Capturing and Editing Reality – Performance Capture of the Real World in Motion

Christian Theobalt

Graphics, Vision, and Video

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The Modeling Bottleneck

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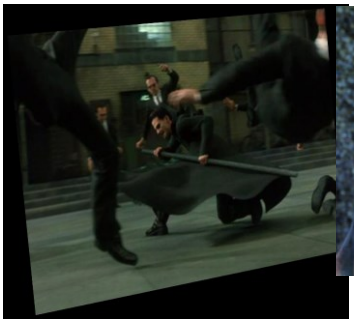
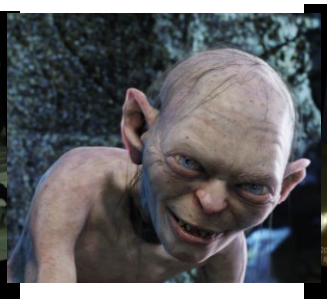
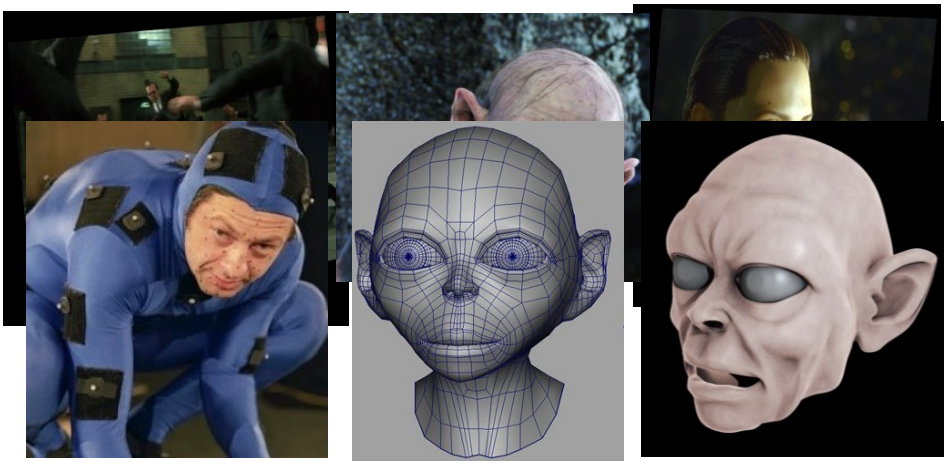




[Lord of the Rings]

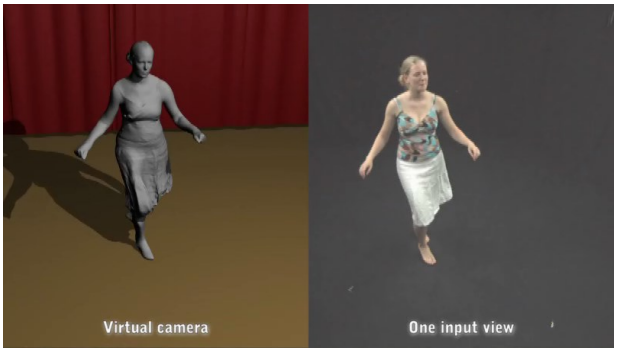
[Beowulf]

The Modeling Bottleneck



Motion Shape Textures

Performance Capture



[de Aguiar et al,, SIGGRAPH 2008]

- High-quality shape, motion and texture of people in general clothing from multi-view video
- Handful of cameras to single camera, no markers
- Exceed capabilities of existing Mocap technology by far

Skeleton + Surface

Template-based pose and shape optimization + multi-view segmentation

[Liu et al. CVPR 2011 oral, IEEE Trans. PAMI 2013]

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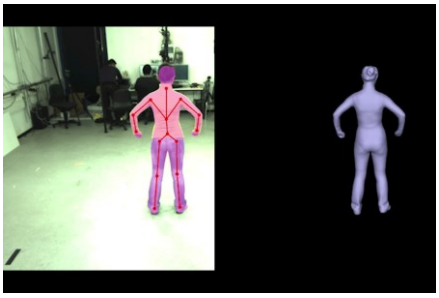
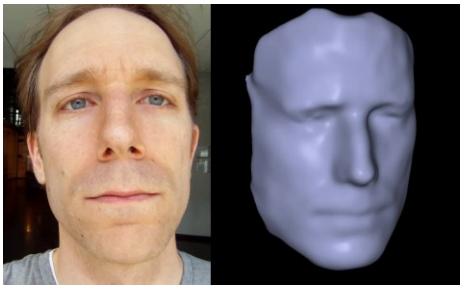
Important Limitations





- Limited accuracy
- Limited scene complexity
- Starkly restricted capture environment

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What We Want: Capture Reality

- Complex appearance
- Uncontrolled recording and lighting settings
- Tremendous scene complexity
- Simple and sparse camera setups
- Ability to edit captured footage

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Improving Reconstruction Quality and Ability

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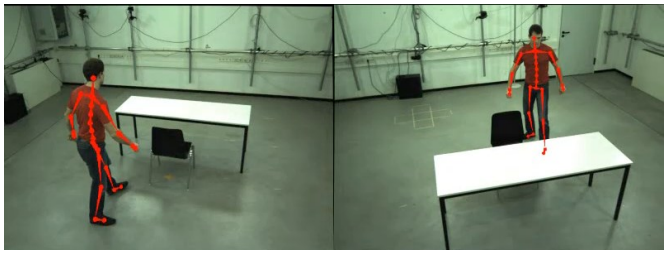
Capturing in Less Constrained Environments

Occlusions,
fast motions,
dynamic backgroud...



[Stoll et el. ICCV 2011]

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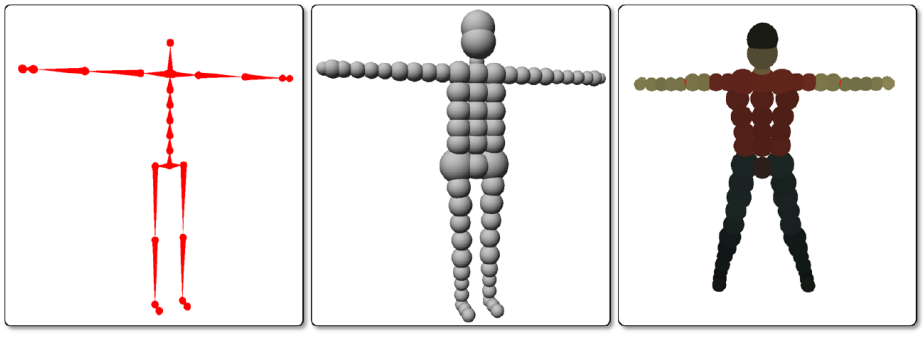
3D Sum of Gaussians Body Model

- Skeleton + Gaussians with color model



58 DoFs

63 Gaussians

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2D Sum of Gaussians Body Model

- Each video frame converted to 2D SoG

Video frame

Quad tree –
each region one 2D Gaussian

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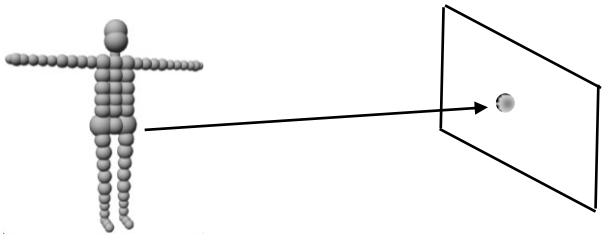
3D-2D Similarity Function

- Projection of 3D Gaussians into cameras



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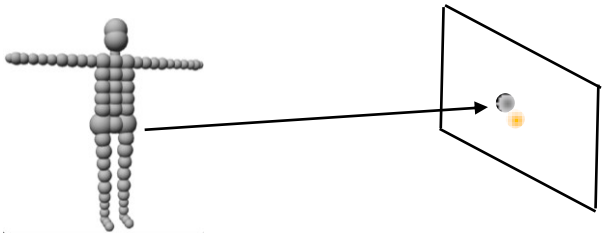
3D-2D Similarity Function

- Projection of 3D Gaussians into cameras



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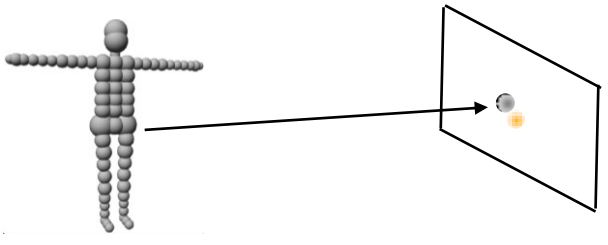
3D-2D Similarity Function

