4D Shape Modeling

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MORPHEO - INRIA Grenoble Rhône-Alpes

Introduction

- [Computer] Vision: Using visual cues to infer information on the real environment.

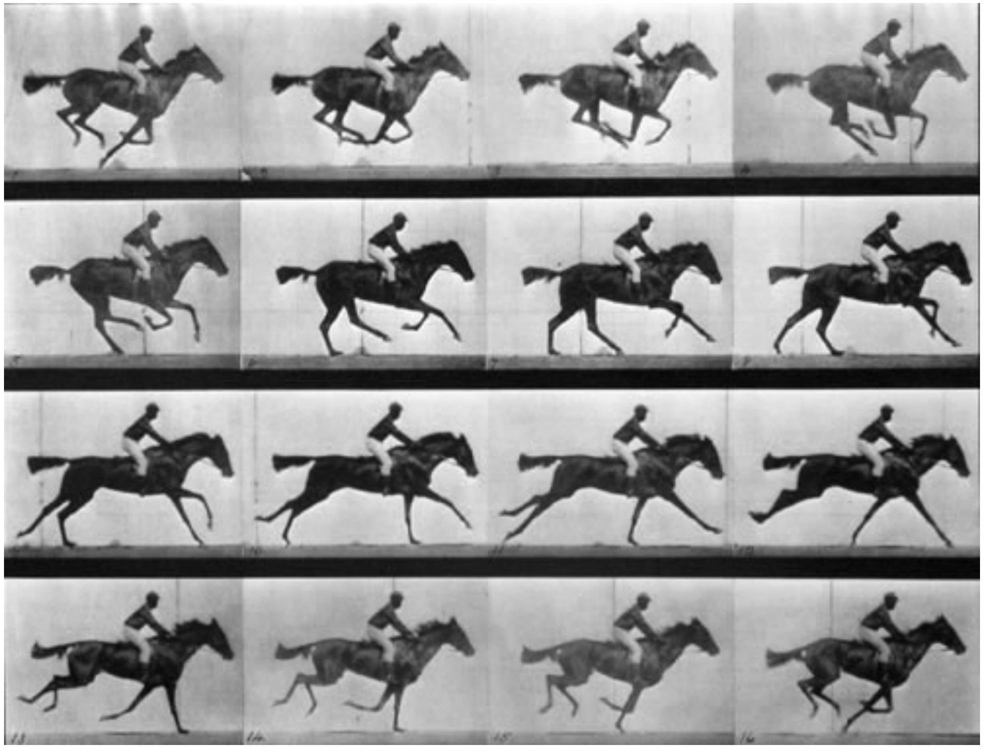
- 4D Scene Modeling: analysis of 3D scenes composed of real objects, possibly moving and deforming
  1. Shape Modeling: Static->3D, dynamic->4D (3D+t).
  2. Motion Modeling.
  3. Motion Semantic Modeling (e.g. modeling actions, activities).

- Applications :

  Contents Production: TV3D, Virtual/Augmented Reality, Interactions.
  Intelligent Environments: smart rooms,
  Surveillance. Medical applications. Etc.

Introduction

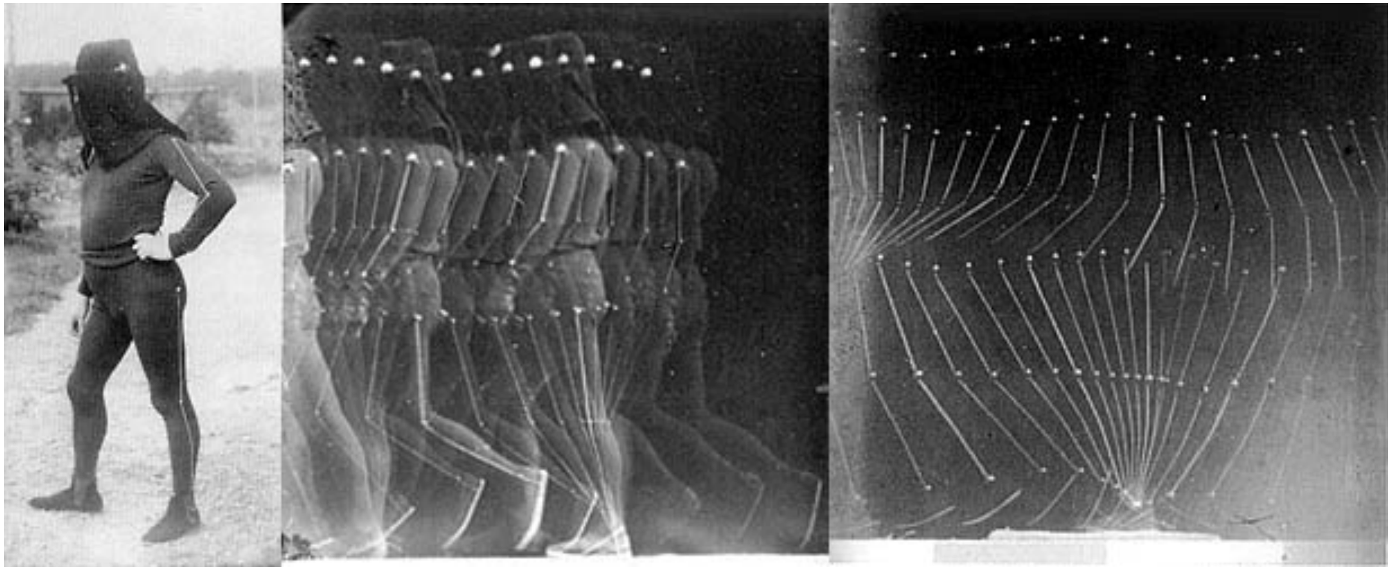
Early use of visual information to infer moving shape features



Eadweard Muybridge (1878): *Animal locomotion.*

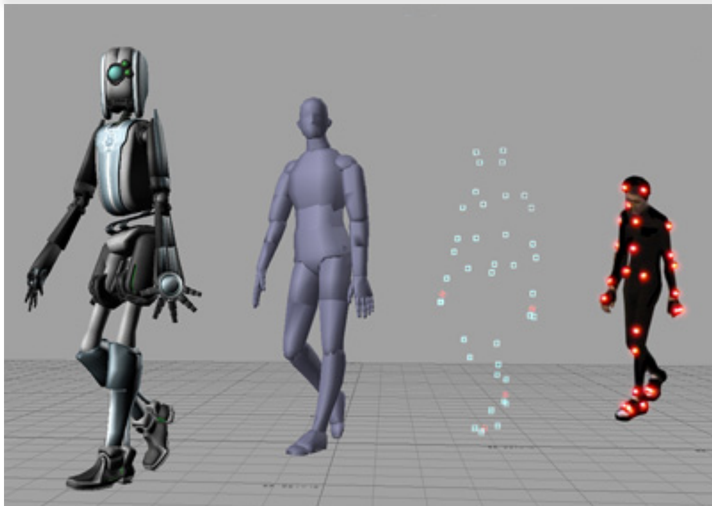
Introduction

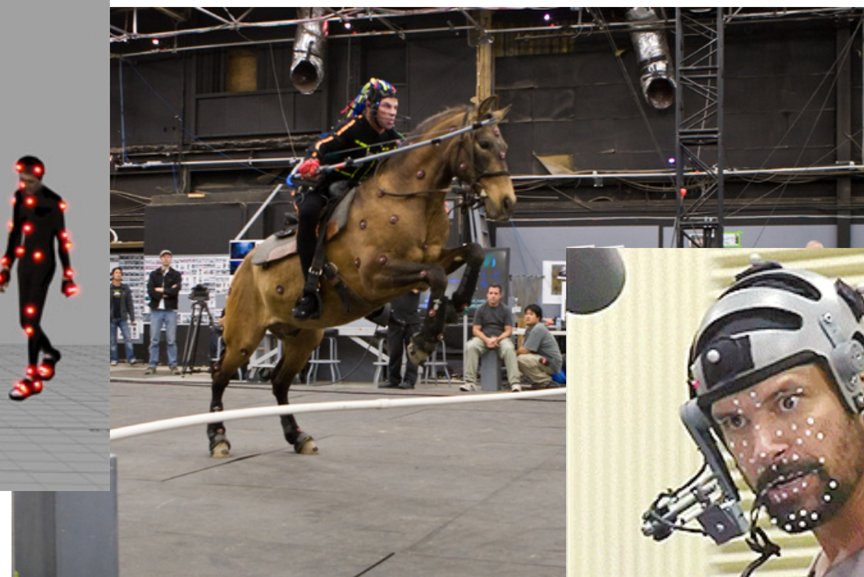
Early use of visual information to infer moving shape features



Etienne Jules Marey (1883): *Chronophotographie géométrique, man locomotion.*

Introduction



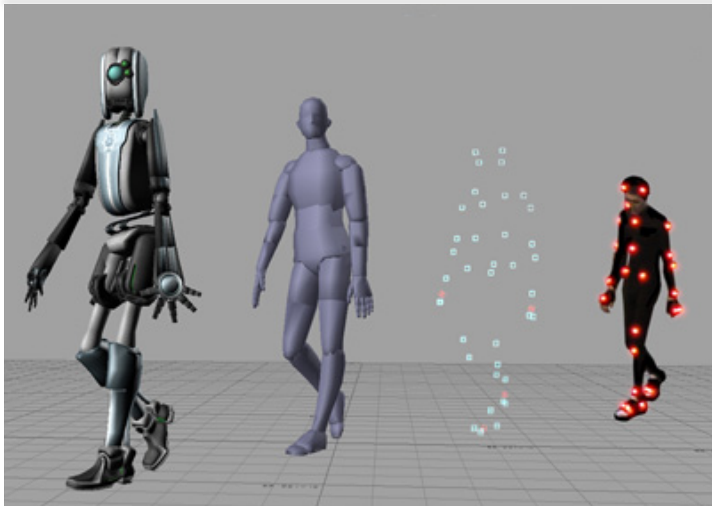


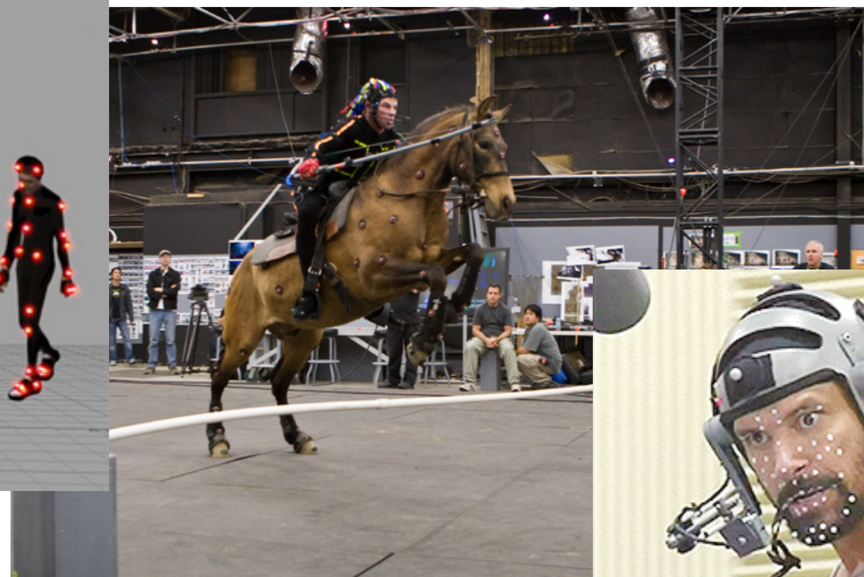
Avatar

The Hobbit

Motion Capture systems using markers:

Introduction





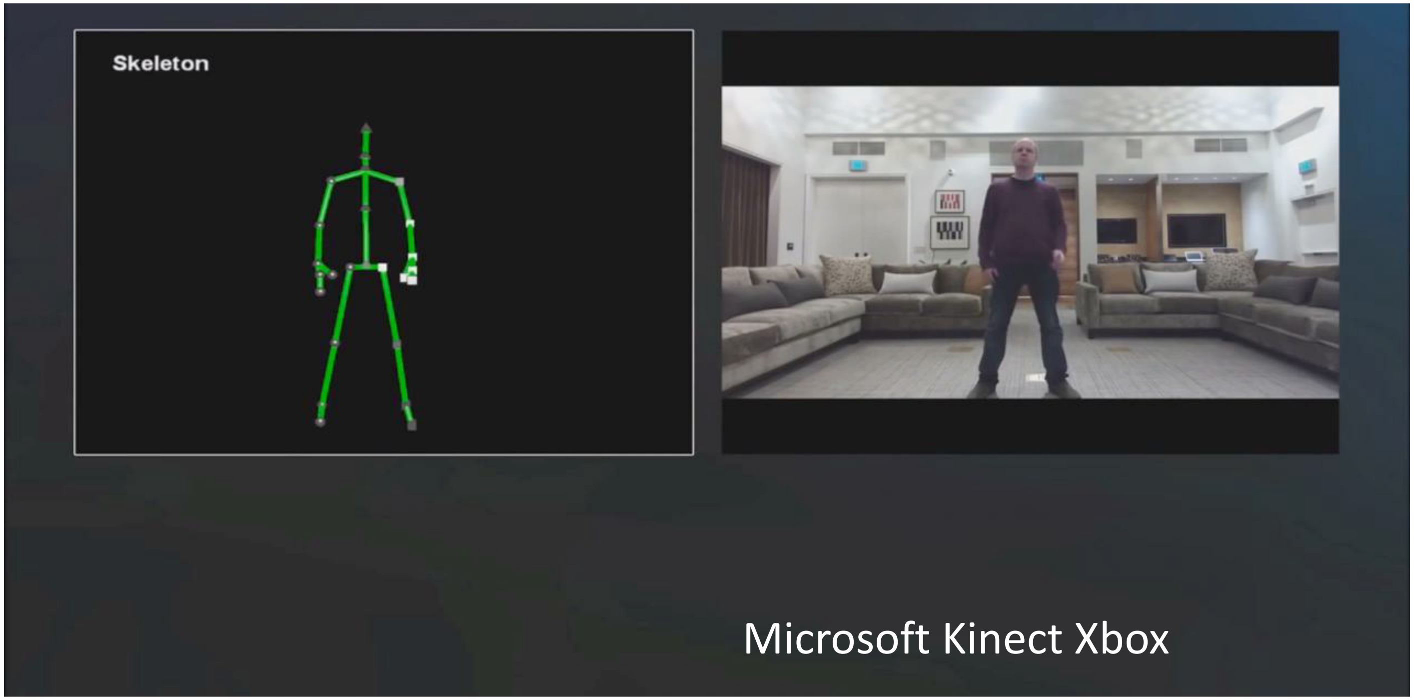
Avatar

The Hobbit

Motion Capture systems using markers:

- Markers provide sparse motion information;
- No information on shapes or their appearances.

Introduction



- Observations: depth fields;
- Outputs: skeleton poses, orientations, etc.

Introduction

Instead of sparse marker locations or depth fields, multi-view systems can consider full color image information to produce 4D models.

Introduction

Introduction

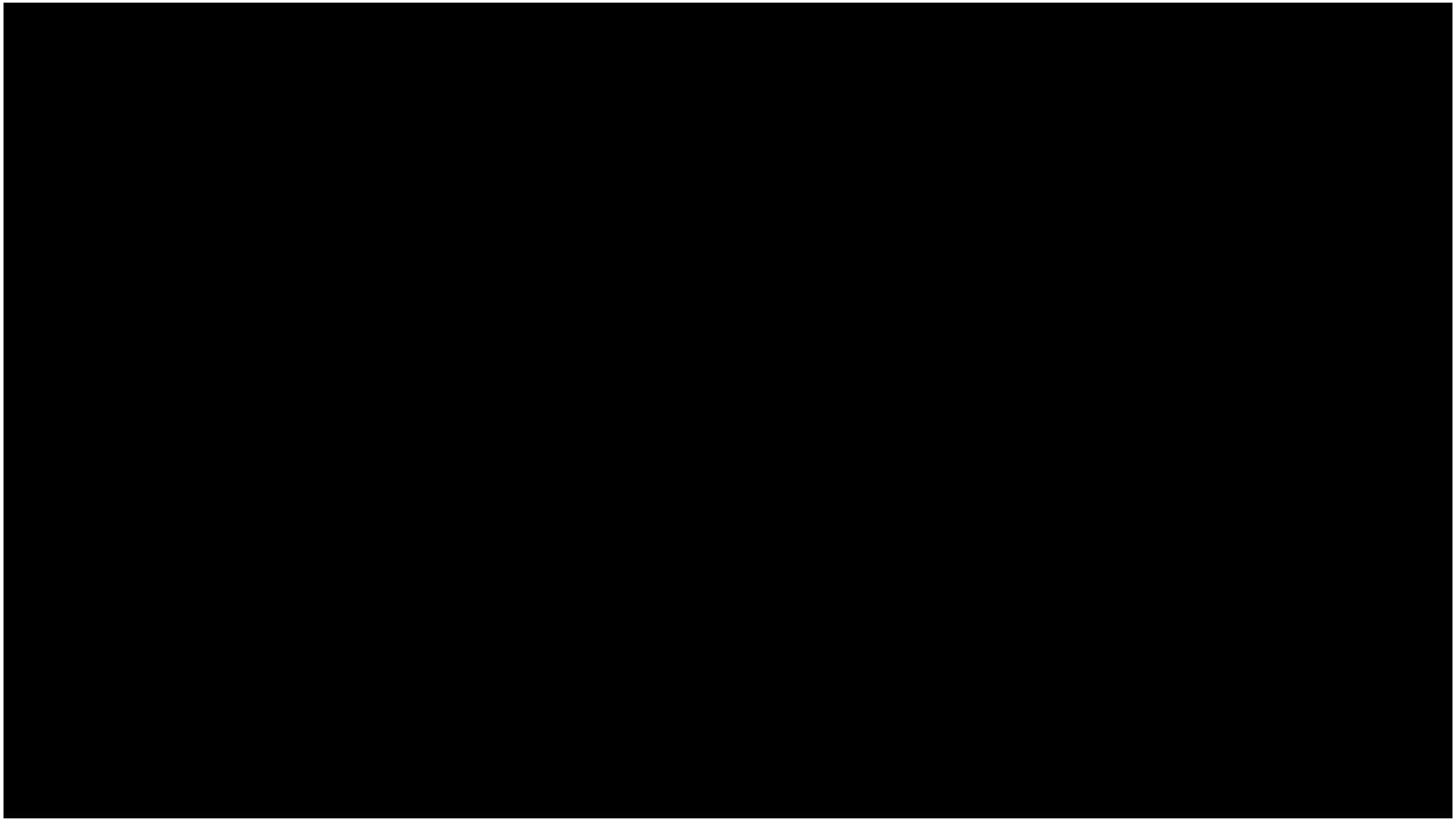
4D Modeling Applications:

- Media contents.

- Motion Analysis:
  - Sport analysis;
  - Diagnostics in medical applications.

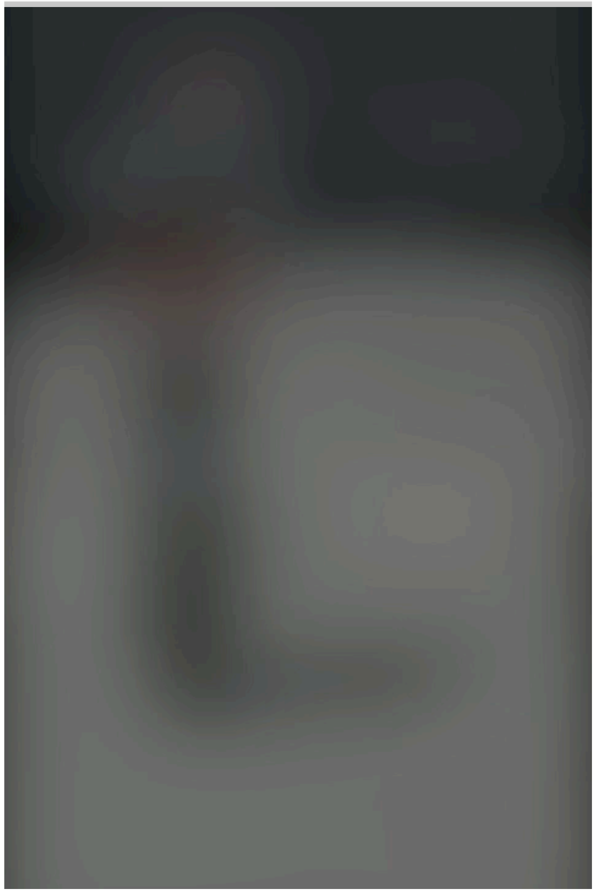
- Interactive and Immersive environments:
  - Gesture interfaces;
  - Games.

