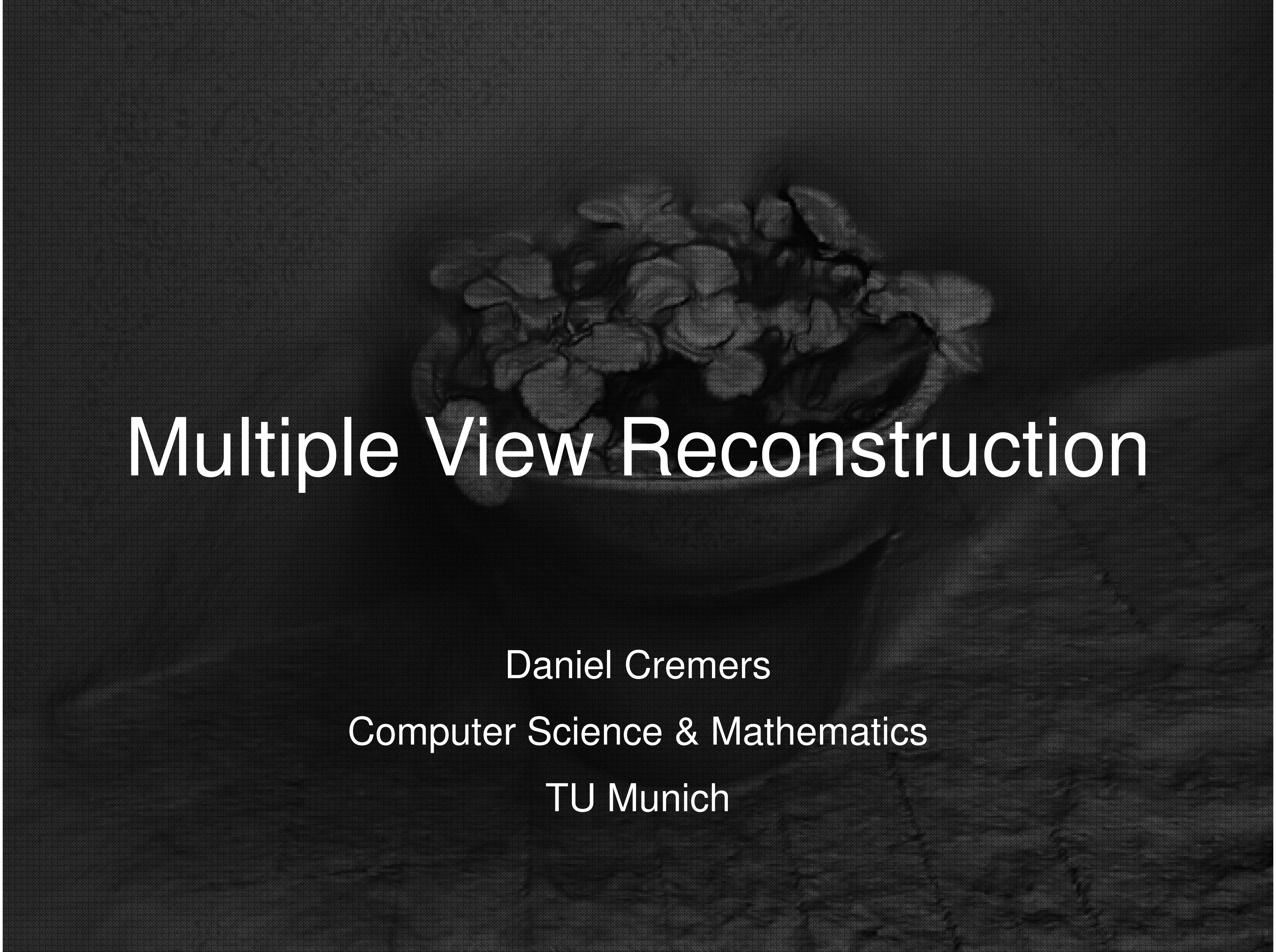
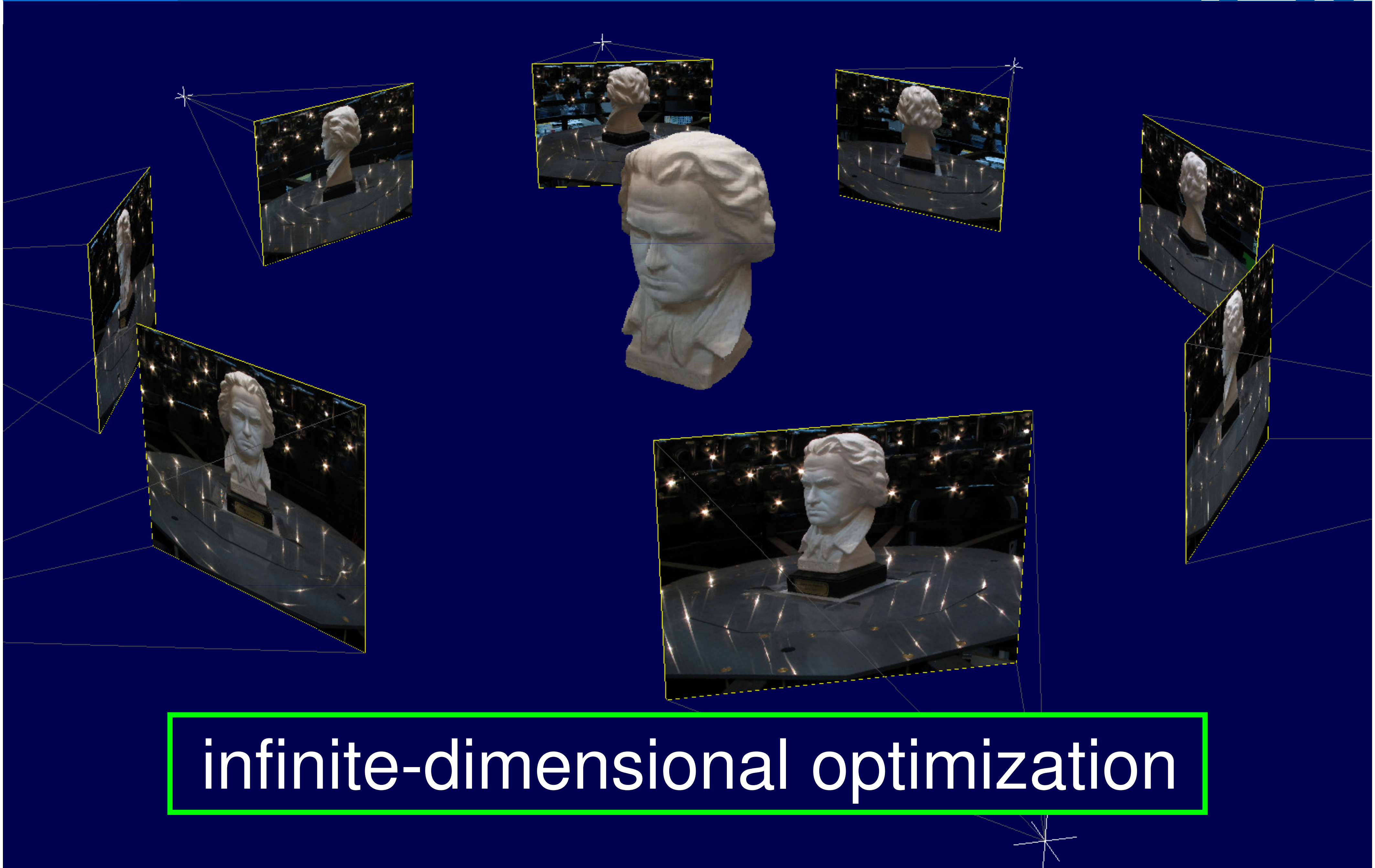