- Projection of 3D Gaussians into cameras



- 2D-2D SoG similarity in one camera view

$$E_{ij} = d(\mathbf{c}_i, \mathbf{c}_j) \int_{\Omega} \mathcal{B}_i(x)\mathcal{B}_j(x)\mathrm{d}\mathbf{x}$$

Color similarity

Projected model Gaussian

Image Gaussian

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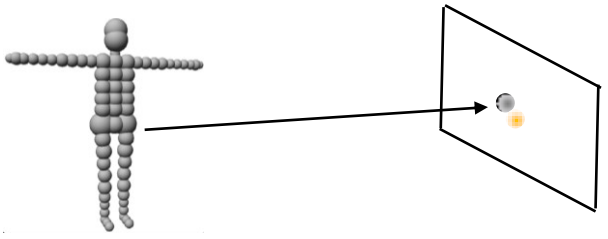
3D-2D Similarity Function

- Projection of 3D Gaussians into cameras



- 2D-2D SoG similarity – closed form solution

$$E_{ij} = d(\mathbf{c}_i, \mathbf{c}_j) \int_{\Omega} \mathcal{B}_i(x)\mathcal{B}_j(x)\mathrm{d}\mathbf{x}$$

$$= d(\mathbf{c}_i, \mathbf{c}_j) 2\pi \frac{{\sigma_i}^2 {\sigma_j}^2}{{\sigma_i}^2 + {\sigma_j}^2} \exp\left(-\frac{\|\mu_i - \mu_j\|^2}{{\sigma_i}^2 + {\sigma_j}^2}\right)$$

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Pose Similarity Measure

- Find pose parameters Θ that maximize

$$\mathcal{E}(\Theta) = E(\Theta) - w_l E_{lim}(\mathcal{M}\Theta) - w_a E_{acc}(\Theta)$$

SoG similarity over all Gaussians and cameras

Joint limits

acceleration penalty

- Energy function smooth
- Analytic derivatives convenient to compute
- Occlusion conveniently handled
- Efficient gradient-based optimization

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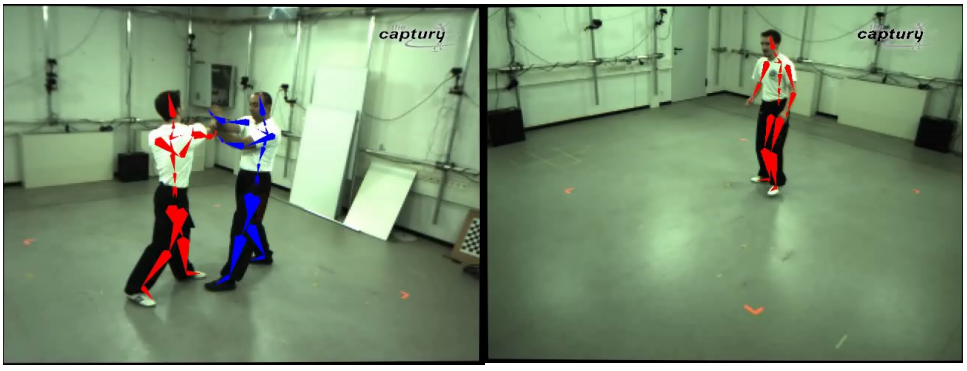
More Results



Min nr. of cameras: 5
Pose estimation > 30 fps

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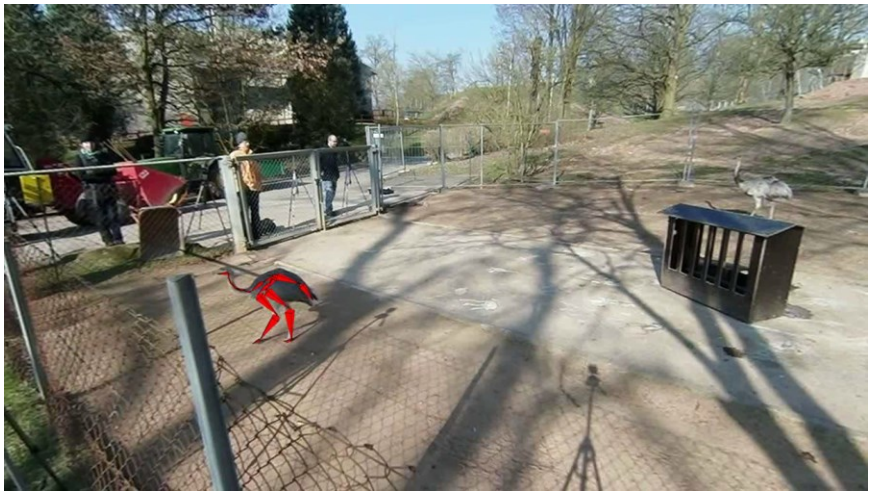
Space-time Reconstruction



8 GoPros, 30 fps, not frame synchronized

[Elhayek et al., CVPR 2012]

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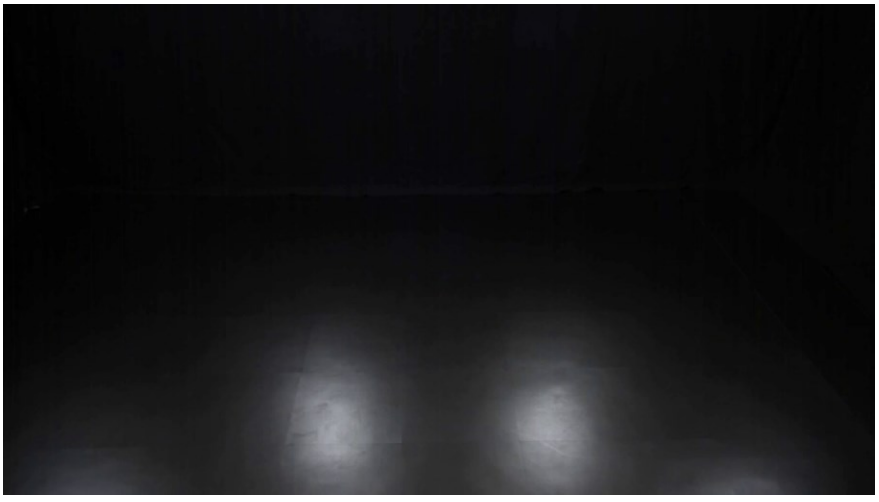
www.thecaptury.com



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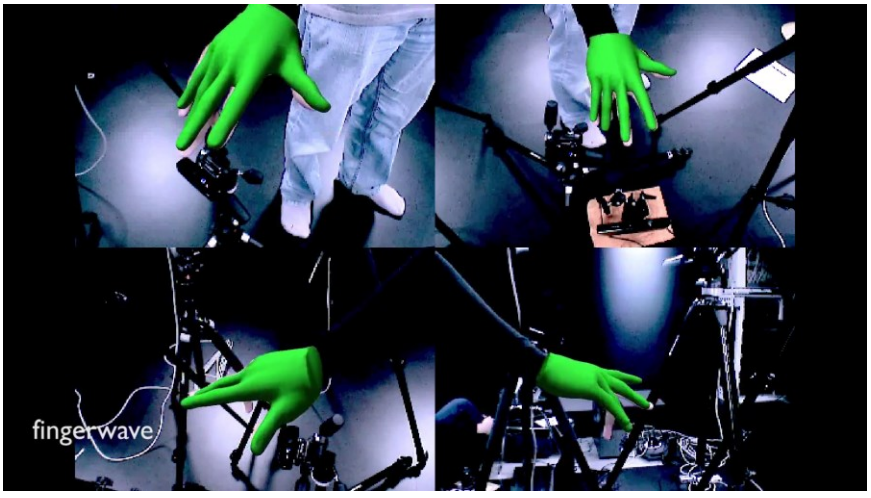
Extension to Hands



S. Sridhar, A. Oulasvirta, and C. Theobalt, *Interactive Markerless Articulated Hand Motion Tracking using RGB and Depth Data*, ICCV 2013

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Real-time Hand-Tracking: Setup

5 video cameras

1 Creative TOF Camera

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Real time Hand Tracking with Single Depth Camera

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How can we reconstruct more detail in uncontrolled environments ?

