



Computer Vision I: Variational Methods

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Exercises



Marvin Eisenberger



Mohammed Brahimi

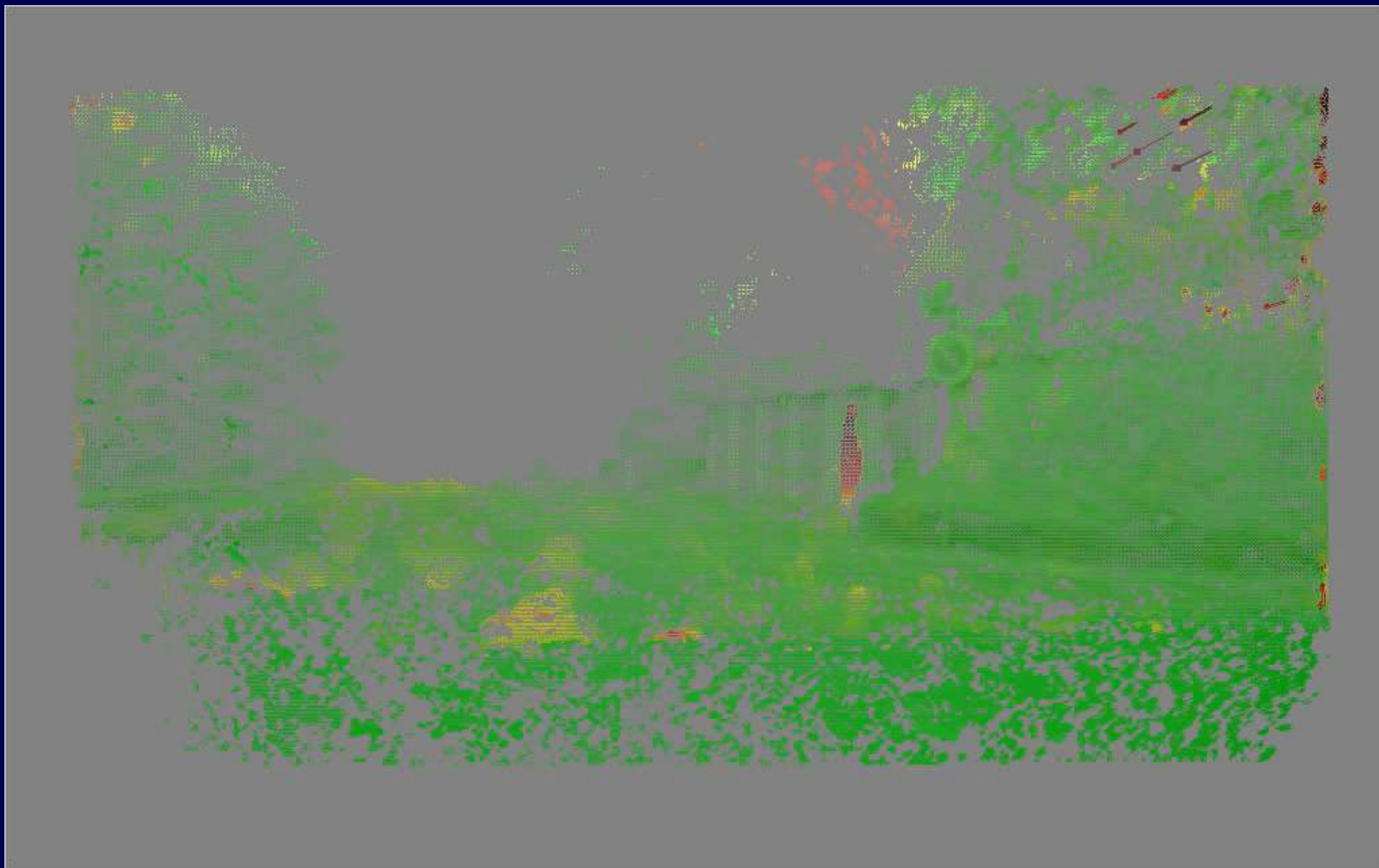


Original left image





Variational Scene Flow



Wedel et al. IJCV '11, Wedel & Cremers, Springer 2011



ECCV 2018

European Conference
on Computer Vision

8 – 14 September 2018 | Munich, Germany



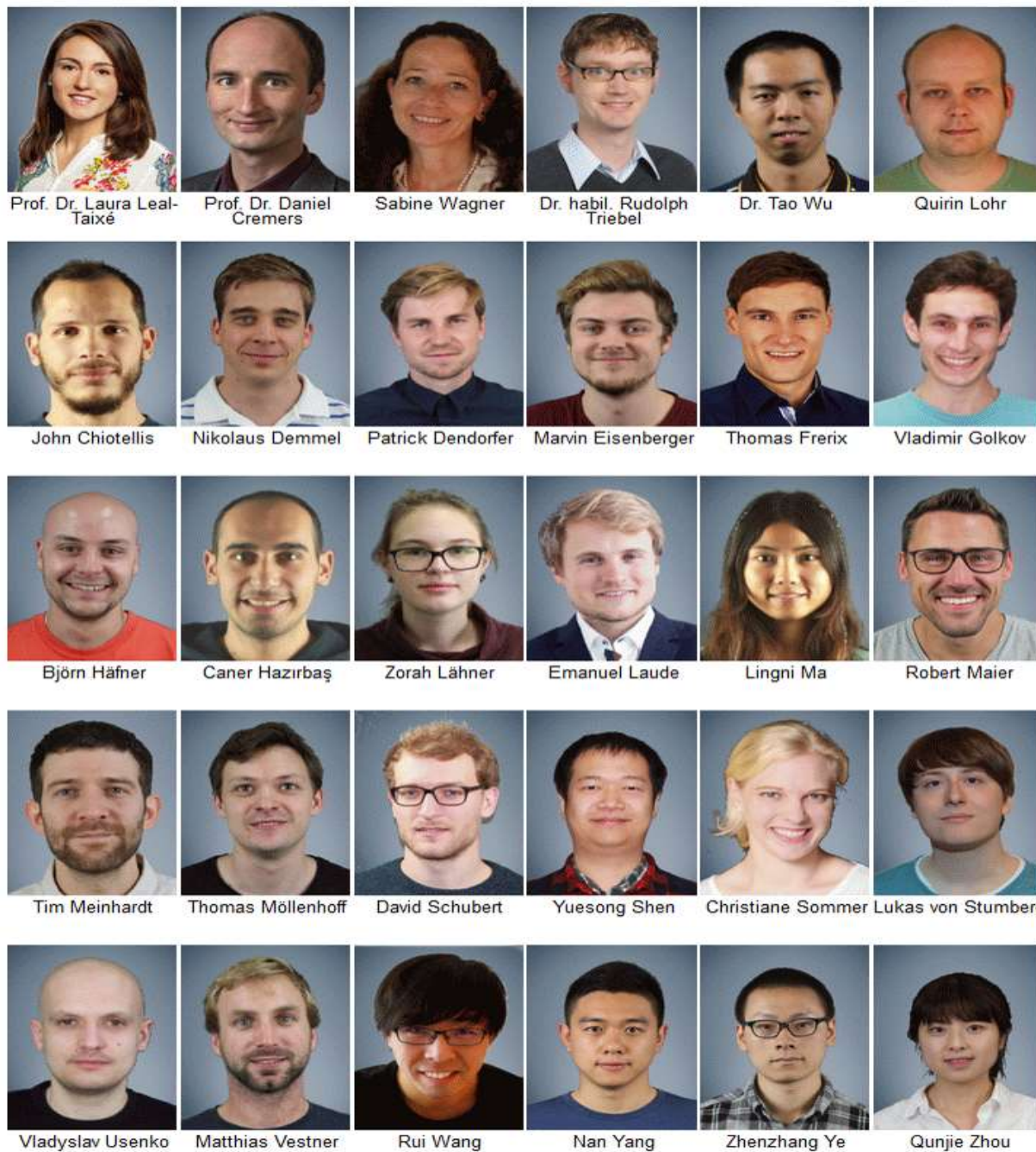
3300 delegates!

Technische
Universität
München





The TUM Computer Vision Group



Spatially Dense 3D Reconstruction



infinite-dimensional optimization

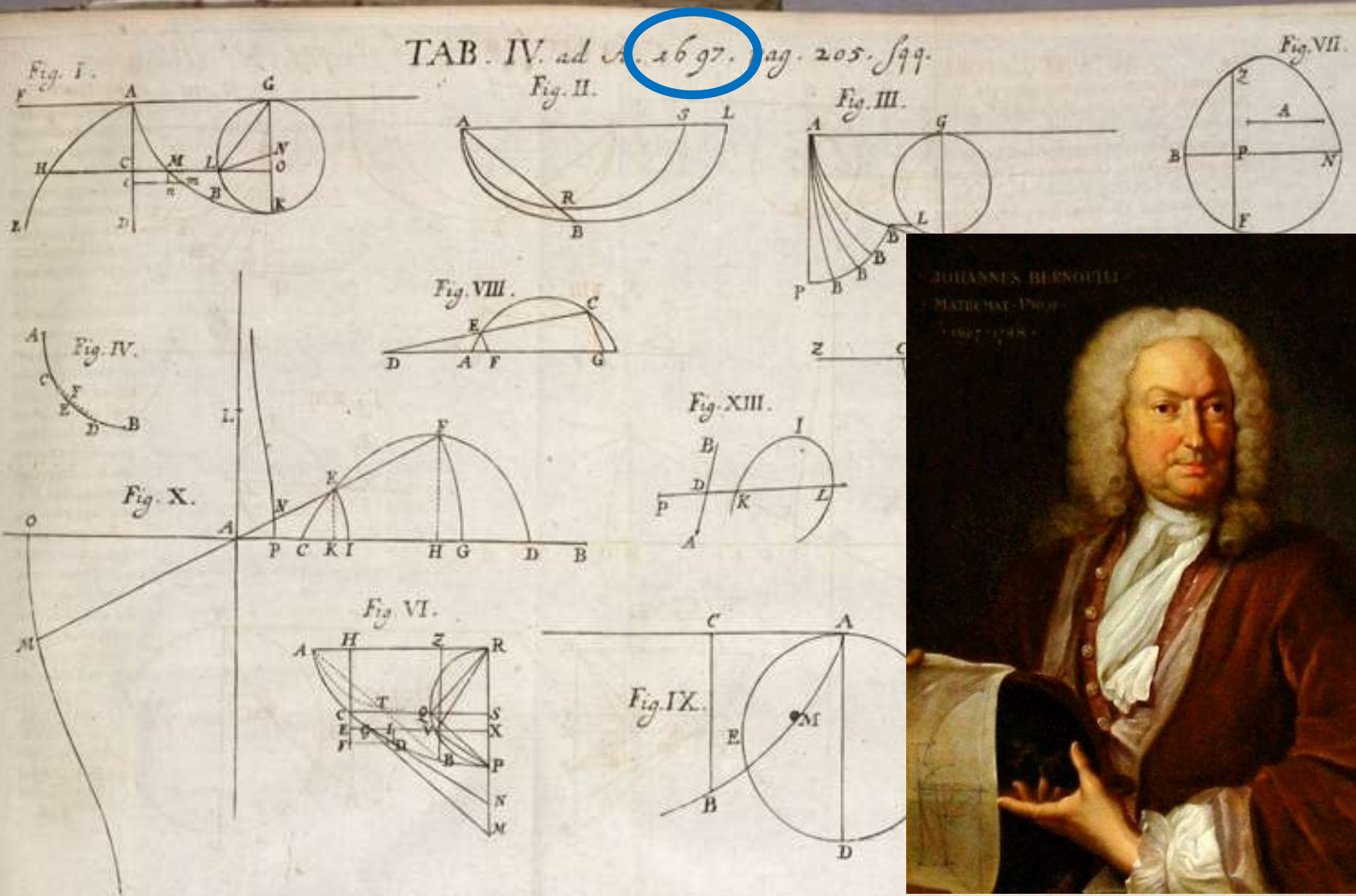


Which path is the fastest?