Introduction



4D Modeling Applications: Media content production (4D View Solutions - startup INRIA)

Introduction



4D Modeling Applications: VR and AR contents (Holooh@Paris)

Introduction

[INRIA DEMO SIGGRAPH 2009]

4D Modeling Applications: Interactive and Immersive environments.

Introduction

Some 4D modeling research issues:

- Modeling both shapes and appearances of complex scenes:
  - Acquisition issues: camera with different modalities, segmentation;
  - Shapes and appearances: learning over time;
- Recovering robust motion information.
- Modeling and analyzing motions/gaits.
- Animation Synthesis.

Outline

1. Multi-View platforms.
2. Shape recovery: basics.
3. Motion recovery: shape tracking.

Outline

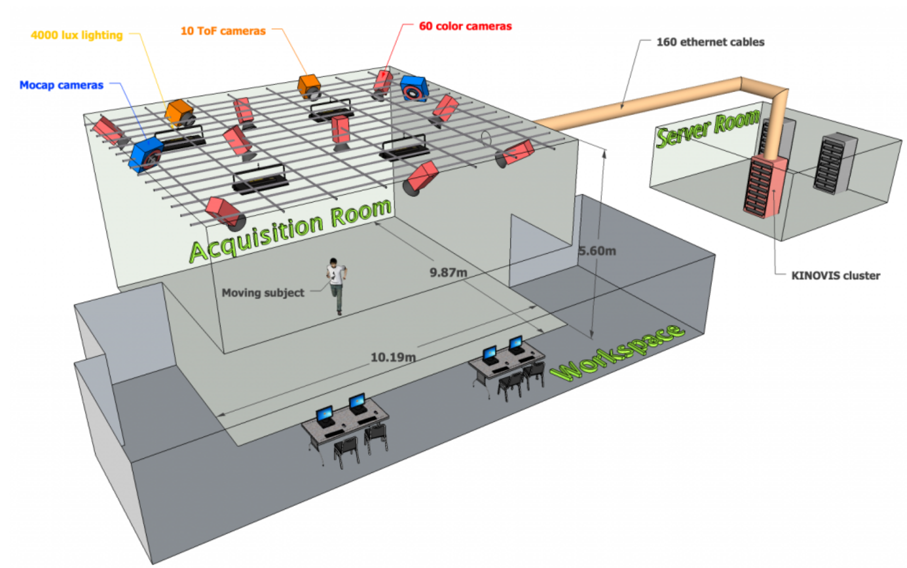
1. Multi-View platforms.
2. Shape recovery: basics.
3. Motion recovery: shape tracking.

Multi-View Platforms

MPI Tubingen 4D Scanner [Siggraph'15]: Active system

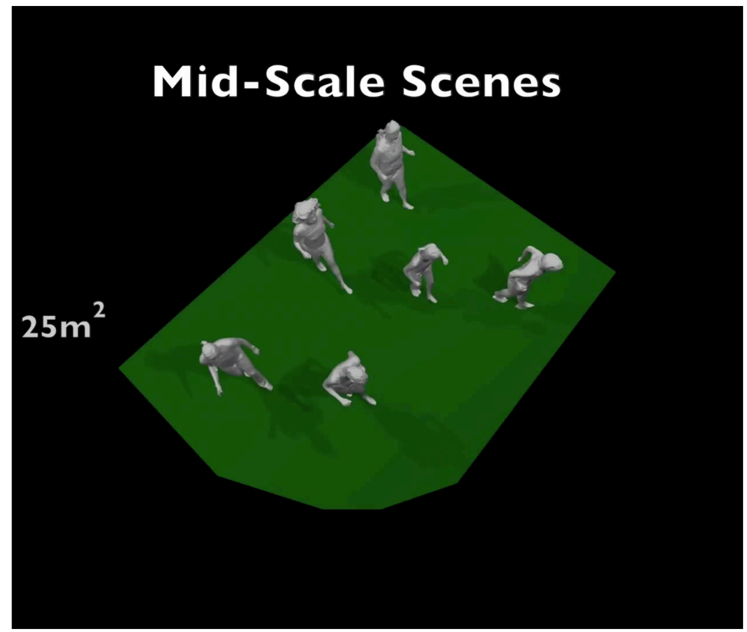
Multi-View Platforms

Multi-View Platforms



Kinovis platform at INRIA Grenoble

Multi-View Platforms



Kinovis platform@inria (64 cameras)

Multi-View Platforms

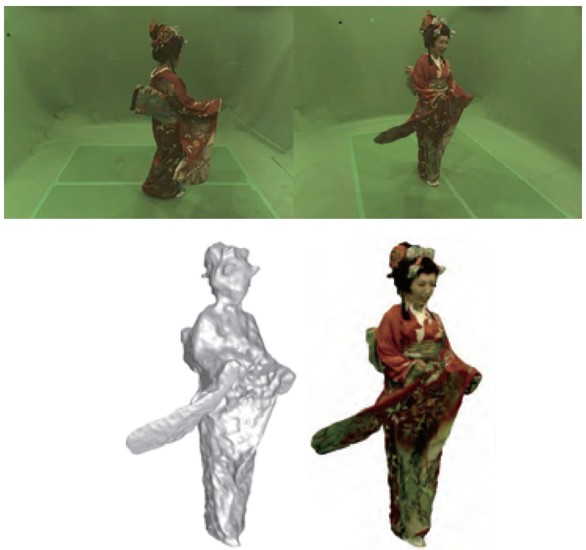
@Microsoft, High-Quality Streamable Free-Viewpoint Video, Siggraph'15
Combined passive and active system

Multi-View Platforms

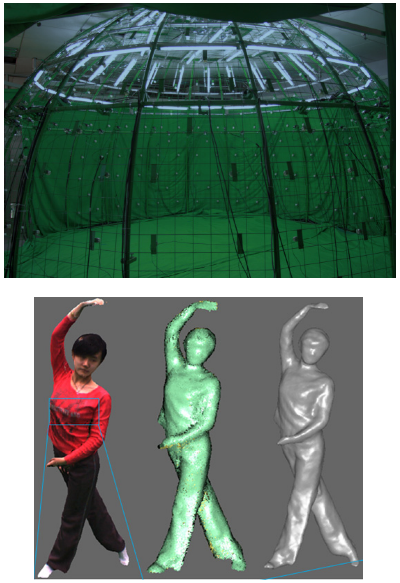
@Microsoft, High-Quality Streamable Free-Viewpoint Video, Siggraph'15

Multi-View Platforms

University of Surrey



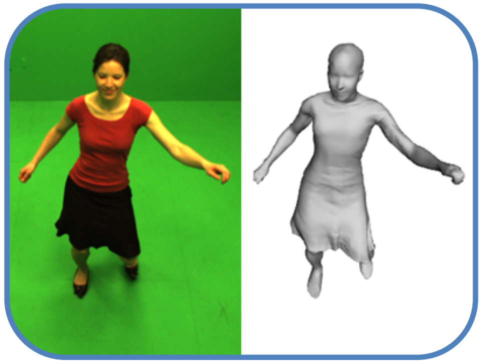
University of Kyoto



University of Tsinghua

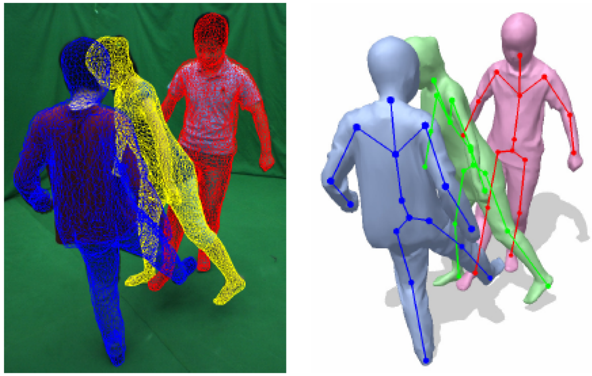
Model free shape estimation

Multi-View Platforms



MIT

MPI Tubingen



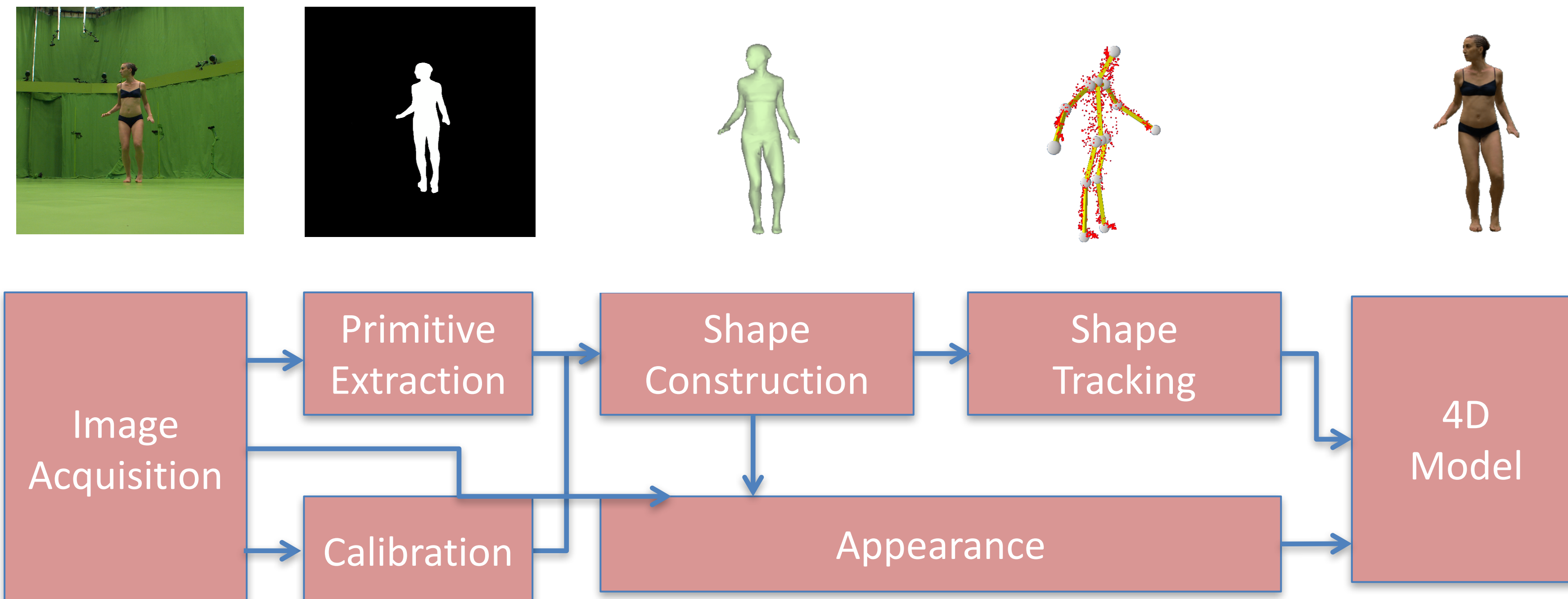
MPI Sarrebrucken

Model based shape estimation

Outline

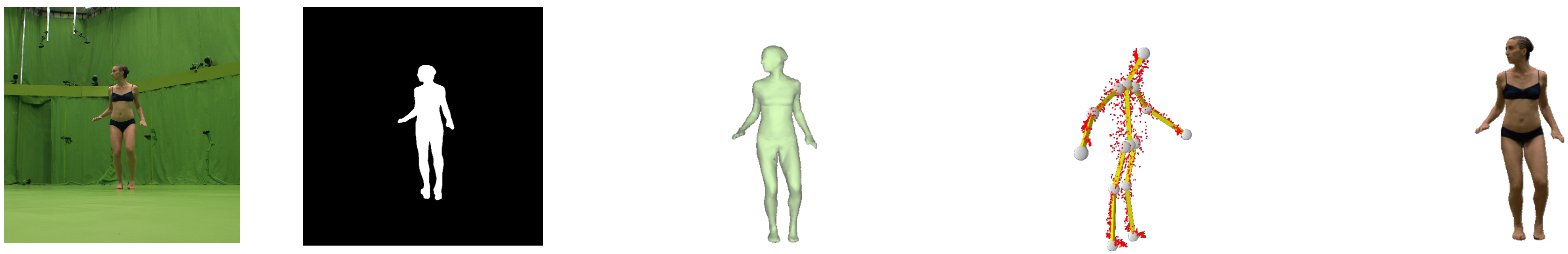
1. Multi-View platforms.
2. Shape recovery: basics.
3. Motion recovery: shape tracking.

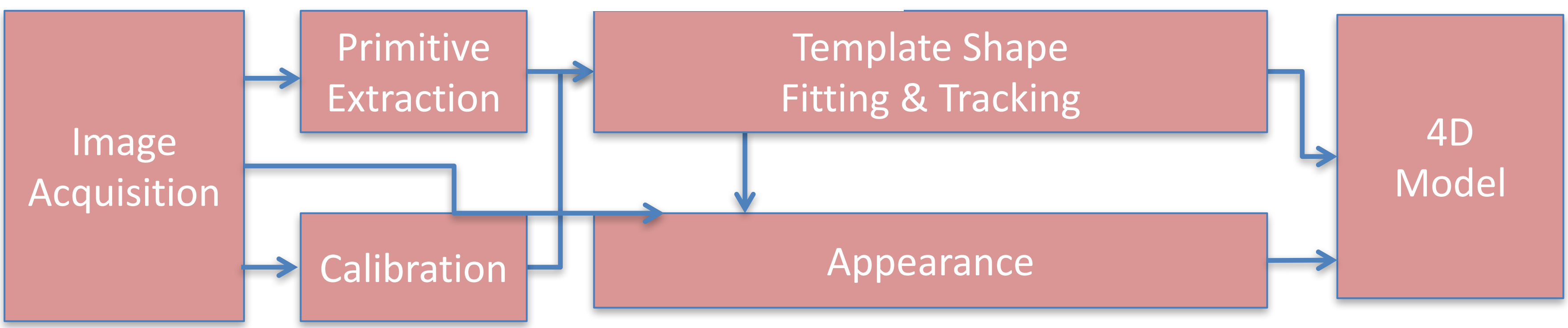
Shape Recovery: Basics



General 4D modeling pipeline: no prior model

Shape Recovery: Basics





General 4D modeling pipeline: prior model

Shape Recovery: Basics

Primitive Extraction

- Regions (silhouettes) -> surfaces, volumes
- Points (image features) -> 3D point clouds

Shape Recovery: Basics

Primitive Extraction

- **Regions (silhouettes) -> surfaces, volumes**
- Points (image features) -> 3D point clouds

Shape Recovery: Basics

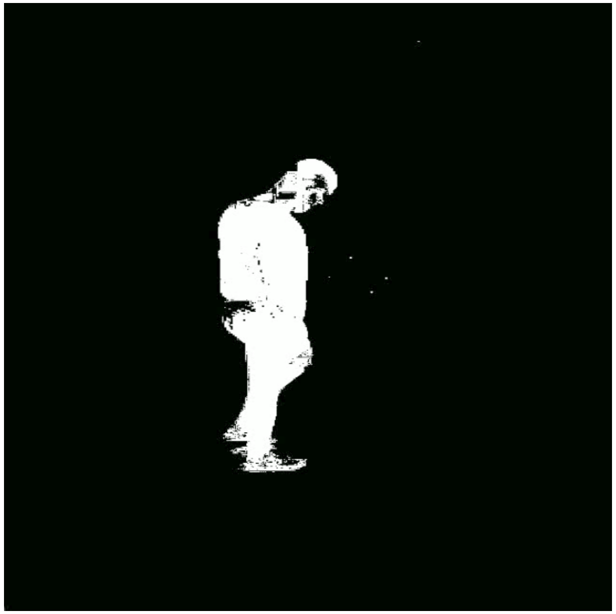
Silhouette

- Silhouettes are regions in the images where object of interest project.
- Silhouettes are estimated using low-level processes.
- Silhouettes give information on the observed surfaces.
- Extraction:
  - Chroma keying (blue or green background != skin color)
  - Background subtraction (static background)

Shape Recovery: Basics

Silhouette Segmentation

- Background subtraction:
  - Statistical background model
    - Gaussian
    - Gausian mixtures
    - Non parametric: e.g. histograms.
- Issues:
  - Image digitalization (noise);
  - Color ambiguities between background and foregroud objects;
  - Luminosities changes, etc.

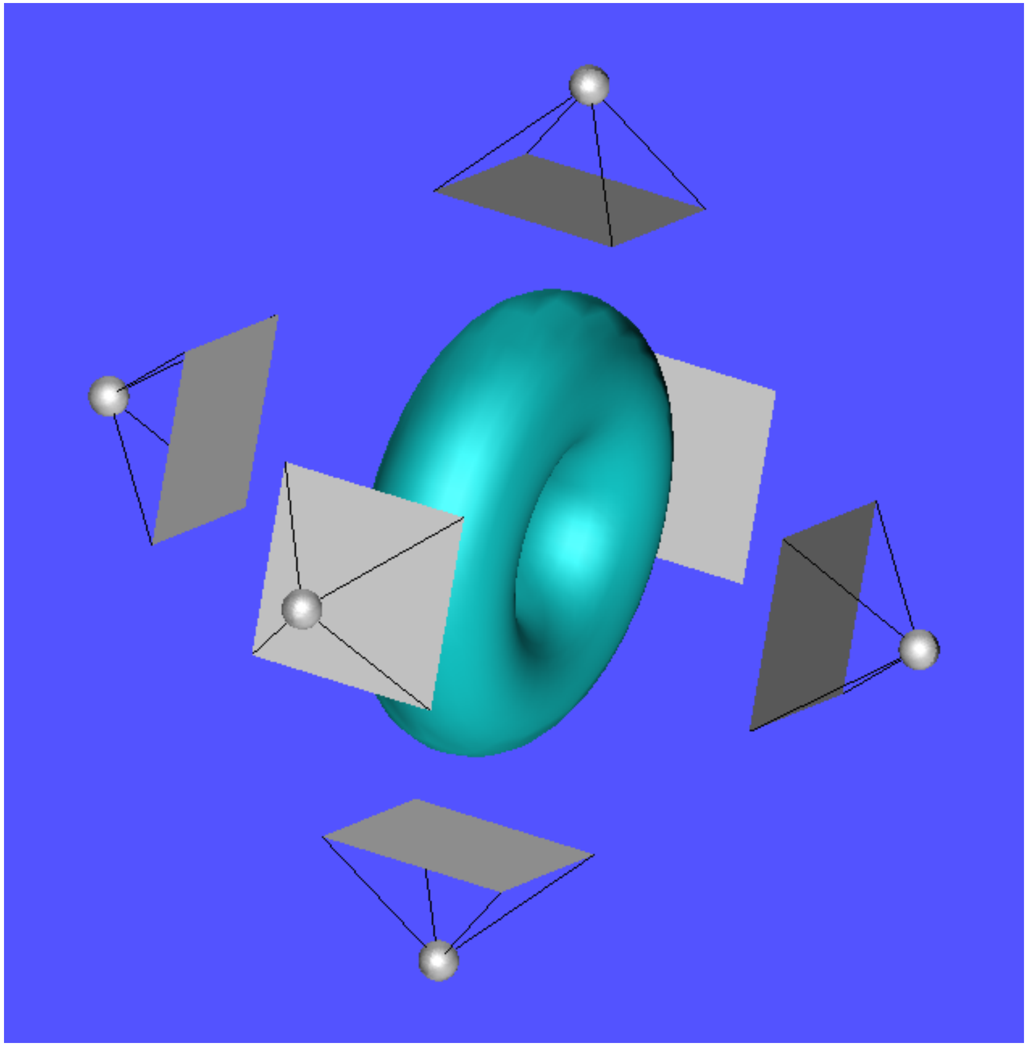


Shape Recovery: Basics

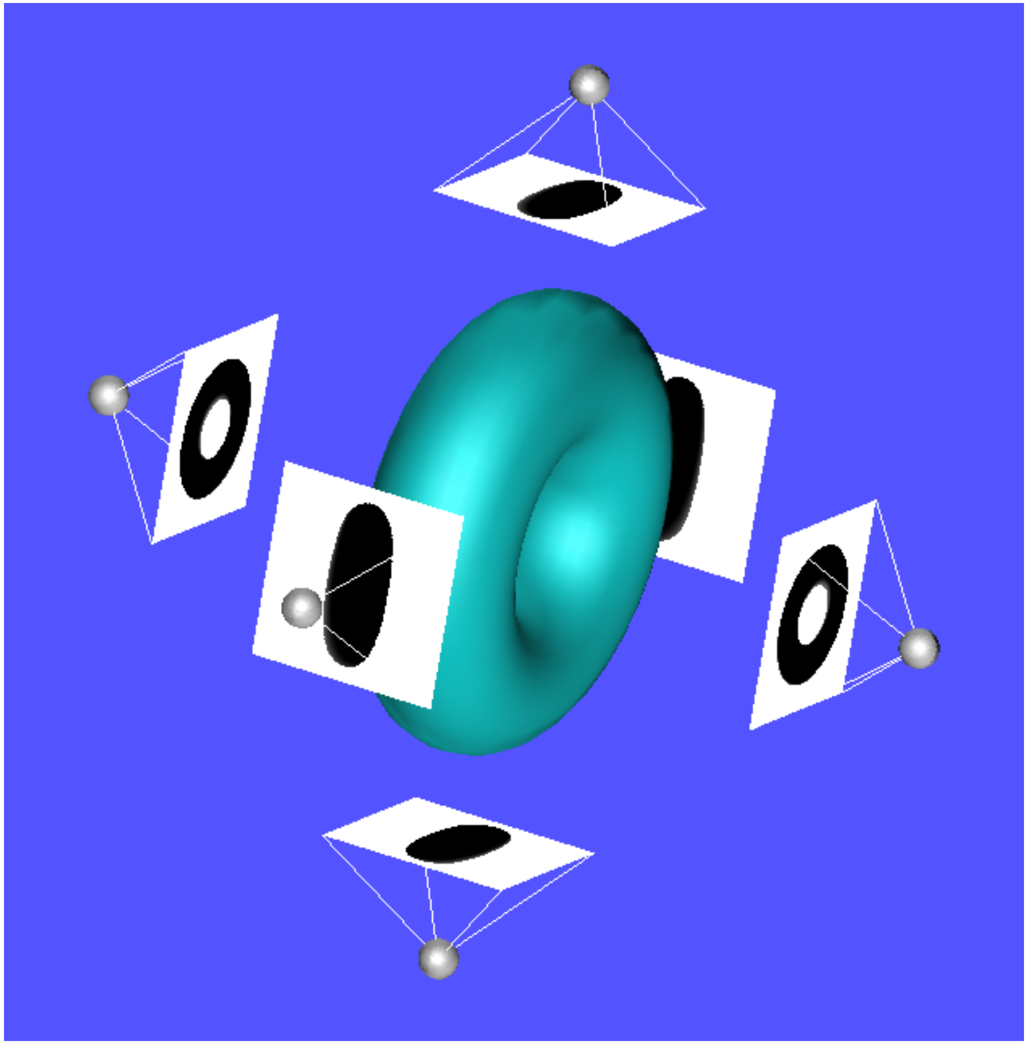
From silhouettes to shapes:

2D silhouettes define a volume in 3D called the visual hull. It is the maximal volume compatible with a set of silhouettes.