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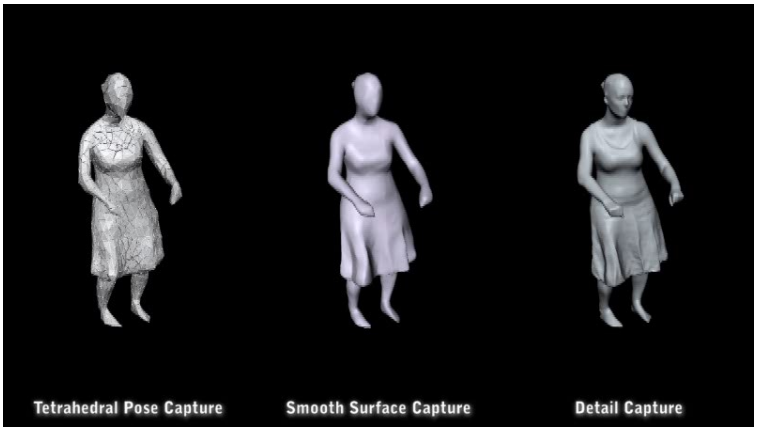
Current Methods

- Limit to amount of captured detail



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Exploit Shading / Lighting Cues

- Shading / lighting effects around high frequency features

[http://www.verycoolphotoblog.com/2012/11/05/old-man-3]

Related Work

Photometric Stereo

[Woodham '80, Hernandez et al. 2007...]

Shape-from-Shading

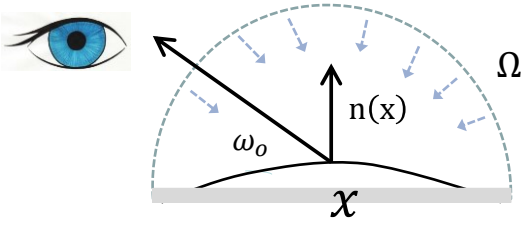
[Zhang '99, Prados et al. 2005...]

Dynamic Photometric Stereo

[Vlasic et al., SIGASIA '09]

Shape Refinement – Inverse Rendering

- Reflectance Equation (Kajiya'86)

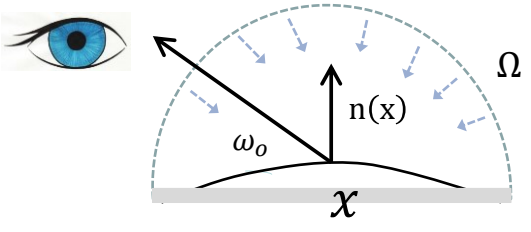


$$B(x,\omega_o) = \int_{\Omega} \rho(\omega_i,\omega_o) L(\omega_i) V(x,\omega_i)\ \max(\omega_i \cdot \mathrm{n}(\mathrm{x}), 0)\, \mathrm{d}\omega_i$$

Rendering

Shape Refinement – Inverse Rendering

- Reflectance Equation (Kajiya'86)



$$B(x,\omega_o) = \int_{\Omega} \rho(\omega_i,\omega_o) L(\omega_i) V(x,\omega_i)\ \max(\omega_i \cdot \mathrm{n}(\mathrm{x}), 0)\, \mathrm{d}\omega_i$$

Rendering

Inverse rendering: find illumination, reflectance, shape

[Wu et al. CVPR2011, ICCV 2011, ECCV2012]

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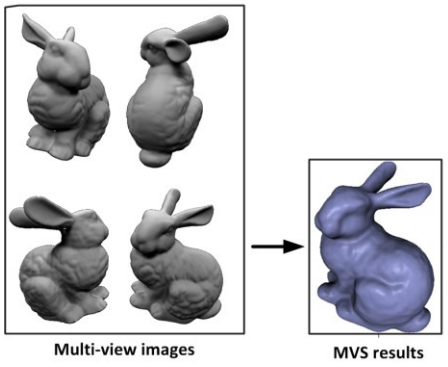
Shading-based Static Scene Refinement



[Wu et al. CVPR 2011]

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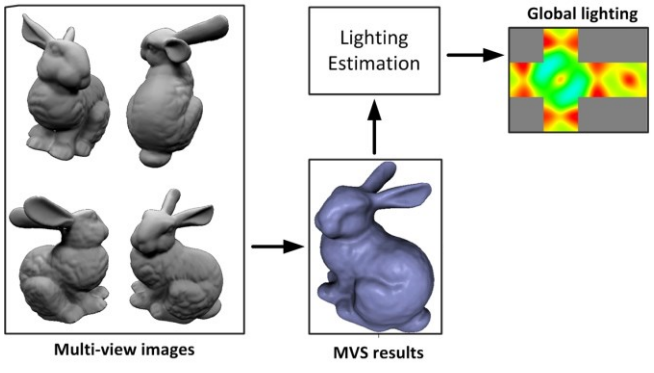
Shading-based Static Scene Refinement



[Wu et al. CVPR 2011]

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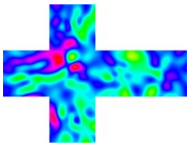
Step I: Lighting Estimation

$$\hat{l} = \arg\min_{l} \sum_{i} \sum_{c} \left| l \cdot t_i - I_c(P_c(x_i)) \right|$$

Coefficients of lighting

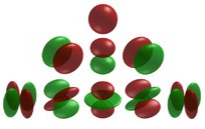
Rendering equation in spherical harmonics

image intensity



Estimated

Environment map



Spherical harmonics ([Sloan et al. '02])

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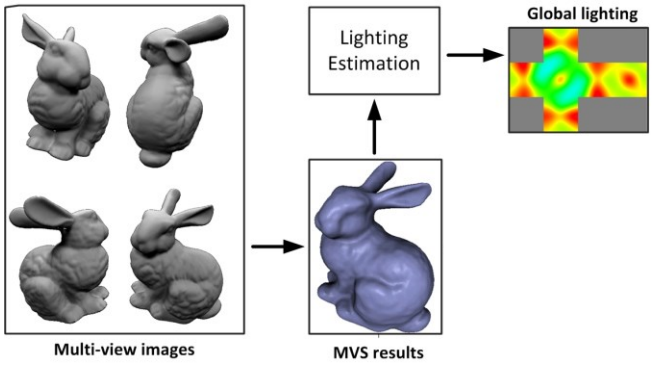
Shading-based Static Scene Refinement



[Wu et al. CVPR 2011]

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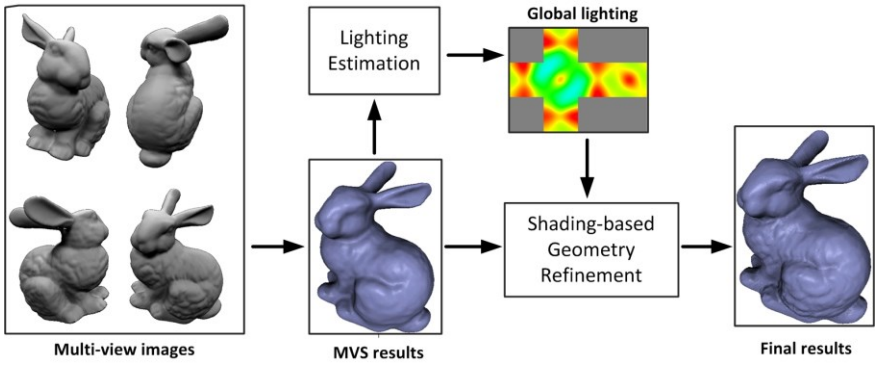
Shading-based Static Scene Refinement



[Wu et al. CVPR 2011]

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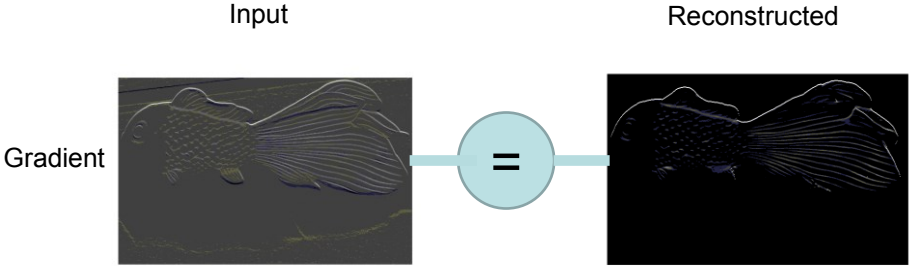
Shading-based Geometry Refinement



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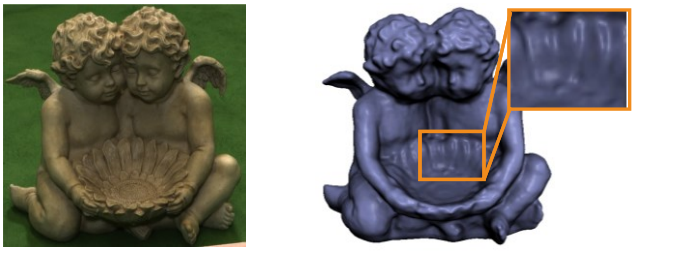
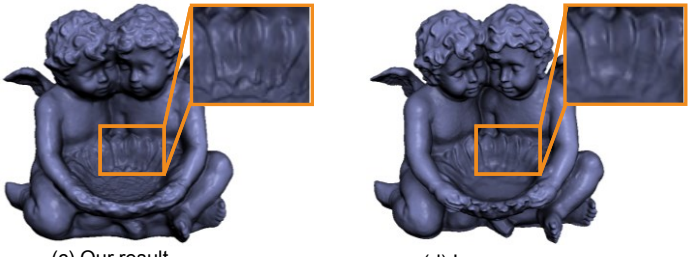
Combine Stereo + Shading



