Perspectives in Computer Graphics – From Acquisition to Rendering

Hans-Peter Seidel

Max-Planck-Institut für Informatik

Computergraphik in Saarbrücken

- Computergraphik in Saarbrücken seit 1999
- Einer der führenden Standorte weltweit
  - ACM Symposium SM'02, EUROGRAPHICS'02
- 11 Berufungen auf Professuren in 3 Jahren
  - P. Bekaert (Limburg, Belgium), T. Ertl (Stuttgart), S. Ghali (Edmonton, Canada), G. Greiner (Erlangen), W. Heidrich (Vancouver, Canada), L. Kobbelt (Aachen), A. Kolb (FH Wedel), Ph. Slusallek (Saarbrücken), C. Soler (INRIA, France), M. Stamminger (Erlangen), R. Westermann (Aachen/München)
- Studenten möglichst frühzeitig in die Forschung integriert

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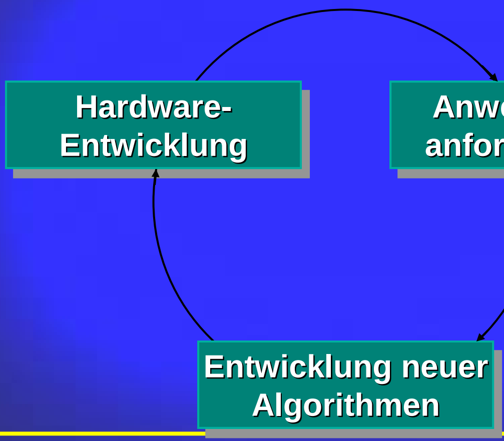
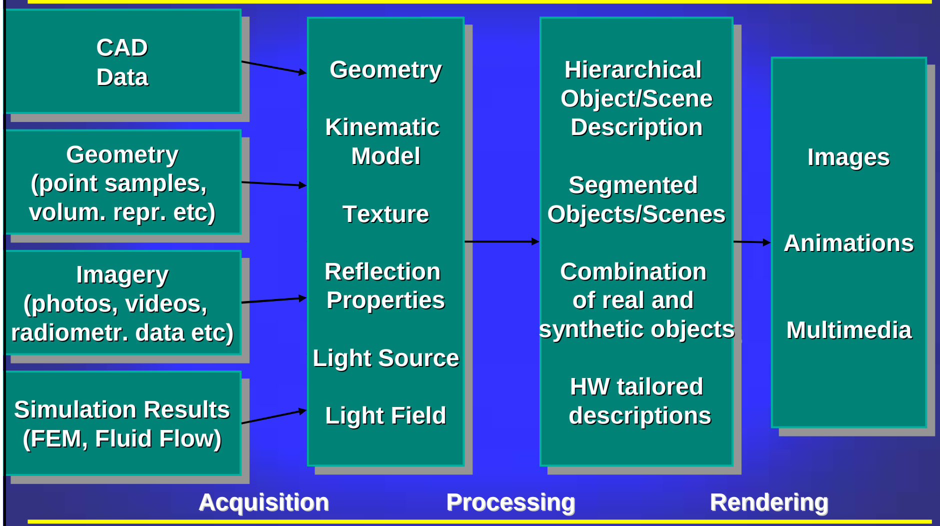
Perspektiven der Informatik



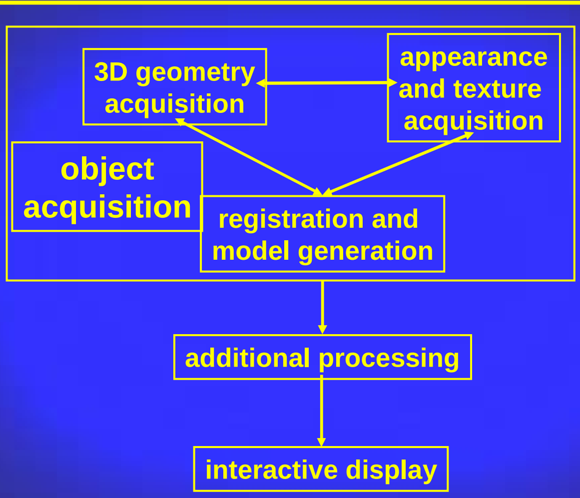
Perspektiven der Computergraphik

- 3D-Bildanalyse und -synthese
  - Zusammenwachsen von Computer Vision und Computergraphik
- Effiziente Handhabung großer 3D-Datensätze
  - 3D-Rekonstruktion / Komplexität / Interaktion
- 3D-Graphik im Internet
  - Akquisition / Codierung / Suche / Interaktion
- Menschmodelle in virtuellen Umgebungen
  - Rekonstruktion u. Modellierung / Simulation u. Animation / Darstellung / Editieren

Perspektiven der Computergraphik



The 3D Acquisition Pipeline



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Acquisition and Rendering

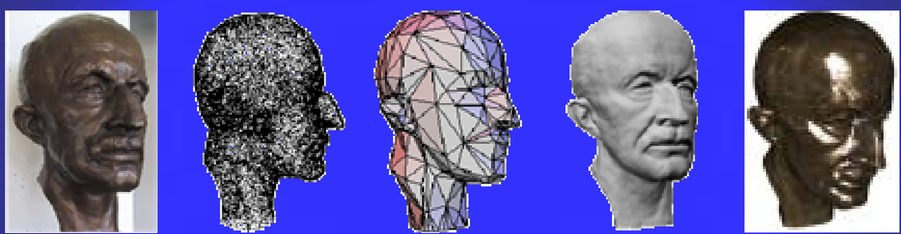
Objects in the real world are high quality!

- Three-Dimensional
- High Resolution
- Perfectly Colored and Textured
- Interaction

Why should a computer user be satisfied with less?

- E-Commerce
- Virtual Museum
- Shared Virtual Environments

The 3D Acquisition Pipeline



Overview

- Introduction
- Geometry Acquisition
- Geometry Processing
- Textured 3D Objects
- Image-Based BRDF Measurement
- Interactive and Predictive Rendering

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Problem Statement

- Point clouds (contact probes)
- Volumetric data (MRT, CT)
- Range images (3D range scanners)
- CAD model (design process)

"Given some measured input data convert it into a single triangle mesh."

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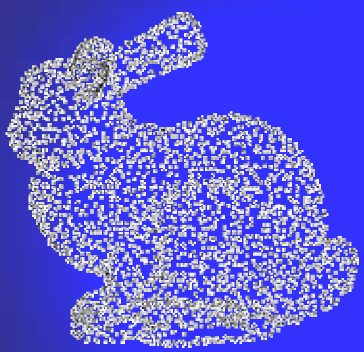
Sources for 3D-Models

Surface generation by point cloud triangulation



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Volume scanning

Build voxel structure by scanning slices

CT

MRT

Tomograph

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Iso-Surface Extraction

Given: Distance field $f : R^{2,3} \rightarrow R$

Wanted: Iso-surface

Marching Cubes Algorithm:

(Lorensen & Cline, SIGGRAPH '87)

1. Build a regular grid.
2. Calculate scalar values at grid points.
3. Generate a linear approximation to the iso-surface for each grid cell.