Multiple View Reconstruction

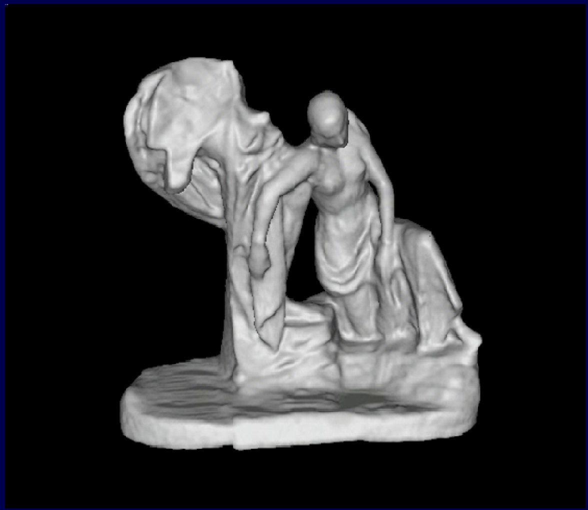
Daniel Cremers

Computer Science & Mathematics

TU Munich

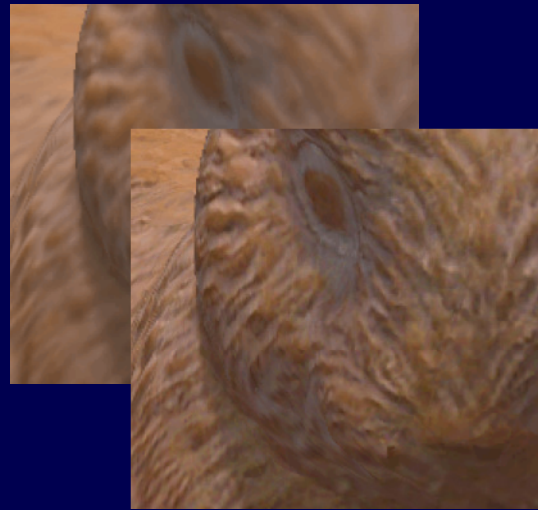


infinite-dimensional optimization

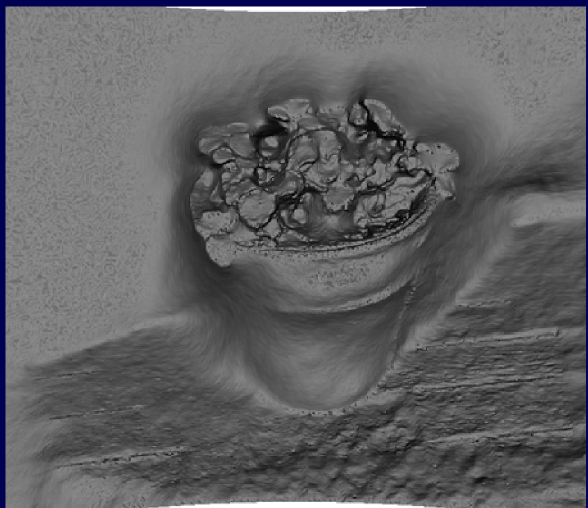


Multiview reconstruction

Single view reconstruction

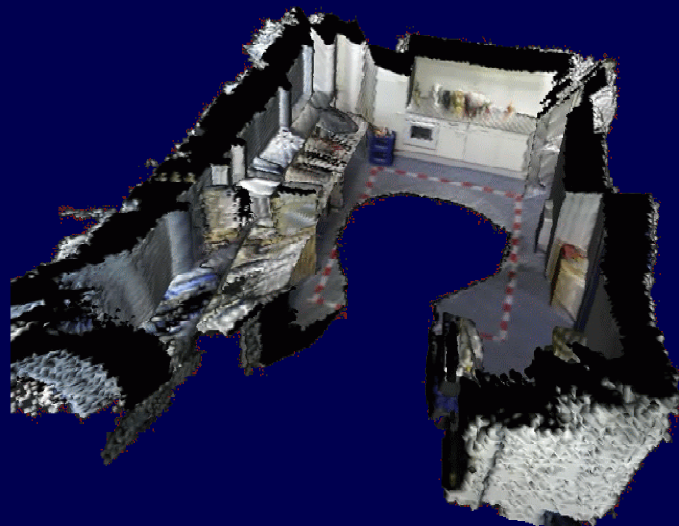


Super-res.textures



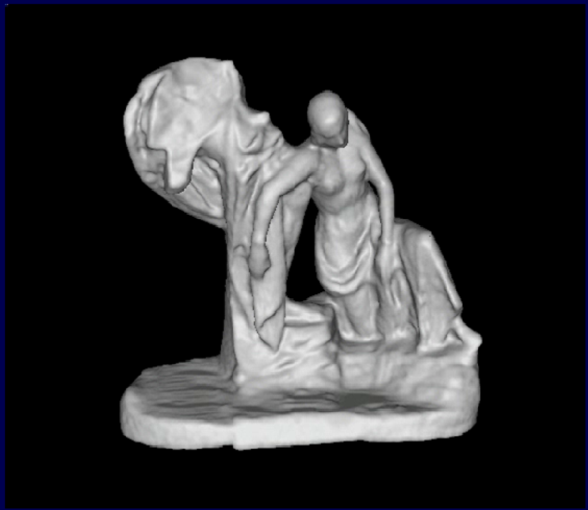
Realtime dense geometry

RGB-D scanning



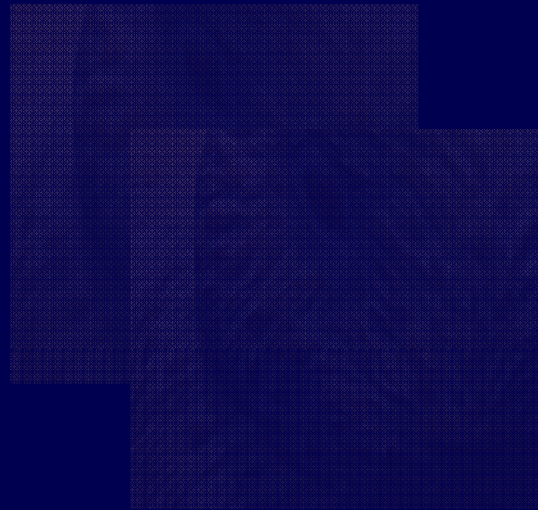
Reconstruction on the fly

Overview

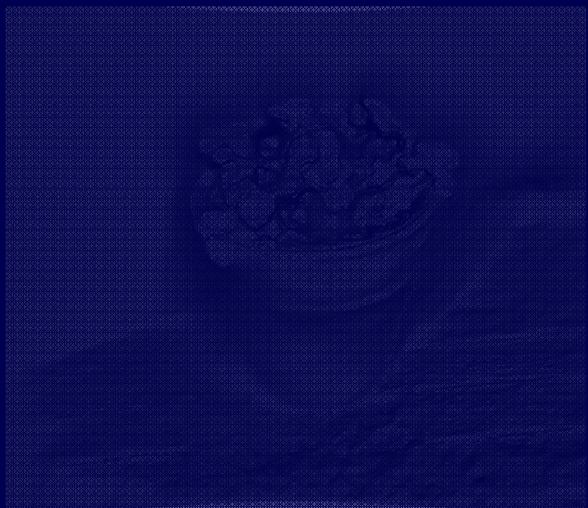


Multiview reconstruction

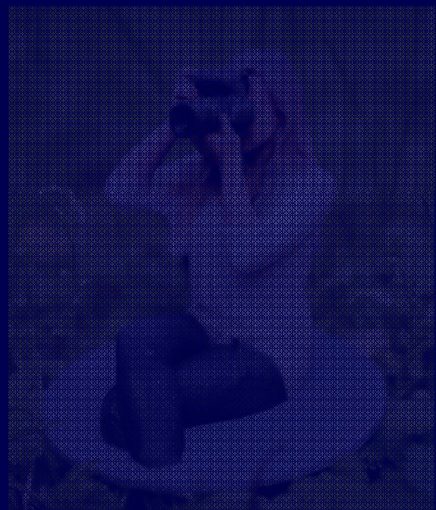
Single view reconstruction



Super-res.textures



Realtime dense geometry



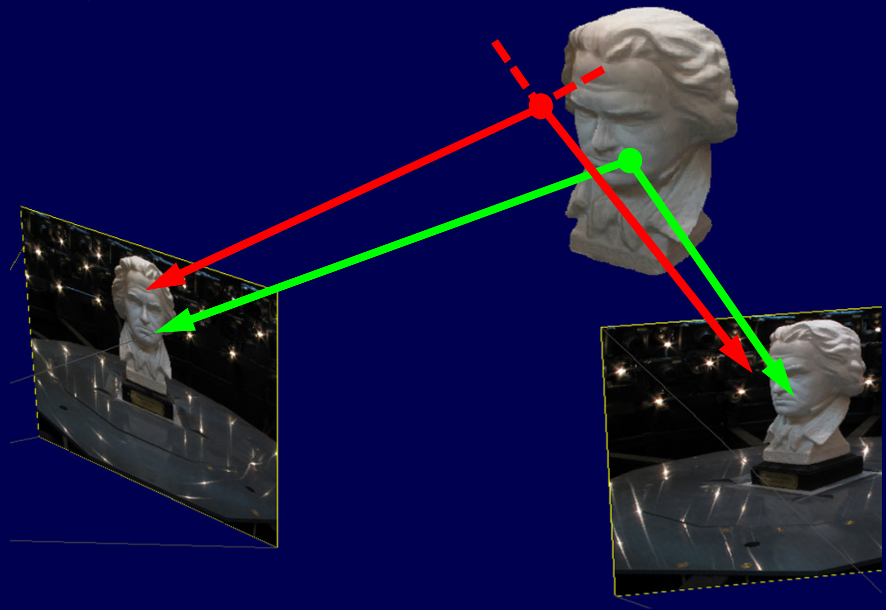
RGB-D scanning

Reconstruction on the fly

Photoconsistency:

$$\rho : \left(V \subset \mathbb{R}^3\right) \to [0,1]$$

$$E(S) = \int_S \rho(s)\, ds$$



3D Reconstruction: *Faugeras, Keriven '98, Duan et al. '04*

Segmentation: *Kichenassamy et al. '95, Caselles et al. '95*

Optimal solution is the empty set: $\arg\min_S E(S) = \emptyset$

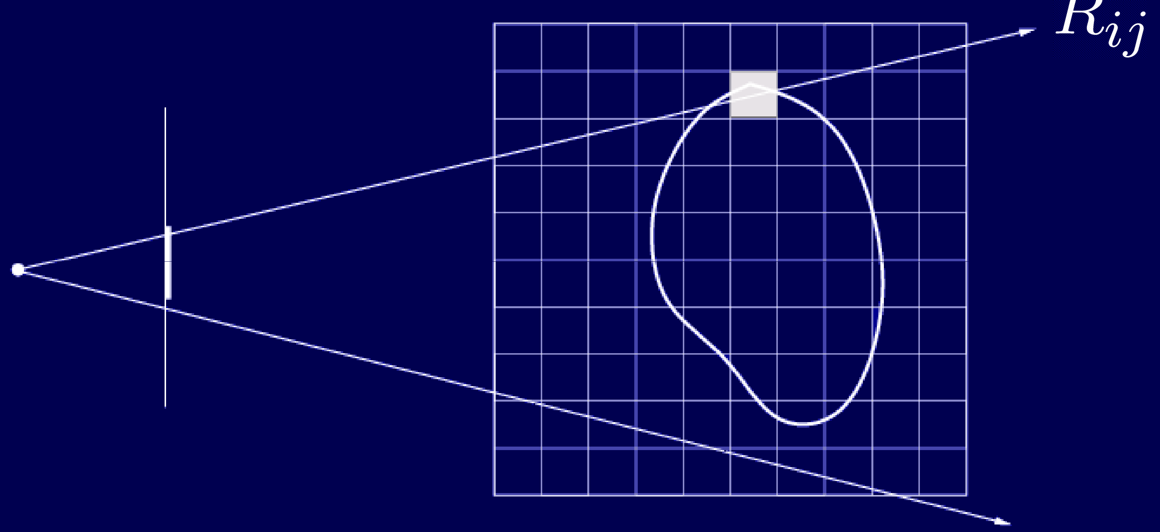
Silhouette Consistent Reconstructions

$$\min_S \int_S \rho \, ds$$

$$\text{s. t.} \quad \pi_i(S) = S_i \;\; \forall\, i = 1, \ldots, n$$

$$\pi_i : V \to \Omega_i$$

$$S_i \subset \Omega_i$$



Kolev et al., IJCV 2009, Cremers, Kolev, PAMI 2011

Silhouette Consistent Reconstructions

$$\min_S \int_S \rho \, ds$$

$$\text{s. t.} \quad \pi_i(S) = S_i \;\; \forall\, i = 1, \ldots, n$$

$$u = 1_{\text{int}(S)}$$

$$\min_u \int_V \rho(x) |\nabla u(x)| \, dx$$

$$\Sigma = \begin{cases} \text{s. t.} \quad \cancel{u : V \to \{0, 1\}} \quad u : V \to [0, 1] \\ \int_{R_{ij}} u(x)\, dx \geq 1 \quad \text{if } j \in S_i \\ \int_{R_{ij}} u(x)\, dx = 0 \quad \text{if } j \notin S_i \end{cases}$$

Proposition: The set Σ of silhouette-consistent solutions is convex.

Kolev et al., IJCV 2009, Cremers, Kolev, PAMI 2011

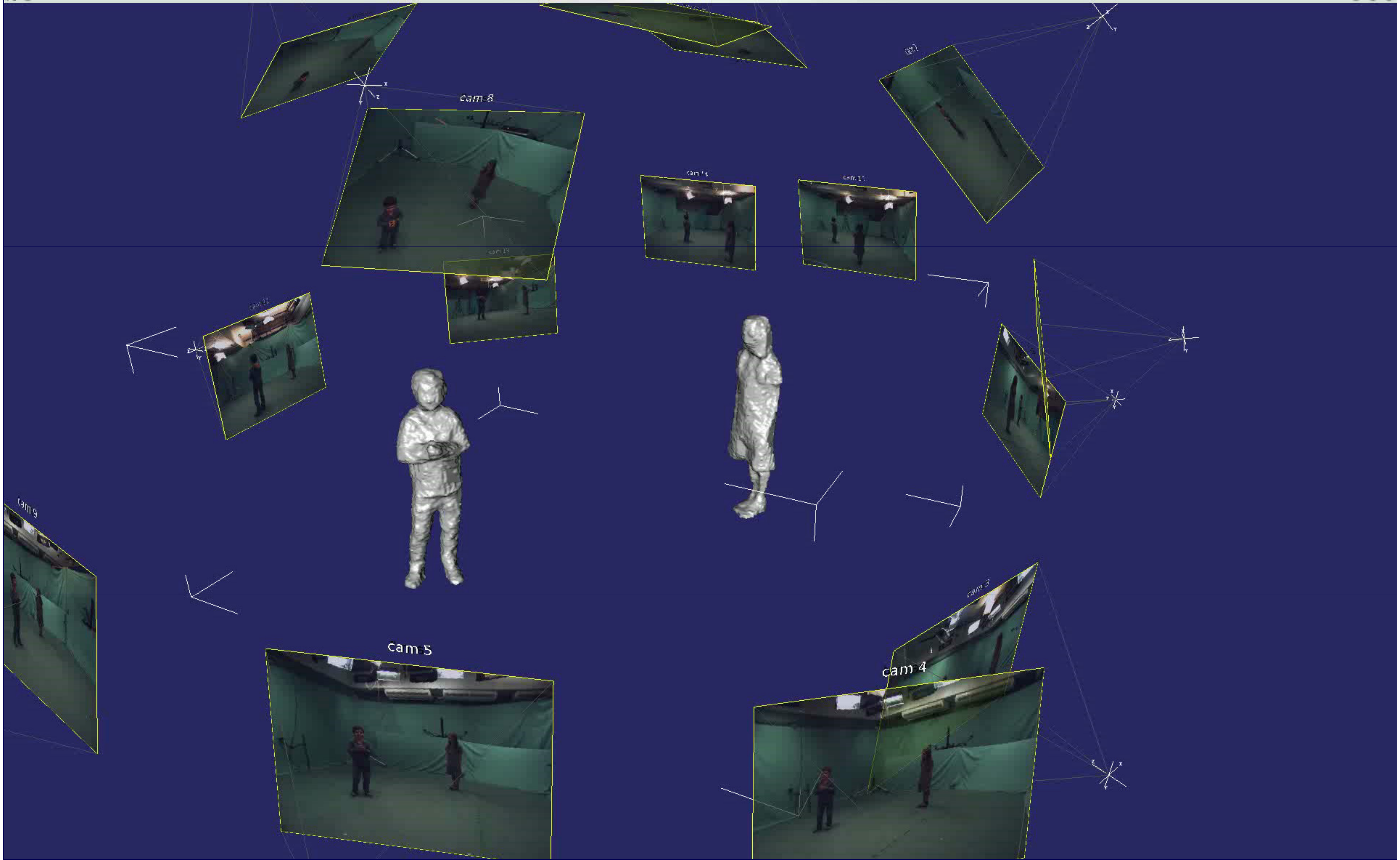
Reconstruction of Fine-scale Structures

Image data courtesy of Yasutaka Furukawa.

