Aspects of Computer . . .

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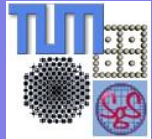
Component Hierarchy . . .

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15. Animation

- tremendous increase in data:
 - one image: some 4 MB, e.g. (1024×1280, 4 B per point)
 - video: some 25–30 images per second!
 - compression necessary (mpg,...)
- pay attention:
 - smooth transitions (w.r.t. movement, colour,...)
 - choice of scale:
 - * stationary state: too restricted colour-scale at the beginning may suggest convergence even if there are still (small) oscillations
 - * increasing differences: now, whole-spectrum colour-state at the beginning may prevent the actual values from being represented
 - if interpolation / inbetweening / frame techniques necessary: don't neglect (or even hide) disturbing details!



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