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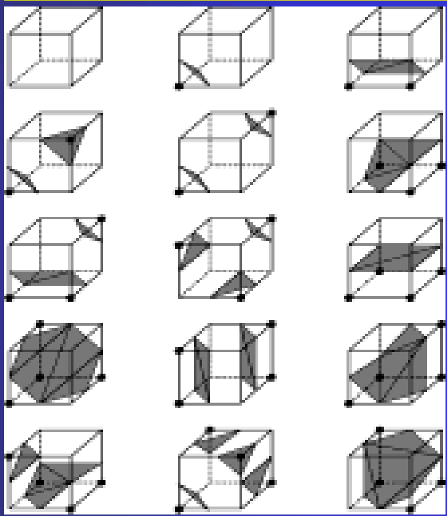
Marching Cubes (3D)



Marching Cubes
templates
in 3D

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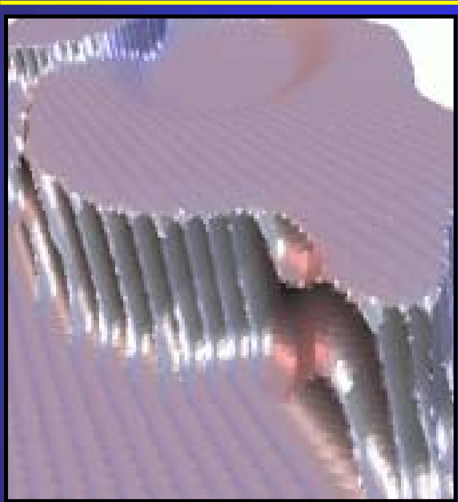
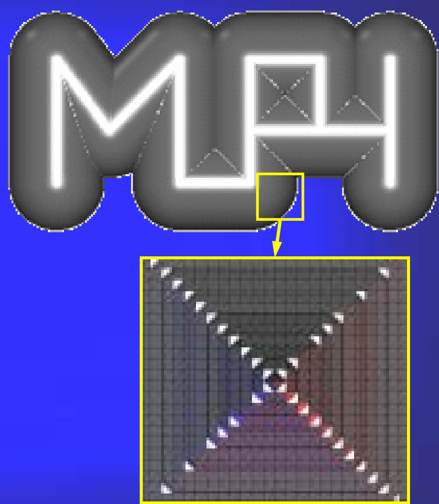
Alias Effects





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MC Improvements [Siggraph'2001]

Feature sensitive surface extraction

- Directed distance field representation
  - Directed distances in x,y,z direction
- Extended Marching Cubes Algorithm
  - Detecting grid cells through wich a sharp feature (edge or corner) of the considered surface passes
  - Computation and insertion of additional sample points lying on the features

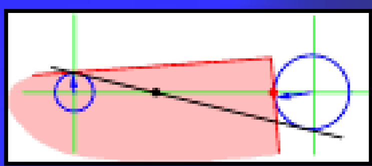
Directed Distance Fields

Problems with standard distance fields

- Samples not necessarily close to S in the vicinity of sharp features, directional information not captured

Directional distance fields

- Store at each grid point three directional distances in x-,y-,z-directions
- This enables computation of exact intersections points
- Standard MC applies



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Directed Distance Fields

Directed distances improve the surface quality significantly in the vicinity of sharp features

Original	Scalar distance values	Three directed distances

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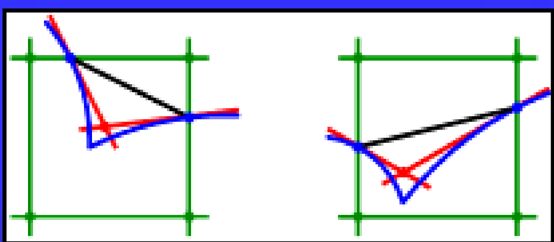
Extended Marching Cubes

Extrapolate the behavior of the surface near the feature using point and normal information



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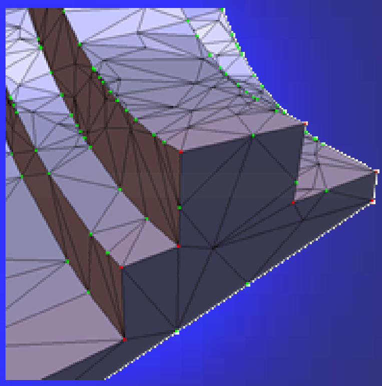
Extended Marching Cubes

Different types ot features

- Feature edges
  (two smooth surface
  regions meet along a
  sharp feature line)

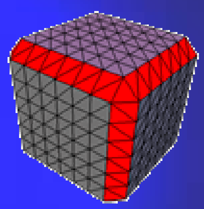
- Corners
  (more than two feature
  edges intersect)

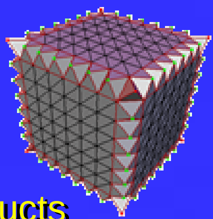


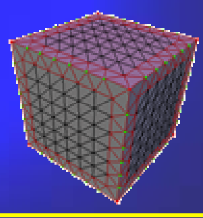
Extended Marching Cubes

Feature sensitive sampling of EMC

1. Identify cells containing a feature
   and decide on type of feature
2. Include one new
   sample per cell
   plus triangle fan
3. Edge flipping reconstructs
   the feature

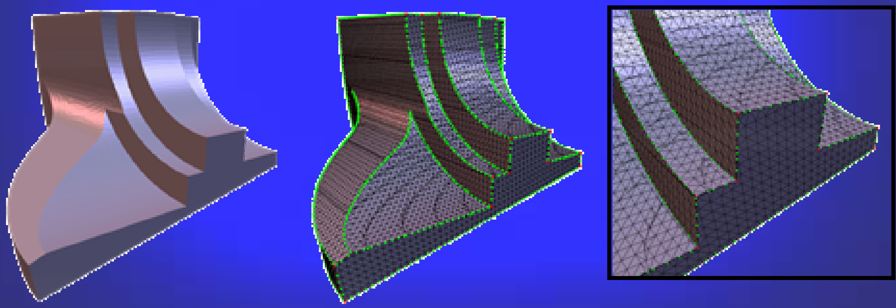






Example

- Feature points of the „fandisk“



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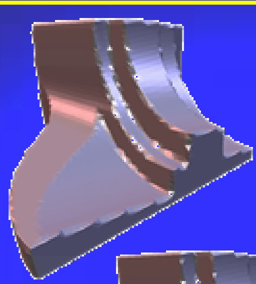
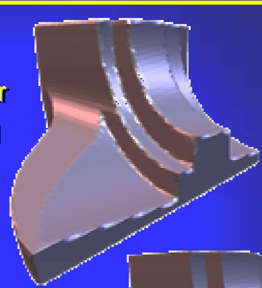
EMC & Directed Distance field

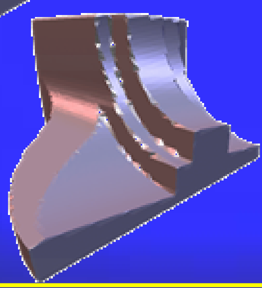
Standard MC



EMC & scalar distance field



Standard MC & enhanced distance field



EMC & enhanced distance field

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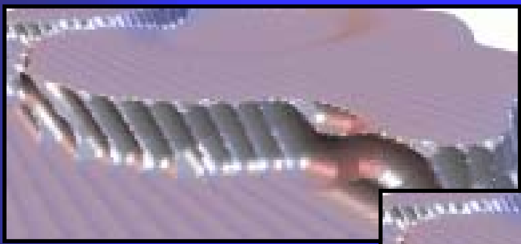
EMC & Directed Distance Field