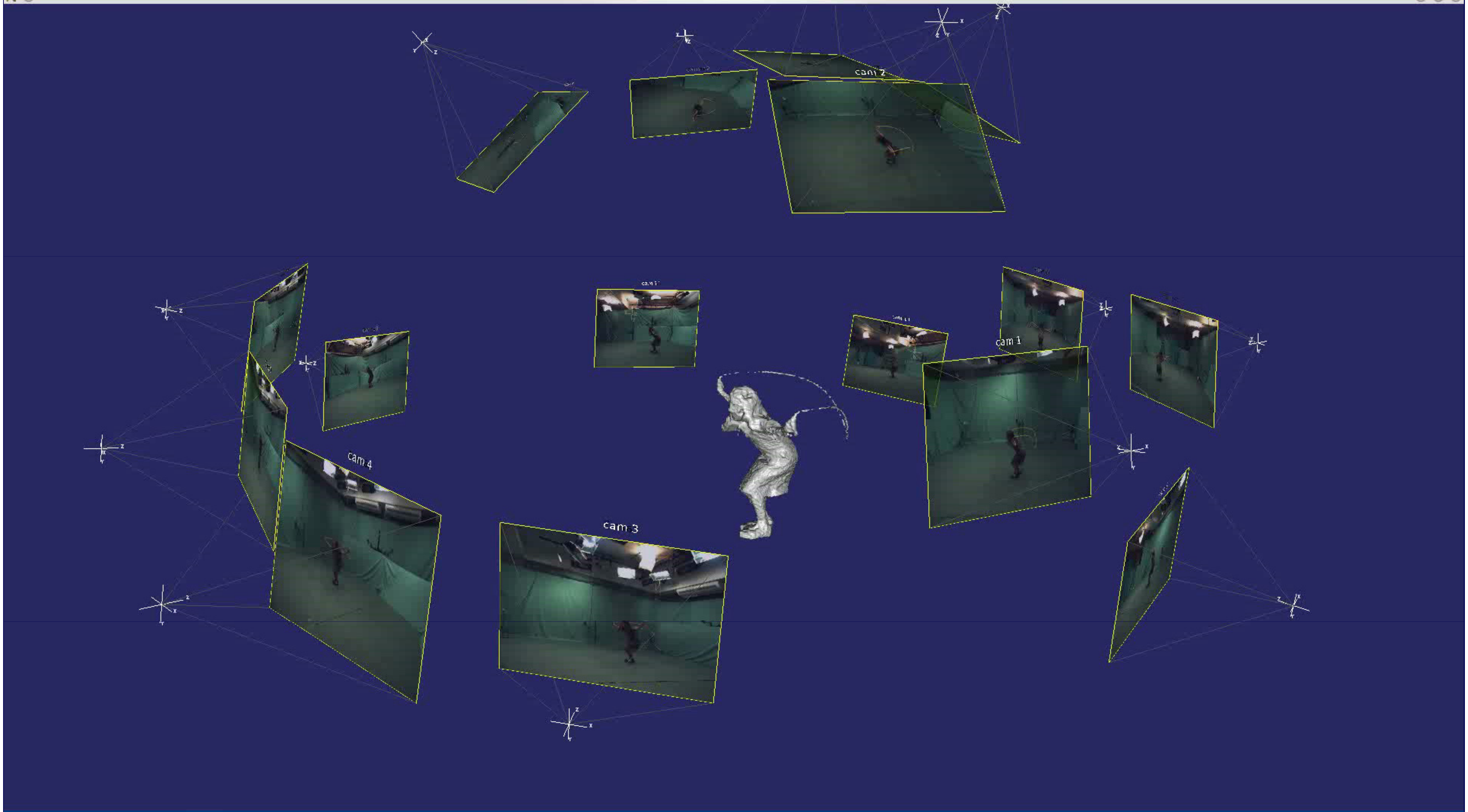
Reconstructing the Niobids Statues

Kolev, Cremers, ECCV '08, PAMI 2011

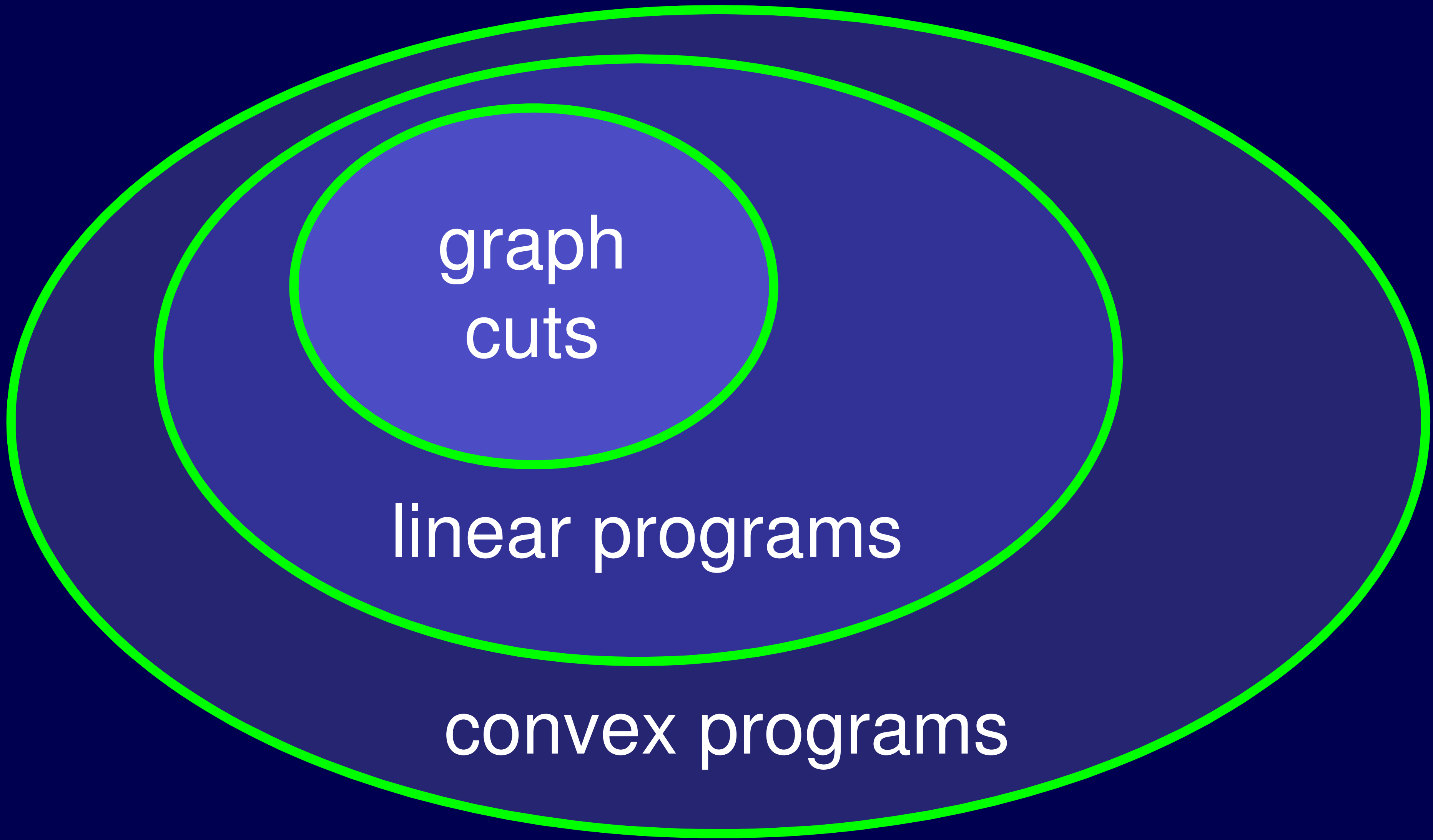
Action Reconstruction



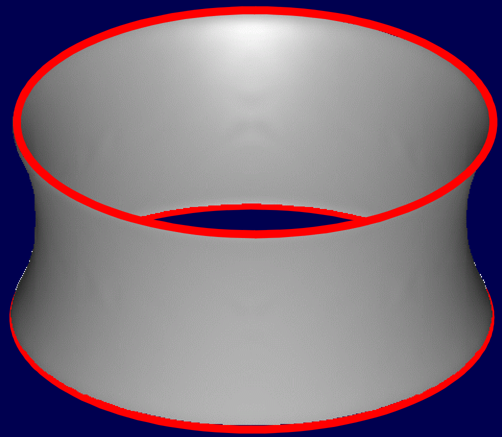
Action Reconstruction



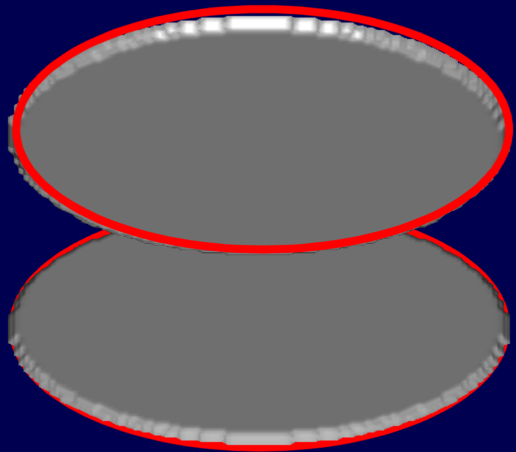
Convex Relaxation vs. Graph Cuts



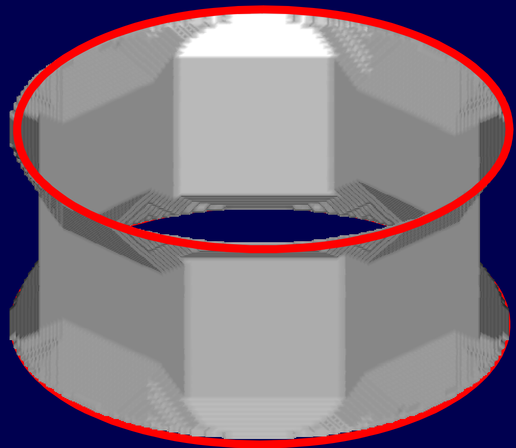
Klodt et al., ECCV '08, Nieuwenhuis et al. PAMI '13



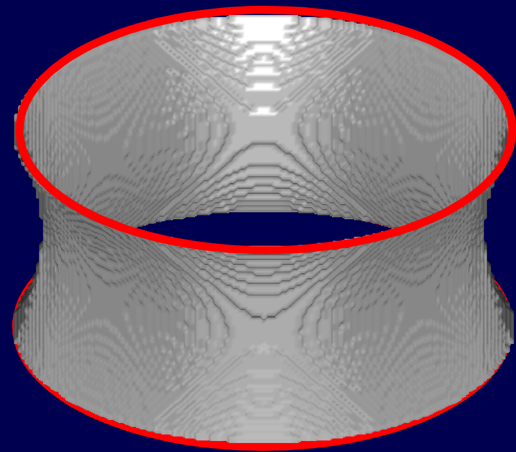
catenoid



graph cut
(6-connected grid)



graph cut
(26-connected grid)



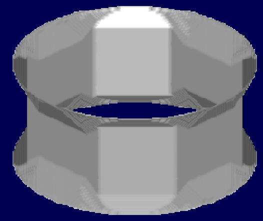
convex formulation
(6-connected grid)

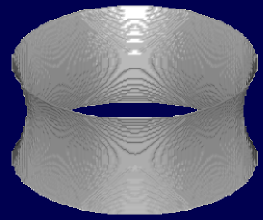
Klodt et al., ECCV '08

12 min. 32 sec. (CPU)

9 min. 34 sec. (CPU)

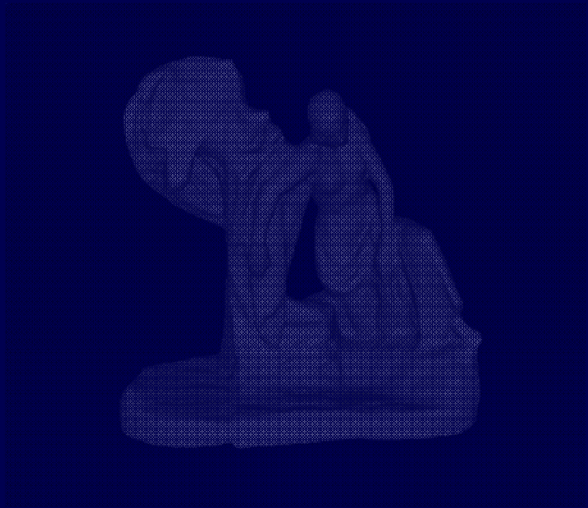
8 sec. (GPU)





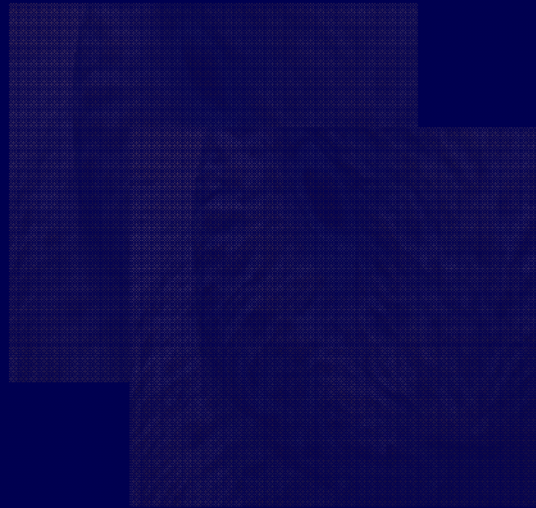
Klodt et al., ECCV '08

Overview

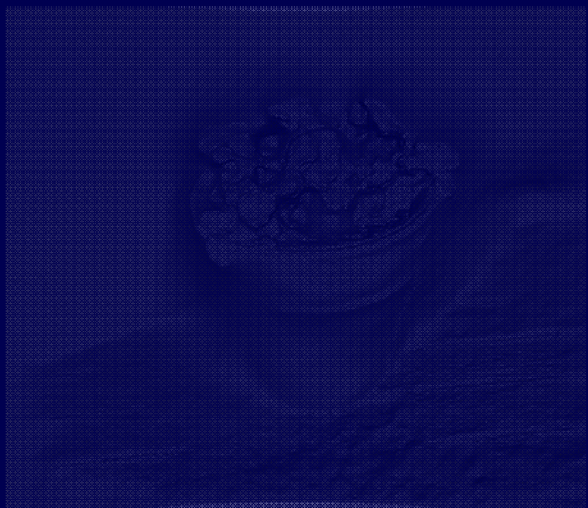


Multiview reconstruction

Single view reconstruction



Super-res.textures



Realtime dense geometry

RGB-D scanning

Reconstruction on the fly

Can we recover geometry from a single image?

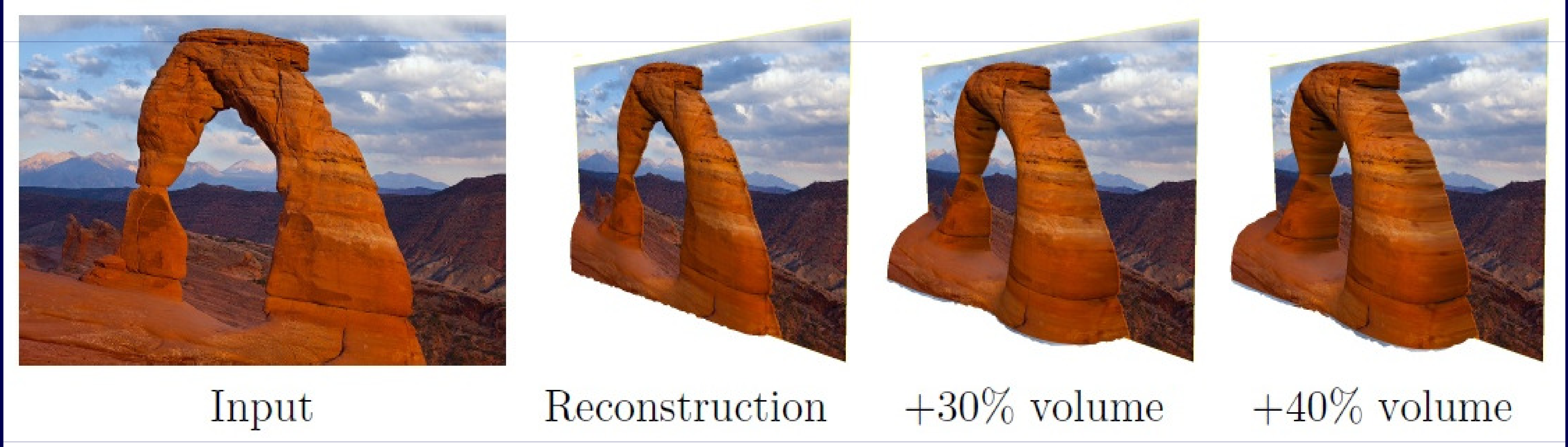
Yes: Shape-from-shading, shape-from-focus, shape from symmetry,…

