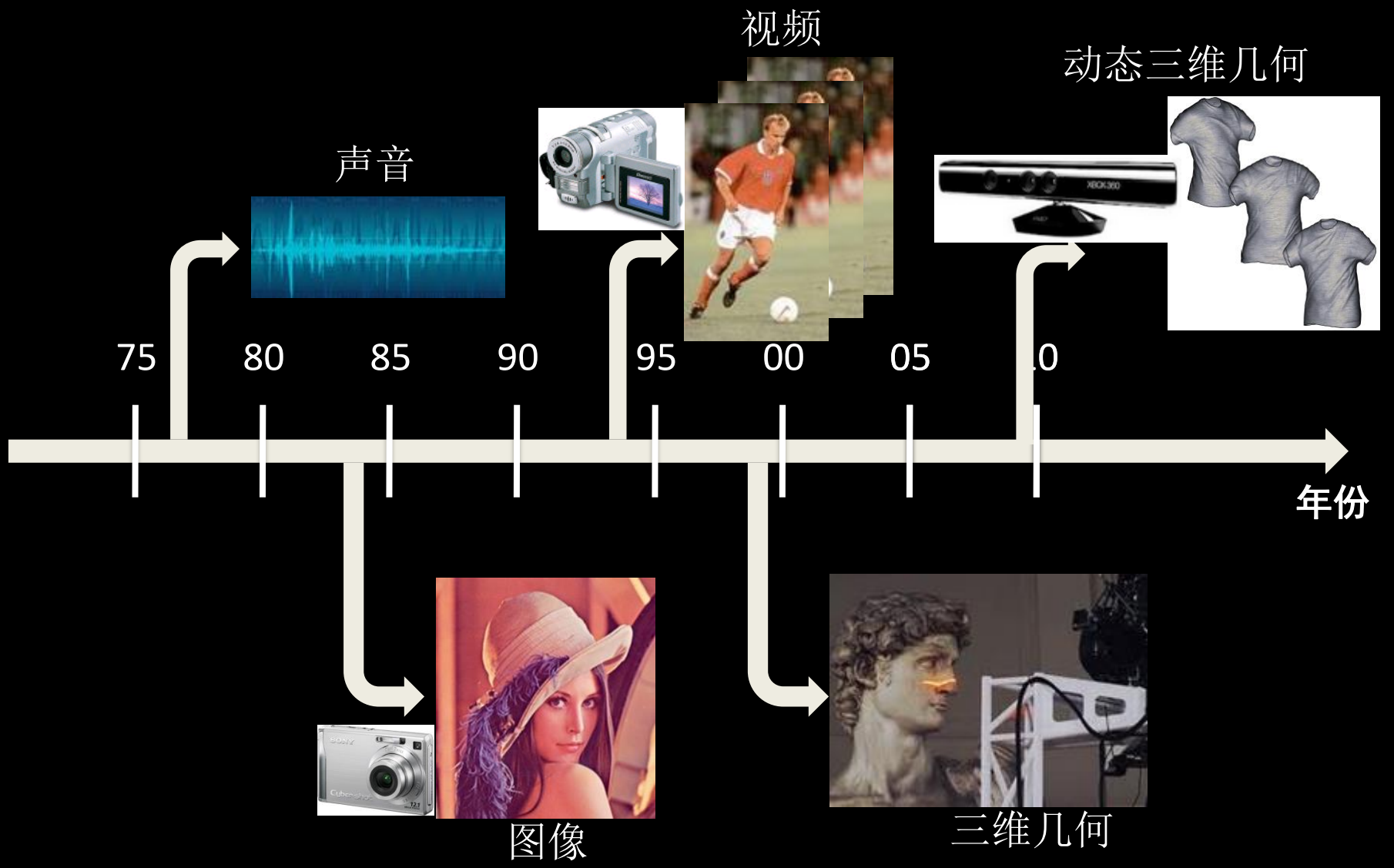
几何引导的图像处理及生成

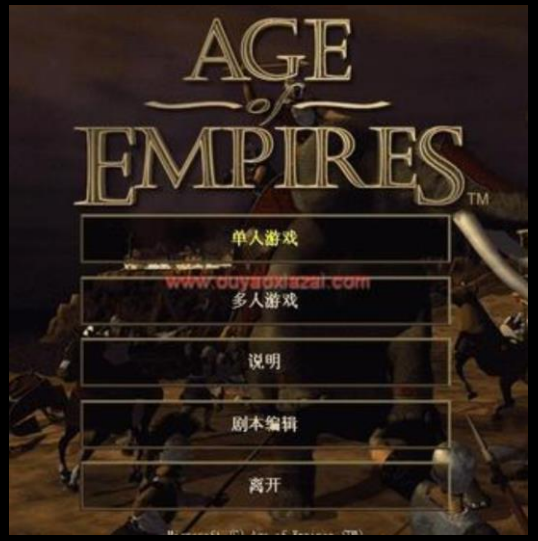
刘利刚

中国科学技术大学

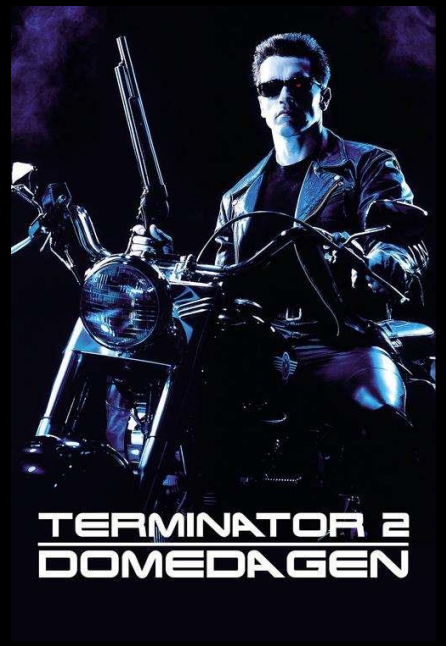
可视媒体与可视计算



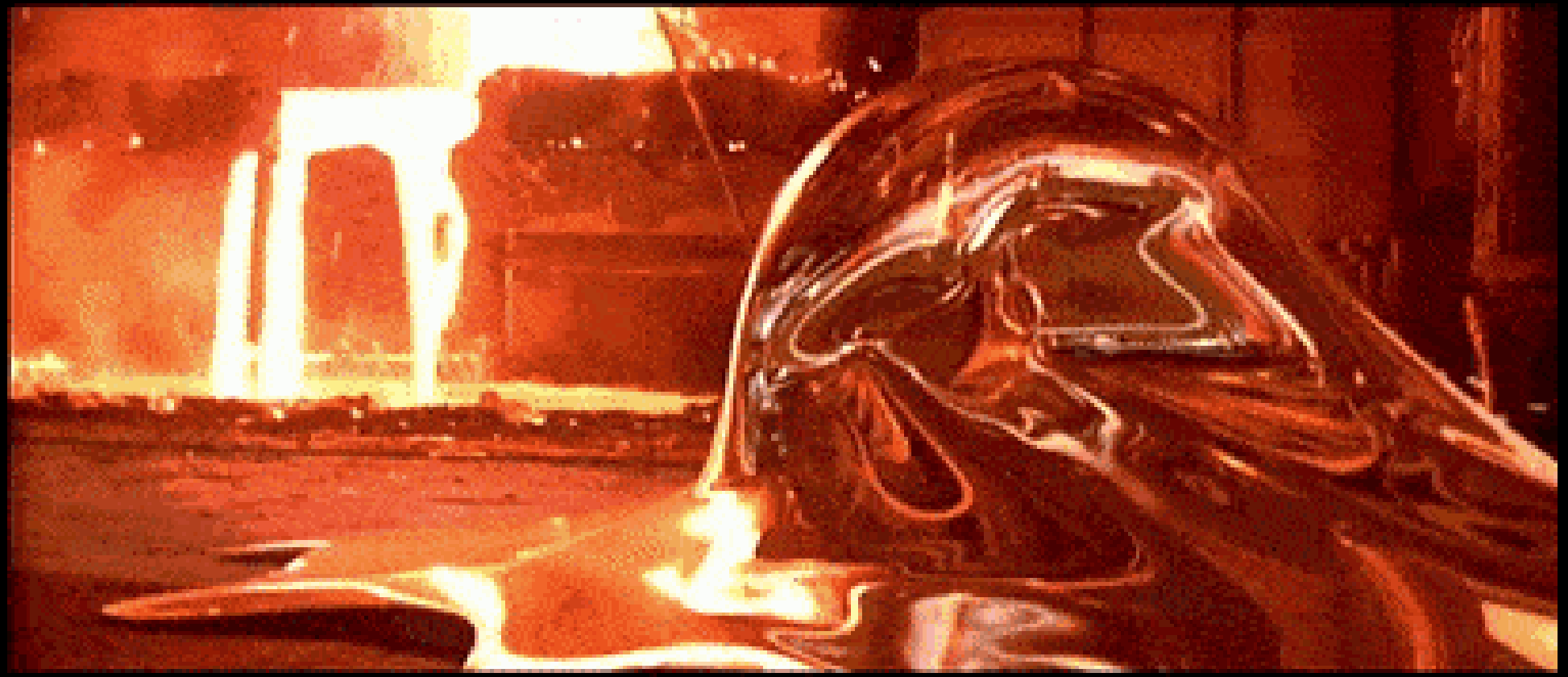
计算机图形学：缘起



游戏：《帝国时代》



电影：《终结者2》

















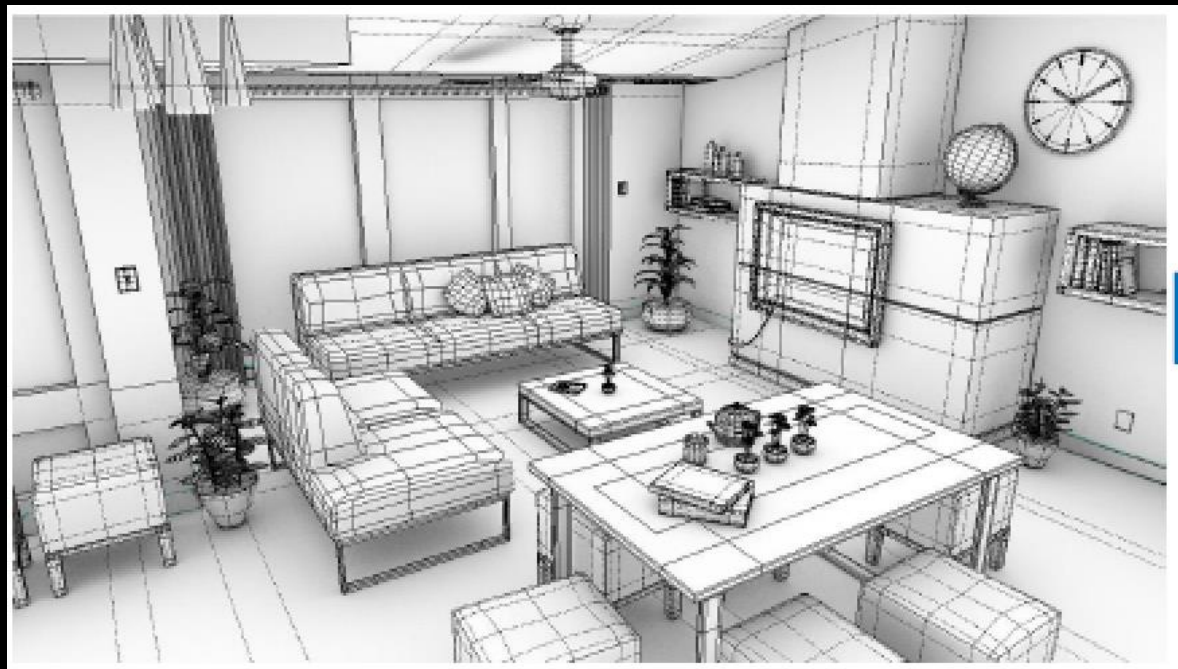

哪吒
之魔童降世
2019 暑期上映

图形计算：仿真计算创造新世界

- 渲染计算：仿色彩之真，再造世界之“彩”-- 求美
- 模拟计算：仿运动之真，再造世界之“动”-- 求真
- 建模计算：仿几何之真，再造世界之“形”-- 求精

工业
建模
设计
特效
影视
动画
游戏
广告
…

图形计算1：渲染—仿色彩之真



输入：几何、纹理、材质、光照、视点等

输出：类照片的图像

求解积分方程：

$$L_o(p,\omega_o) = L_e(p,\omega_o) + \int_{\Omega^+} L_i(p,\omega_i) f_r(p,\omega_i,\omega_o)(n\cdot\omega_i)\,\mathrm{d}\omega_i$$

真实感渲染：照片级的色彩计算

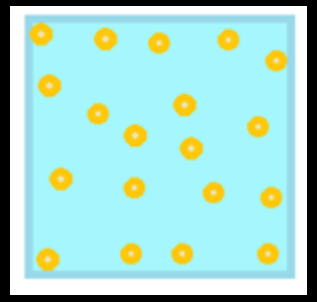
(a)

(b)

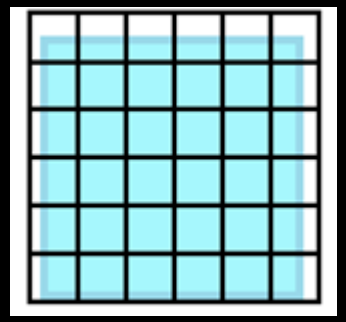
(c)

(d)

图形计算2： 动画—仿运动之真

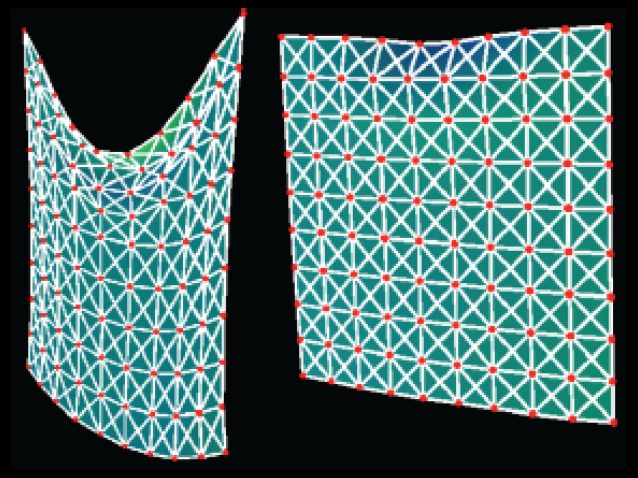


拉格朗日视角
（粒子采样）



欧拉视角
（网格格点采样）

$$\rho(\mathbf{u}_t + \mathbf{u}\cdot\nabla\mathbf{u}) = -\nabla p + \mu\Delta\mathbf{u} + \mathbf{f},$$
$$\nabla\cdot\mathbf{u} = 0,$$



$$f_p = k_d\left(\frac{v_q - v_p}{r}\cdot\frac{x_q - x_p}{\|x_q - x_p\|}\right)\frac{x_q - x_p}{\|x_q - x_p\|}$$

求解微分方程：

刚体：动力学方程

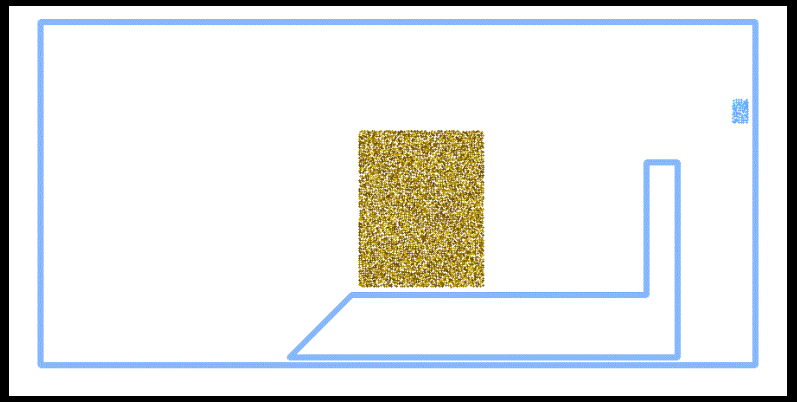
$$M\ddot{x} + B\dot{x} + Kx = 0$$

柔体：本构方程

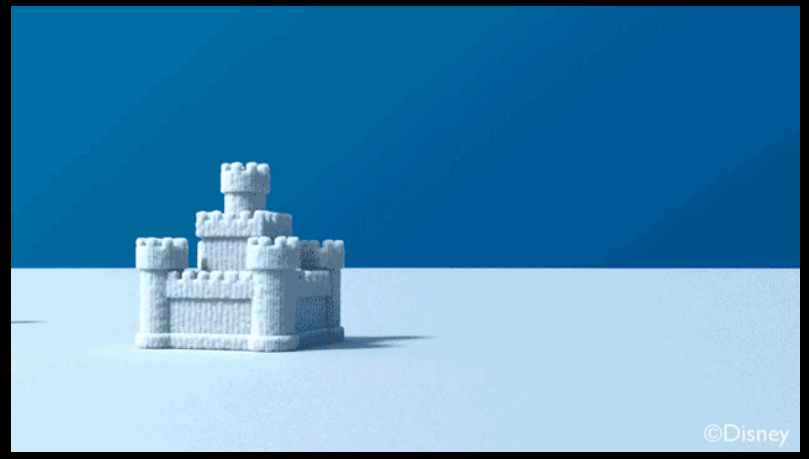
$$\sigma = f(\varepsilon)$$

流体：Navier-Stokes方程

$$\rho(\mathbf{u}_t + \mathbf{u}\cdot\nabla\mathbf{u}) = -\nabla p + \mu\Delta\mathbf{u} + \mathbf{f},$$
$$\nabla\cdot\mathbf{u} = 0,$$