Bernoulli & The Brachistochrone



Johann Bernoulli (1667-1748)



Image segmentation:

*Geman, Geman '84, Blake, Zisserman '87, Kass et al. '88,
Mumford, Shah '89, Caselles et al. '95, Kichenassamy et al. '95,
Paragios, Deriche '99, Chan, Vese '01, Tsai et al. '01, ...*

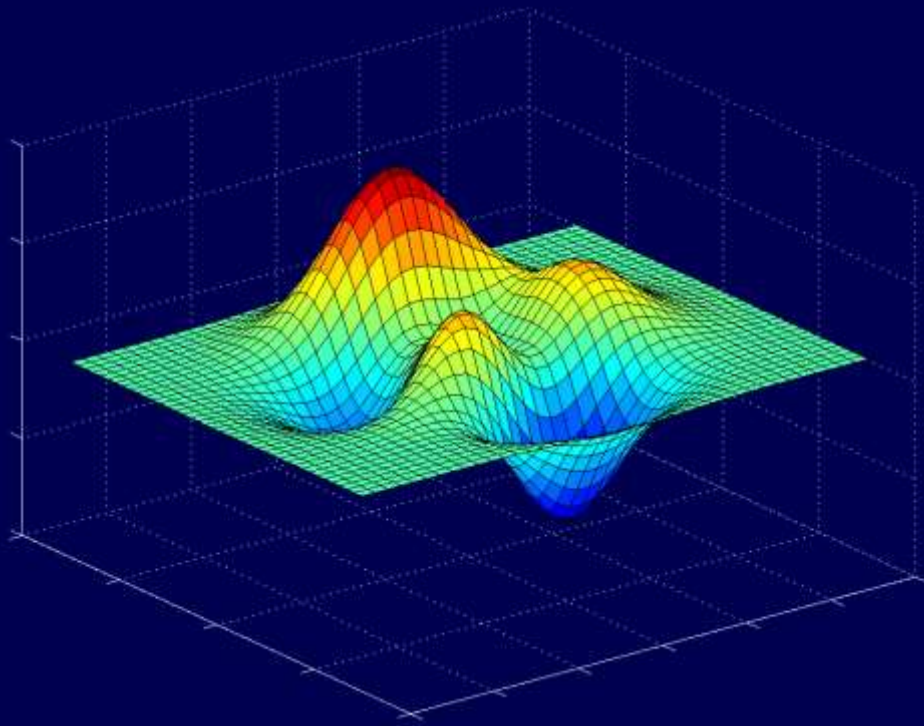
Multiview stereo reconstruction:

Non-convex energies

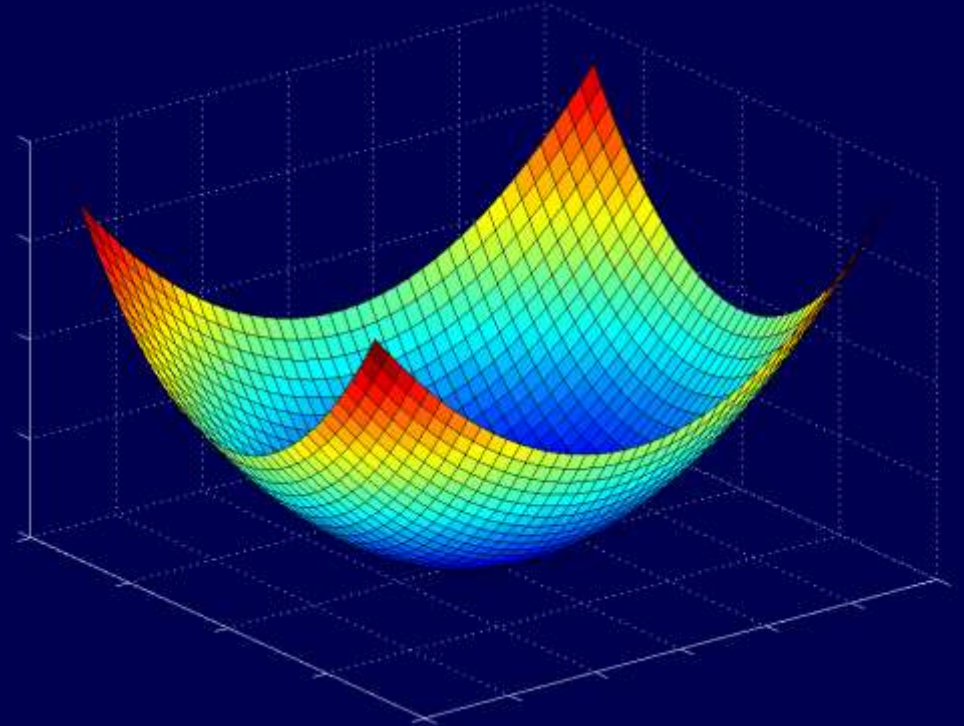
*Faugeras, Keriven '96, Duan et al. '04, Yezzi, Sapiro '03,
Seitz et al. '06, Hernandez et al. '07, Labatut et al. '07, ...*

Optical flow estimation:

*Horn, Schunck '81, Nagel, Enkelmann '86, Black, Anandan '93,
Alvarez et al. '99, Brox et al. '04, Baker et al. '07, Zach et al. '07,
Sun et al. '08, Wedel et al. '09, ...*



Non-convex energy



Convex energy

Inverse Problems: Denoising



image $f : \Omega \rightarrow \mathbb{R}^3$, $\Omega \subset \mathbb{R}^2$

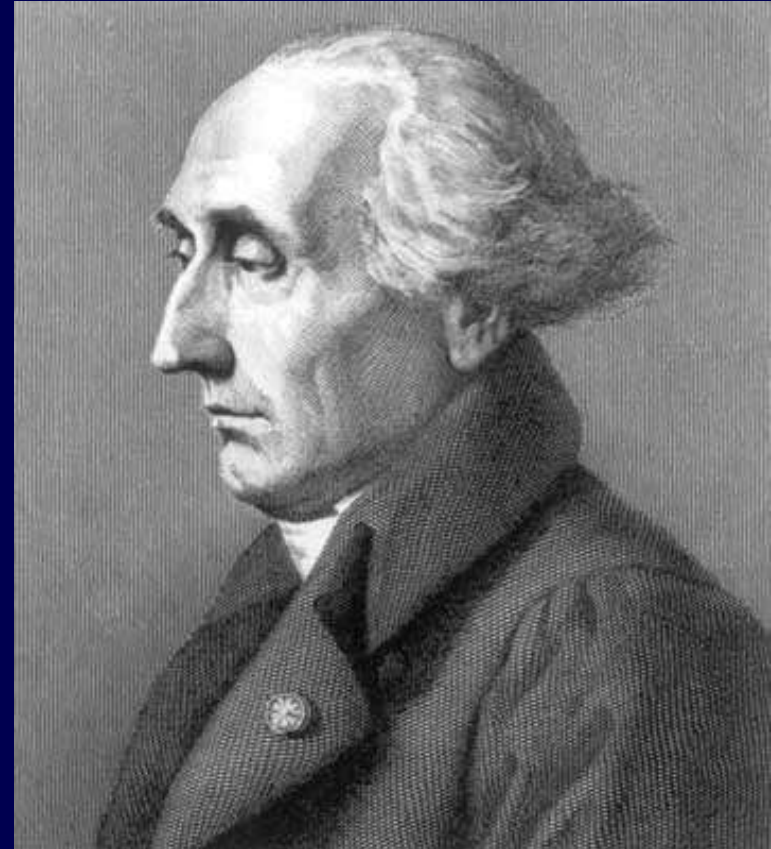
denoised image $u_{den} : \Omega \rightarrow \mathbb{R}^3$

$$u_{den} = \arg \min_u \int_{\Omega} (u - f)^2 dx + \lambda \int_{\Omega} |\nabla u| dx$$

Rudin, Osher, Fatemi 1992, Goldlücke, Strekalovskiy, Cremers 2012



Leonhard Euler
(1703-1783)

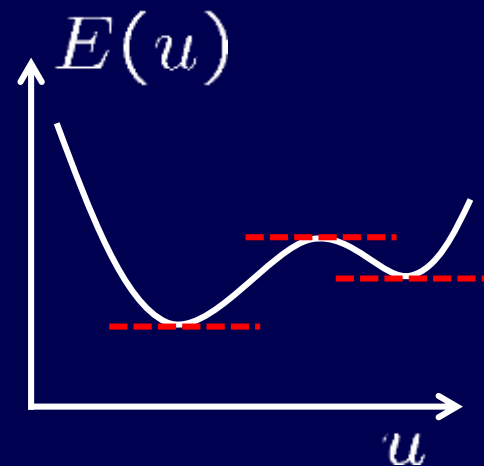


Joseph-Louis Lagrange
(1736 – 1813)

$$E(u) = \int_{\Omega} (u - f)^2 + \lambda |\nabla u| dx = \int_{\Omega} \mathcal{L}(u, u') dx$$

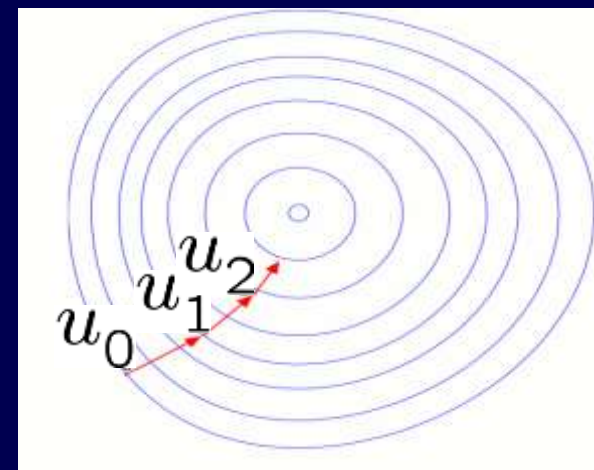
Euler-Lagrange equation as necessary condition:

$$\frac{dE}{du} = \frac{\partial \mathcal{L}}{\partial u} - \frac{d}{dx} \left(\frac{\partial \mathcal{L}}{\partial u'} \right) = 0$$



Gradient descent:

$$\frac{\partial u}{\partial t} = - \frac{dE}{du}$$





Overview



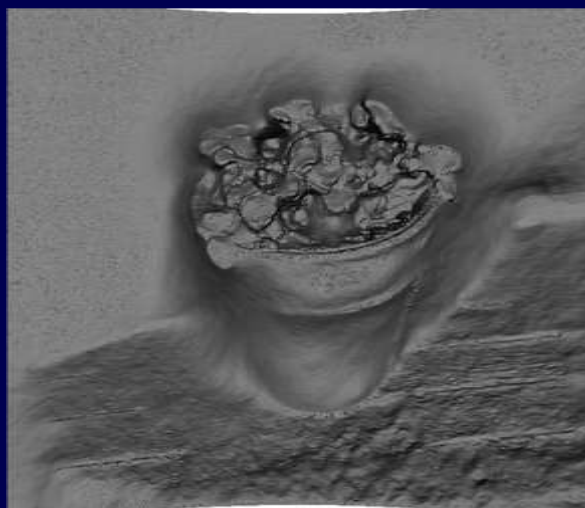
Multiview reconstruction



Super-res.textures



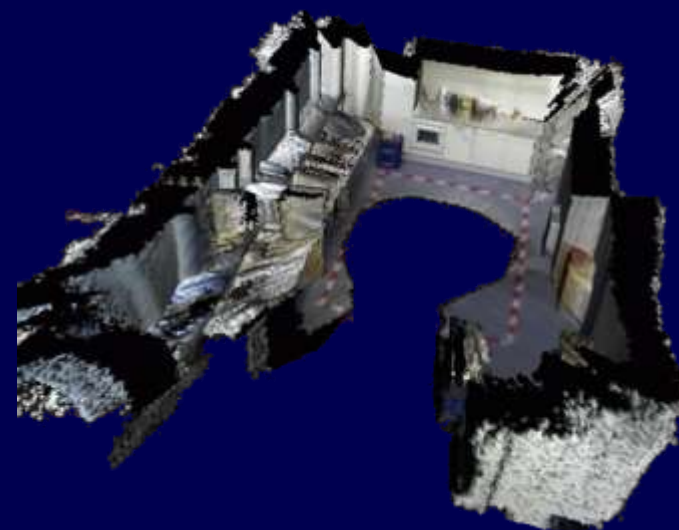
Stereo reconstruction



Realtime dense geometry



RGB-D cameras



Reconstruction on the fly



Overview



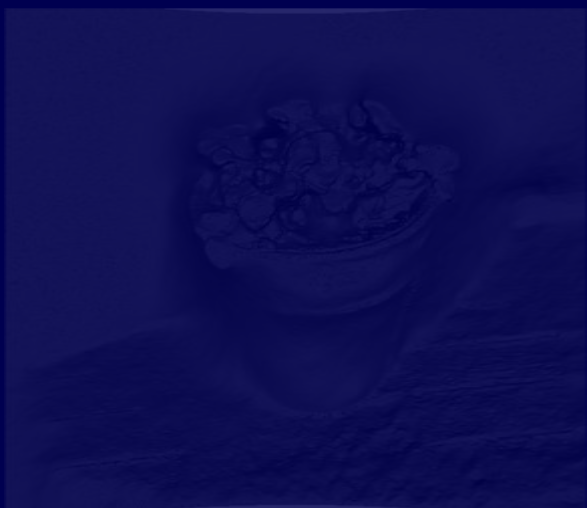
Multiview reconstruction



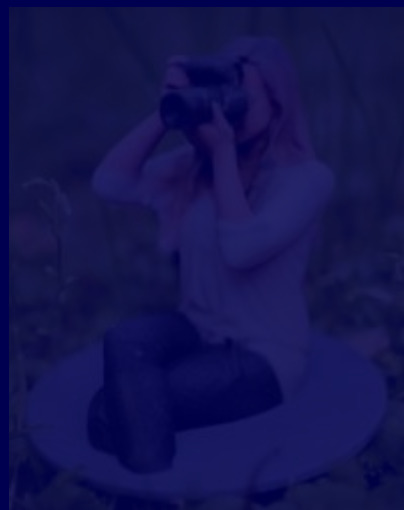
Super-res.textures



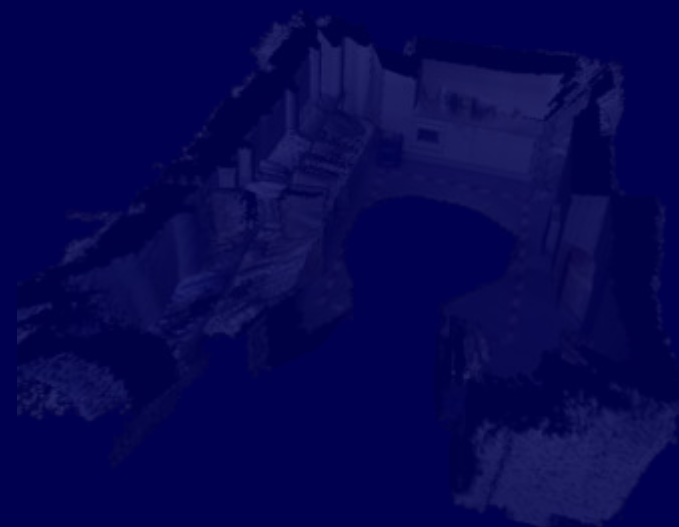
Stereo reconstruction



Realtime dense geometry

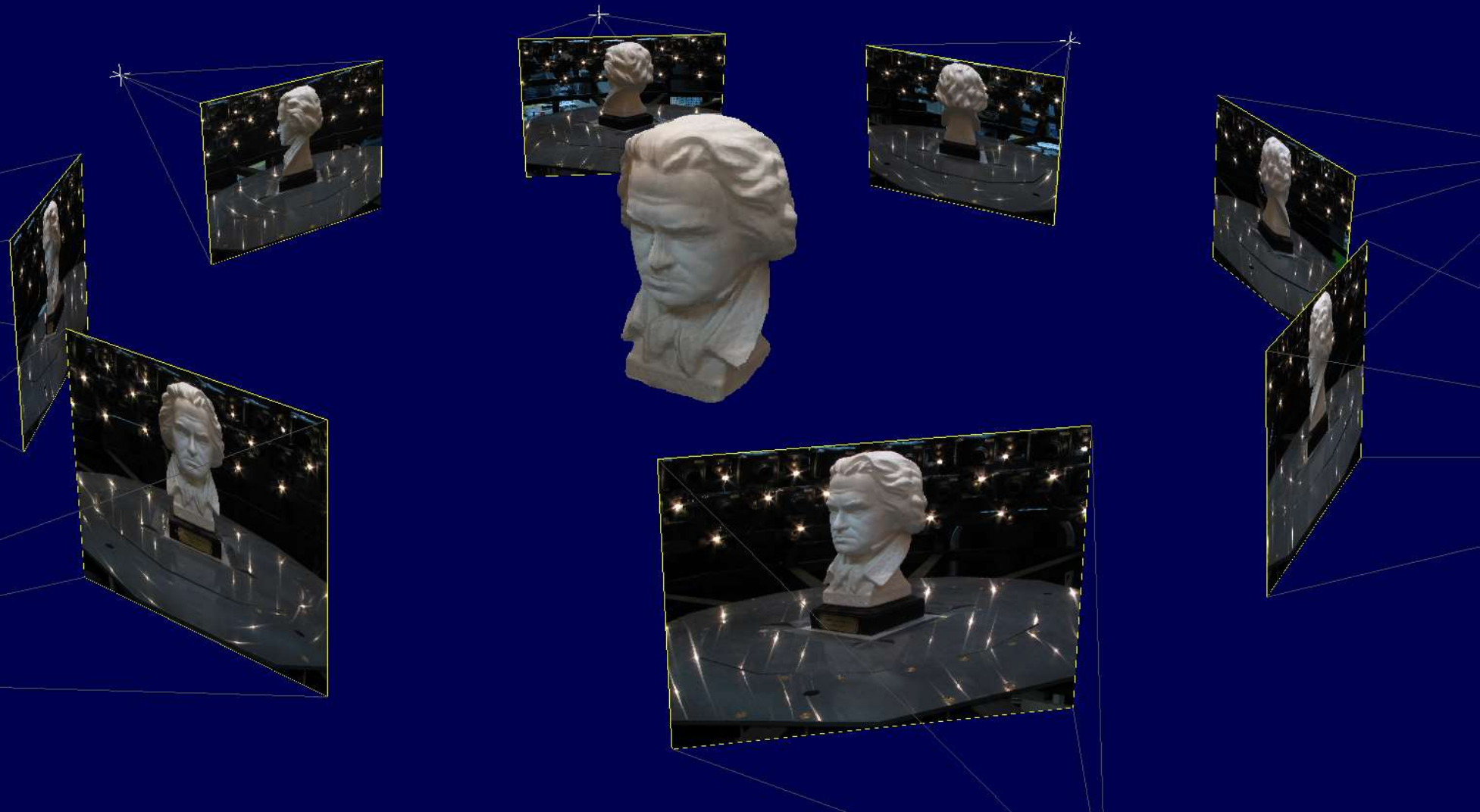


RGB-D cameras



Reconstruction on the fly

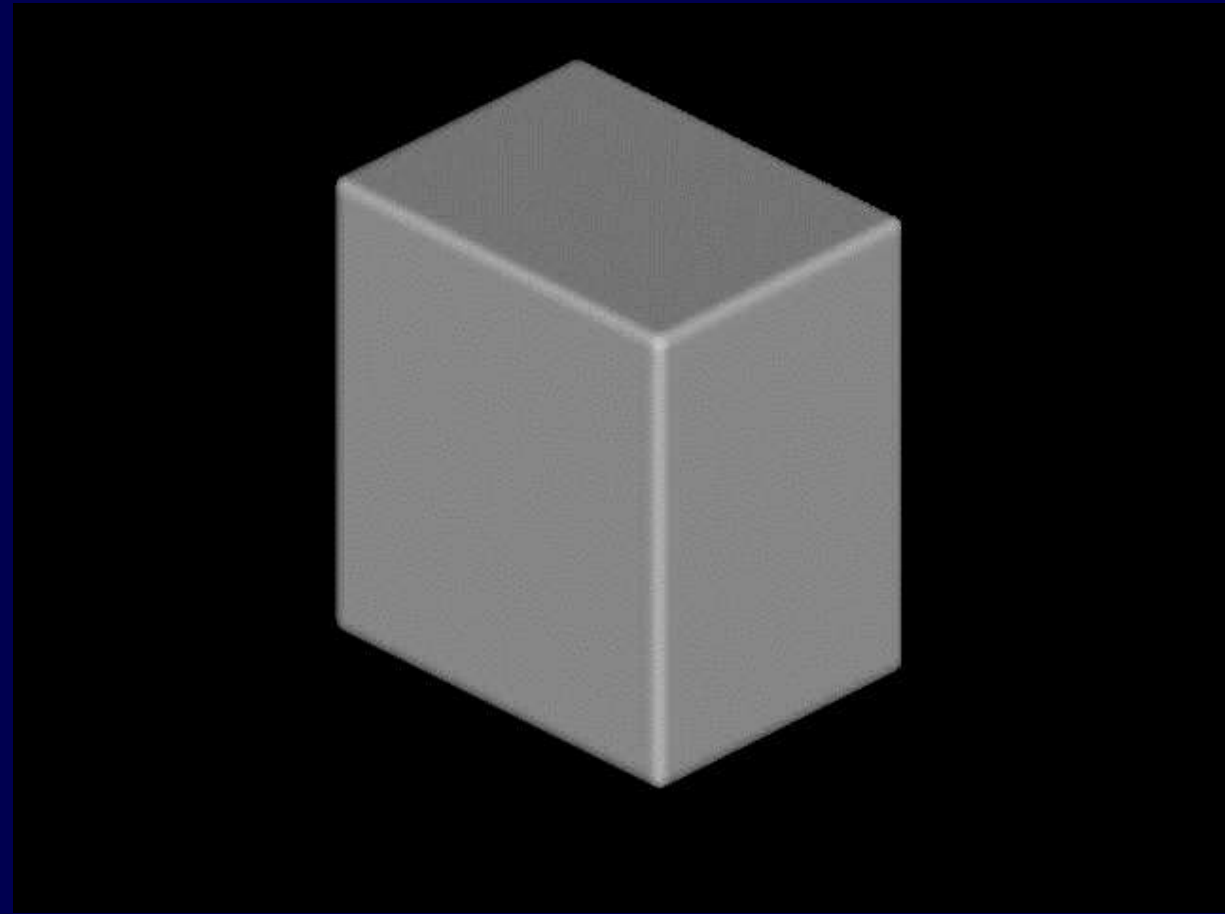
3D Reconstruction from Multiple Views



Kolev, Klodt, Brox, Cremers, Int. J. of Computer Vision '09:

Theorem: Globally optimal surfaces can be computed by convex optimization.

Evolution to Global Optimum



Kolev, Klodt, Brox, Cremers, Int. J. of Computer Vision '09:

Theorem: Globally optimal surfaces can be computed by convex optimization.



Reconstruction of Fine-scale Structures



Image data courtesy of Yasutaka Furukawa.



Reconstructing the Niobids Statues



Kolev, Cremers, ECCV '08, PAMI '11

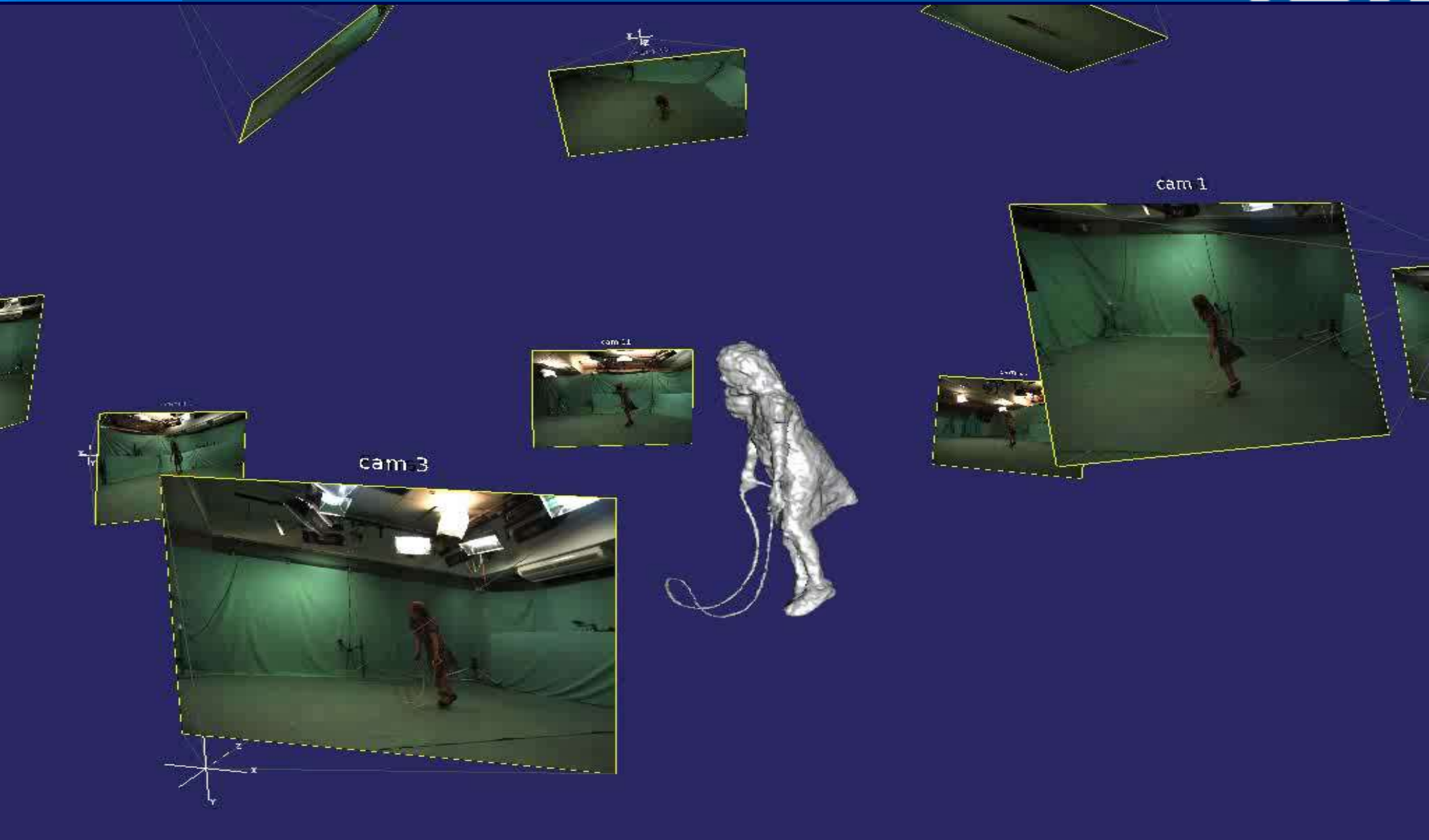


Multiview Reconstruction



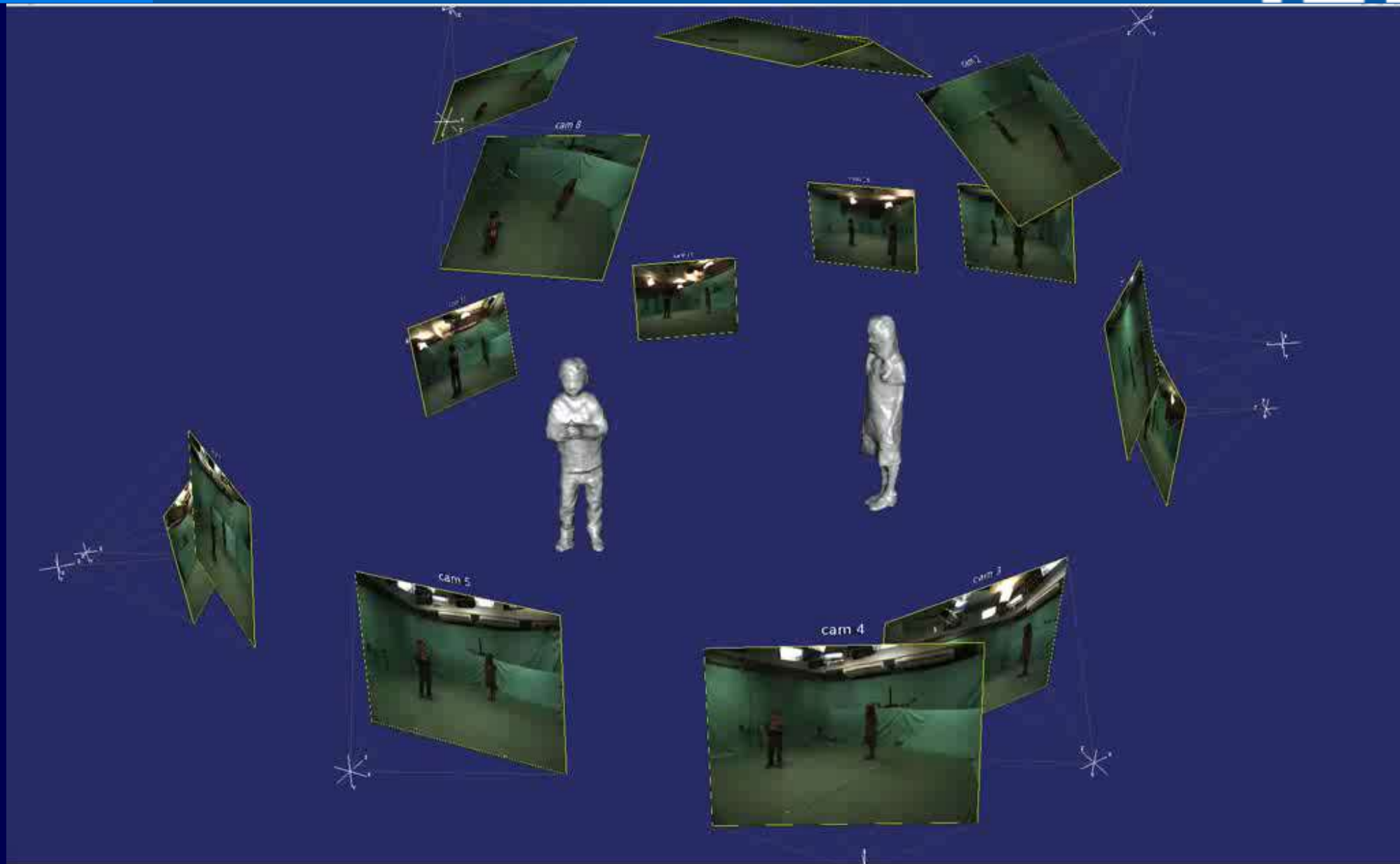
Kolev, Cremers, ECCV '08, PAMI '11

Reconstructing Dynamic Scenes



Oswald, Stühmer, Cremers, ECCV '14

Action Reconstruction



Oswald, Stühmer, Cremers, ECCV '14

Single View Reconstruction



Can we recover geometry from a single image?