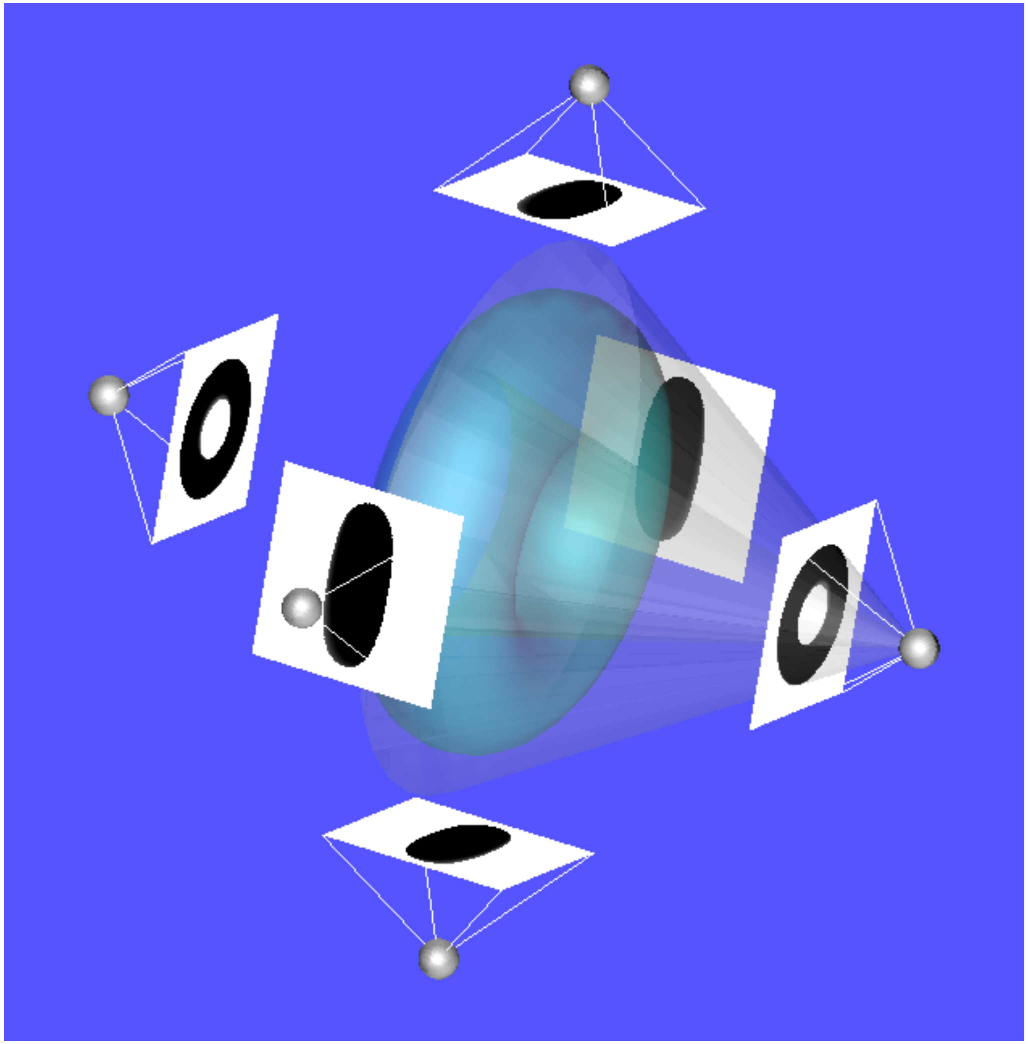
Shape Recovery: Basics



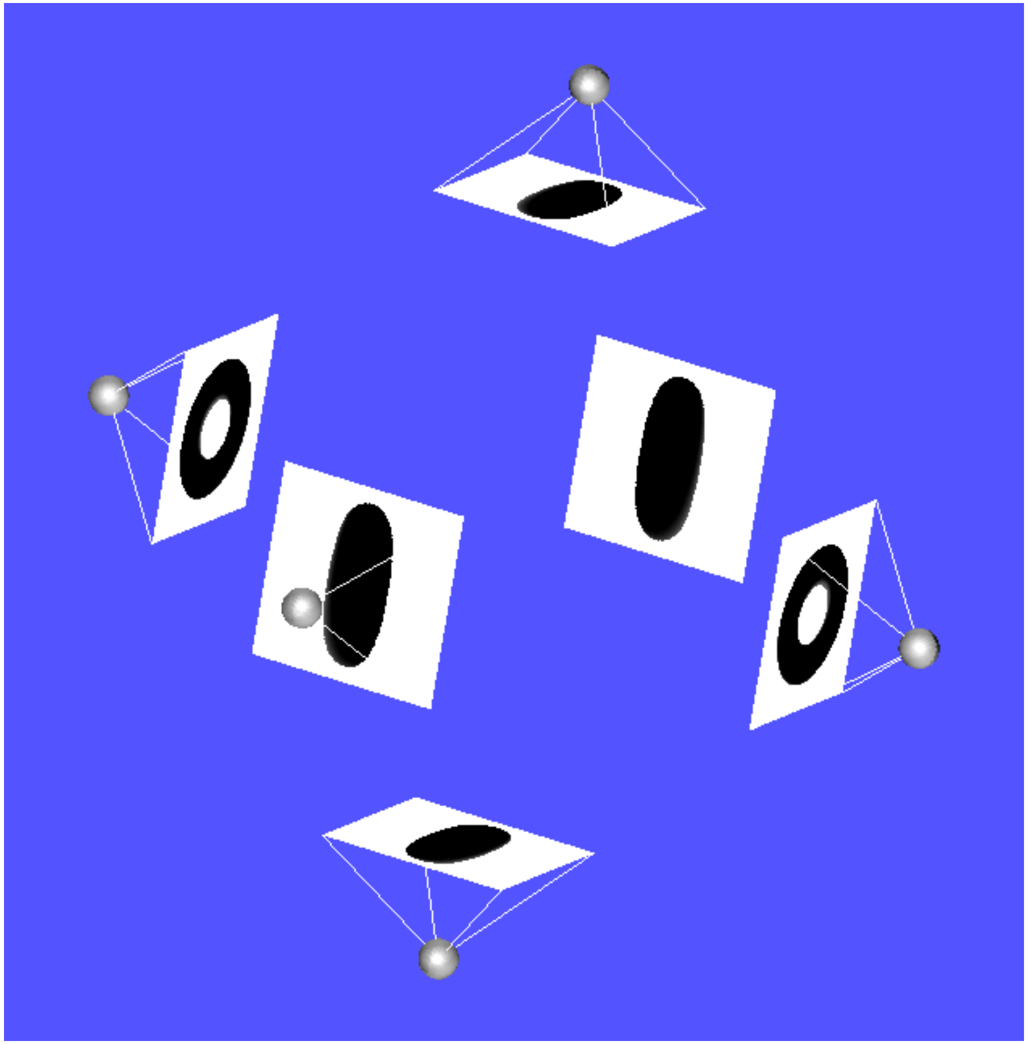
Shape Recovery: Basics



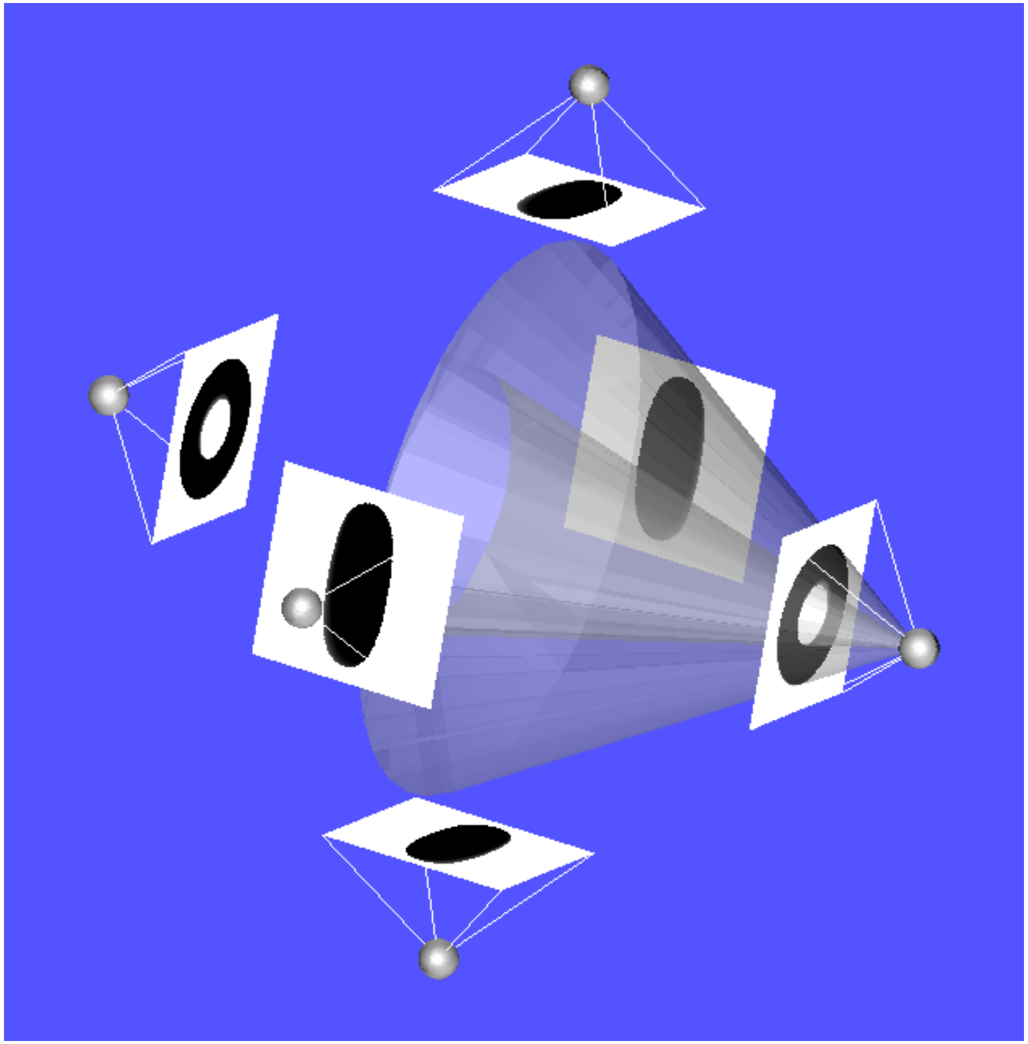
Shape Recovery: Basics



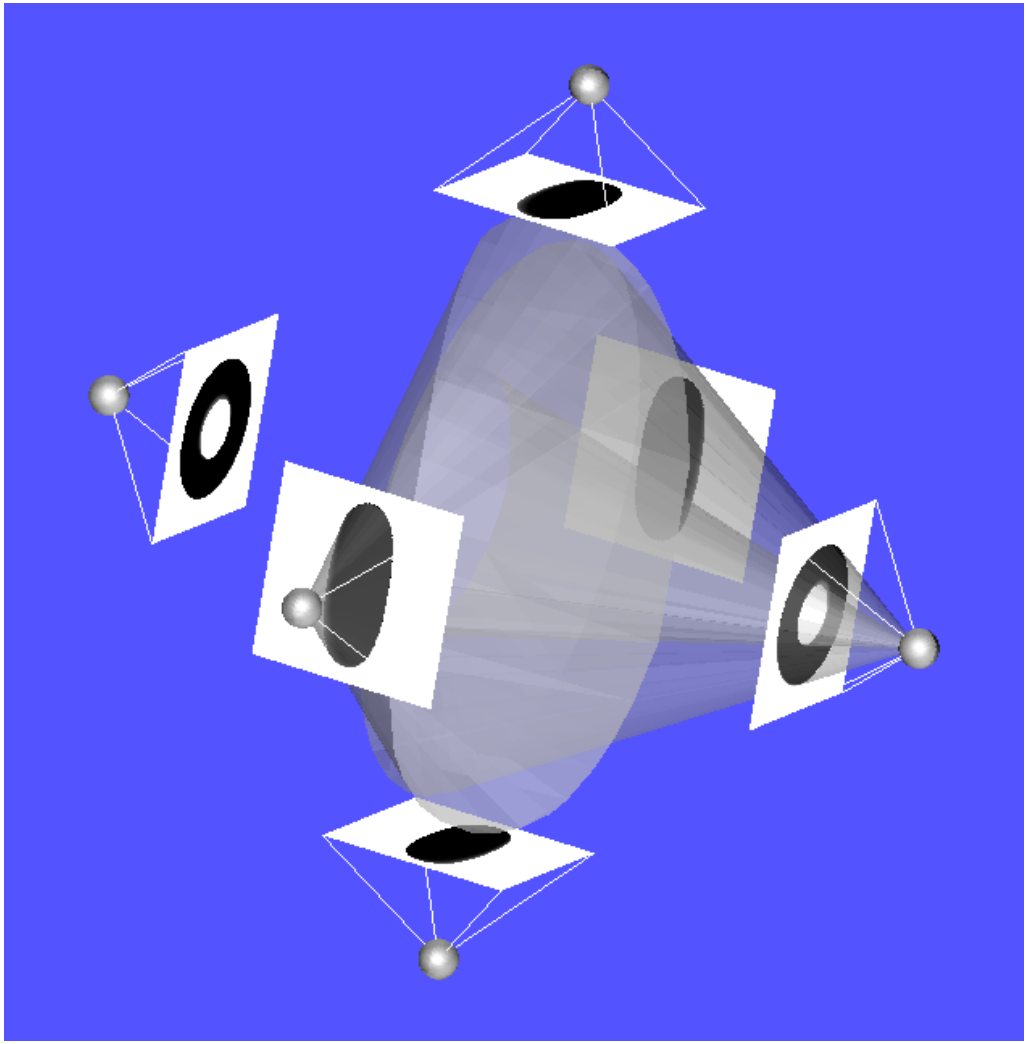
Shape Recovery: Basics



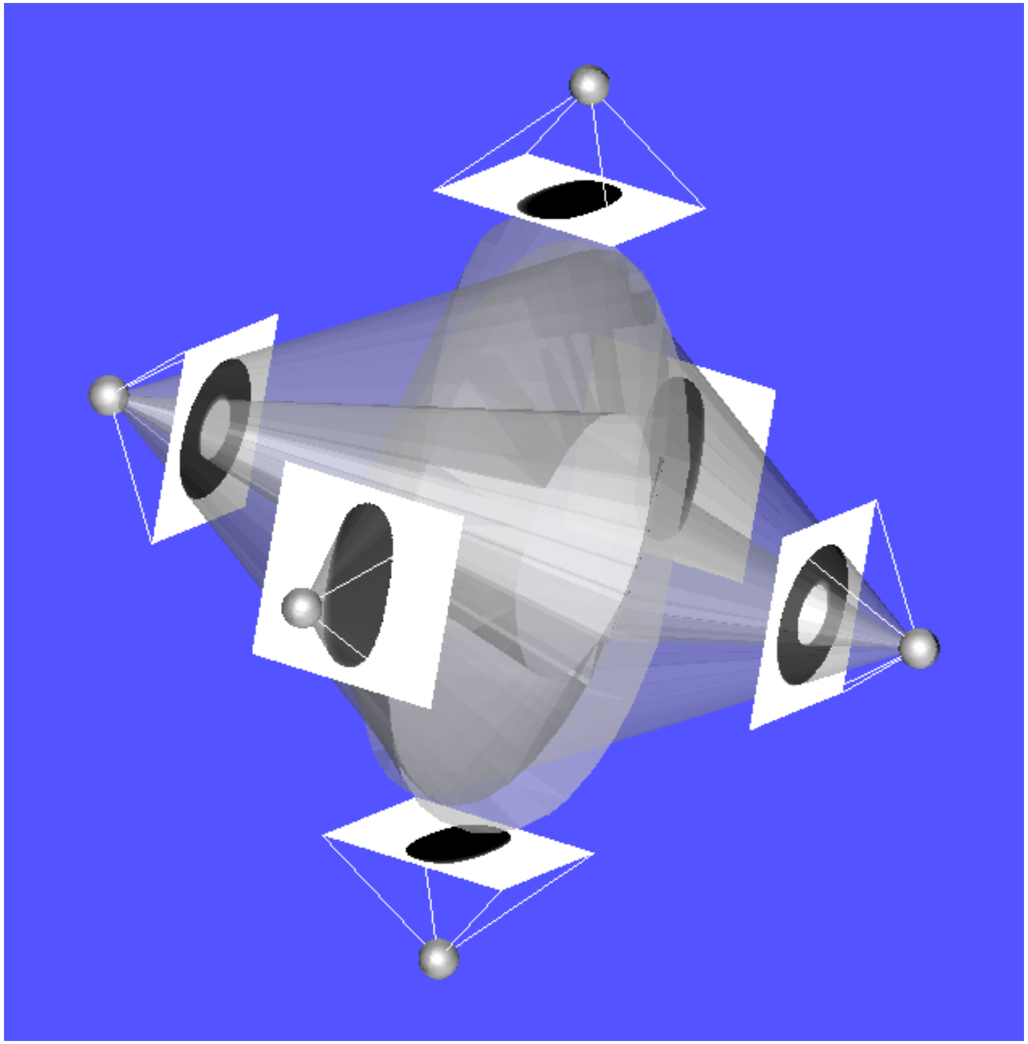
Shape Recovery: Basics



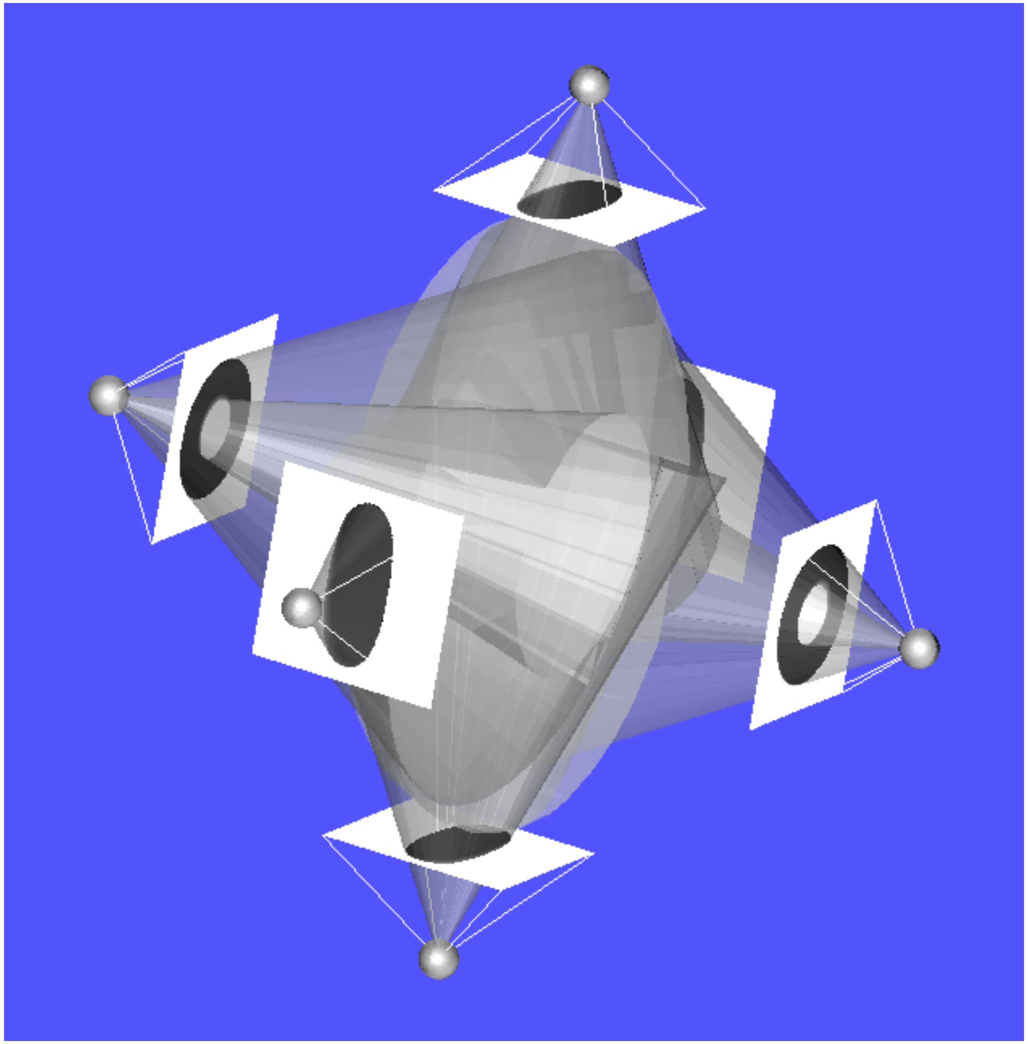
Shape Recovery: Basics



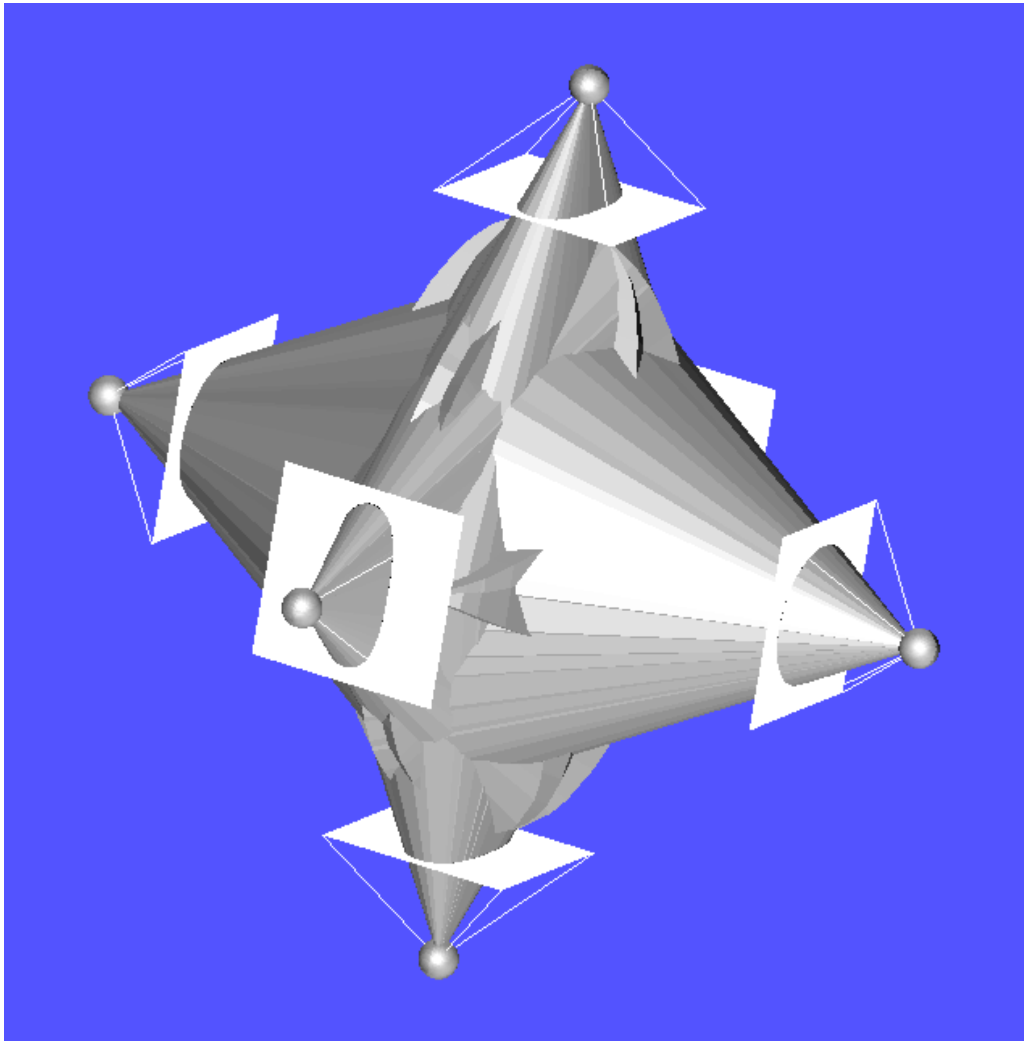
Shape Recovery: Basics



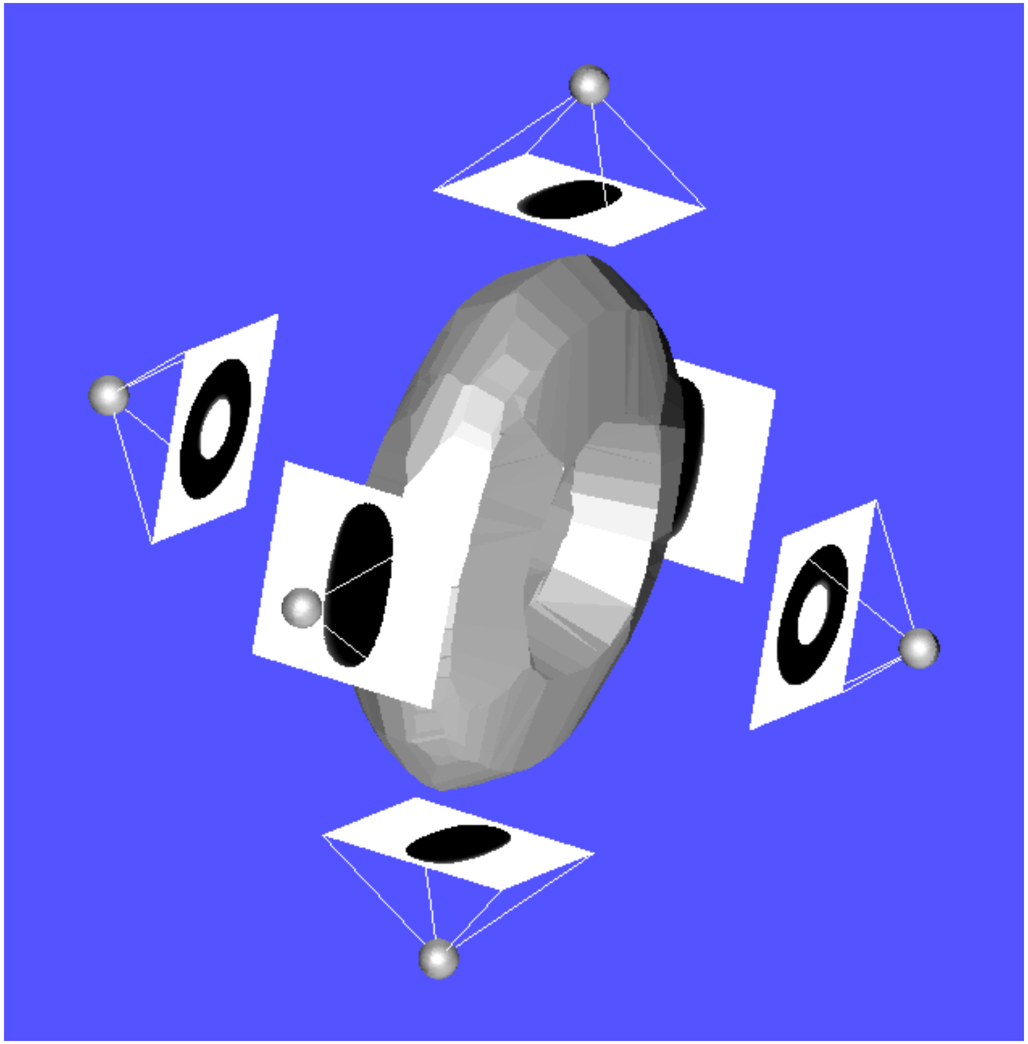
Shape Recovery: Basics



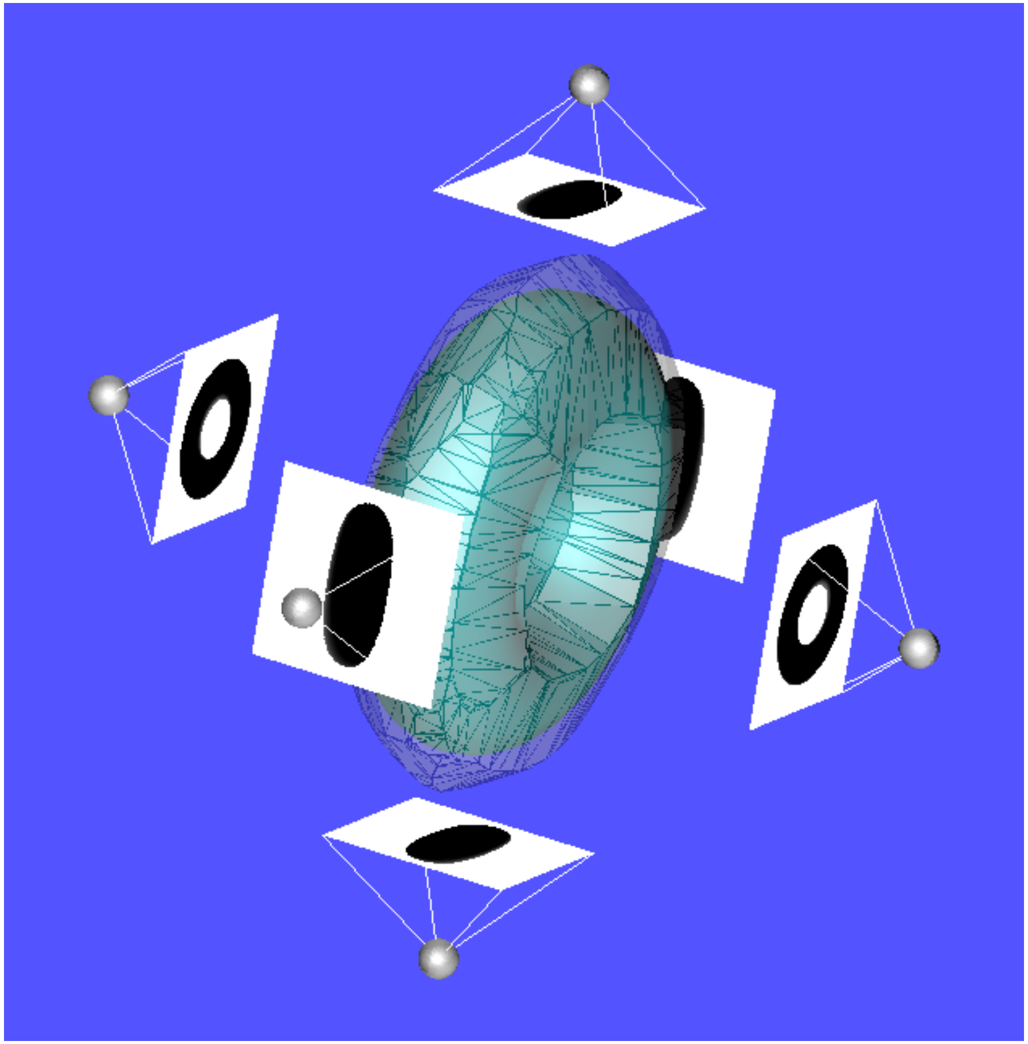
Shape Recovery: Basics



Shape Recovery: Basics

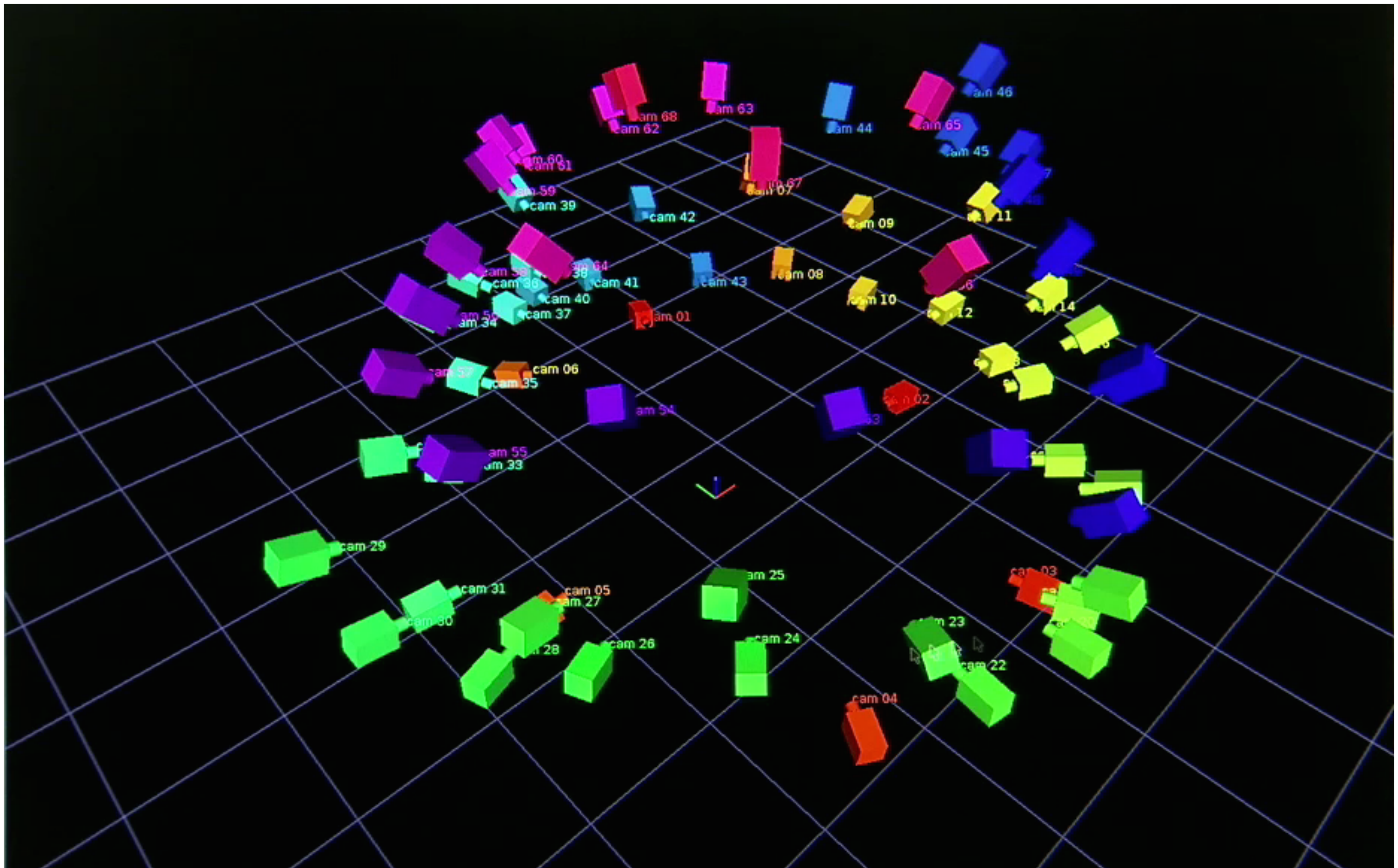


Shape Recovery: Basics



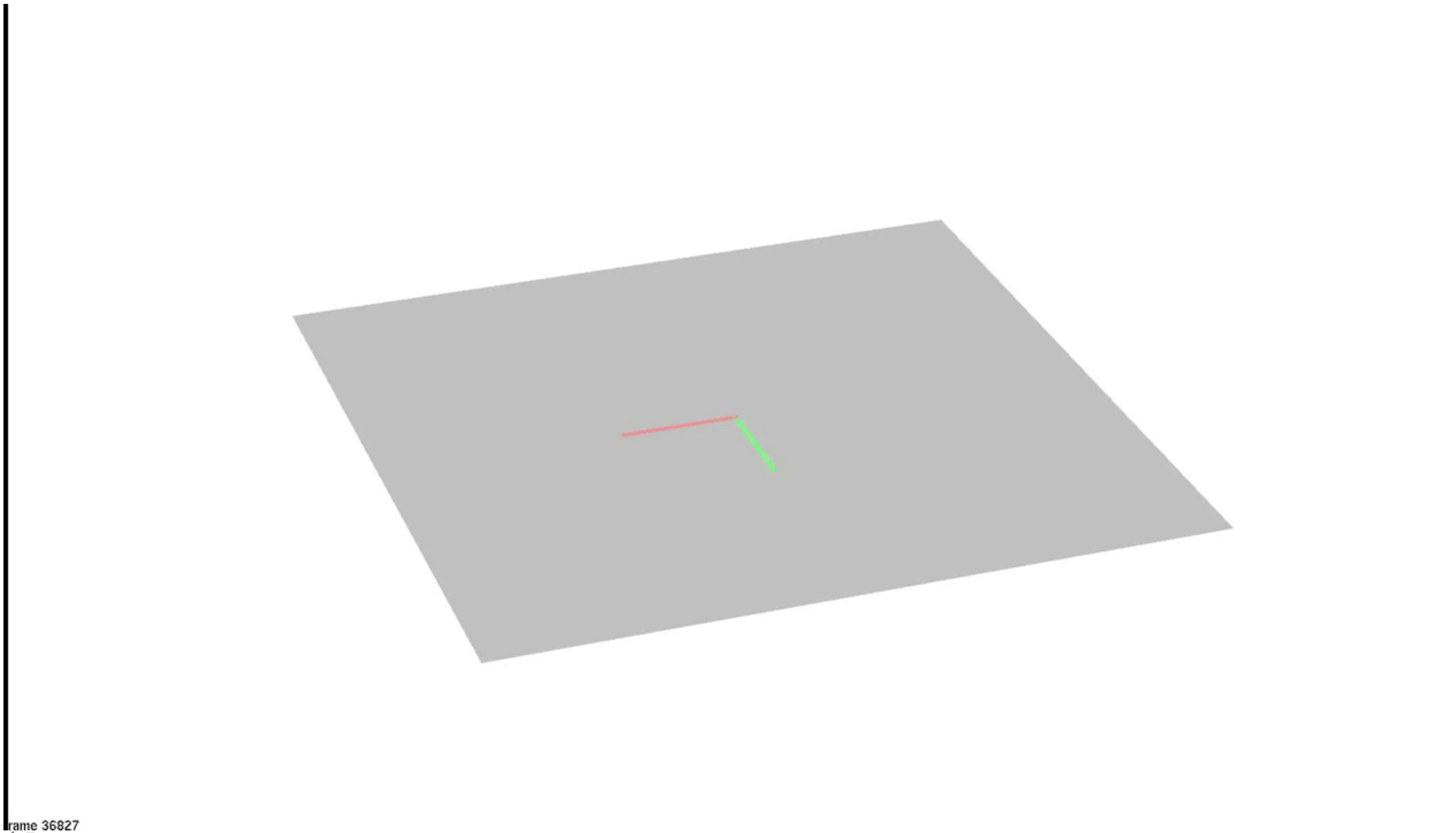
Shape Recovery: Basics