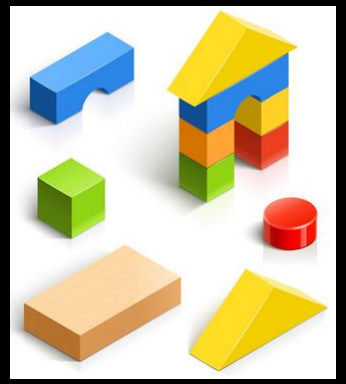
真实感模拟：物理级的运动计算

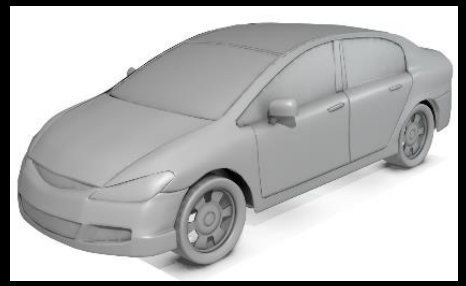


《冰雪奇缘》

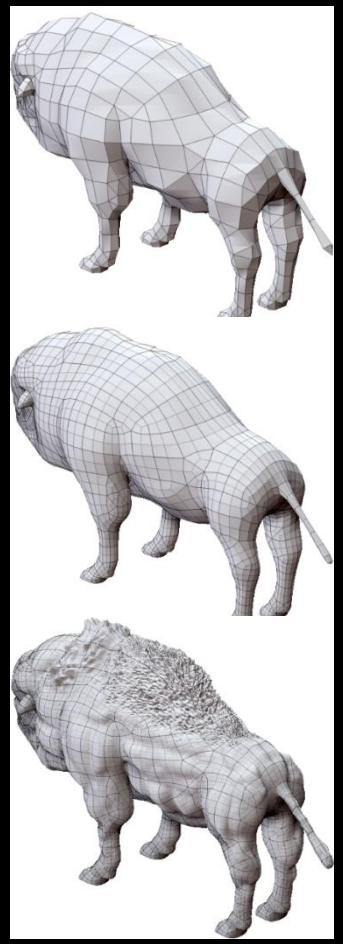
《海洋奇缘》

图形计算3：建模—仿几何之真





几何外形



几何细节

几何微观

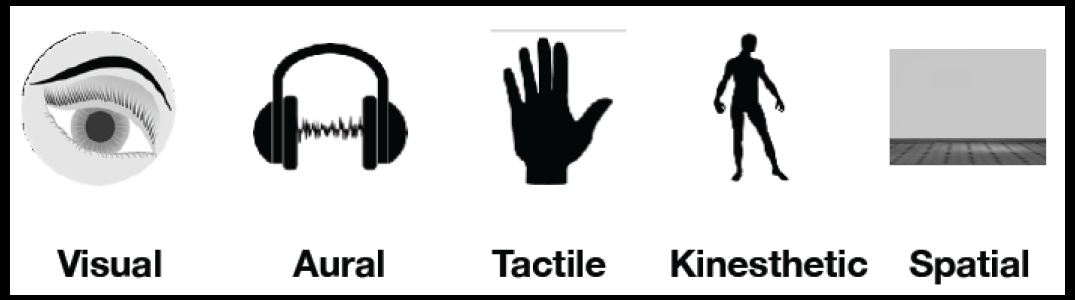
求解优化方程

Turing Award 2020 （图灵奖）

创造逼真世界的贡献

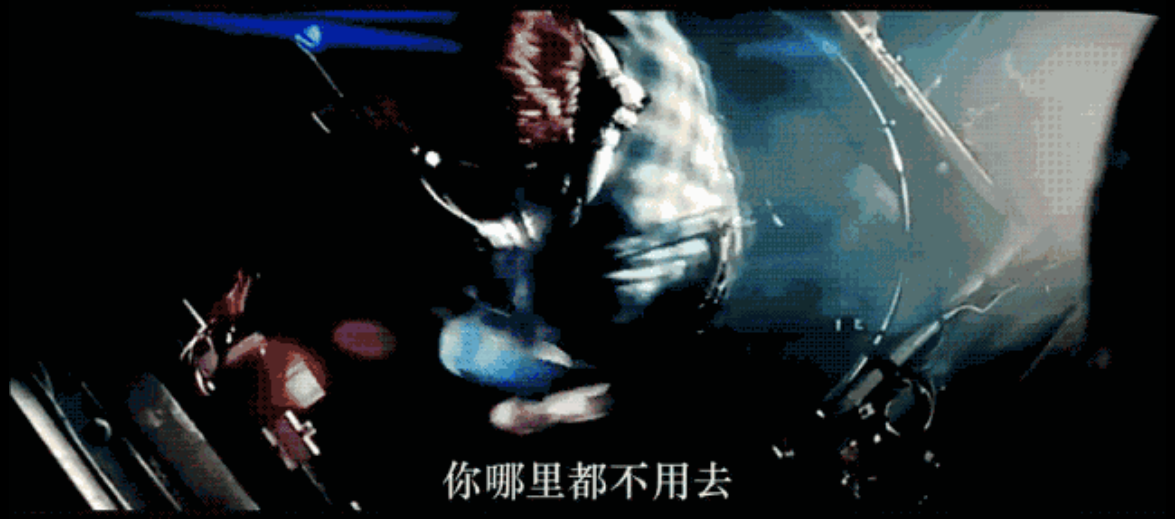
终极虚拟现实：再造平行世界

- 借助适当设备，通过欺骗人体感官（视觉、听觉、嗅觉、触觉、味觉等）的方式，创造出完全虚拟的世界，并与其进行体验和交互



畅想终极VR的电影：《头号玩家》

- VR头显头盔
- 环绕四声道音响
- 全身触觉套装
- 力反馈手套
- 力反馈动捕（跑步、弹跳…）
- 脸部情绪识别
- VR虚拟世界在线社区



电影《头号玩家》：再造平行世界

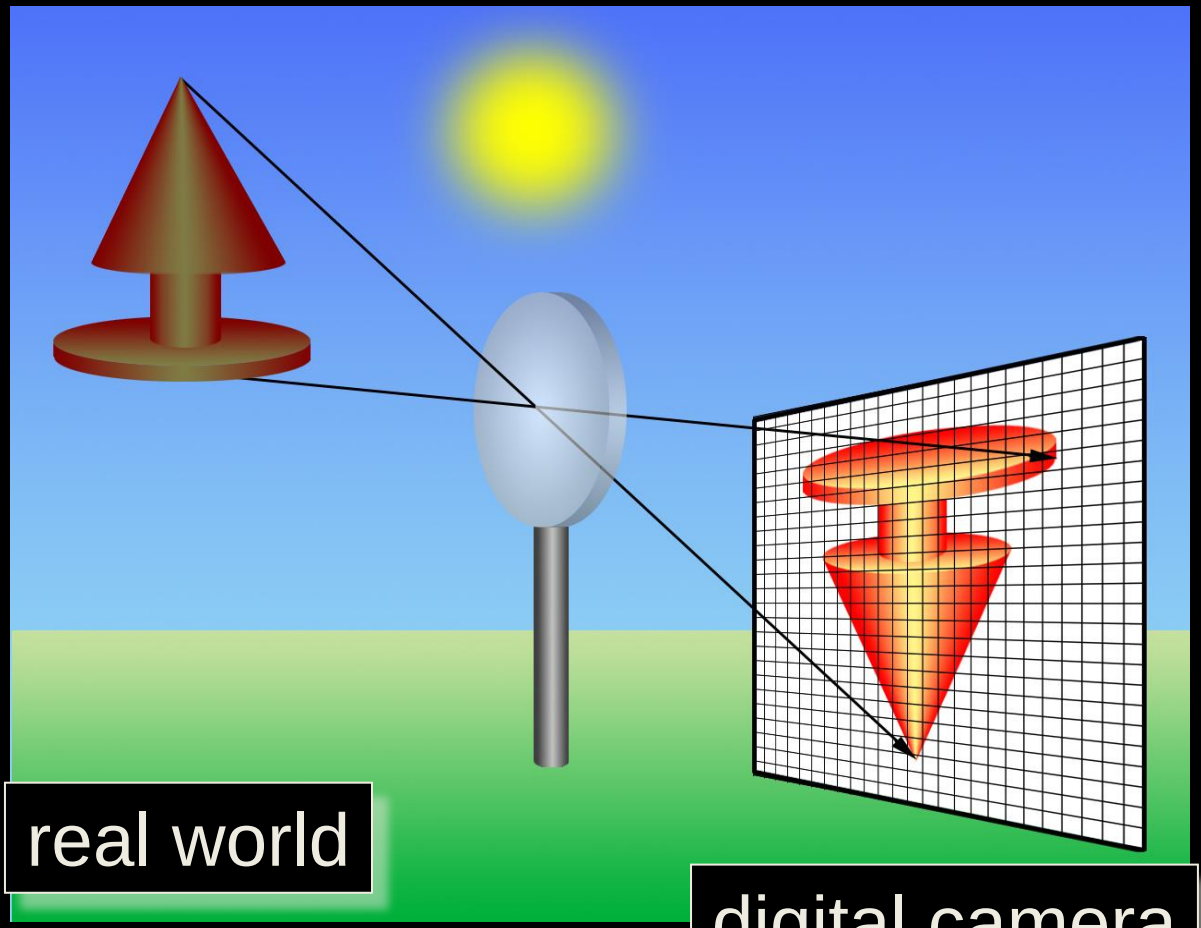
电影《头号玩家》：再造平行世界

电影《头号玩家》：再造平行世界

电影《头号玩家》：再造平行世界

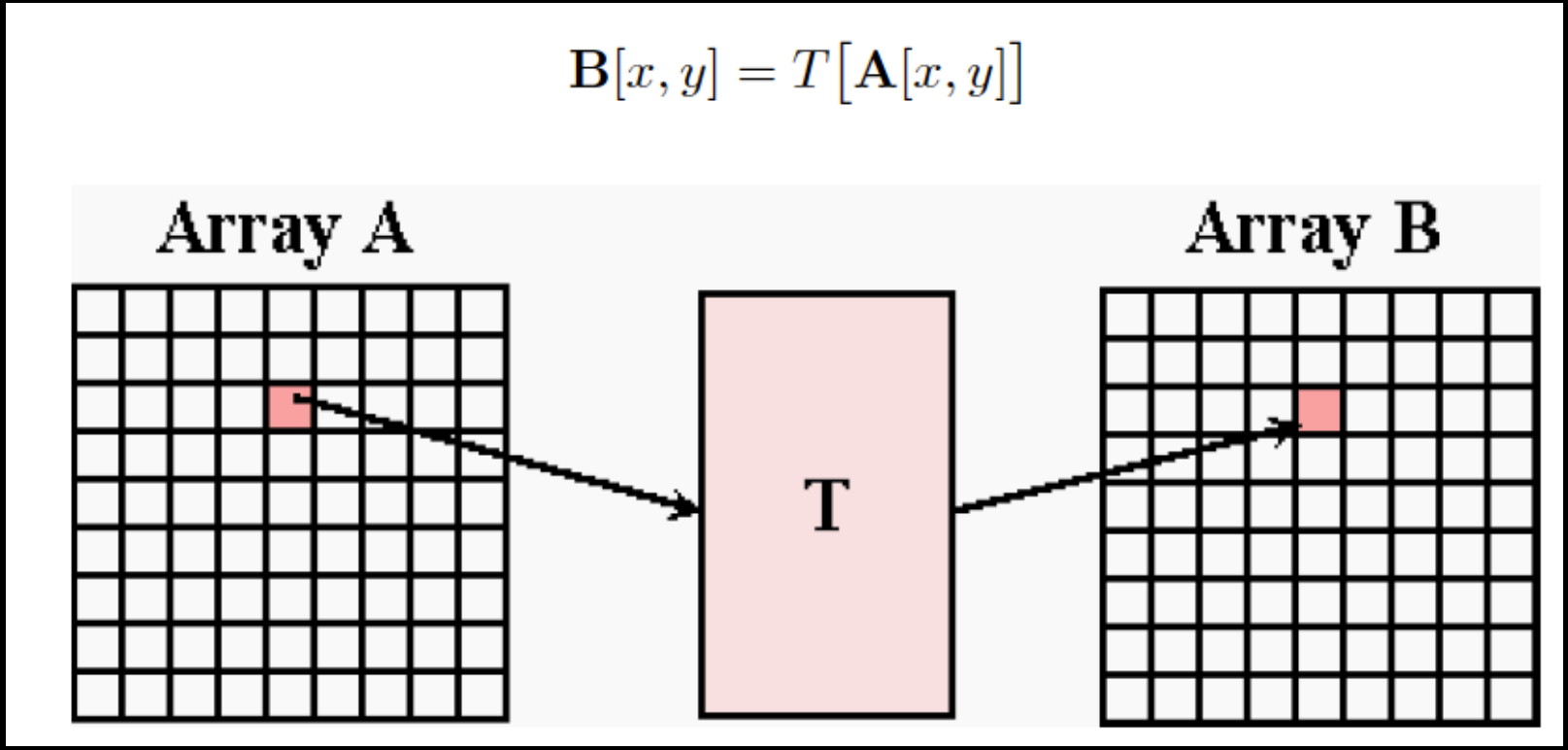
几何驱动的图像处理及生成

图像（照片）：3D世界在2D平面的投影影像



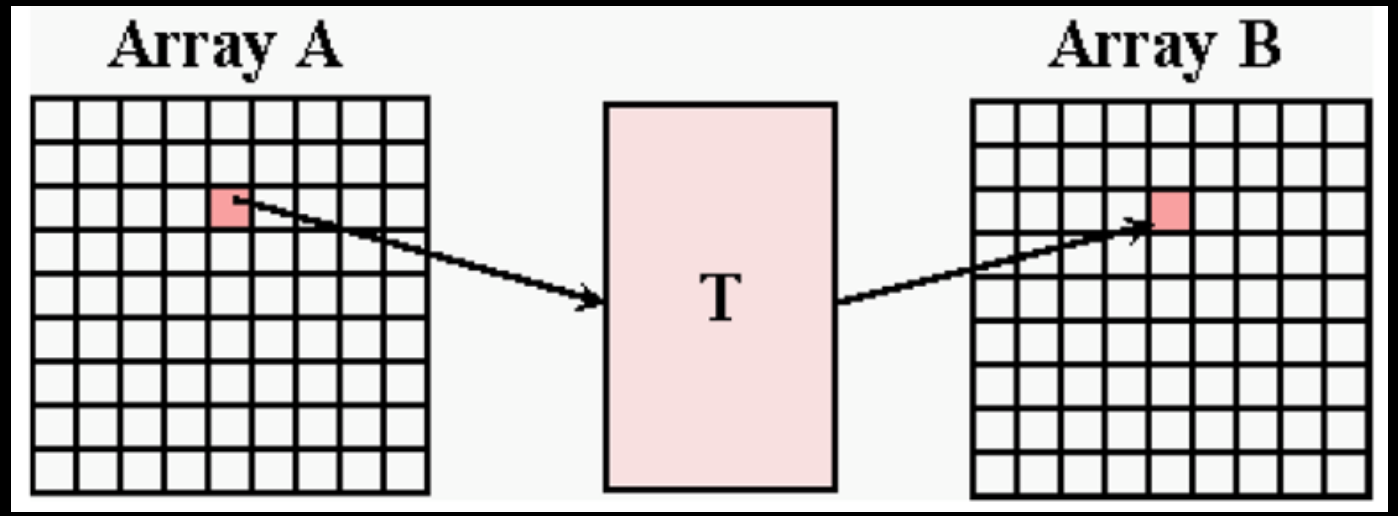
图像处理：空间与颜色的变换

- 局限性：图像到图像的处理，可能导致结果物理不正确
  - 原因：缺少三维信息介入（不真实）



几何引导的图像处理

- 利用图像中蕴含的三维几何信息来引导处理计算



3D几何模型计算

Example 1： Human Body Reshaping

[Sigggraph 2010]

Human Body Reshaping in a Single Image

Input

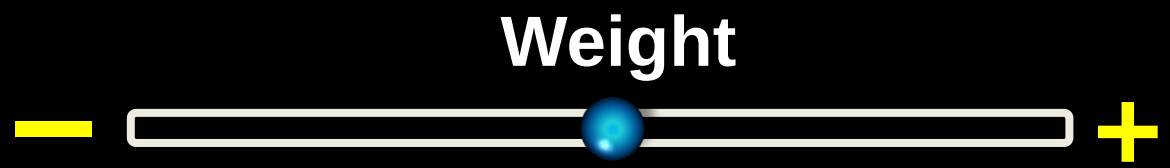
Output

Reshaping with Existing Software

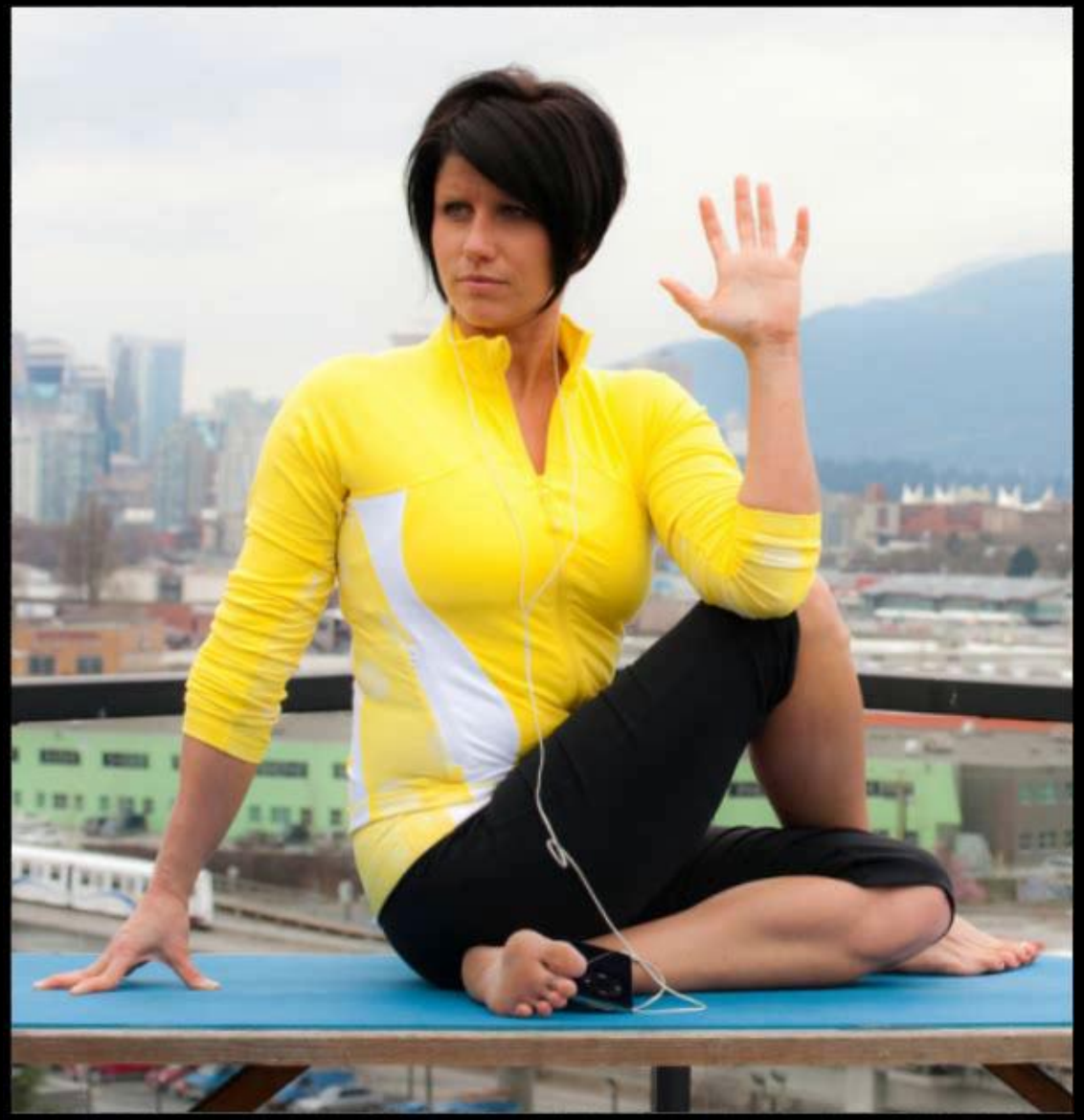
- E.g., Photoshop, PaintShop
- Use **local editing operations**
- **Hard** to achieve **global consistency**
  - Need professional skills
  - Time-consuming

Reshaping with Our Method (Parameters)

- **Intuitive control**
  - By manipulating **a small set of semantic attributes**
    - E.g., weight, height, etc.

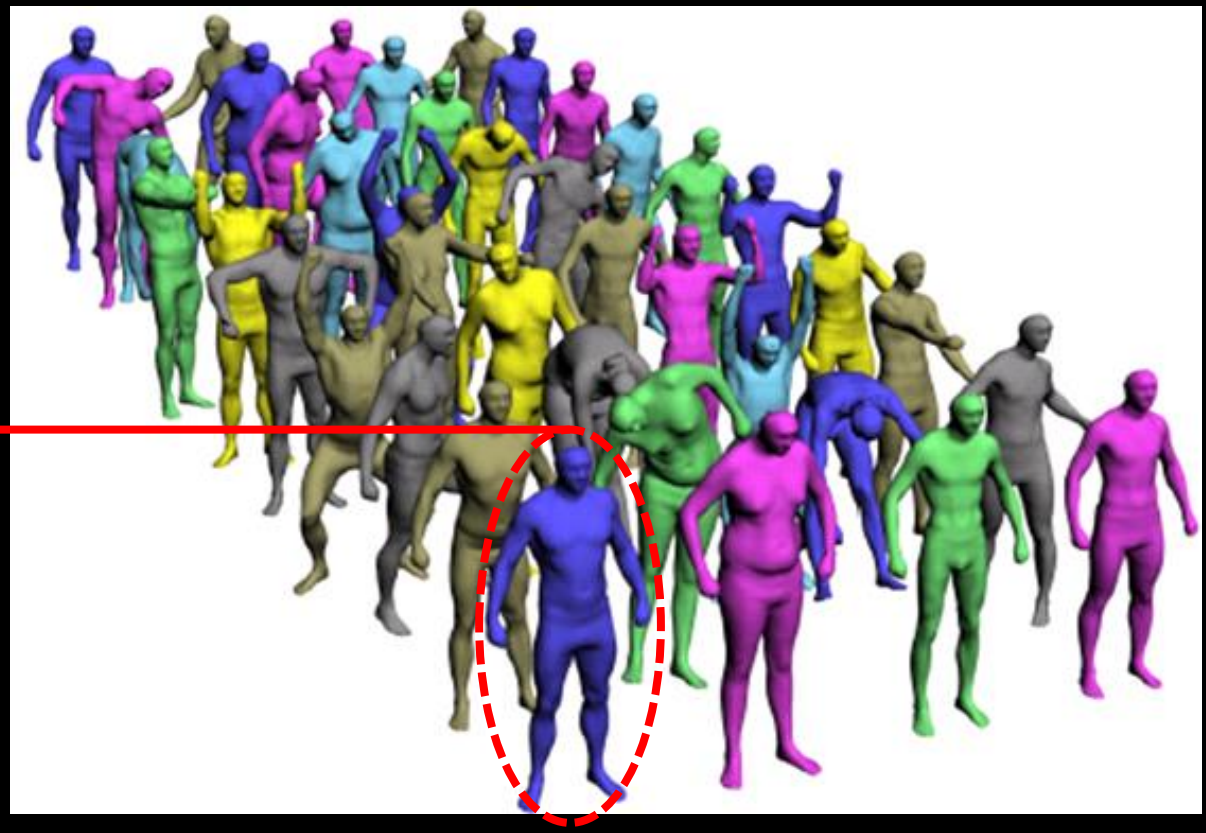


- **Global consistency automatically achieved**



Observation

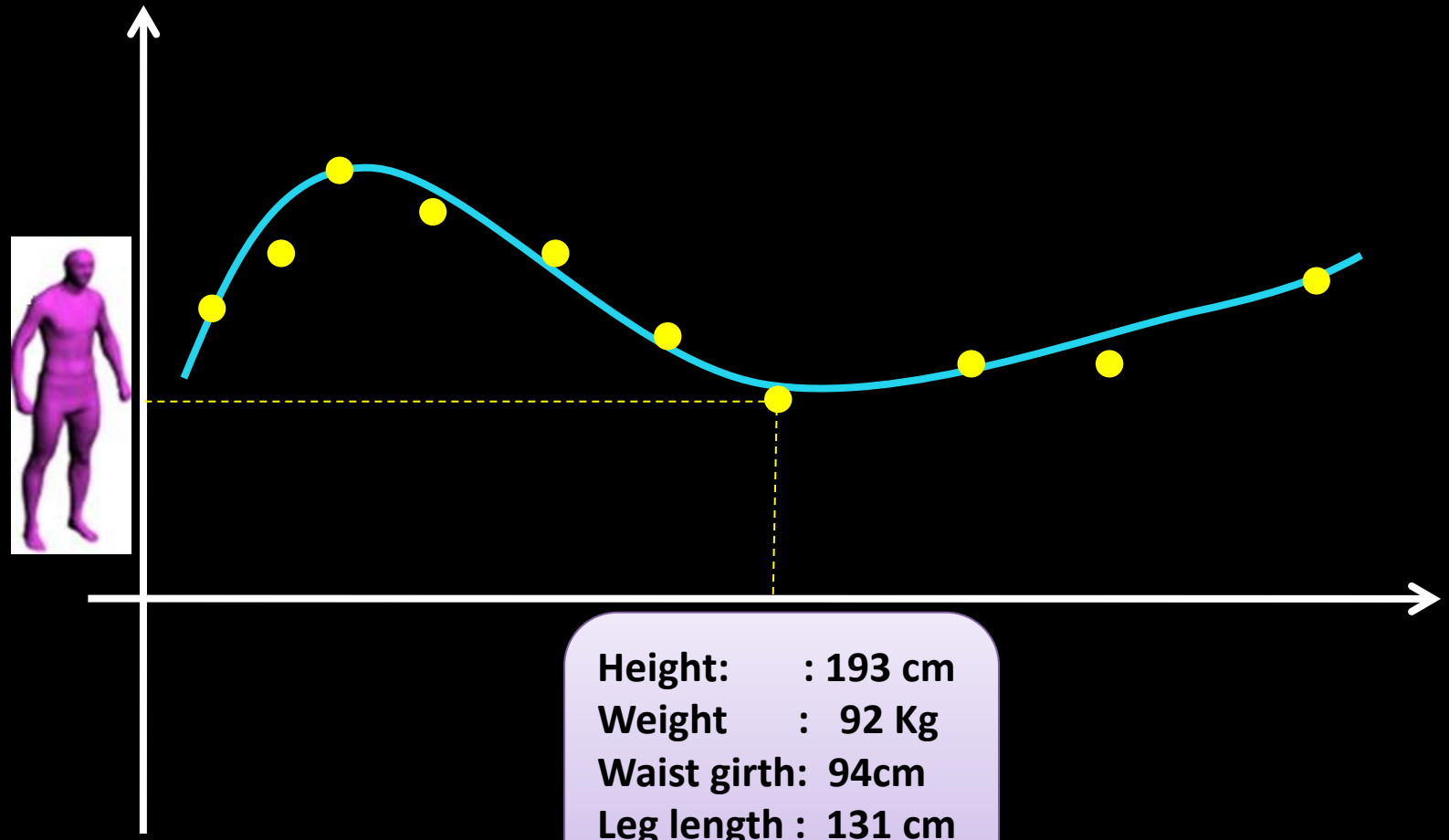
- Human body scanning database is available in the internet



