

MoSculp: Interactive Visualization of Shape and Time



**Xiuming
Zhang¹**



Tali
Dekel^{1,2}



Tianfan
Xue^{1,2}



Andrew
Owens^{1,3}



Qiurui
He^{1,2}



Jiajun
Wu¹



Stefanie
Mueller¹



William T.
Freeman^{1,2}



¹ MIT CSAIL

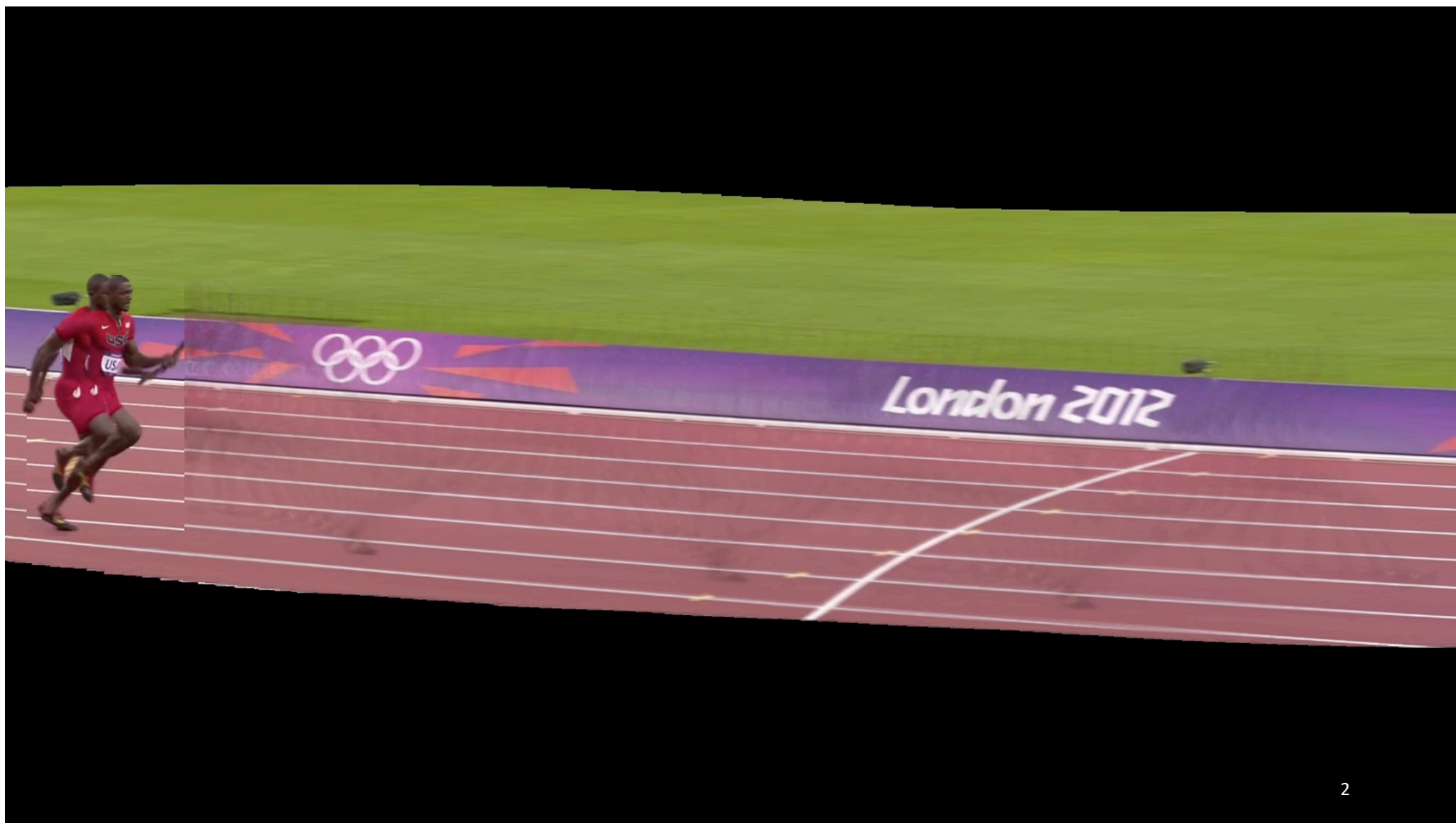


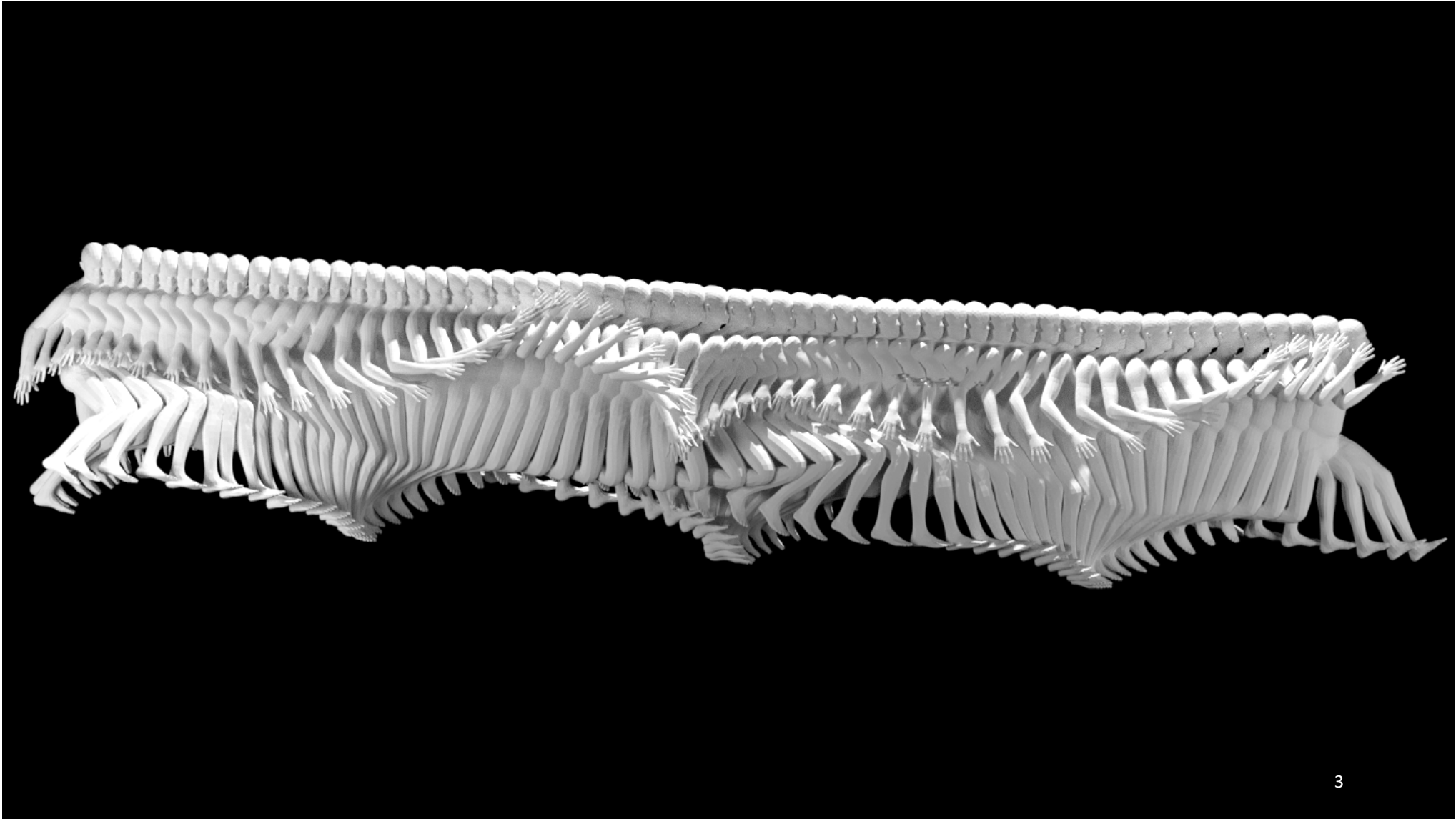
² Google Research



³ UC Berkeley













Video Courtesy of Tom Buehler (MIT CSAIL)

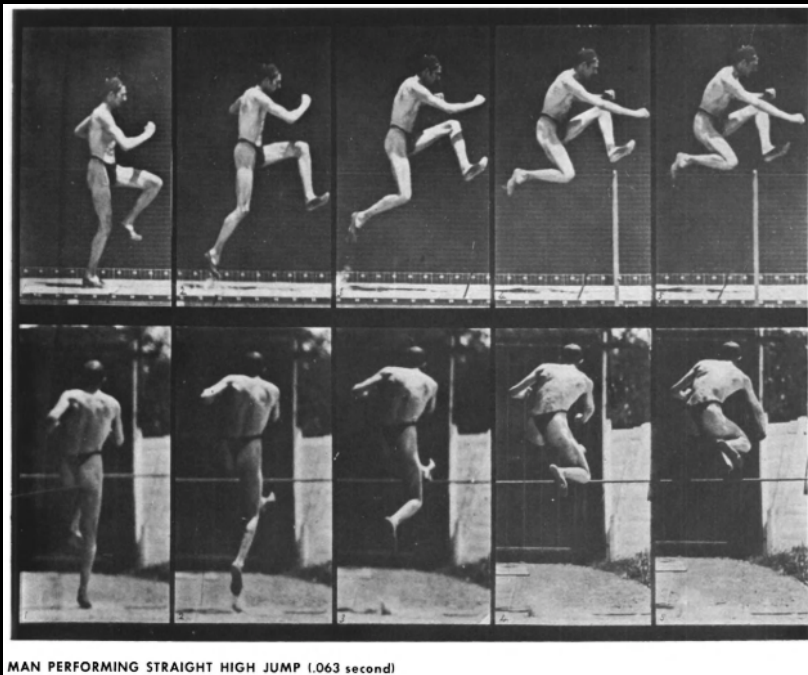
Outline

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

Outline

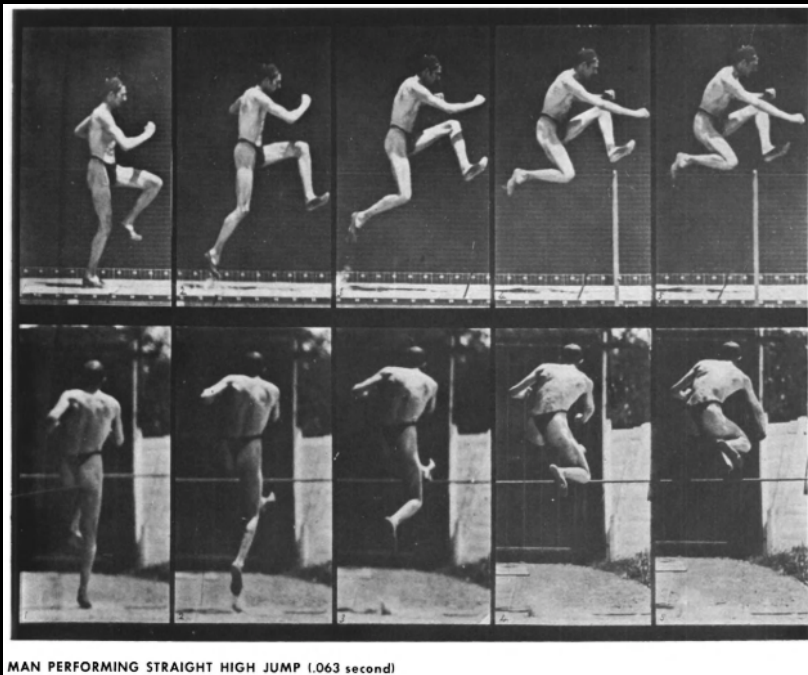
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Motivation