(a) Captured image (b) MVS result



(c) Our result (d) Laser scan

[Wu et al. CVPR 2011]

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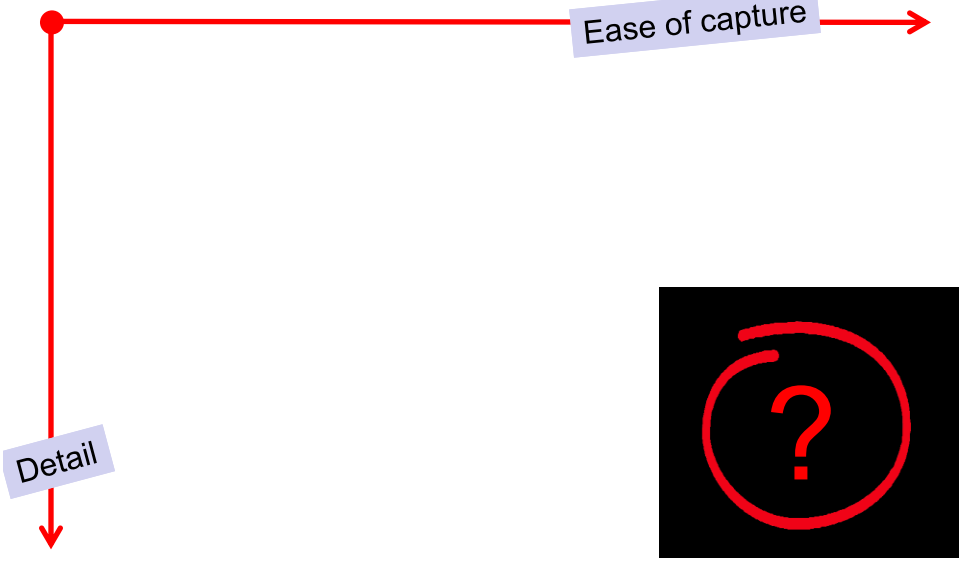
Facial Performance Capture



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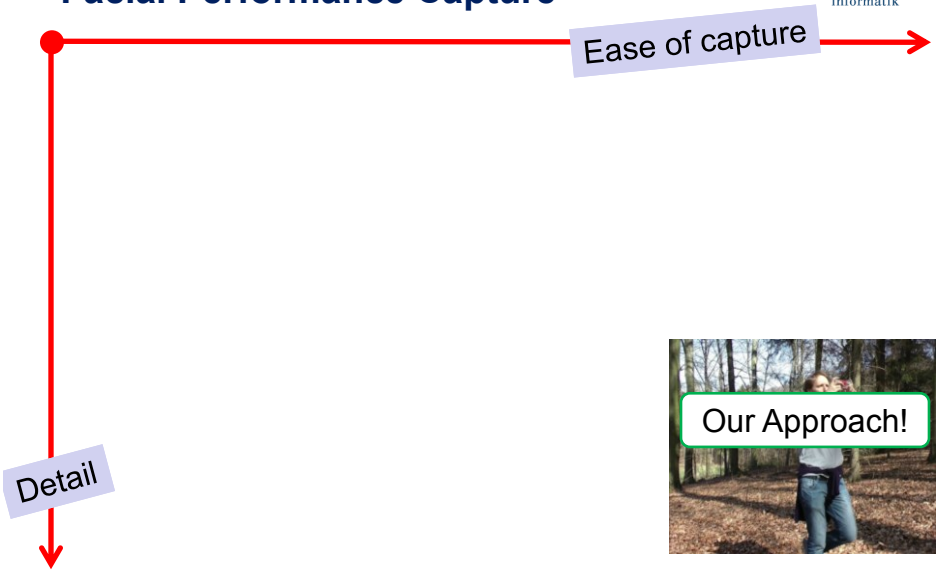
Facial Performance Capture



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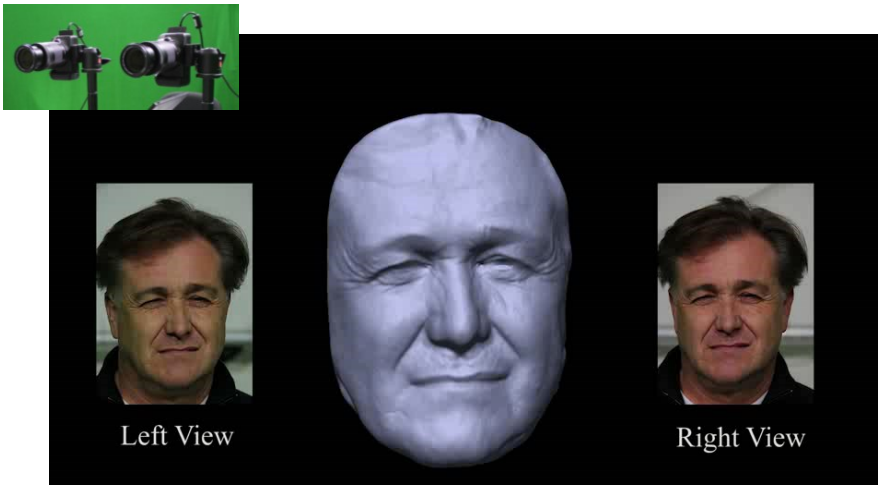
High-quality Binocular Face Capture



L.Valgaerts, C. Wu, A. Bruhn, H.-P. Seidel, C. Theobalt, Binocular Facial Performance Capture under Uncontrolled Illuminationm, SIGGRAPH Asia 2012

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Method Overview

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Left view

Right view

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Method Overview

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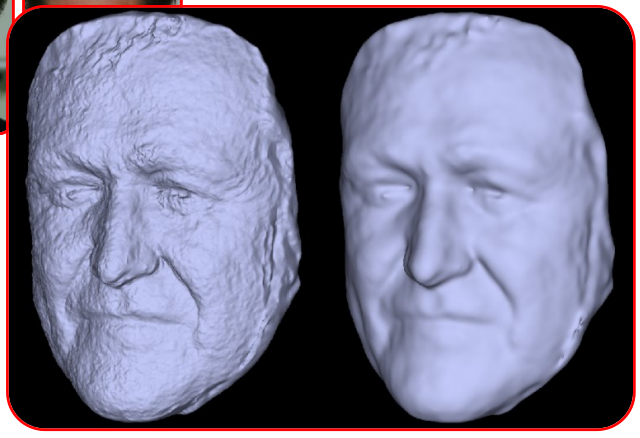
Template reconstruction



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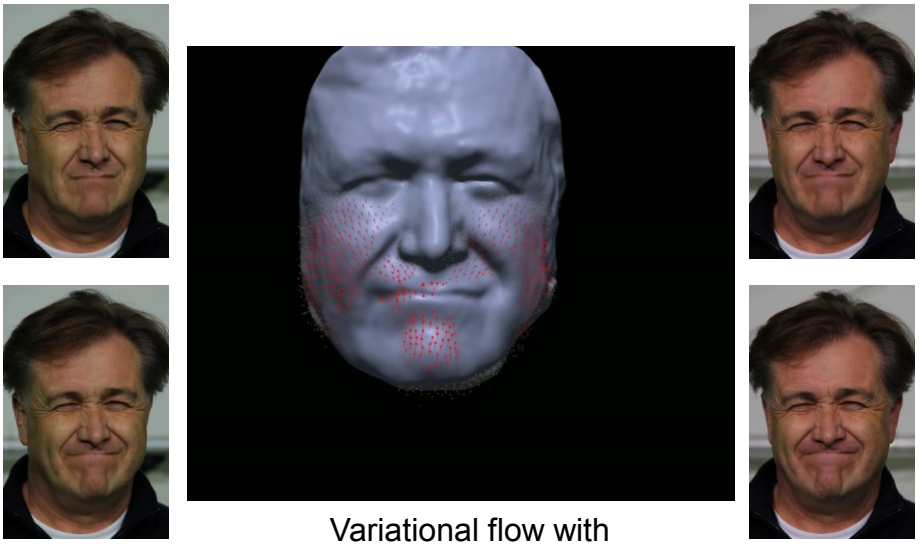
Scene Flow Result