Height: : 193 cm
Weight : 92 Kg
Waist girth: 94cm
Leg length : 131 cm
… …

[Hasler et al. 2009]

Shapes Interpolation/Fitting (Learning)



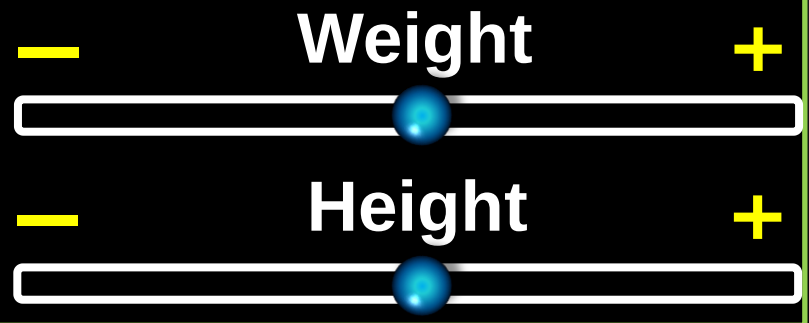
Height: : 193 cm
Weight : 92 Kg
Waist girth: 94cm
Leg length : 131 cm
… …

Key Idea: Semantic Reshaping 3D

- **Parameterize** 2D reshaping effects via **3D parametric model**

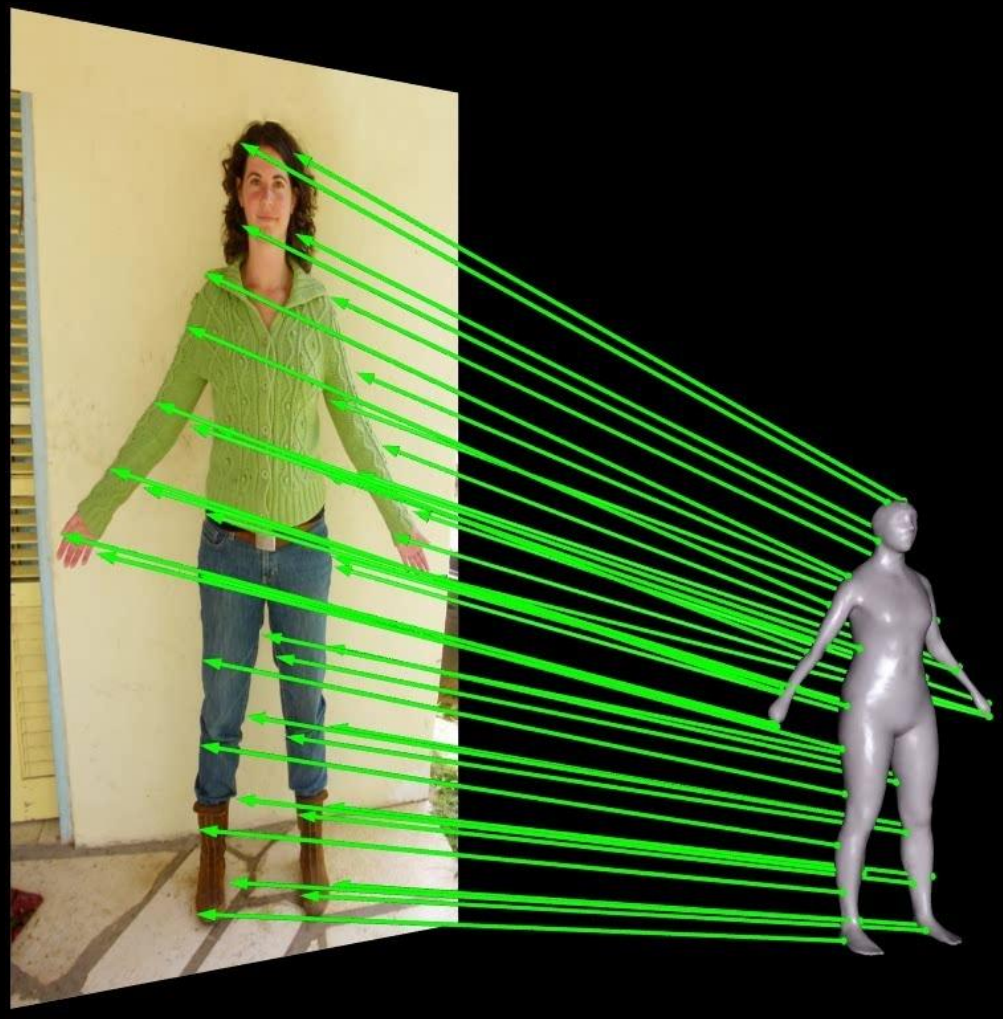
[Hasler et al. 2009]

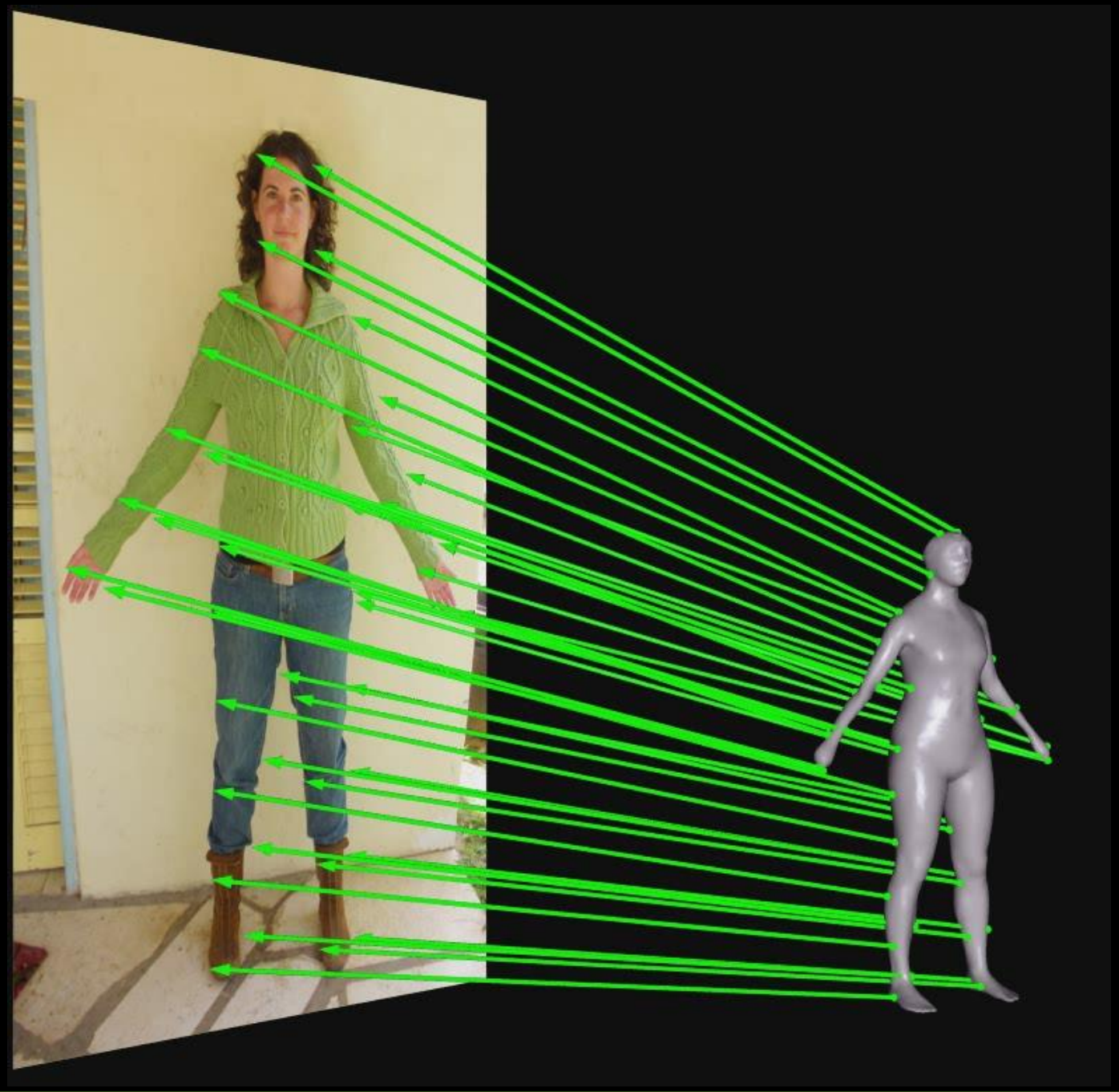
Morphable Model



Basic Idea: 3D Model Driven Manipulation

- Fit a 3D human model to the image





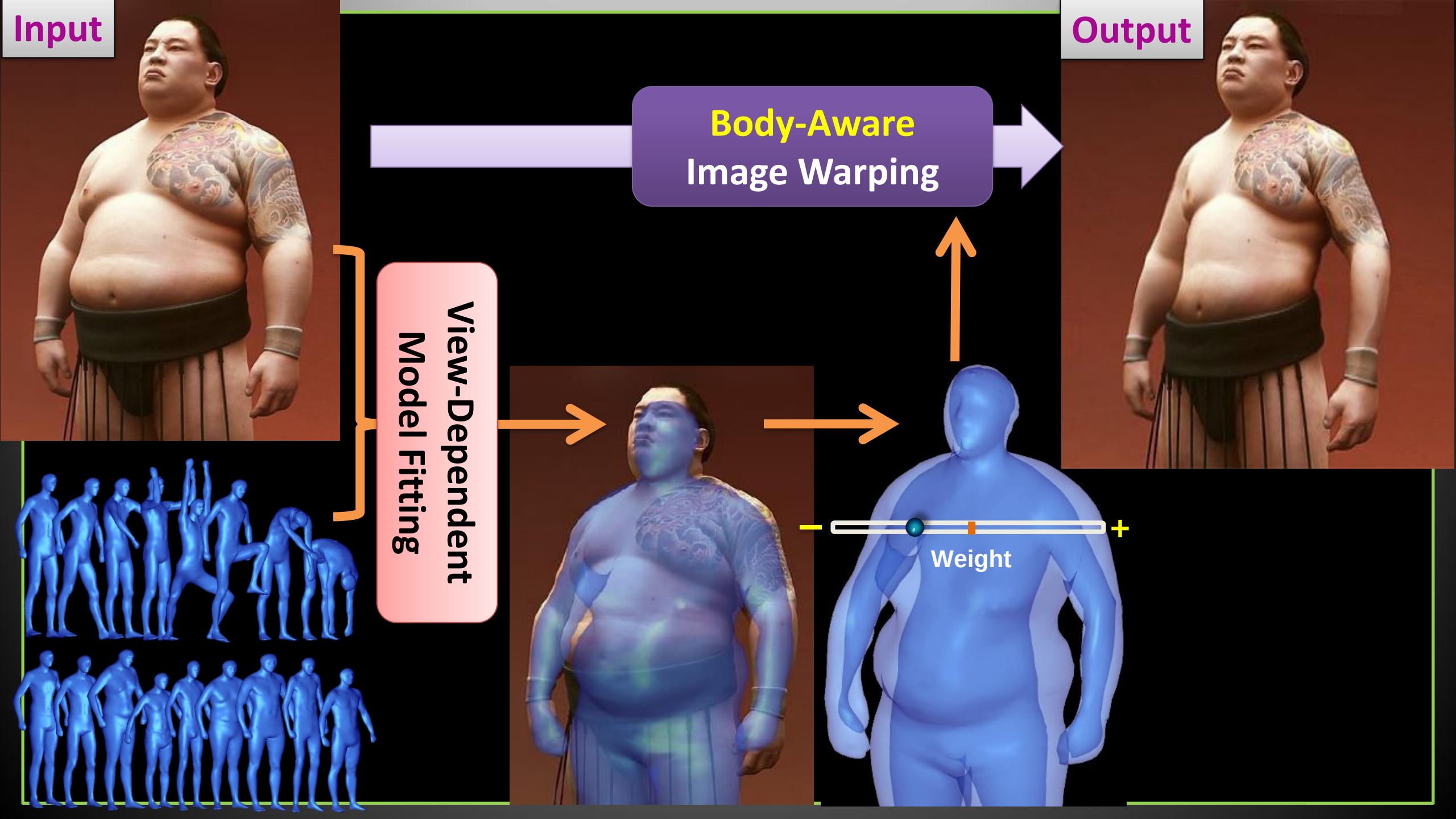
Our Solution

- Straightforward solution: 先重建、后渲染
  - 2D input → 3D textured model → 2D output
    - Too heavily depend on the quality of 3D reconstruction

- Our solution: **3D geometry guided image warping**
  - 2D input → image warping → 2D output

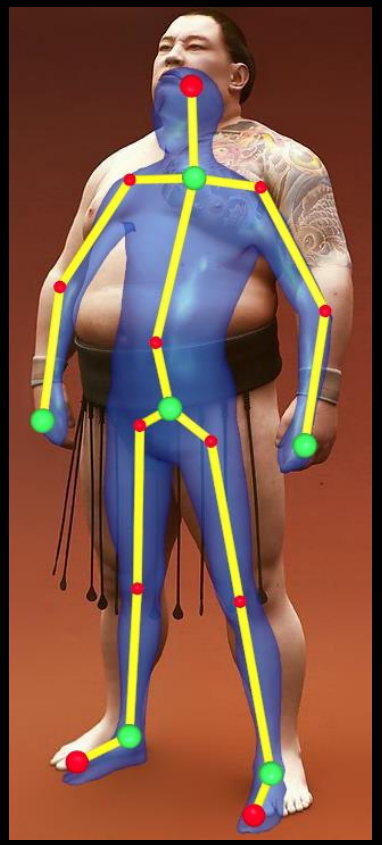
↑

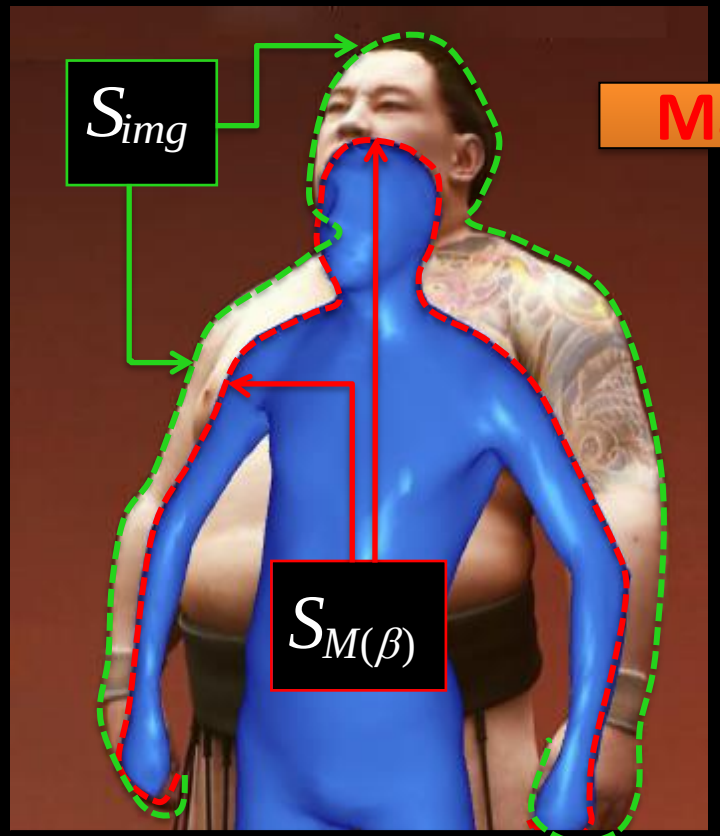
3D body model


Input
Output
Body-Aware
Image Warping
View-Dependent
Model Fitting
Weight
–
+

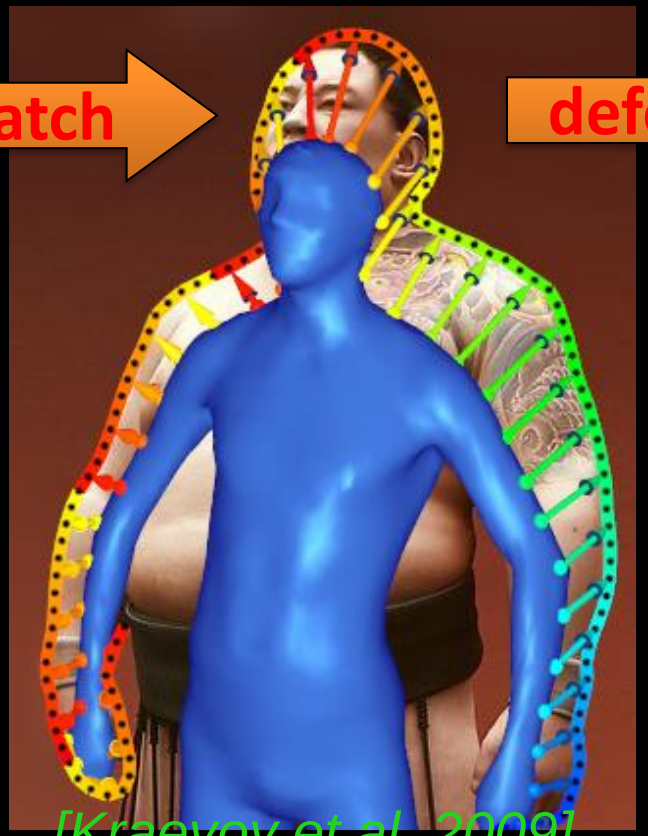
Step 1. Shape Fitting

- Minimize the match error between image contour and the mesh contour.