Muybridge, *The Human Figure in Motion*, 1901

Motivation

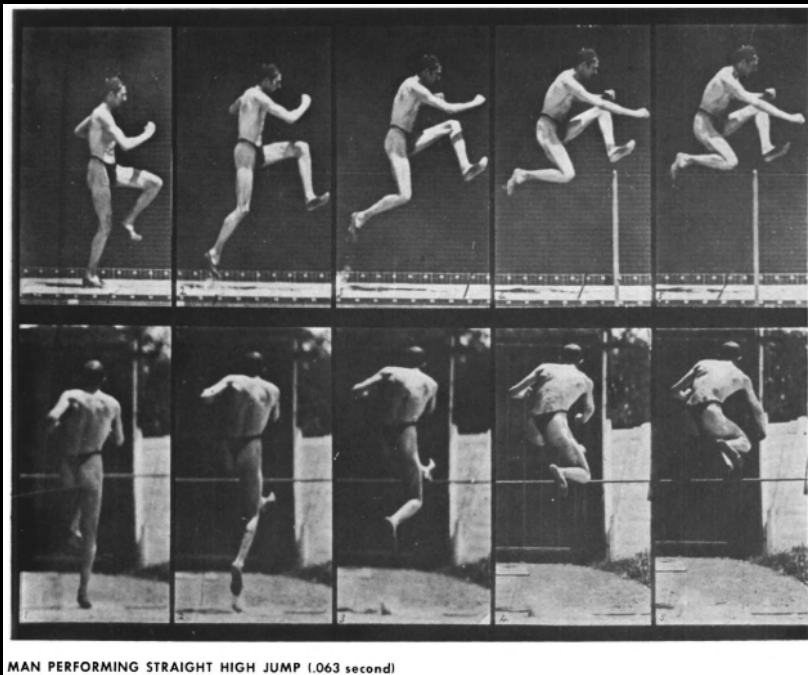


Muybridge, *The Human Figure in Motion*, 1901



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

Outline

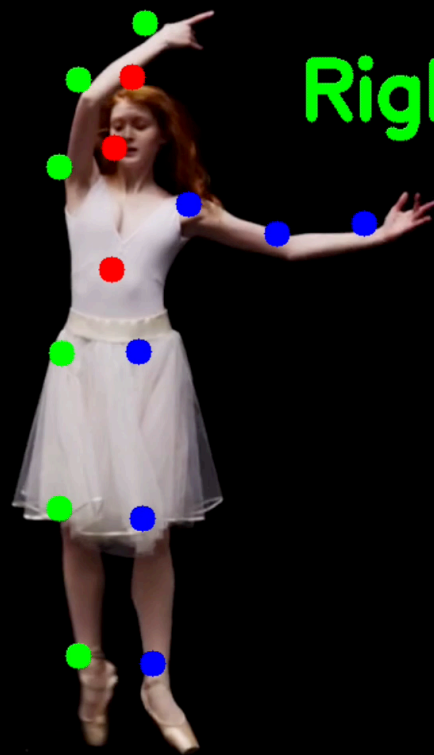
- Related Work
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2D Keypoints

3D Model

Rendering

System Walkthrough



Left
Right

Open...



Frame: 1

Click here if left/right correct

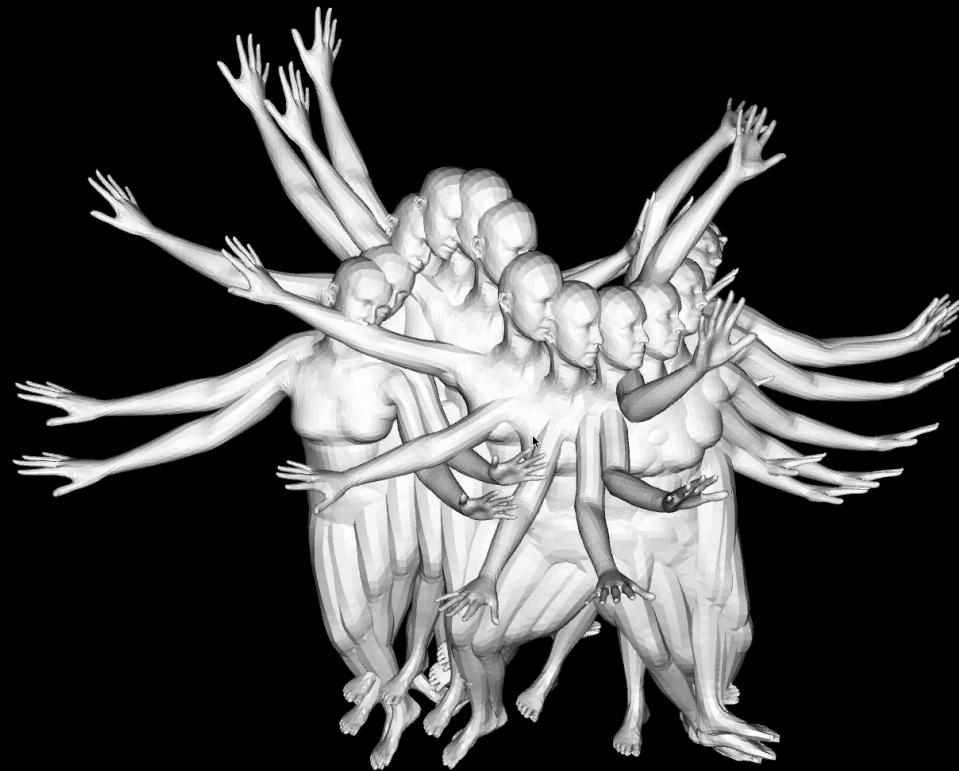
Done Annotating

16

2D Keypoints

3D Model

Rendering



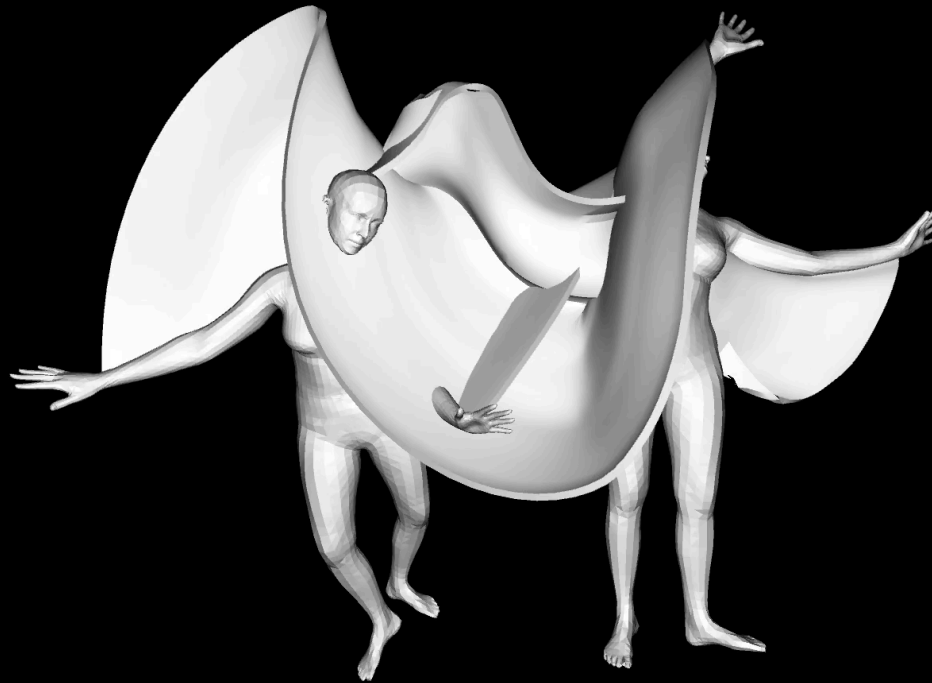
Open...

Mode: Collection of Humans

2D Keypoints

3D Model

Rendering



Open...