NC machining simulation

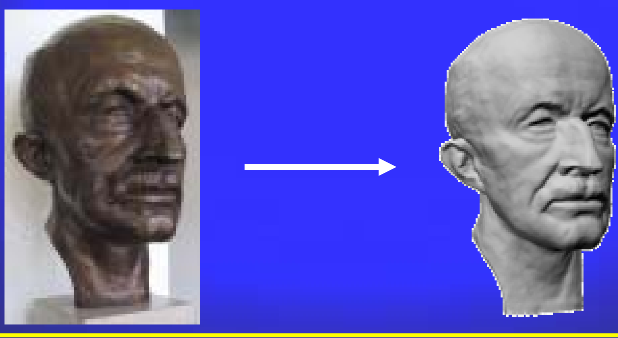


Standard MC
(1.1M triangles)

EMC
(1.2M triangles)

Range scanning

- Generate range from stereo information
  - Scales from desktop to whole body scanners



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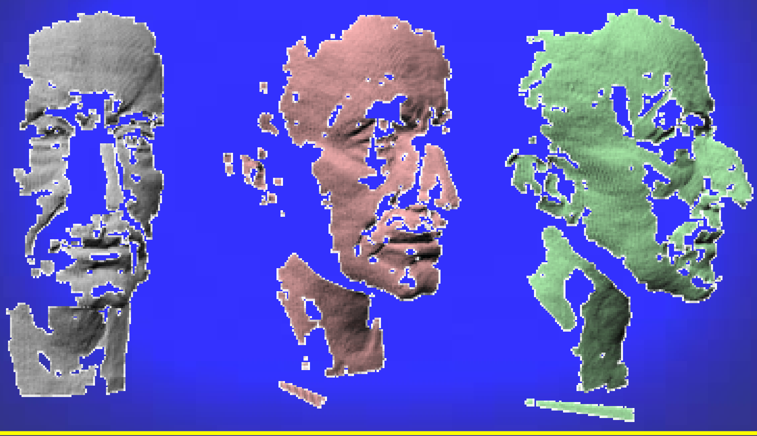
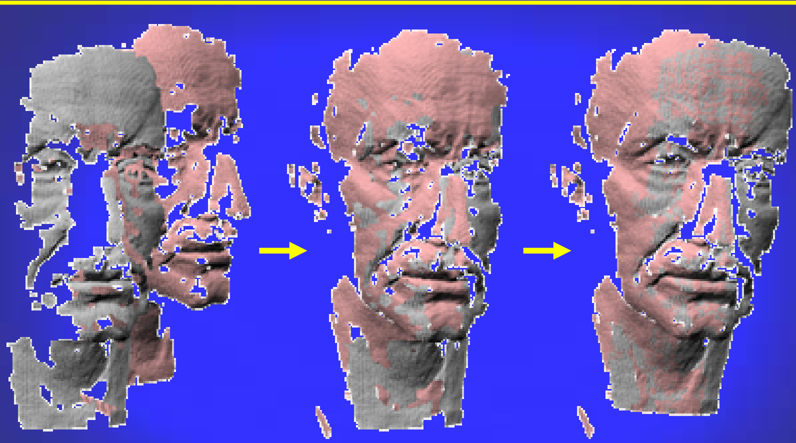
Registration

Scanner acquires separate range images:



Pair-wise ICP



Rough manual alignment

run ICP

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Incremental Mesh Decimation

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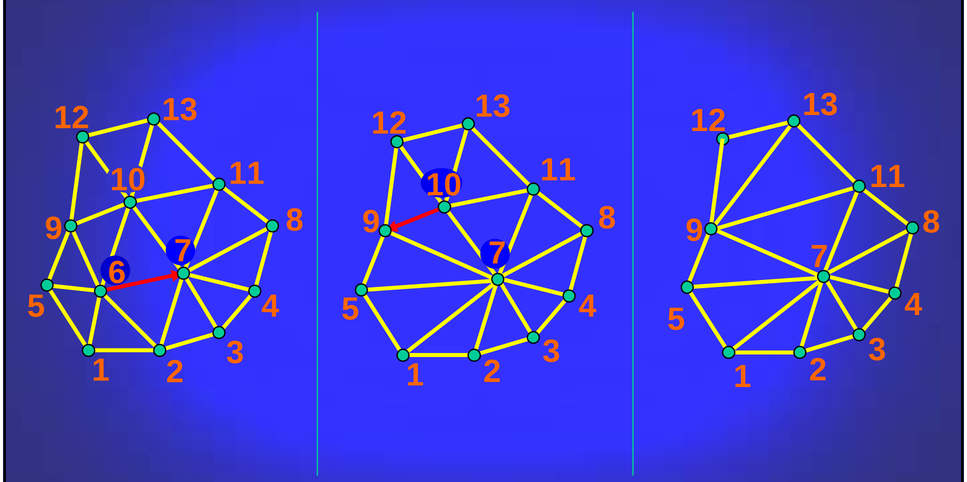
Incremental Mesh Decimation

- Incremental decimation algorithms
- Priority queue driven
  - Local simplification operation (e.g. edge collapse)
  - Global error control (e.g Hausdorff distance)
  - Quality metrics (e.g. well shaped triangles)
- Fine-to-coarse hierarchy

Half Edge Collapse



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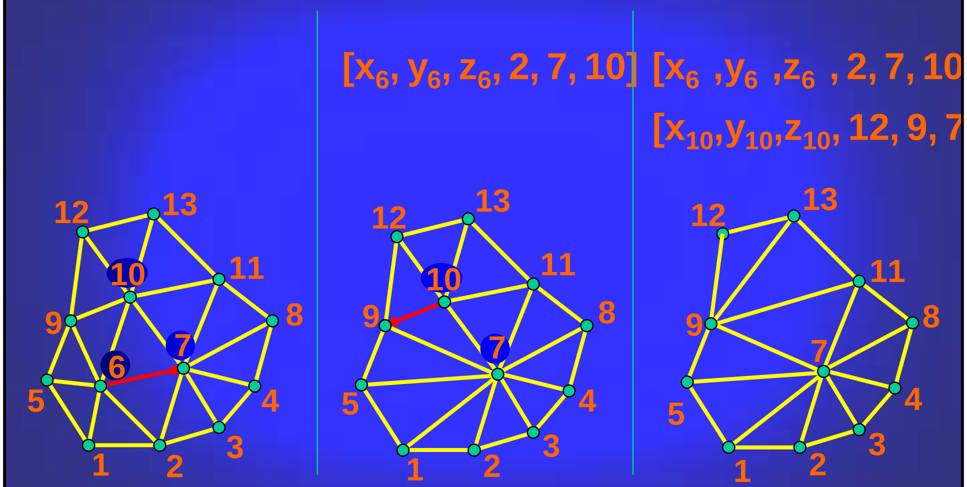
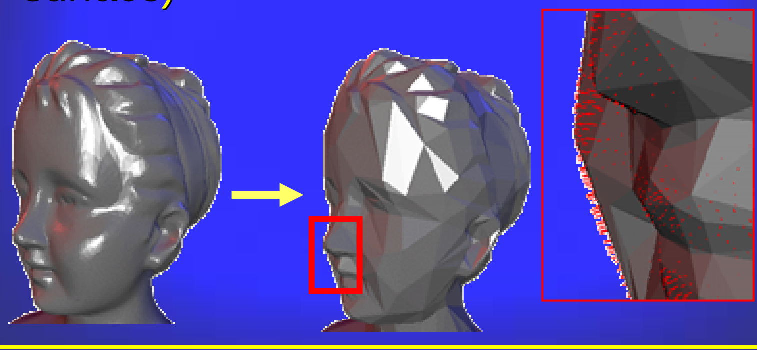
Progressive Transmission