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

Solution: Fixed-volume silhouette-consistent minimal surface.

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

Single View Reconstruction



Toeppe, Oswald, Rother, Cremers, ACCV 2010

Single View Reconstruction



Input



Reconstruction



+30% volume



+40% volume

Reconstruction computed in fractions of a second on GPU

Toeppe et al. ACCV 2010, Oswald et al. CVPR 2012

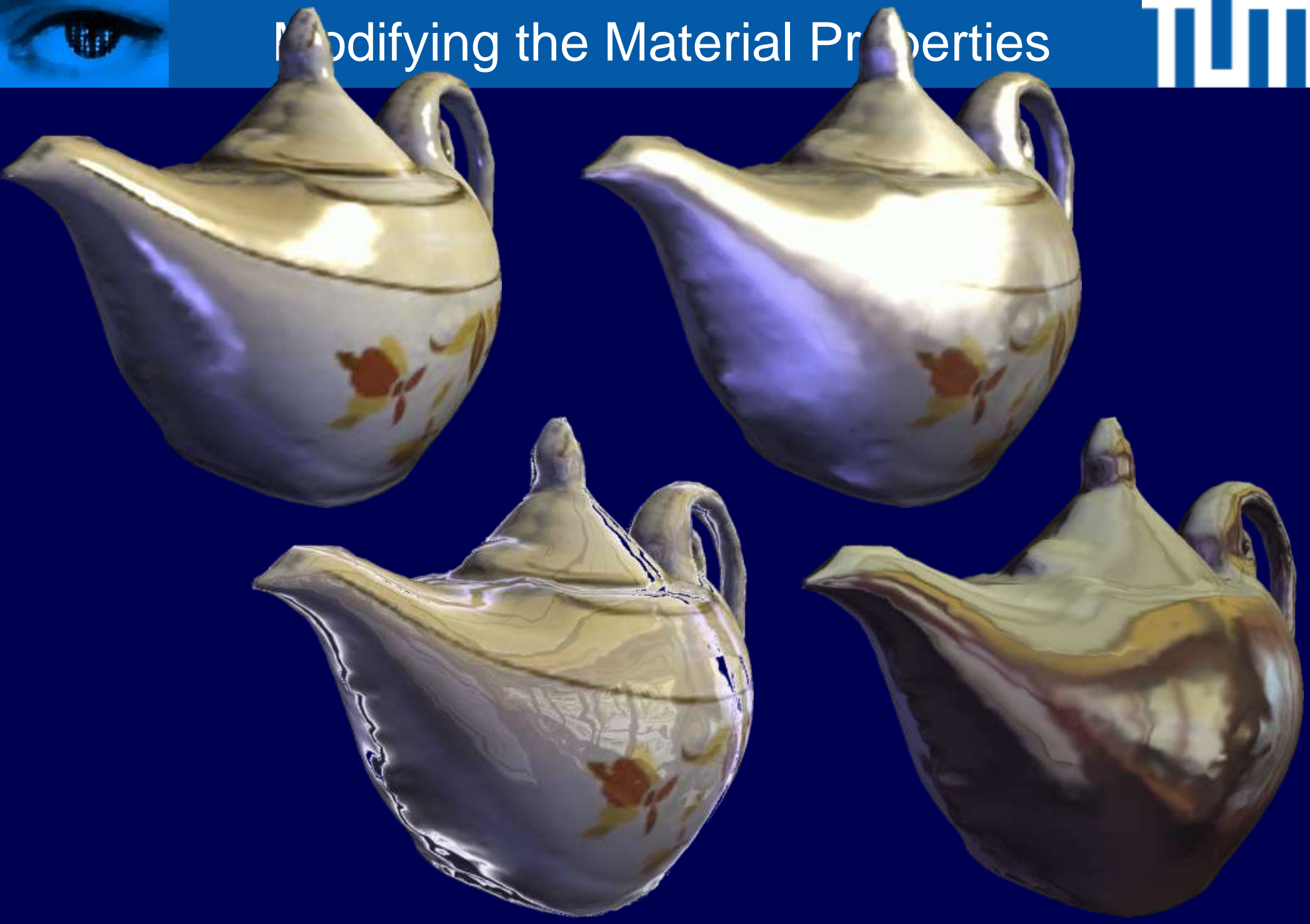
Single View Reconstruction



Toeppe, Oswald, Rother, Cremers, ACCV 2010



Modifying the Material Properties

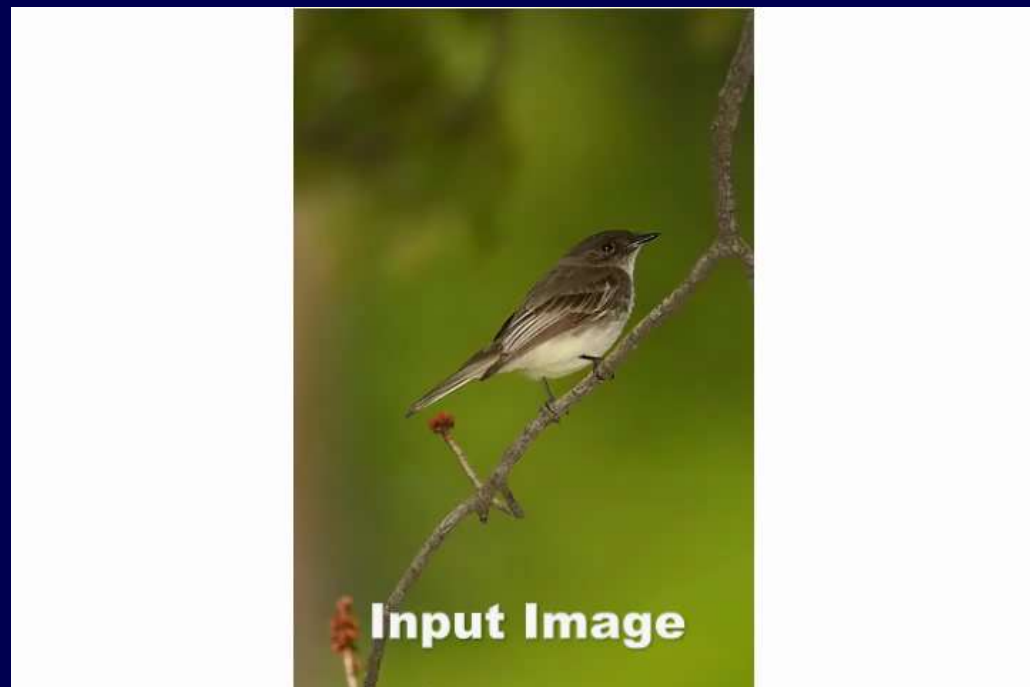


Single View Reconstruction



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



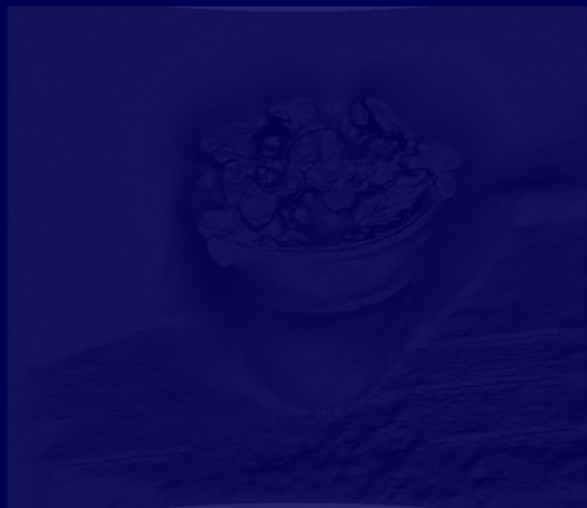
Multiview reconstruction



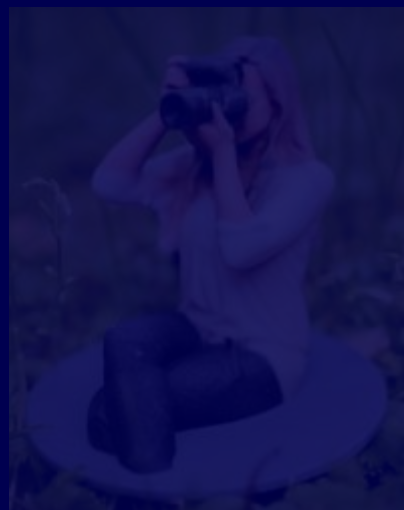
Super-res.textures



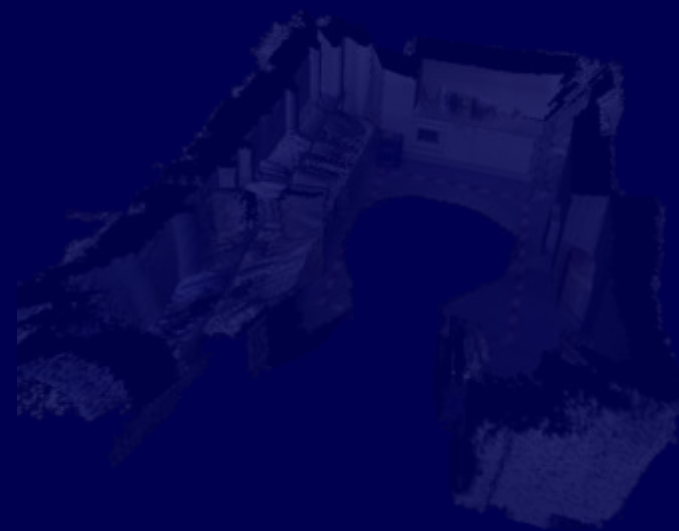
Stereo reconstruction



Realtime dense geometry

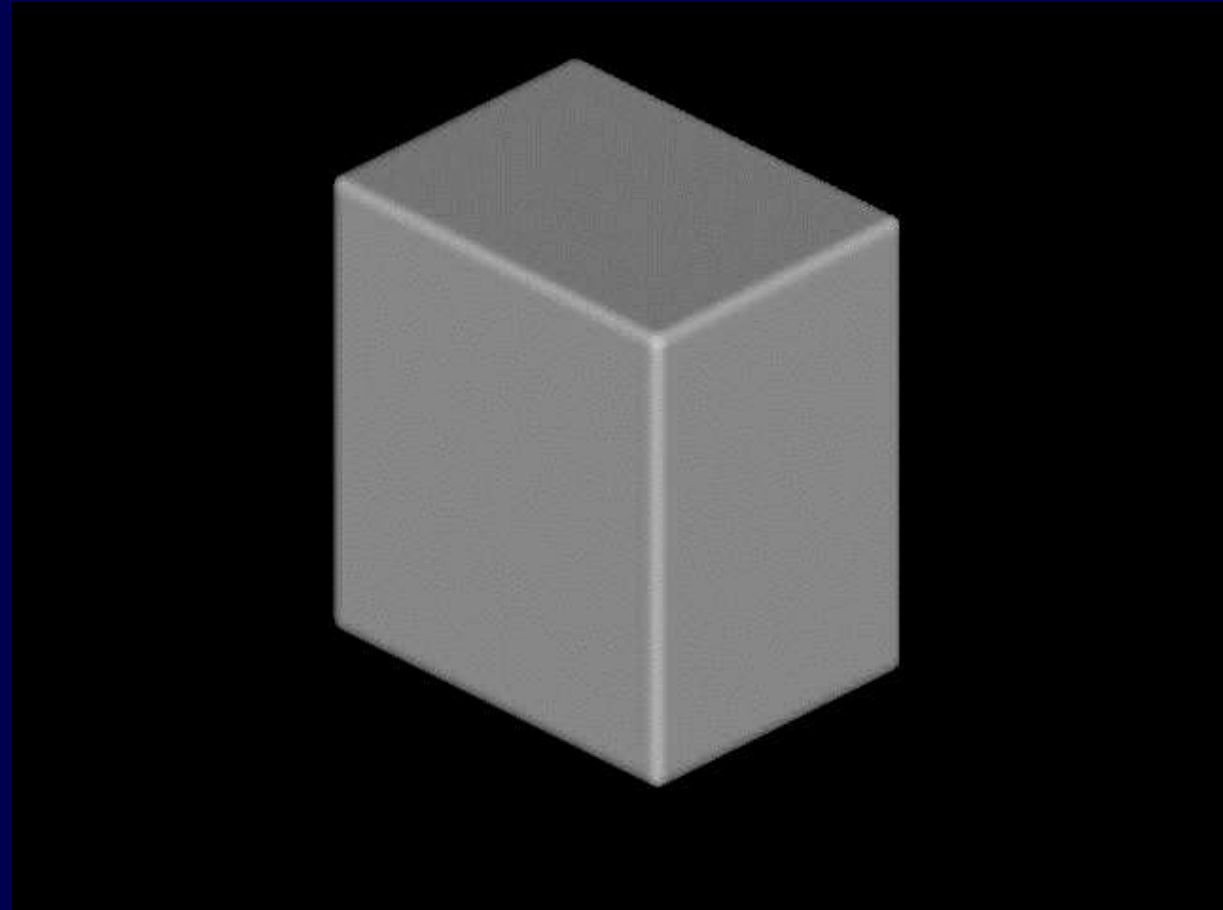
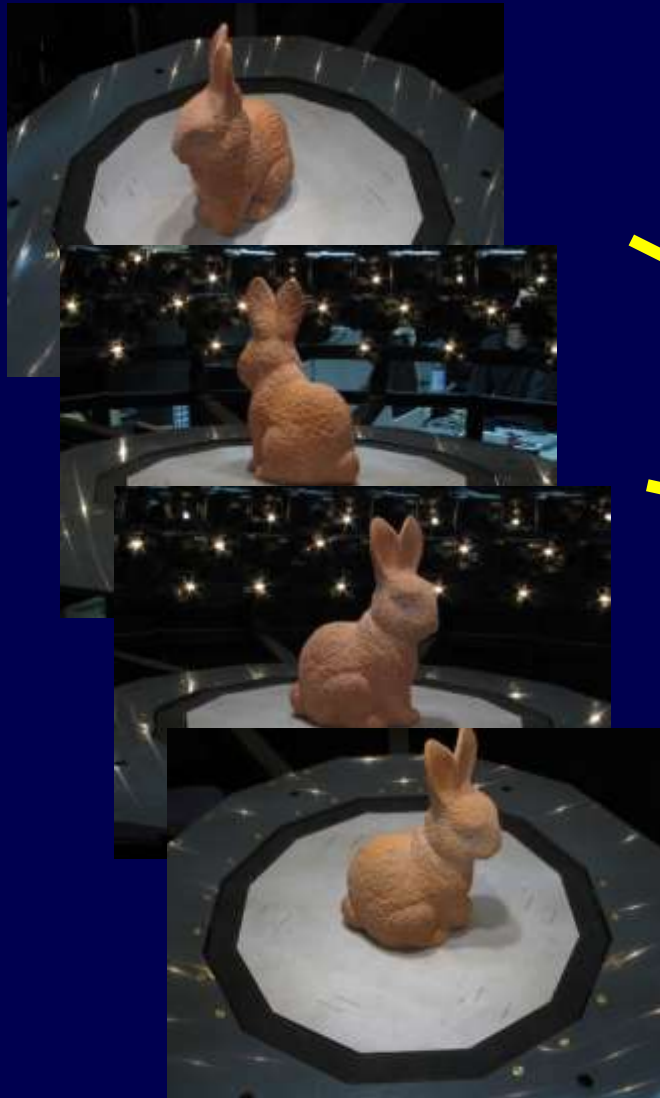


RGB-D cameras



Reconstruction on the fly

Evolution to Global Optimum



Kolev, Klodt, Brox, Cremers, IJCV 2009

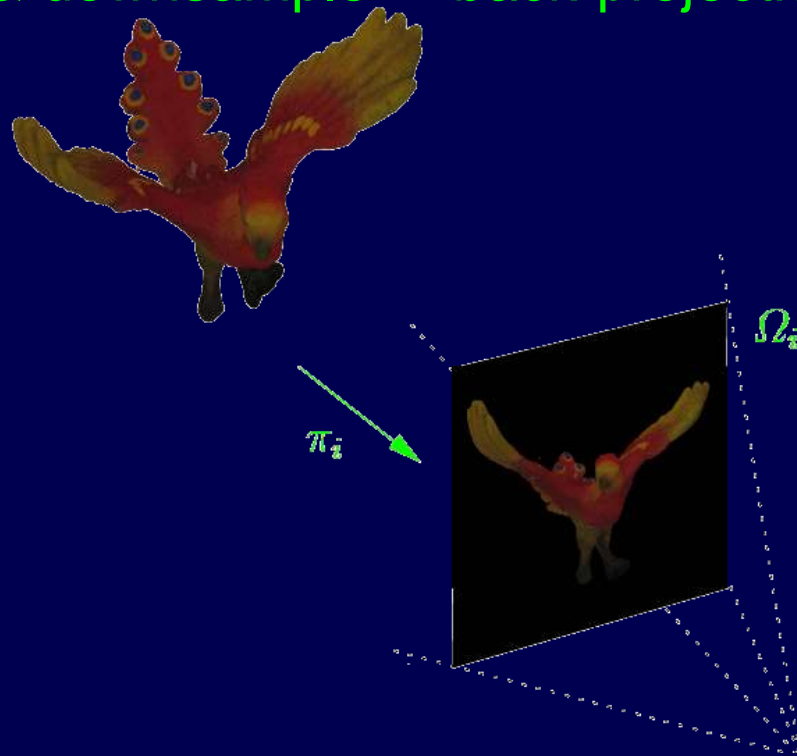
Super-Resolution Texture Map

