# MoSculp: Interactive Visualization of Shape and Time









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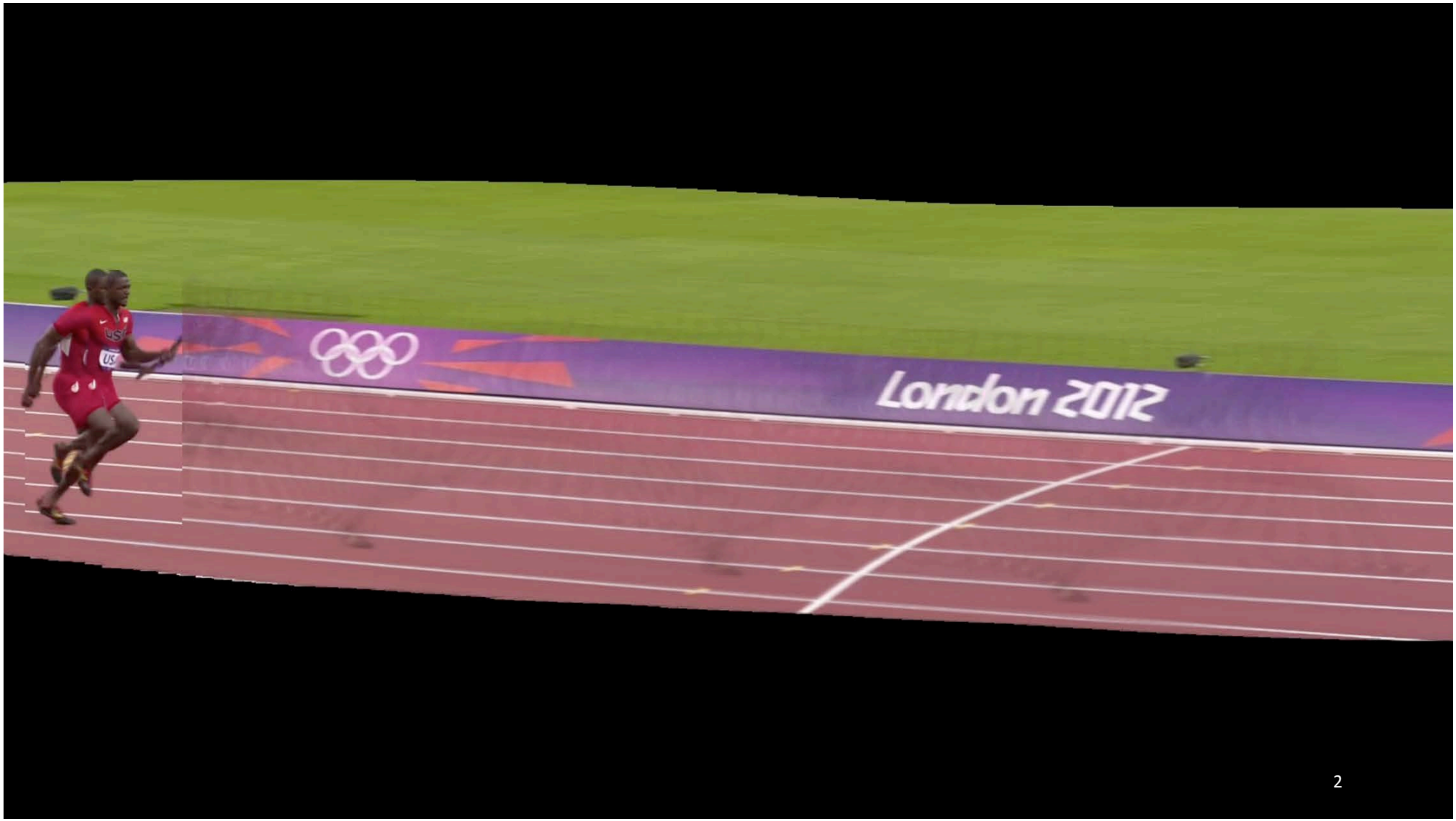
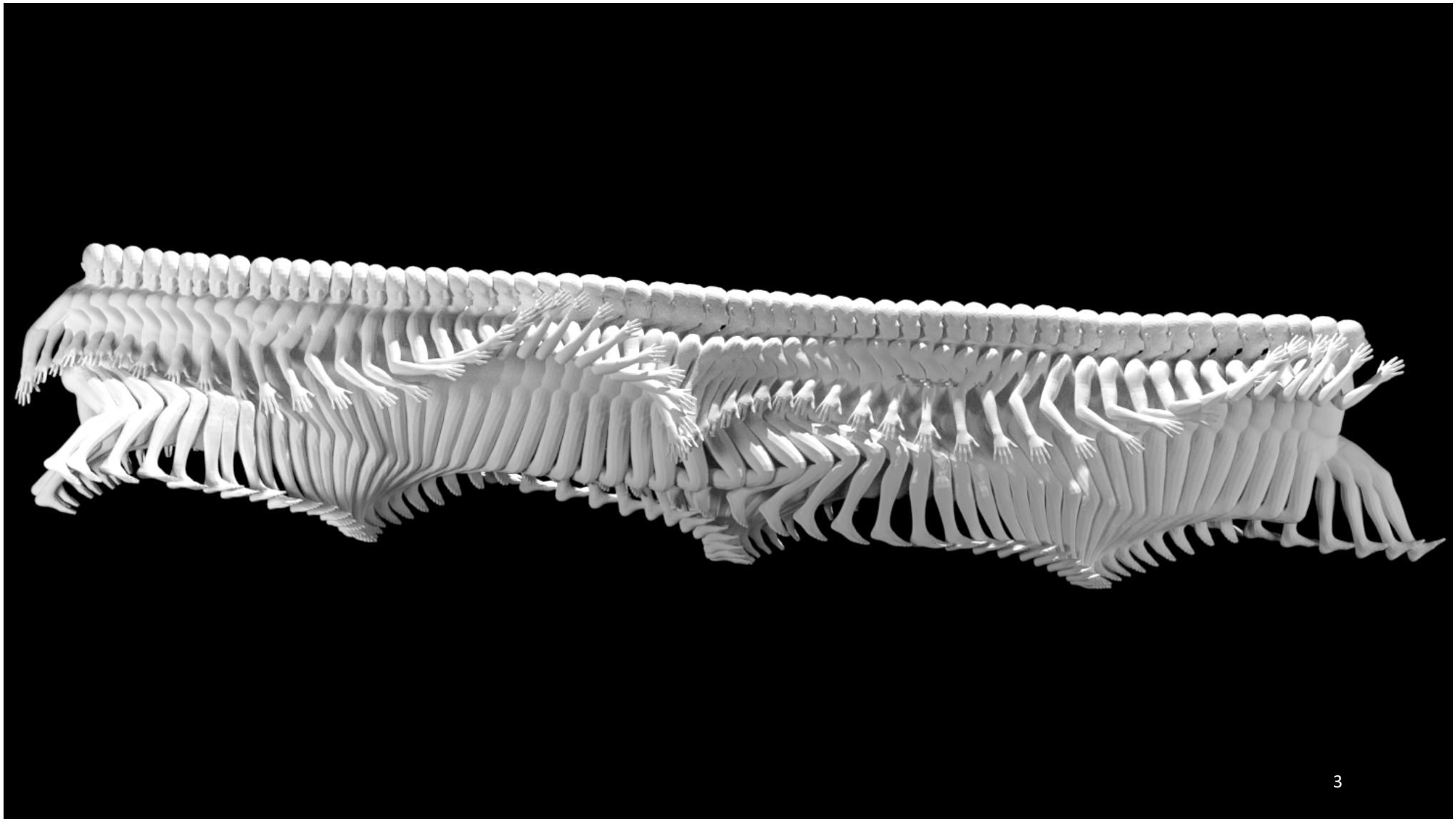
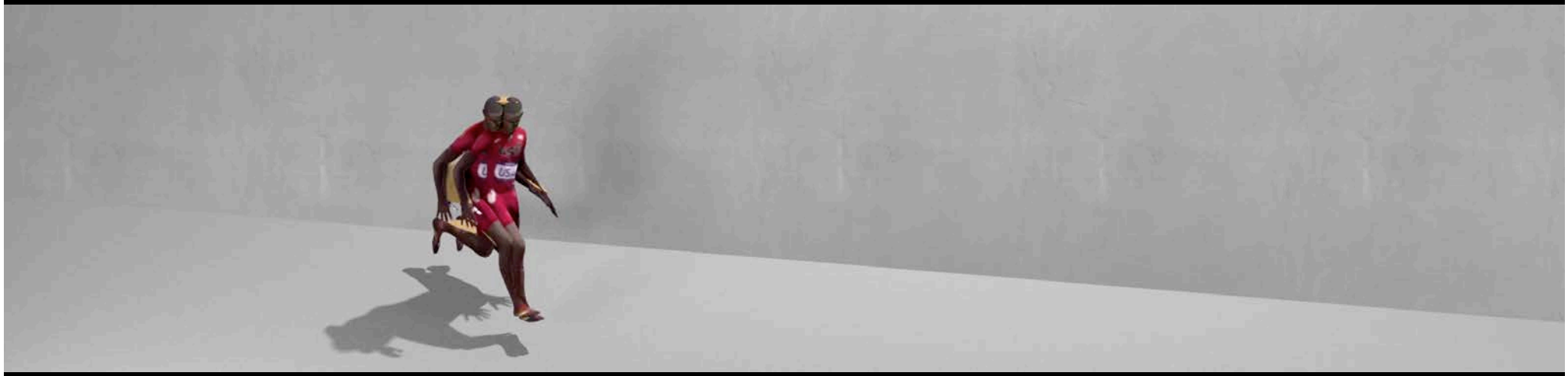
USA


London 2012






Video Courtesy of Tom Buehler (MIT CSAIL)

# Outline

- Related Work
- System Walkthrough
- User Studies
- Approach
- Results
- Conclusion

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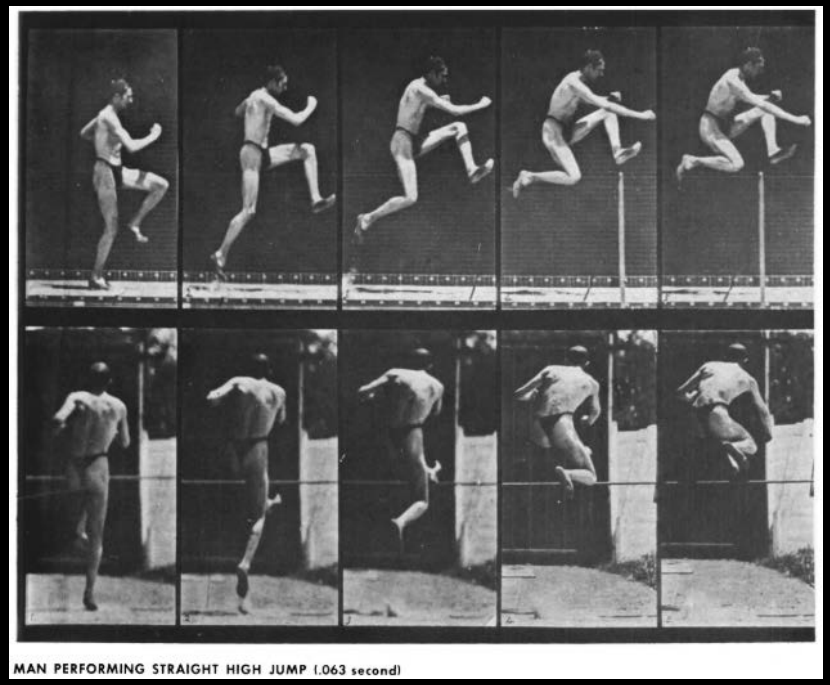
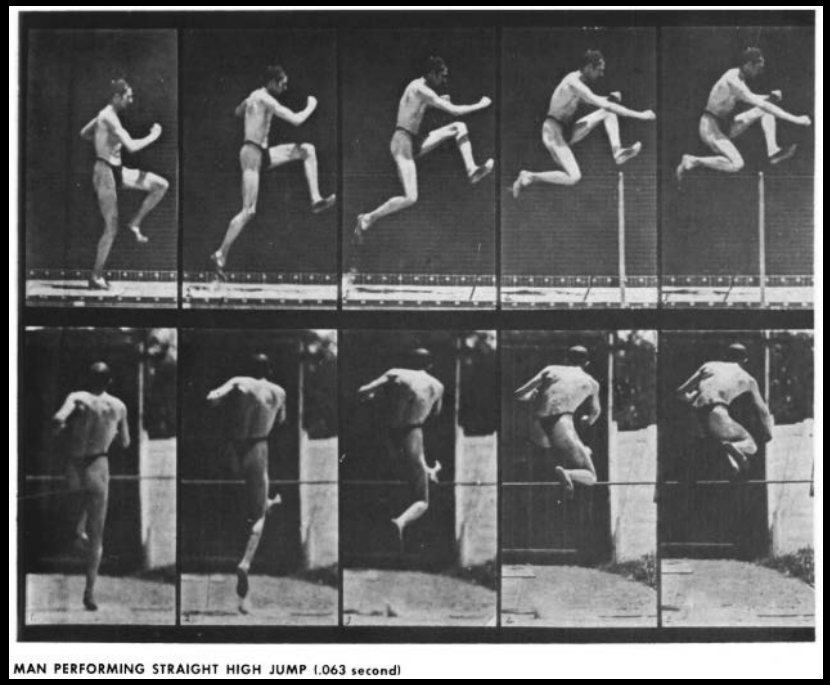
# Motivation