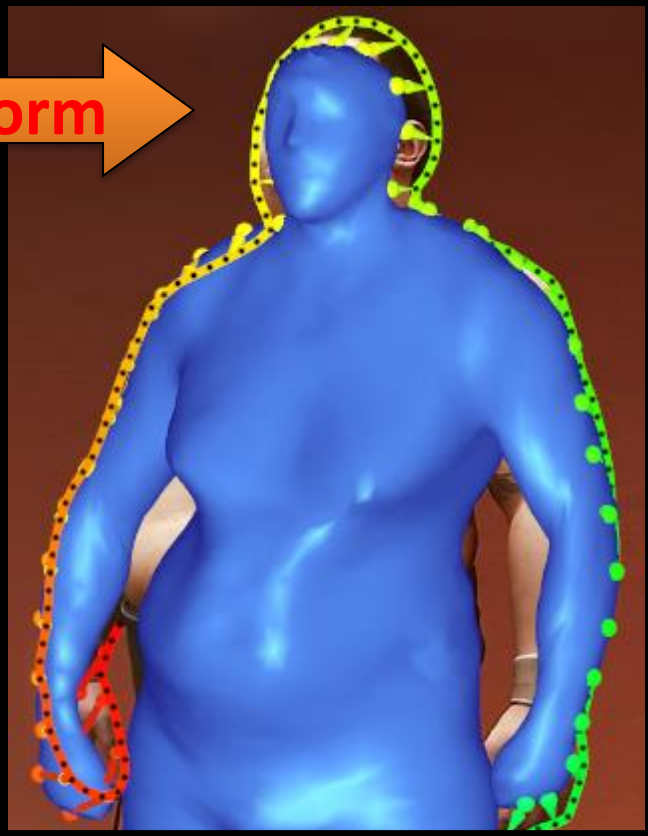




Match

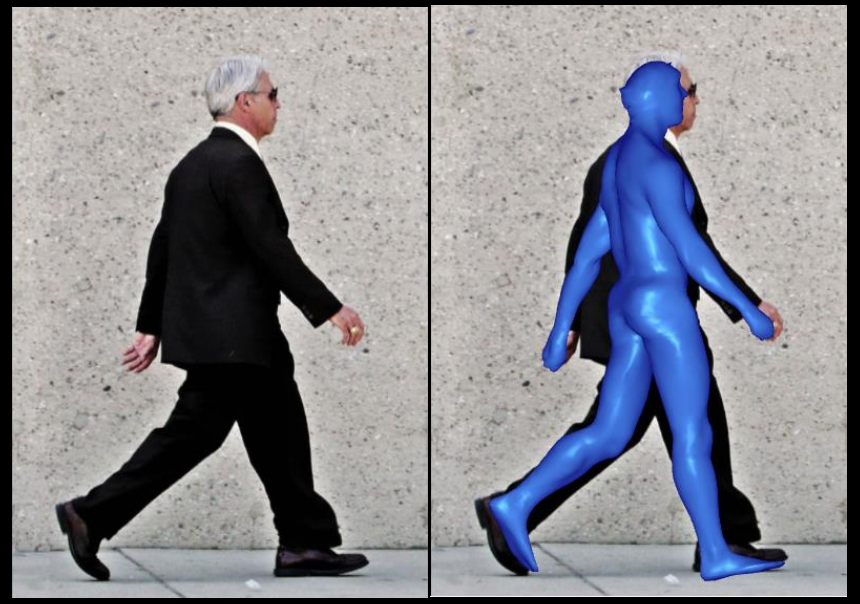


deform

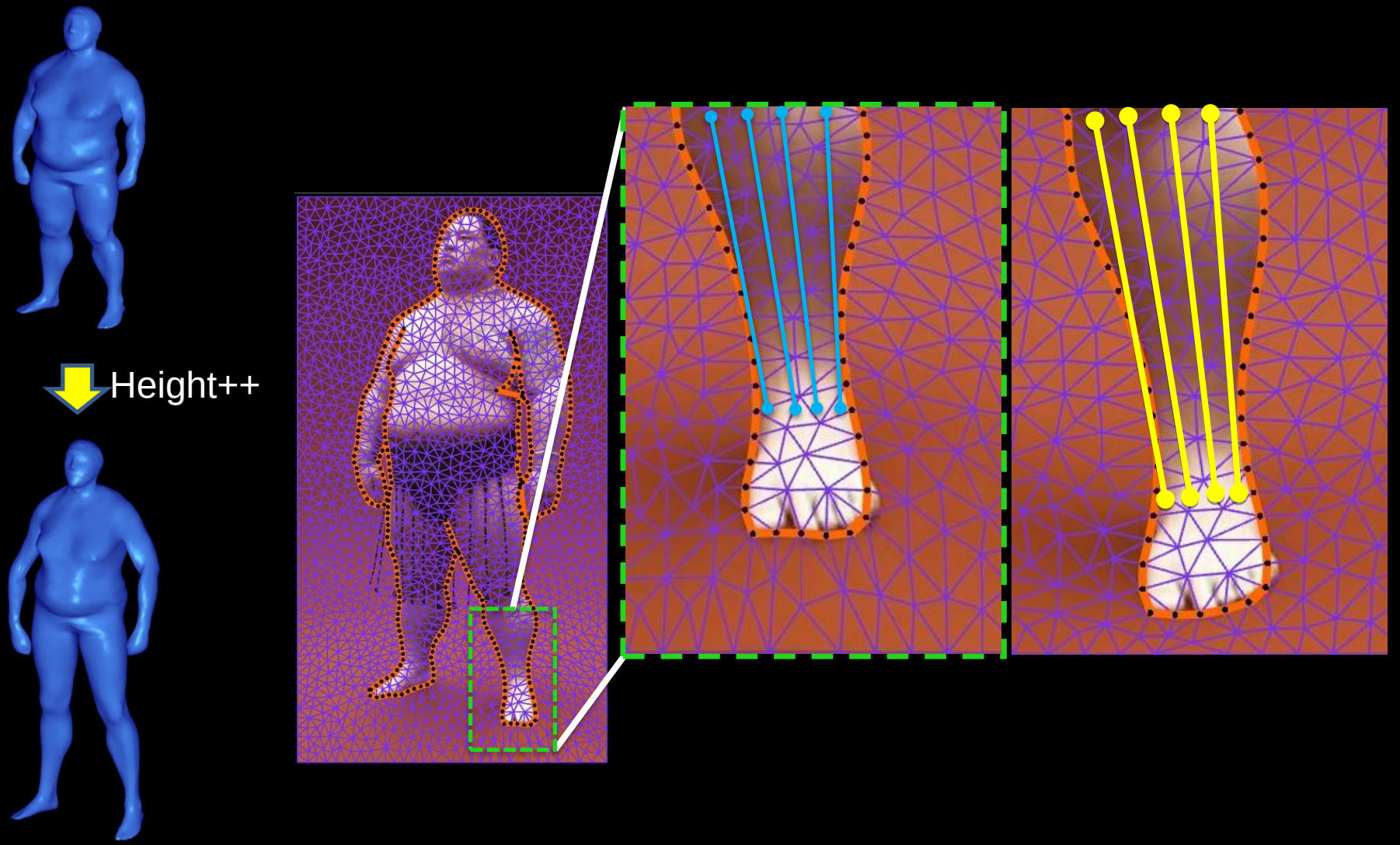


[Kraevoy et al. 2009]

Fitting Examples



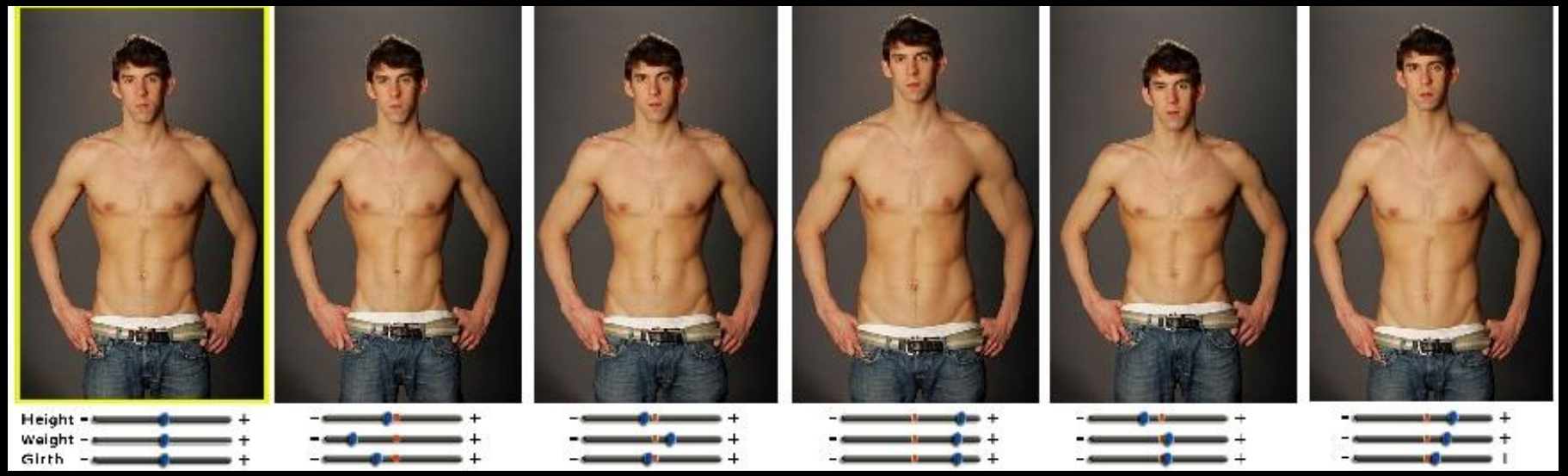
Step 2. Skeletal Aligned Warping



Results

Experimental Results

More Results: Which is the real one?



Example 2： Garment Personalization

[IEEE CG&A 2013]

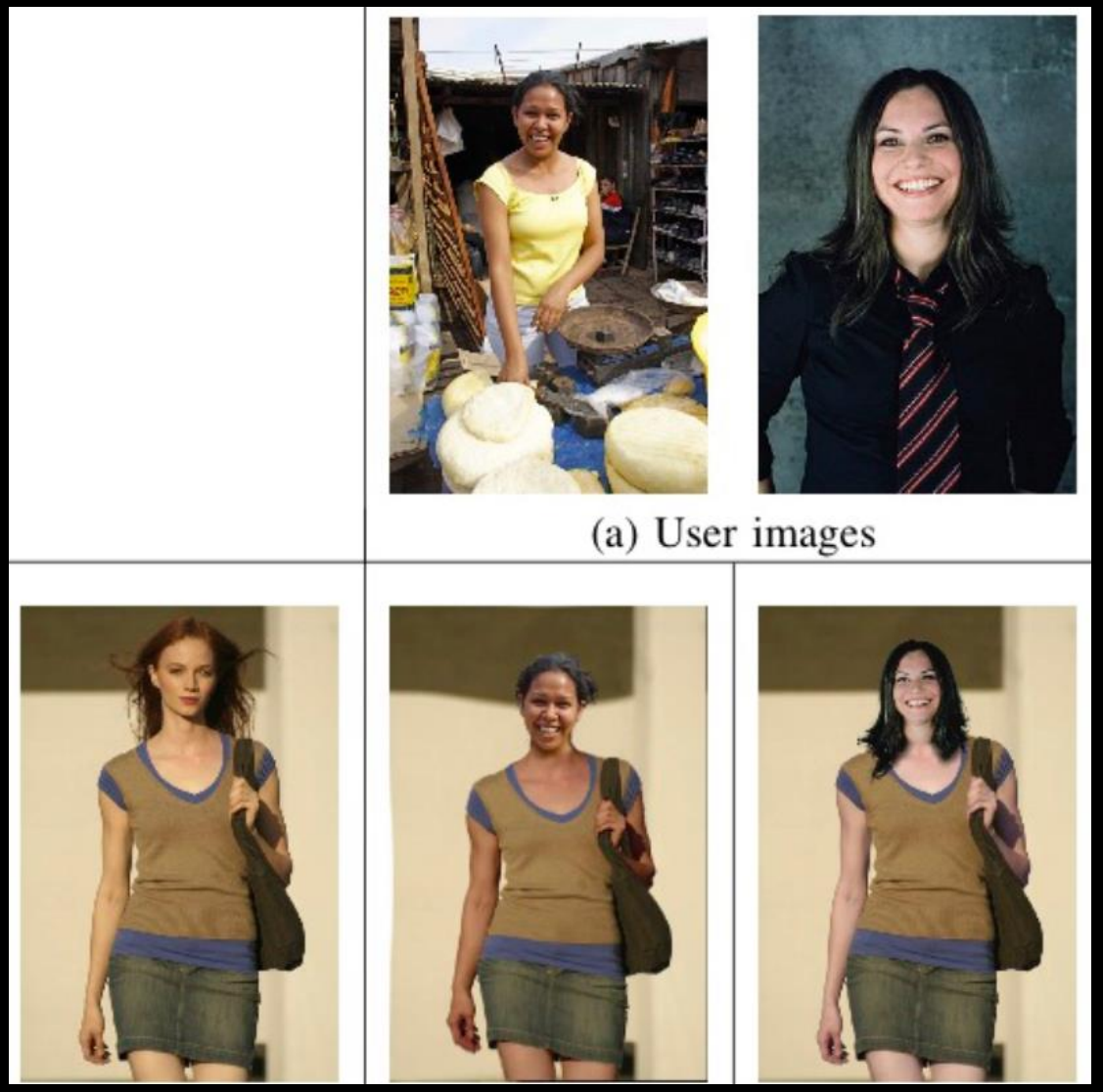
Garment Personalization

User

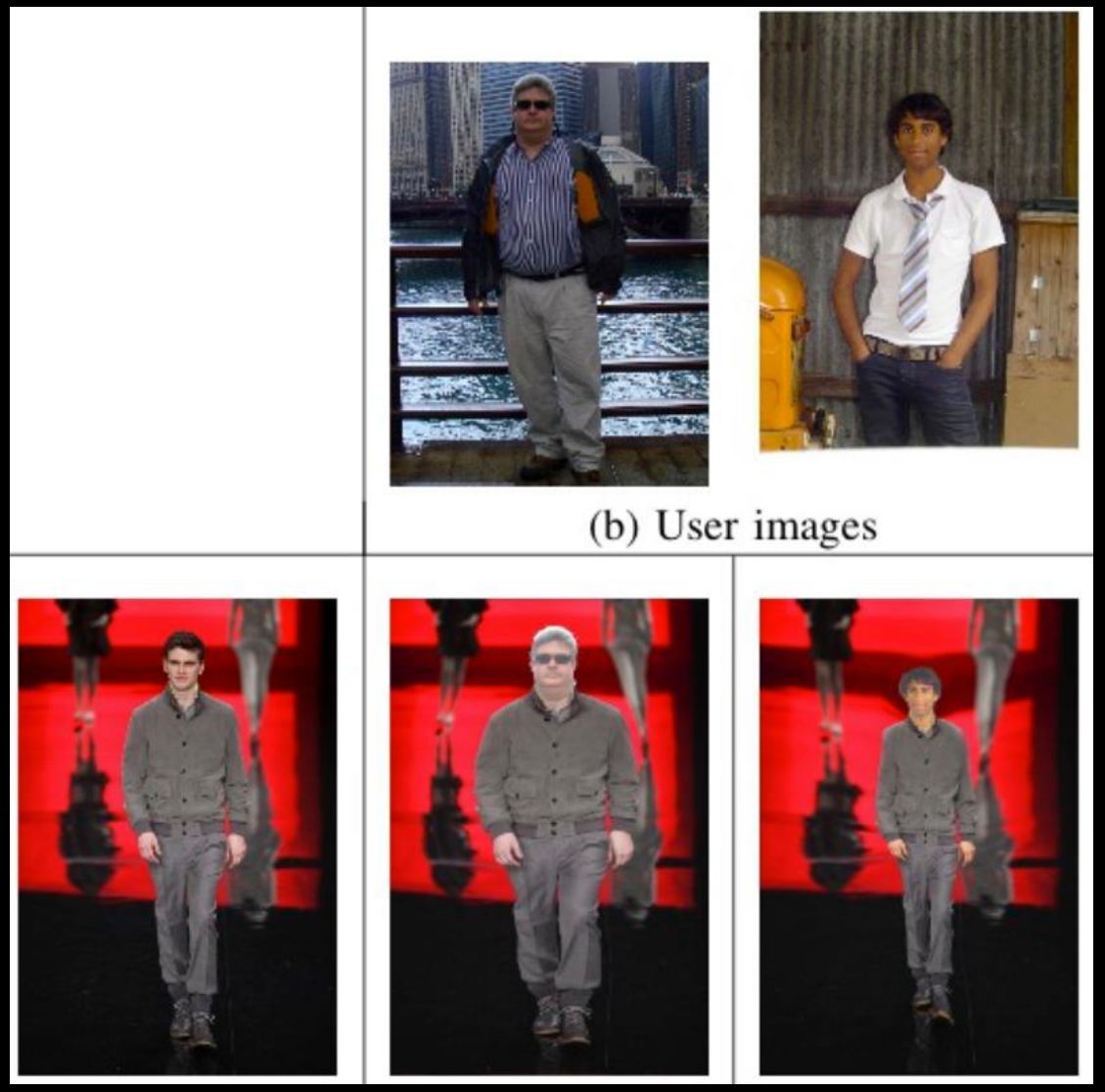
Catalogue

Result

Results



(a) User images



(b) User images

Example 3：View Morphing

[Pacific Graphics 2019]

MOTIVATION

- Human performance synthesis
  - Essential requirement for VR, AR and telepresence

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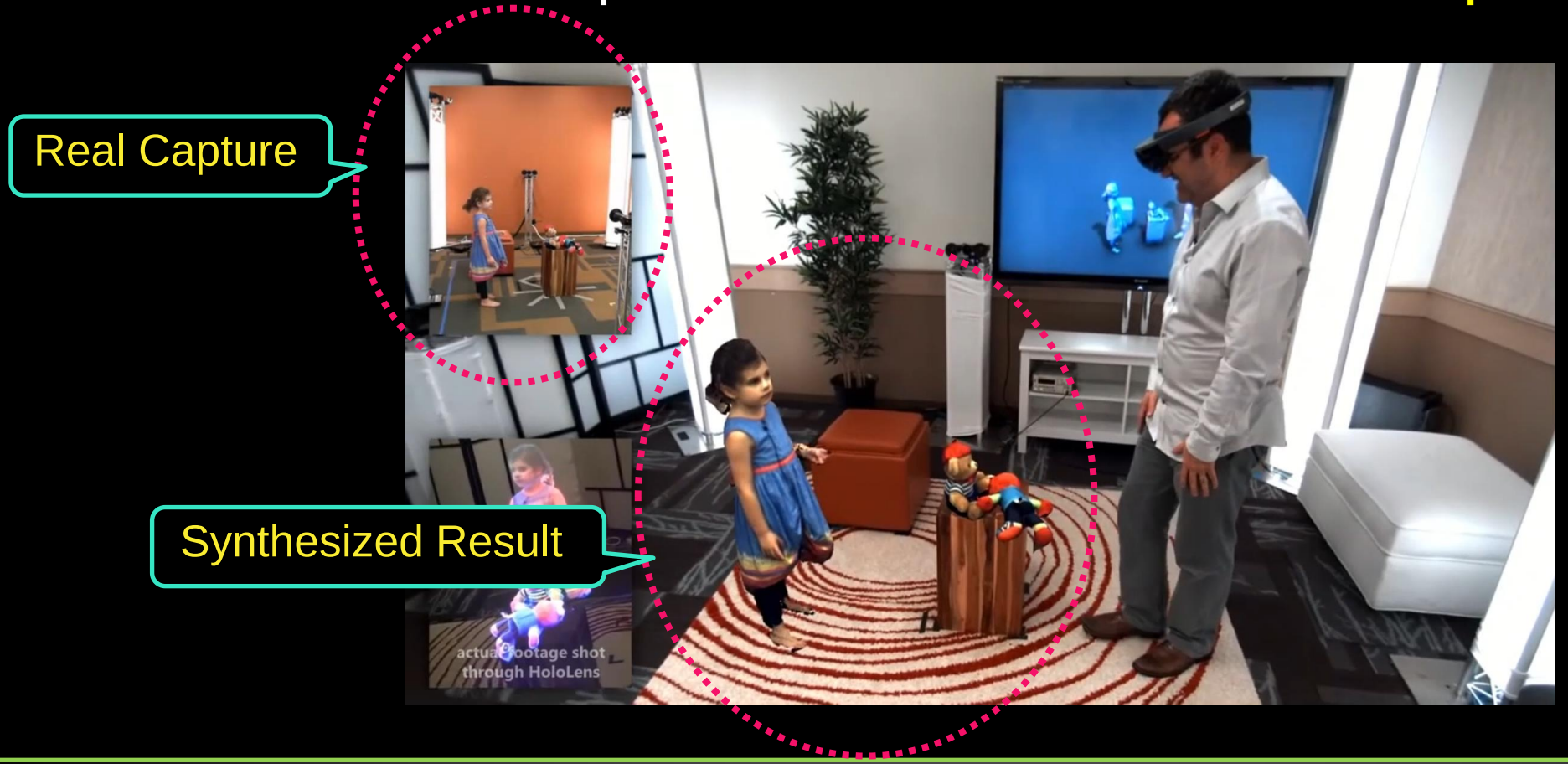
- Human performance synthesis
  - Essential requirement for VR, AR and telepresence