Variational flow with
structure-aware regularization

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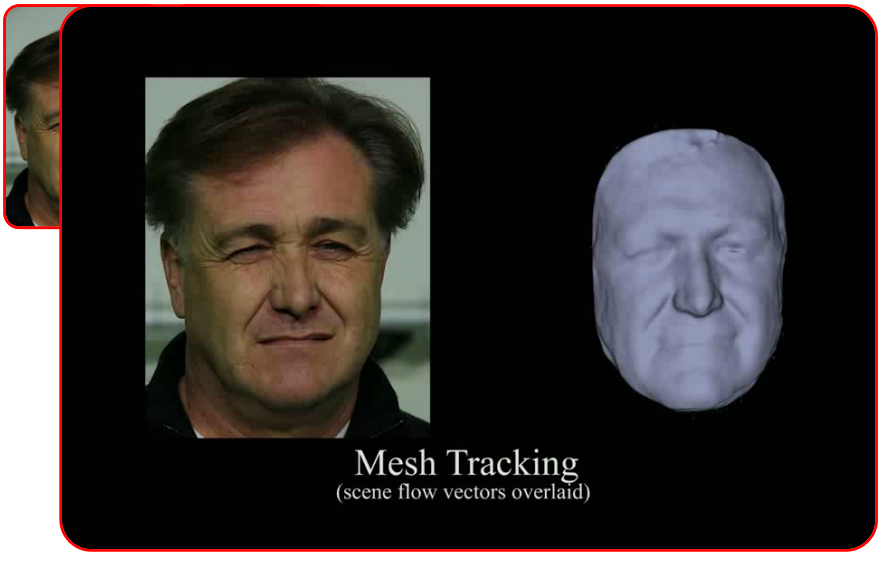
Method Overview



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Method Overview

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Dynamic Shape Refinement

Previous frame

Fine Scale Shape?

Lighting?

Current frame

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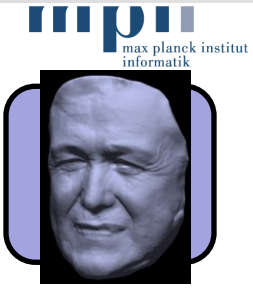
Dynamic Shape Refinement



Previous frame

Current frame

⇒ Compute lighting + shape jointly (extends [Wu et al. 2011])

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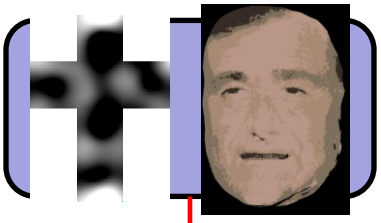
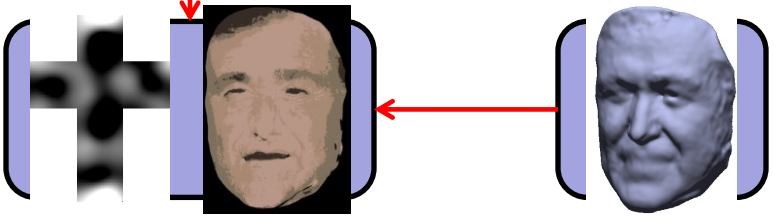
Dynamic Shape Refinement

Previous frame



Lighting estimation

Current frame



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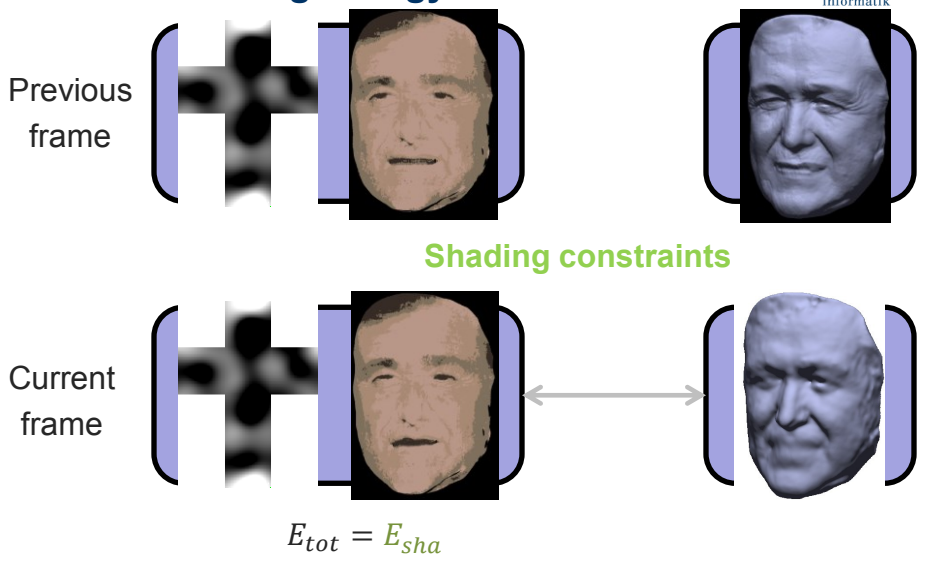
Novel Shading Energy



$$E_{tot} = E_{sha}$$

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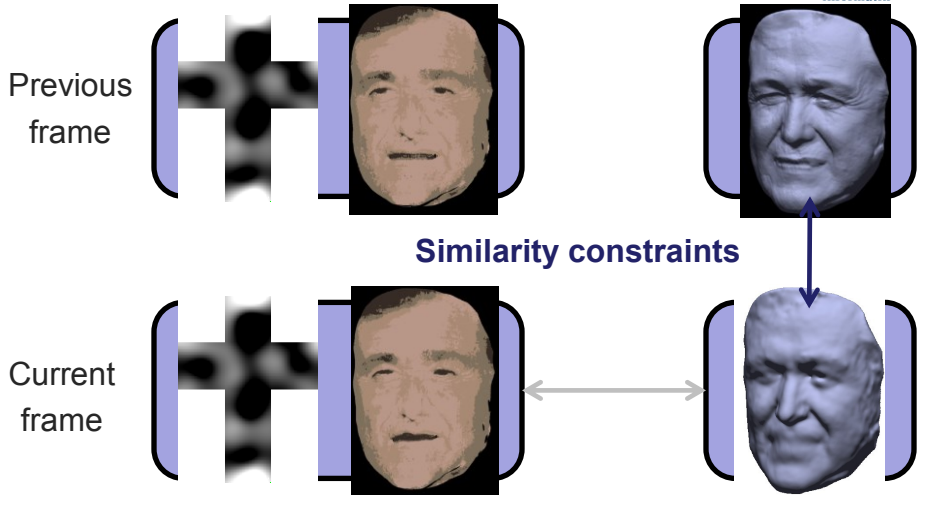
Novel Shading Energy



$$E_{tot} = E_{sha} + \alpha E_{sim}$$

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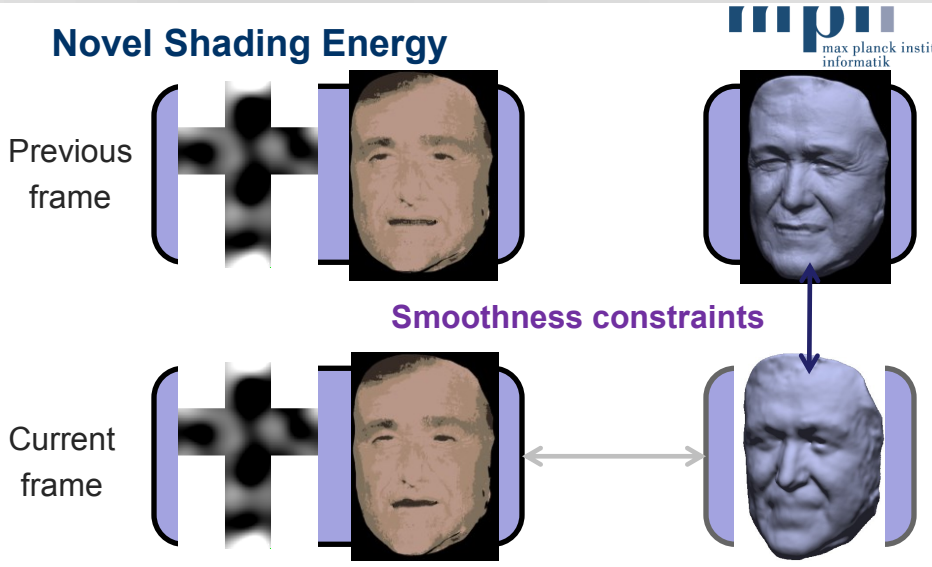
Novel Shading Energy