Mode: Sculpture

2D Keypoints

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

3D Model



Rendering

2D Keypoints

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

3D Model



Rendering

2D Keypoints

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

3D Model



Rendering

2D Keypoints

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

3D Model



Rendering

2D Keypoints

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

3D Model



Rendering

2D Keypoints

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

3D Model

Rendering



2D Keypoints

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

3D Model

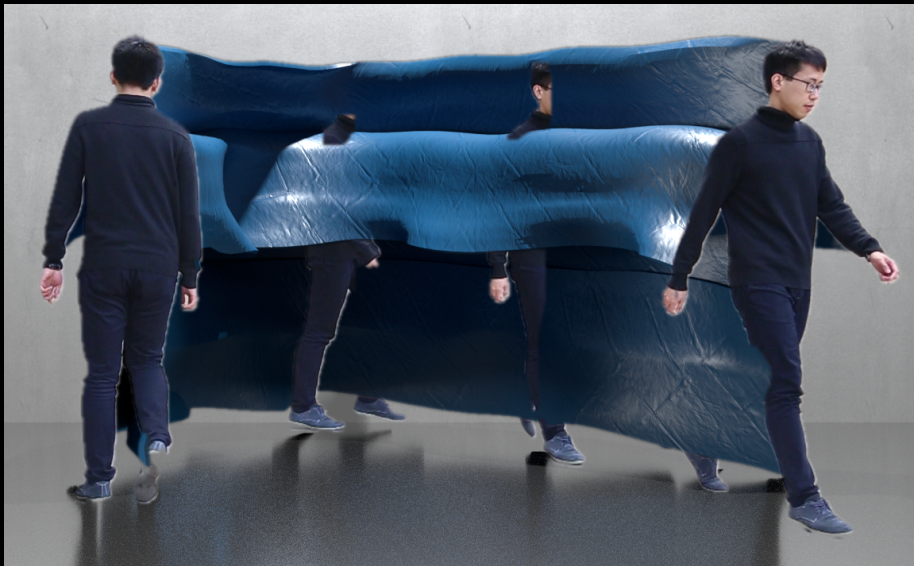


Rendering

Outline

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

User Studies: Design Choices



With Floor Reflections
Preferred by 82%



Without

User Studies: Efficacy in Conveying Motion

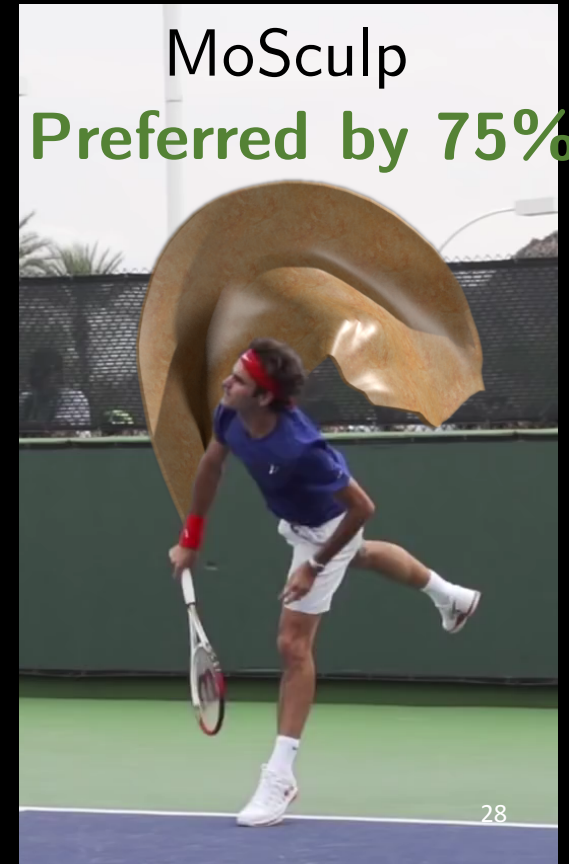
Baseline 1
(Stroboscopic)



Baseline 2
(Shape-Time)

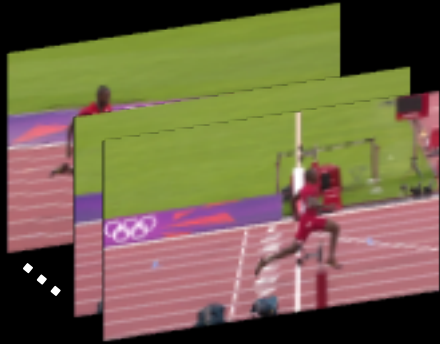


MoSculp
Preferred by 75%



Outline

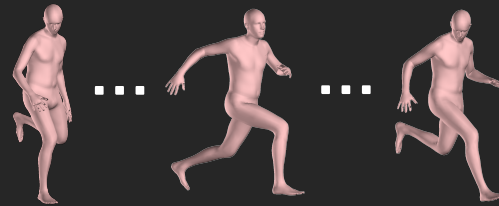
- Related Work
- System Walkthrough
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- Results
- Conclusion



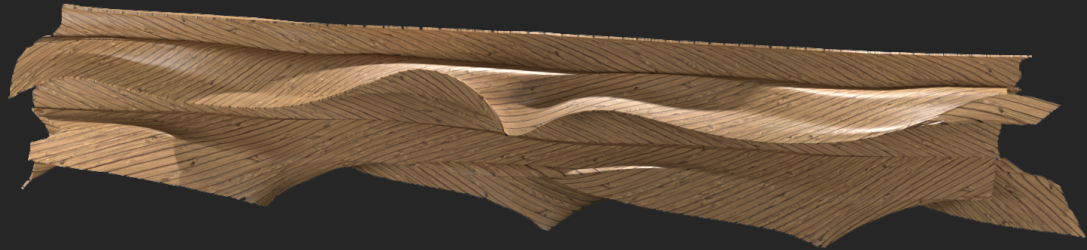
Input Video



3D Shape & Pose Estimation



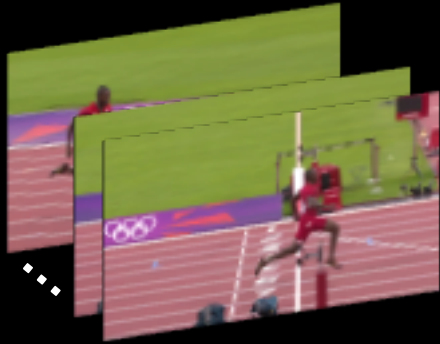
Motion Sculpture Generation



Depth-Preserving Compositing



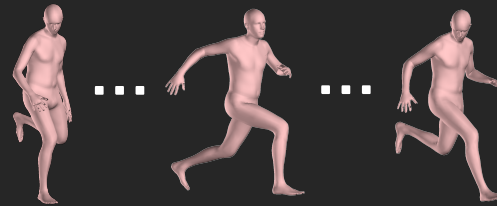
Overview



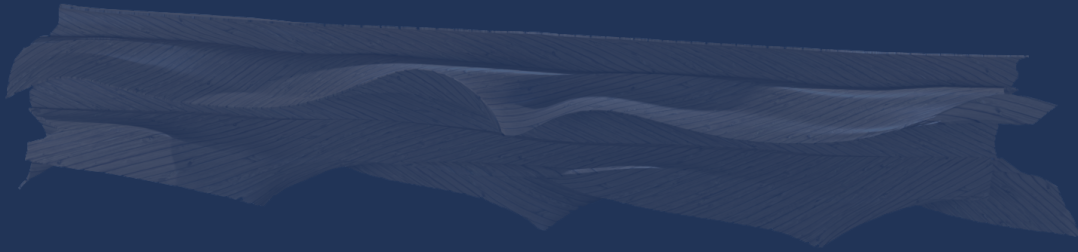
Input Video



3D Shape & Pose Estimation



Motion Sculpture Generation



Depth-Preserving Compositing




Overview

Approach: 2D Keypoint Detection

Time: t

2D Keypoints 3D Model Rendering



Left
Right

[Cao et al.,
CVPR '17]

Open... Frame: 43 Left/right correct Done Annotating

The image shows a person in a handstand position inside a room with large windows. The person's body is marked with 2D keypoints: blue dots for the head, shoulders, hips, and ankles; red dots for the elbows and knees; and green dots for the wrists and ankles. The keypoints are used to detect the person's pose. The interface includes a 'Time: t ' label, a '2D Keypoints' tab, a '3D Model' tab, and a 'Rendering' tab. A 'Left/Right' label is present in the top right corner of the video frame. At the bottom, there is a navigation bar with buttons for 'Open...', 'Frame: 43', 'Left/right correct', and 'Done Annotating'.

Approach: 2D Keypoint Detection

2D Keypoints

3D Model

Rendering

Time: $t + 1$



[Cao et al.,
CVPR '17]

Open...



Frame: 44

Click here if left/right correct

Done Annotating

33

2D Keypoints

3D Model

Rendering

Hidden
Markov
Model



Open...