MOTIVATION

- Human performance synthesis
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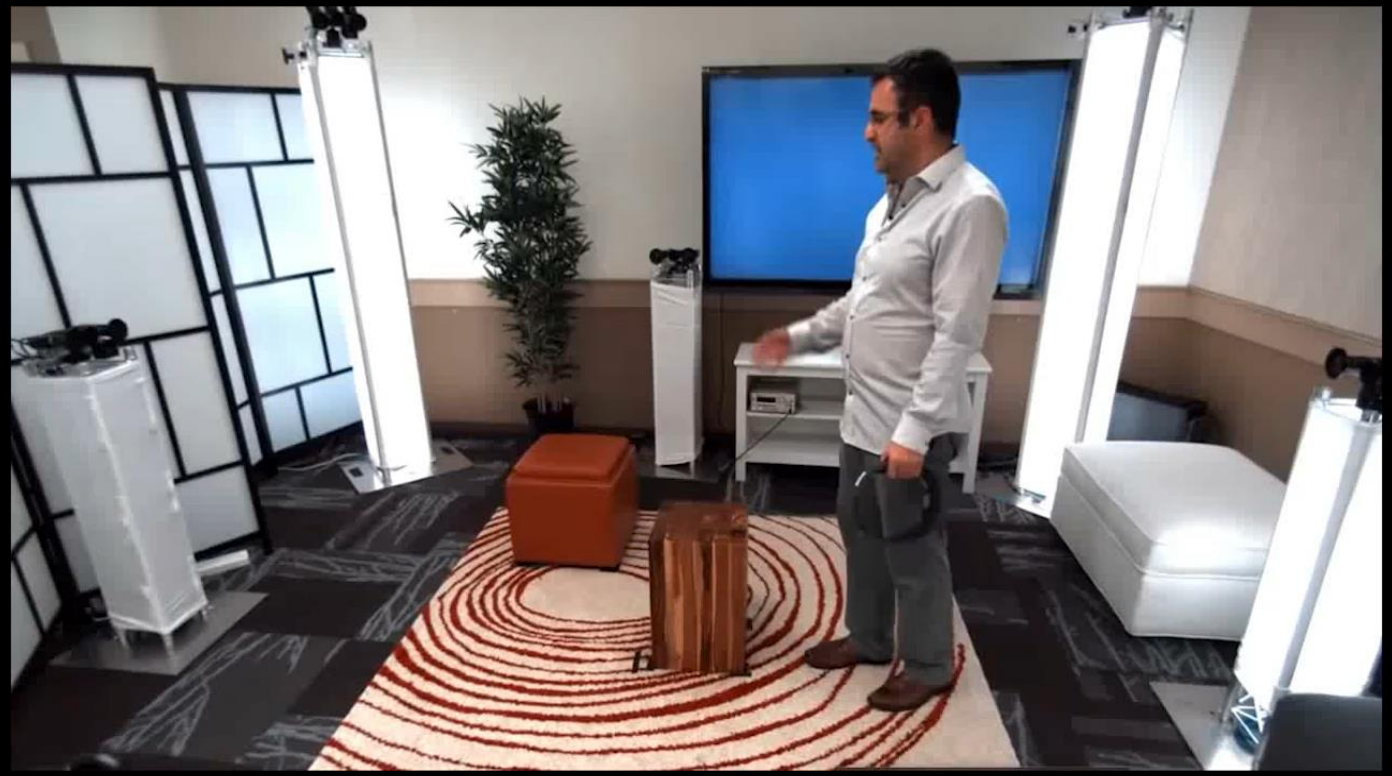
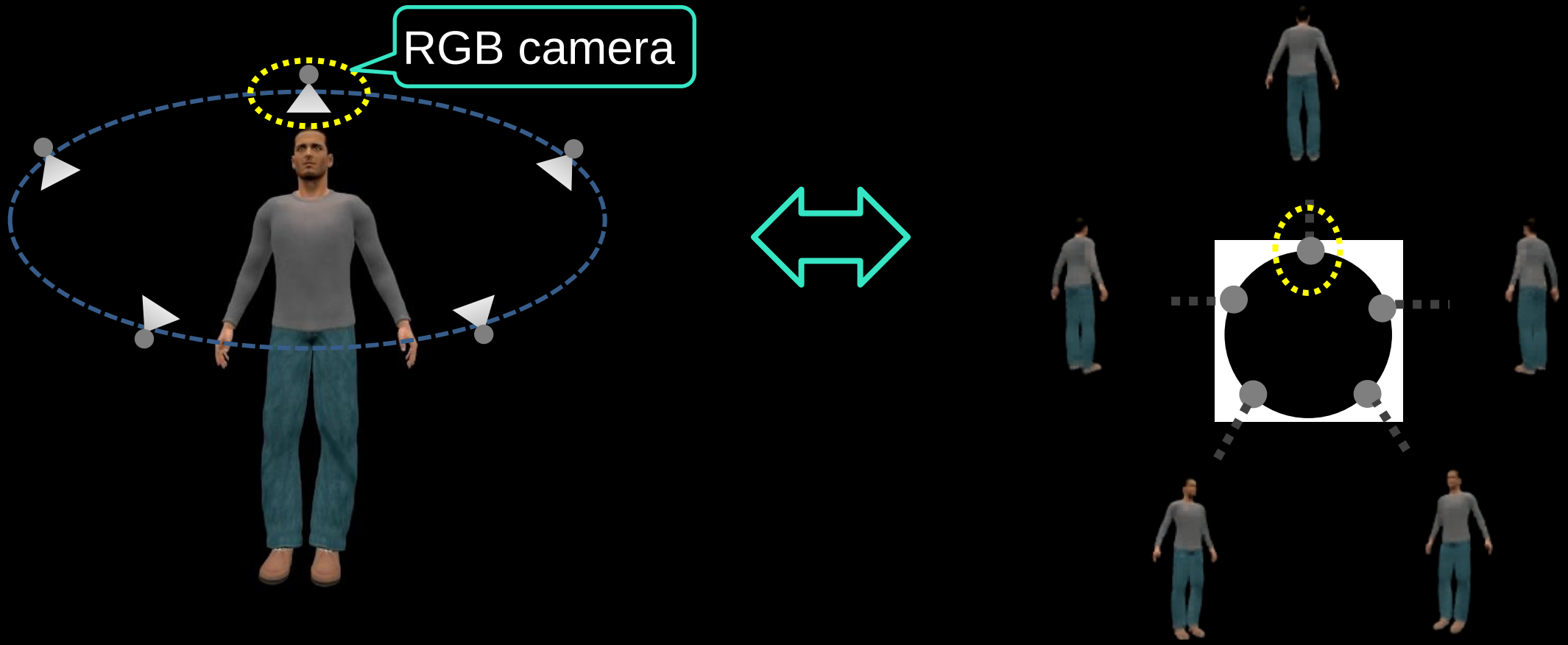


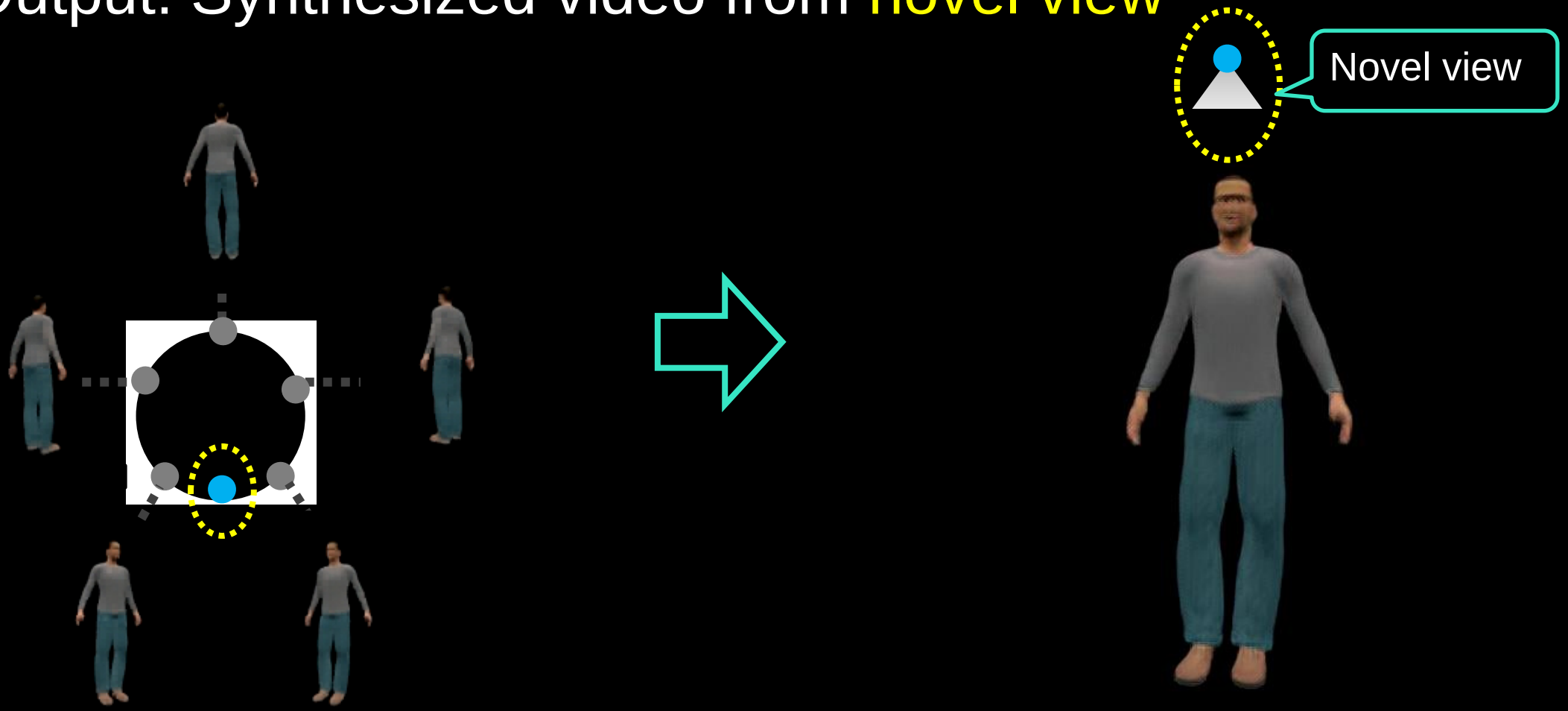
GOAL

- Input: Sparse multi-view RGB captures



GOAL

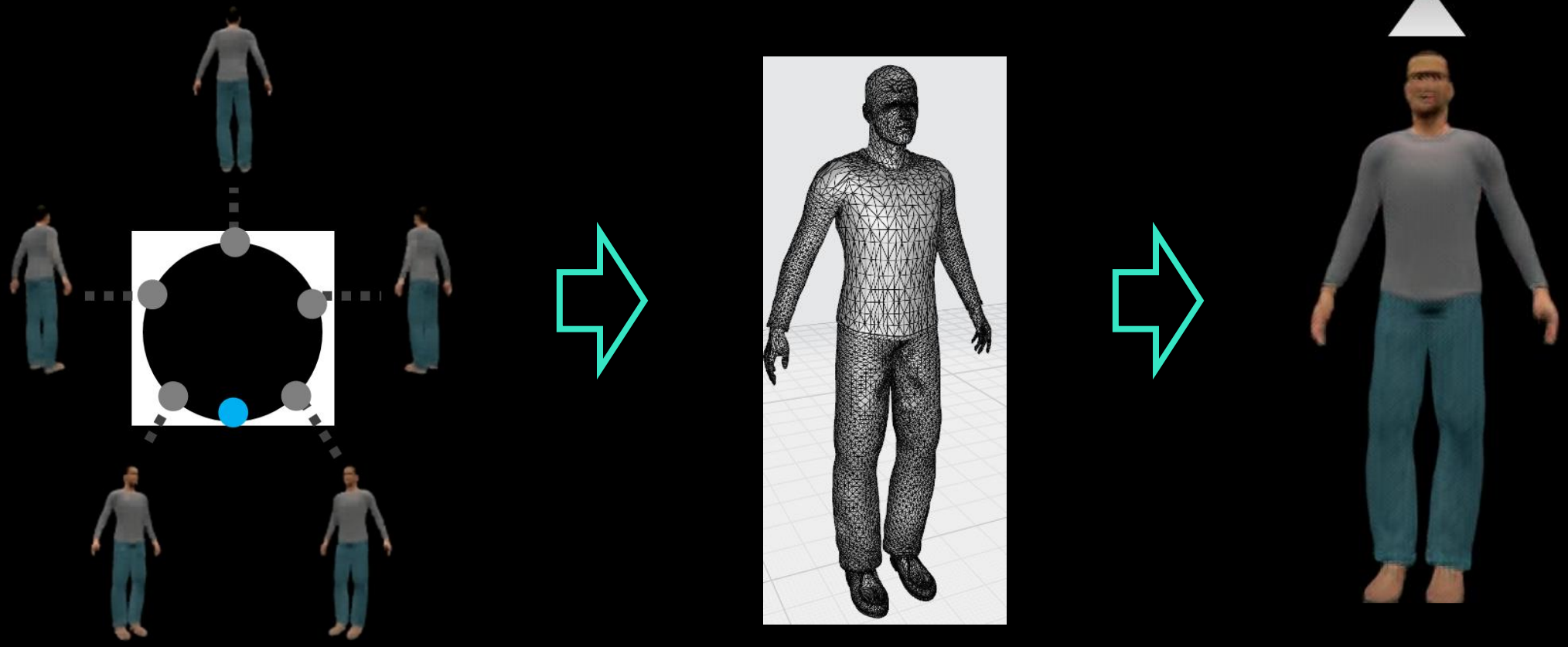
- Output: Synthesized video from novel view



KEY IDEA

- Learn to understand human performance

Modeling – rendering pattern !



KEY IDEA

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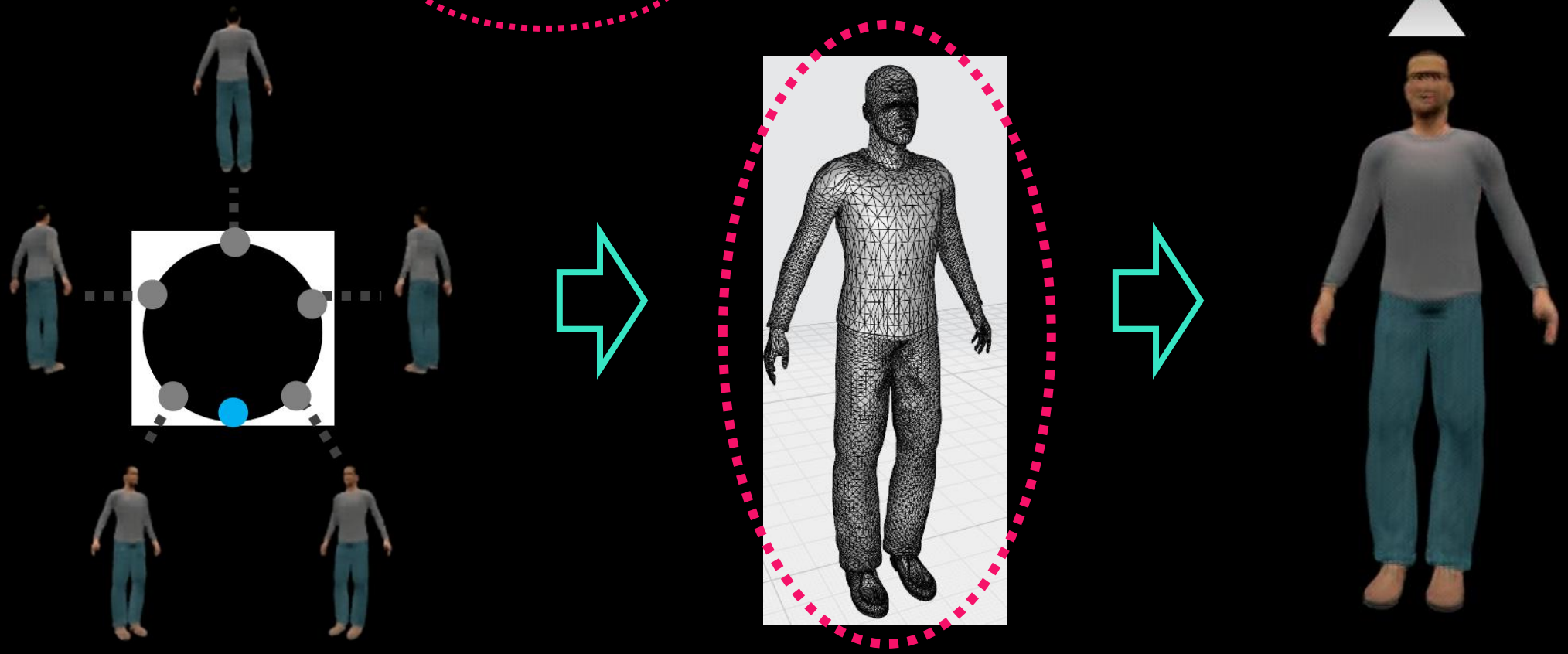
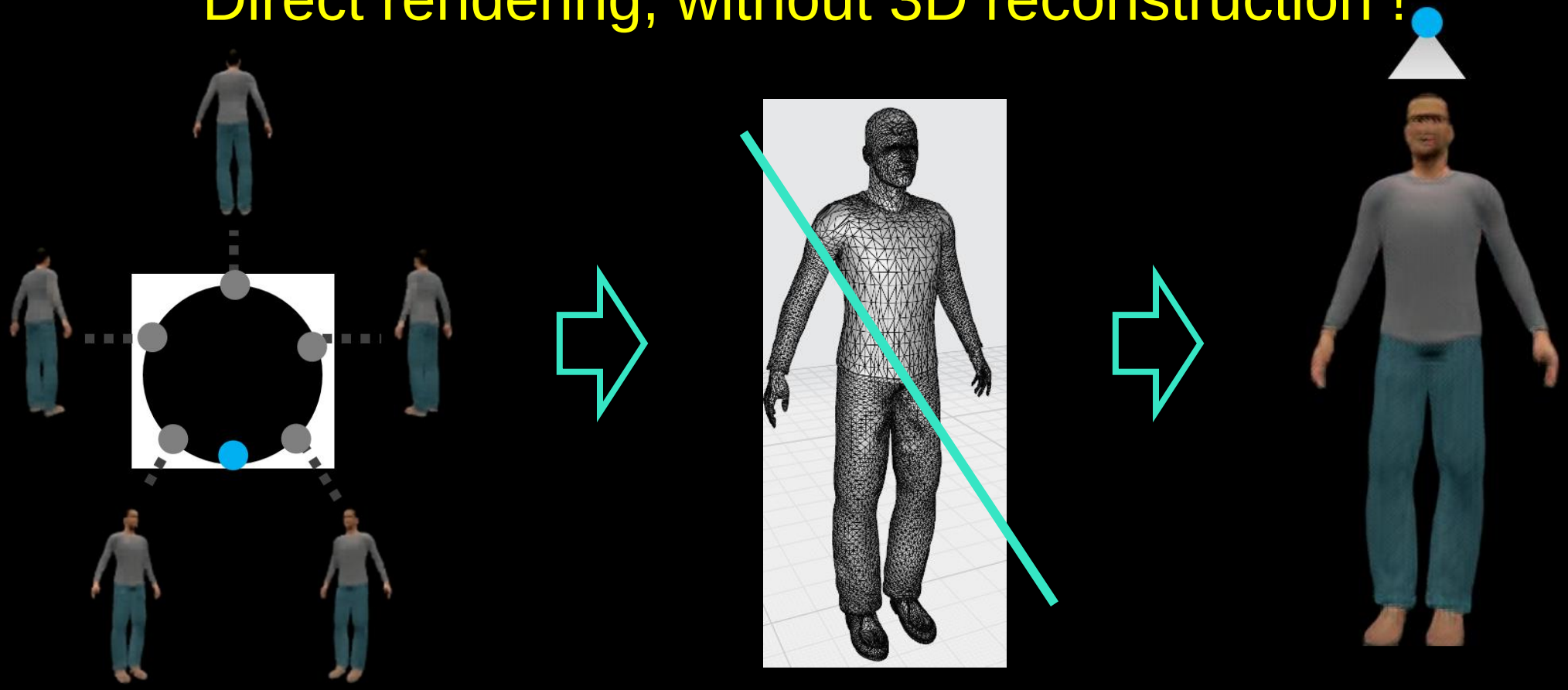
Modeling – rendering pattern !



KEY IDEA

- Learn to understand human performance

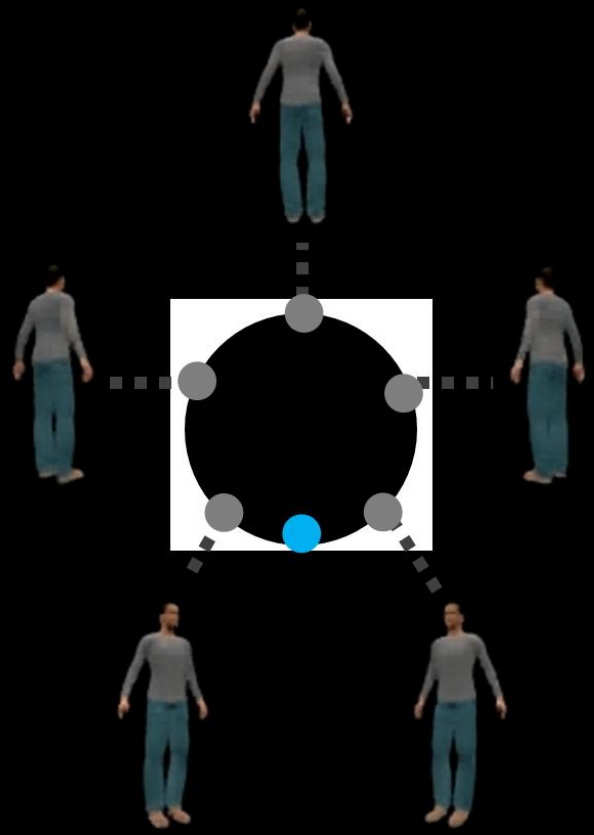
  Direct rendering, without 3D reconstruction !



KEY IDEA

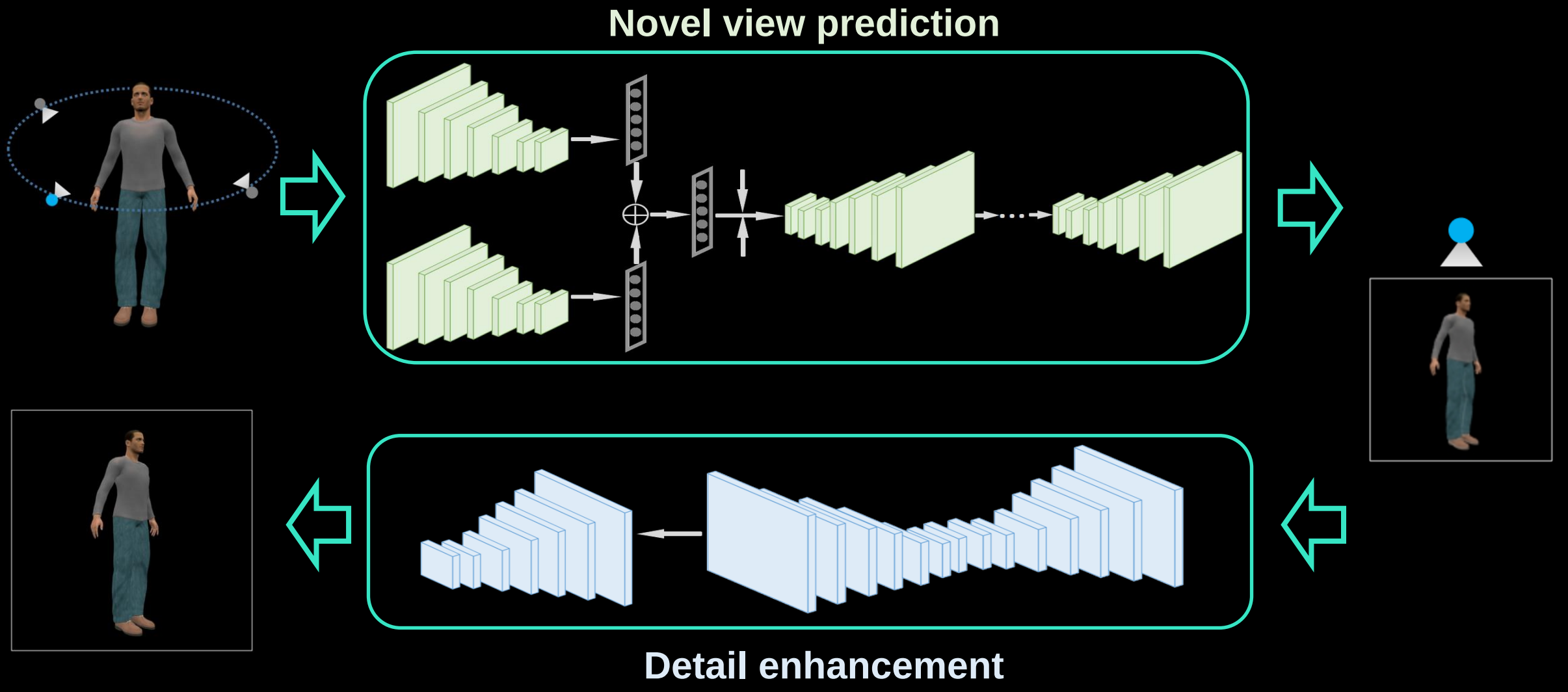
- Learn to understand human performance

Direct rendering, without 3D reconstruction !