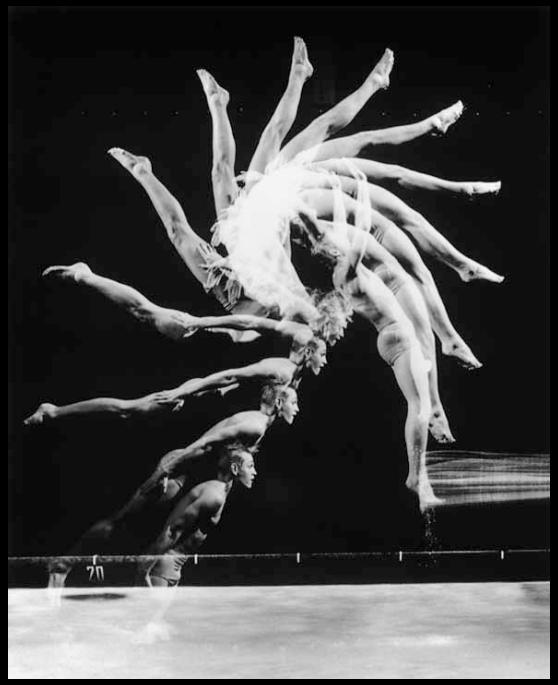



Muybridge, *The Human Figure in Motion*, 1901

# Motivation

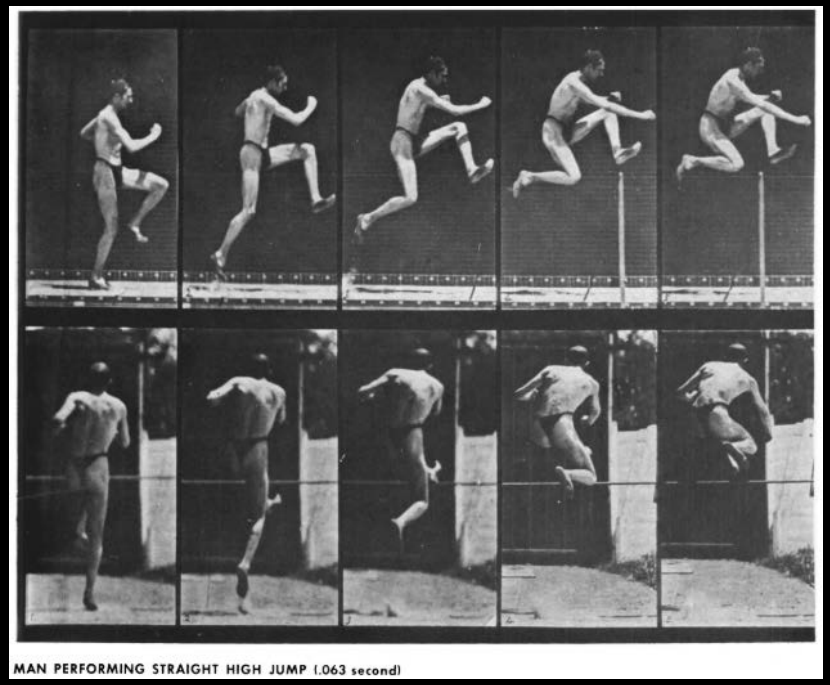



Muybridge, *The Human Figure in Motion*, 1901

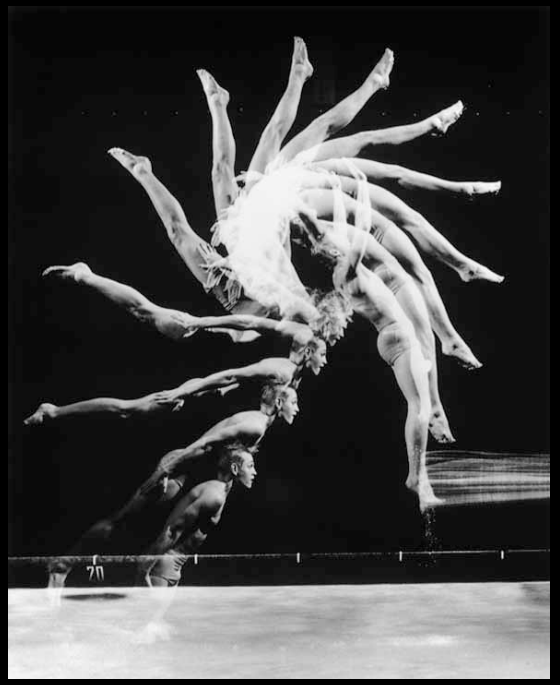


Edgerton, *Back Dive*, 1954

# Motivation




Muybridge, *The Human Figure in Motion*, 1901



Edgerton, *Back Dive*, 1954

Duchamp, *Nude Descending a Staircase, No. 2*, 1912

# Related Work

Edgerton, *Stroboscopic Photography*, 1927–1931

2D

# Related Work

Edgerton, *Stroboscopic Photography*, 1927–1931

2D

Freeman & Zhang, *Shape-Time Photography*, CVPR '03

Requires a depth camera

# Related Work vs. Ours

Edgerton, *Stroboscopic Photography*, 1927–1931

2D

Freeman & Zhang, *Shape-Time Photography*, CVPR '03

Requires a depth camera

MoSculp

3D w/ an RGB camera

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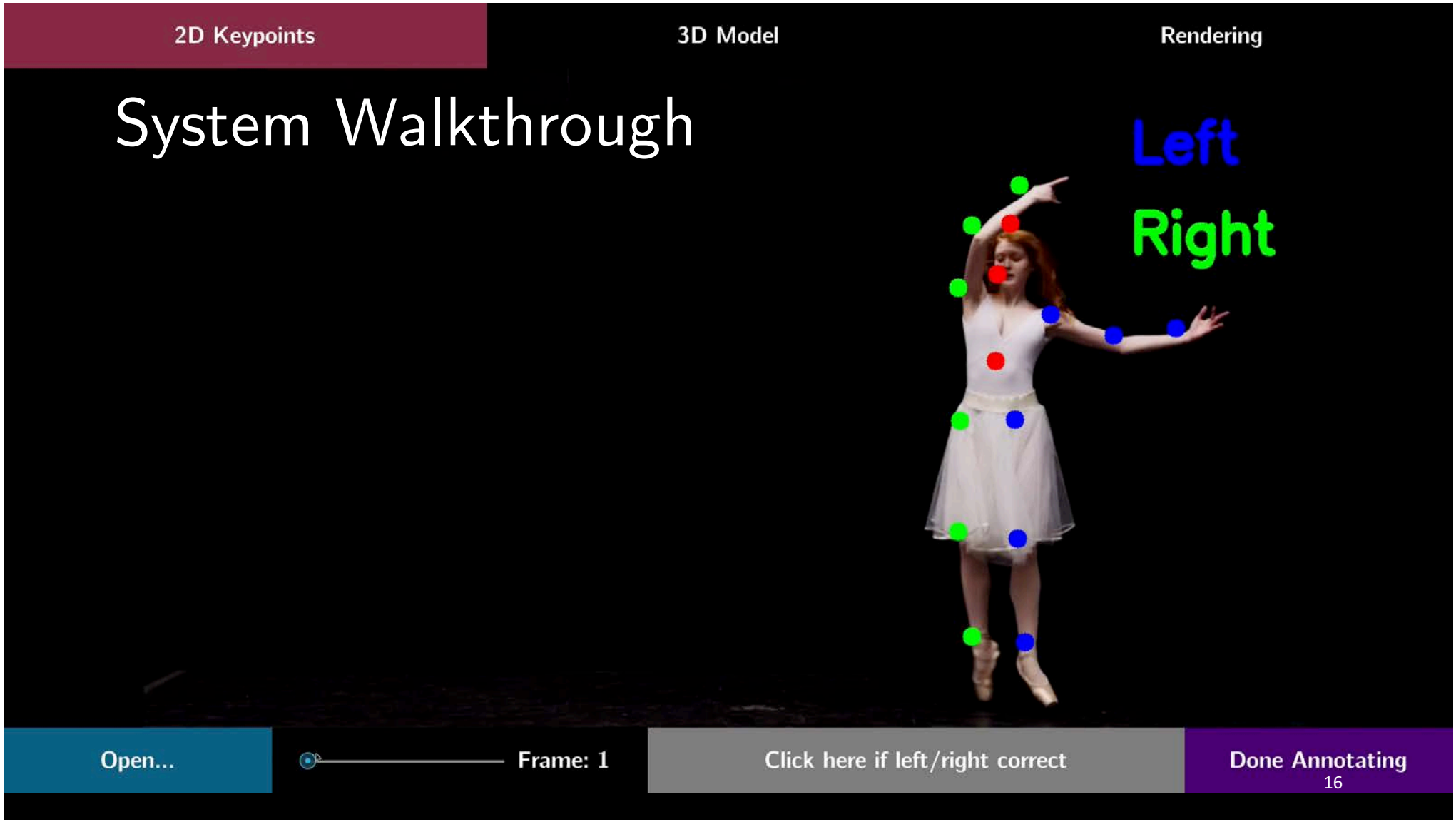
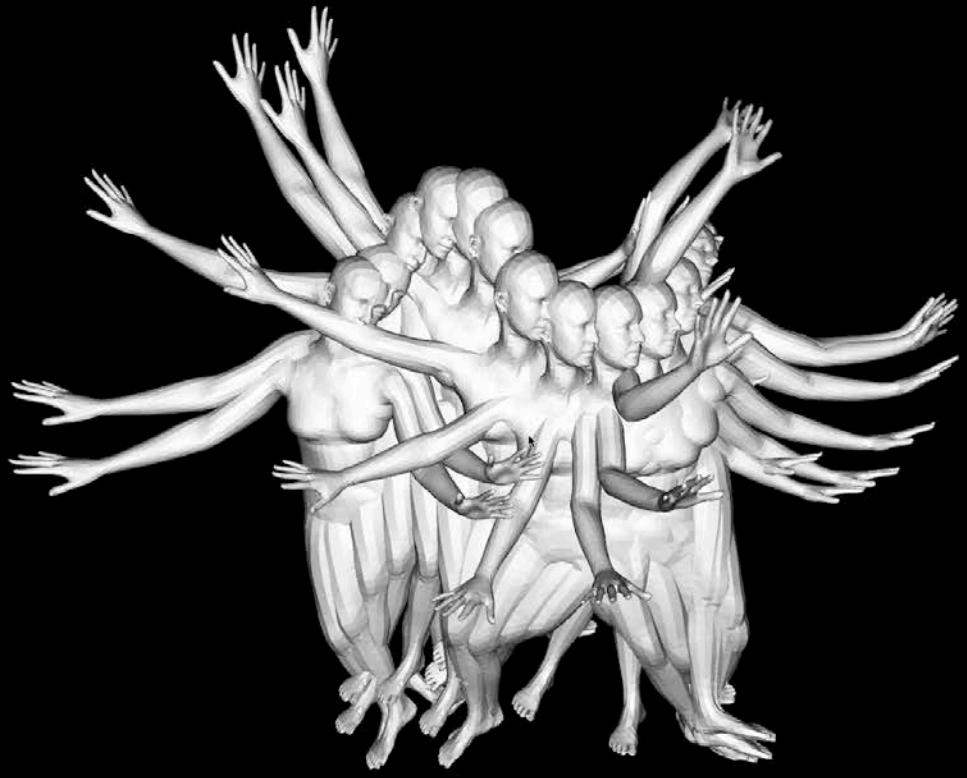
# System Walkthrough

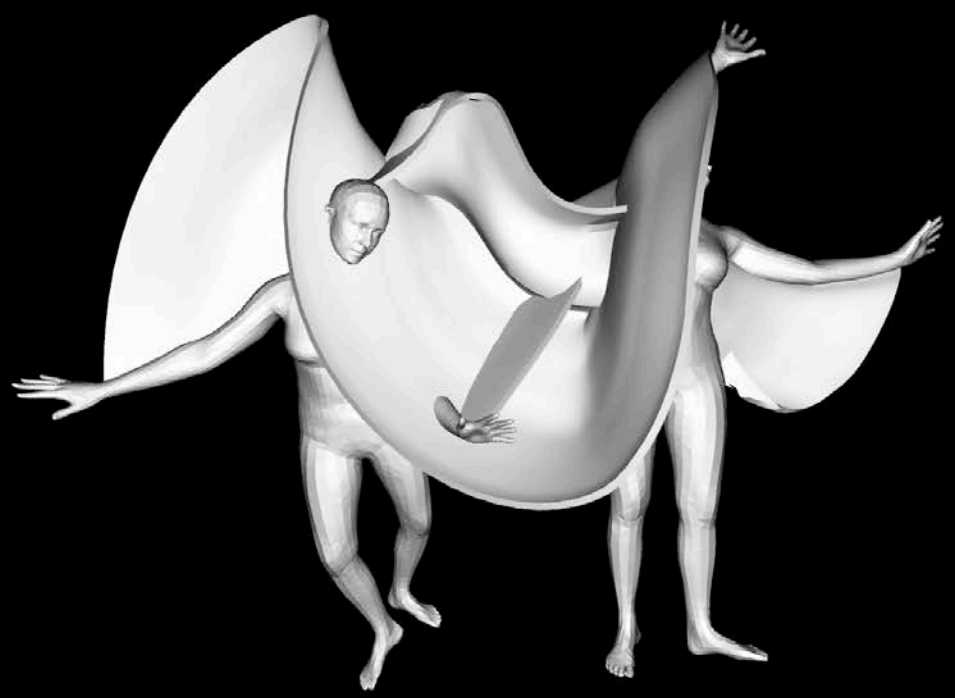


2D Keypoints | 3D Model | Rendering



Open... | Mode: Collection of Humans

2D Keypoints | 3D Model | Rendering



Open... | Mode: Sculpture

2D Keypoints | 3D Model | Rendering

Body Parts

- ✓ Body (Leather)
- ✓ Left Upper Arm (Leather)
- ✓ Left Lower Arm (Leather)
- ✓ Right Upper Arm (Leather)
- ✓ Right Lower Arm (Leather)
- ✓ Left Upper Leg (Leather)
- ✓ Left Lower Leg (Leather)
- ✓ Right Upper Leg (Leather)
- ✓ Right Lower Leg (Leather)