Real time Visual hulls with 67 cameras



Shape Recovery: Basics

Real time Visual hulls with 67 cameras



Shape Recovery: Basics

Primitive Extraction

- Regions (silhouettes) -> surfaces, volumes
- **Points (image features) -> 3D point clouds**

UNIVERSITÉ Grenoble Alpes

Morpheo

Shape Recovery: Basics

Getting 3D points

- Depth cameras (active system)
- Multi-view stereo with color cameras (passive system)

Shape Recovery: Basics

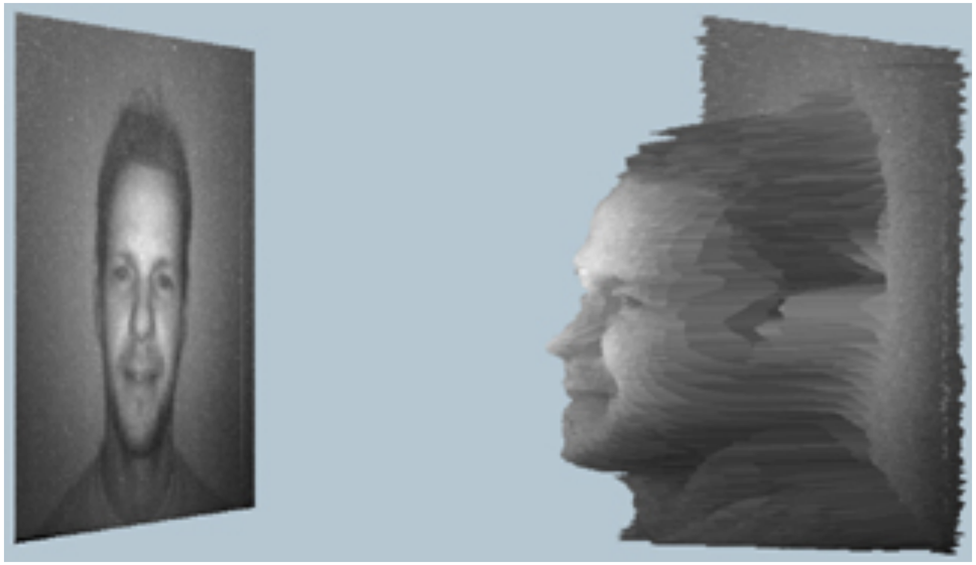
Getting 3D points

– Depth cameras (active system)
– Multi-view stereo with color cameras (passive system)

– Some platforms (e.g. Microsoft) are using both.
– While directly providing 3D information, active system have inherently more limitations than passive ones (e.g. scale, illumination).