$$E_{tot} = E_{sha} + \alpha E_{sim} + \beta E_s$$

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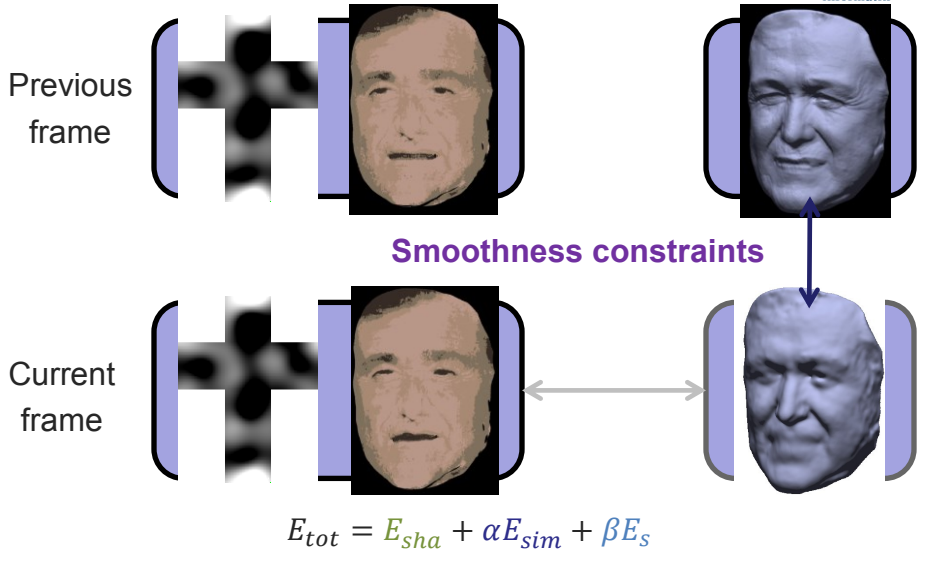
Novel Shading Energy



$$E_{tot} = E_{sha} + \alpha E_{sim} + \beta E_s$$

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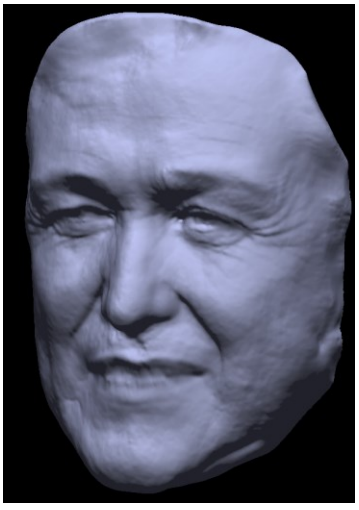
Refinement Result



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Result - outdoors, changing lighting

Stereo pair of GoPro bike helmet cams, handheld

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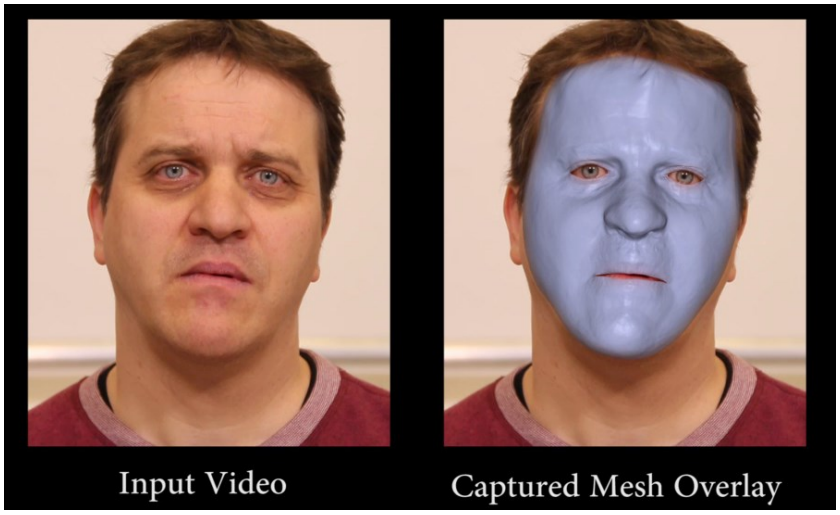
Monocular Face Reconstruction



P. Garrido, L. Valgaerts, C. Wu, C. Theobalt, Reconstructing Detailed Dynamic Face Geometry from Monocular Video, SIGGRAPH Asia 2013

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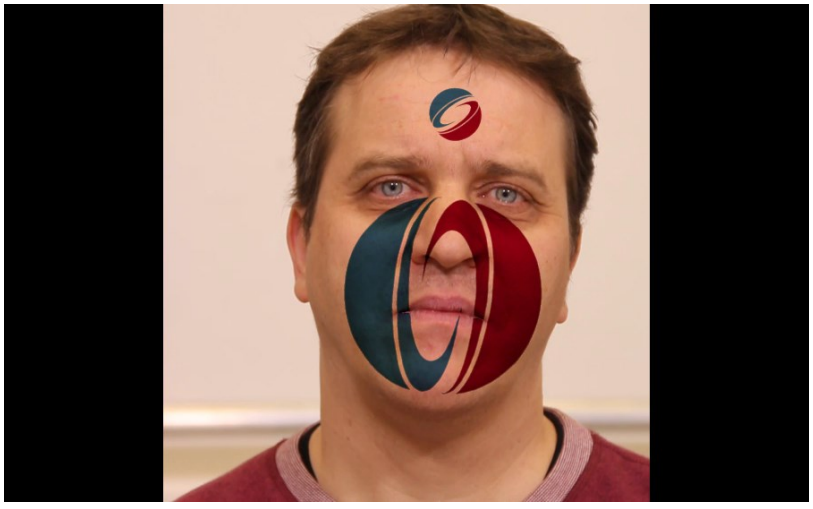
Monocular Face Reconstruction



P. Garrido, L. Valgaerts, C. Wu, C. Theobalt, Reconstructing Detailed Dynamic Face Geometry from Monocular Video, SIGGRAPH Asia 2013

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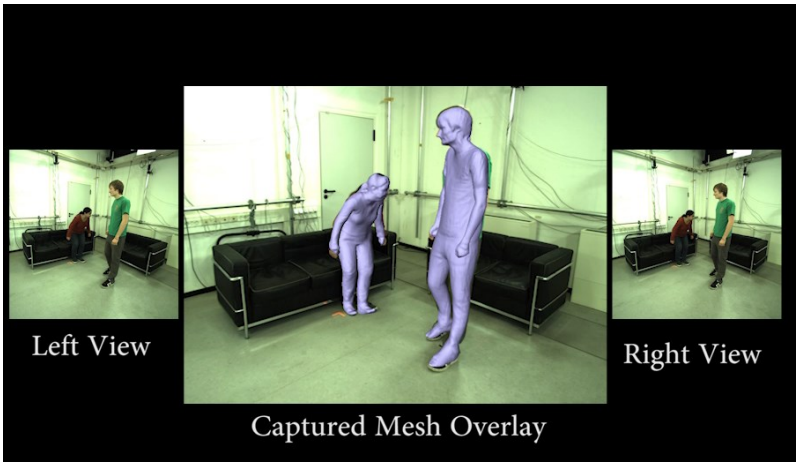
On-Set Performance Capture with a Stereo Camera



C. Wu, C. Stoll, L. Valgaerts, C. Theobalt, On-set Performance Capture of Multiple Actors with a Stereo Camera, SIGGRAPH Asia 2013

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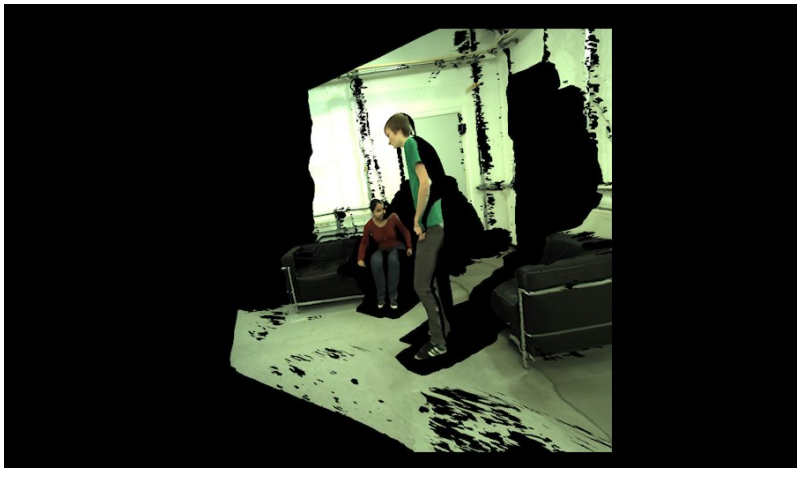
On-Set Performance Capture with a Stereo Camera



C. Wu, C. Stoll, L. Valgaerts, C. Theobalt, On-set Performance Capture of Multiple Actors with a Stereo Camera, SIGGRAPH Asia 2013