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

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

blur & downsample

back-projection

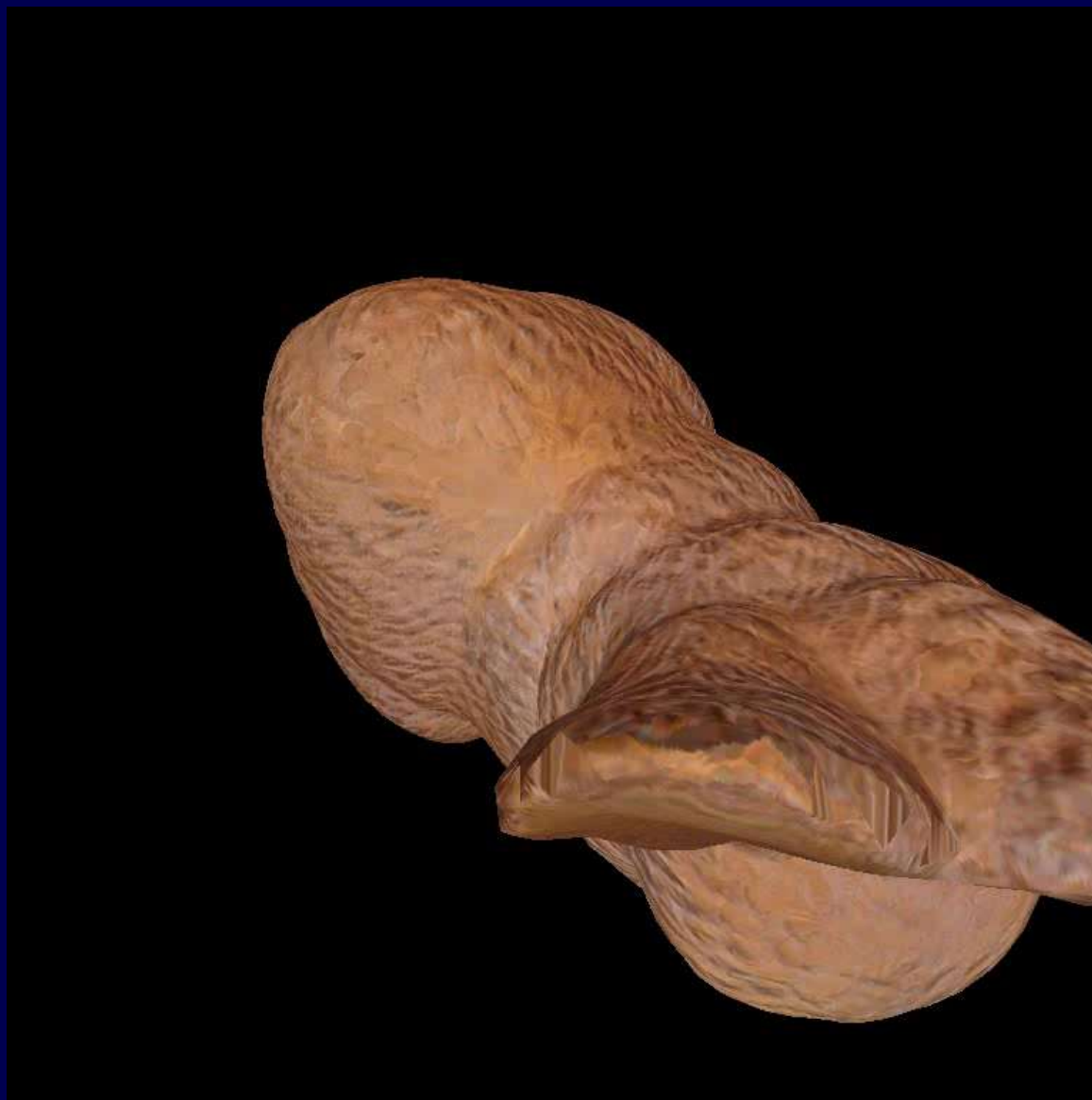


Goldlücke, Cremers, ICCV '09, DAGM '09*, IJCV '13

* Best Paper Award



Super-Resolution Texture Map



Goldlücke, Cremers, ICCV '09, DAGM '09, IJCV '13*

** Best Paper
Award*



Super-Resolution Texture Map



Weighted average



Super-resolution texture

Goldlücke, Cremers, ICCV '09, DAGM '09, IJCV '13* * Best Paper Award



Super-Resolution Texture Map



Closeup of input image



Super-resolution texture

Goldlücke, Cremers, ICCV '09, DAGM '09, IJCV '13* * Best Paper Award



Overview



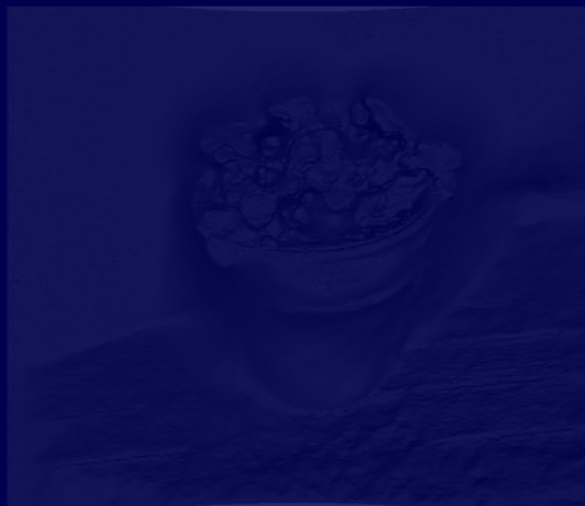
Multiview reconstruction



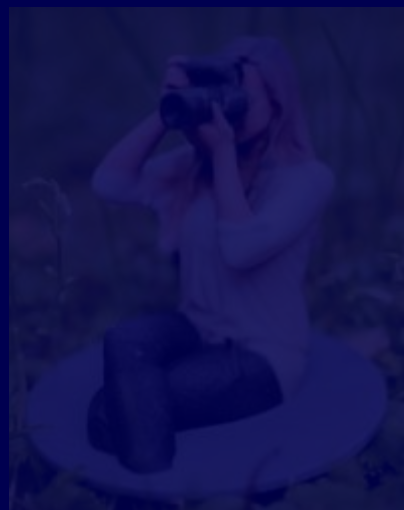
Super-res.textures



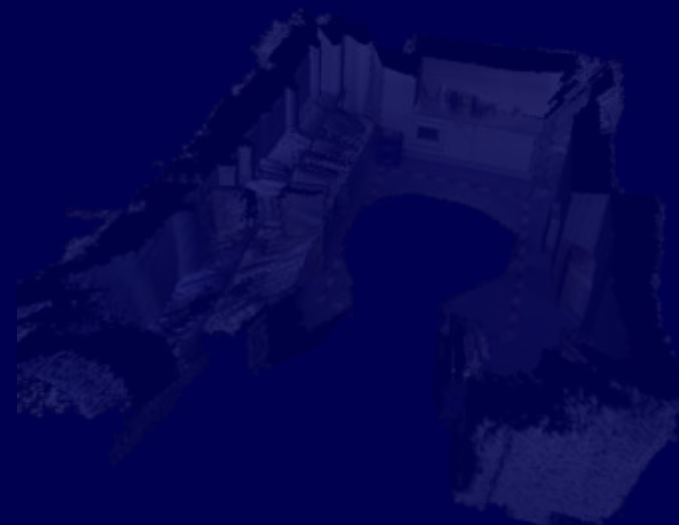
Stereo reconstruction



Realtime dense geometry



RGB-D cameras



Reconstruction on the fly

From Binary to Multilabel Optimization

$$u : \Omega \rightarrow \Gamma = [\gamma_{min}, \gamma_{max}]$$



Example: Stereo Reconstruction

Pock, Schoenemann, Bischof, Cremers, Europ. Conf. on Computer Vision '08:
Theorem: Stereo reconstruction can be solved by convex optimization.