Frame: 37

Smoothed, Corrected Keypoints

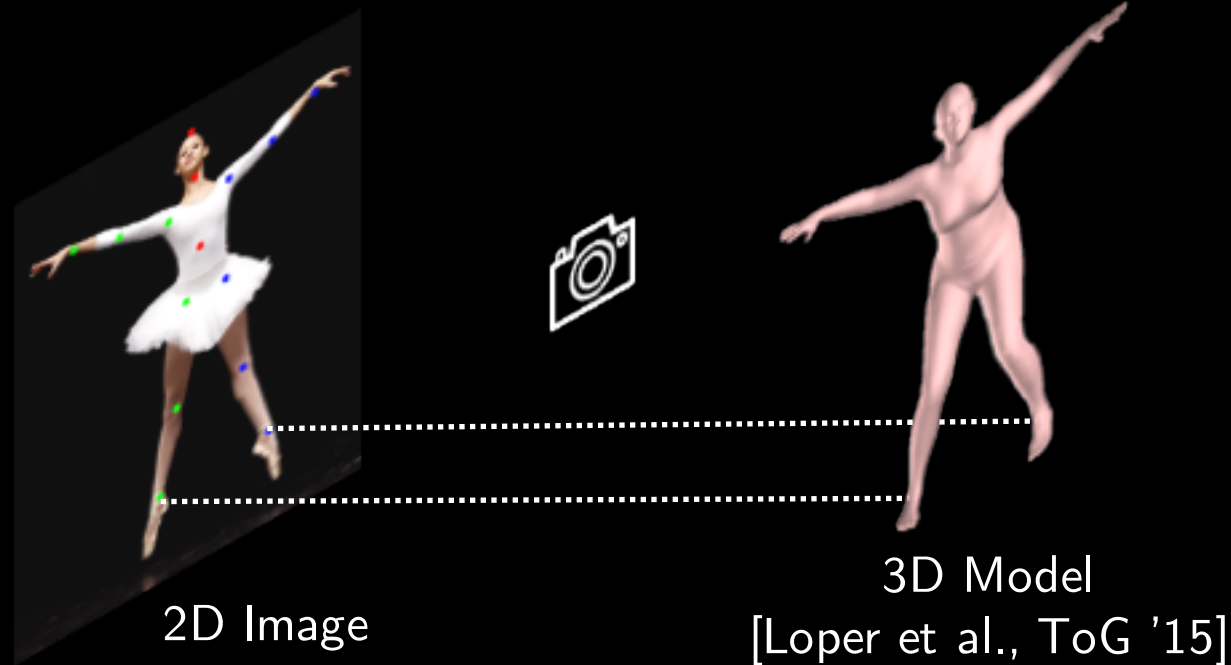
34

Approach: 3D Estimation

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

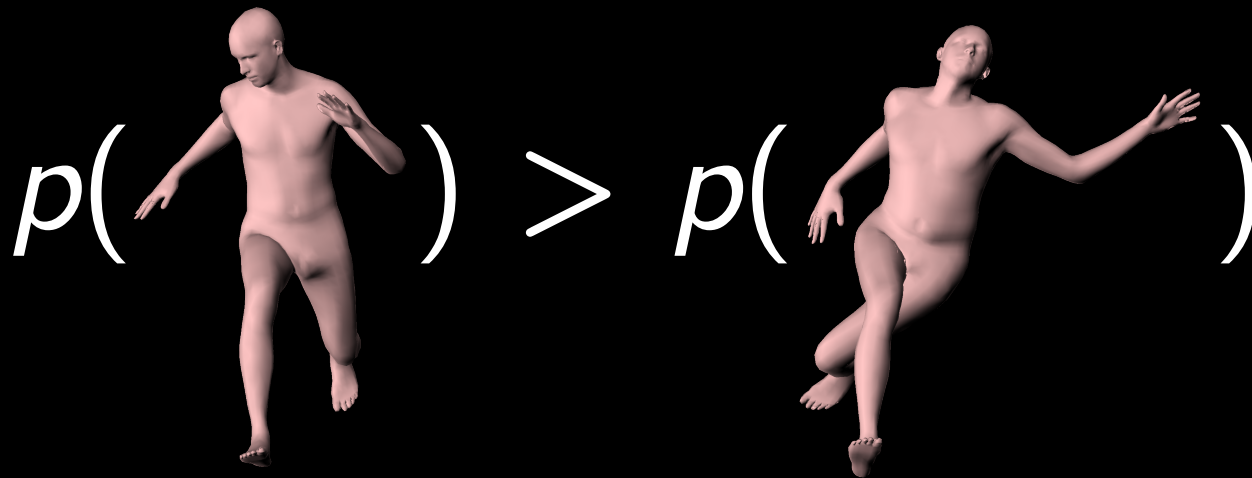
Approach: 3D Estimation

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



Approach: 3D Estimation

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



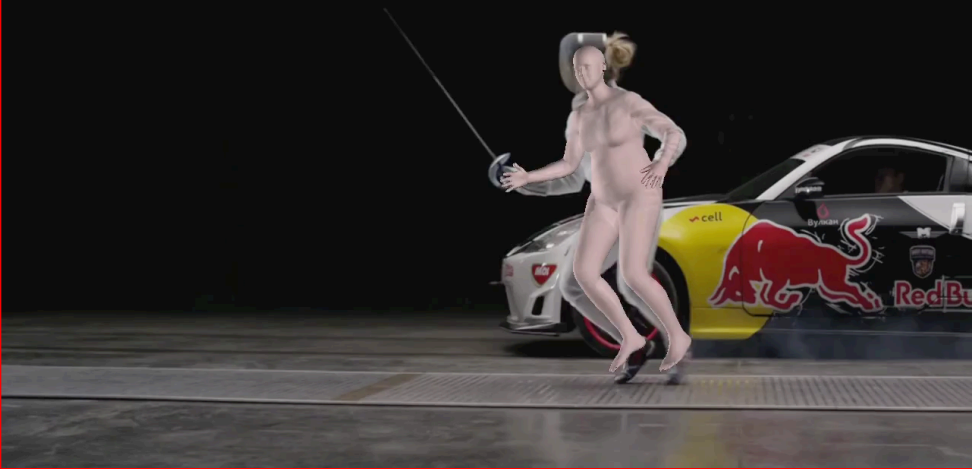
Approach: 3D Estimation

- 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

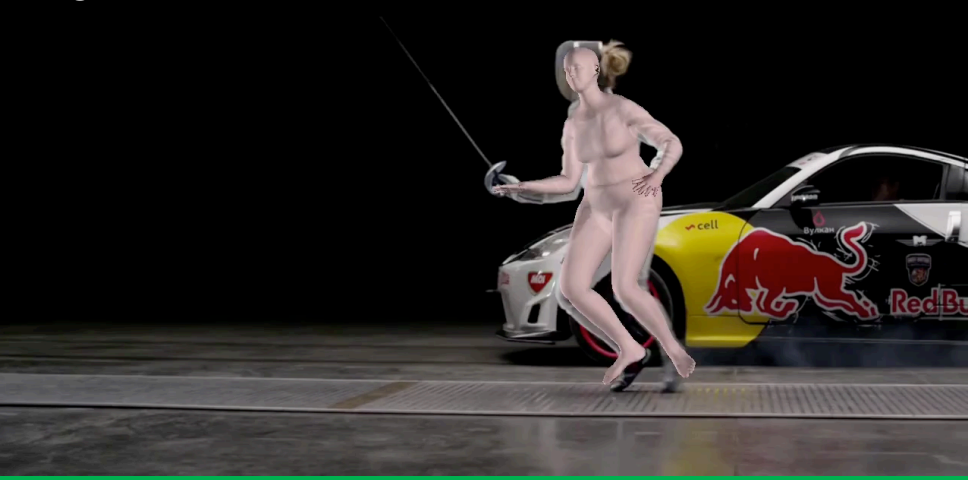


Per-Frame
Optimization
[Bogo et al.,
ECCV '16]