<u>Solution:</u> Fixed-volume silhouette-consistent minimal surface.

$$\min_S |S| \quad \text{s.t. } \operatorname{Vol}(S) = V_0,\ \pi(S) = S_0$$

Toeppe, Oswald, Rother, Cremers, ACCV 2010

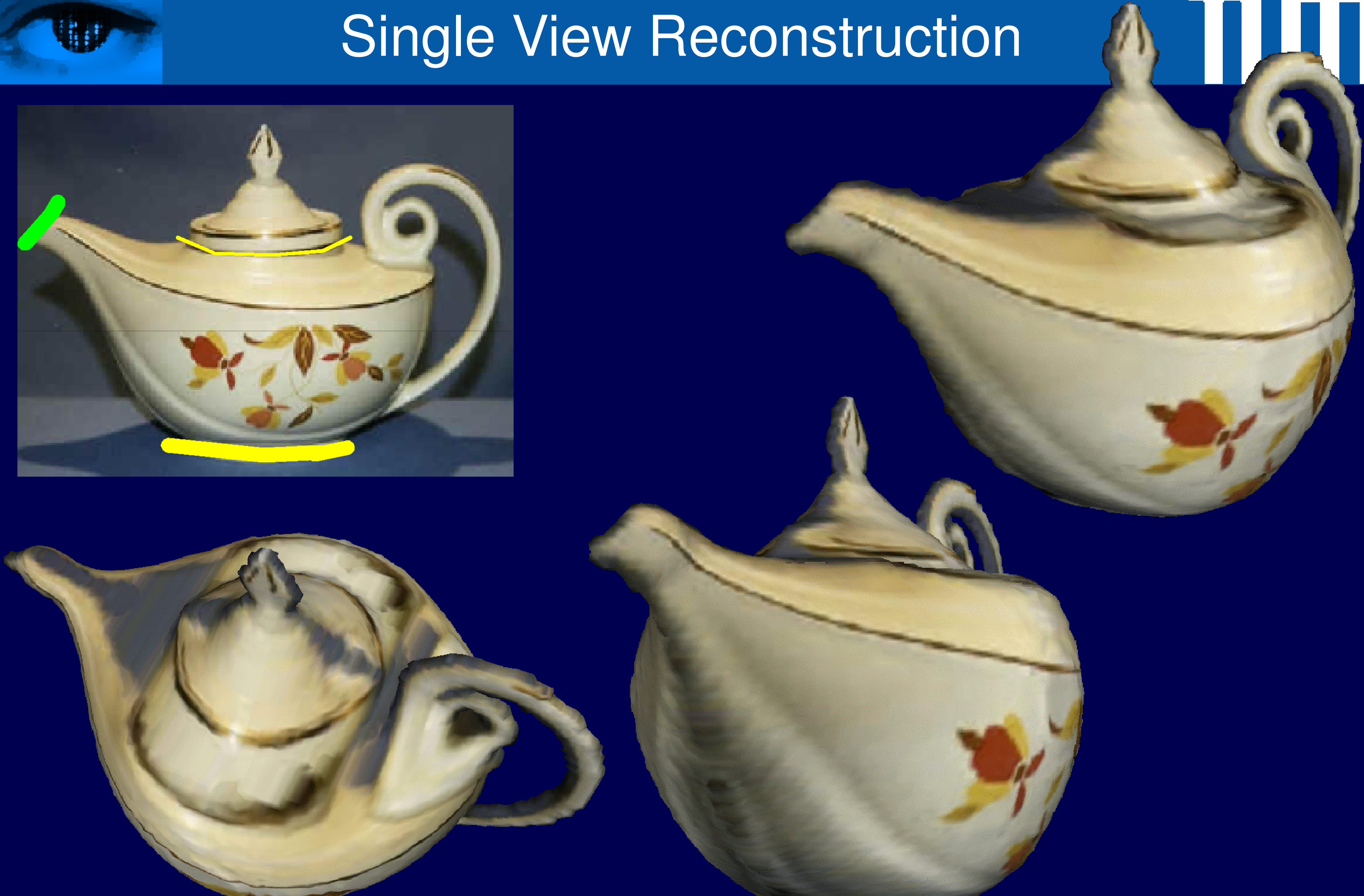
Single View Reconstruction



Computation time approximately 1 second on GPU.

Toeppe, Oswald, Rother, Cremers, ACCV 2010

Single View Reconstruction



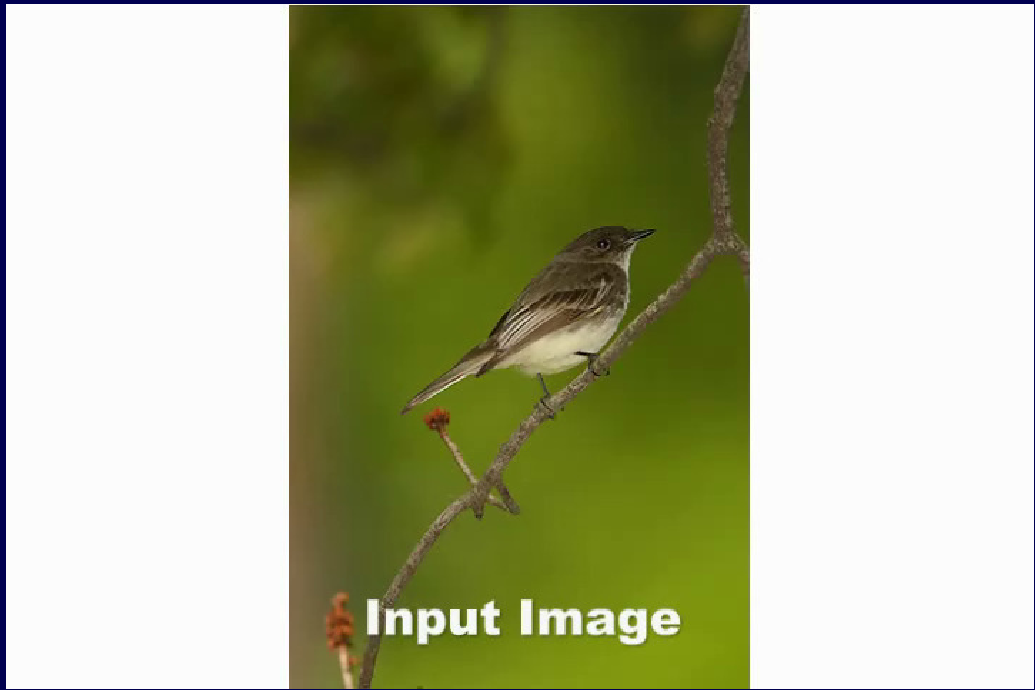
Toeppe, Oswald, Rother, Cremers, ACCV 2010

Modifying the Material Properties

Single View Reconstruction

Toeppe, Oswald, Rother, Cremers, ACCV 2010

Single View Reconstruction



*Toeppe, Oswald, Rother, Cremers, ACCV 2010**

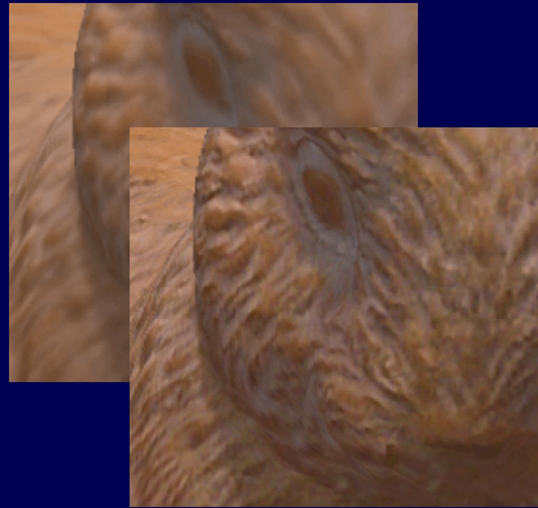
** Best Paper Honorable Mention*

In collaboration with Microsoft Research

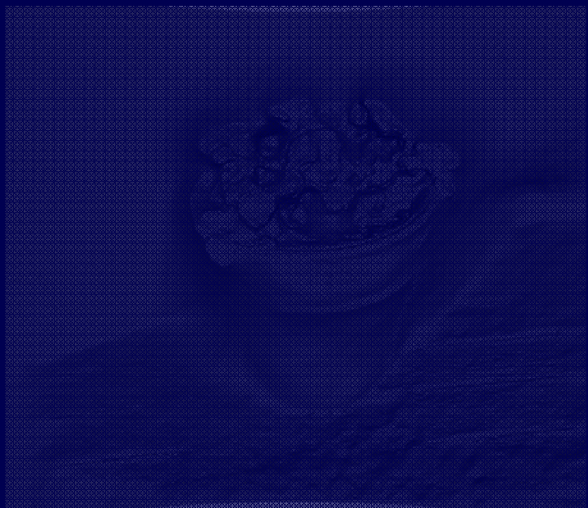
Overview

Multiview reconstruction

Single view reconstruction



Super-res.textures

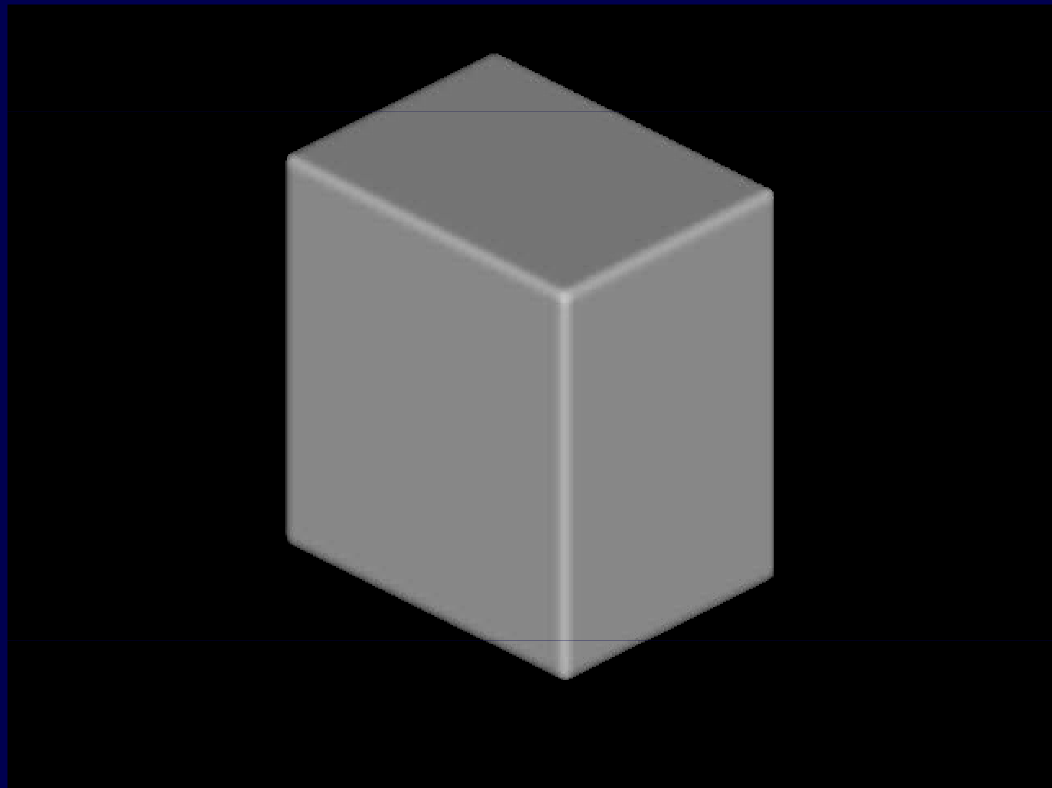


Realtime dense geometry

RGB-D scanning

Reconstruction on the fly

Surface Evolution to Optimum

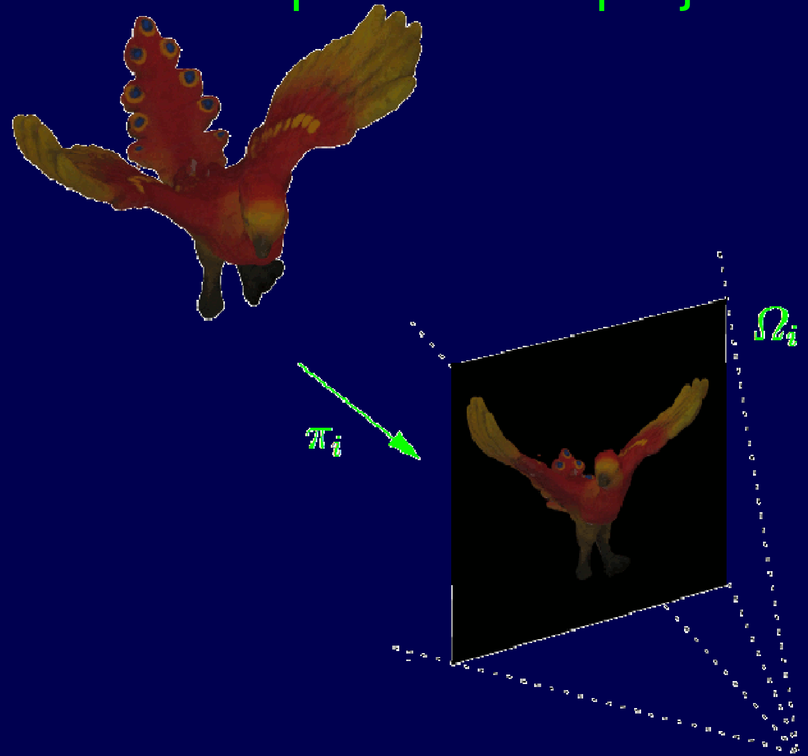


Super-Resolution Texture Map

Given all images $\mathcal{I}_i : \Omega_i \to \mathbb{R}^3$, determine the surface color $T : S \to \mathbb{R}^3$