Shape Recovery: Basics

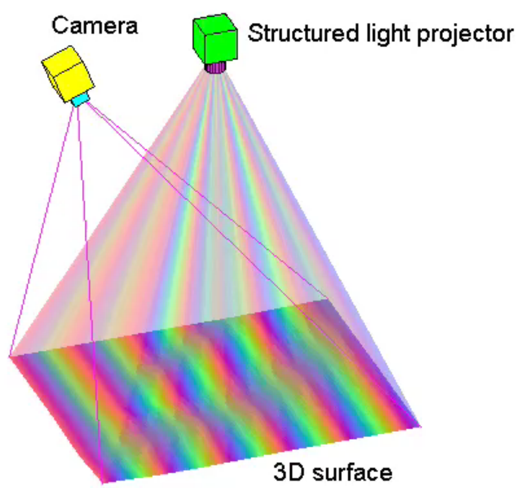
Depth cameras



Time of flight cameras

Shape Recovery: Basics

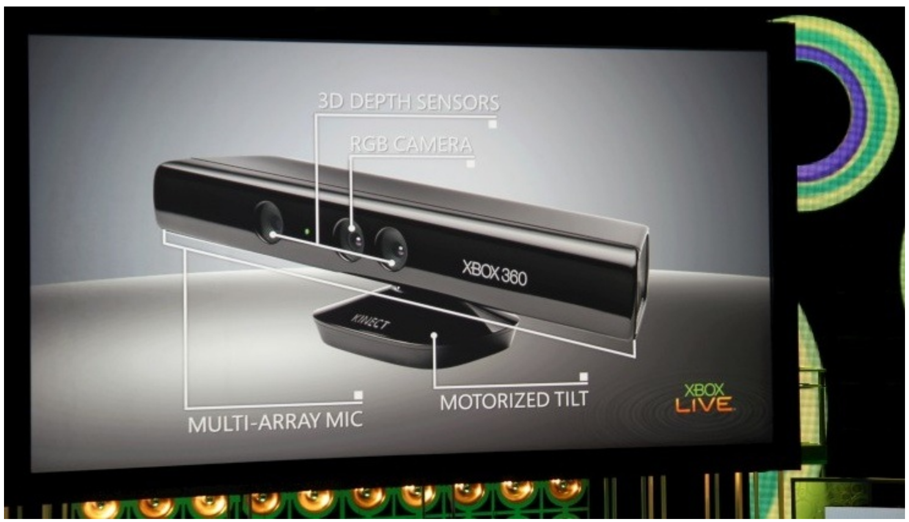
Depth cameras



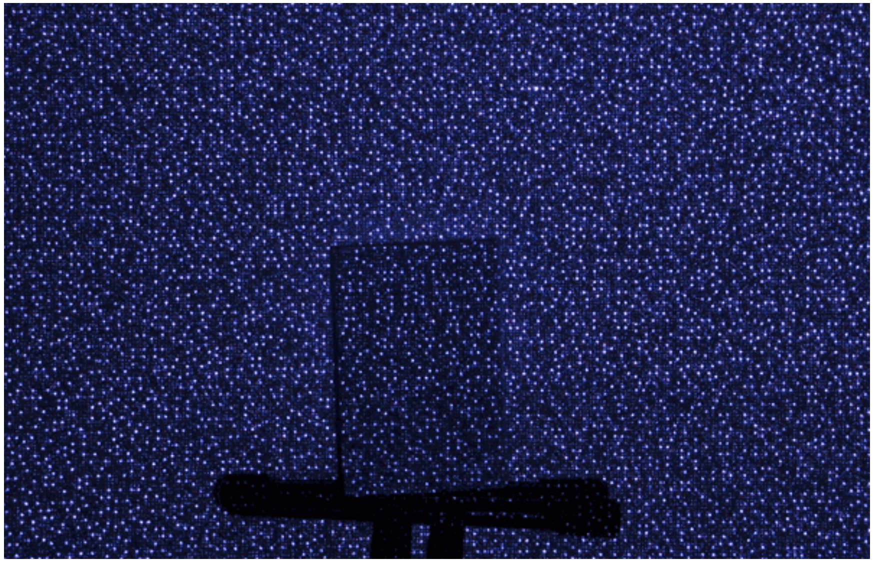
Structured light systems

Shape Recovery: Basics

Depth cameras



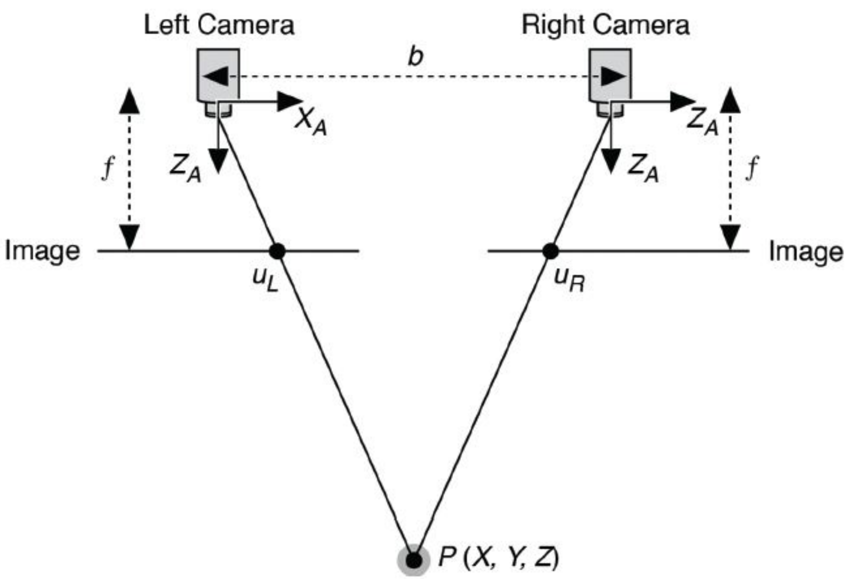
Microsoft Kinect 1 (Primesense)



Infrared pseudorandom pattern (©PrimeSense)
with a book in front.

Shape Recovery: Basics

Depth cameras

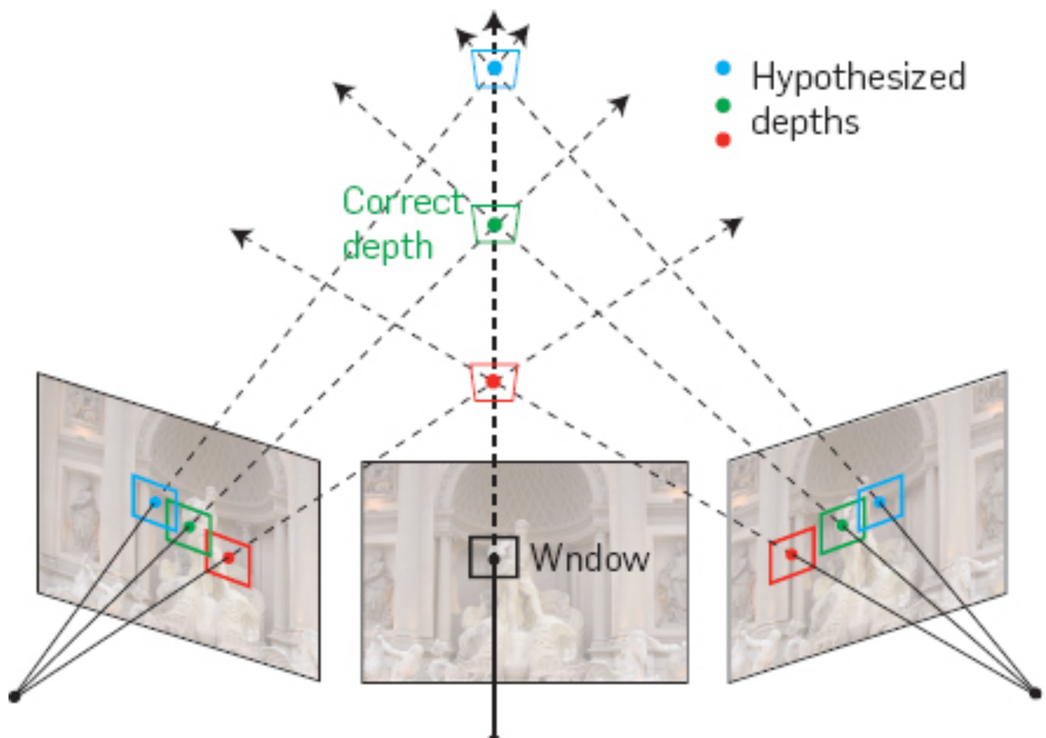


Bumblebee camera @FLIR

Stereovision cameras: point must be matched in the 2 images

Shape Recovery: Basics

Multi-view Stereo



[Building Rome in a Day
ICCV 2009]

As with the stereo, image points are matched but more than 2 images are considered.

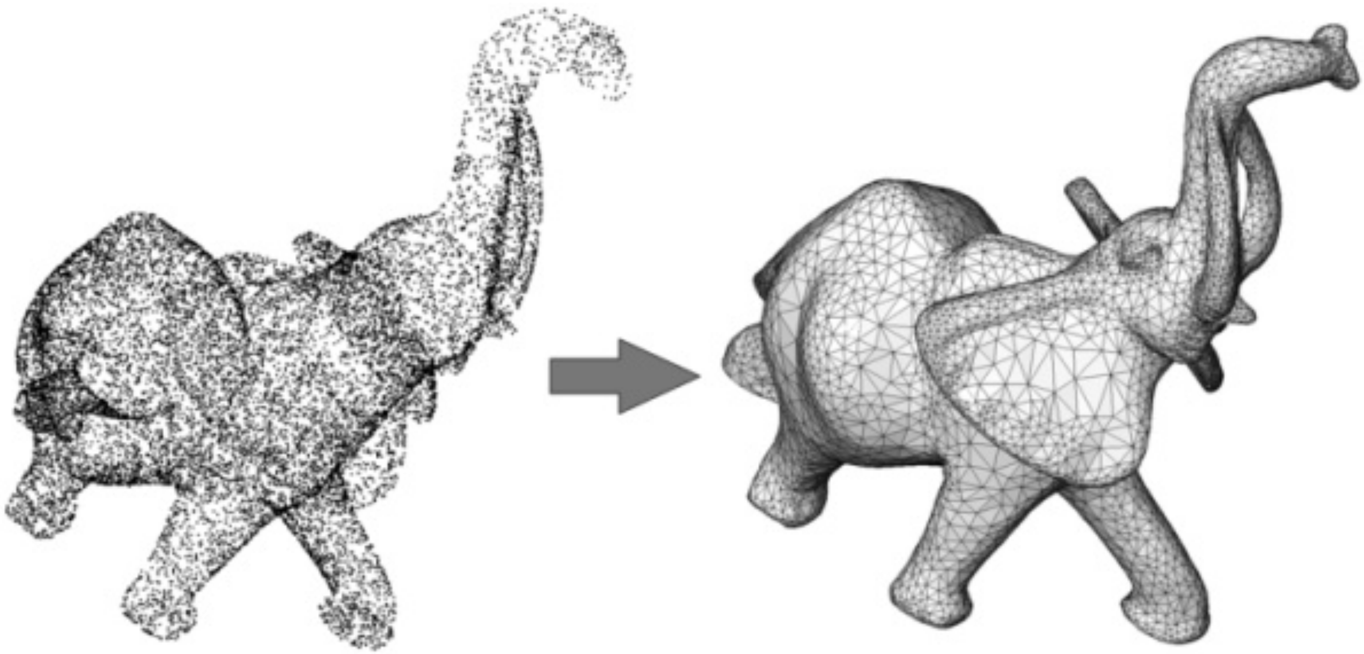
Shape Recovery: Basics

Multi-view Stereo

Building Rome in a Day, ICCV 2009
Agarwal, Furukawa, Snavely, Simon, Curless, Seitz, Szeliski.

Shape Recovery: Basics

From 3D points to Shapes

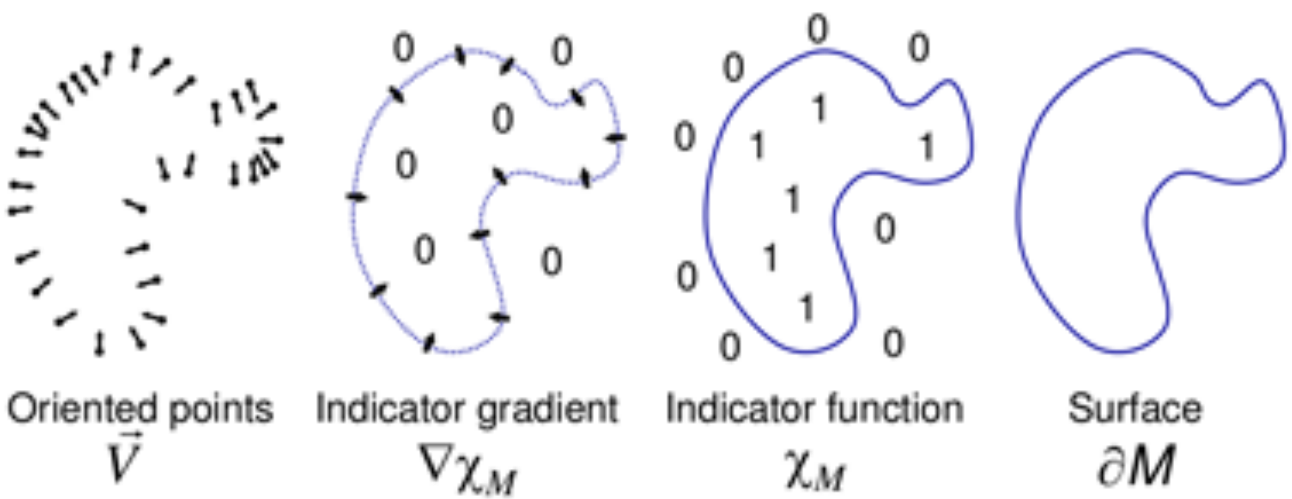


Example with: Poisson Surface Reconstruction, SGP 2006
M. Kazhdan, M Bolitho & H Hoppe

.

Shape Recovery: Basics

From 3D points to Shapes

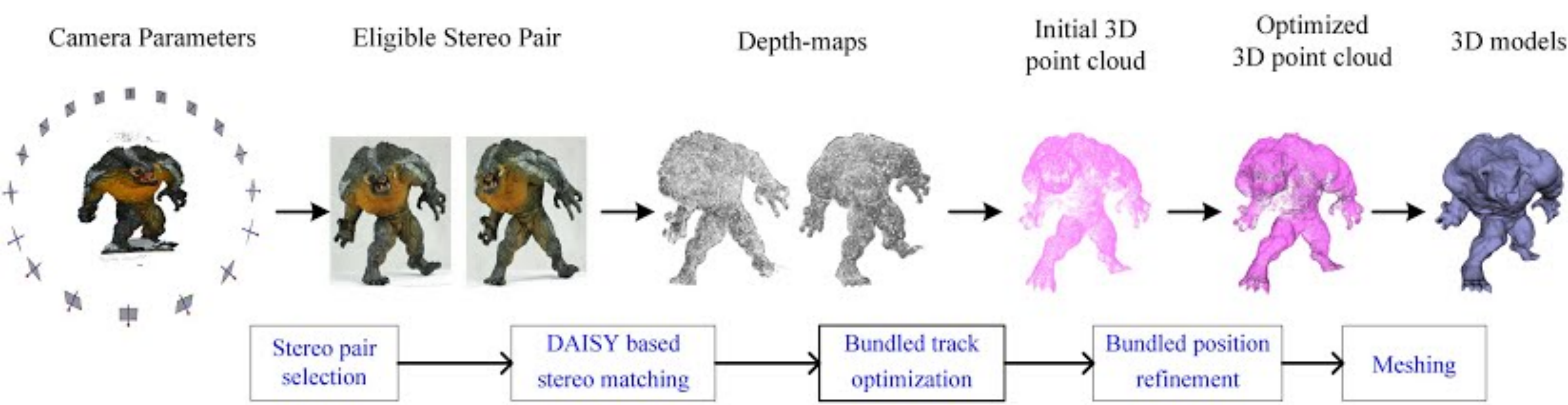


Poisson Surface Reconstruction, SGP 2006
M. Kazhdan, M Bolitho & H Hoppe

.