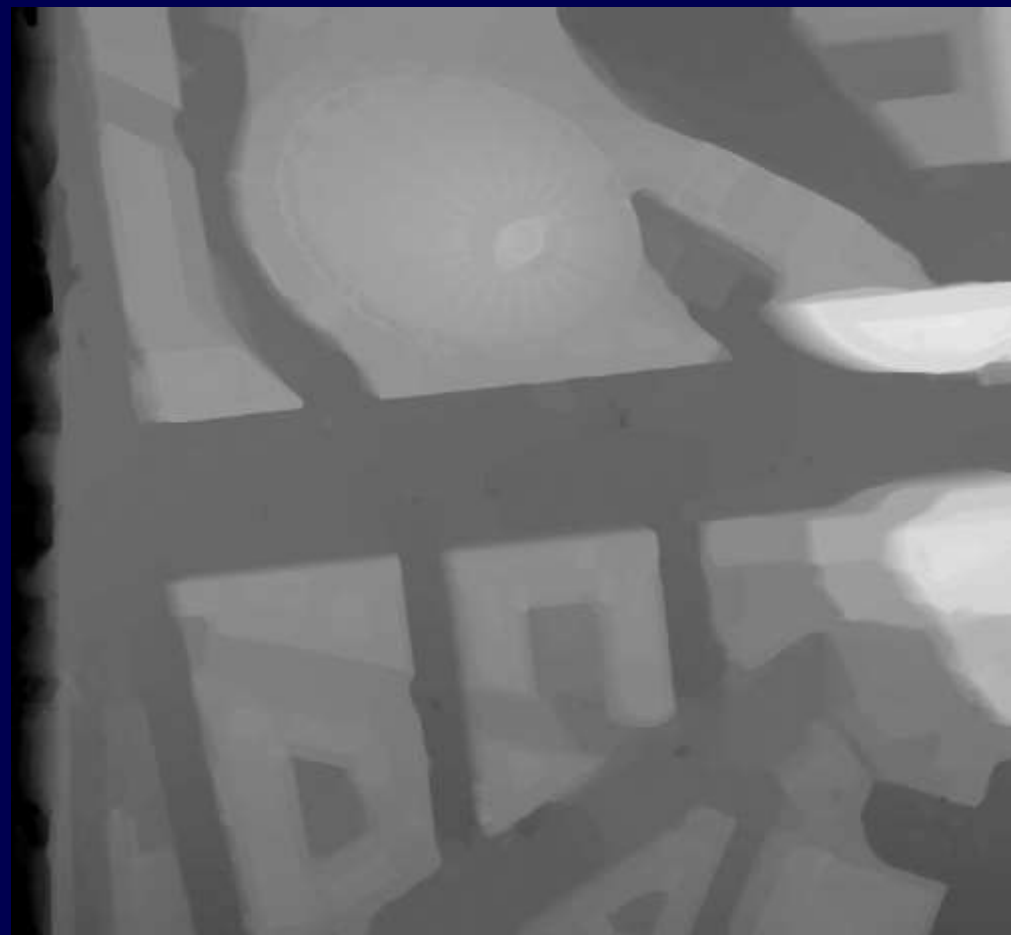


Evolution to Global Minimum





Reconstruction from Aerial Images



1/2 input images (6 Mpixel)
Courtesy of H. Hirschmüller

Depth reconstruction
77 seconds

Stangl, Souiai, Cremers, GCPR '13



Reconstruction from Aerial Images



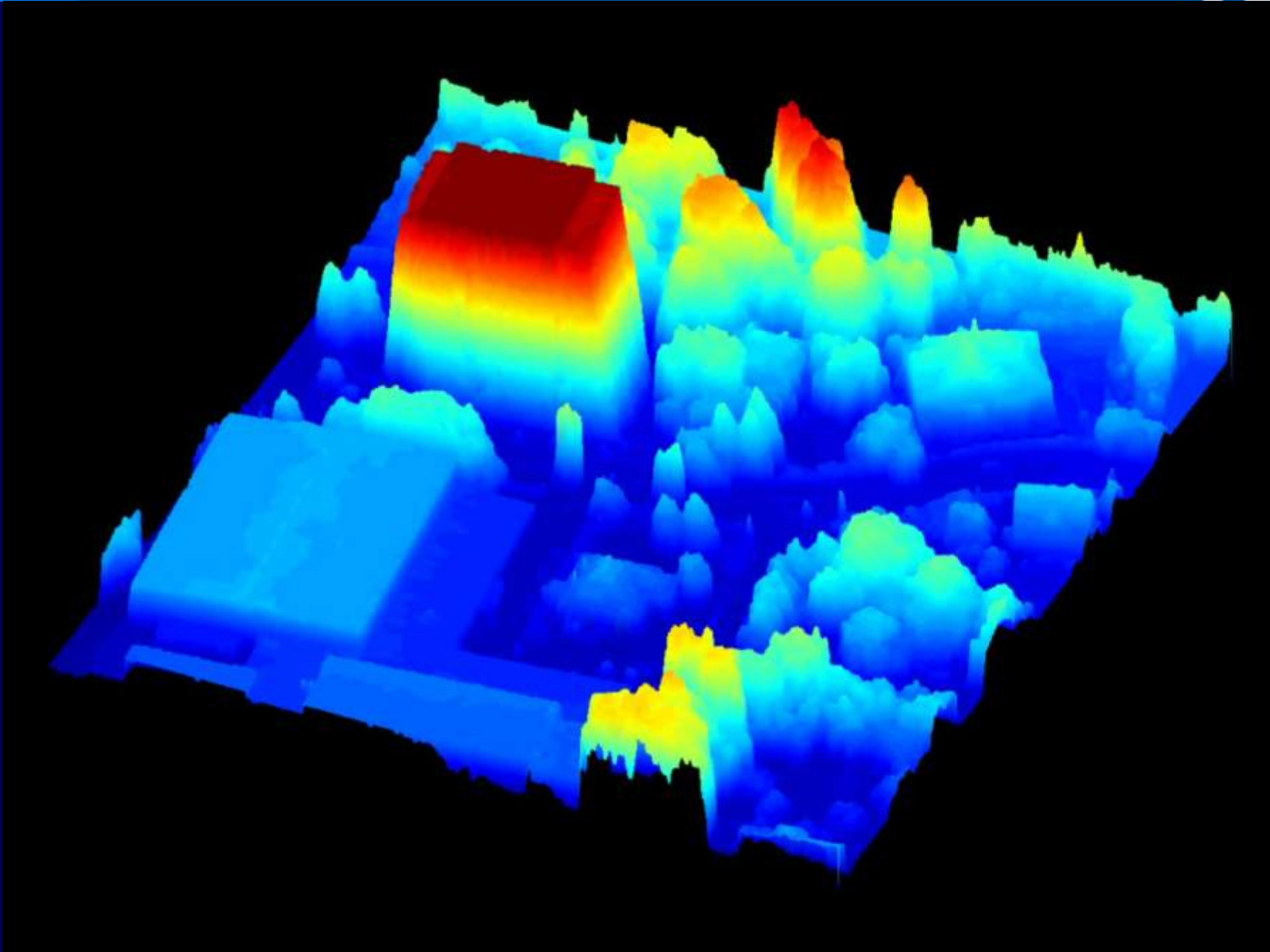
One of two input images
Courtesy of Microsoft



Depth reconstruction



Reconstruction from Aerial Images

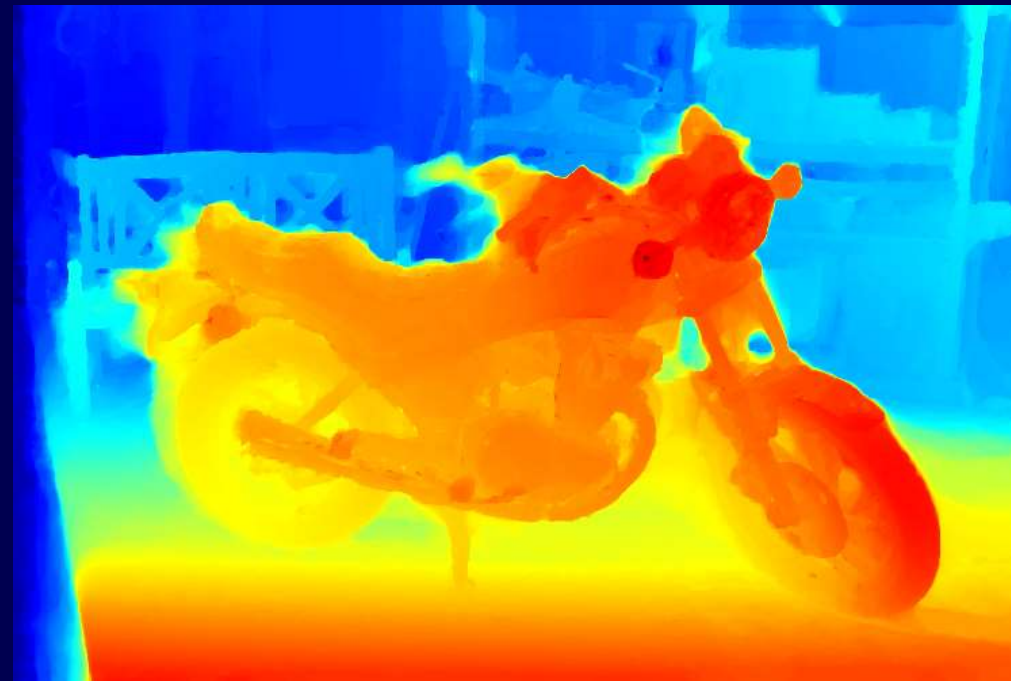




Highly accurate Stereo Reconstruction



Stereo input



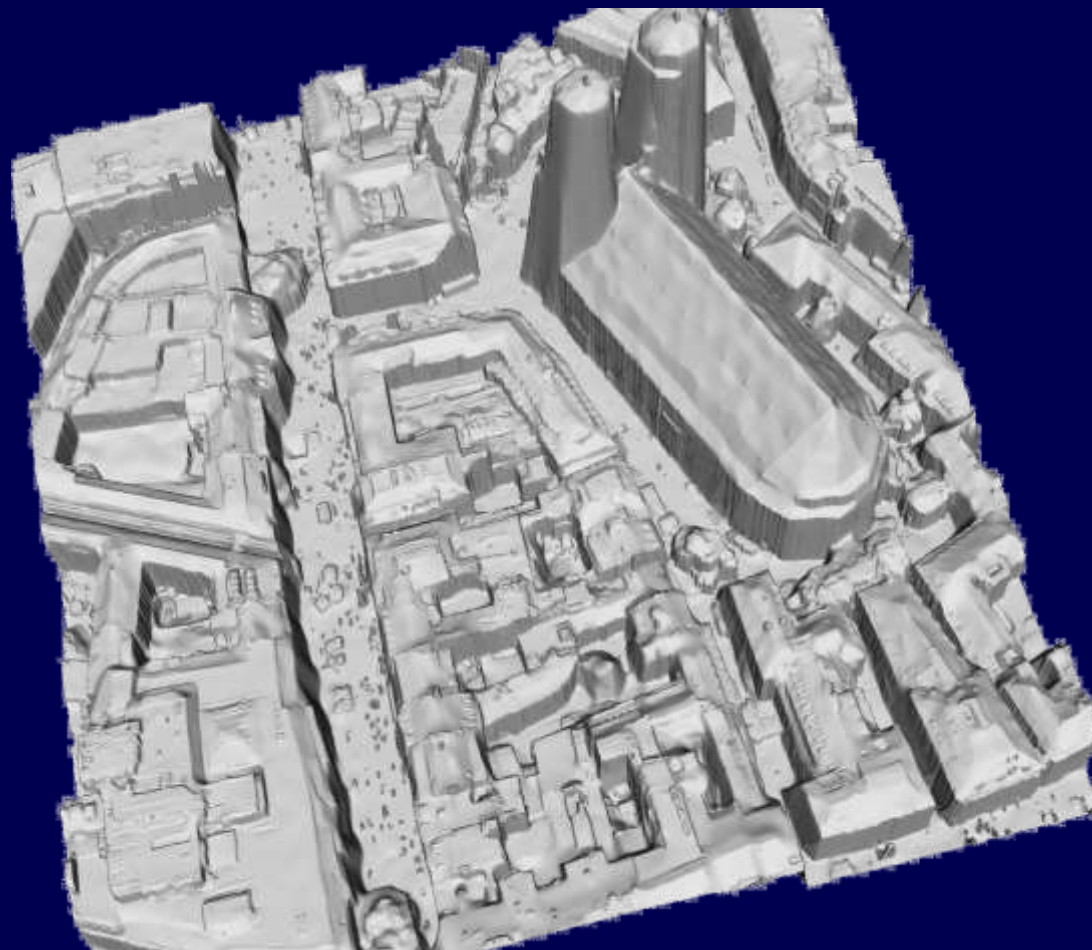
Depth reconstruction

*Möllenhoff, Laude, Möller, Lellmann, Cremers, CVPR '16 **

** Best Paper Honorable Mention*



Munich from the Air



1/2 input images (1000x1000)