$$\min_T \sum_{i=1}^{n} \int_{\Omega_i} \Big(b * (T \circ \beta_i) - \mathcal{I}_i \Big)^2 dx + \lambda \int_S \|\nabla_S T\| ds$$

blur & downsample　　back-projection



Goldlücke, Cremers, ICCV '09, DAGM '09

Super-Resolution Texture Map

*Goldlücke, Cremers, ICCV '09, DAGM '09**

** Best Paper Award*

Super-Resolution Texture Map

Closeup of input image

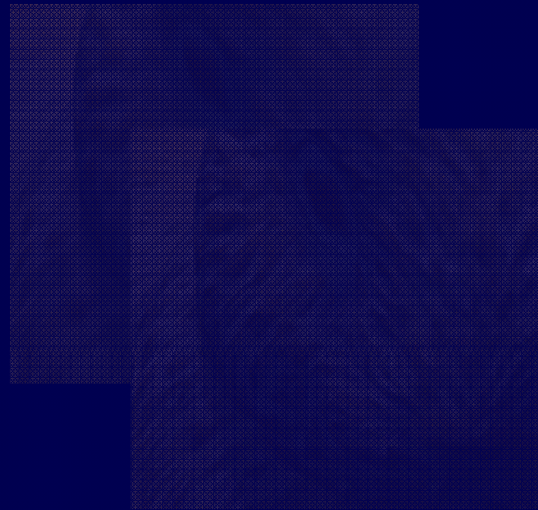
Super-resolution texture

*Goldlücke, Cremers, ICCV ’09, DAGM ’09**

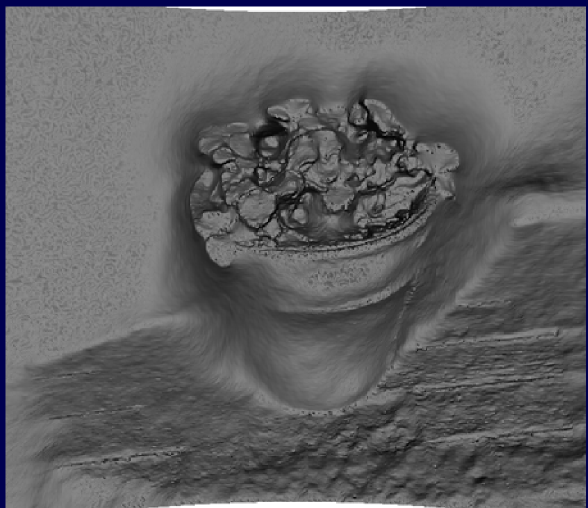
** Best Paper Award*

Multiview reconstruction

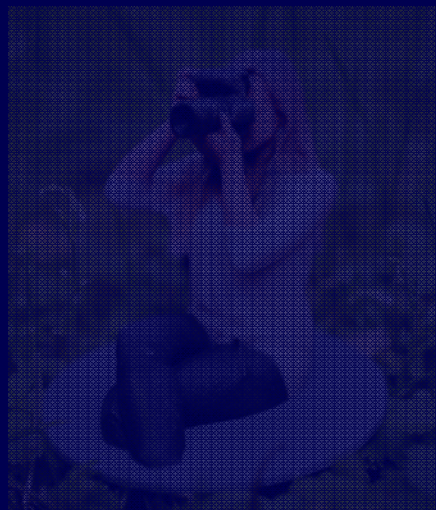
Single view reconstruction



Super-res.textures



Realtime dense geometry



RGB-D scanning

Reconstruction on the fly

Input video

Optical flow field

$$\min_{u:\Omega \to \mathbb{R}^2} \int_{\Omega} \left| I_1(x) - I_2(x+u) \right| dx + J(u)$$

Horn & Schunck '81, Zach et al. DAGM '07, Wedel et al. ICCV '09

Dense geometry from hand-held camera

Much related work on structure and motion, stereo, and optic flow:

Fitzgibbon, Zisserman, ECCV '98

Jin, Favaro, Soatto, CVPR '00

Nister, ICCV '03

Davison, ICCV '03

Pollefeys et al., IJCV '04

Wang et al., 3DPVT '06

Zach et al., DAGM '07

Gallup et al. CVPR '07

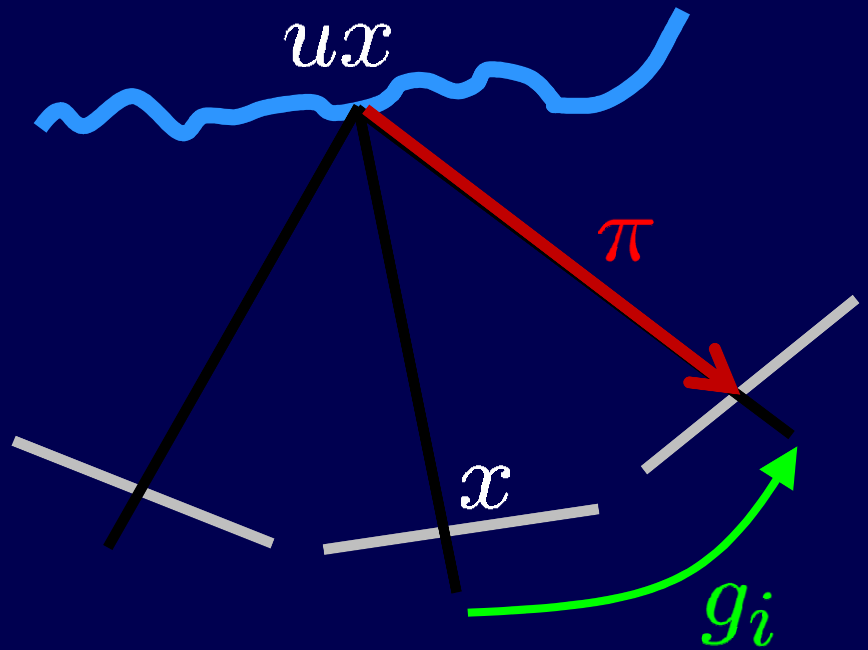
Klein, Murray, ISMAR '07 — Real-time calibration

Wedel et al., ICCV '09

Newcombe, Davisson, CVPR '10 — Compute optic flow between consecutive images and use it to update a depth map.

PTAM (*Klein, Murray ISMAR ‘07*)

Dense geometry from hand-held camera



Brightness constancy:

$$I_0(x) \overset{!}{=} I_i\Big(\pi\big(g_i(ux)\big)\Big)$$

$$\min_{u,v} \sum_i \int_\Omega \Big| I_0(x) - I_i\Big(\pi\big(g_i(u \cdot x)\big)\Big) \Big| \, dx + \int_\Omega \cancel{|\nabla u(x)| \, dx}$$

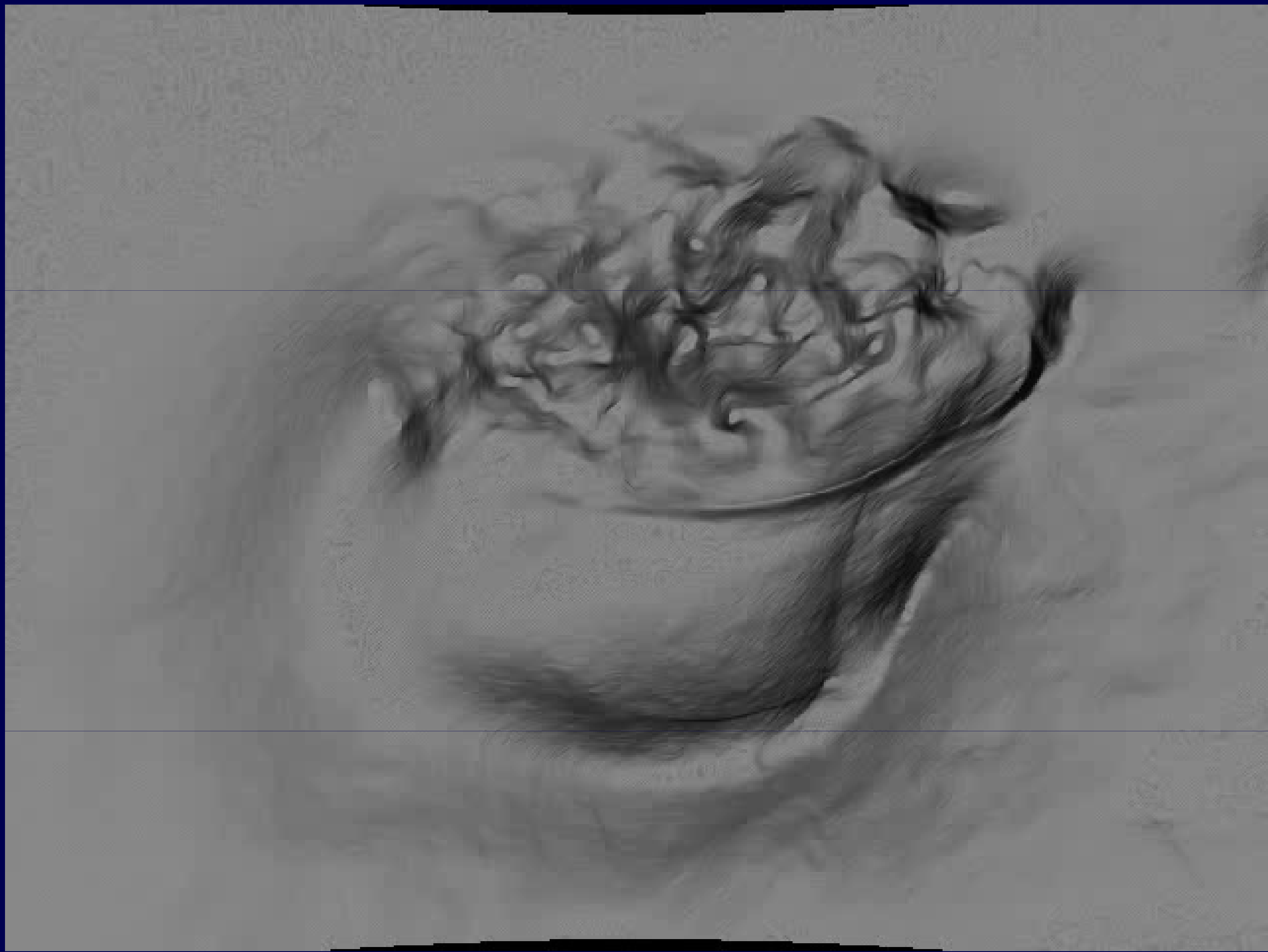
$$+ \frac{1}{\theta} \int_\Omega (u - v)^2 \, dx + \int_\Omega |\nabla v(x)| \, dx$$