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

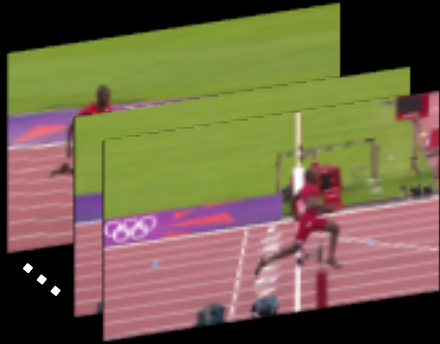
Original Camera View



Novel View



Our Joint
Optimization



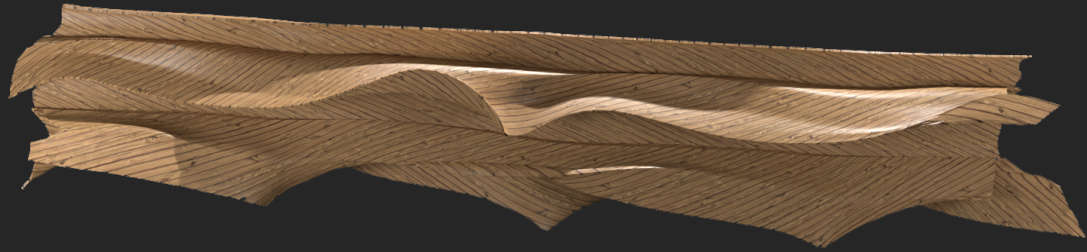
Input Video



3D Shape & Pose Estimation



Motion Sculpture Generation

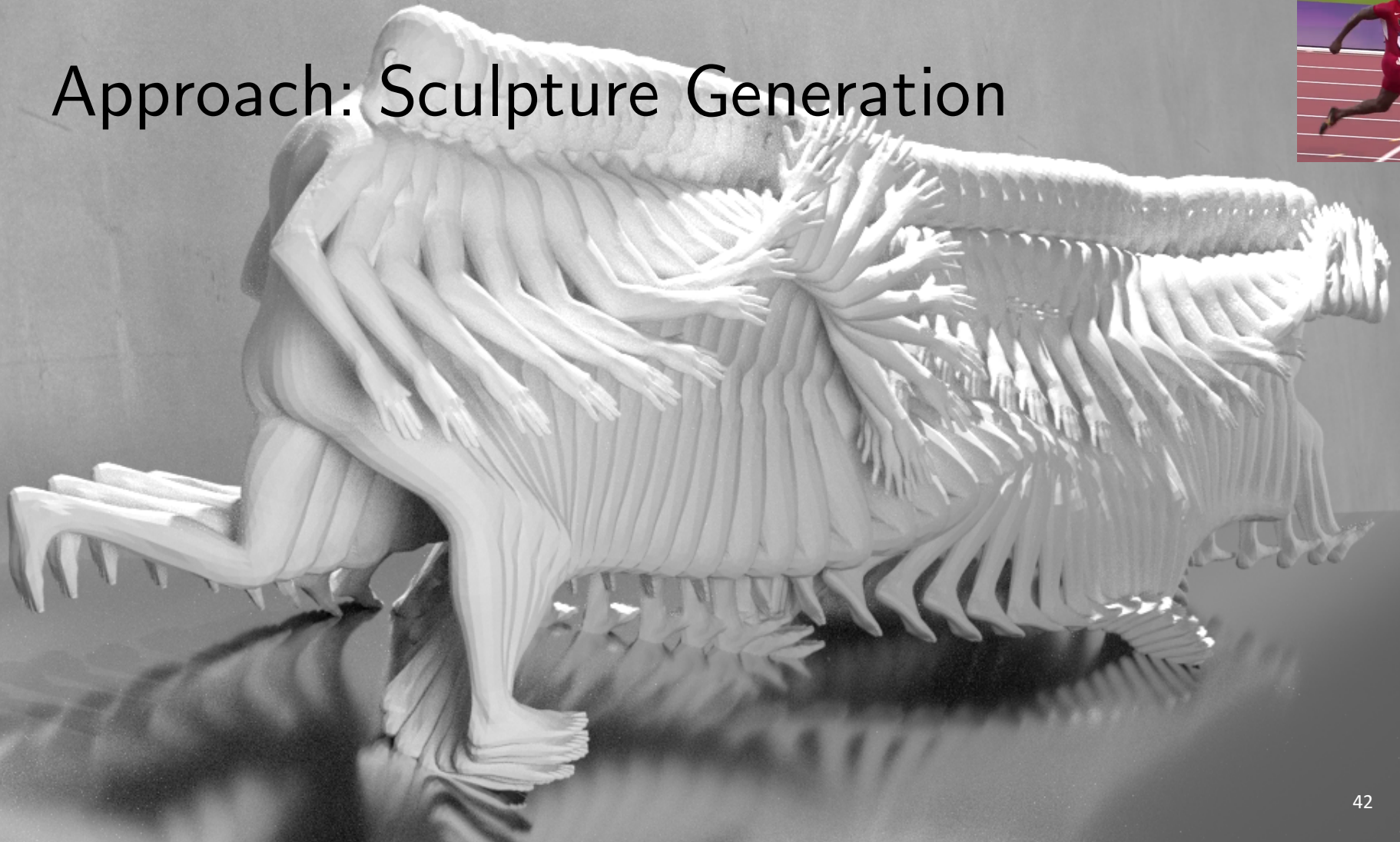


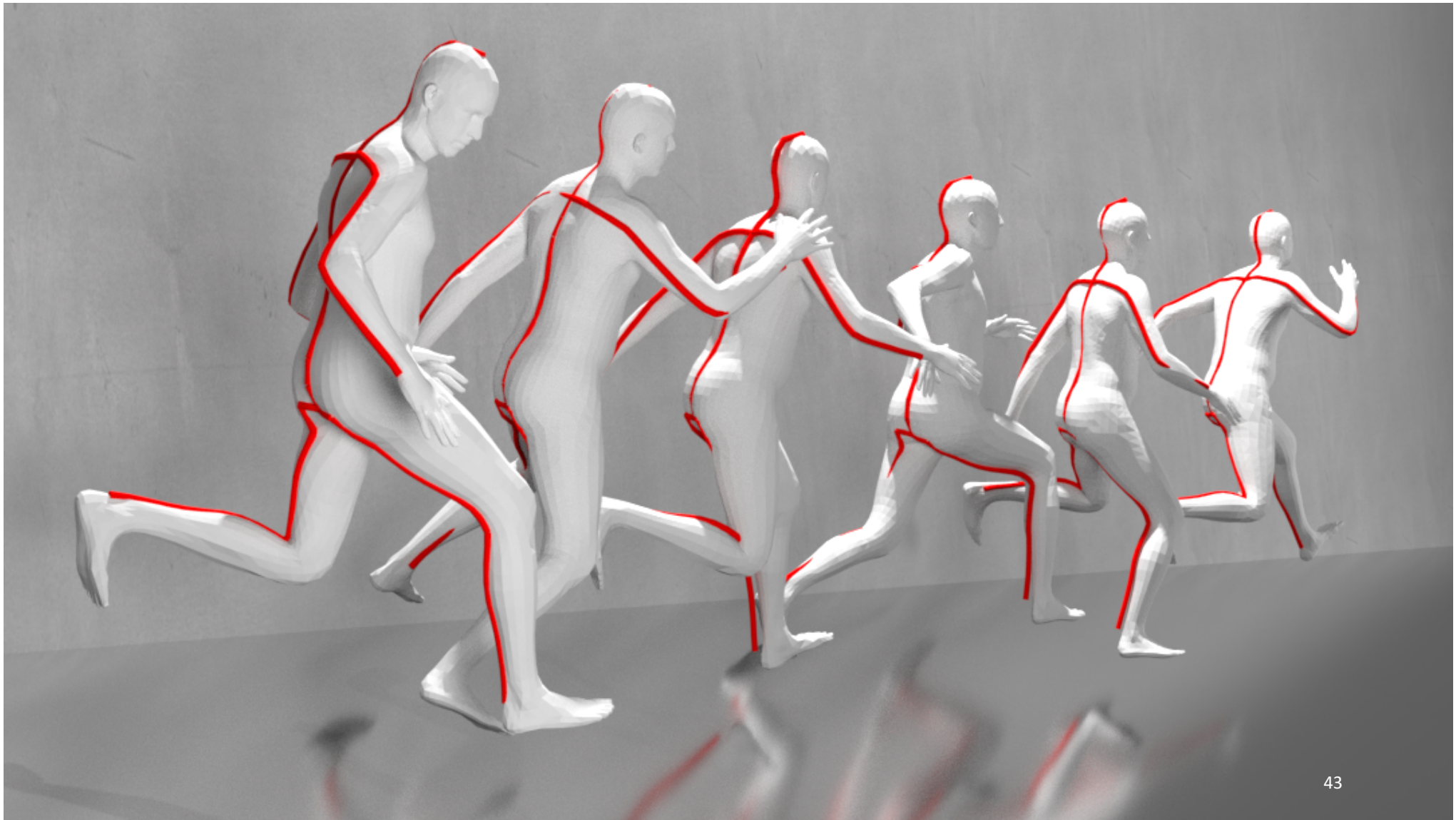
Depth-Preserving Compositing

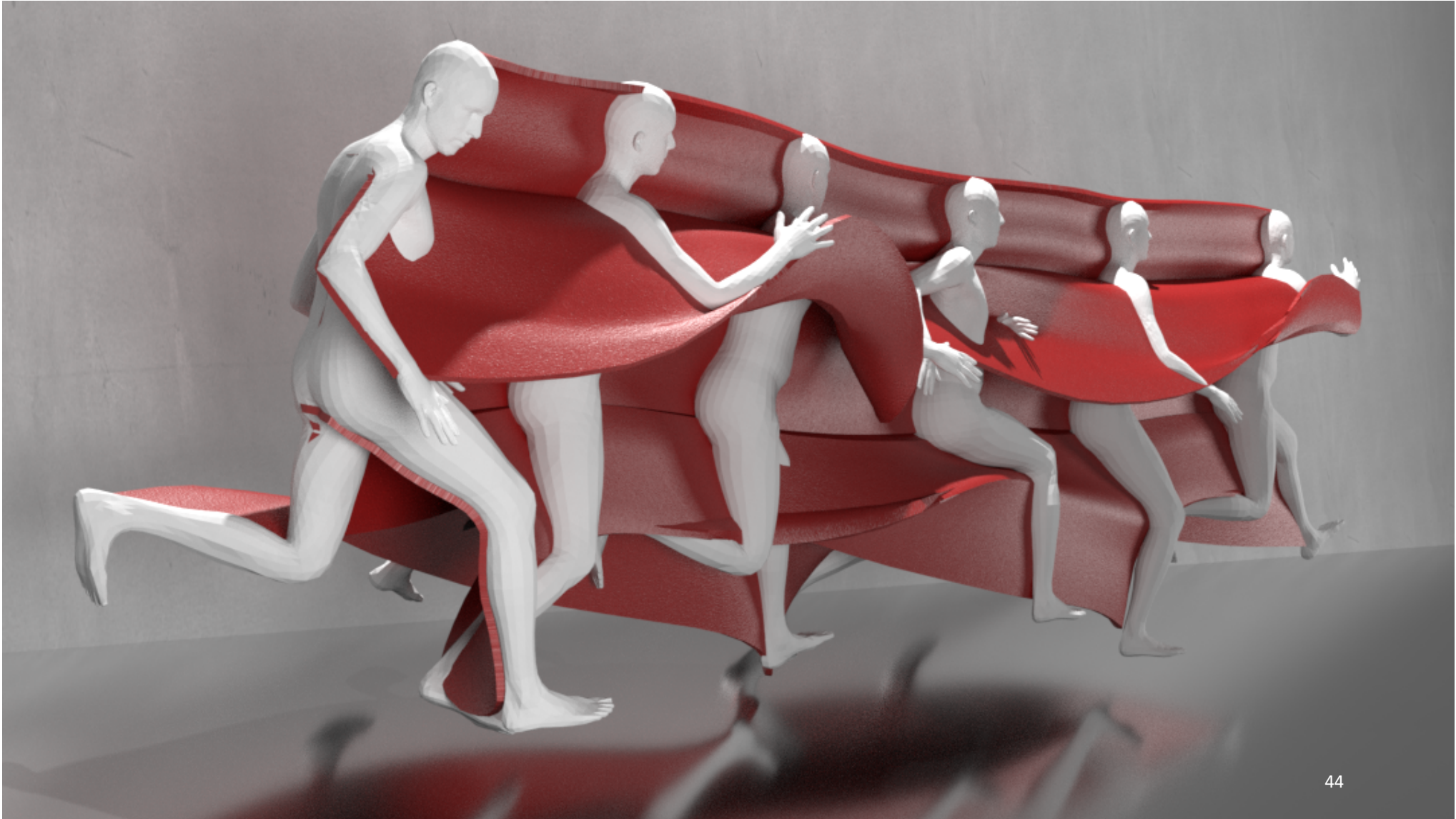


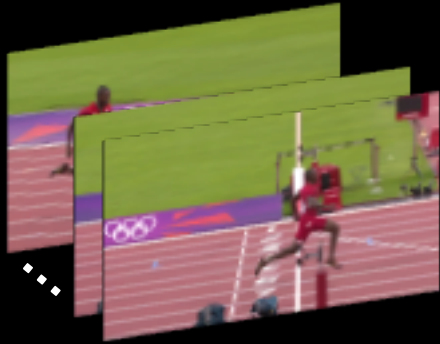
Overview

Approach: Sculpture Generation









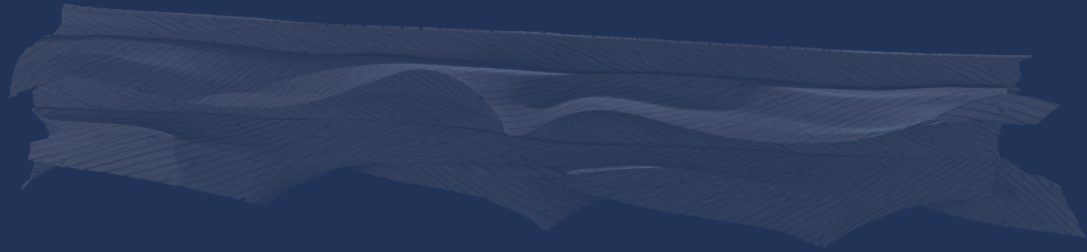
Input Video



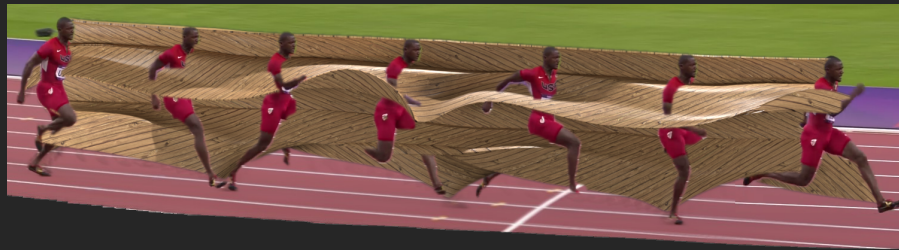
3D Shape & Pose Estimation



Motion Sculpture Generation



Depth-Preserving Compositing



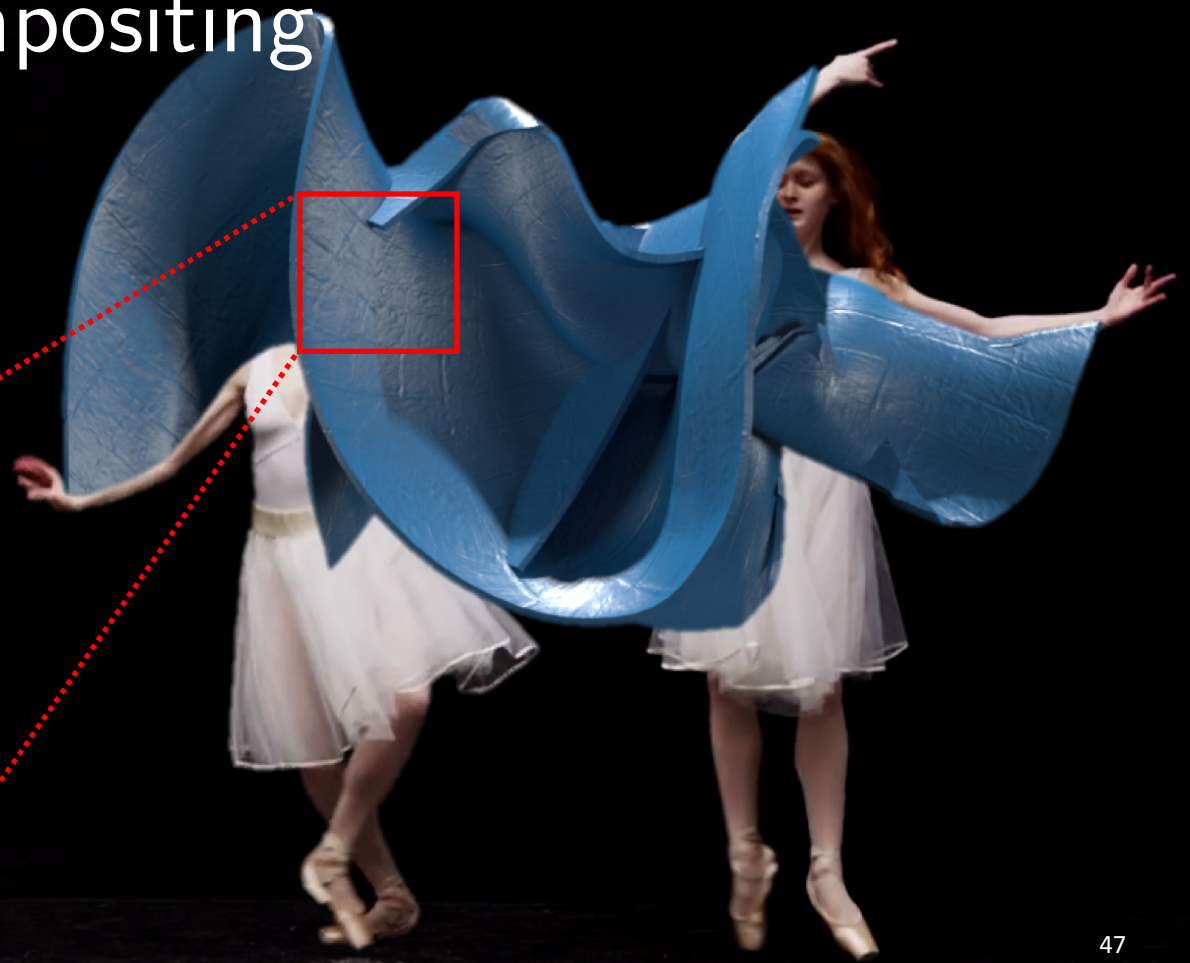