Global Error Control

- Scan data: *One-sided* Hausdorff distance often sufficient (original-vertices-to-current-surface)



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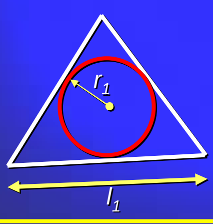
Quality metrics

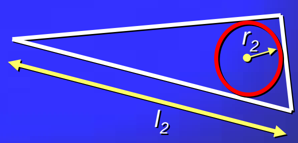
- Surface quality vs. surface error
- Error metrics provide bounds
- Quality metrics guide the process
- Binary vs. scalar (often combined)
  - Geometry: Well shaped triangles, normals
  - Topology: No valence excess
  - Attributes: Minimize texture distortion

Quality: Geometry

- Limits on surface curvature
- Avoid badly shaped triangles
  - E.g. in-circle radius over max. edge length



$$\frac{r_1}{l_1} > \frac{r_2}{l_2}$$



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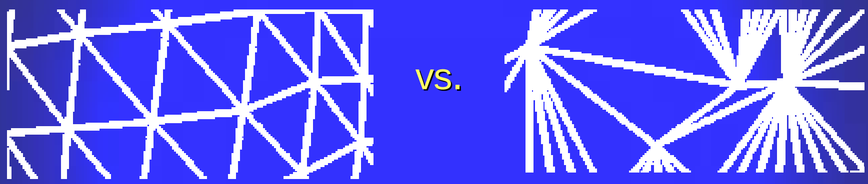
Quality: Topology

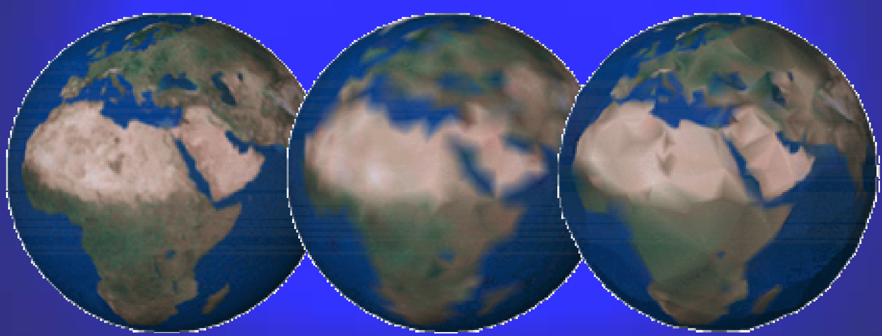
- Try to keep mesh structure regular:



- Topology-changing algorithms:
  - Try to minimize number of components

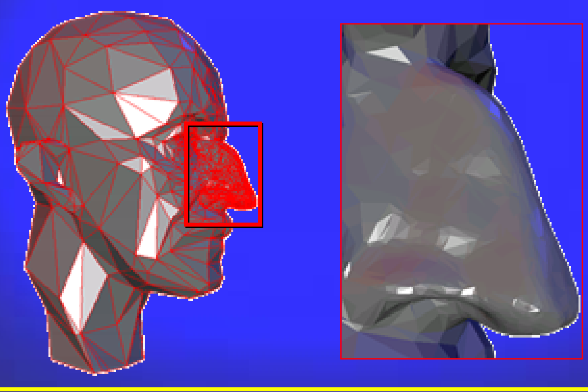
Attribute preservation

- Extend metric to scalar attributes
  - Texture distortion, color/normal discontinuities



Adaptive Refinement

- Adaptive refinement often desirable



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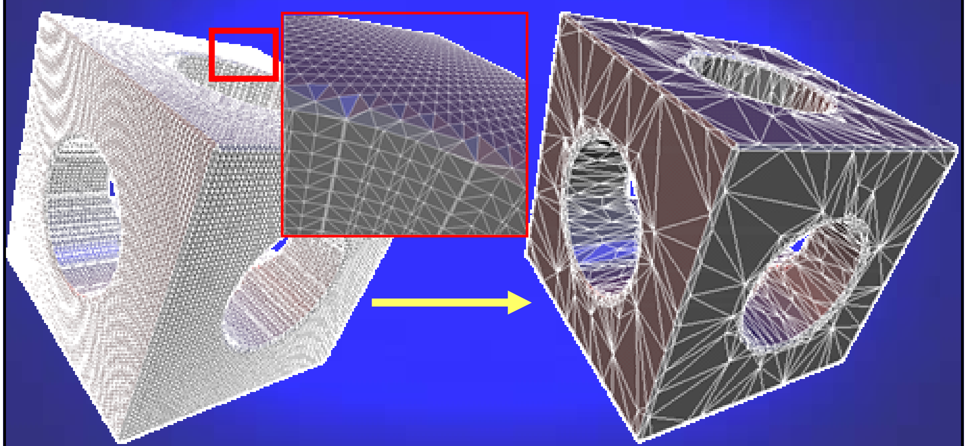
Example

Overtessellation: E.g. iso-surface extraction



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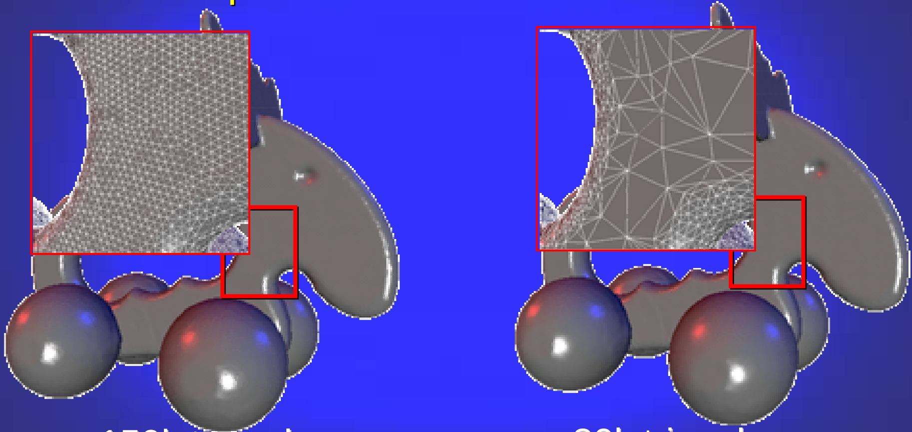
Example

Oversampled scan data



~150k triangles ~80k triangles

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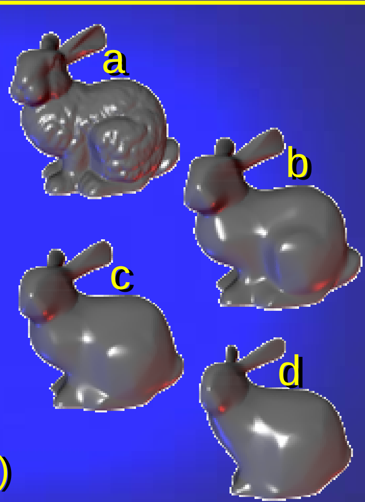
Multiresolution Modeling



Hierarchy of decreasing detail

New representation:

a = d + (c-d) + (b-c) + (a-b)

Editing means:

– d → d´

– a´ = d´ + (d-c) + (b-c) + (a-b)