Shape Recovery: Basics

Points / Features

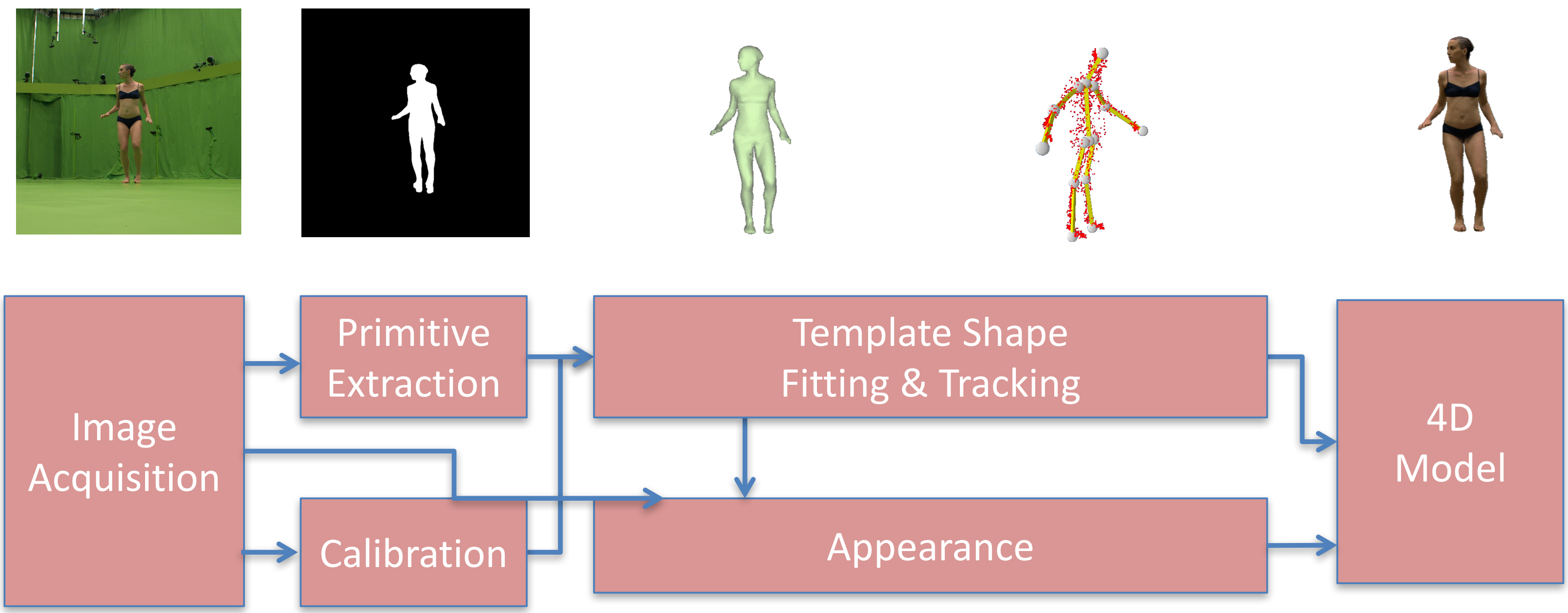


@ Jianguo Li, Eric Li, Yurong Chen, Lin Xu, Intel Labs China

Shape Recovery: Basics

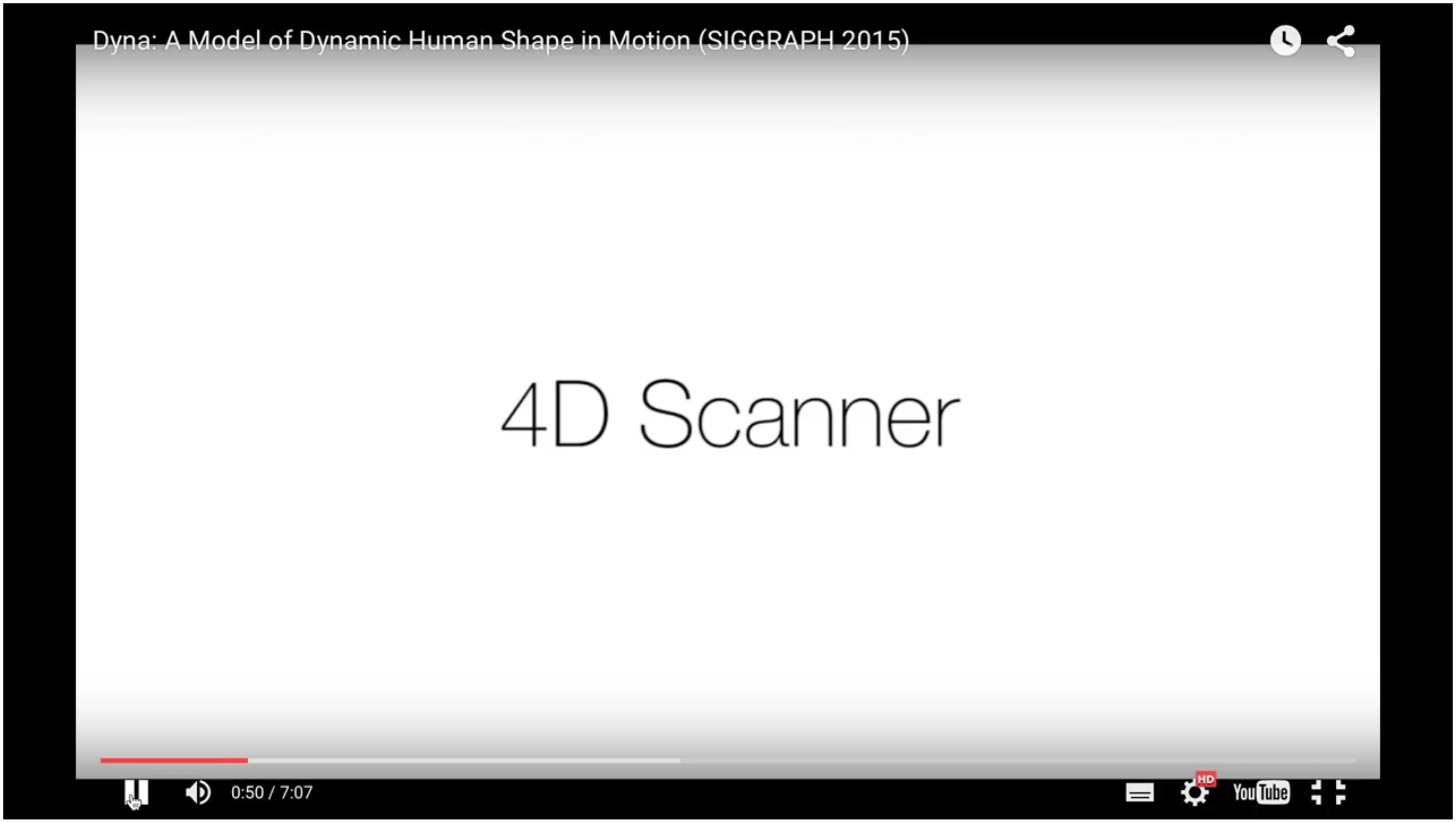
@Microsoft, High-Quality Streamable Free-Viewpoint Video, Siggraph'15

Shape Recovery: Basics



General 4D modeling pipeline: prior model

Shape Recovery: Basics



Shape Recovery: Basics

Prior Models: Shape Spaces

[Caesar human dataset, Siggraph 2003, Allen, Curless, Popovic]

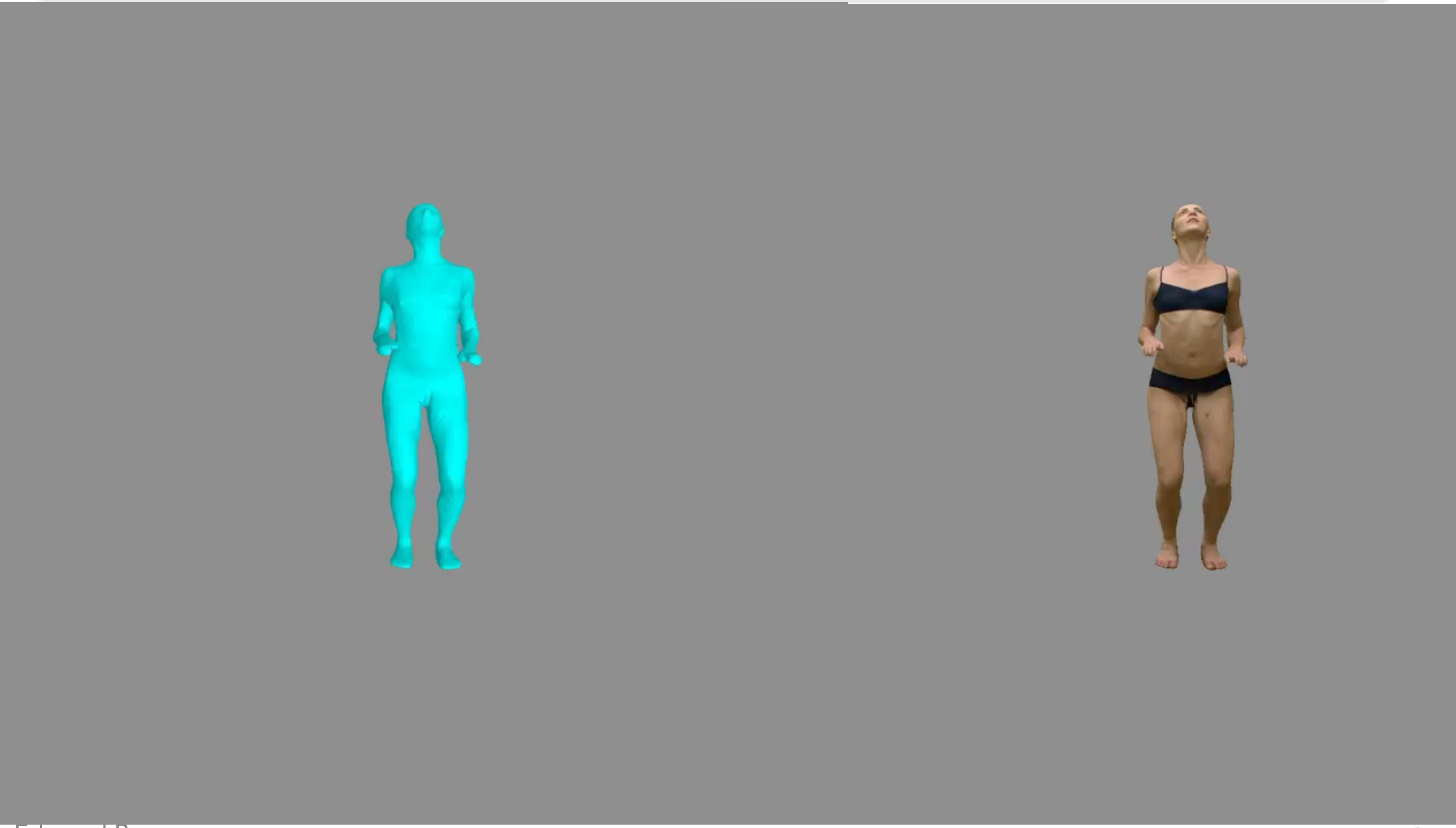
PCA strategy allows to represent shapes with « eigen » shapes

Shape Recovery: Basics

Appearance

INRIA Kinovis

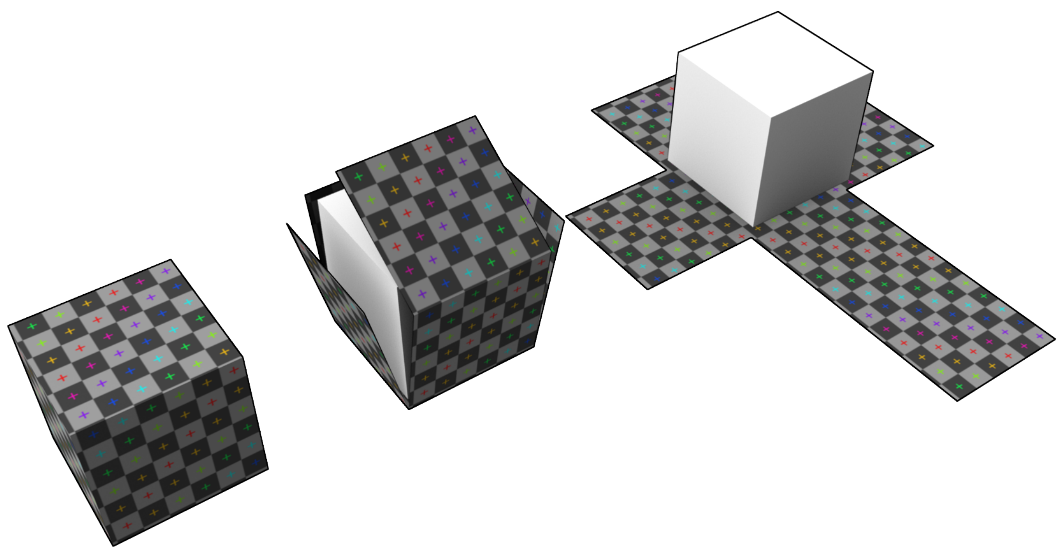
Shape Recovery: Basics



Shape Recovery: Basics

Appearance

1. At each frame, unwrap the mesh to define a 2D atlas where appearance (texels) can be specified.

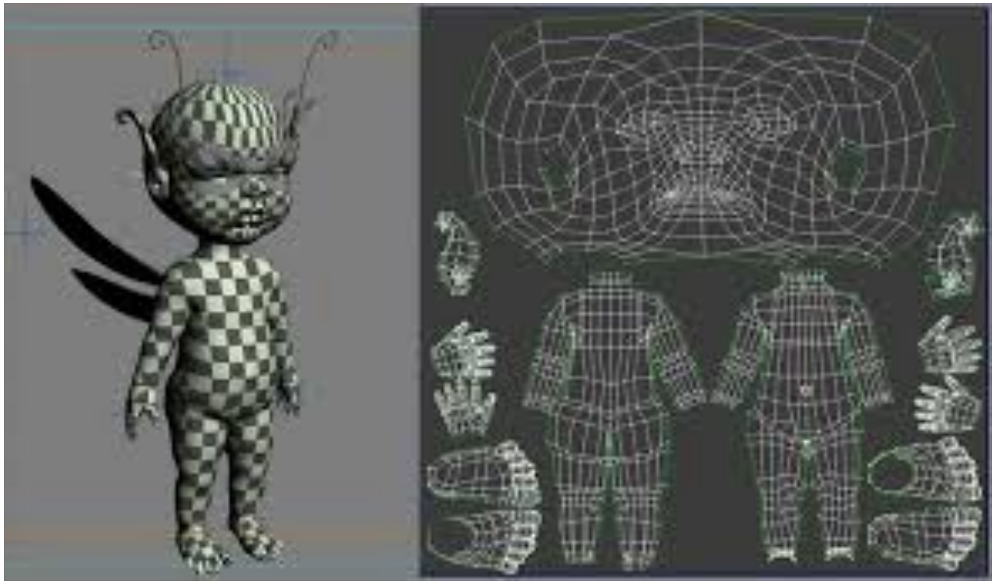

@wikipedia

1. Map the observed images at the given frame onto the UV atlas to define a 2D texture map at each frame.

Shape Recovery: Basics

Appearance

1. At each frame, unwrap the mesh to define a 2D atlas where appearance (texels) can be specified.



@Blender

1. Map the observed images at the given frame onto the UV atlas to define a 2D texture map at each frame.

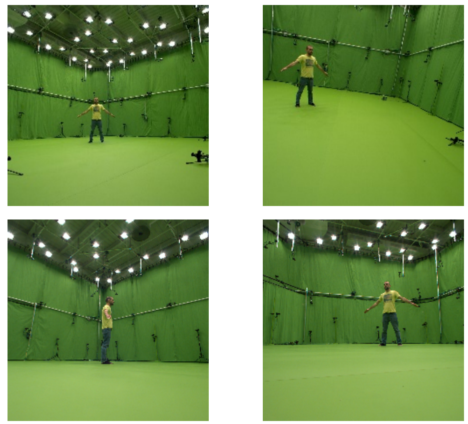
Shape Recovery: Basics

Appearance

Some challenges

- Noisy input images

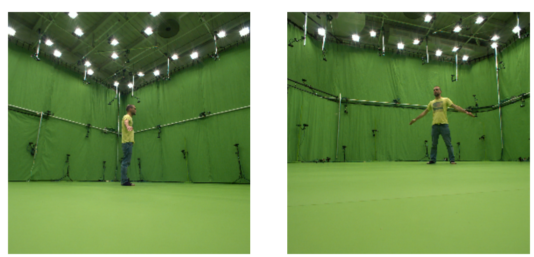
- Visual redundancy over space



- Camera inaccuracies

- Reconstruction inaccuracies

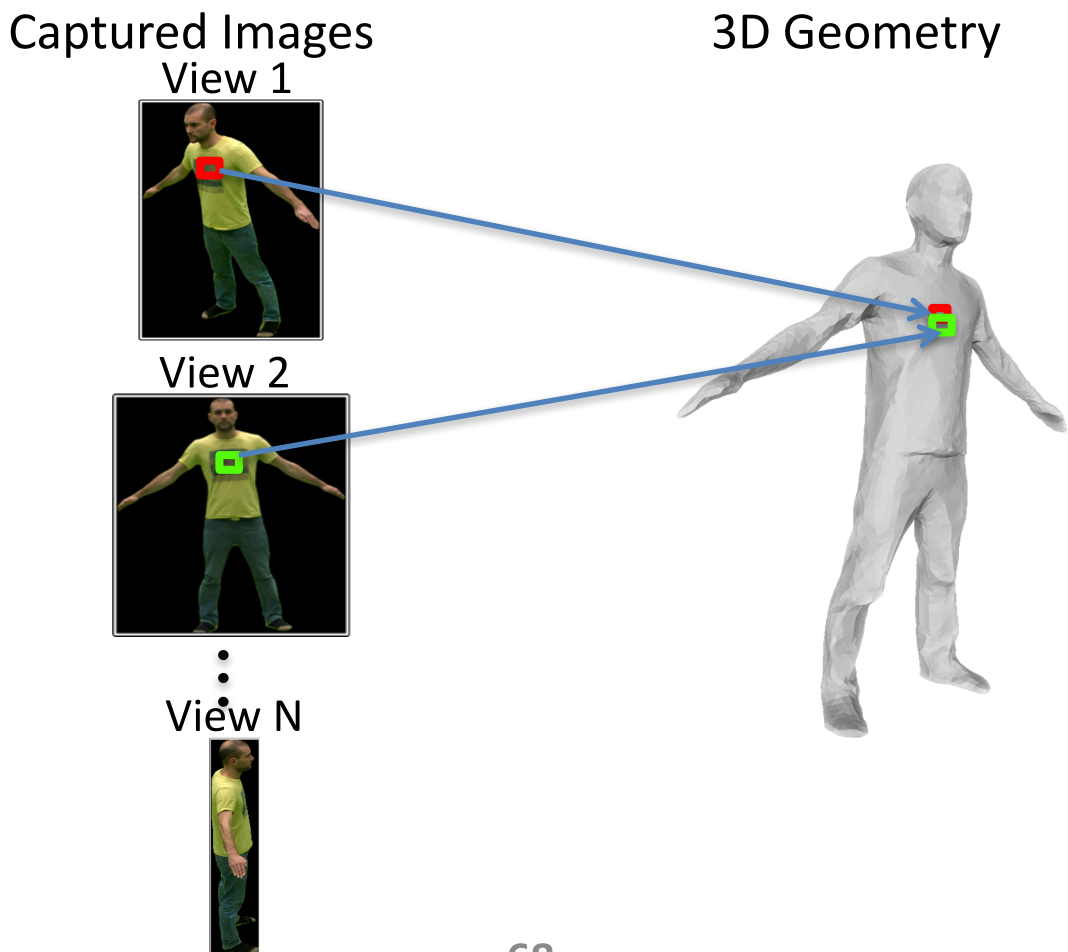
- Occlusions



- Visual redundancy over time

Shape Recovery: Basics

Appearance: Naive Strategy Blending



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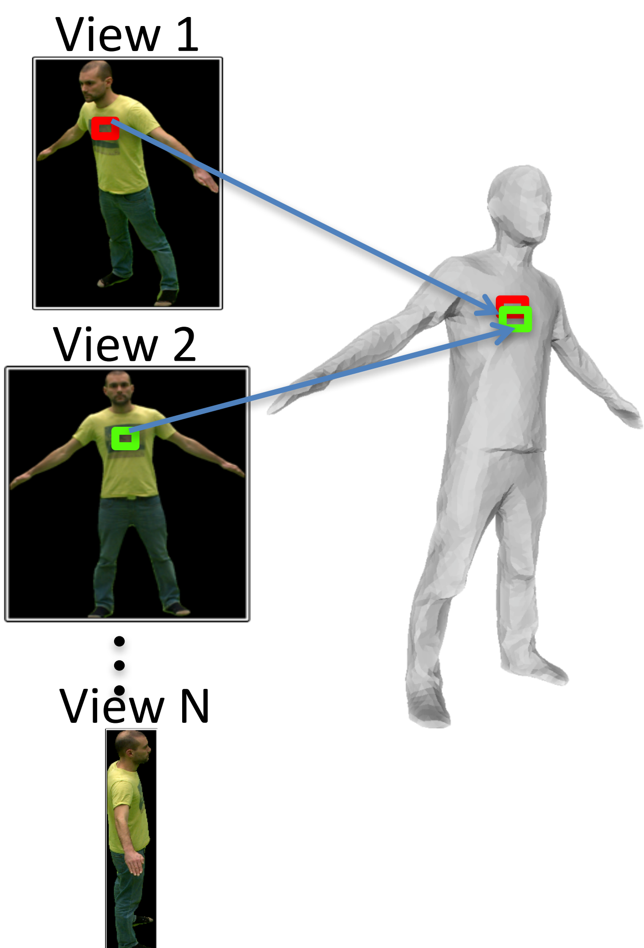
Shape Recovery: Basics

Appearance: Naive Strategy Blending



Example

Limitation:
Geometric inaccuracies lead to strong blurring effects.