Part Material: Body

- ● Leather
- Tarp
- Wood
- Original

Lighting

- ✓ Left
- ✓ Middle
- ✓ Right

Keyframe Density 0

Sculpture Transparency 0

Sculpture Specularity: On

Synthetic Background: Off


2D Keypoints
3D Model
Rendering
Body Parts
Body (Leather)
Left Upper Arm (Leather)
Left Lower Arm (Leather)
Right Upper Arm (Leather)
Right Lower Arm (Leather)
Left Upper Leg (Leather)
Left Lower Leg (Leather)
Right Upper Leg (Leather)
Right Lower Leg (Leather)
Part Material: Body
Leather
Tarp
Wood
Original
Lighting
Left
Middle
Right
Keyframe Density
0
Sculpture Transparency
0
Sculpture Specularity: On
Synthetic Background: Off

2D Keypoints | 3D Model | Rendering

Body Parts
- Body (Leather)
- Left Upper Arm (Leather)
- Left Lower Arm (Leather)
- Right Upper Arm (Leather)
- ✓ Right Lower Arm (Leather)
- Left Upper Leg (Leather)
- Left Lower Leg (Leather)
- Right Upper Leg (Leather)
- Right Lower Leg (Leather)

Part Material: Body
- ● Leather
- Tarp
- Wood
- Original

Lighting
- ✓ Left
- ✓ Middle
- ✓ Right

Keyframe Density 0

Sculpture Transparency 0

Sculpture Specularity: On

Synthetic Background: Off

2D Keypoints | 3D Model | Rendering

Body Parts

- Body (Leather)
- ✓ Left Upper Arm (Leather)
- ✓ Left Lower Arm (Leather)
- Right Upper Arm (Leather)
- ✓ Right Lower Arm (Original)
- Left Upper Leg (Leather)
- Left Lower Leg (Leather)
- Right Upper Leg (Leather)
- Right Lower Leg (Leather)

Part Material: Right Lower Arm

- Leather
- Tarp
- Wood
- ● Original

Lighting

- ✓ Left
- ✓ Middle
- ✓ Right

Keyframe Density 0

Sculpture Transparency 0

Sculpture Specularity: On

Synthetic Background: Off

2D Keypoints | 3D Model | Rendering

Body Parts

- Body (Leather)
- ✓ Left Upper Arm (Tarp)
- ✓ Left Lower Arm (Leather)
- Right Upper Arm (Leather)
- ✓ Right Lower Arm (Original)
- Left Upper Leg (Leather)
- Left Lower Leg (Leather)
- Right Upper Leg (Leather)
- Right Lower Leg (Leather)

Part Material: Left Upper Arm

- Leather
- ● Tarp
- Wood
- Original

Lighting

- ✓ Left
- ✓ Middle
- ✓ Right

Keyframe Density 0

Sculpture Transparency 0

Sculpture Specularity: On

Synthetic Background: Off

2D Keypoints | 3D Model | Rendering

Body Parts

- Body (Leather)
- Left Upper Arm (Tarp)
- ✓ Left Lower Arm (Tarp)
- Right Upper Arm (Tarp)
- ✓ Right Lower Arm (Leather)
- Left Upper Leg (Leather)
- Left Lower Leg (Leather)
- Right Upper Leg (Leather)
- Right Lower Leg (Leather)

Part Material: Right Lower Arm

- ● Leather
- Tarp
- Wood
- Original

Lighting

- ✓ Left
- ✓ Middle
- ✓ Right

Keyframe Density 0.0

Sculpture Transparency 0.0

Sculpture Specularity: On

Synthetic Background: Off


2D Keypoints
3D Model
Rendering
Body Parts
Body (Leather)
Left Upper Arm (Tarp)
Left Lower Arm (Tarp)
Right Upper Arm (Tarp)
Right Lower Arm (Leather)
Left Upper Leg (Leather)
Left Lower Leg (Leather)
Right Upper Leg (Leather)
Right Lower Leg (Leather)
Part Material: Right Lower Arm
Leather
Tarp
Wood
Original
Lighting
Left
Middle
Right
Keyframe Density
0.0
Sculpture Transparency
0.0
Sculpture Specularity: On
Synthetic Background: Off

# Outline

- Related Work
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- User Studies
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# User Studies: Design Choices

With Floor Reflections

**Preferred by 82%**

Without

# User Studies: Efficacy in Conveying Motion

Baseline 1
(Stroboscopic)

Baseline 2
(Shape-Time)

MoSculp
**Preferred by 75%**

# Outline

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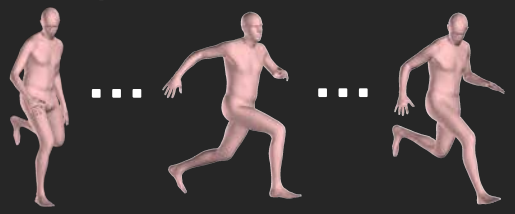
Input Video