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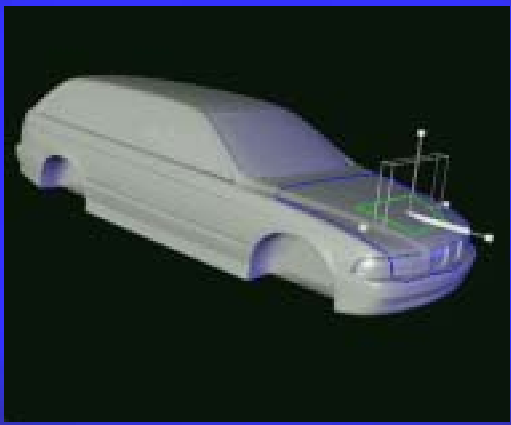
Multiresolution Modeling

Multiresolution Editing



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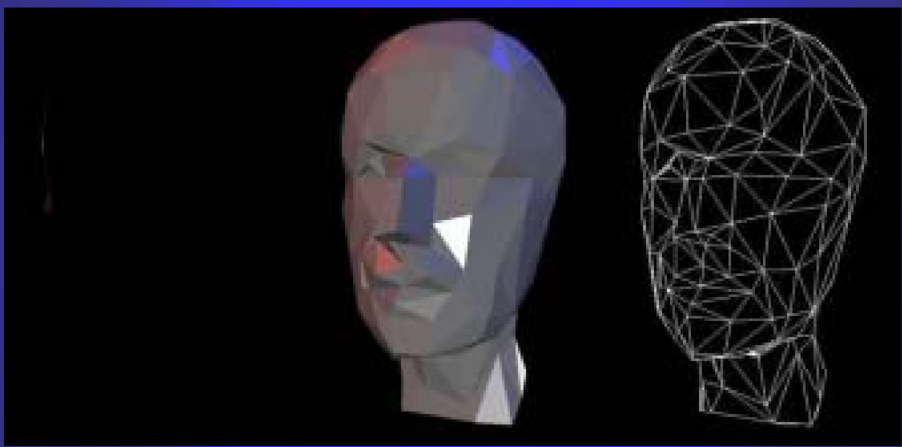

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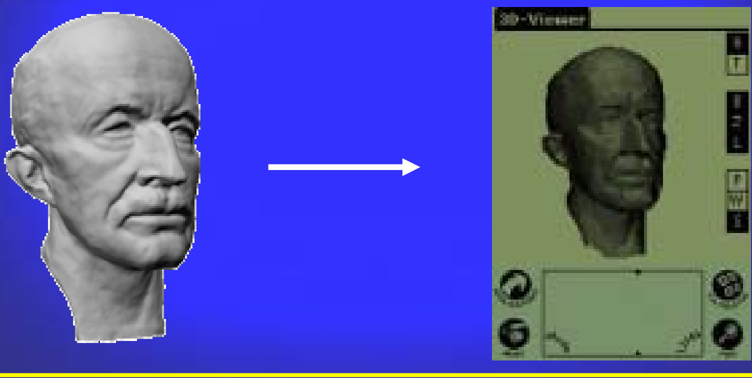
Low-Cost-Platforms

- Automatic LOD generation
  - E.g. for adaptation to hardware capabilities



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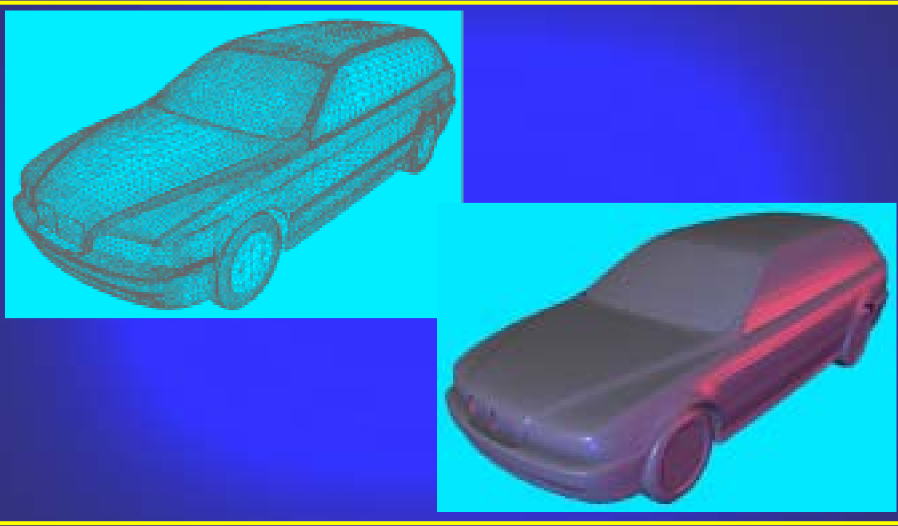
Industrial Design



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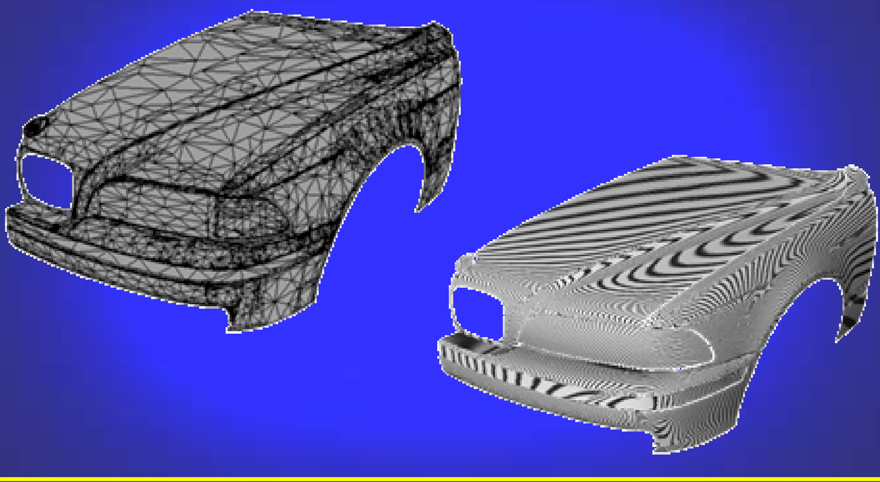
Reflection lines



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Lighting Simulation

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Lighting Simulation

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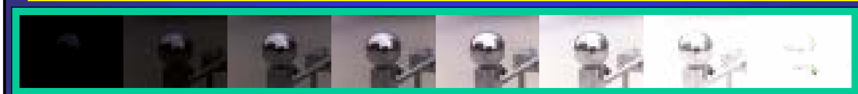
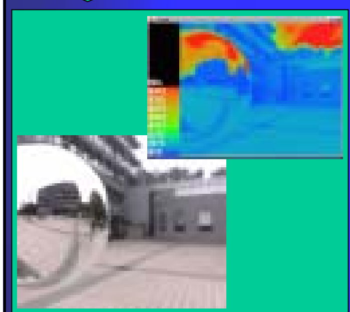
Real World Lighting