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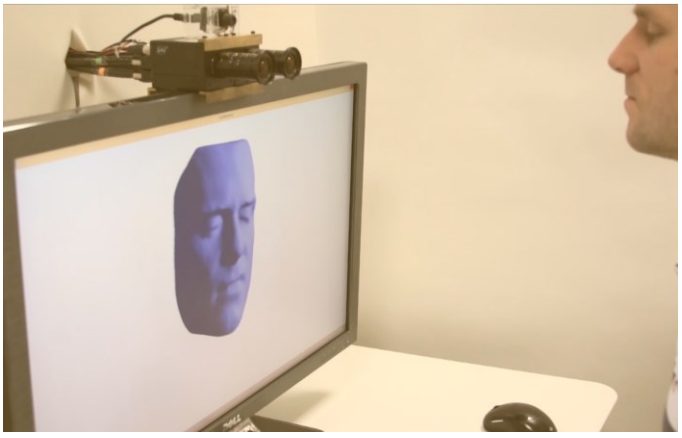
Real-time Deformable Mesh Tracking

max planck institut informatik

Surface Deformation



M. Zollhoefer, M Niessner, S. Izadi, C. Rehmann, C. Zach, M. Fisher, C. Wu, A. Fitzgibbon, C. Loop, C. Theobalt, M. Stamminger, Real-time Non-rigid Reconstrution Using an RGB-D Camera, ACM TOG (SIGGRAPH 2014)

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Modifying Captured Content

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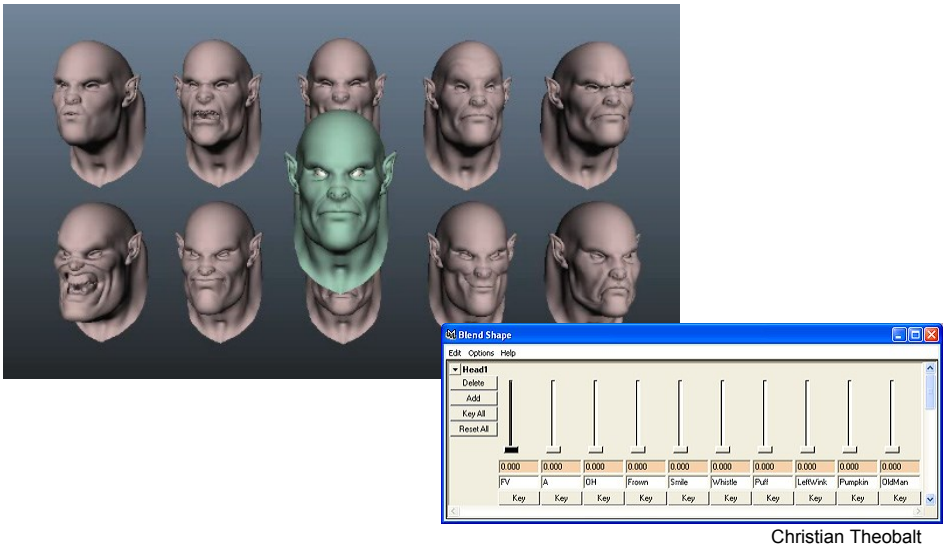
Sparse Localized Deformation Components

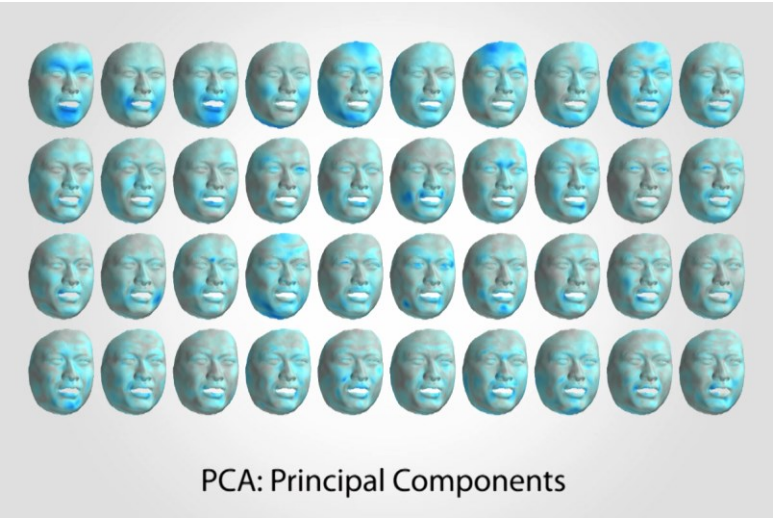
T. Neumann, K. Varanasi, S. Wenger, M. Wacker, M. Magnor, C. Theobalt,
Sparse localized deformation components, *ACM TOG (SIGGRAPH ASIA) 2013*

Blend Shape Model

- Linear blend of artist defined deformations from rest shape



Sparse Localized Deformation Components



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Sparse localized deformation components, *ACM TOG (SIGGRAPH ASIA) 2013*

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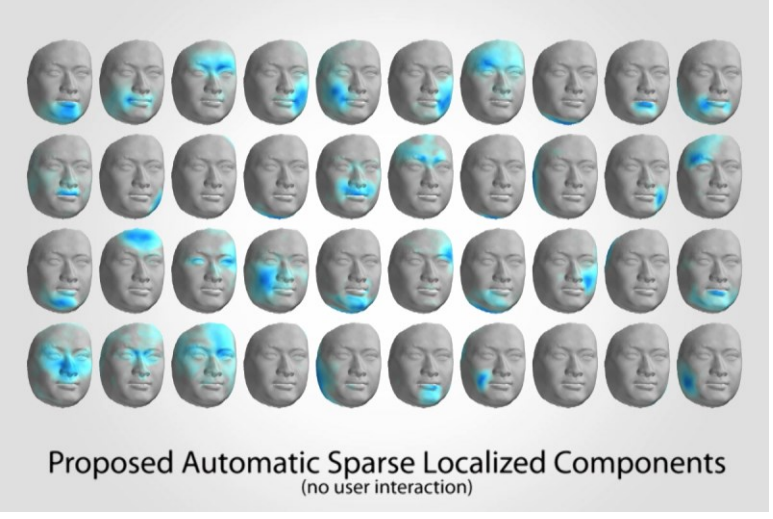
Sparse Localized Deformation Components



T. Neumann, K. Varanasi, S. Wenger, M. Wacker, M. Magnor, C. Theobalt,
Sparse localized deformation components, *ACM TOG (SIGGRAPH ASIA) 2013*

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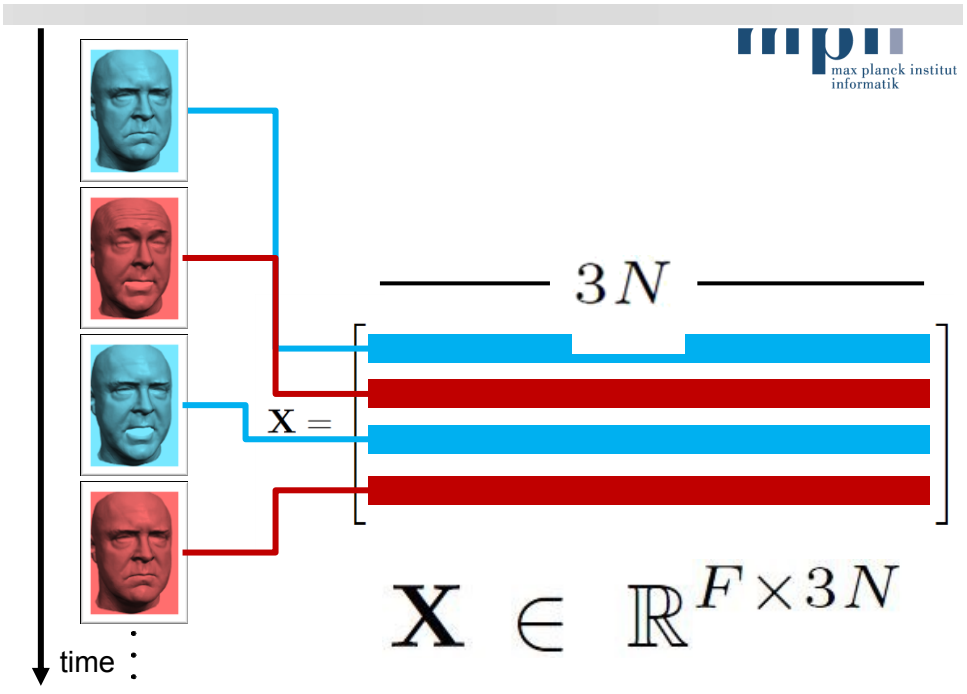