3D Shape & Pose Estimation

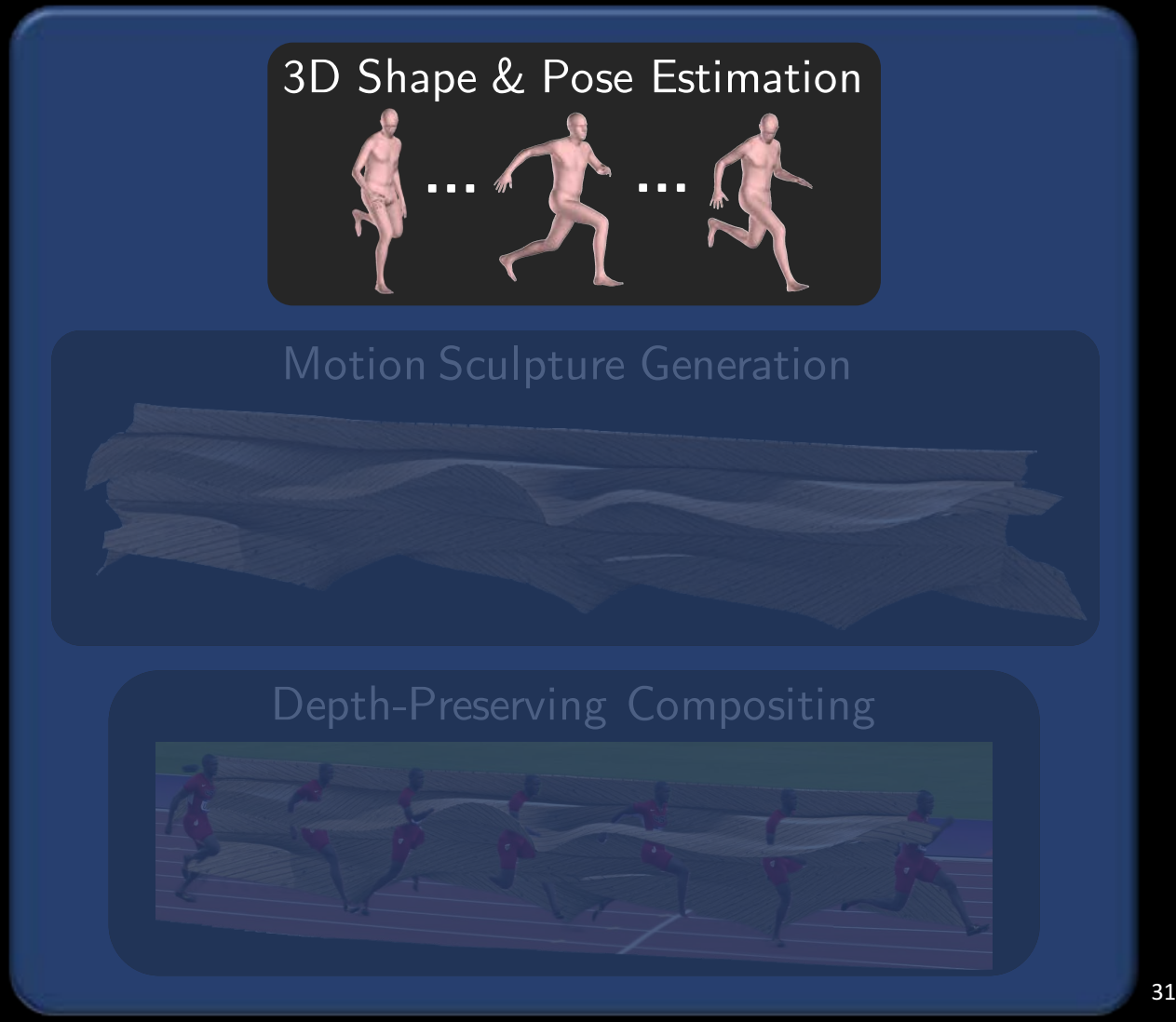


Motion Sculpture Generation

Depth-Preserving Compositing

# Overview

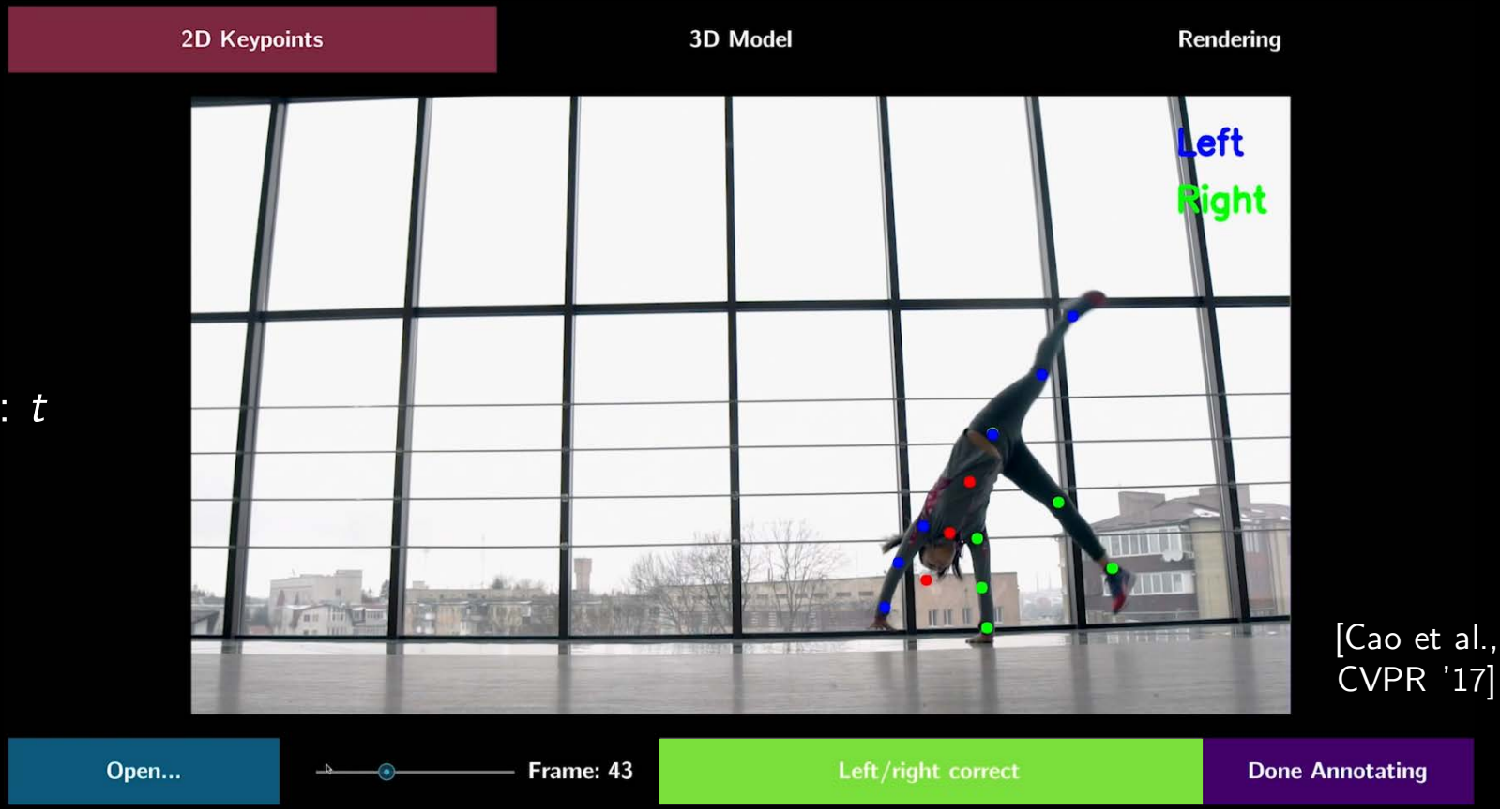
Input Video




# Overview

# Approach: 2D Keypoint Detection

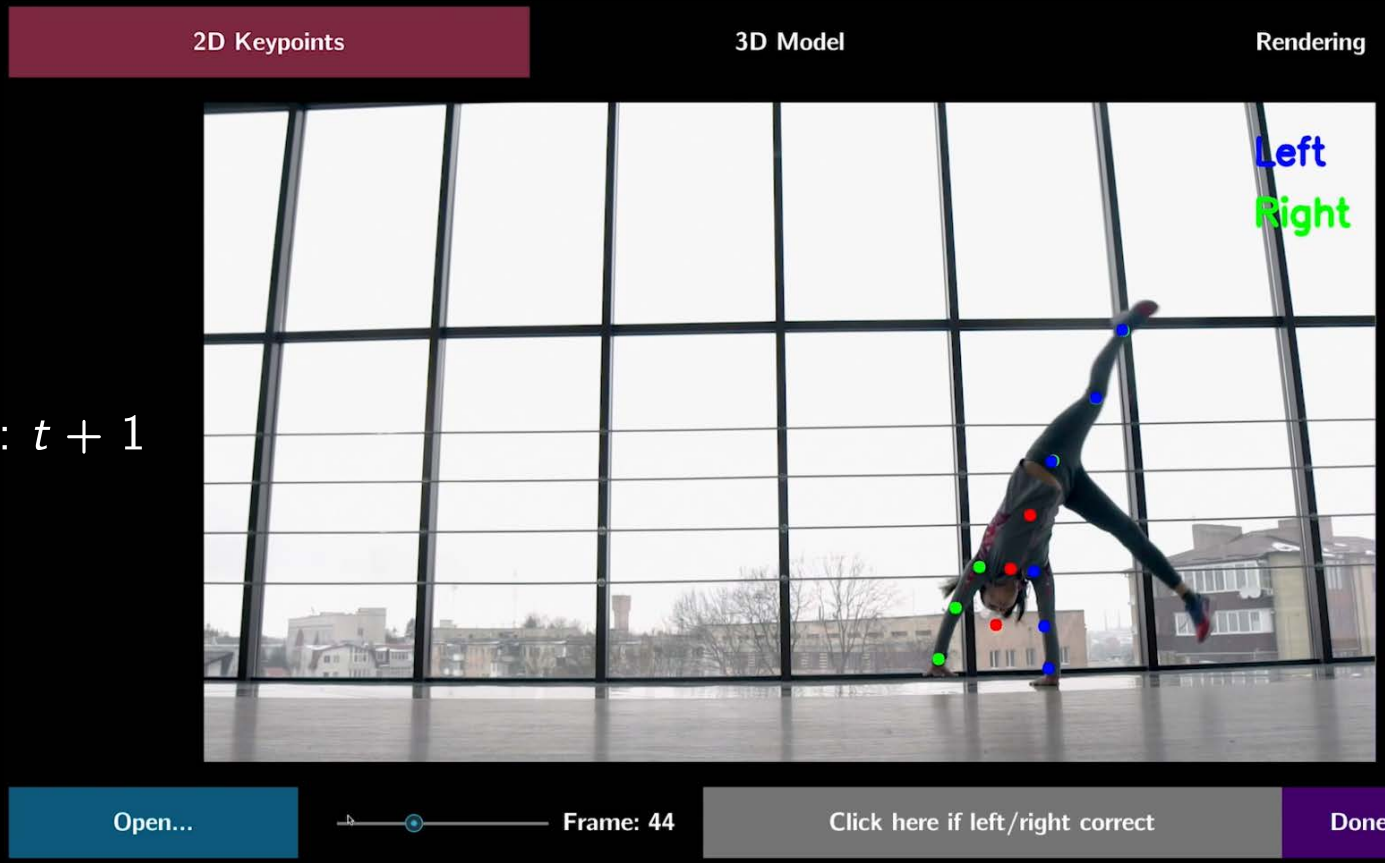
Time: $t$



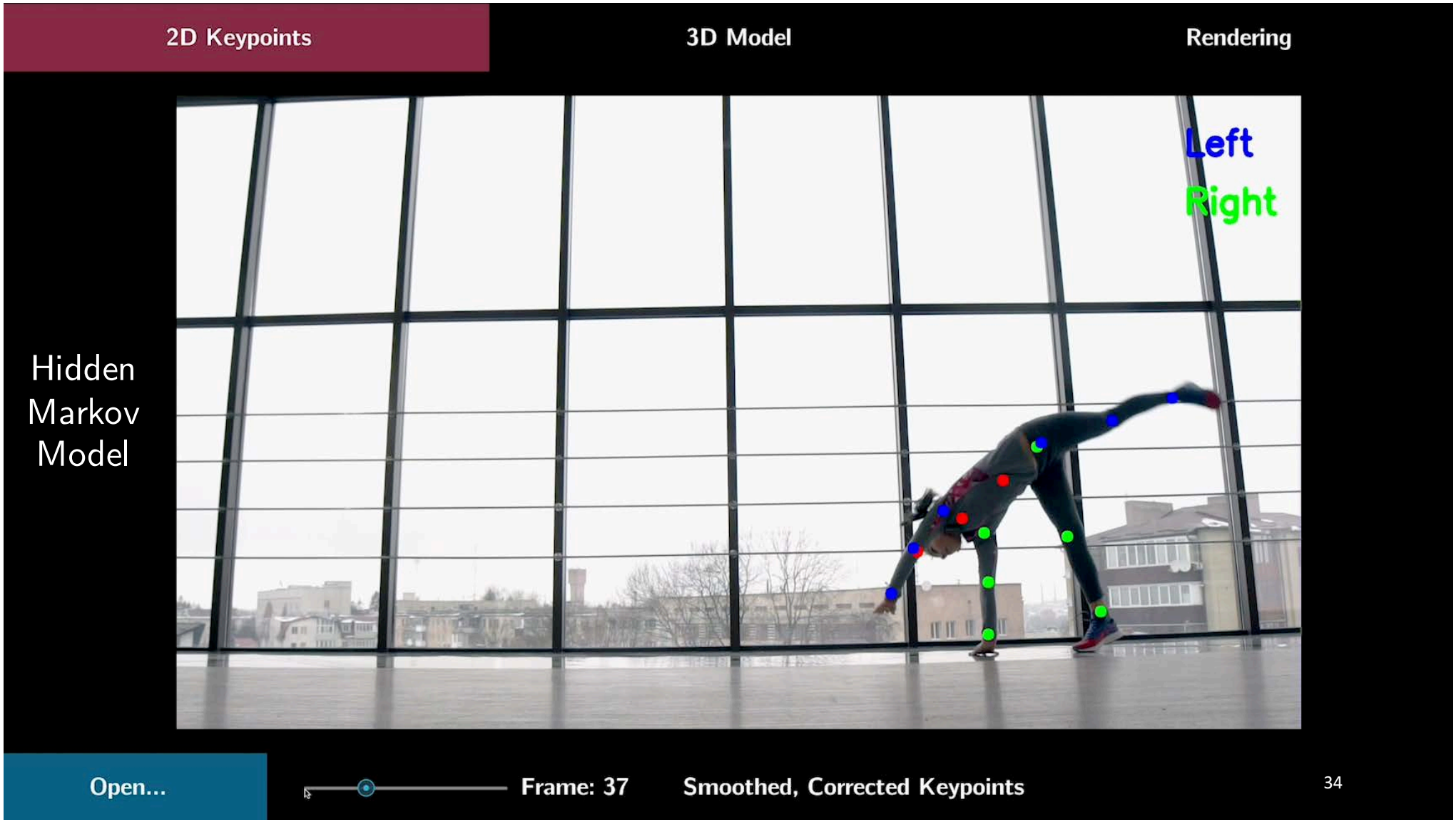

[Cao et al., CVPR '17]

# Approach: 2D Keypoint Detection

Time: $t + 1$




[Cao et al., CVPR '17]

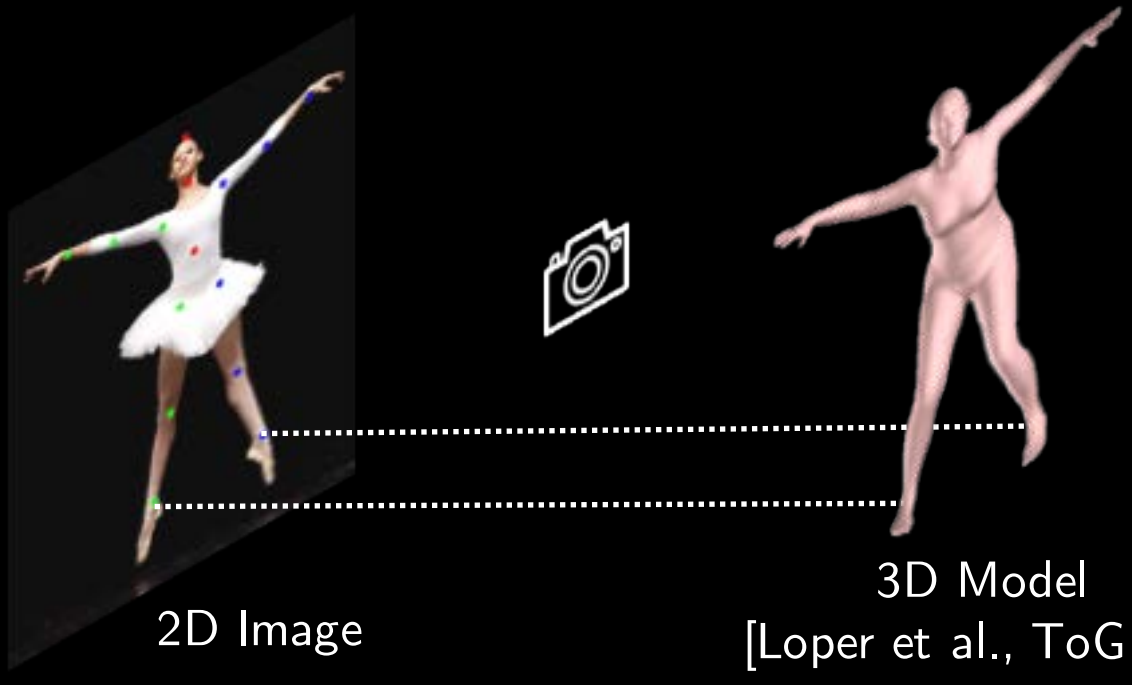

2D Keypoints
3D Model
Rendering
Left
Right
Hidden Markov Model
Open...
Frame: 37
Smoothed, Corrected Keypoints

# Approach: 3D Estimation

- Solve for the best shape and poses jointly for the clip

# Approach: 3D Estimation

- Solve for the best shape and poses jointly for the clip
  - Small reprojection error

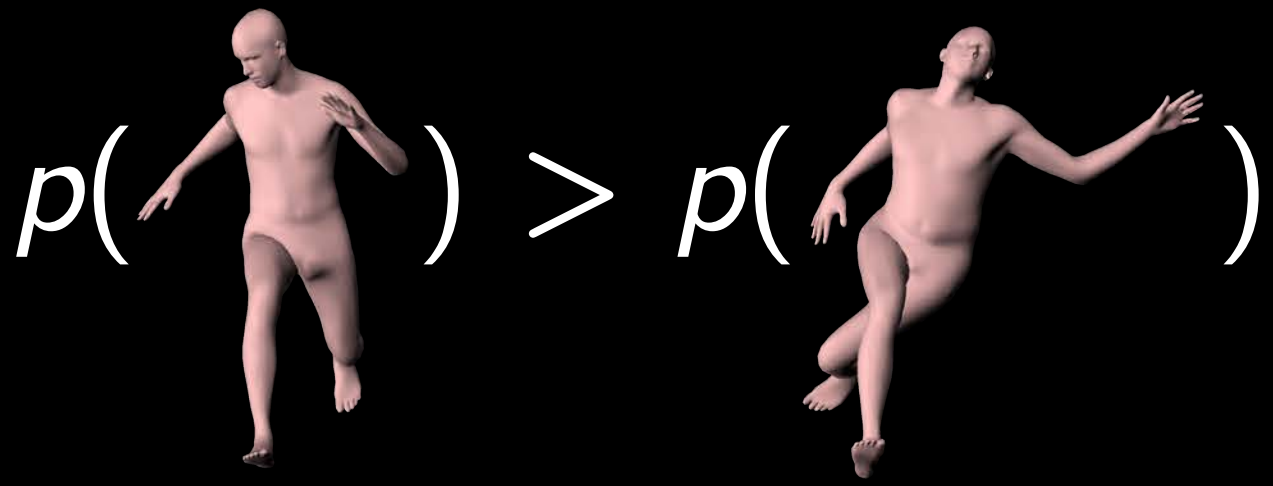


2D Image

3D Model
[Loper et al., ToG '15]

# Approach: 3D Estimation

- Solve for the best shape and poses jointly for the clip
  - Small reprojection error
  - Large probability of the poses



# Approach: 3D Estimation

- Solve for the best shape and poses jointly for the clip
  - Small reprojection error
  - Large probability of the poses
  - Smooth evolution of poses

# Approach: 3D Estimation

- Solve for the best shape and poses *jointly* for the clip
  - Small reprojection error
  - Large probability of the poses
  - Smooth evolution of poses

Original Camera View

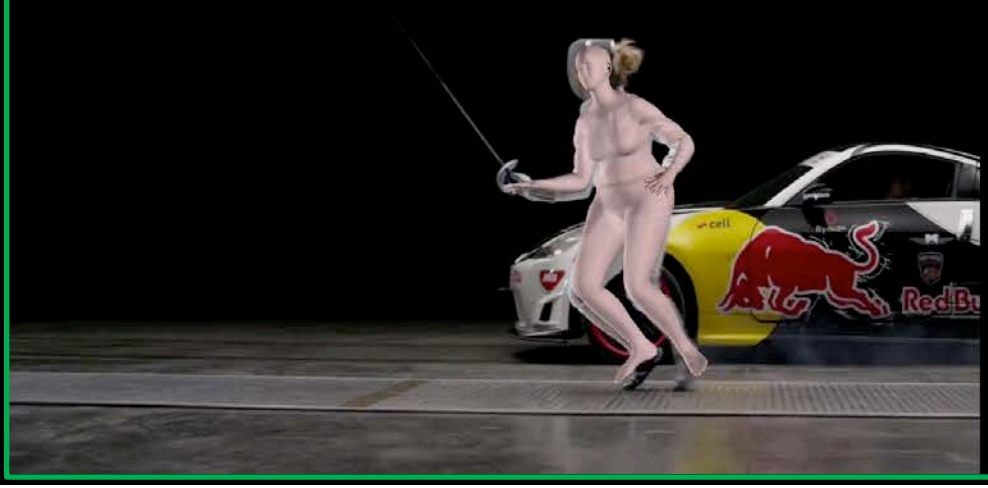
Novel View

Per-Frame Optimization [Bogo et al., ECCV '16]

# Approach: 3D Estimation

- Solve for the best shape and poses *jointly* for the clip
  - Small reprojection error
  - Large probability of the poses
  - Smooth evolution of poses