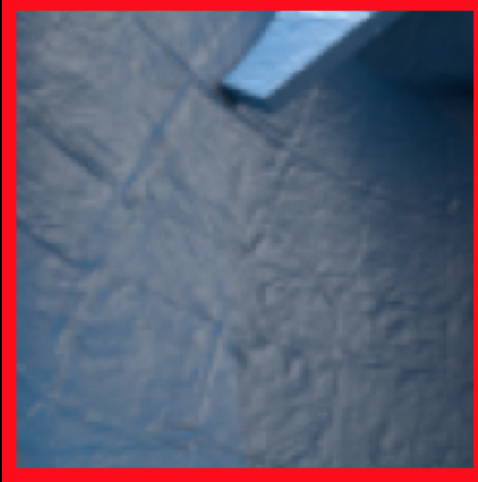
Overview

Approach: Compositing

- Key challenge: how to “put together” 3D sculpture and 2D video?

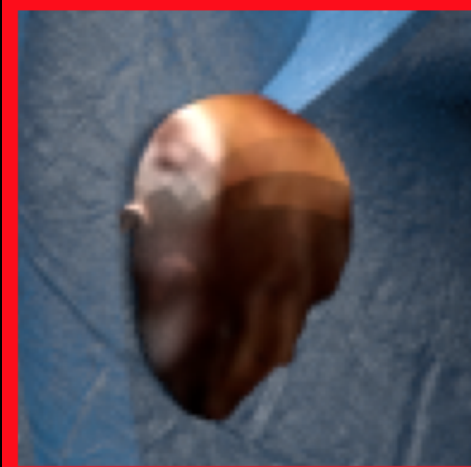
Approach: Compositing

- Naive
Compositing:
sculpture on top of
the frames



Approach: Compositing

- Full 3D
Rendering:
texturing the 3D
models



Skirt Not
Covered by
3D Model

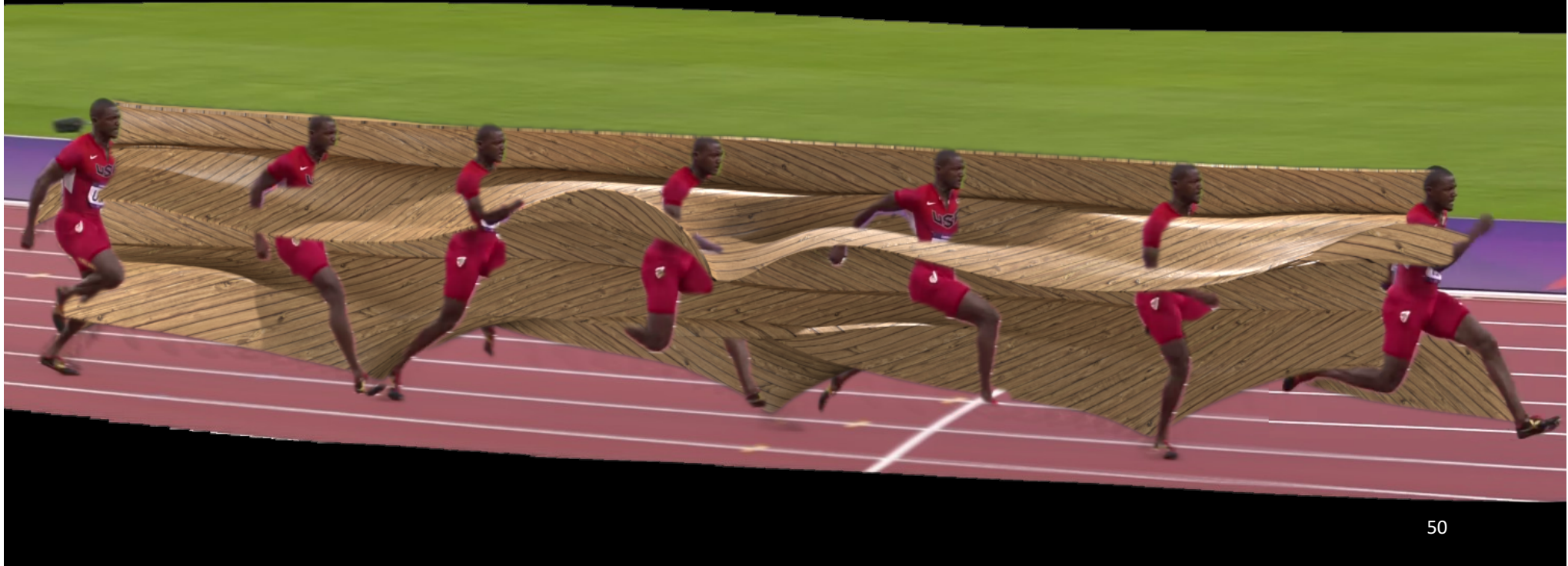
Approach: Compositing

- **Solution**: depth-preserving composite



Approach: Compositing

- Solution: depth-preserving composite



Approach: Before Refinement



Approach: After Refinement



Outline

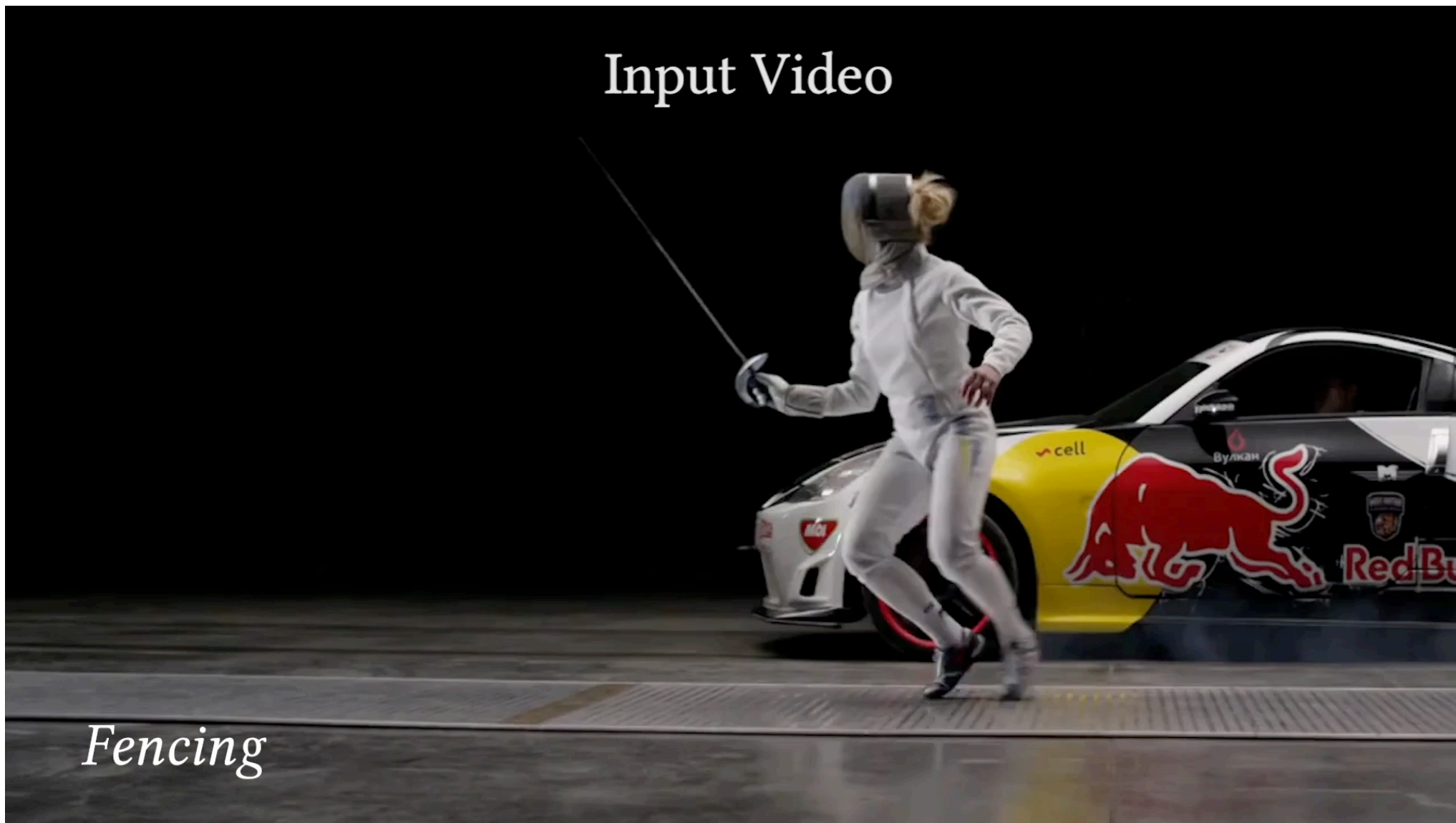
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Input Video