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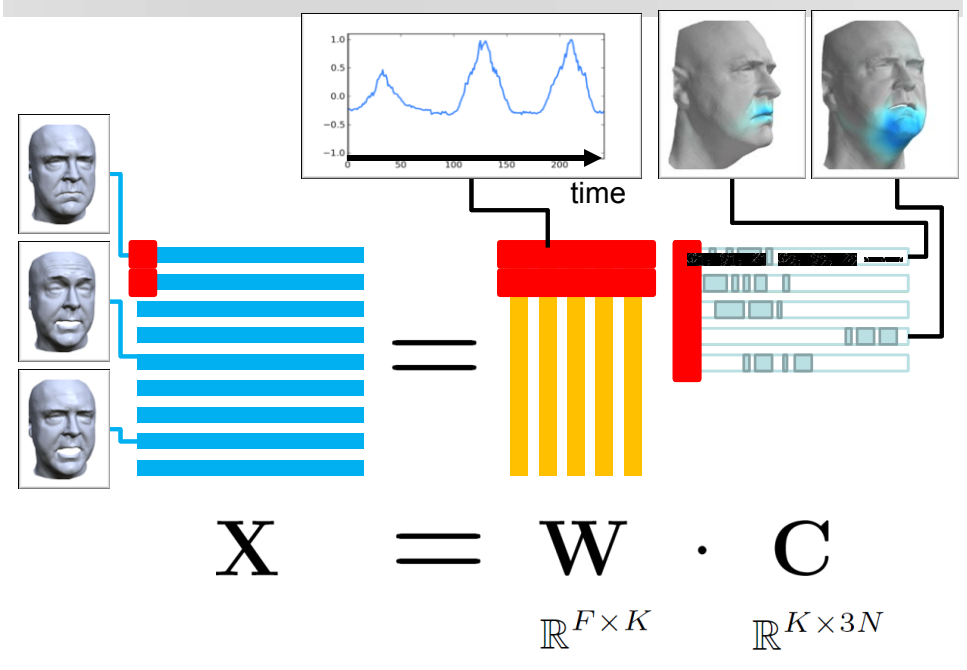

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$$\min_{\mathbf{W},\mathbf{C}} \|\mathbf{X} - \mathbf{W}\cdot\mathbf{C}\|_{\mathrm{F}}^2 + \sum_{k=1}^{K}\sum_{i=1}^{N} \|\mathbf{c}_k^{(i)}\|_2 \quad \text{subject to} \quad \max(|\mathbf{W}_{:,k}|) = 1$$

Data Term

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$$+ \sum_{k=1}^{K}\sum_{i=1}^{N} \|\mathbf{c}_k^{(i)}\|_2$$

Sparse, but **not localized**

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$$+\sum_{k=1}^{K}\sum_{i=1}^{N}\Lambda_k^{(i)}\|\mathbf{c}_k^{(i)}\|_2$$

Sparse and **localized**

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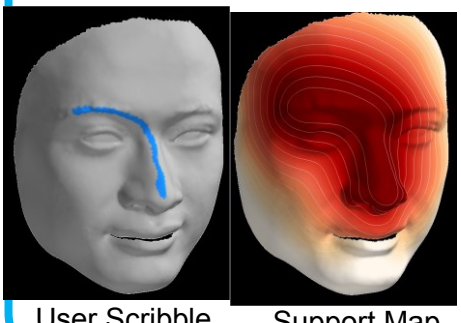
Support Maps

- Geodesic distance to center vertices (on rest shape)

User Interaction

(rough binary mask)

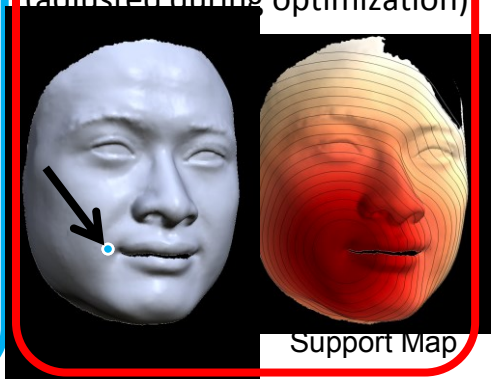


User Scribble

Support Map

Automatic

(adjusted during optimization)



Support Map

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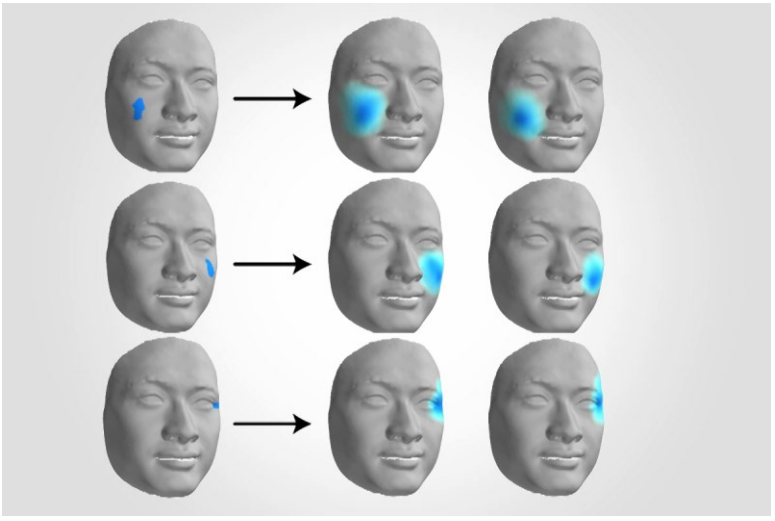
Sparse Localized Deformation Components



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Sparse localized deformation components, *ACM TOG (SIGGRAPH ASIA) 2013*

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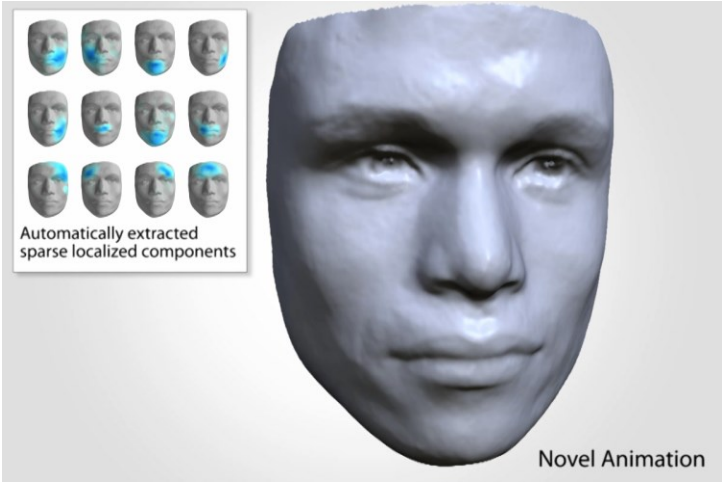
New Animation

Input



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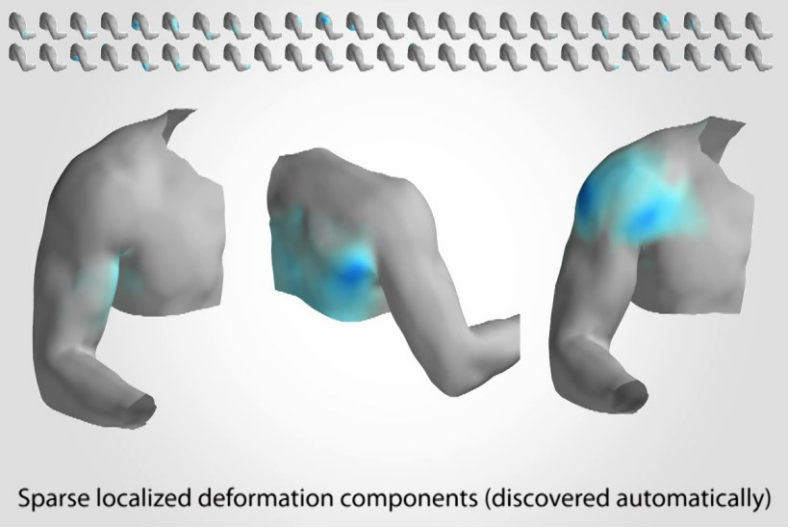
“Physiological” Components



Conclusions

- 4D reconstruction has made great progress
- Many open challenges until we capturing reality
- Needed: Rethinking fundations of 4D reconstruction
- First steps:
  - Estimation and exploitation of more expressive light transport models
  - New parameterizations of dynamic scenes

Thank You !

gvv.mpi-inf.mpg.de

www.thecaptury.com

Thanks to:

ERC Starting Grant
CapReal

Christian Theobalt