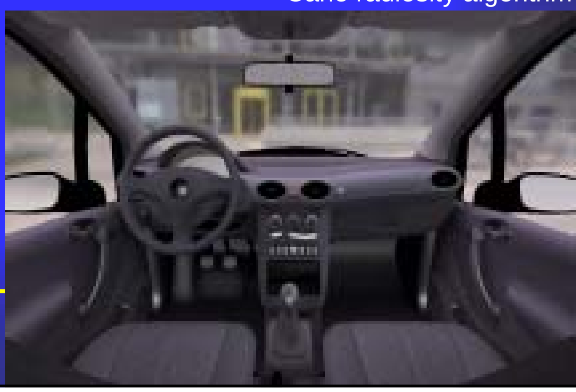


1) Photographs of mirror sphere at varying exposure times



2) High-dynamic range environment map

3) Use as light source in Monte Carlo radiosity algorithm



Terrain Data

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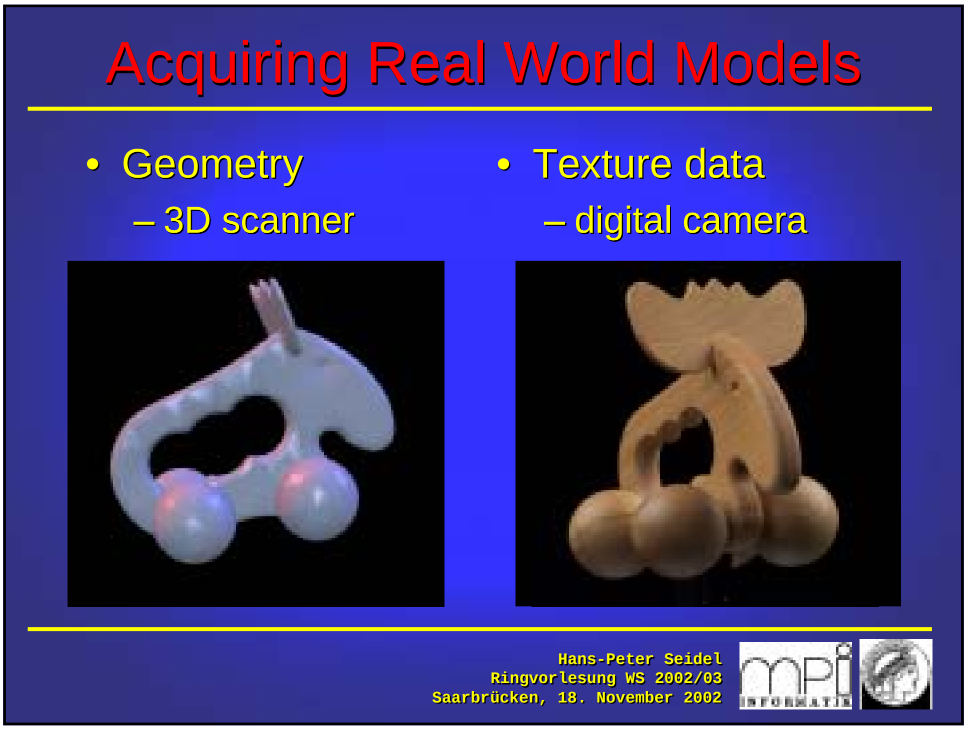
Acquiring Real World Models
• Geometry
– 3D scanner
• Texture data
– digital camera
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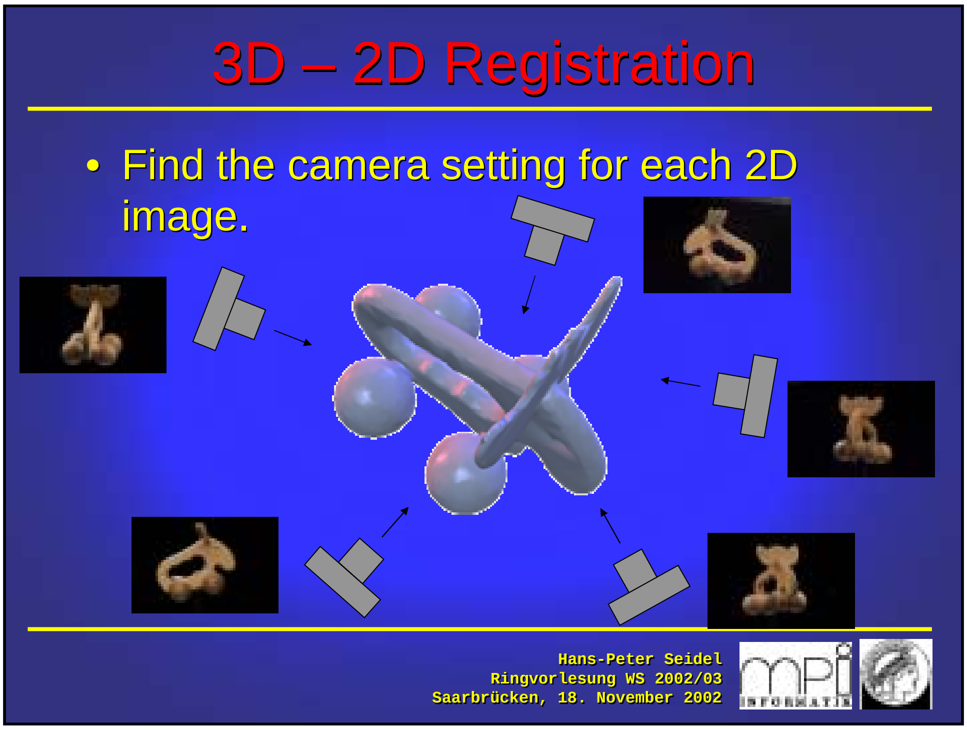
3D – 2D Registration
• Find the camera setting for each 2D image.
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Similarity Measure

- Which features to investigate?
  - no color information on the model
  - correspondence of geometric features hard to find


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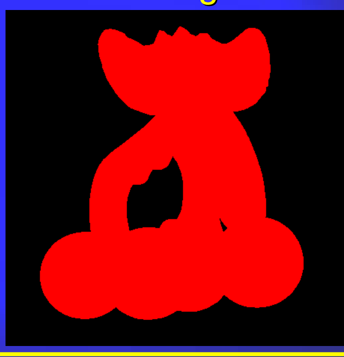
Similarity Measure

- Compare silhouettes [E. de Silhouette 1709-1767]
  - model: render monochrome
  - photo: automatic histogram-based segmentation

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Pixel-based Similarity Measure

- Count the number of pixels covered by just one silhouette.
  - XOR the images
  - compute histogram (hardware)

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Hierarchical Optimization

- optimize on low resolution first
- restart optimization to avoid local minima
- switch to higher resolution

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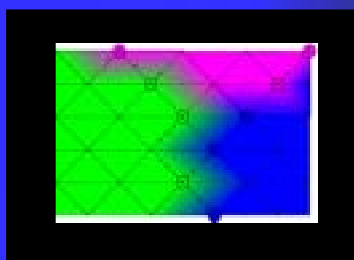
Texture Stitching

- Projective texture mapping
- Assign one image to each triangle
  - Triangle visible in image? (test every vertex)
  - Select best viewing angle
  - Discard data near depth discontinuities

Blending Across Borders

- Find border vertices
- Release all triangles around them
- Assign boundary vertices to best region
- Assign alpha-values for each region
  - 1 to vertices included in the region
  - 0 to all others.