Stuehmer , Gumhold, Cremers, DAGM '10

Dense geometry from hand-held camera

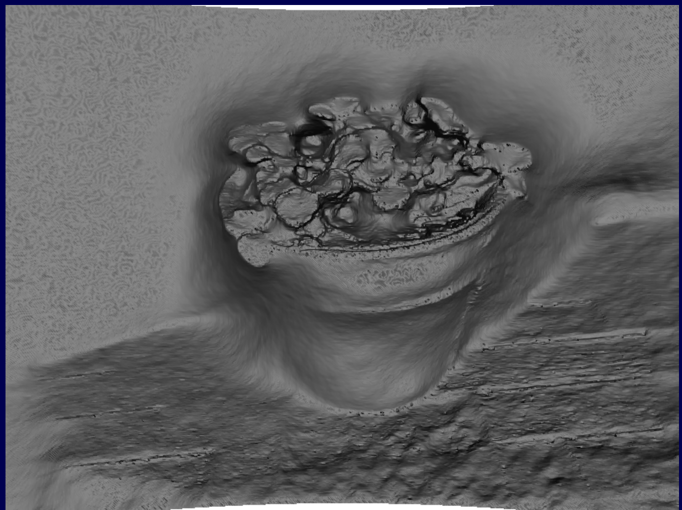
Stuehmer , Gumhold, Cremers, DAGM '10

Dense geometry from hand-held camera

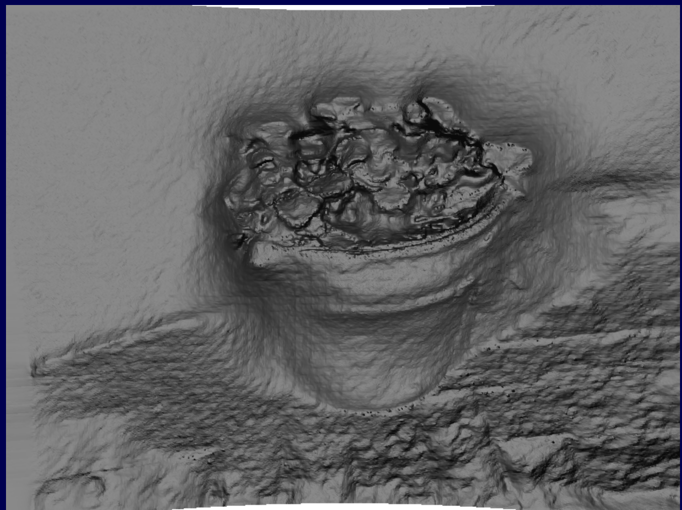


Stuehmer , Gumhold, Cremers, DAGM '10

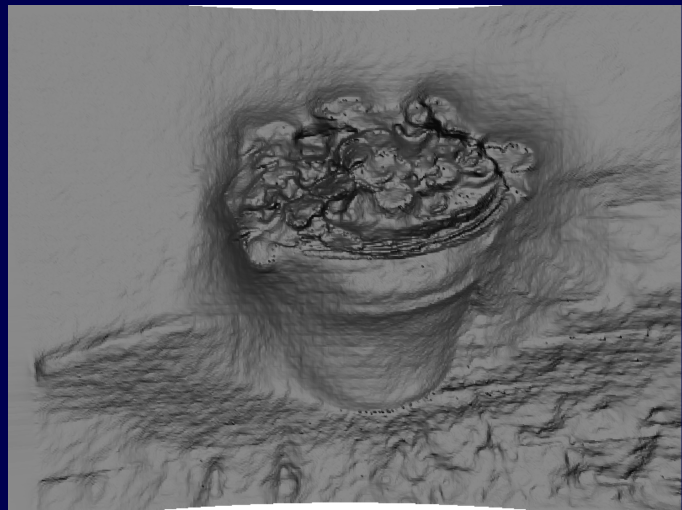
Dense geometry from hand-held camera



1.8 fps



11.3 fps

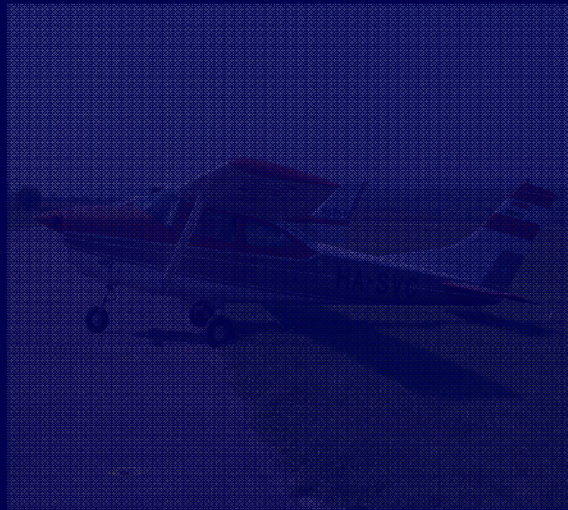


24 fps

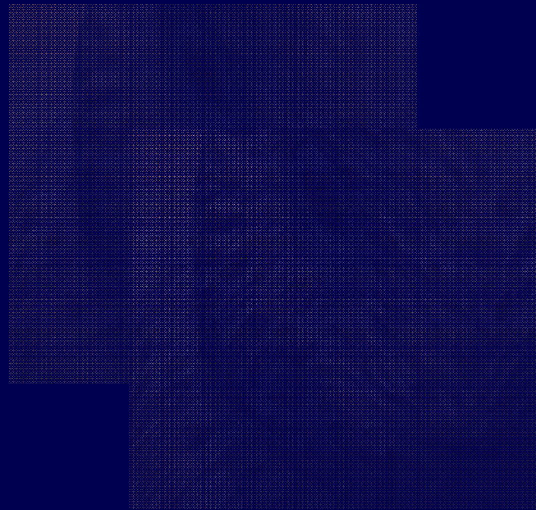
Stuehmer , Gumhold, Cremers, DAGM '10

Overview

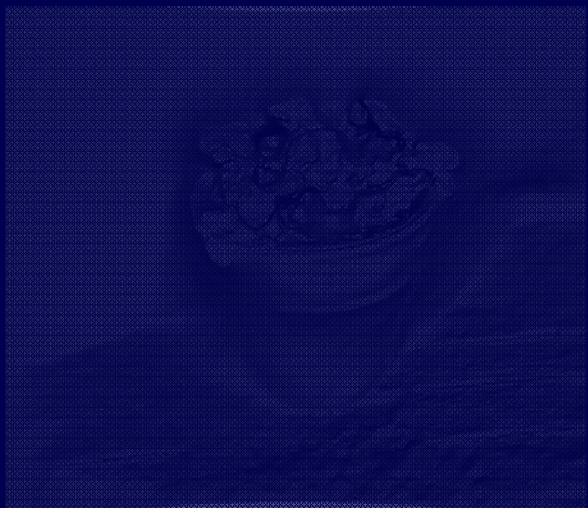
Multiview reconstruction



Single view reconstruction



Super-res.textures

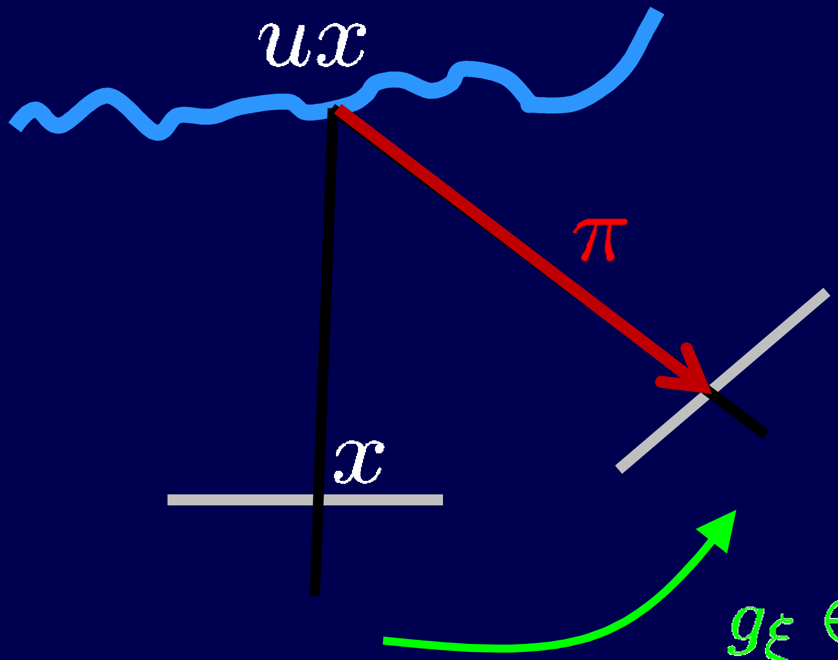


Realtime dense geometry

RGB-D scanning

Reconstruction on the fly

RGB-D Camera Tracking



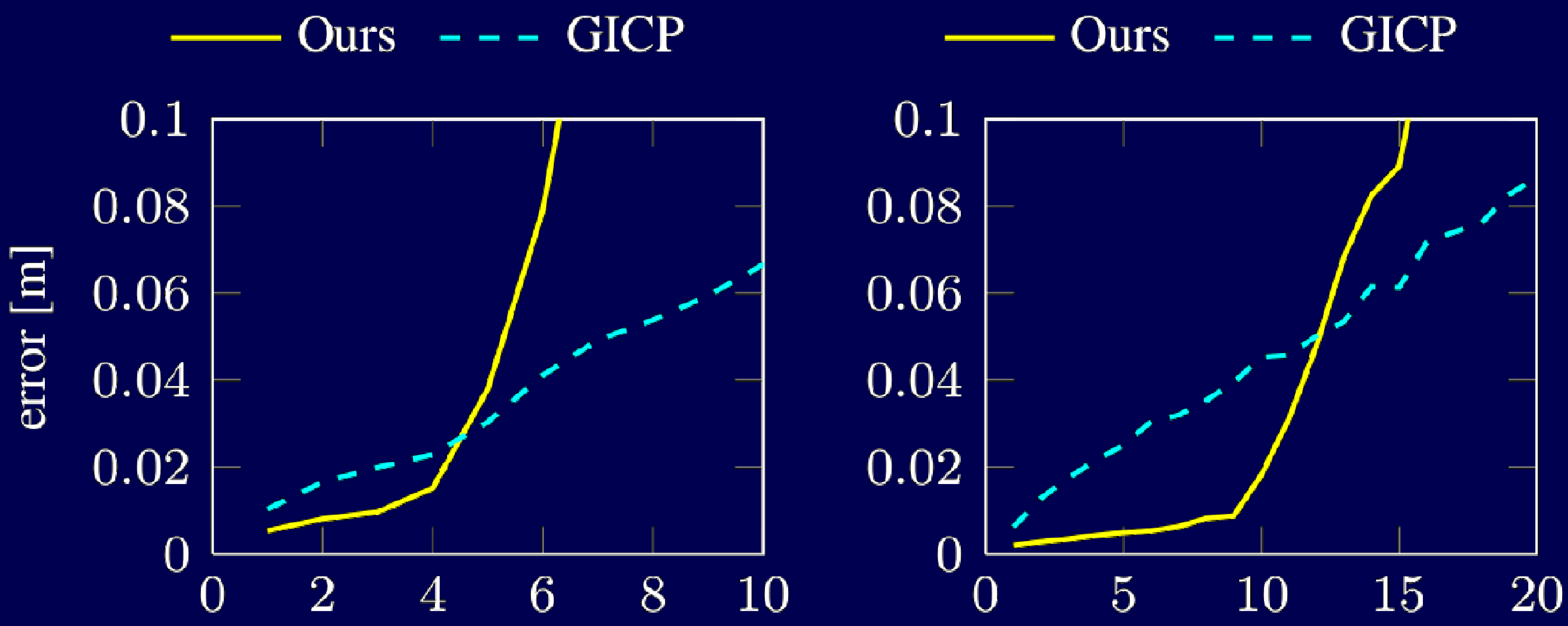
$$g_\xi \in SE(3), \qquad \xi \in \mathbb{R}^6$$

Optimize dense photo-consistency:

$$\min_{\xi \in \mathbb{R}^6} \int_\Omega \left| I_0(x) - I_i\Big(\pi\big(g_\xi(u \cdot x)\big)\Big) \right| dx$$