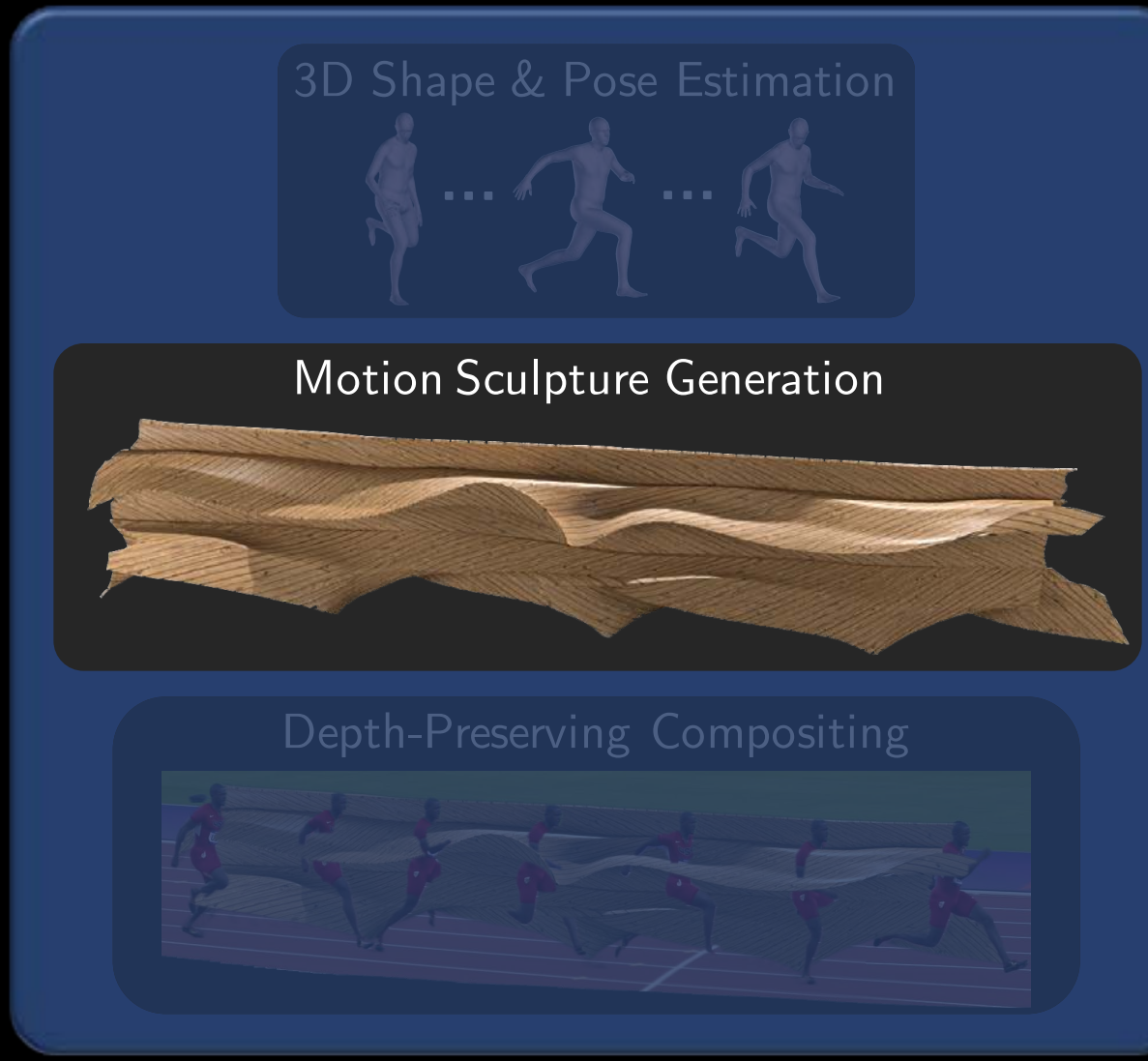
Original Camera View



Novel View

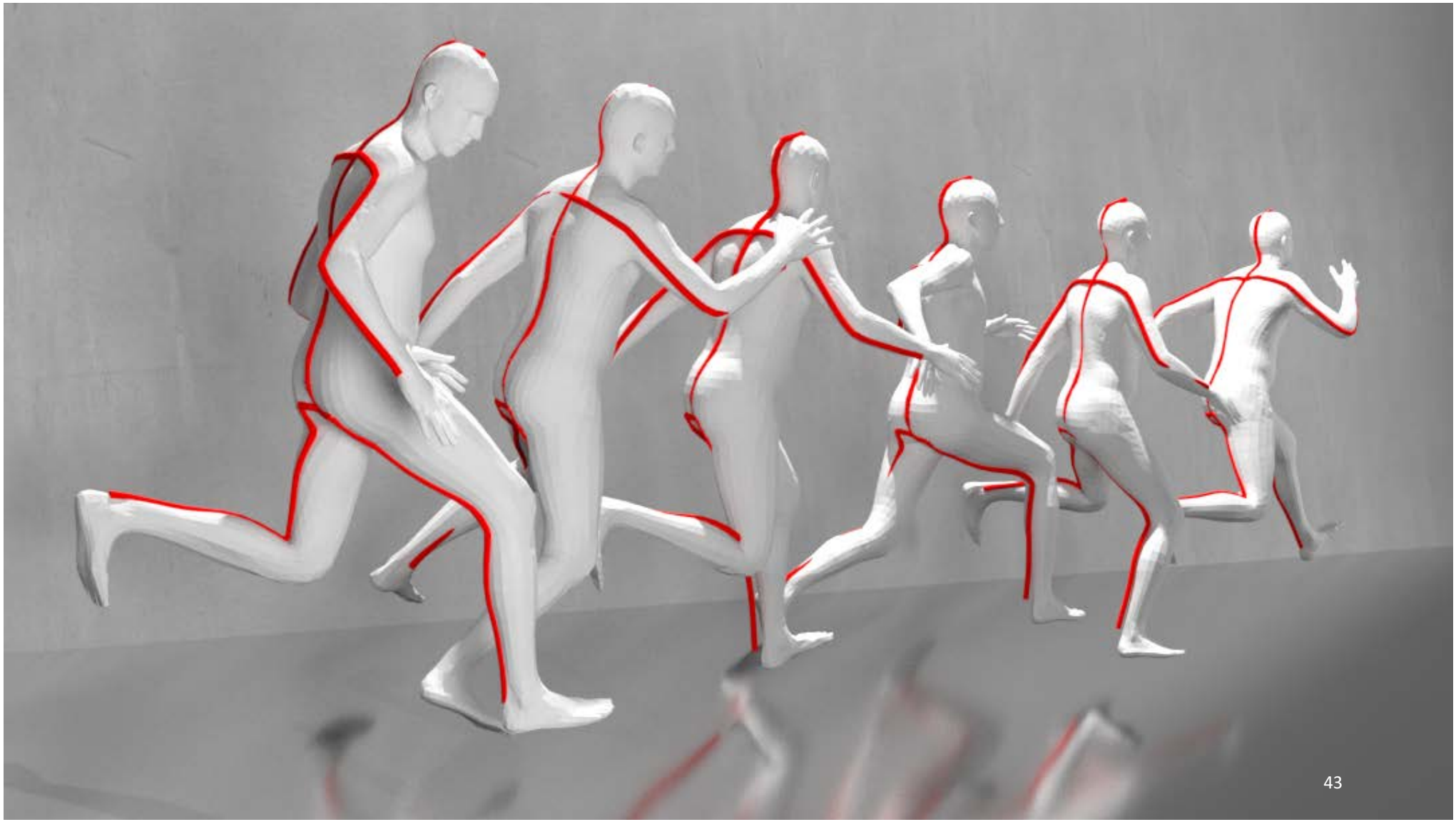
Our Joint Optimization

Input Video

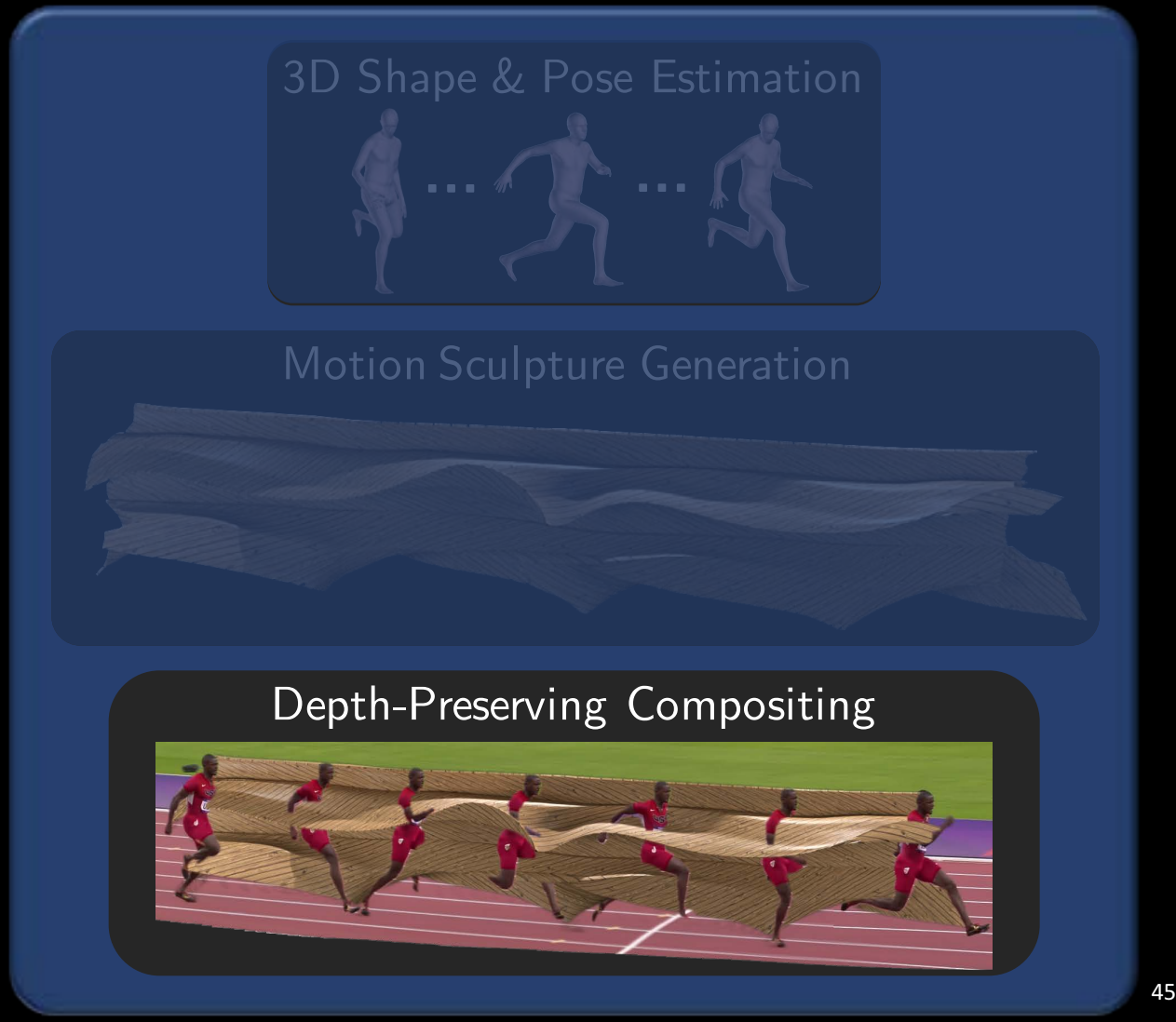



# Overview

# Approach: Sculpture Generation



Input Video



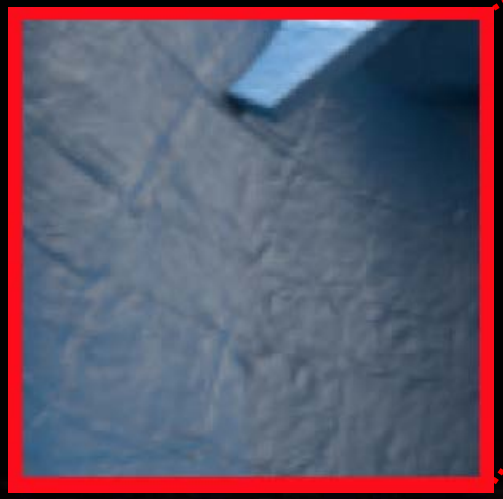

# Overview

# Approach: Compositing

- **Key challenge:** how to "put together" 3D sculpture and 2D video?