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Textured 3D Objects

Overview

- Introduction
- Geometry Acquisition
- Geometry Processing
- Textured 3D Objects
- Image-Based BRDF Measurement
- Interactive and Predictive Rendering

Digitizing Real World Objects

- 3D geometry alone
  - no texture

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Digitizing Real World Objects

- by geometry plus texture
  - no relighting

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Digitizing Real World Objects

- by geometry plus a single BRDF

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Digitizing Real World Objects

- by geometry plus spatially varying BRDFs

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Acquiring Reflection Properties

- collecting data per surface point
- fitting a reflection model (Lafortune)
- separating basic materials
- spatially varying properties

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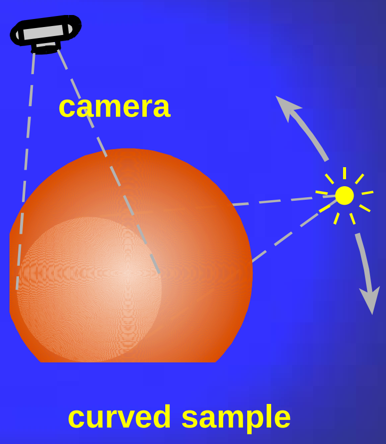
BRDF Measurement

- Image-based BRDF Measurement [Marschner 1999]
  - capture lots of BRDF samples at one shot by a sensor array / camera.



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Acquisition Equipment

– 3D scanner (structured light, CT)
– digital camera (high dynamic range)
– point-light source
– dark room
– calibration targets (checkerboard, metal spheres)

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Lumitexels

- A lumitexel collects all data available for a point on the surface:
  - 3D position
  - normal
  - list of radiance samples (one for every image where it is visible and lit) including:
    - *radiance value*
    - *light source direction*
    - *viewing direction*

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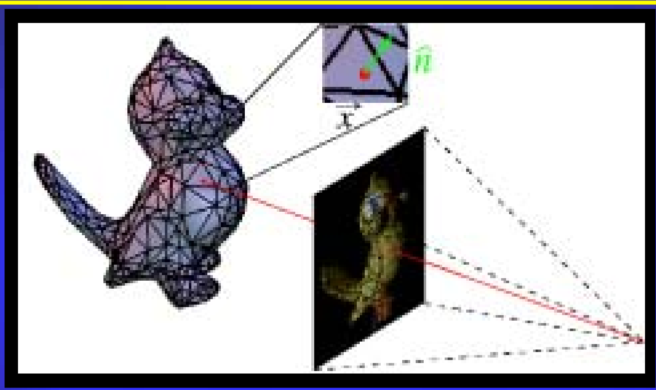
Assembling Lumitexels



For each triangle:

- Find the image with the highest sampling rate
- Generate one lumitexel for each pixel

Fitting Result

same BRDF for the whole object

Clustering

- Goal: separate the different materials
  - similar to Lloyd iteration
  - start with a single cluster containing all lumitexels
  - split cluster along direction of largest variance
  - stop after *n* clusters have been constructed

Clustering Results

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Spatially Varying Materials

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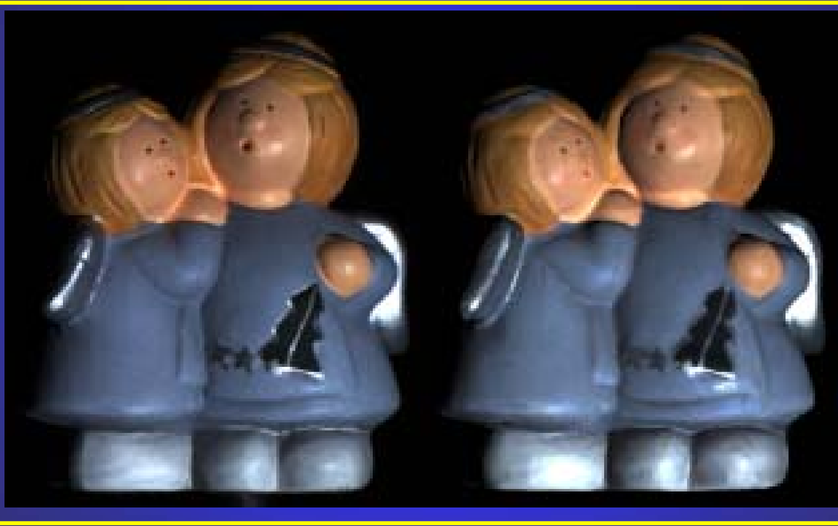
Results



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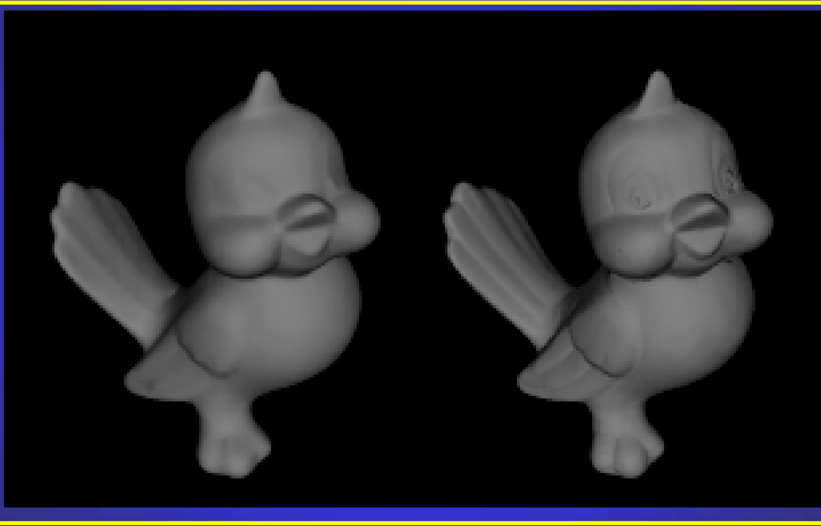
Normal Maps for arbitrary BRDFs

Complex BRDFs require optimization

- start with $f = t_1 f_1 + t_2 f_2 + \ldots + t_m f_m$ using the previously determined $t_1, t_2, \ldots, t_m$ and the normal provided by the initial mesh,
- optimize for the **normal direction** and $t_1, t_2, \ldots, t_m$ at the same time using Levenberg-Marquardt

Normal Maps Results



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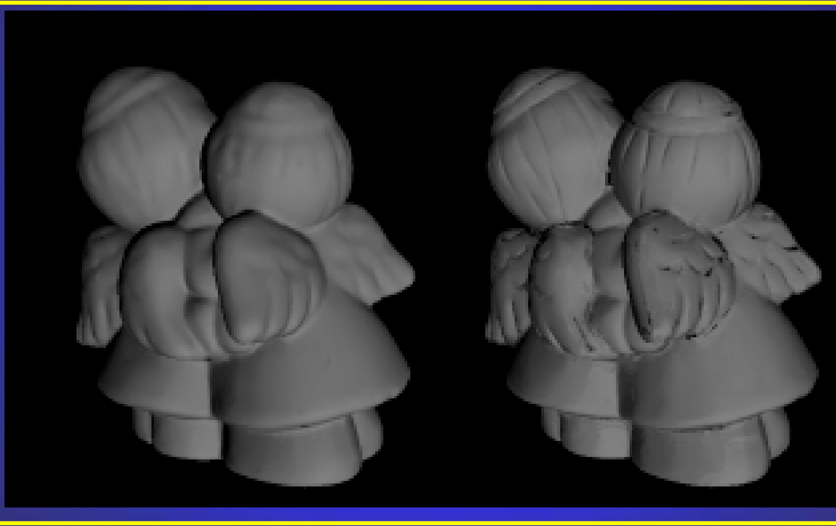
Normal Maps Results