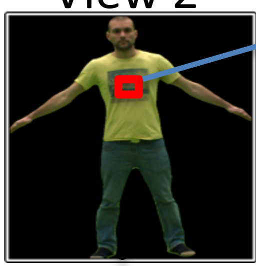
Shape Recovery: Basics

Appearance: Best value

Captured Images

View 1

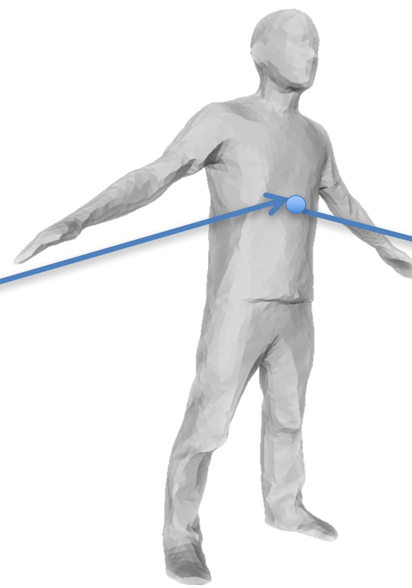
View 2



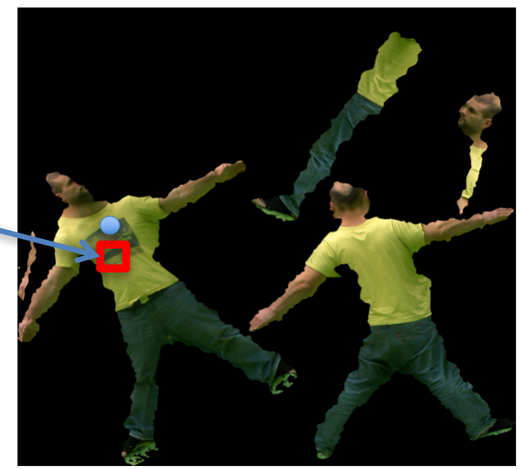
⋮

View N

3D Geometry



Texture Atlas



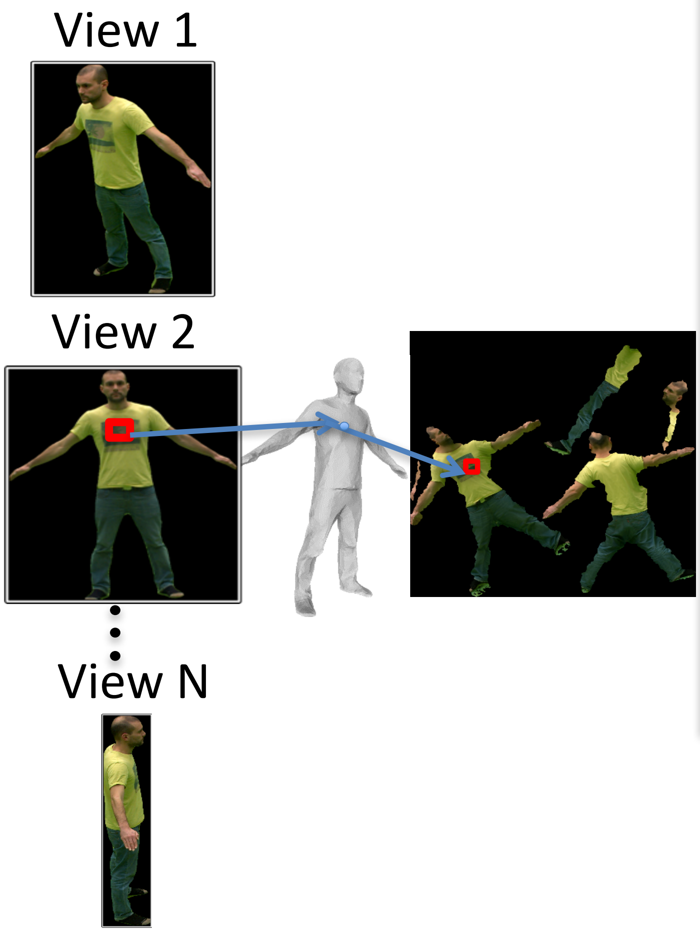
Janko and Pons. [2009]

Strategy:

Pick the best value among views.

Shape Recovery: Basics

Appearance: Best value



Example

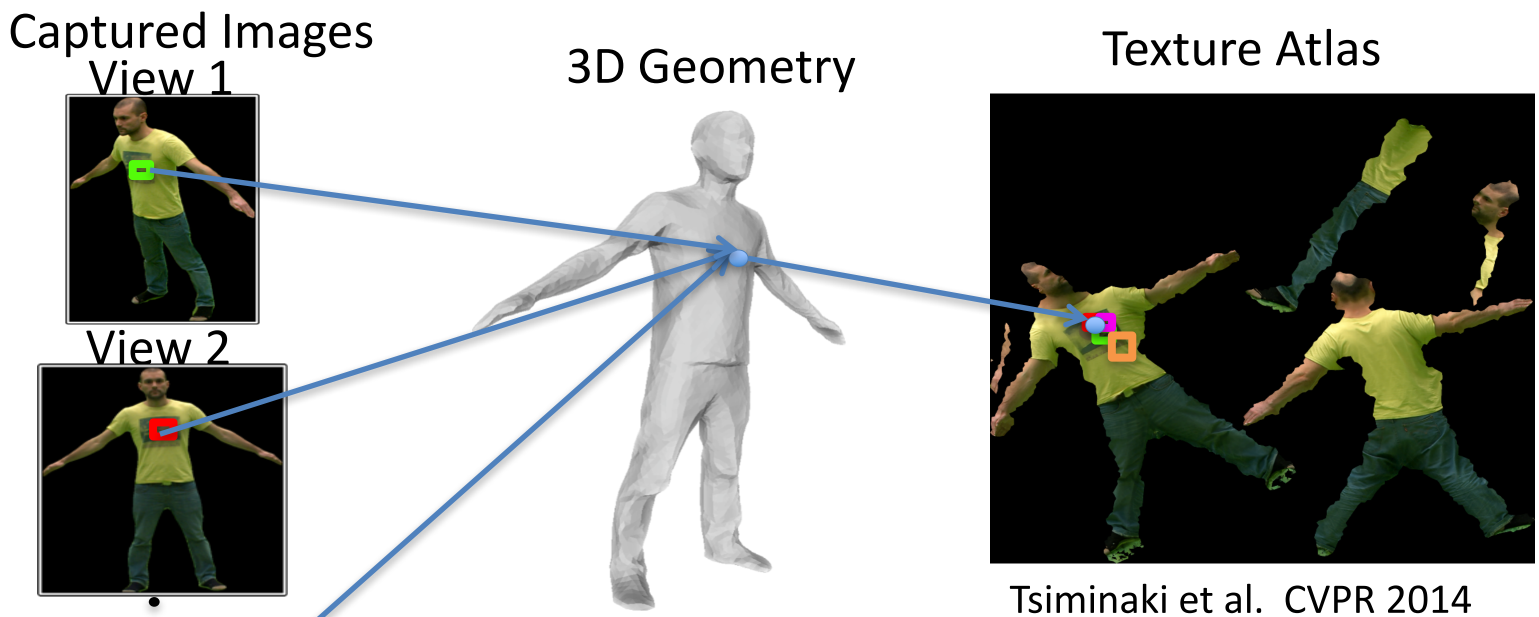
Janko and Pons. [2009]

Limitation:

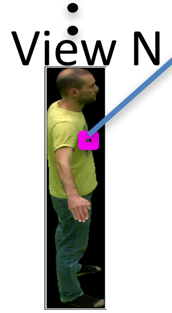
Visual redundancy is not exploited.

Shape Recovery: Basics

Appearance: Super Resolution Strategy



Tsiminaki et al. CVPR 2014

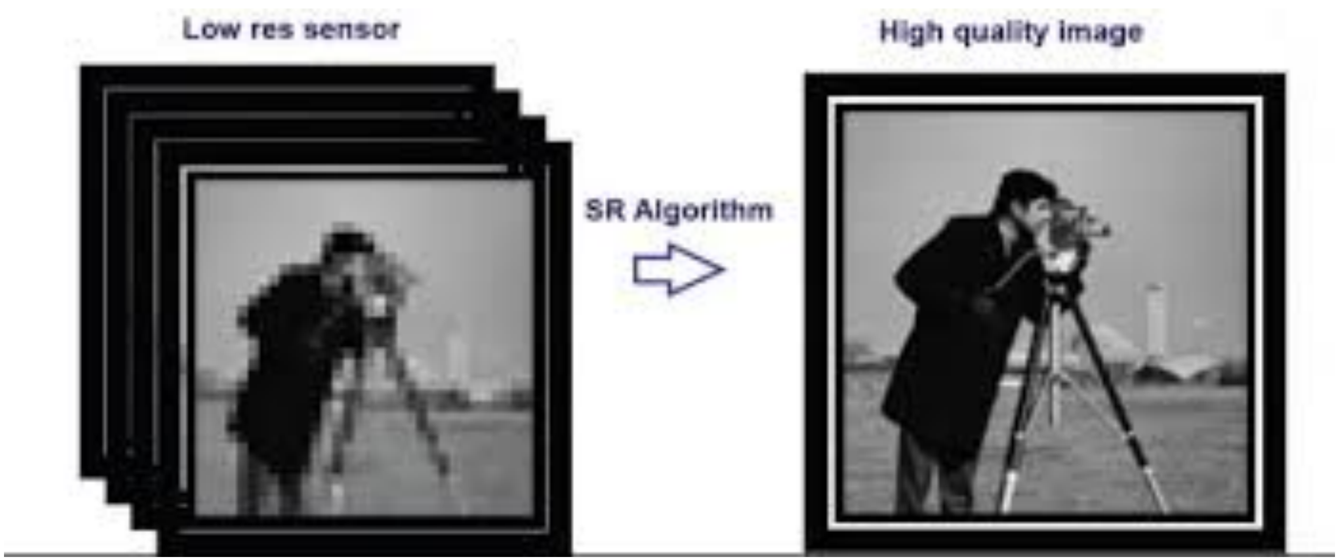


Strategy:

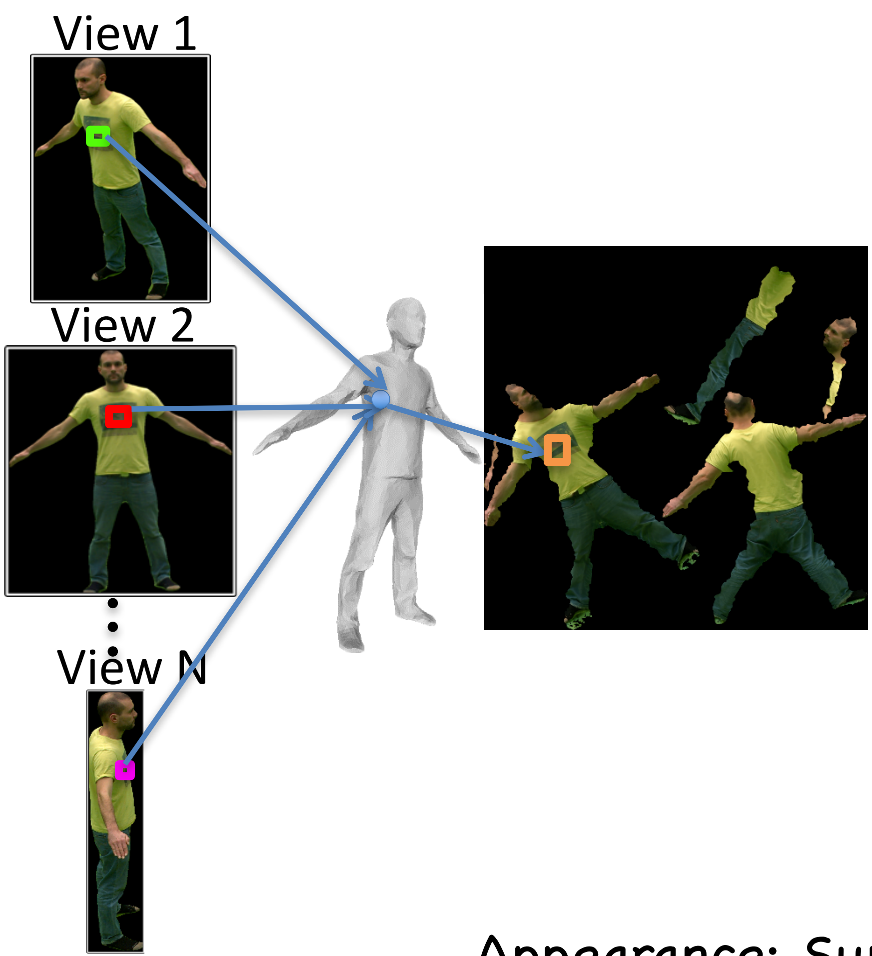
- Compute the value that is close to observations.
- Impose TV prior to minimize discontinuities.

Shape Recovery: Basics

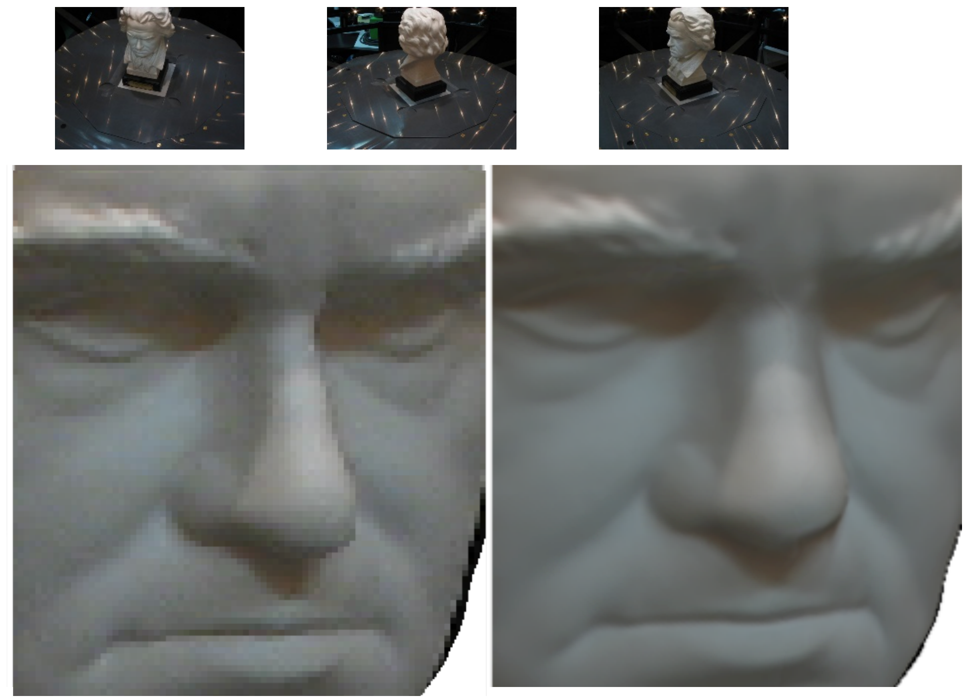
Image Super-resolution



Shape Recovery: Basics



Example: Input Images

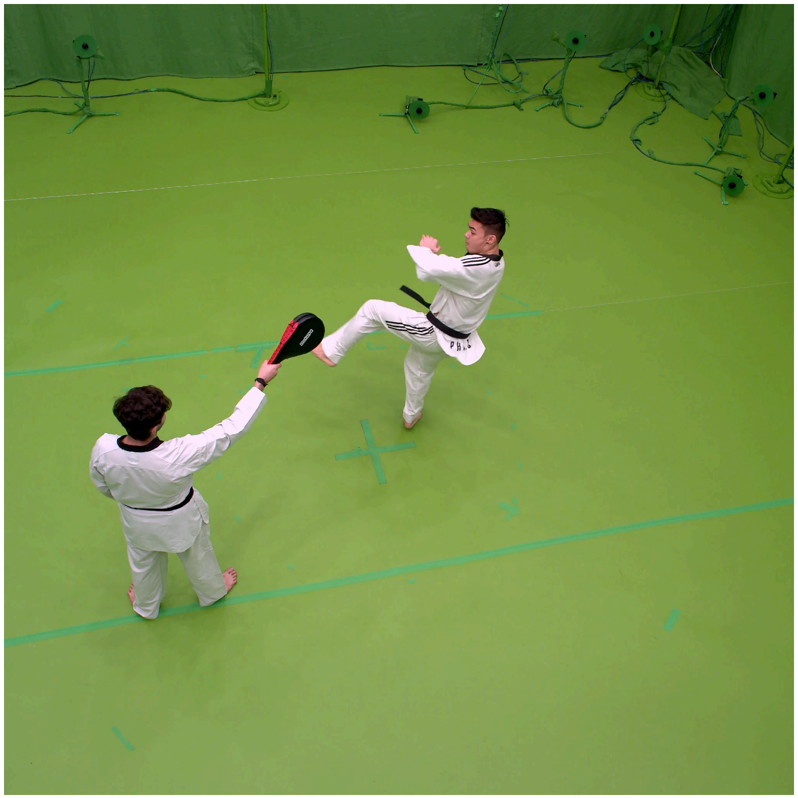


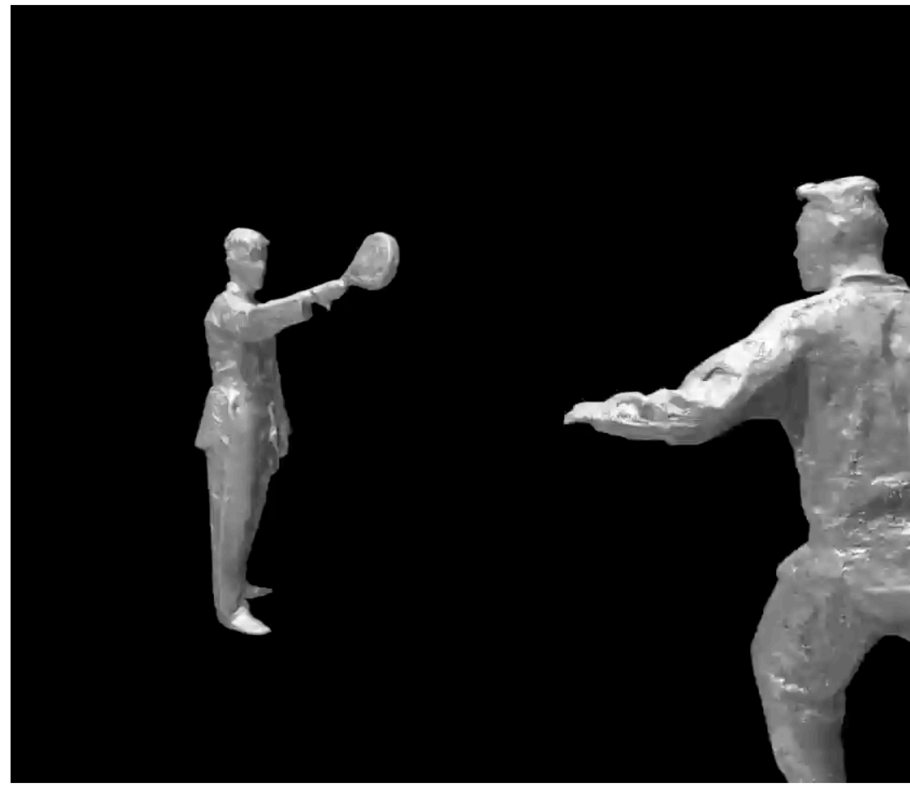
Input

Tsiminaki et al. CVPR 2014

Appearance: Super Resolution Strategy

Shape Recovery: Basics



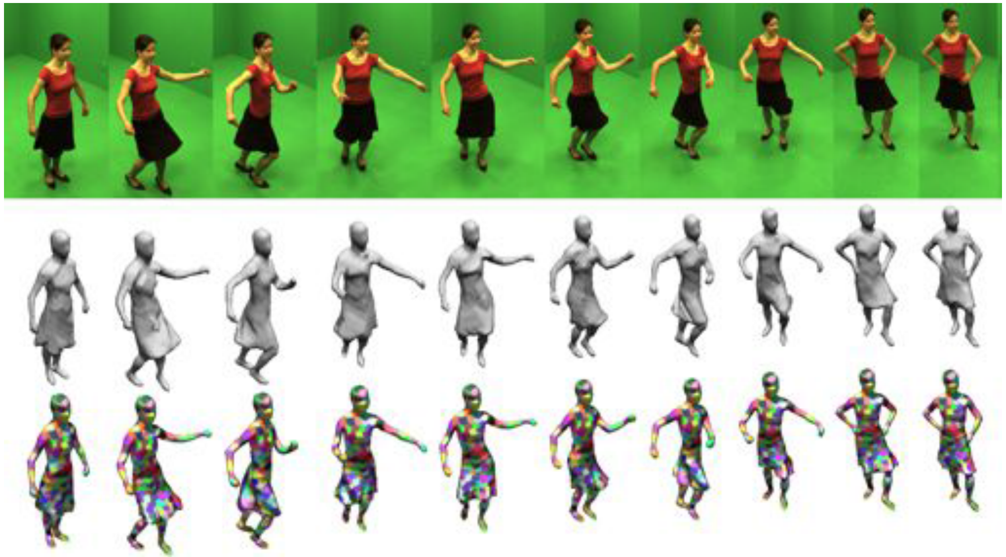


Outline

1. Multi-View platforms.
2. Shape recovery: basics.
3. Motion recovery: shape tracking.

Motion Recovery

- Problem: Given visual data (images, 3D shapes, etc.) and a motion model (parametric, non-parametric) recover motion parameters, e.g. the joint angles in the case of a skeleton model.
- Motivation: Motion is an important information to model shape evolutions
- Remark: In many vision applications this consists in recovering the pose of a given model (e.g. skeleton, shape) at each time instant over a sequence.