Steinbruecker et al. ICCV '11, Kerl et al., ICRA '13

Quantitative Comparison



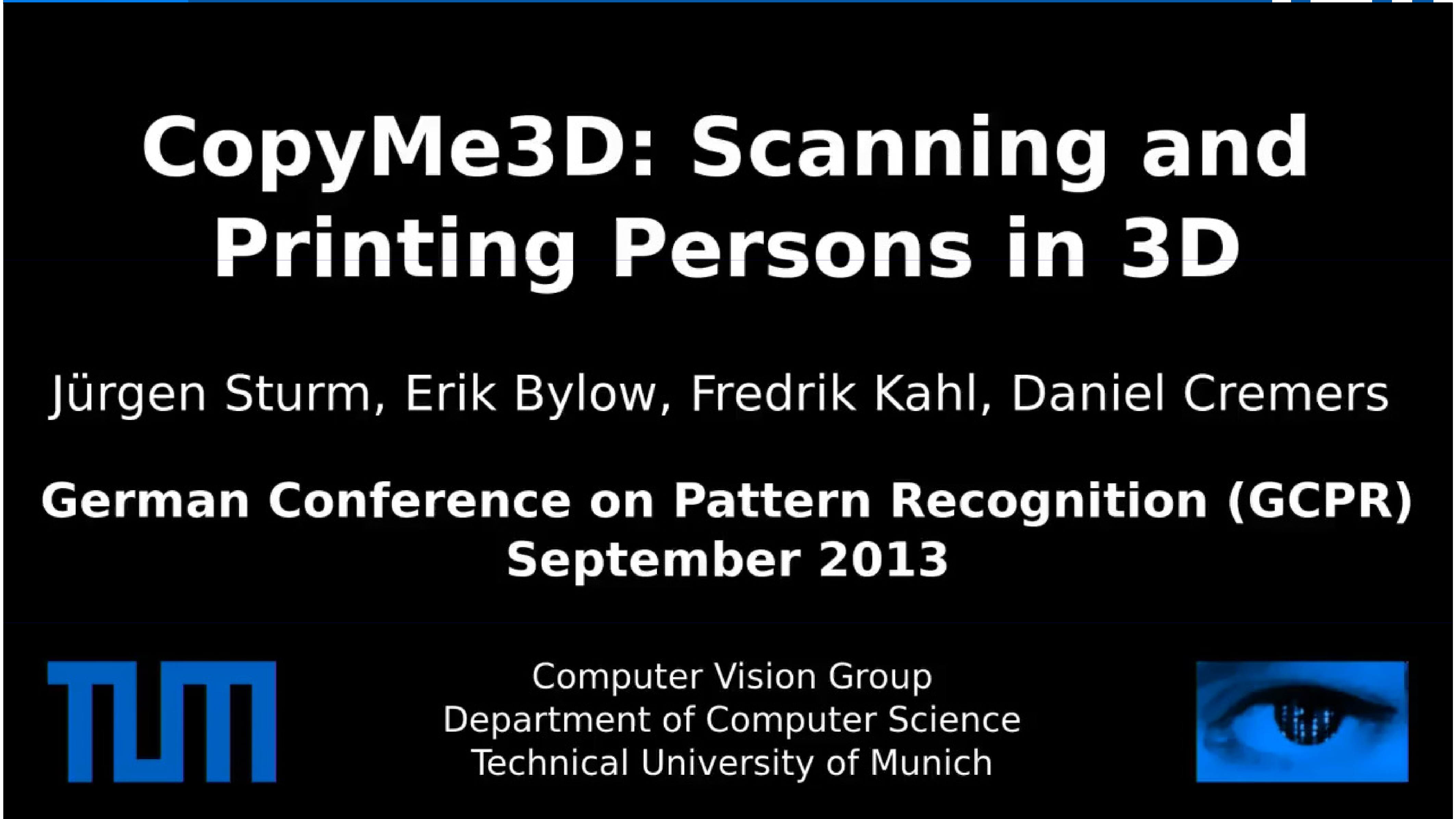
frame difference *k* — freiburg1/desk

frame difference *k* — freiburg2/desk

Pose accuracy for increasing baseline

Steinbruecker et al. ICCV '11, Kerl et al., ICRA '13

Realtime 3D Modeling



Download demo @ http://www.fablitec.com

Download demo @ http://www.fablitec.com

Realtime 3D Modeling

Download demo @ http://www.fablitec.com

Download demo @ http://www.fablitec.com

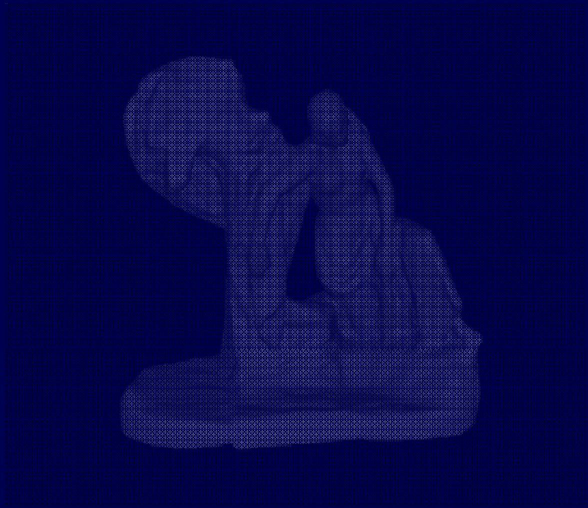
Realtime 3D Modeling

Download demo @ http://www.fablitec.com

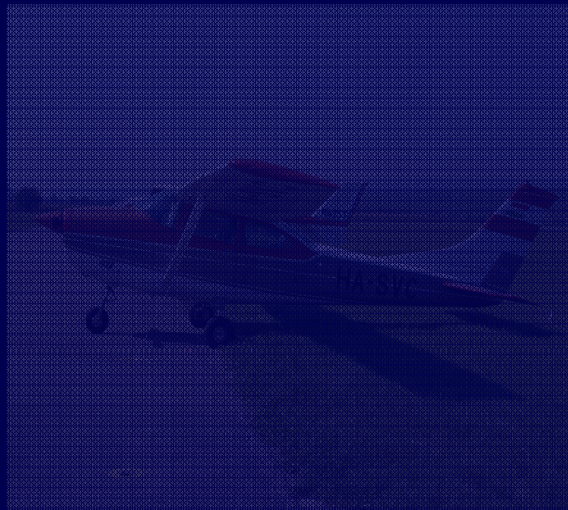
Realtime 3D Modeling

Download demo @ http://www.fablitec.com

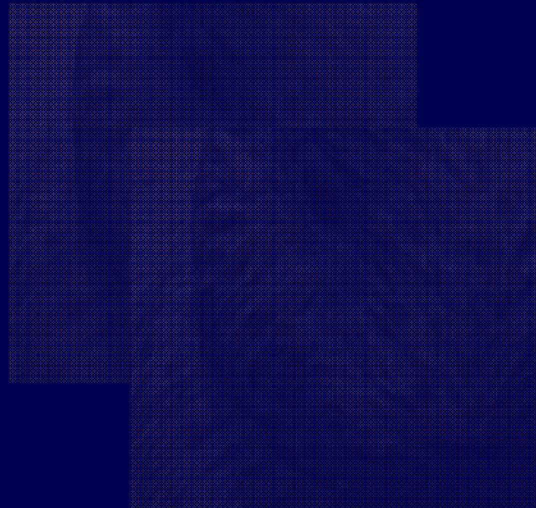
Overview



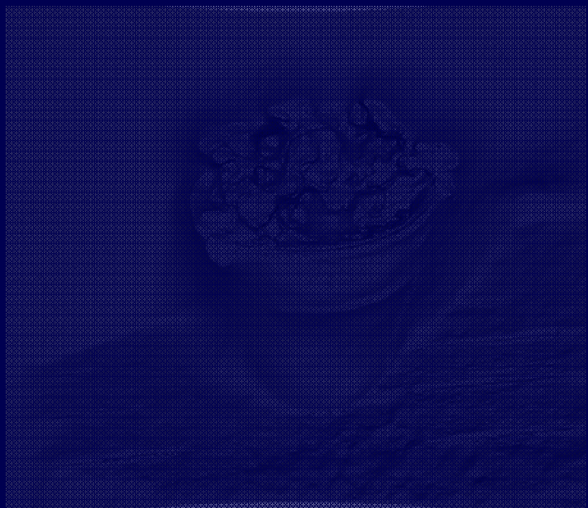
Multiview reconstruction



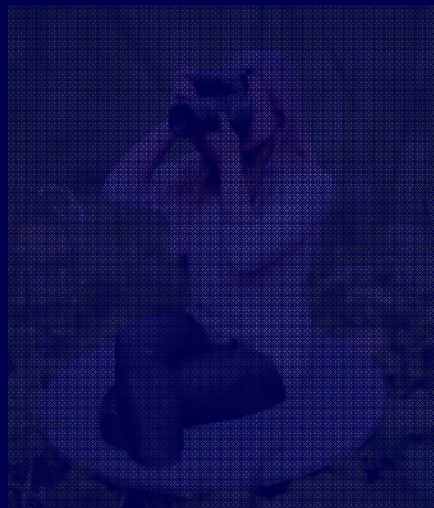
Single view reconstruction



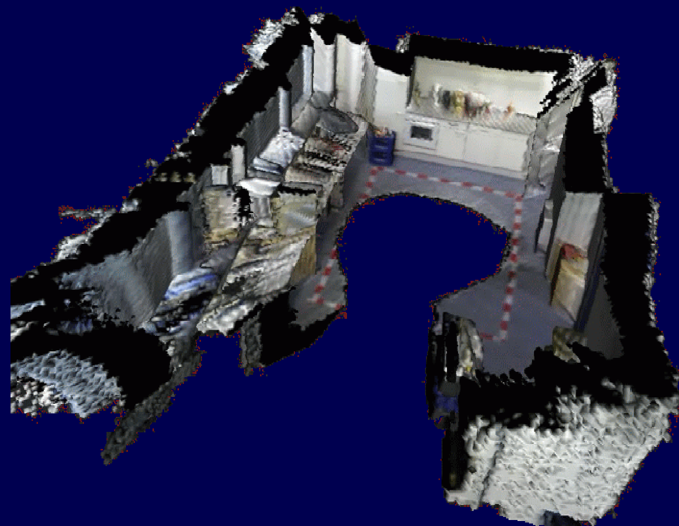
Super-res.textures



Realtime dense geometry

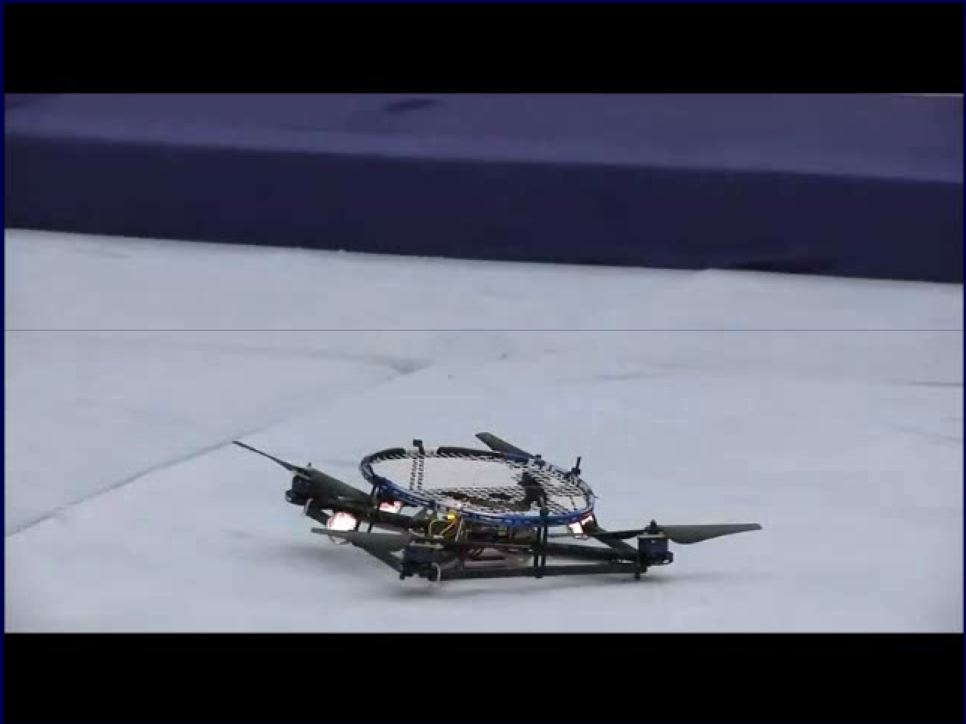


RGB-D scanning



Reconstruction on the fly

Quadrocopters



Quadrocopters juggling
Mueller, Lupashin, D'Andrea IROS '11

Swarms of quadcopters
Kushleyev, Mellinger, Kumar RSS '12

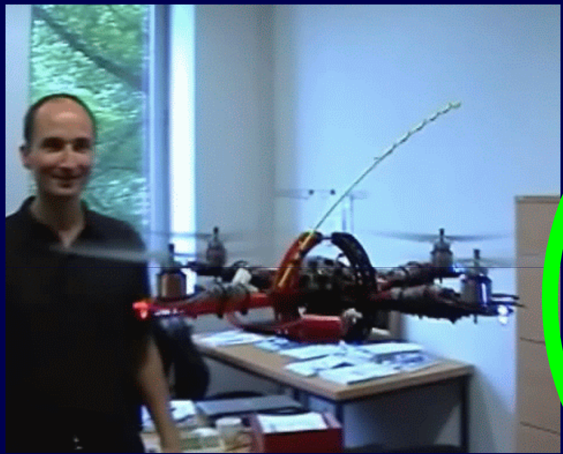
Drawbacks:
- Controlled environment
- Marker points
- External sensors / mocap systems

Realworld Environments





Quadcopters



Home-made

Parrot ARDrone

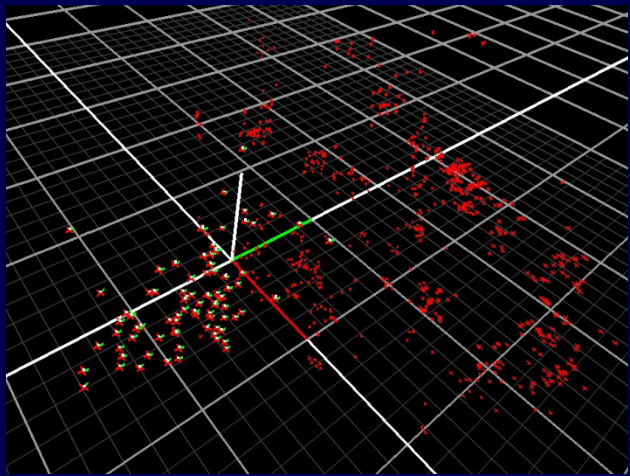
AscTec Pelican

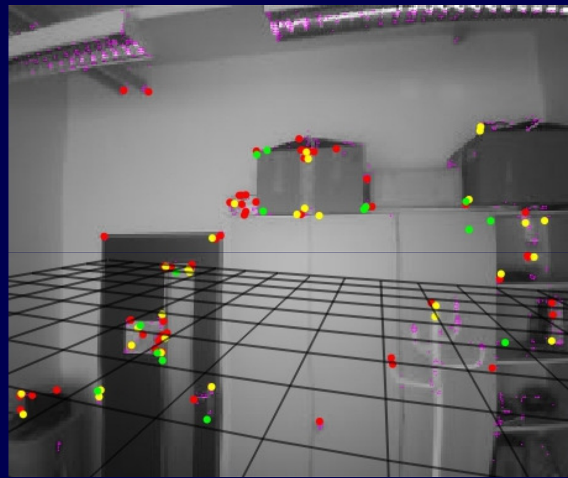
<u>Onboard sensors:</u>

- front camera (320 x 240 @ 18fps)
- inertial measurement unit
- ultrasound altimeter

Sensor Fusion

Open source mono-SLAM system PTAM *(Klein & Murray '07)*





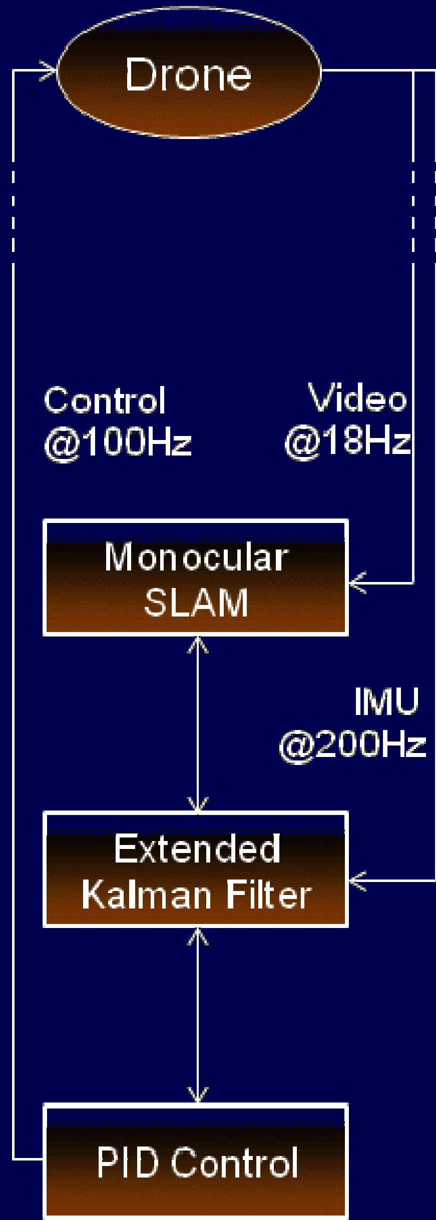
Problems: Unreliable, no scale

Our contribution:

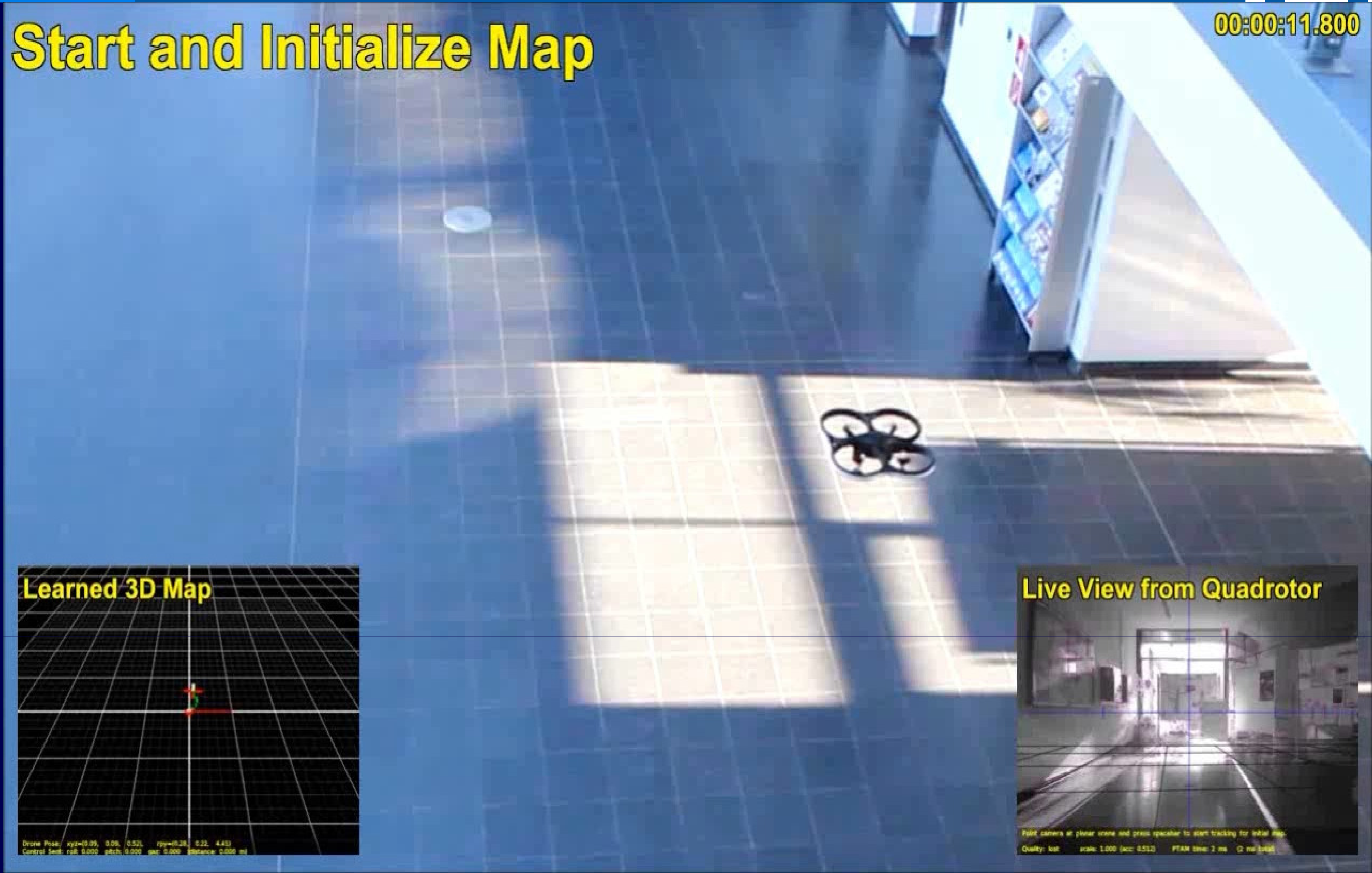
Enhanced reliability by incorporating IMU data

Maximum likelihood estimator for the scale using ultrasound altimeter & velocity estimates

Engel, Sturm, Cremers, IROS '12



Autonomous Flying & Hovering

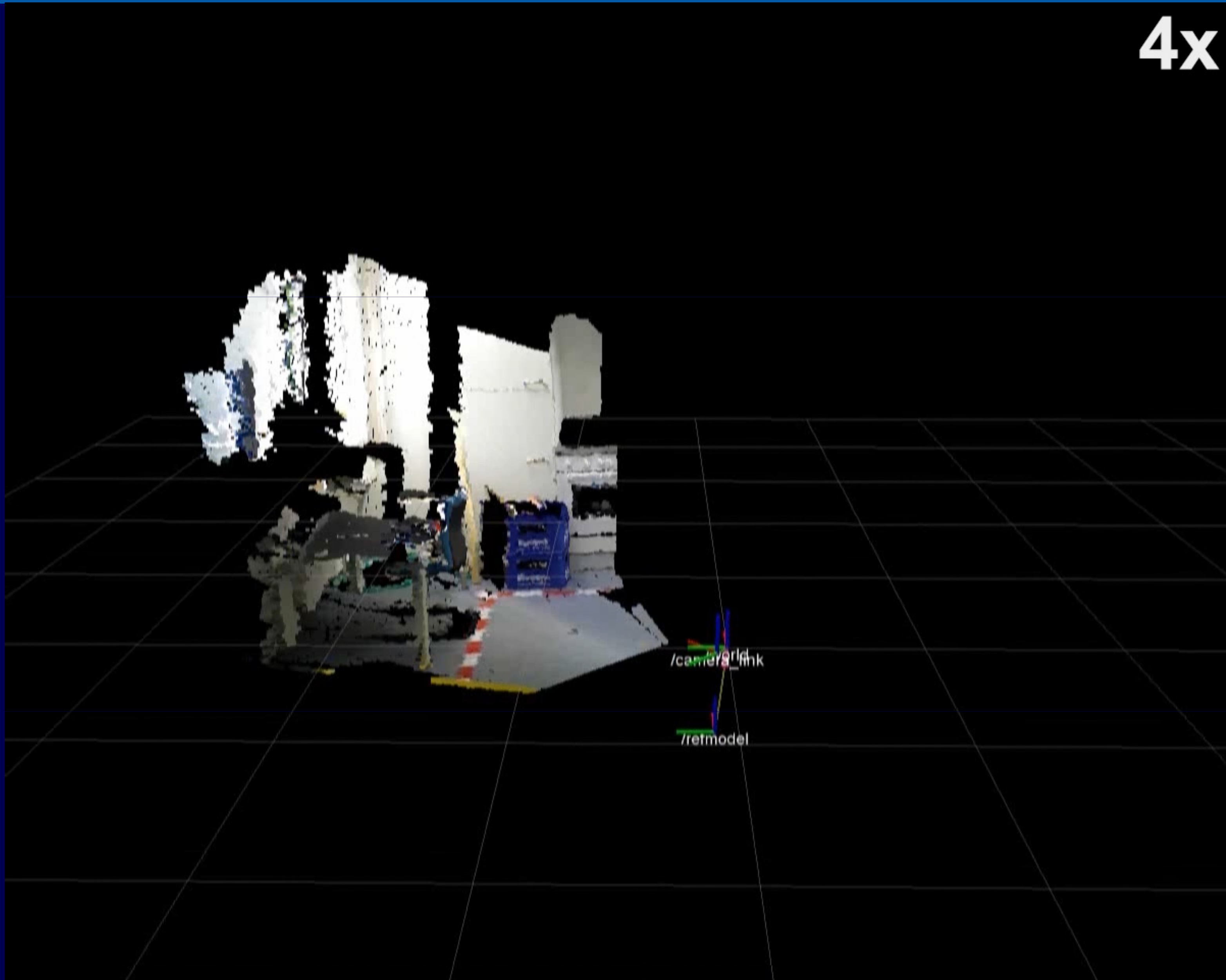


Engel, Sturm, Cremers, IROS '12

Reconstruction on the Fly

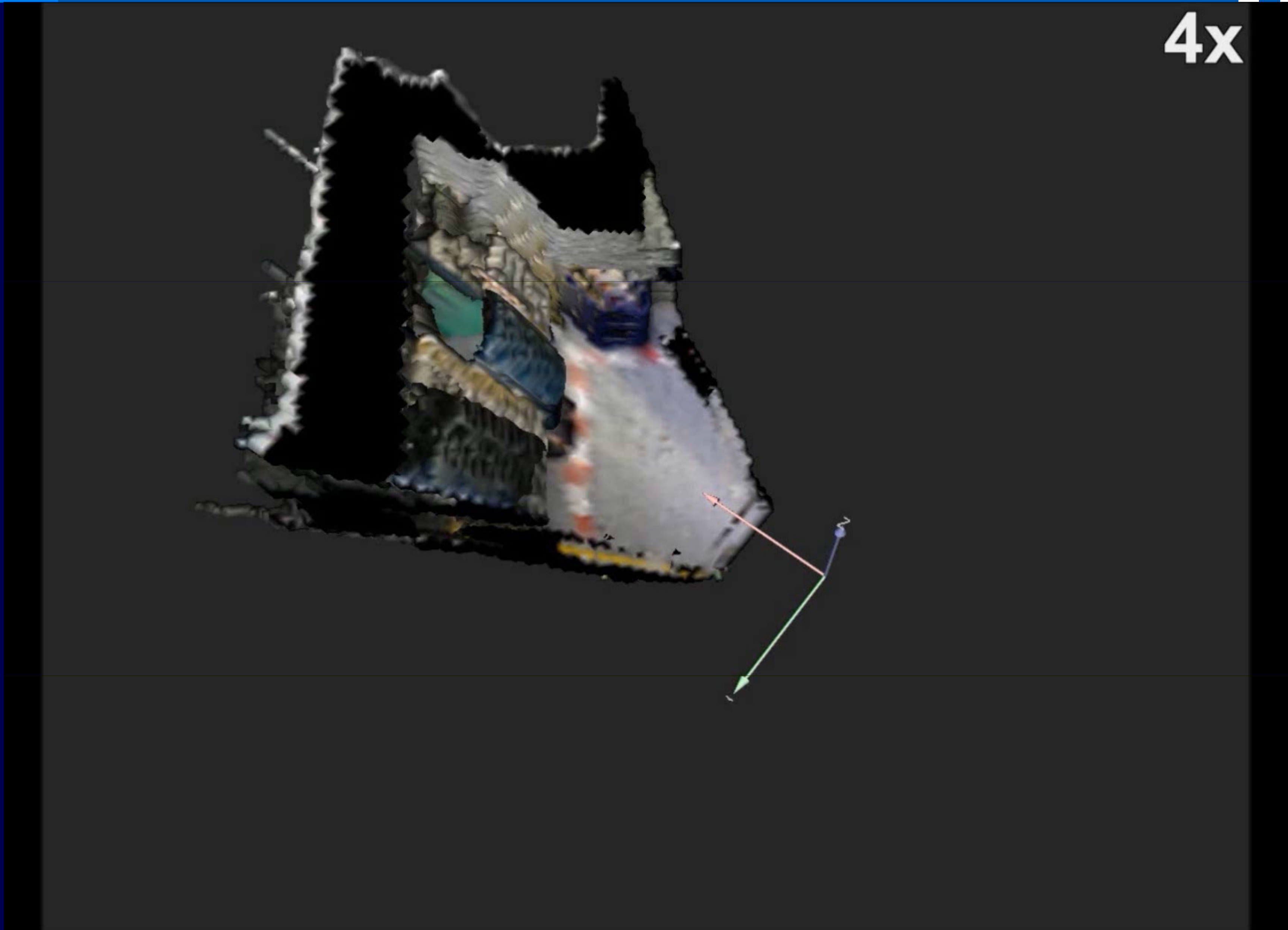
Bylow, Kerl, Sturm, Cremers, RSS '13

Reconstruction on the Fly



Bylow, Kerl, Sturm, Cremers, RSS '13

Reconstruction on the Fly

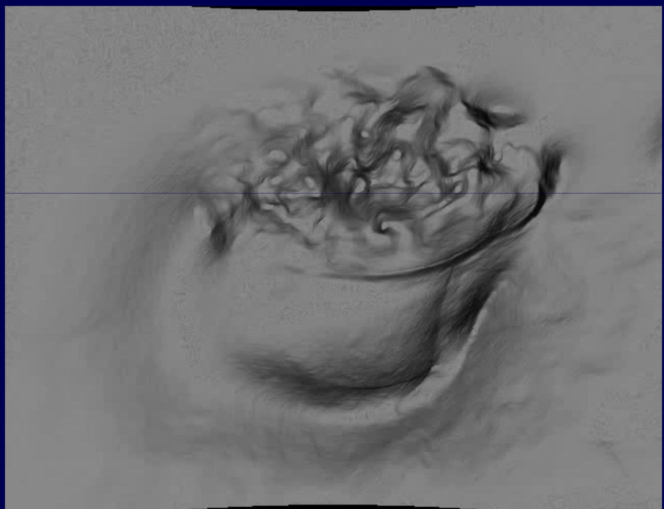


Bylow, Kerl, Sturm, Cremers, RSS '13

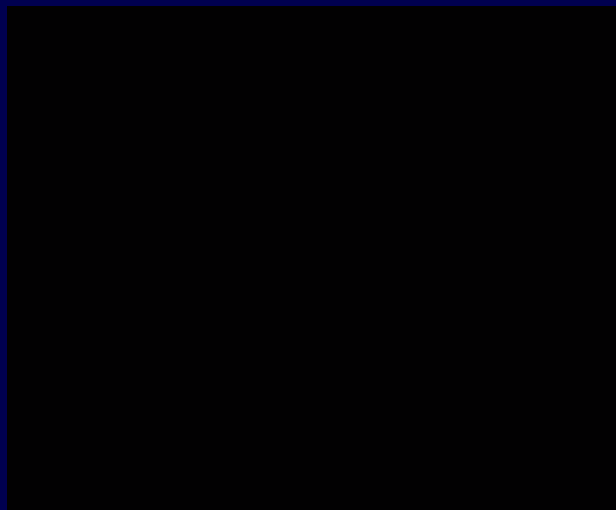
Multiview reconstruction

super-res. textures

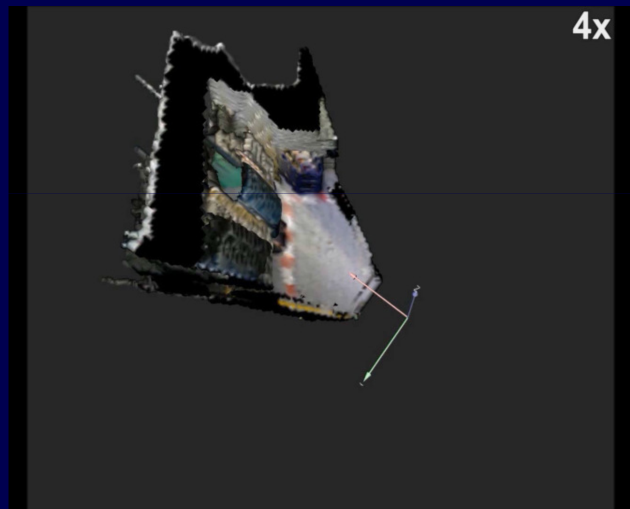
action reconstruction



Realtime reconstruction



RGB-D modeling



reconstruction on the fly