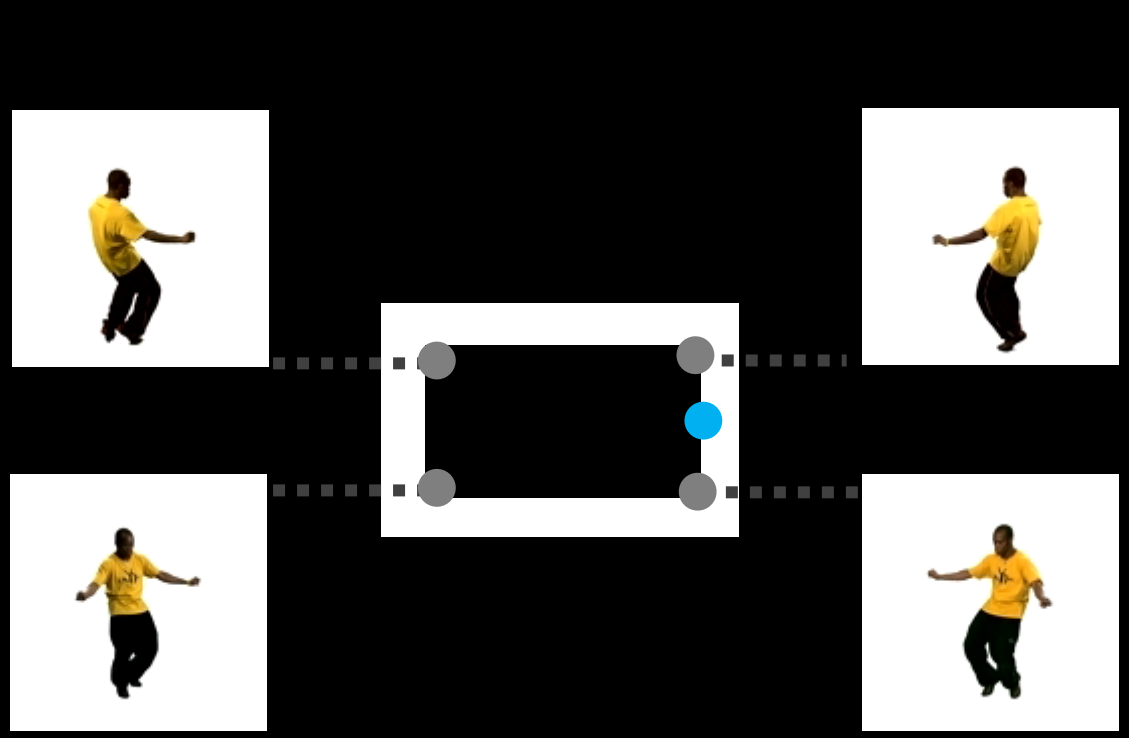


Deep Generative Network

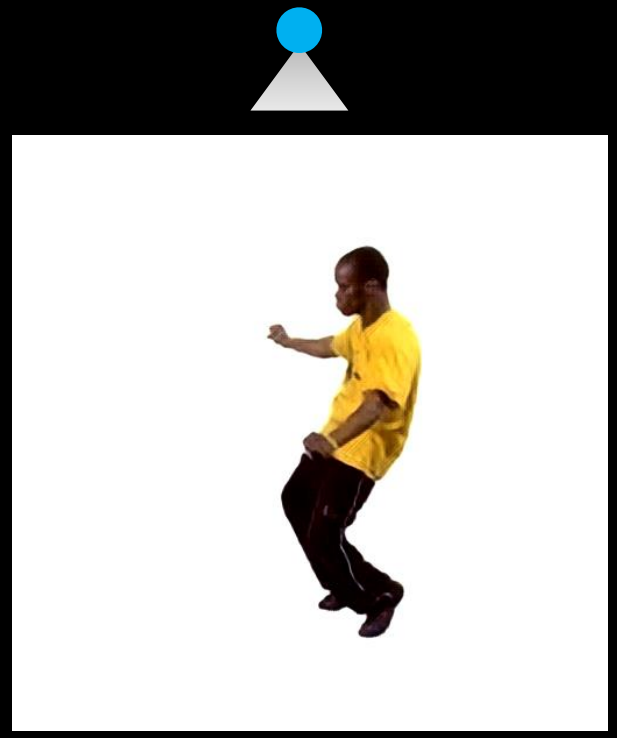
Deep Generative Network



EXAMPLE 1

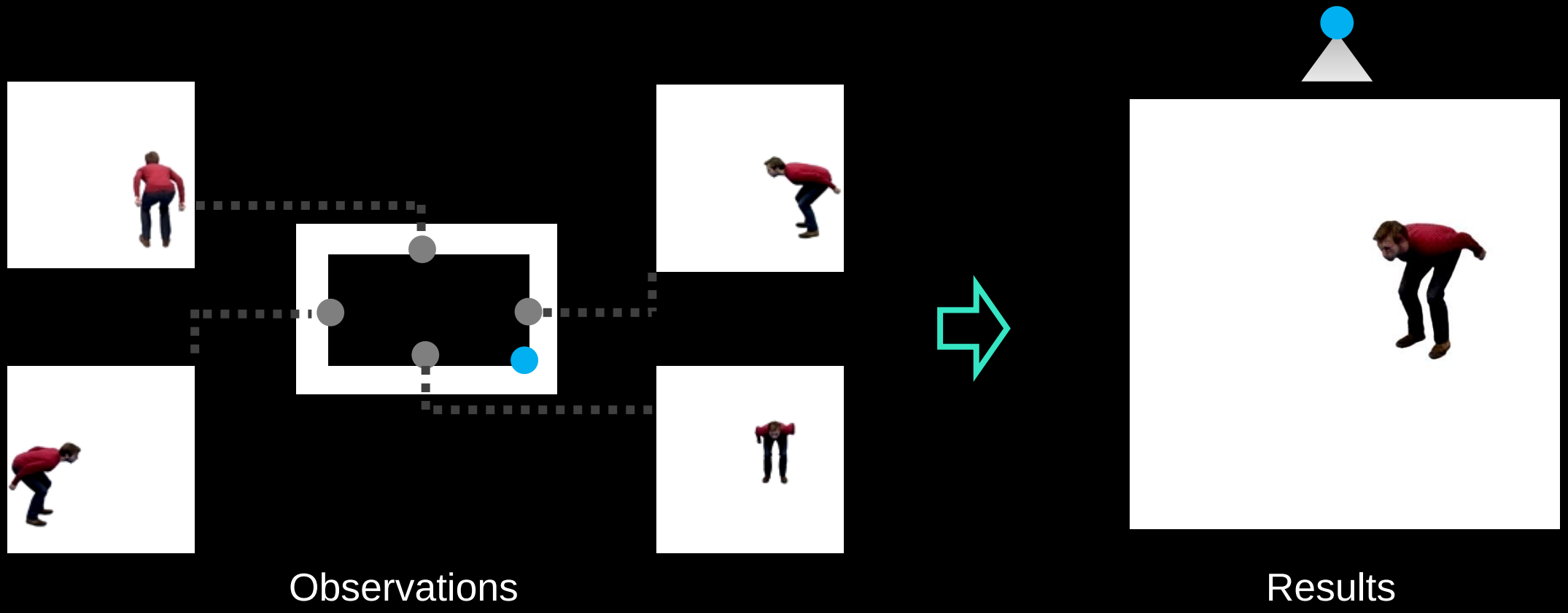


Observations



Results

EXAMPLE 2



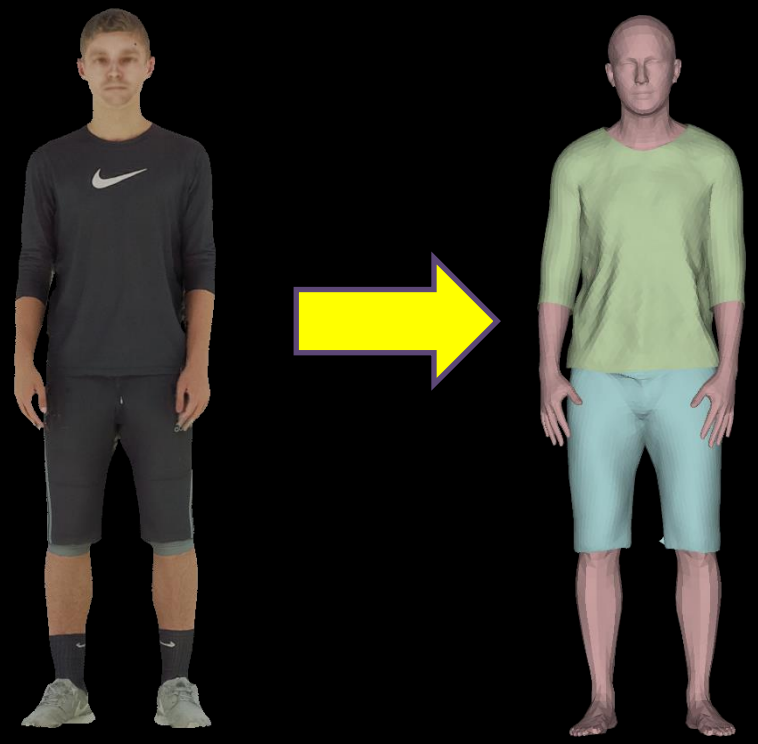
Observations

Results

Example 4： BCNet: Learning Body and Cloth Shape from a Single Image

[ECCV 2020]

Clothed Body Reconstruction from a Single Image



difficult!!

Body shape,
pose variations

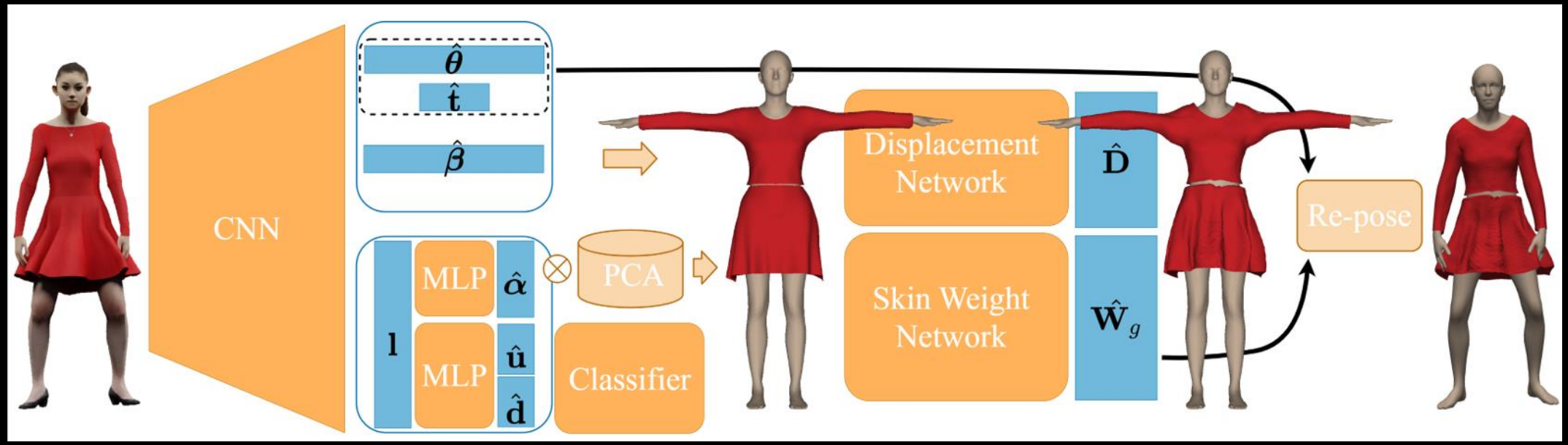
Garment type,
texture and
shape variations

Complicated
interactions

Learning based Method

6 separated garment templates + shared garment skinning weights network + SMPL body model

Parameterized clothed body representation

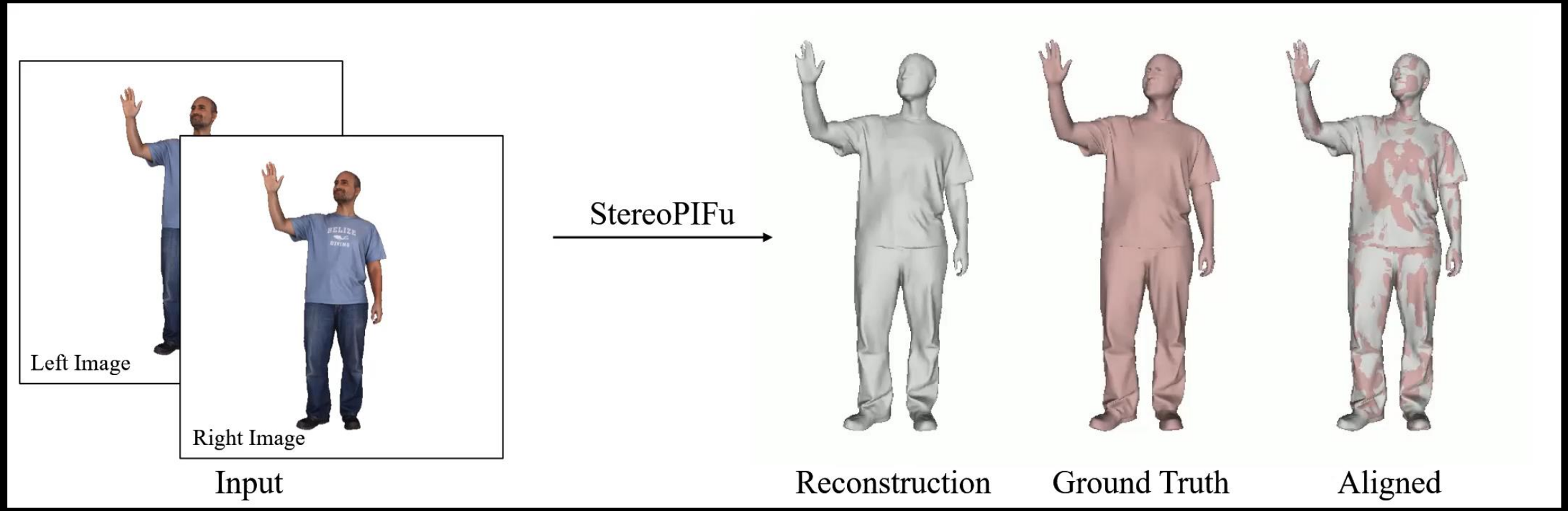


Example 5： StereoPIFu: Clothed Human via Stereo Vision

[CVPR 2021]

Project Page: https://hy1995.top/StereoPIFuProject

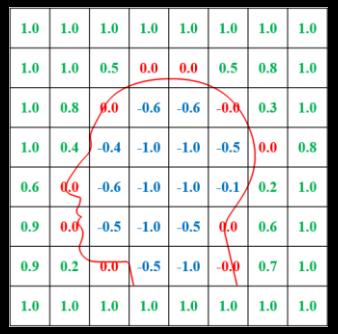
StereoPIFu: Clothed Human Digitization via Stereo Vision



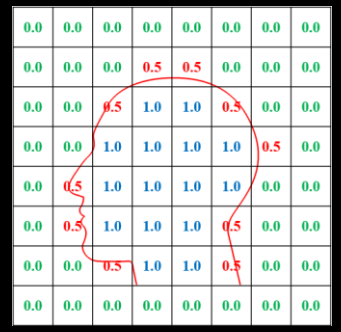
训练数据

隐式函数

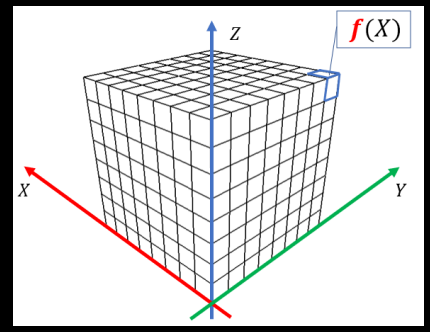
- 类型:
  - SDF(Signed Distance Function):
    - $f(X)$返回空间点X到表面的符号距离，
    - 表面: $f(X) = 0$
  - Occupancy:
    - $f(X) \in [0, 1]$, 指示空间点X是否在目标曲面内部
    - 表面: $f(X) = 0.5$
- 几何重建
  - 隐式函数→体素化表示→网格