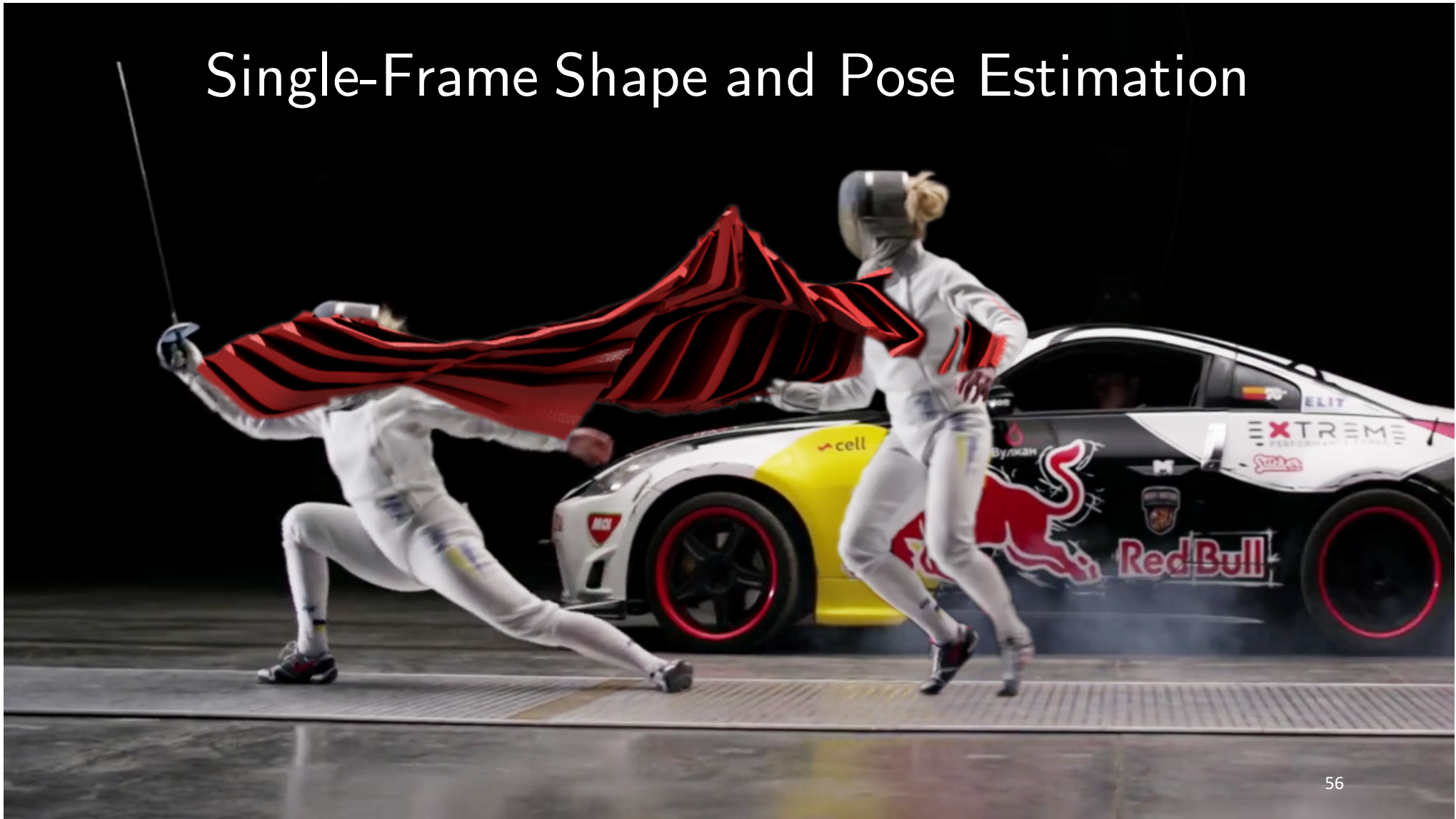
Federer

Input Video

Fencing



Single-Frame Shape and Pose Estimation



Our Joint Estimation



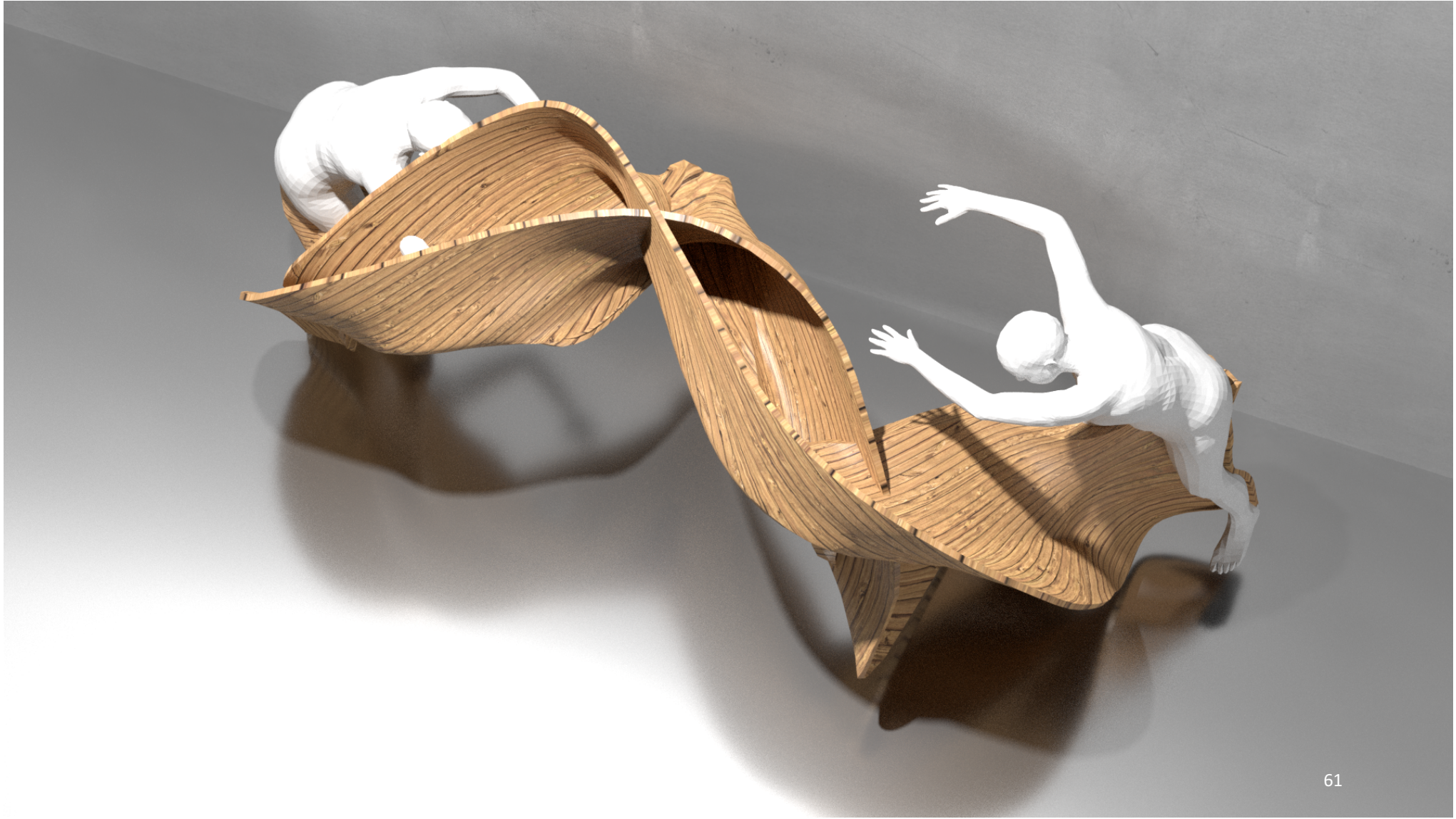
Input Video

Jumping



Input Video

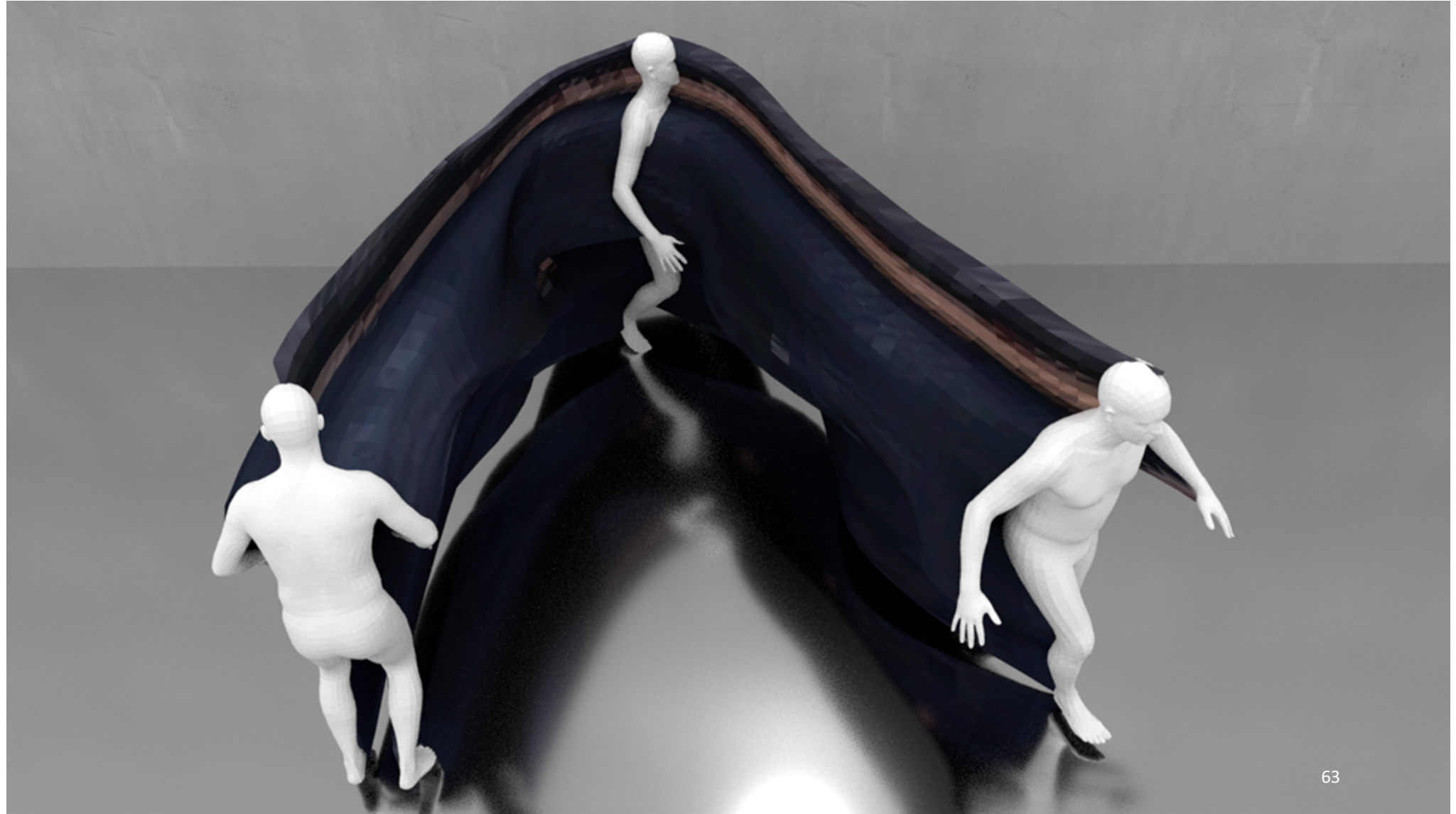
Cartwheel



Texture
from
Original
Frames

Input Video

U-Walking



Input Video

Ballet

Input Video

Handling a