Depth reconstruction

Kuschk, Cremers, ICCV Big Data Workshop 2013



Overview



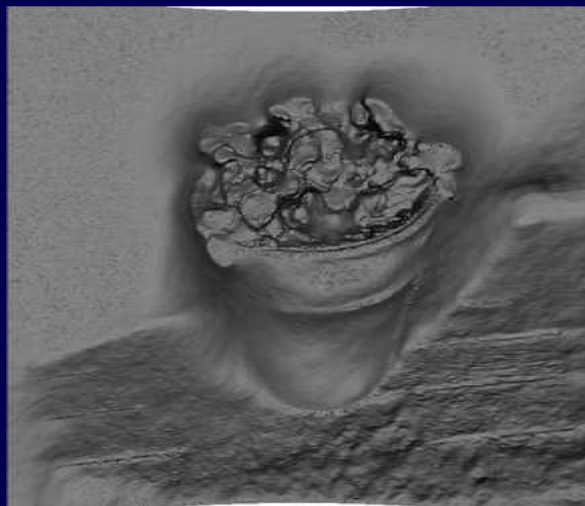
Multiview reconstruction



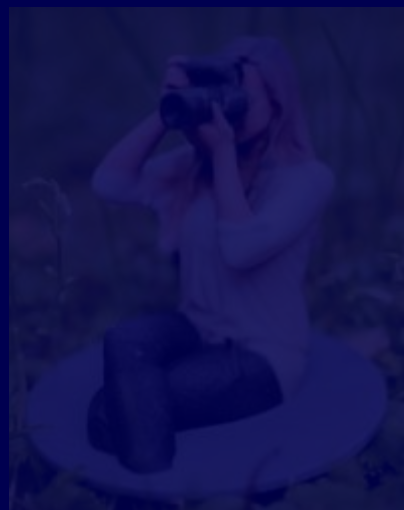
Super-res.textures



Stereo reconstruction



Realtime dense geometry



RGB-D cameras



Reconstruction on the fly

From Dense Flow to Dense Geometry



Input video



Optical flow field

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

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

From Dense Flow to Dense Geometry



Input video

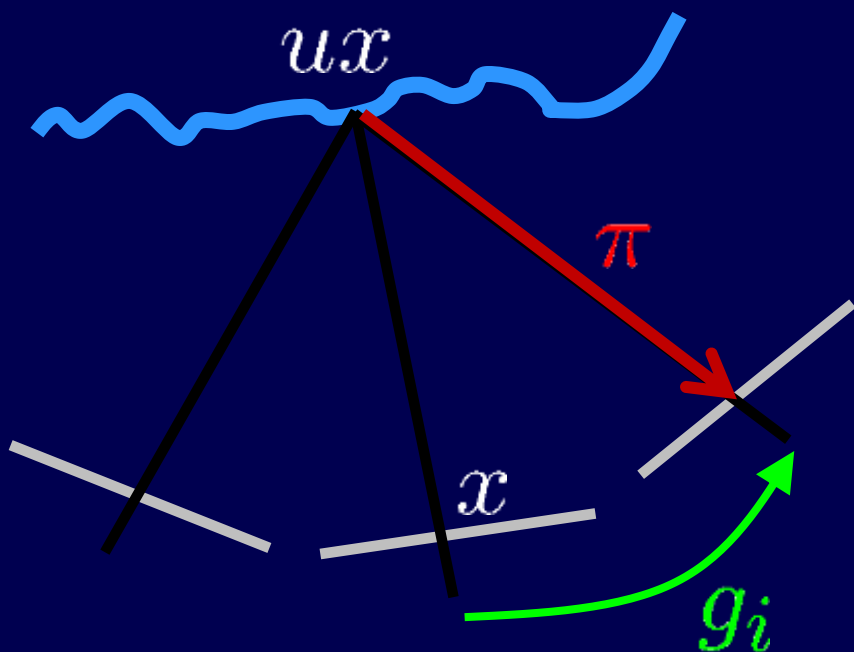


Optical flow field*

* 60 fps @ 640x480

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

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



Brightness constancy:

$$I_0(x) \stackrel{!}{=} I_i\left(\pi\left(g_i(ux)\right)\right)$$

$$\min_u \sum_i \int_{\Omega} \left| I_0(x) - I_i\left(\pi\left(g_i(u \cdot x)\right)\right) \right| dx + \int_{\Omega} |\nabla u(x)| dx$$

Stuehmer, Gumhold, Cremers, DAGM '10



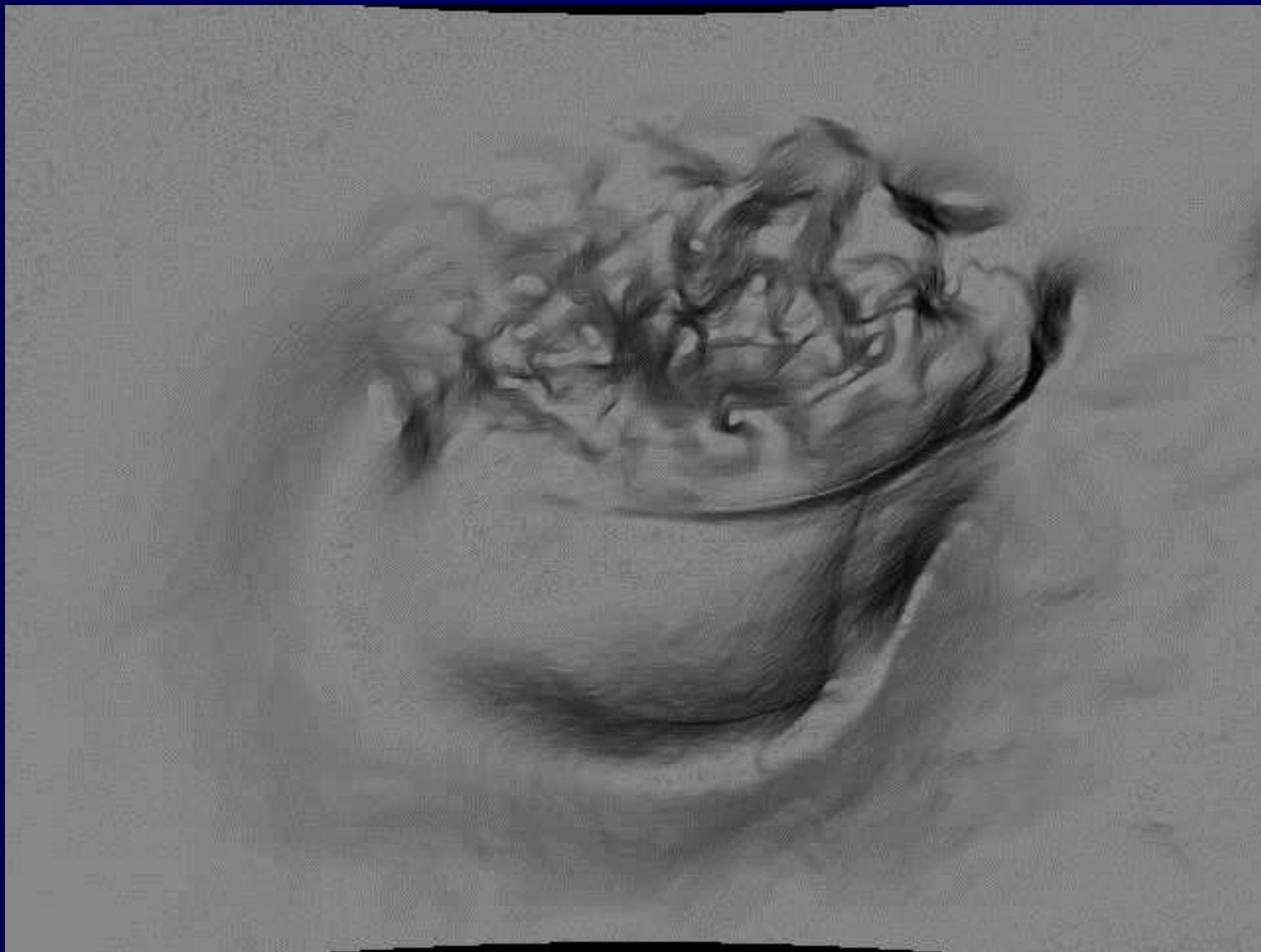
Dense geometry from hand-held camera



Stuehmer, Gumhold, Cremers, DAGM '10



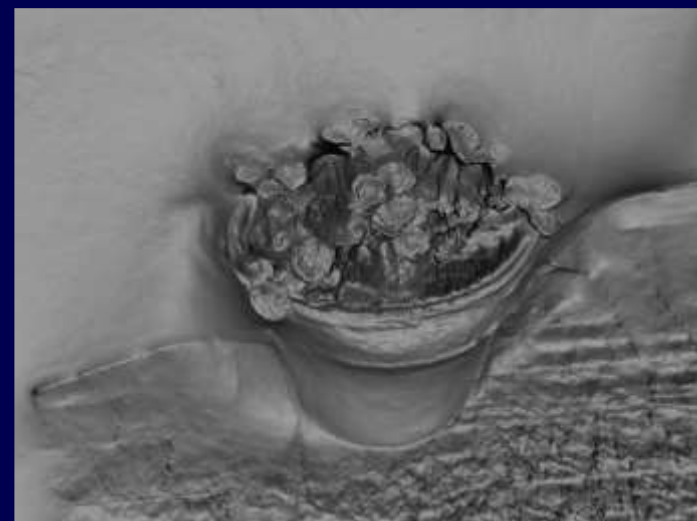
Dense geometry from hand-held camera



Stuehmer, Gumhold, Cremers, DAGM '10



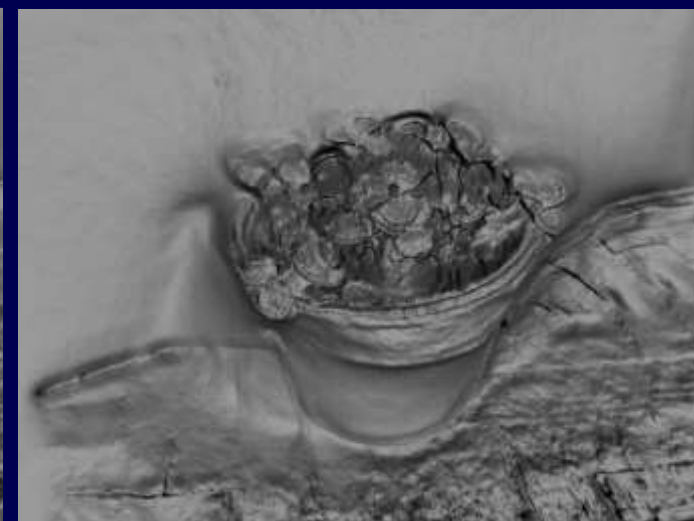
Realtime Dense Reconstruction



16.0 fps



22.0 fps



41.1 fps

Stuehmer, Gumhold, Cremers, DAGM '10



Overview



Multiview reconstruction



Super-res.textures



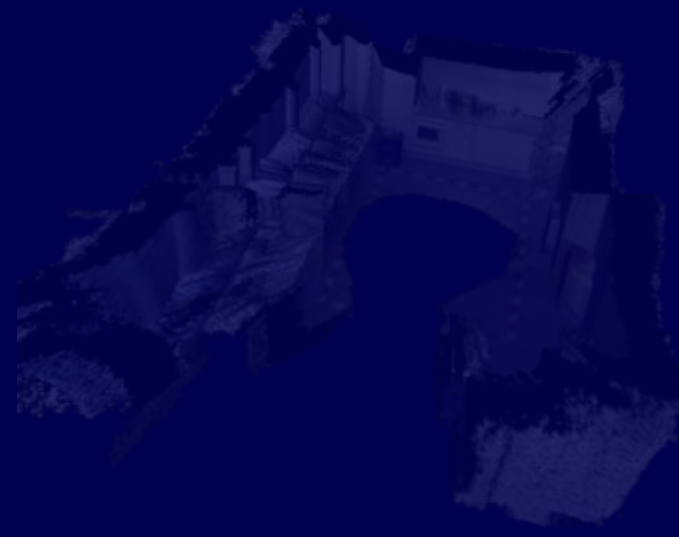
Stereo reconstruction



Realtime dense geometry

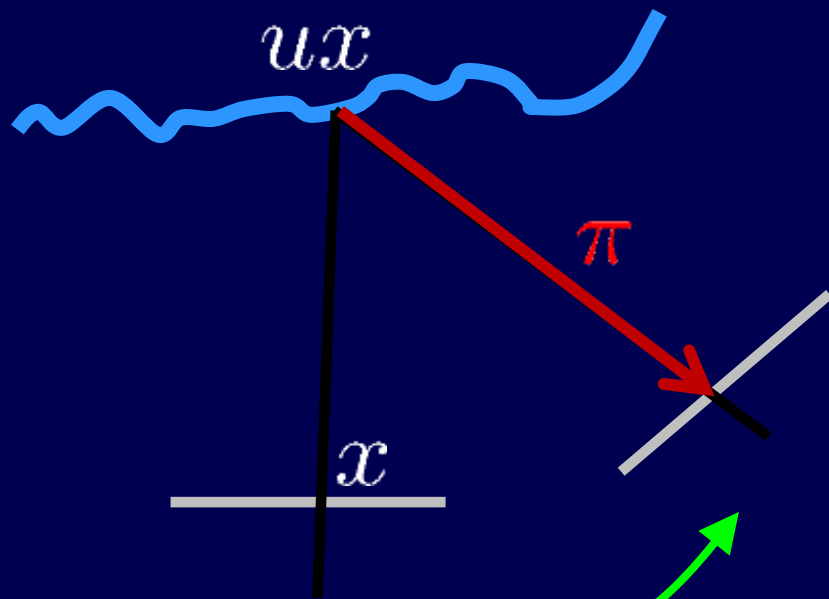


RGB-D cameras



Reconstruction on the fly

RGB-D Camera Tracking



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

Optimize dense photo-consistency:

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

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

Realtime 3D Modeling



Color input



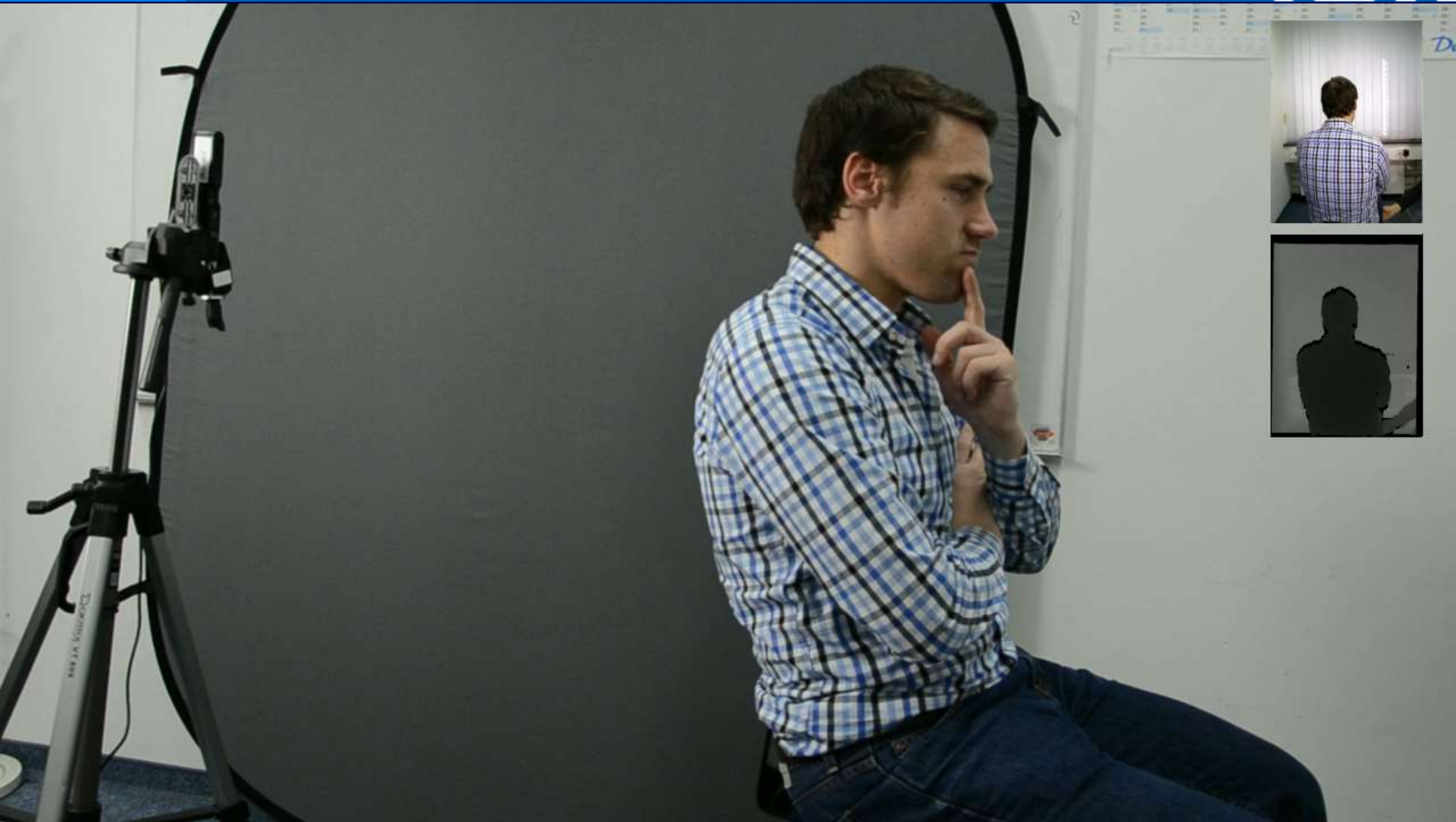
Depth input

Realtime 3D Modeling





Realtime 3D Modeling



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



Realtime 3D Modeling





Realtime 3D Modeling





Realtime 3D Modeling





Realtime 3D Modeling





Realtime 3D Modeling





Full-Body Scanner





Overview



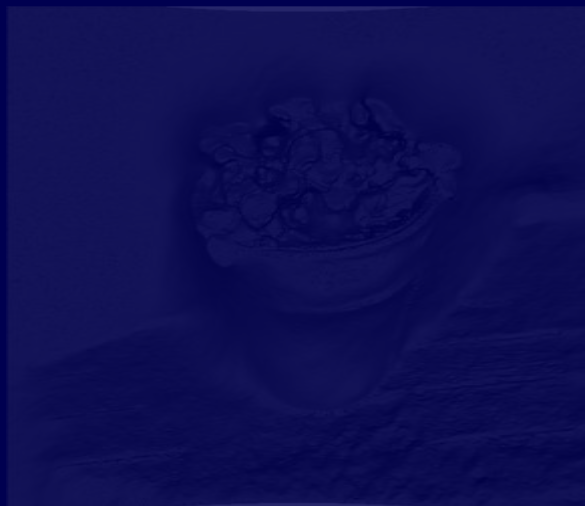
Multiview reconstruction



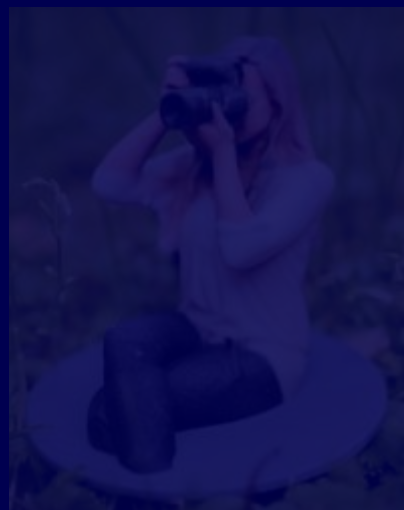
Super-res.textures



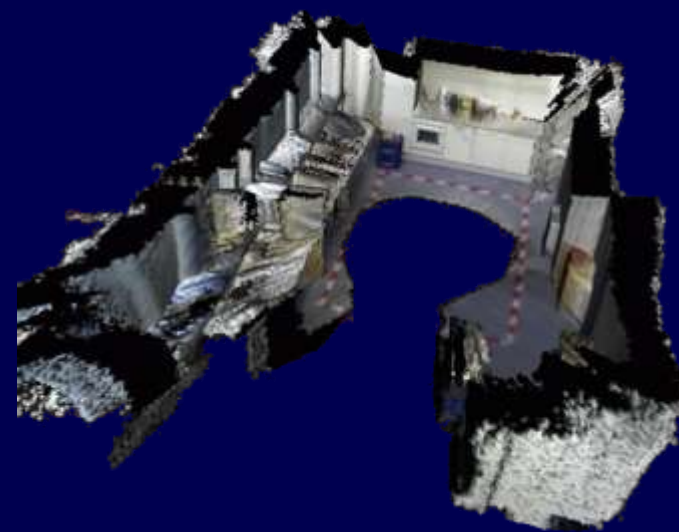
Stereo reconstruction



Realtime dense geometry



RGB-D cameras



Reconstruction on the fly



Reconstruction on the Fly



Bylow, Sturm, Kerl, Kahl, Cremers RSS '13

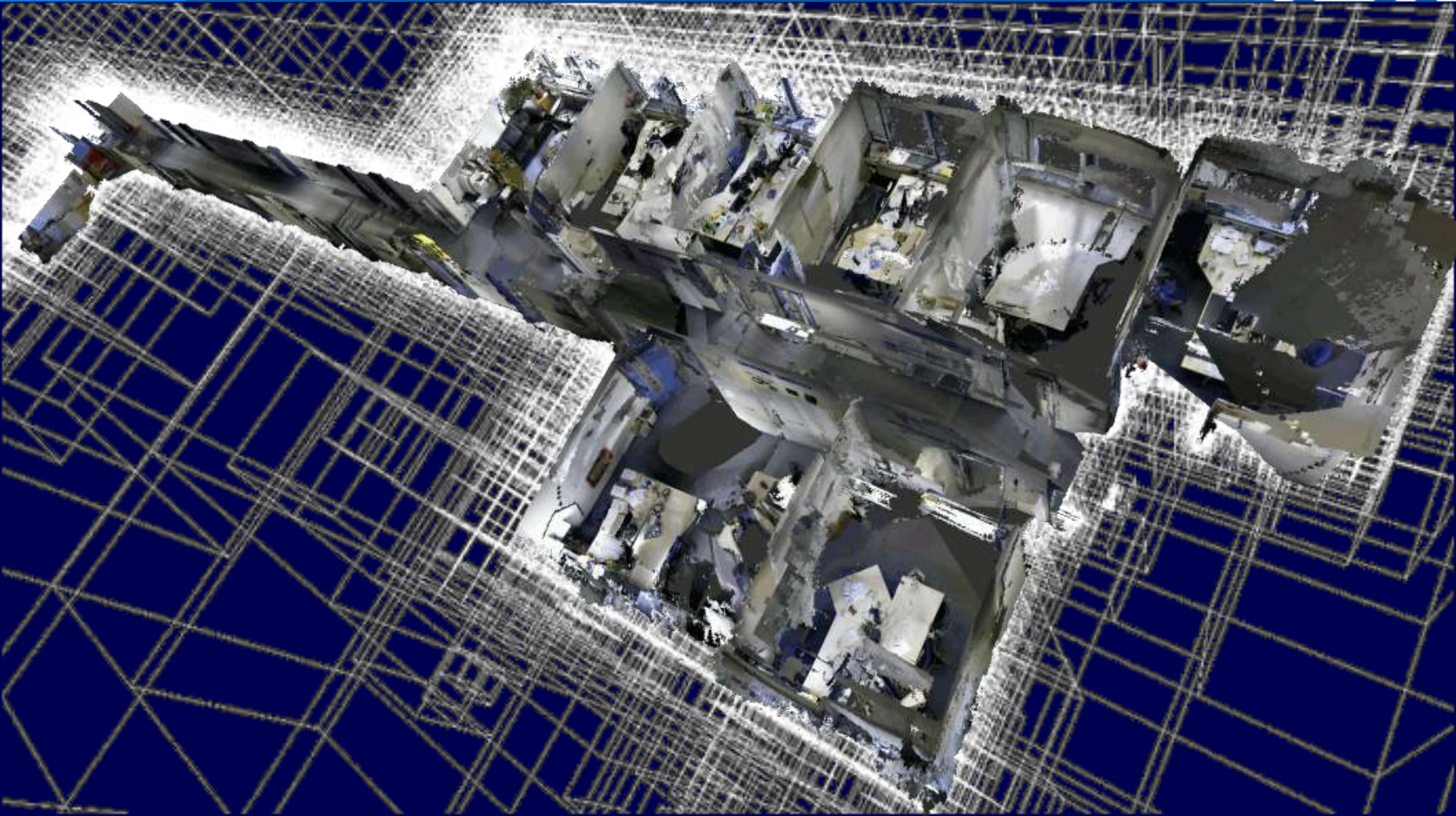
Large Scale: Loop Closure

RGB-D dataset 'fr3/office'

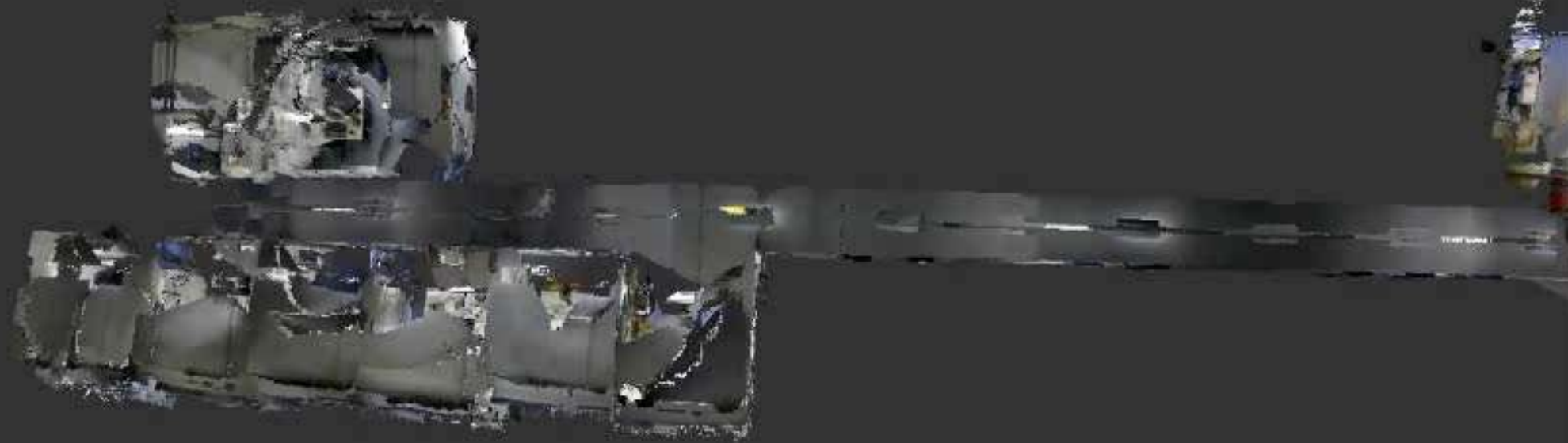
Kerl, Sturm, Cremers ICRA '13



Large Scale: Octrees



Steinbrücker, Kerl, Sturm, Cremers ICCV '13



Large-Scale Reconstruction

Steinbrücker, Kerl, Sturm, Cremers ICCV '13, ICRA '14



Summary



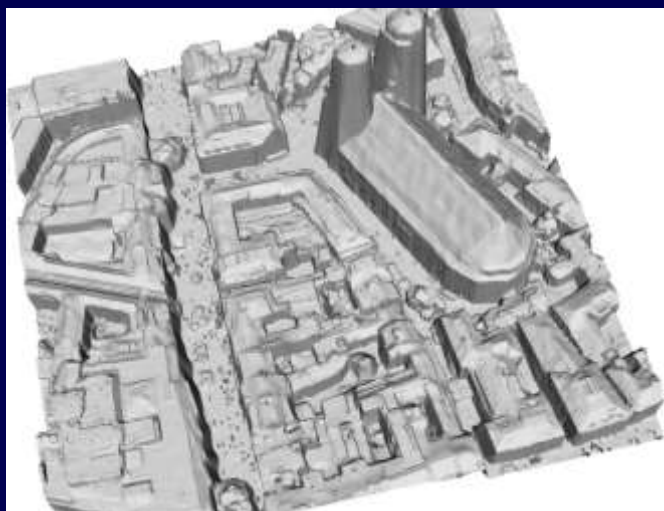
multiview reconstruction



super-res. textures



action reconstruction



stereo reconstruction



RGB-D modeling



3D on the fly