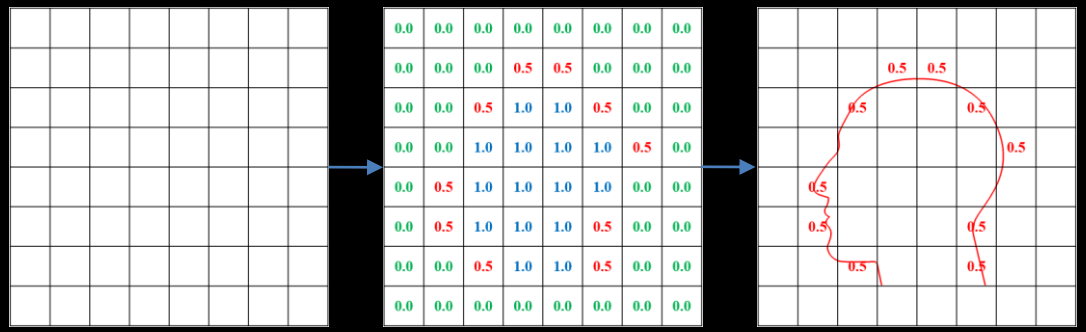
TSDF
$f(X) = 0$



Occupancy:
$f(X) = 0.5$

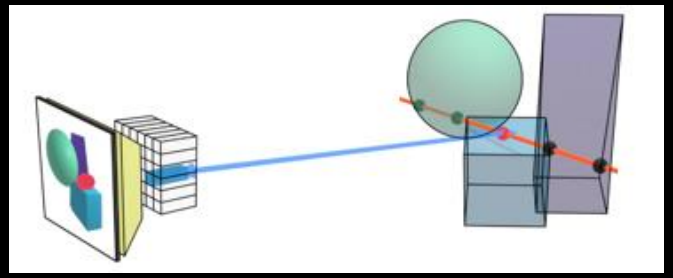


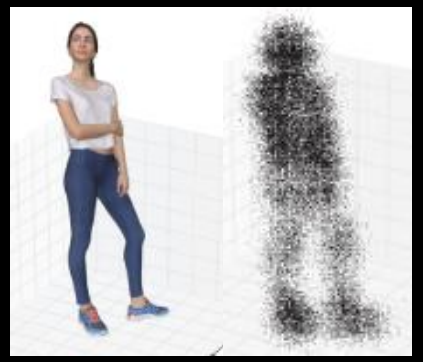
3D体素



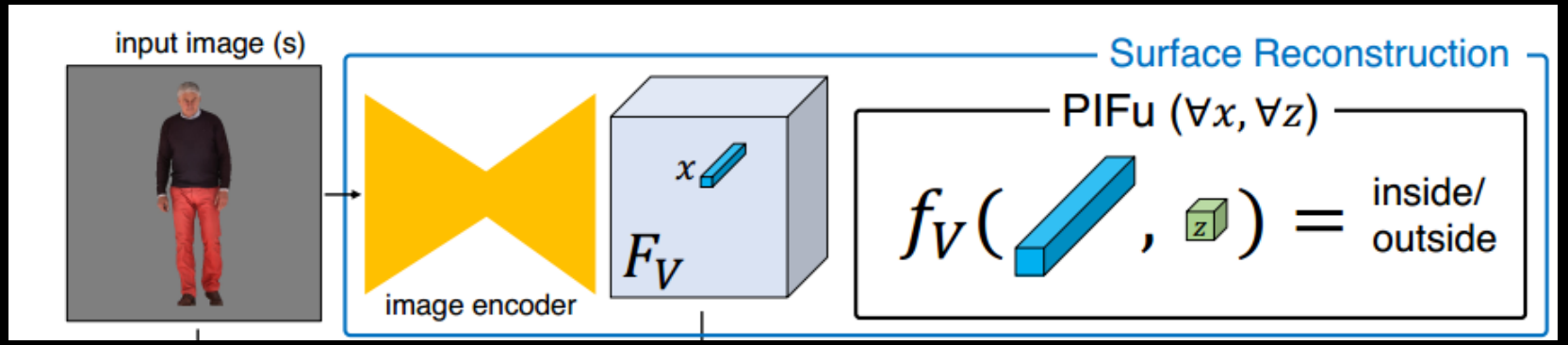
隐式函数的网格重建

学习隐式函数

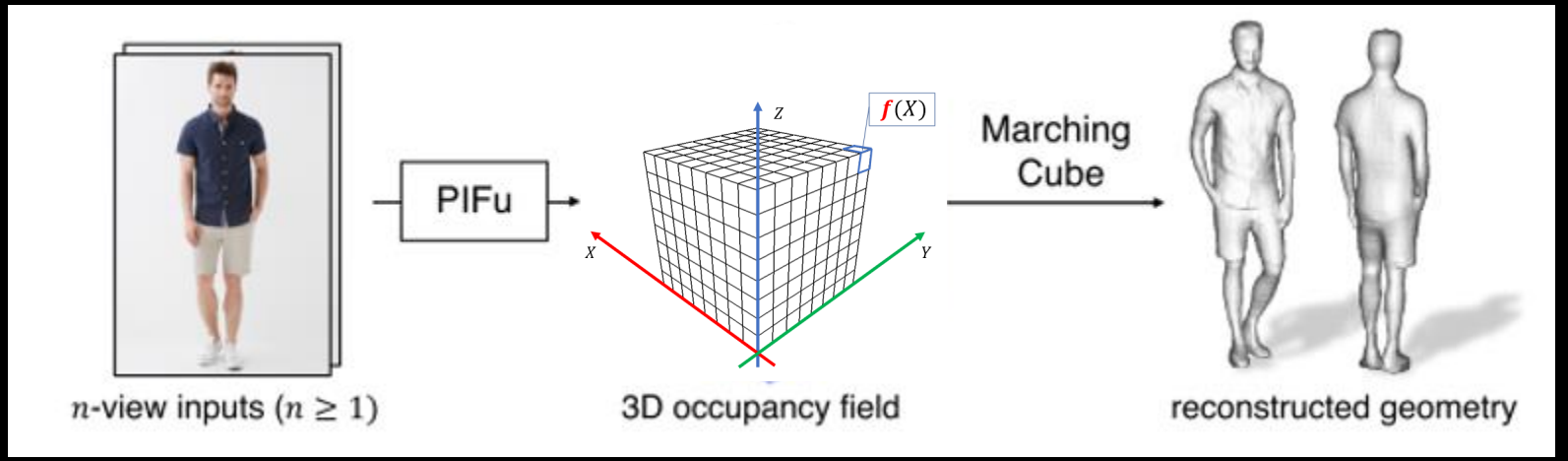




训练数据生成

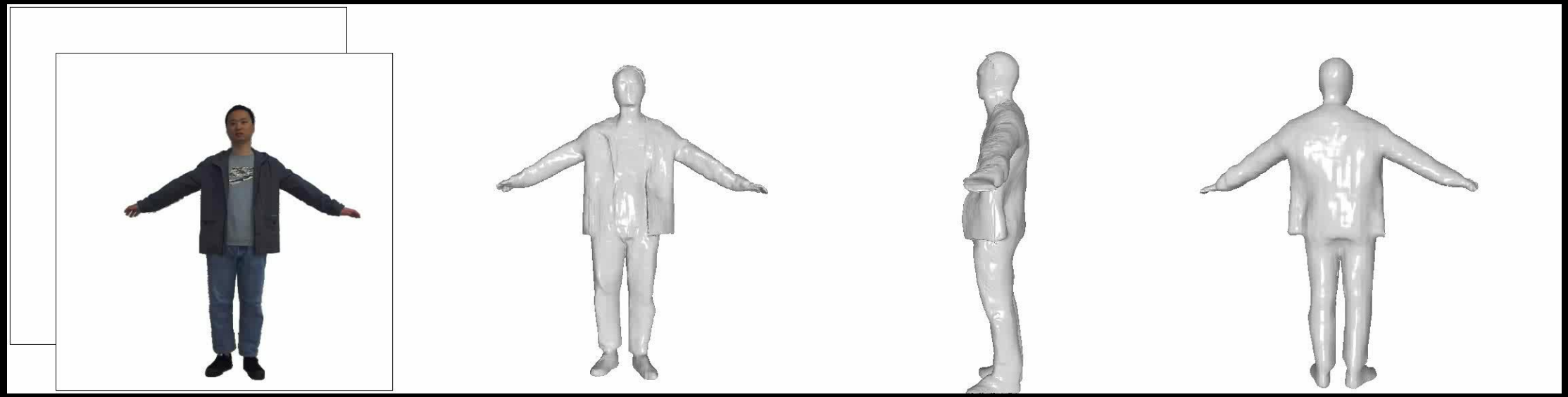


训练过程

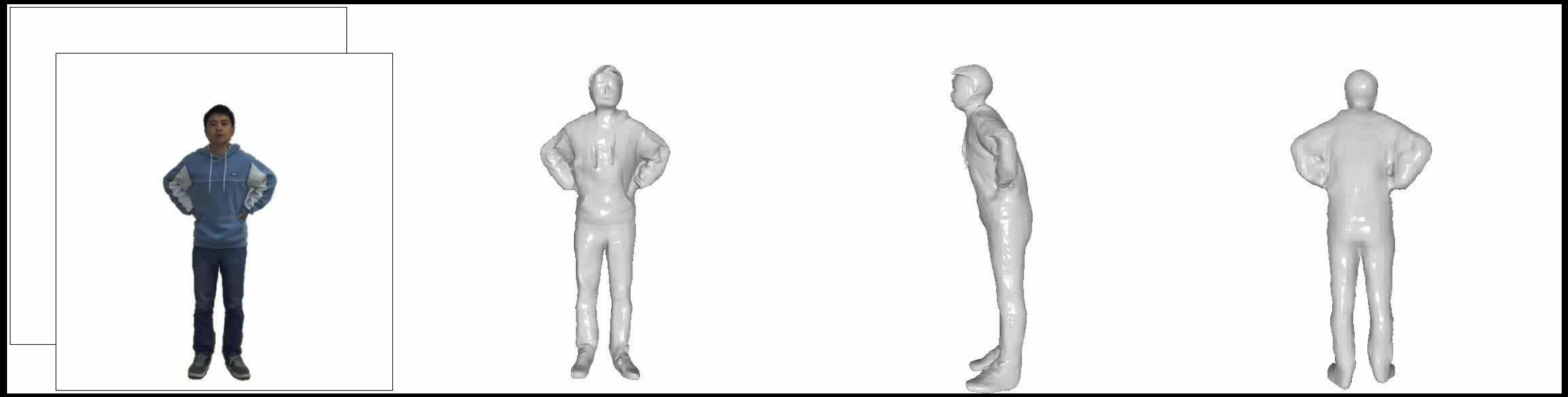


前馈测试过程

Experimental Results



Experimental Results



Example 6： Fabricating 2D Figure by Peeling

[Sigggraph 2019]

1. Peeling Art (by artist Yoshihiro Okada)

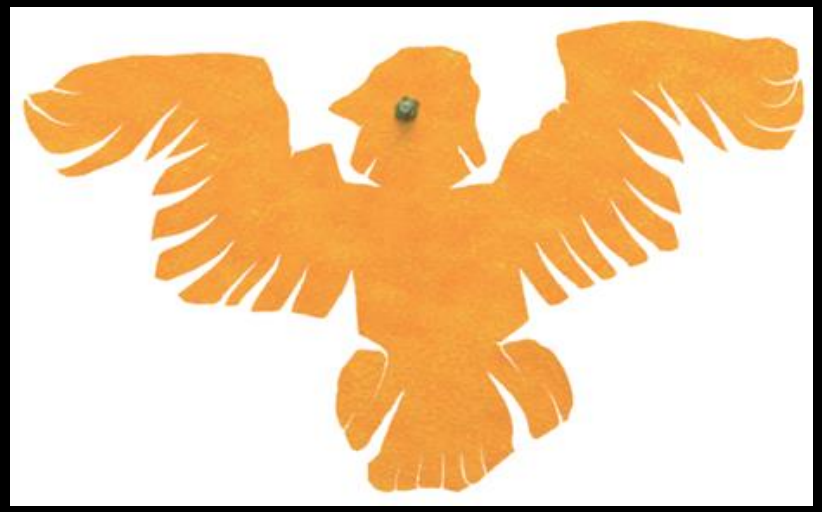
Peeling art examples
(by artist Yoshihiro Okada)

Okada’s method: trial-and-error experiments

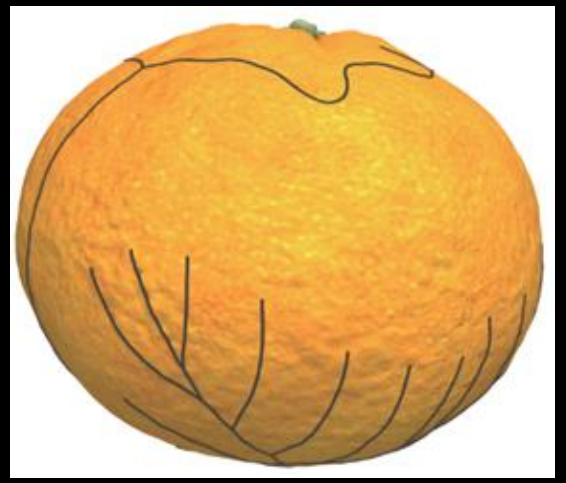
Peeling Art Design: A Geometric Problem

[Liu et al. Siggraph 2019]

- Given a 2D shape, the goal is to find a cutting path on the surface such that the surface is flattened into the shape with low distortion