Moving Camera

Dunking

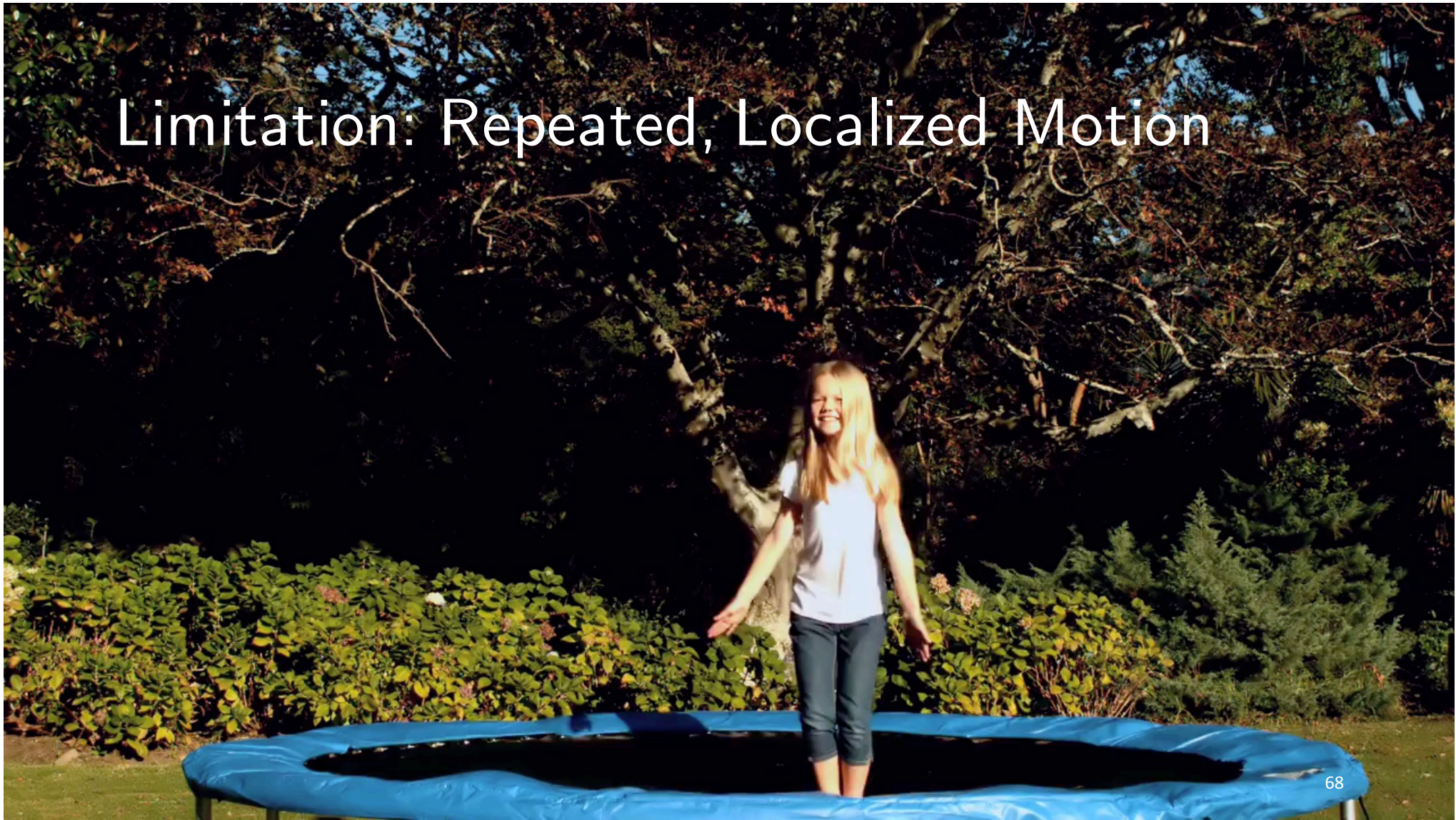
Input Video

Run, Forrest, Run!

Outline

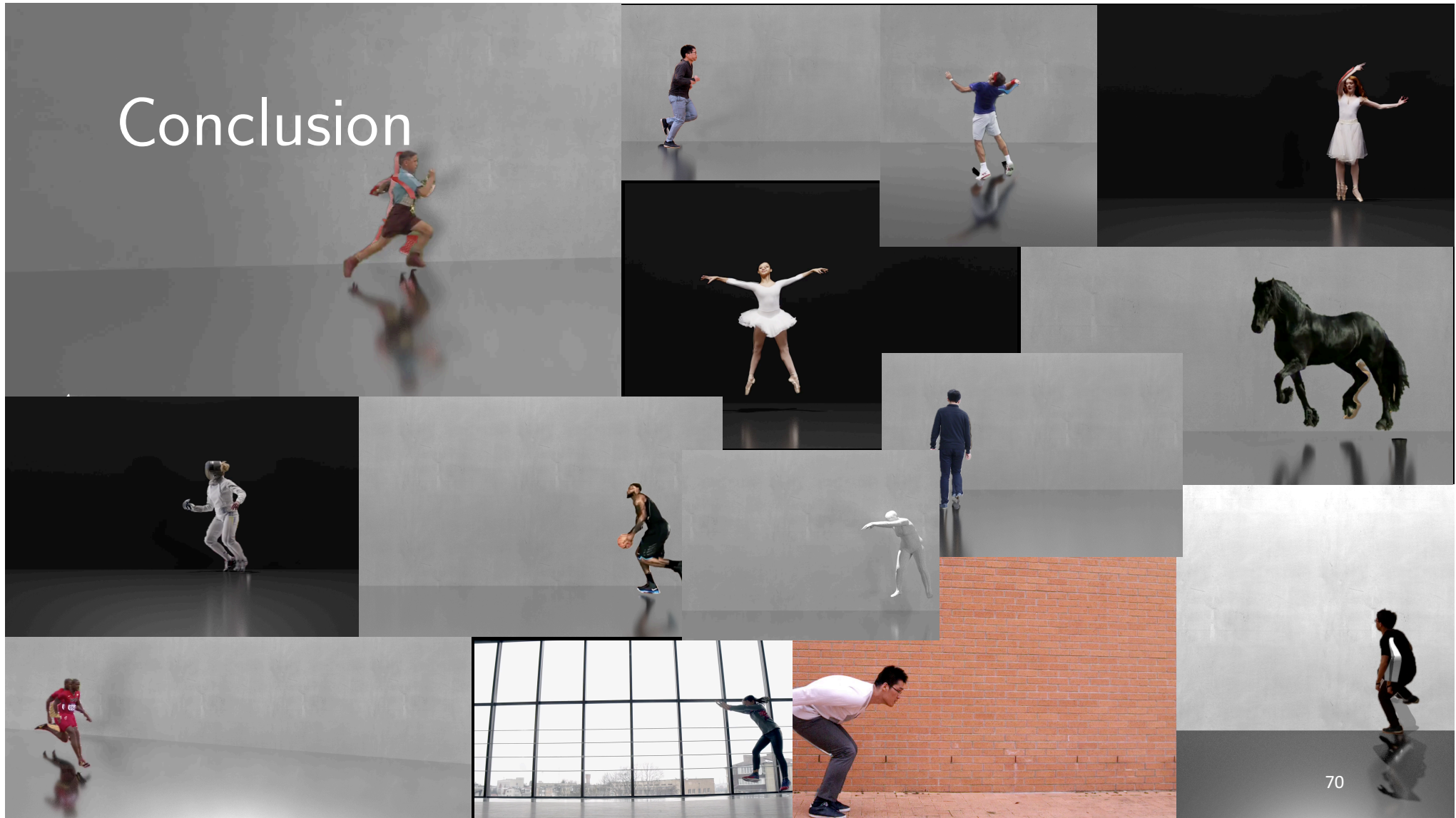
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Limitation: Repeated, Localized Motion





Conclusion



<http://mosculp.csail.mit.edu>

Please come to our demo D-12 for more!



Thank you!

Video Courtesy of Tom Buehler (MIT CSAIL)