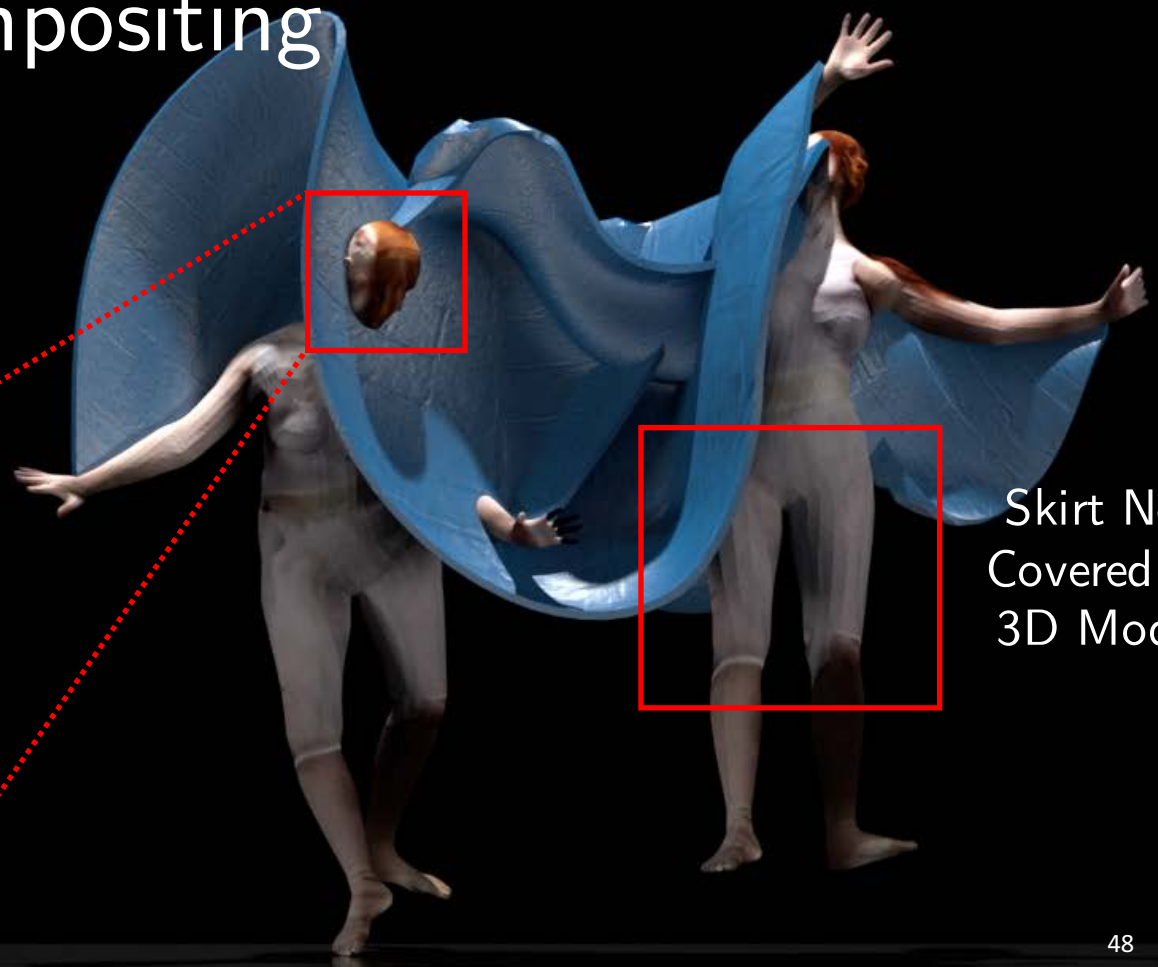
# Approach: Compositing

- **Naive Compositing**: sculpture on top of the frames



# Approach: Compositing

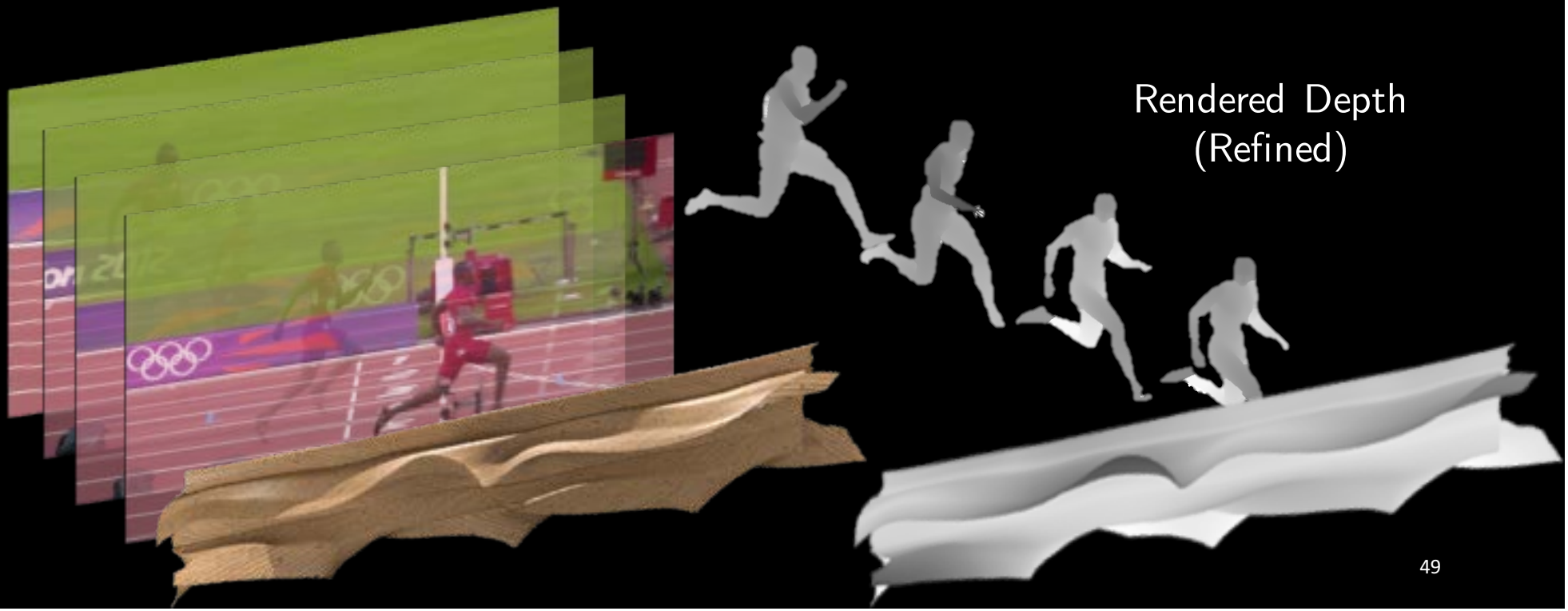
- **Full 3D Rendering**: texturing the 3D models



Skirt Not Covered by 3D Model

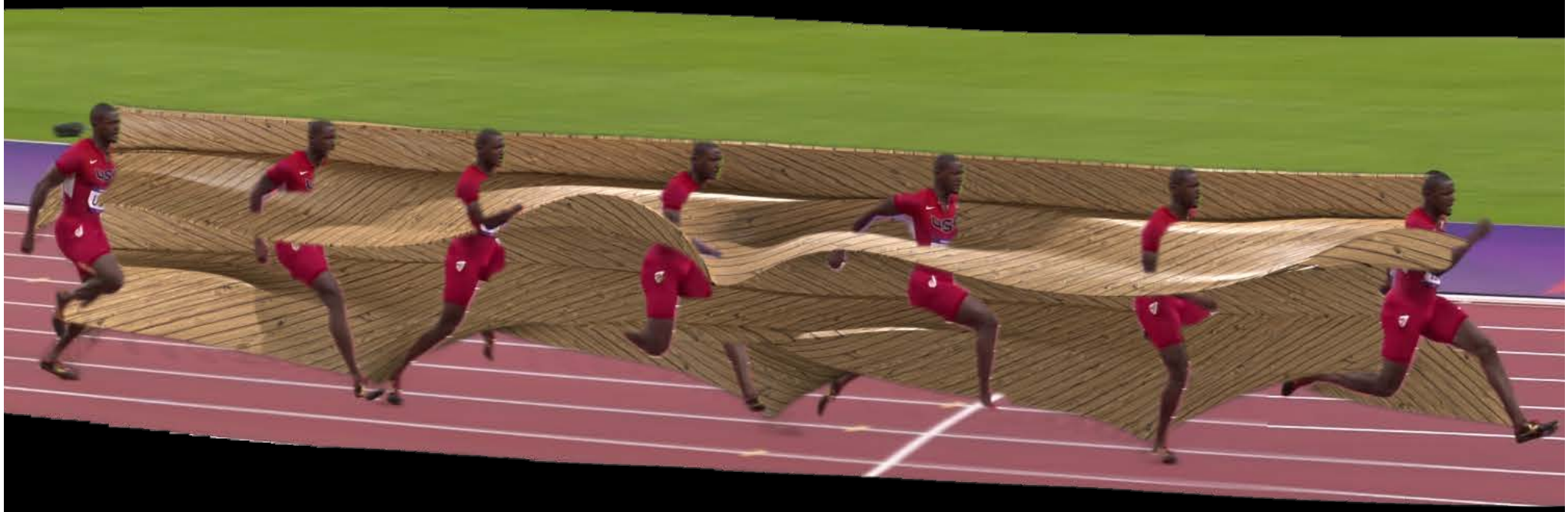
# Approach: Compositing

- **Solution:** depth-preserving composite



# Approach: Compositing

- **Solution:** depth-preserving composite



# Approach: Before Refinement

# Approach: After Refinement

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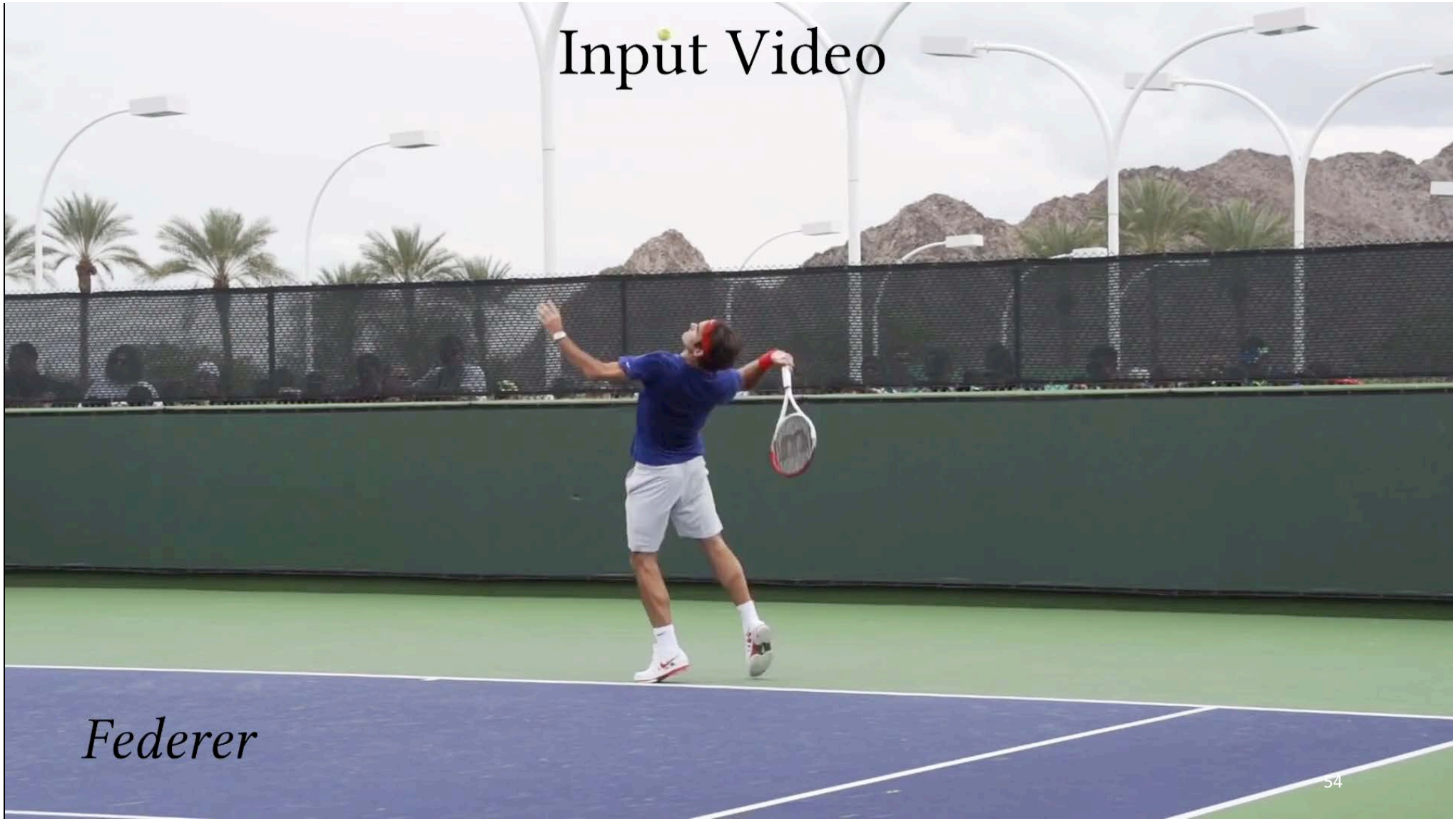
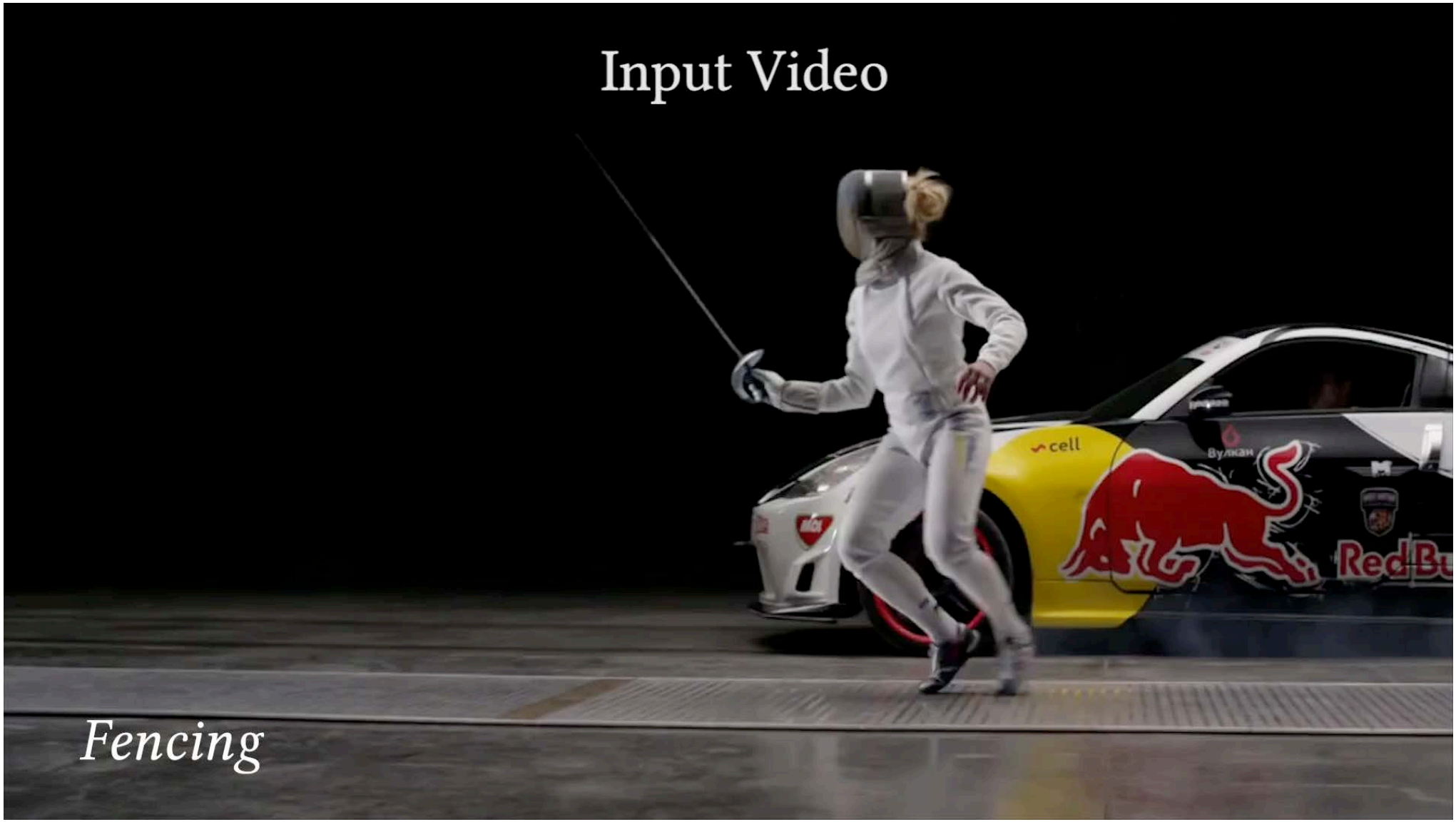
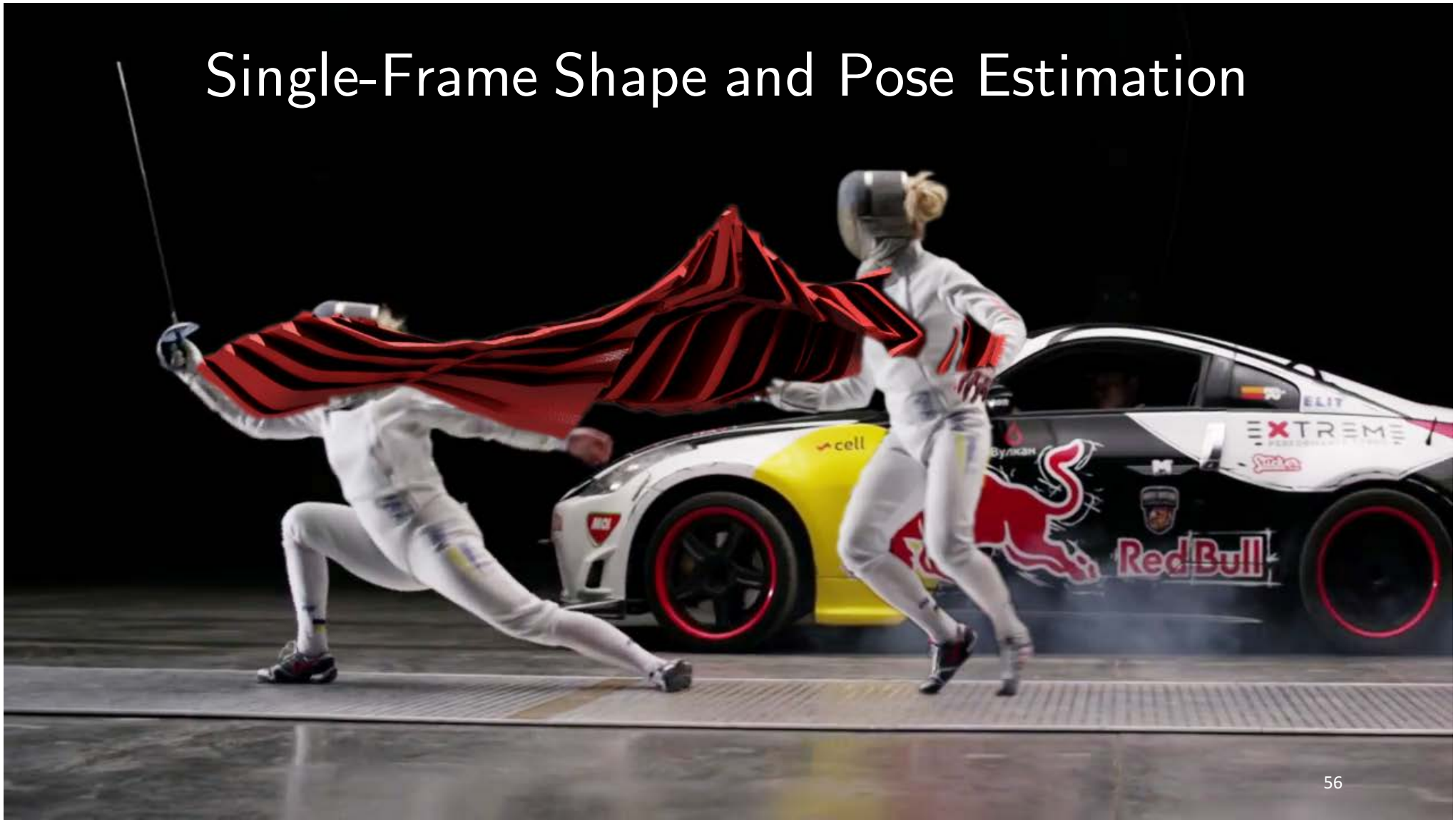