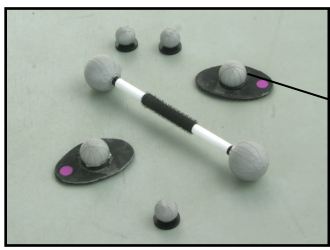


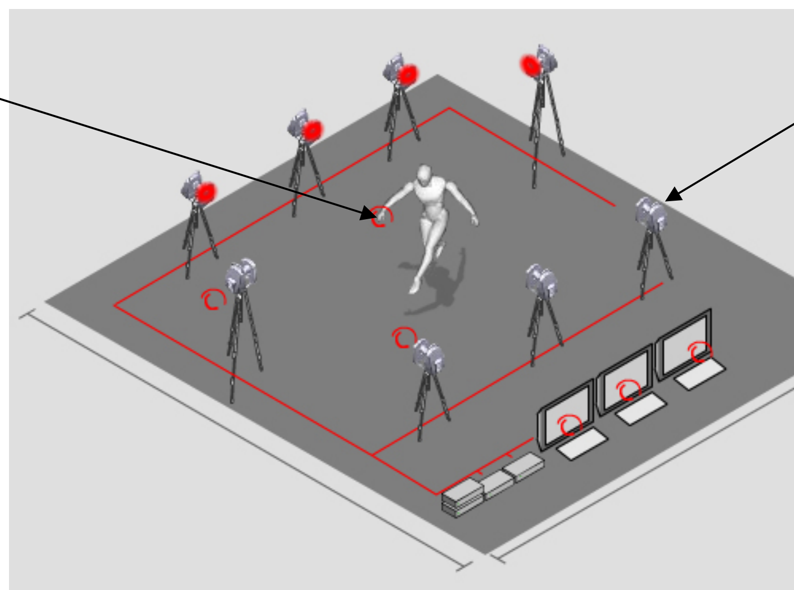
Motion Recovery

- **Optical methods with markers:**
  - Observations: markers are tracked in calibrated images
    - Passive markers: retroreflective markers
    - Active markers: markers emit their own lights for identification (e.g. different pulses per markers).
  - Motion recovery: a motion model (e.g. a skeleton) is matched with the marker locations.
  - Applications: "Motion capture" of bodies (with articuled models), faces (with deformable meshes), etc.
- Non optical methods with markers also exist: inertial or magnetic systems for instance.

Motion Recovery

- **Marker based approaches, e.g. the Vicon system:**
  - High precision cameras (up to 16 Mpixels) and high frequencies (> 400Hz).





Motion Modeling

Markerless approaches:

- Observations: 2D (contours, silhouettes), 3D (points, shapes) in a single or multiple calibrated images.

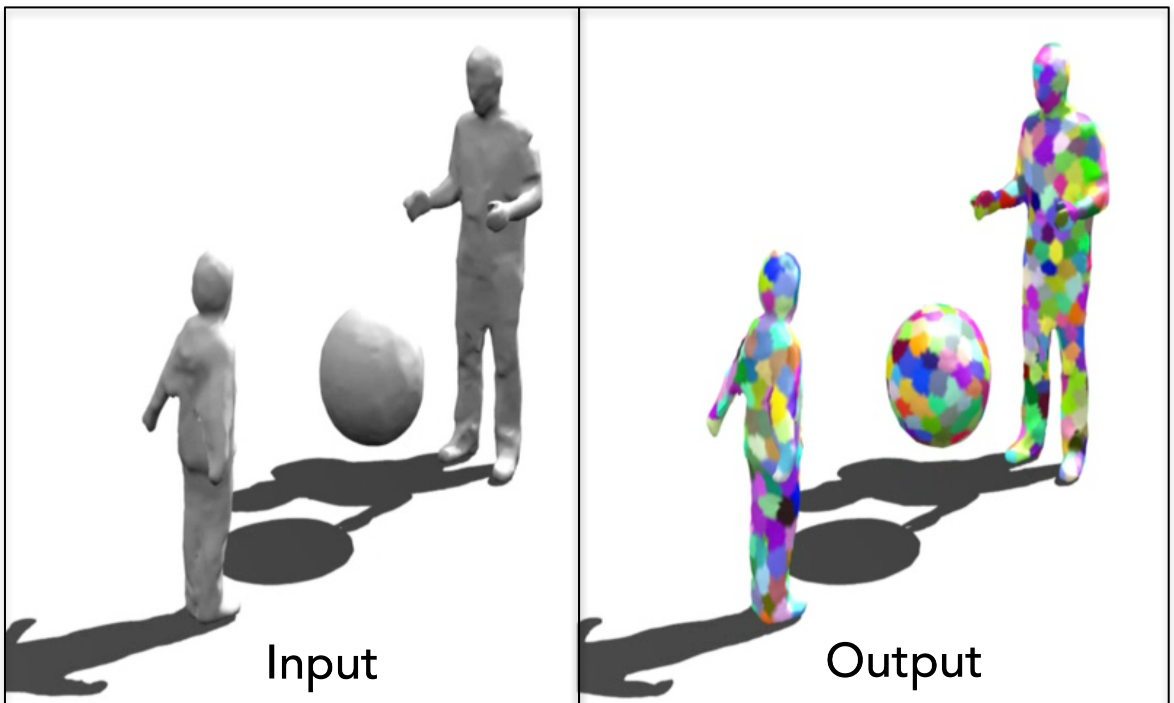
- Motion recovery: the model is matched to the observations:

  - Parametric motion models: find the best model parameters (e.g. joint angles) such that the model explains the observations.
  -> **Shape Tracking**

  - Non parametric models: find the best model (in a database) that explains the observations.

Shape Tracking

Given 2D/3D observations at different instants recover time consistent shape models (4D models).



Shape Tracking

Problem Formulation: MAP estimation

$$\hat{\Theta} = \arg\max_{\Theta} \; P(\Theta|\mathcal{O}) \simeq \arg\max_{\Theta} \; P(\mathcal{O}|\Theta) \; P(\Theta)$$

Shape Tracking

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Shape pose parameters

Observations

Shape pose parameters (motion parameterization):
mesh vertices, locally rigid displacements, joint angles, learned,...

Observations: Meshes, 3D points, 2D silhouettes,..

Shape Tracking

Problem Formulation: MAP estimation

$$\hat{\Theta} = \arg\max_{\Theta} P(\Theta|\mathcal{O}) \simeq \arg\max_{\Theta} P(\mathcal{O}|\Theta)\; P(\Theta)$$

Shape pose parameters

Observations

data term

Regularization term

Shape pose parameters (motion parameterization):
mesh vertices, locally rigid displacements, joint angles, learned,…

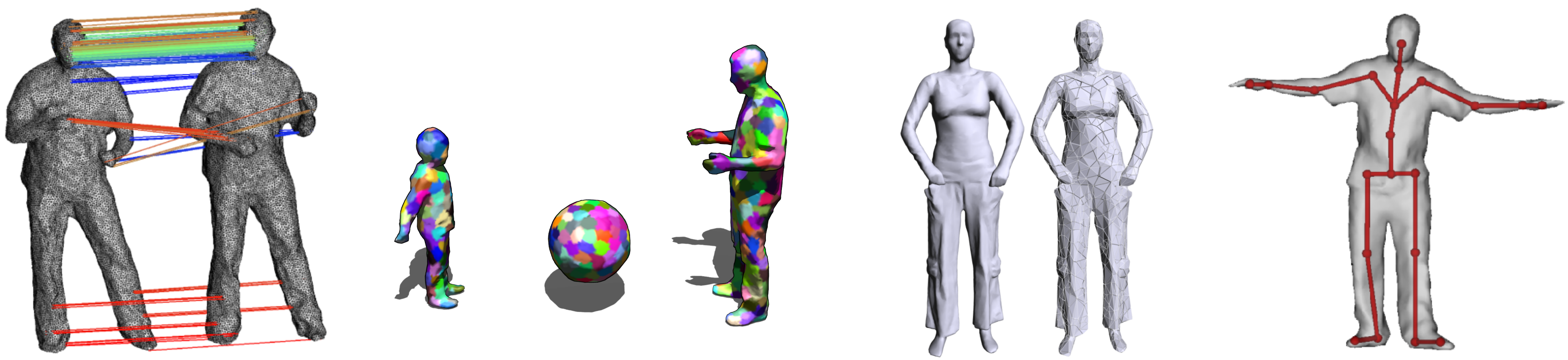
Observations: Meshes, 3D points, 2D silhouettes,..

Regularization (Prior): smooth trajectories, rigidity constraints,..

Shape Tracking

Shape pose parameterization (**deformation model**):

- Prior information that determines the classes of deformations.



[Varanasi et al. eccv08] [Cagniart et al. eccv10] [de Aguiar et al. siggraph08] [Vlasic et al. siggraph08]

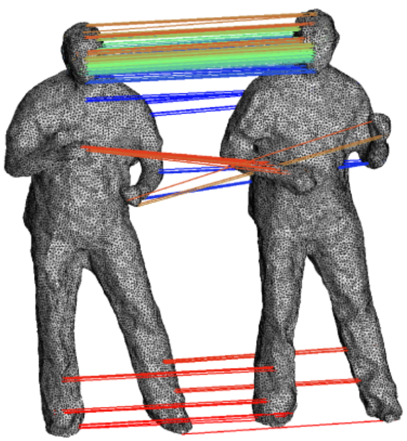
Loose → Constrained

Shape Tracking

Model-free (motion fields)

• Scene flow: Pons et al., Neumann et al., Blache et al. etc.

• Feature based: Starck et al., Bronstein et al., Varanasi et al., etc.

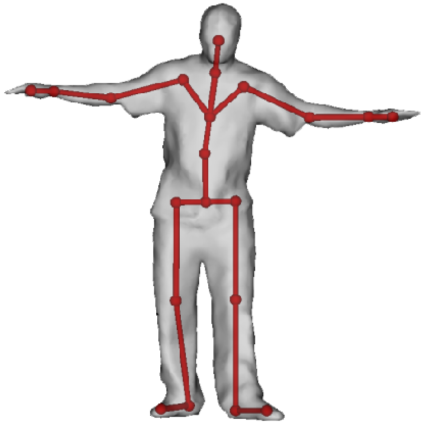


[Varanasi et al. Eccv08]

Model-based

• Locally rigid: Gavrila et al., Kakadiaris et al., Cagniart et al. etc.

• Articulated: de Aguiar et al., Vlasic et al., Furukawa et al., Gall et al., etc



[Vlasic et al. SIGGRAPH08]

Shape Tracking

Model-free (motion fields)

• Scene flow: Pons et al., Neumann et al., Blache et al. etc.

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+ Little prior knowledge
- Drift over time
- Outliers in feature matching

Model-based

• Locally rigid: Gavrila et al., Kakadiaris et al., Cagniart et al. etc.

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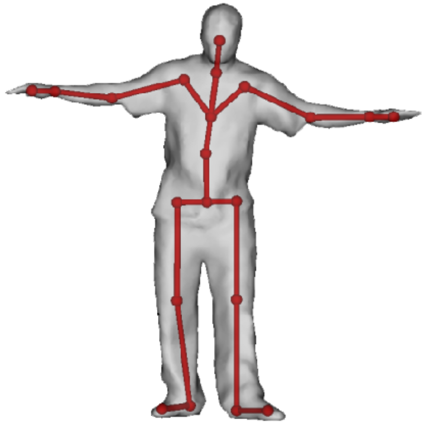

[Vlasic et al. SIGGRAPH08]

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Morpheo

Shape Tracking

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Model-based

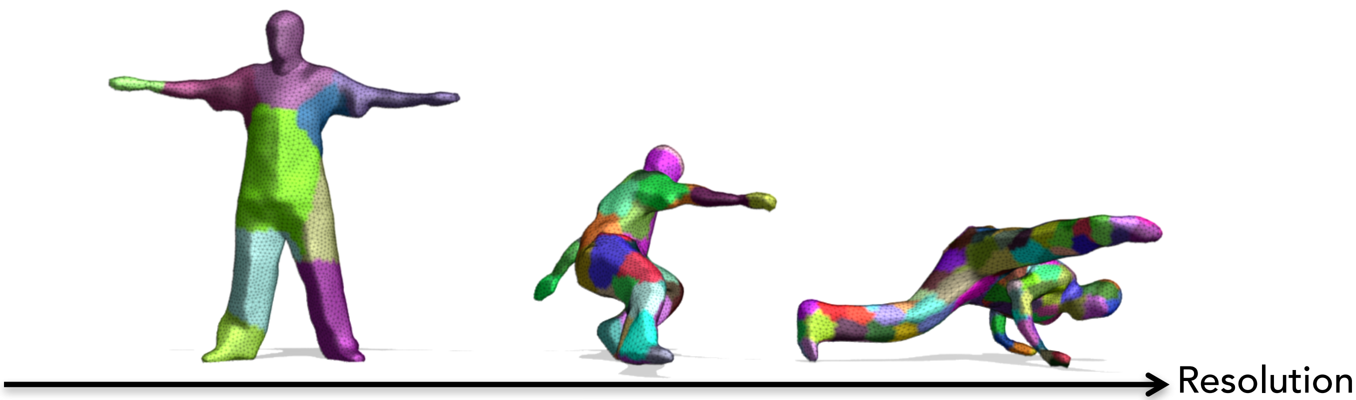
• Locally rigid: Gavrila et al., Kakadiaris et al., Cagniart et al. etc.

• Articulated: de Aguiar et al., Vlasic et al., Furukawa et al., Gall et al., etc

+ Temporally consistent
+ Reduced drift
- Limited class of motion/deformation

Shape Tracking

Patch based deformation model [Cagniart et al. eccv10]



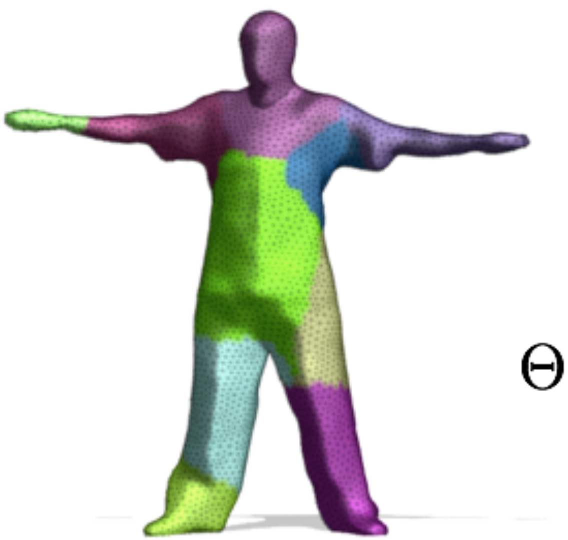
A surface deformation model that is decoupled from the original geometry.

Deformation model:

1. Patches at different level of details are attached to the shape model.
2. Patches are assumed to move rigidly.

Shape Tracking

Shape pose parameterization



Reference Model

$$\Theta = \{R_k, \mathbf{c}_k\}$$

Input Geometry $\mathcal{Y}$

Shape Tracking

$$\hat{\Theta} = \arg\max_{\Theta} \; P(\Theta|\mathcal{O}) \simeq \arg\max_{\Theta} \; P(\mathcal{O}|\Theta) \; P(\Theta)$$

data term

Data term: requires observation-model association

- Local deterministic approaches: closest points (e.g. ICP and most shape tracking methods);
- Local probabilistic approaches: soft associations with respect to distances (e.g. EM-ICP [cagniart 10], Coherent Point Drift [Myronenko & Song10]);
- Local but non-Sequential [Klaudiny et al. 12];
- Global approaches: global association (e.g. with optimal transport);
- Learned (e.g. Vitruvian manifold [Taylor et al. 12]) .

Shape Tracking

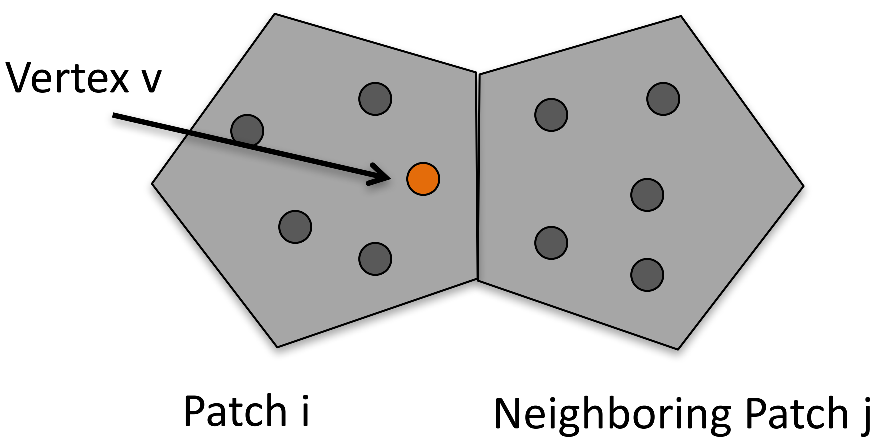
$$\hat{\Theta} = \arg\max_{\Theta} \; P(\Theta|\mathcal{O}) \simeq \arg\max_{\Theta} \; P(\mathcal{O}|\Theta) \; P(\Theta)$$

Regularization term

Regularization term:

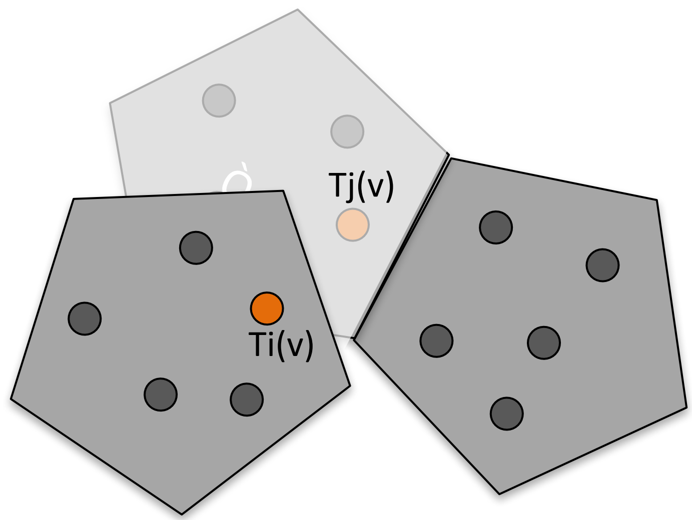
- Motion field Smothness, e.g. Coherent Point Drift [Myronenko & Song10].
- Shape Preservation, e.g. laplacian coordinates [Sorkine et al.04] or local rigidity constraints [cagniart 10].
- Learned models, e.g. motion manifolds [Duveau et al. 12].

Shape Tracking



E. Boyer

Shape Tracking

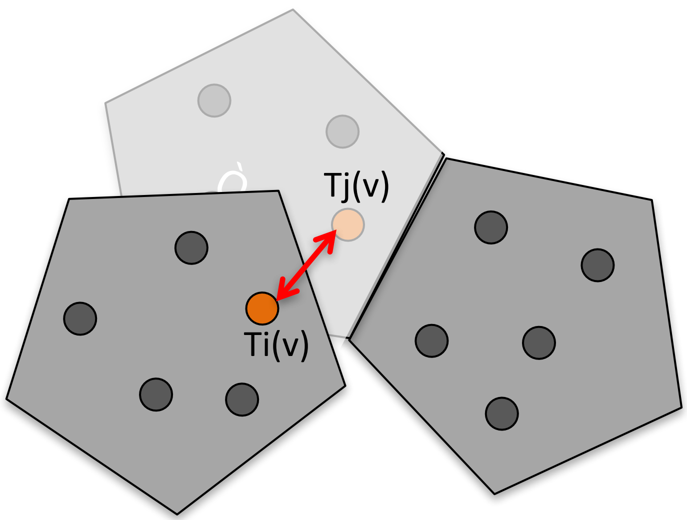


Patch i
Motion Ti -> Ri,Ci

Neighboring Patch j
Motion Tj -> Rj,Cj

E. Boyer

Shape Tracking



Patch i
Motion Ti -> Ri,Ci

Neighboring Patch j
Motion Tj -> Rj,Cj

Associated (soft) rigidity constraints for vertex v:

Ti(v) = Tj(v) for all j in neighbors(i)

E. Boyer

Shape Tracking

Shape Tracking: More

Combined simulated and captured Shape dynamics

Conclusion

Modeling evolving shapes:

- Pretty good models + deformations with simple scenes.
- Some results with the dynamic aspects: information redundancy, statistics for example.

Progress to be made:

- Acquisition: precision, robustness, modalities (X-ray).
- Shape: representation (e.g. clothes), changing appearances,
- Motion: build relevant models, pose spaces and motion spaces; statistical analysis.
- Datasets: benchmarks.

Fundamental issues:

- Shape models that account for material, appearance and anatomical information.
- Fully exploiting the time dimension to build models.
- Learning.

Website: http://morpheo.inrialpes.fr

Datasets: http://4drepository.inrialpes.fr