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Without Normal Fitting

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With Normal Fitting

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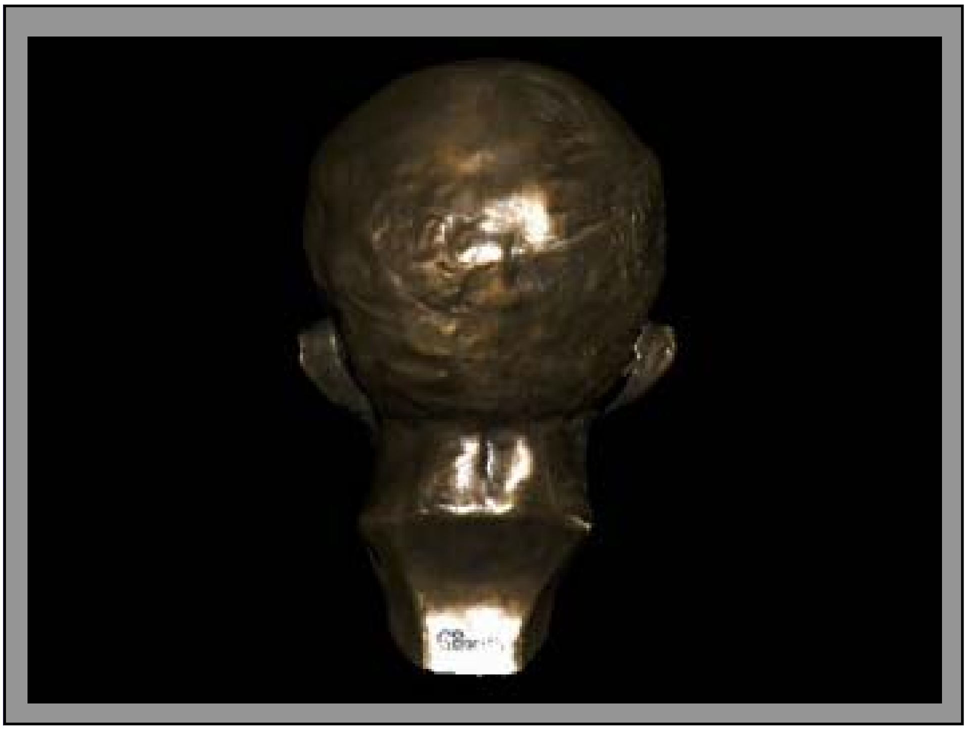

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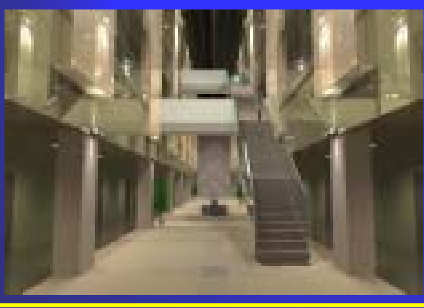
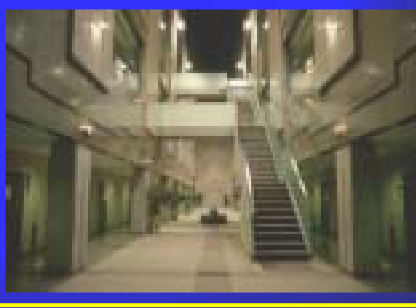
Predictive Rendering

– Our goal is to synthesize images predicting the appearance of real world.
– Valid input data describing the rendered scene
– Physically correct modeling of light scattering by object surfaces and light transport between those surfaces





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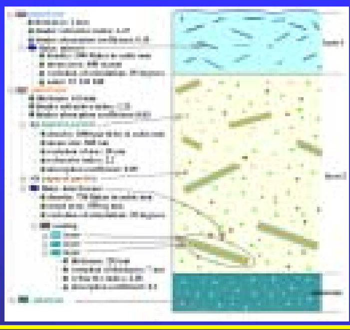
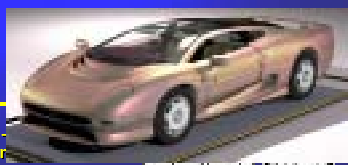
Input Model Complexity

- Complex geometry
- Multiple luminaires
- Complex light reflectance characteristics





Pearlescent Appearance

Sparkles - Paint Texture

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Making Rendering Efficient

- The solution of the global illumination problem is computationally hard
- New global illumination and rendering algorithms:
  - deal well with the scene complexity, in terms of both storage and computation time requirements
  - are general and practical: reliable (fail-safe), user-friendly, automatic, easy to implement and to validate
  - take into account characteristics of the Human Visual System to concentrate the computation exclusively on the visible scene details

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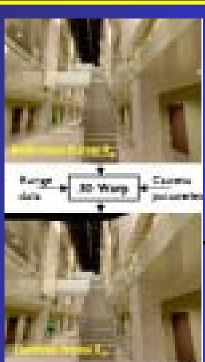
Animation Rendering

– Use ray tracing to compute all key frames and selected glossy and transparent objects.
– For inbetween frames, derive as many pixels as possible using computationally inexpensive Image Based Rendering techniques.
– The animation quality as perceived by the human observer must not be affected.

Keyframe Placement



Animation Quality Predictor

Are the differences acceptable ?

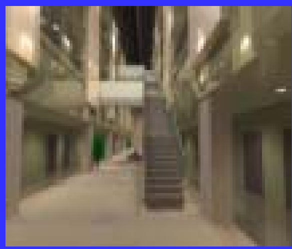
NO

- Split Segment
- Recurse

YES

Generate inbetween images

Animation Example



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Dynamic Environments

- Temporal photon processing
- Energy-based stochastic error metric
  - Steers the photon collection in the temporal domain
  - Computed for each mesh element and for all frames
- Perception-based animation quality metric
  - Decides upon the stopping condition
  - Computed once per animation segment

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Algorithm

1. Initialization: determine the initial number of photons per frame.
2. Adjust the animation segment length depending on temporal variations of indirect lighting which are measured using energy-based criteria.
3. Adjust the number of photons per frame based on the AQM response to limit the perceivable noise.
4. Spatio-temporal reconstruction of indirect lighting.
5. Spatial filtering step.

Temporal Photon Filtering Off

- Scene complexity: 100,000 triangles
- Number of traced photons: 75.000-85.000 / frame
- Density estimation phase: less than 0.3 seconds / frame
- Rendering phase: ~25 seconds / frame

Temporal Photon Filtering On

- Photon temporal processing: up to 40 frames
- Number of traced photons: 75.000-85.000 / frame
- Density estimation phase: less than 2-3 seconds / frame
- Rendering phase: ~25 seconds / frame

ATRIUM Scene

http://www.mpi-sb.mpg.de/resources/atrium

– Complete set of data describing the real-world atrium scene:
  - Geometric model in various formats
  - Light sources with goniometric diagrams (courtesy of Matsushita Electric)
  - Measured surface BRDFs
  - HDR photographs
  - Illumination measurements at selected sample points

– BTFs and more exact BRDF measurements will be performed within RealReflect

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Perspektiven der Computergraphik

- Sehr dynamisches Gebiet
- 3D-Bildanalyse und -synthese
  - Zusammenwachsen von Vision und Computergraphik
- Effiziente Handhabung großer 3D-Datensätze
  - 3D-Rekonstruktion / Komplexität / Interaktion
- 3D-Graphik im Internet
  - Akquisition / Codierung / Suche / Interaktion
- Menschmodelle in virtuellen Umgebungen
  - Modellierung / Animation / Rendering

See you!

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