Input Video
Federer

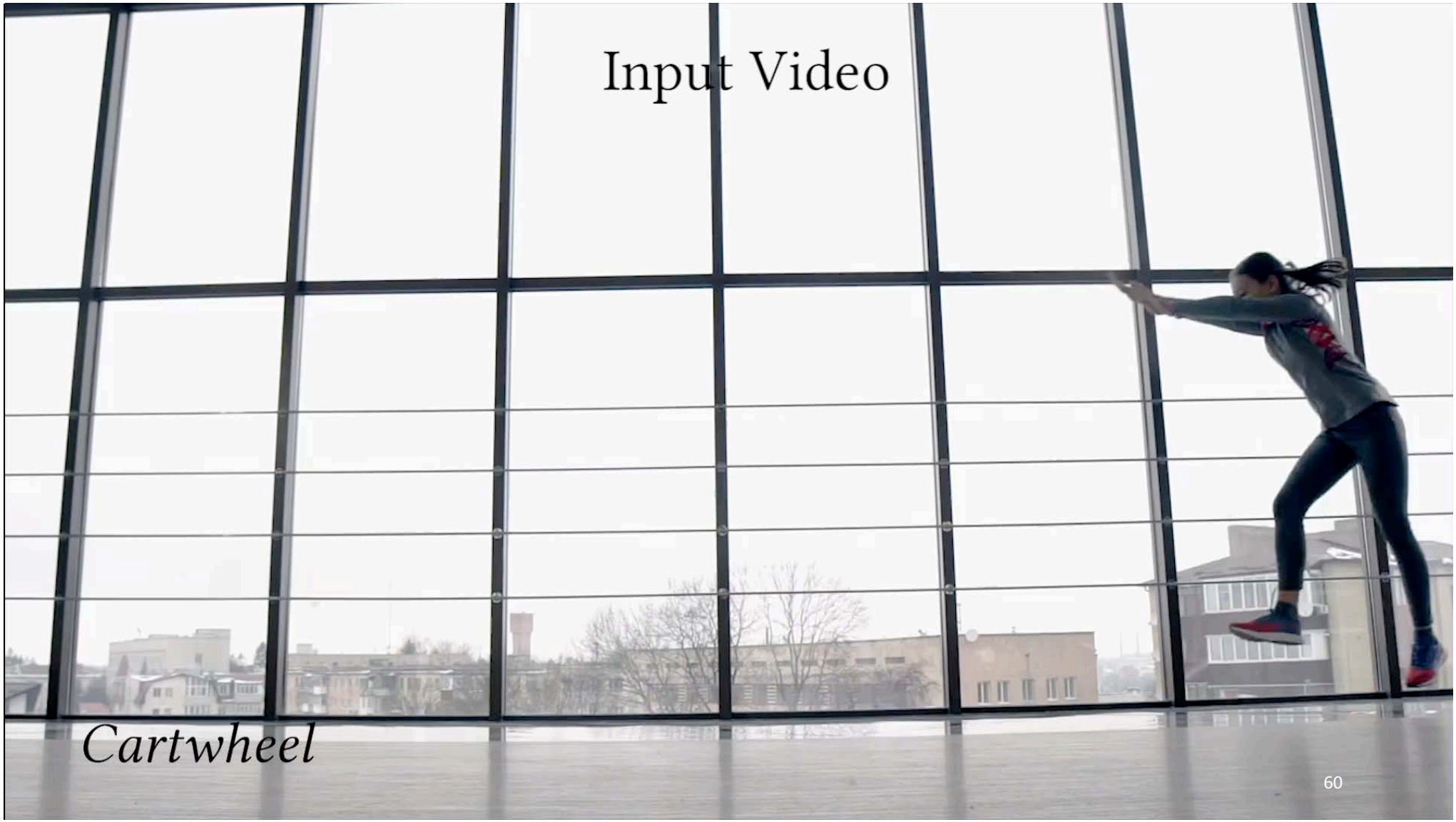

Input Video
Fencing

# Single-Frame Shape and Pose Estimation

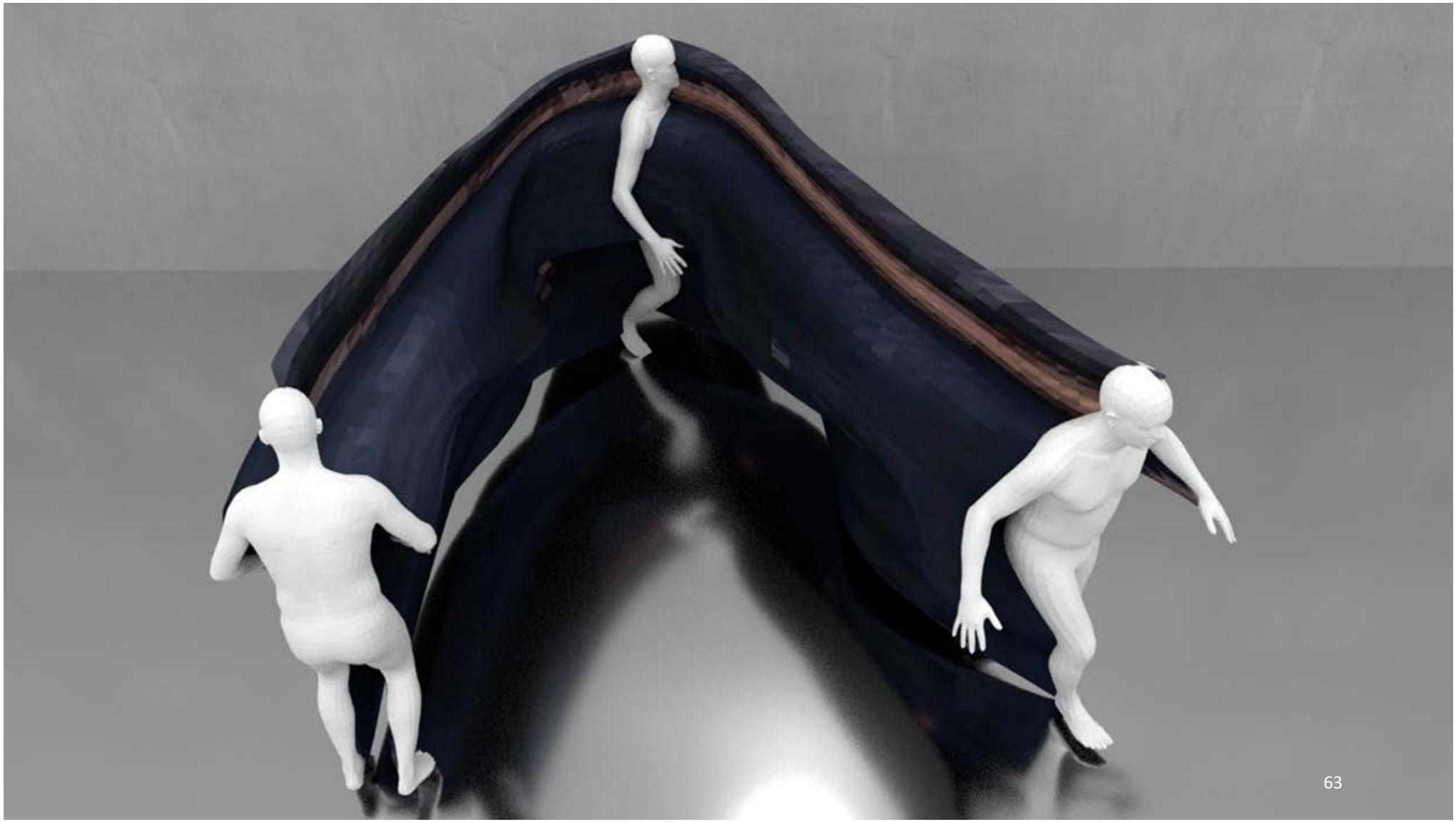


# Our Joint Estimation

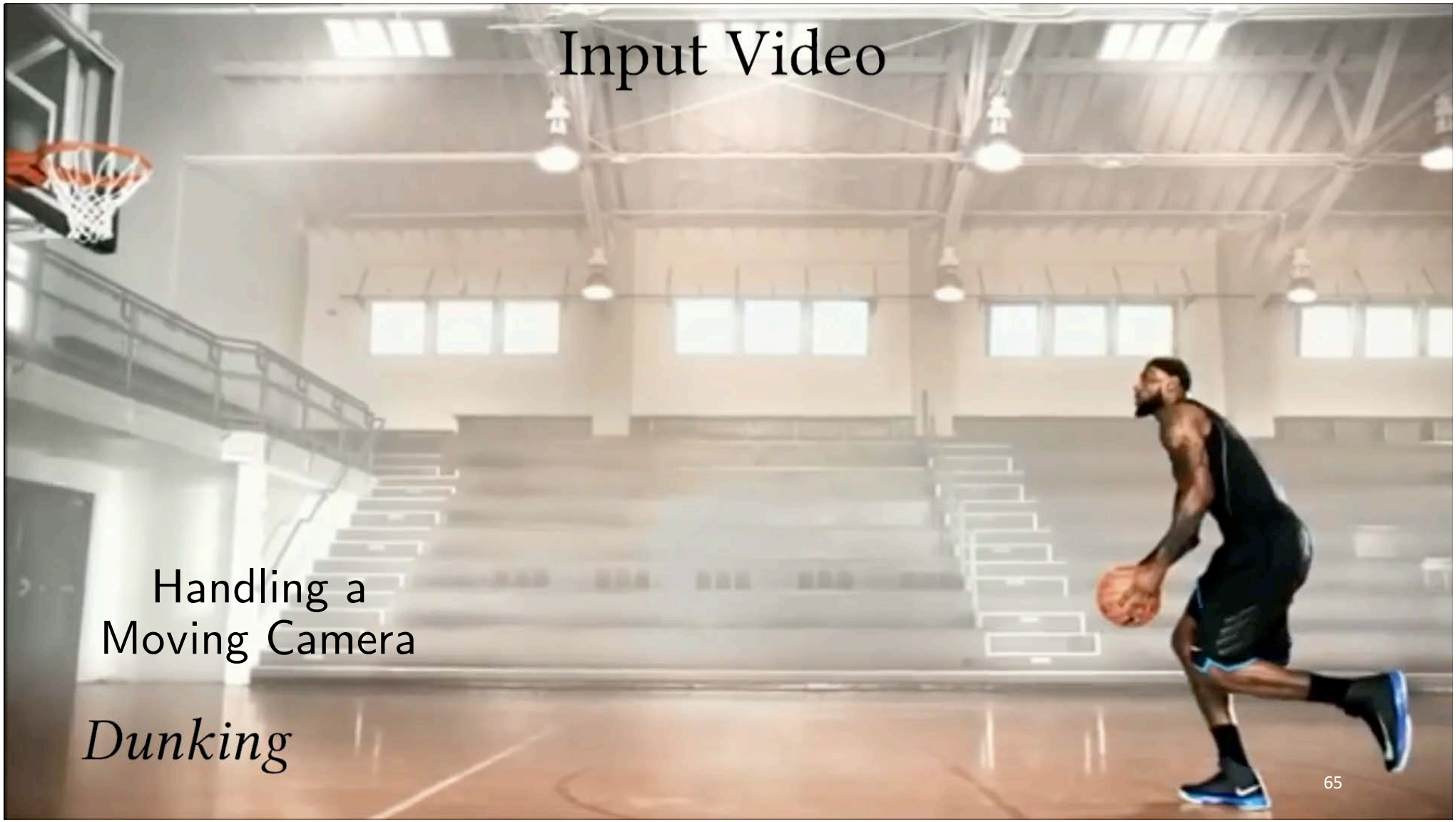

Input Video
Jumping


Input Video
Cartwheel


Texture from Original Frames
Input Video
U-Walking




Input Video
Ballet


Input Video
Handling a
Moving Camera
Dunking


Input Video
Run, Forrest, Run!

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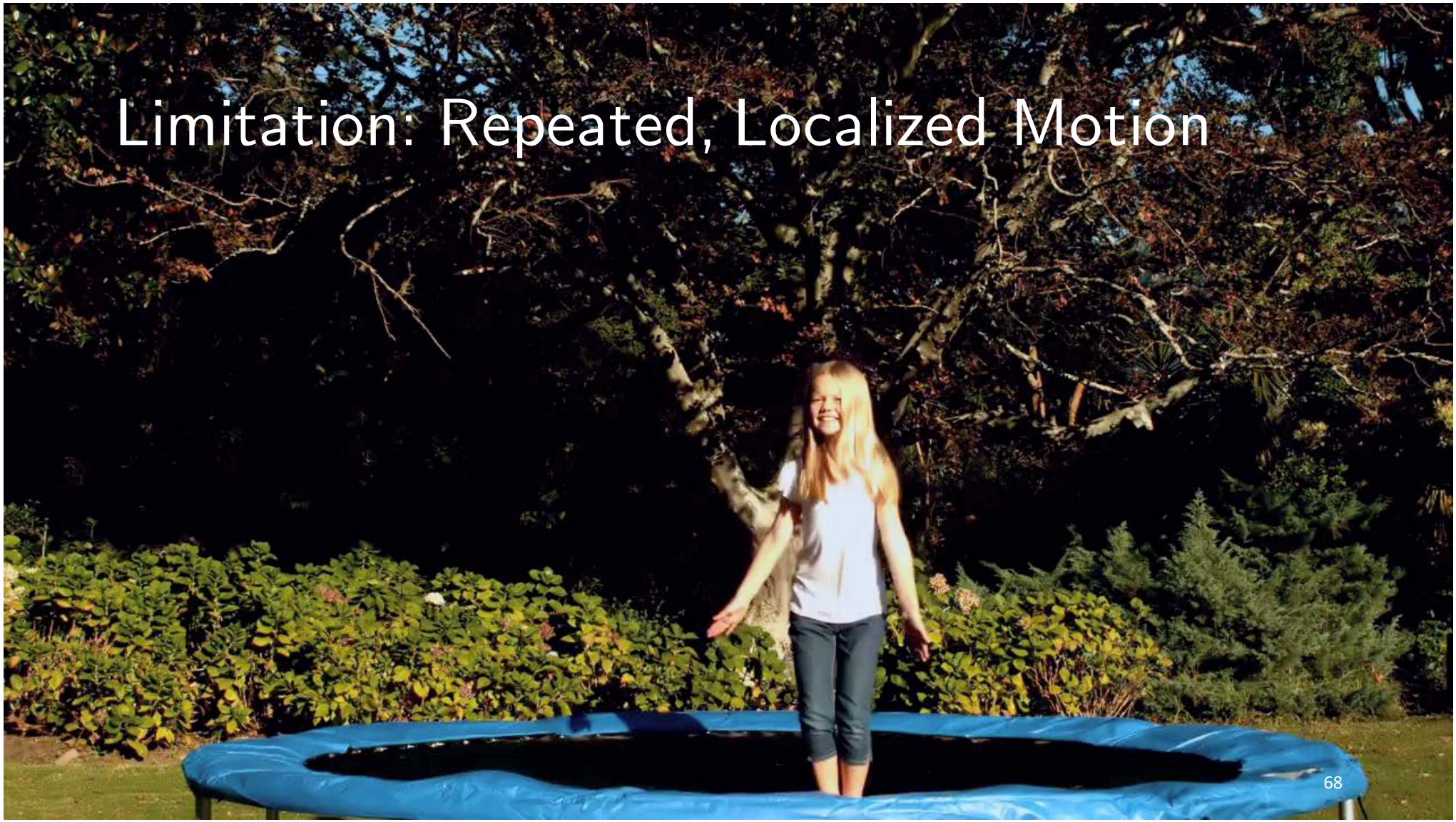
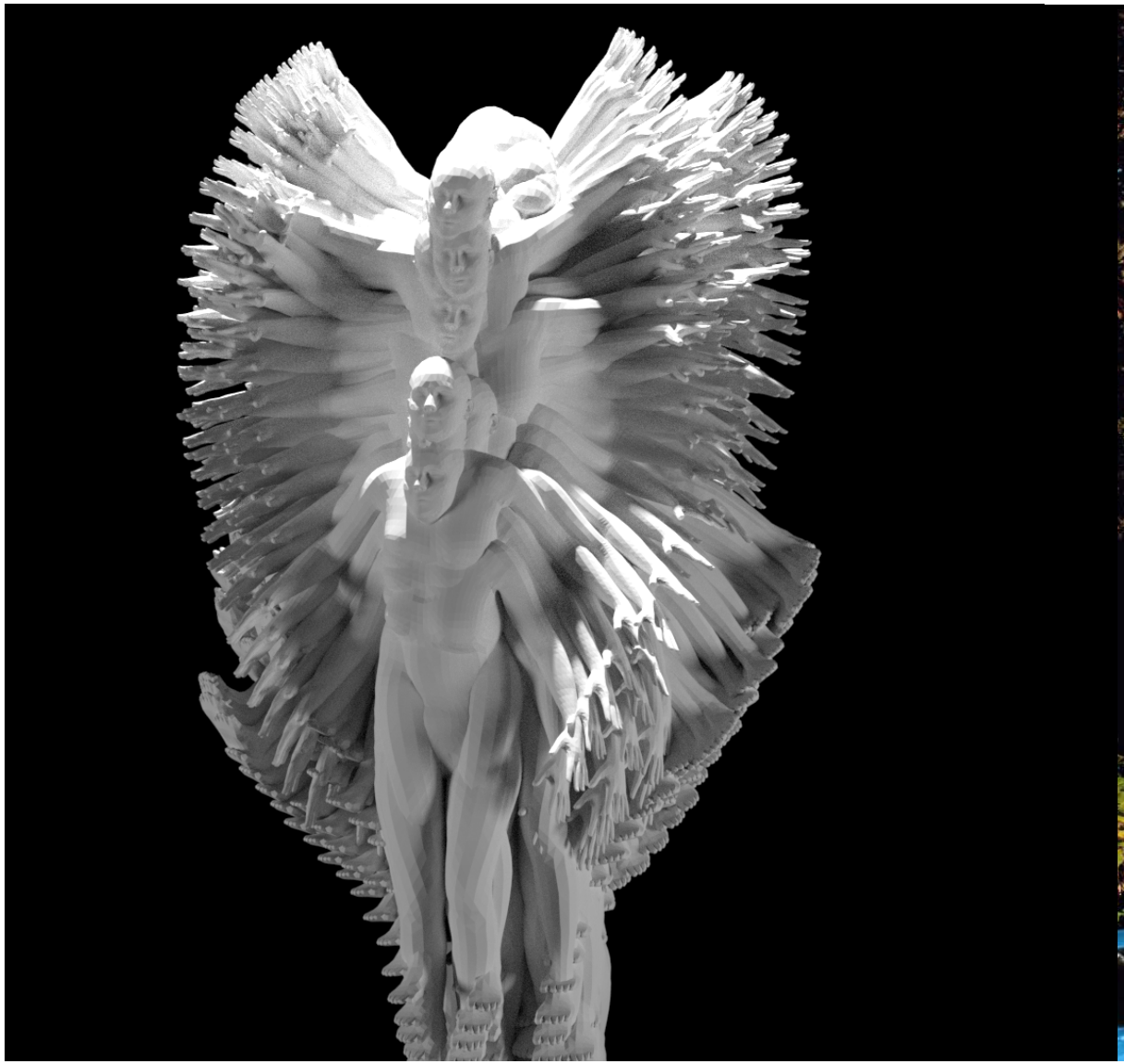
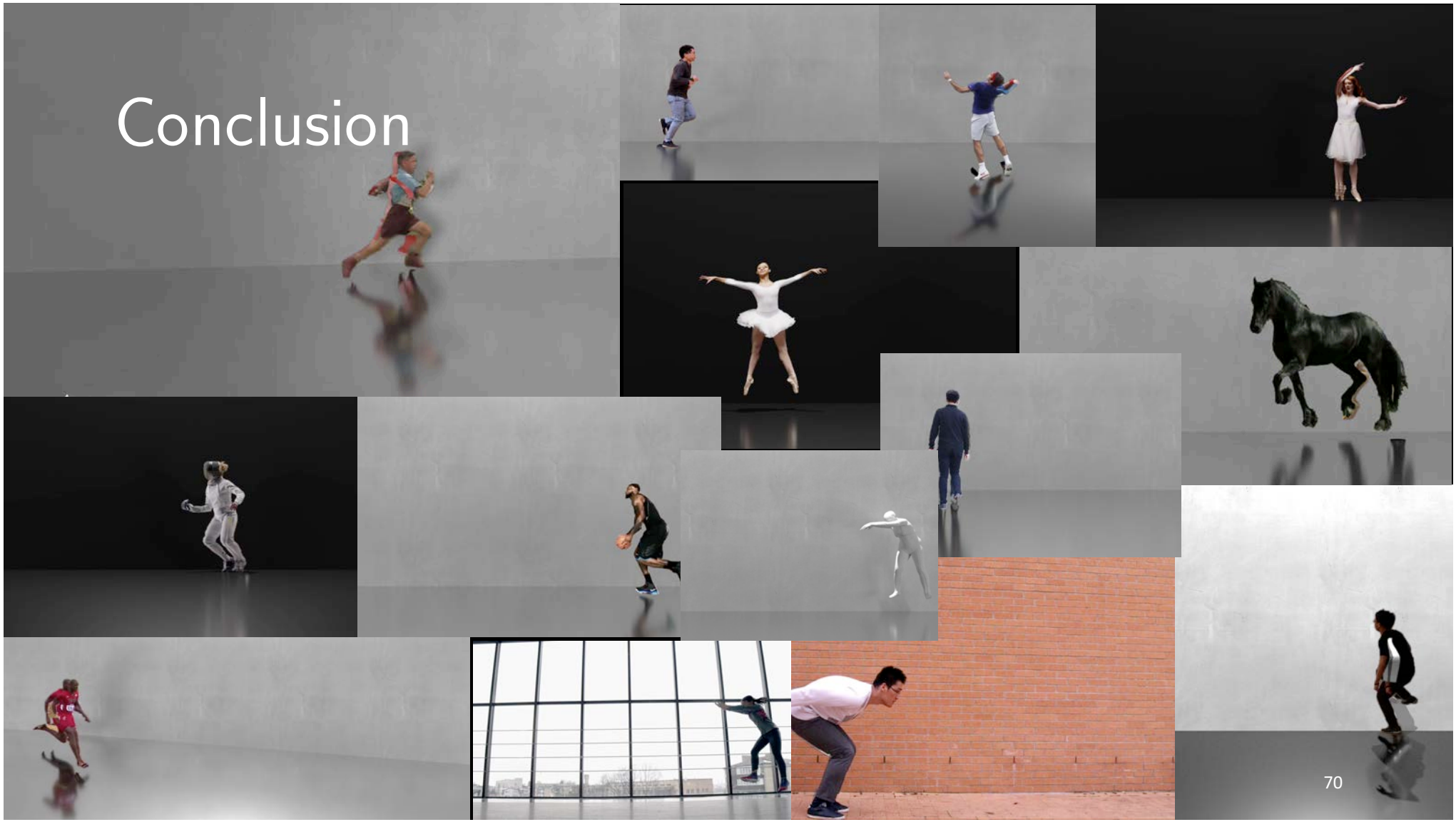
# Limitation: Repeated, Localized Motion





# Conclusion



http://mosculp.csail.mit.edu

Please come to our demo D-12 for more!

Thank you!

Video Courtesy of Tom Buehler (MIT CSAIL)