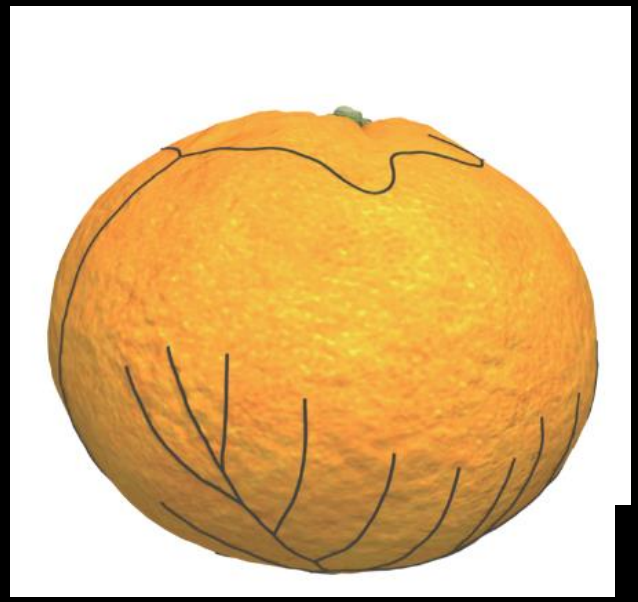


Input: A 2D shape

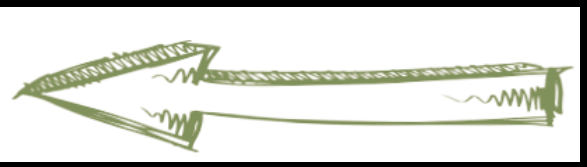


Output: A seam (cutting path) on the surface

Key idea

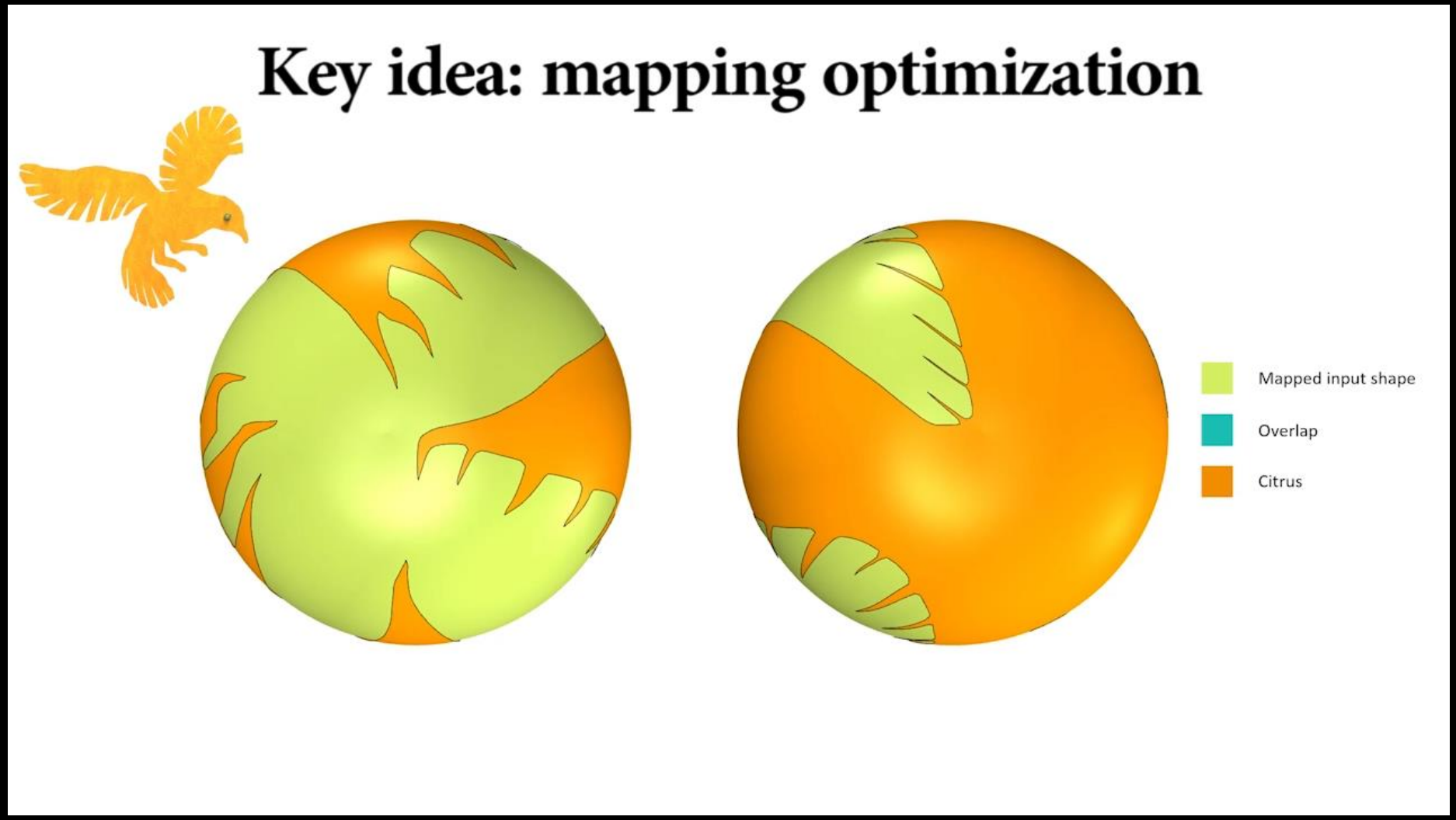


Cut generation
Difficult

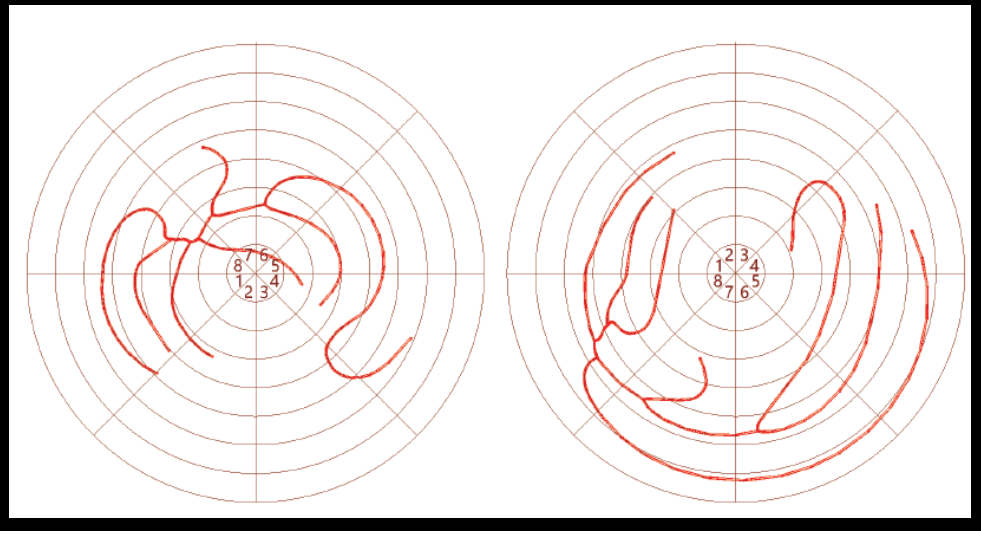


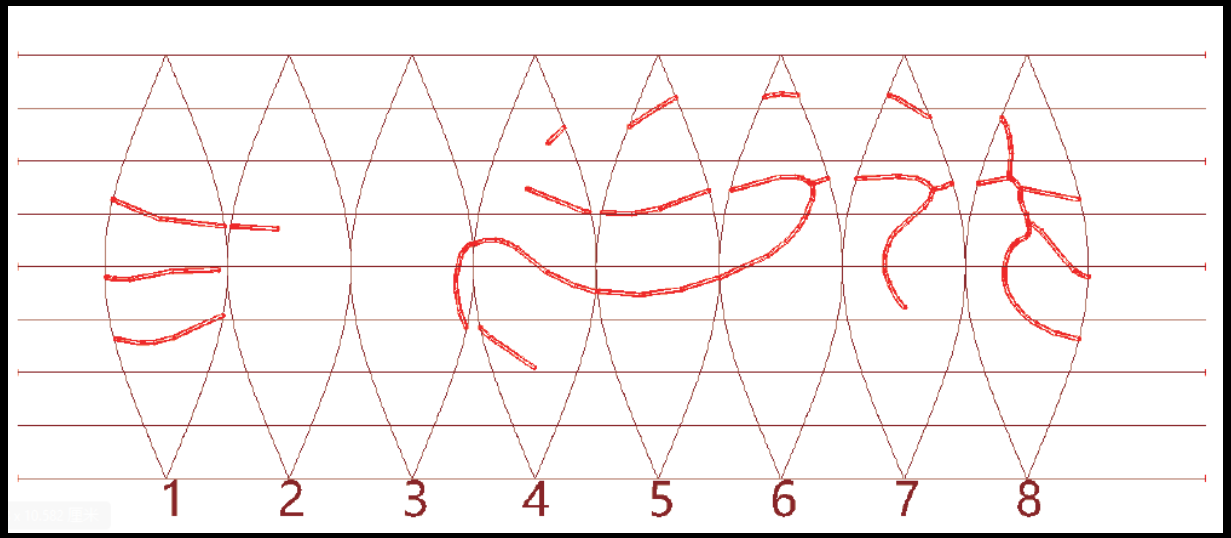
Mapping computation
Easy

Key idea: Mapping from 2D to 3D surface

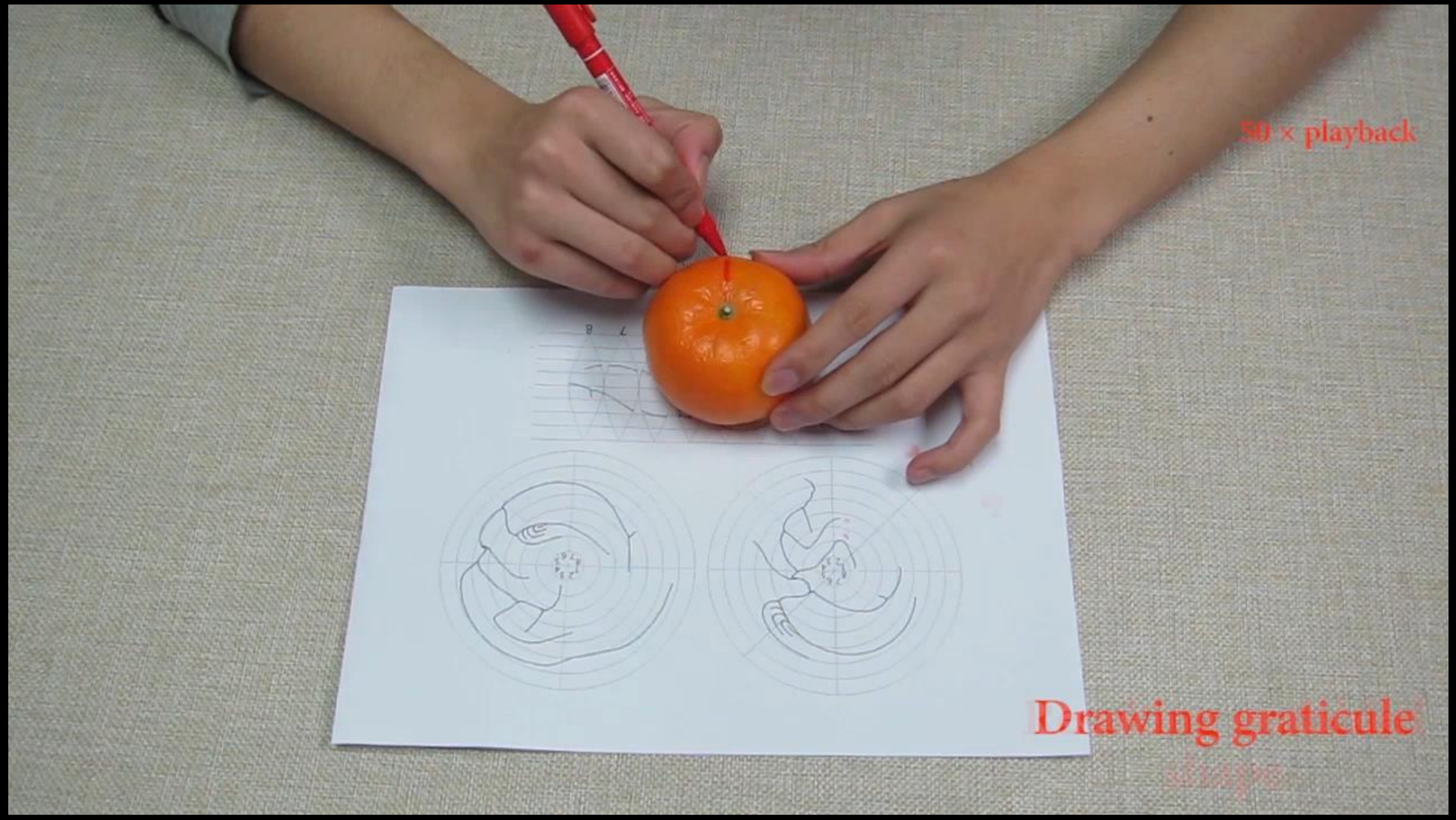


Cutting Guidance Generation





Real Peeling with Guidance



Comparisons to Okada’s works

Okada's

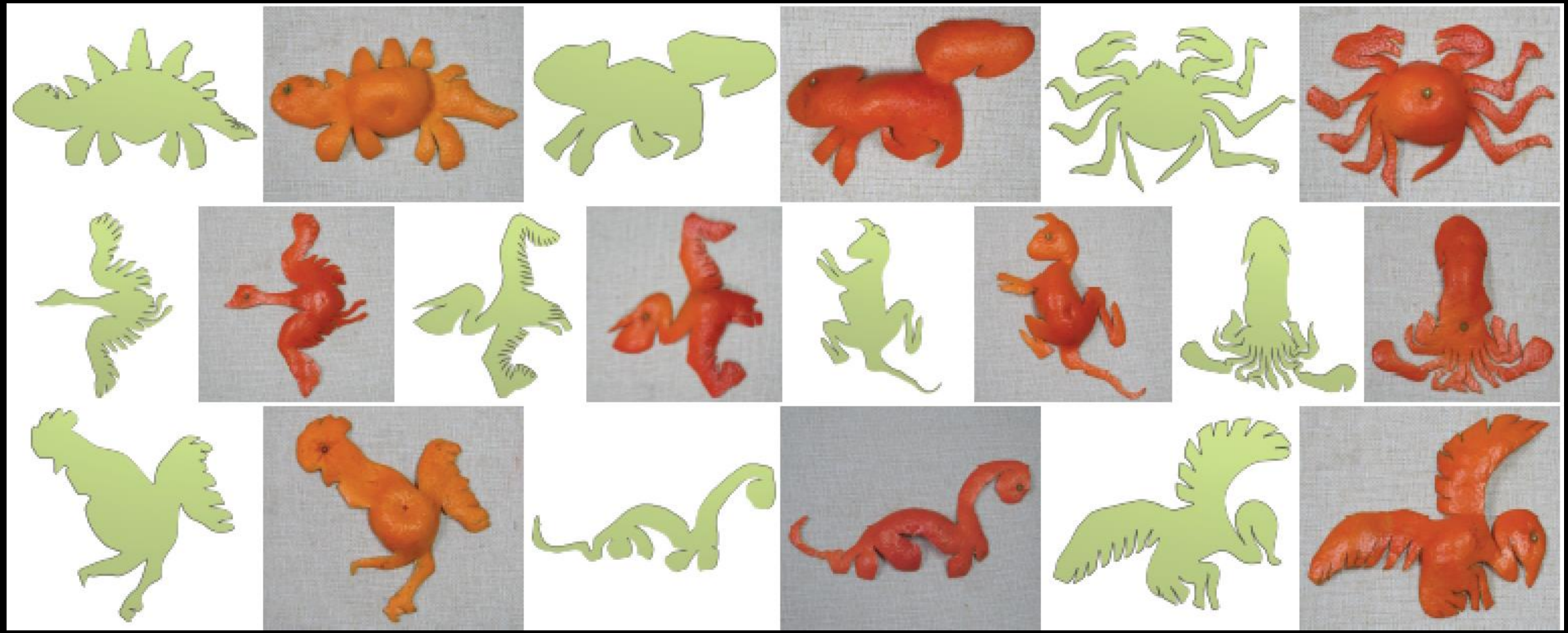
Ours

Dove

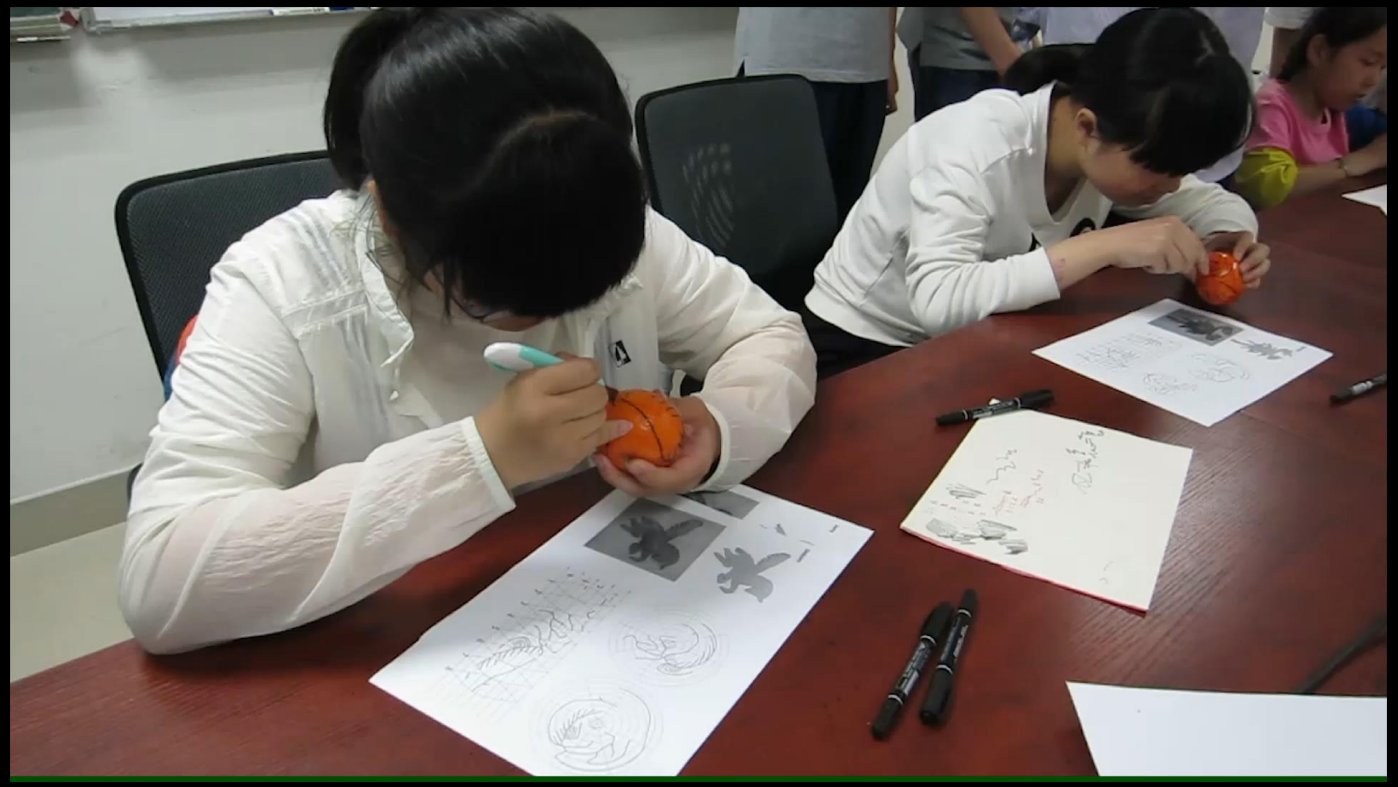
Eagle

Shrimp

Peeling Results using Our Method



Playing by Middle School Students



Playing by Primary School Students

Christmas Holiday Creation Event in UK (2019)

‘New Scientists’

Appealing peels

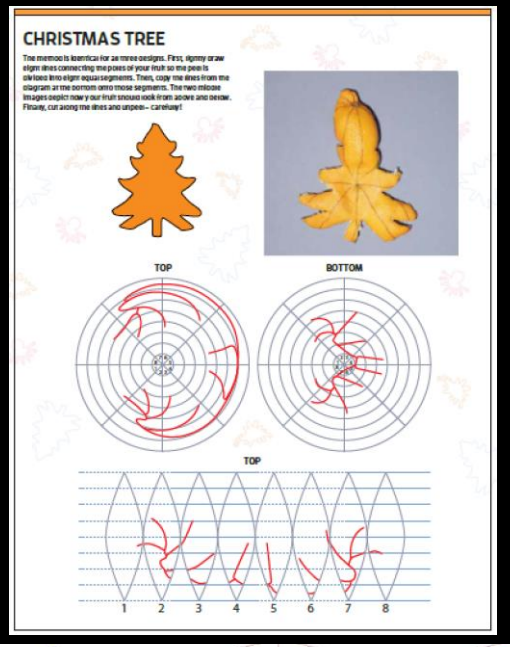
To help you celebrate the end of the year in style, we've teamed up with some computational artists to add a little zest to your holiday decorations.

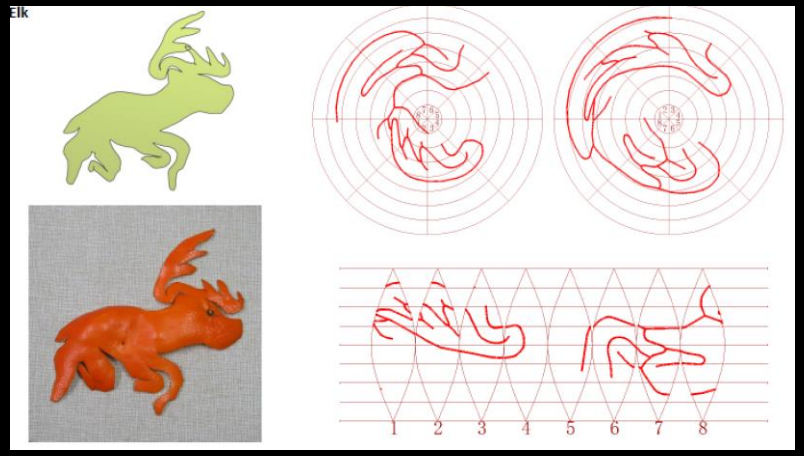
On the next three pages, you will find designs for three pieces of citrus peel art, along with instructions for how to produce them. We've chosen a Christmas tree because it is seasonal, an octopus because of our fantastic octopus feature on page 52 and a stegosaurus because, let's face it, who doesn't love a dinosaur?

Make your own unique holiday diorama and tweet us pictures of your creations with the hashtag #NScitruspeel. So grab a satsuma, a mandarin, a clementine, an orange, a grapefruit, a tangerine or – if you are feeling particularly dextrous – a kumquat – and get peeling!

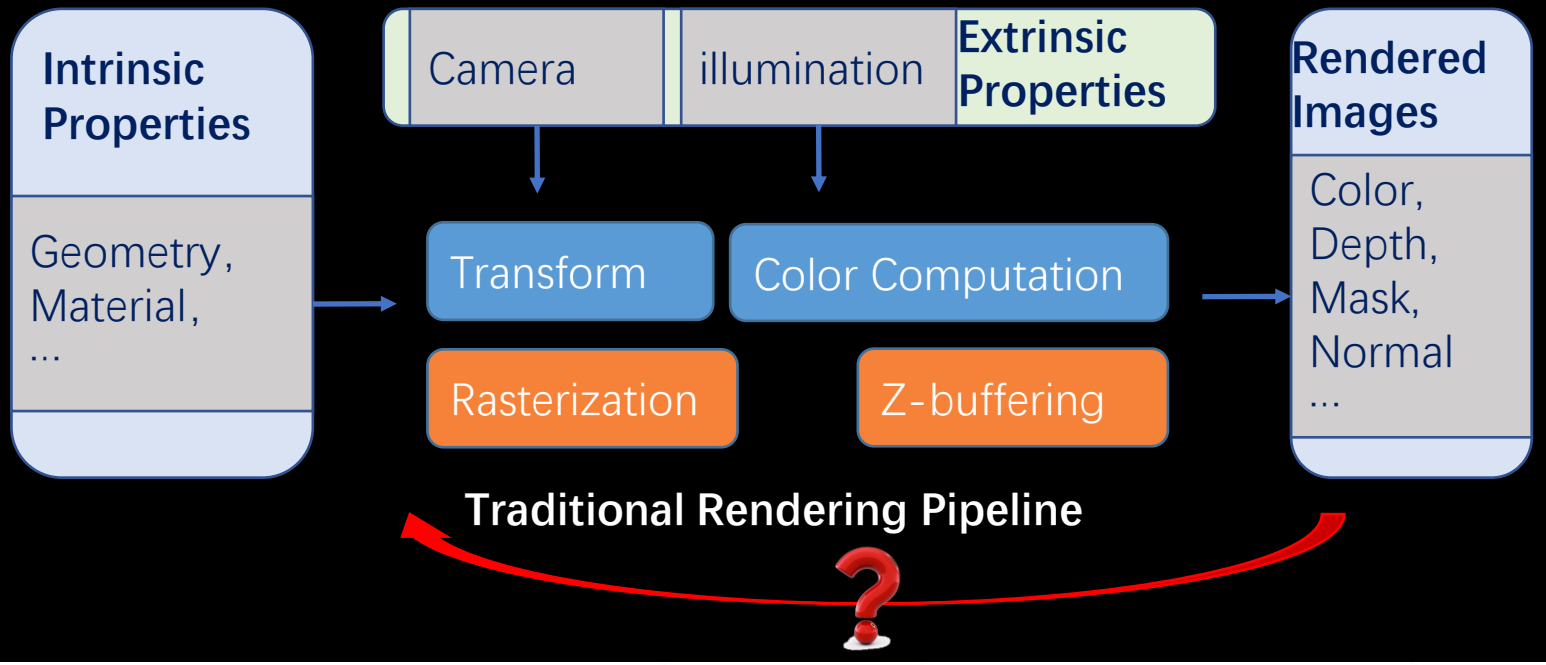
Templates and instructions by Hao Liu phaoliu.github.io

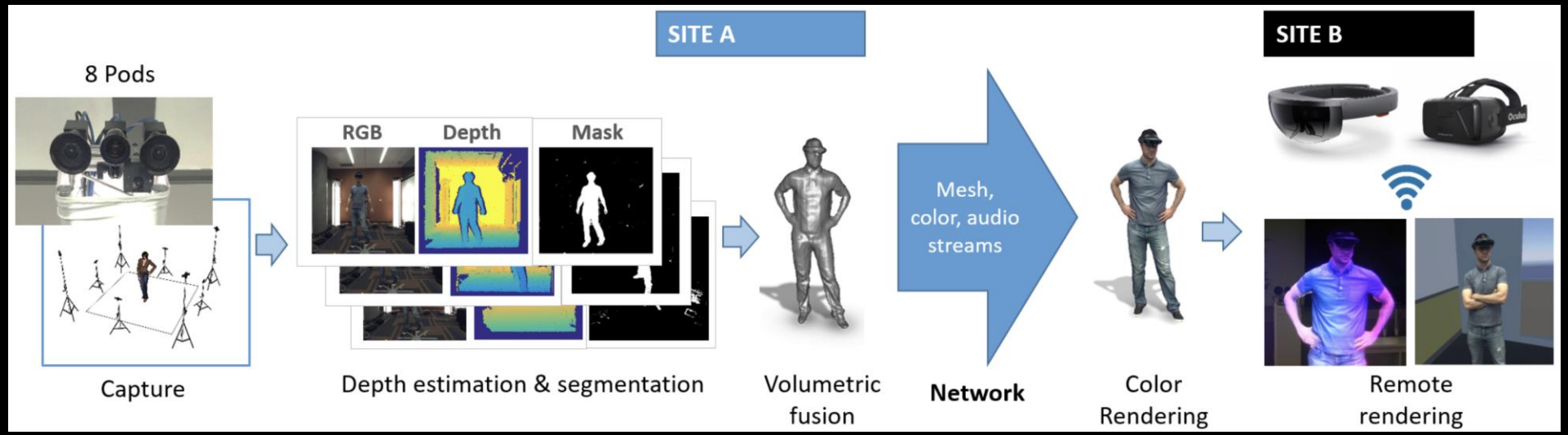
Available for download at: newscientist.com/peel-art



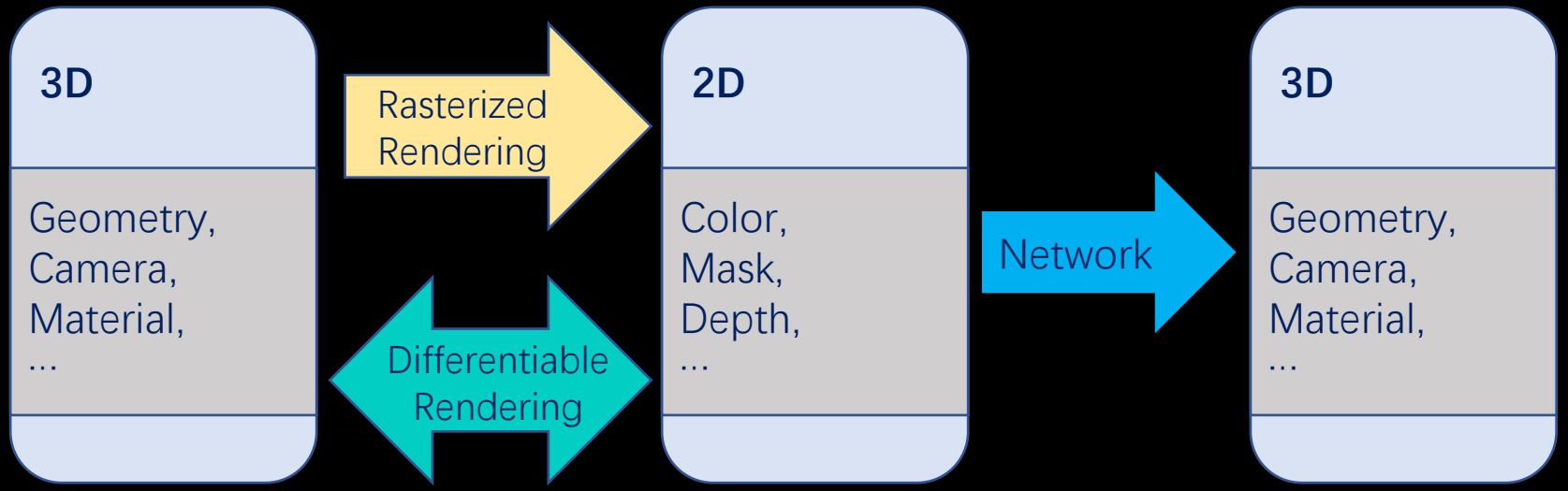


Differentiable Rendering


Intrinsic Properties
Geometry,
Material,
…
Camera
illumination
Extrinsic Properties
Transform
Color Computation
Rasterization
Z-buffering
Rendered Images
Color,
Depth,
Mask,
Normal
…
Traditional Rendering Pipeline

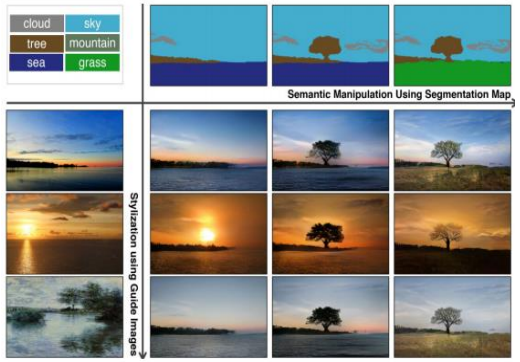

SITE A
SITE B
8 Pods
RGB
Depth
Mask
Mesh, color, audio streams
Capture
Depth estimation & segmentation
Volumetric fusion
Network
Color Rendering
Remote rendering

Differentiable Rendering



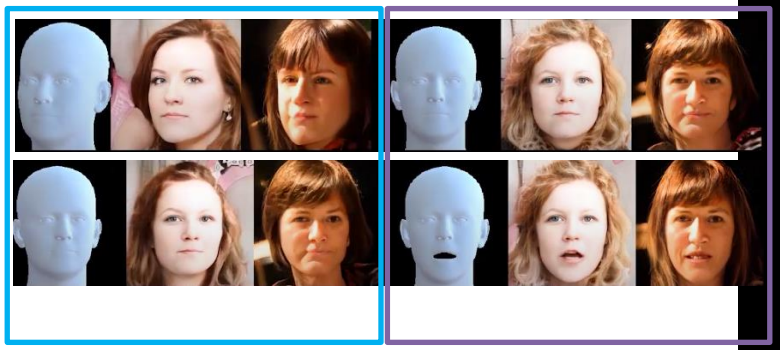
- Learning method:
  - Find a function f, s.t $\boldsymbol{G} = \boldsymbol{f}(\boldsymbol{I})$
- Differentiable/Neural Rendering:
  - Let the optimization: $\underset{\boldsymbol{G}}{\mathbf{argmin}} \, \|\boldsymbol{R}(\boldsymbol{G}) - \boldsymbol{I}\|$ be differentiable.

Differentiable/Neural Rendering

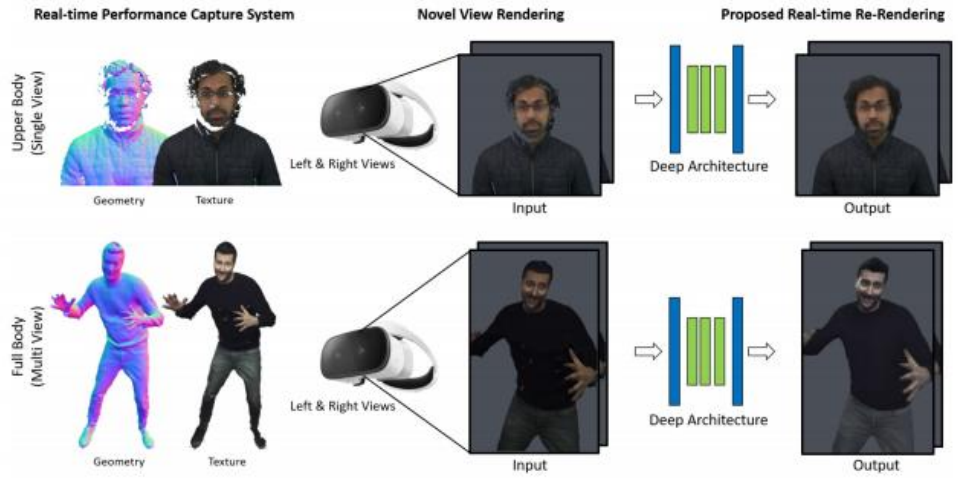


GauGAN. CVPR 2019

GANPaint . ACM ToG 2019



GIF. 3DV 2019



LookinGood. ACM ToG 2018

Portrait relighting. ACM ToG 2019

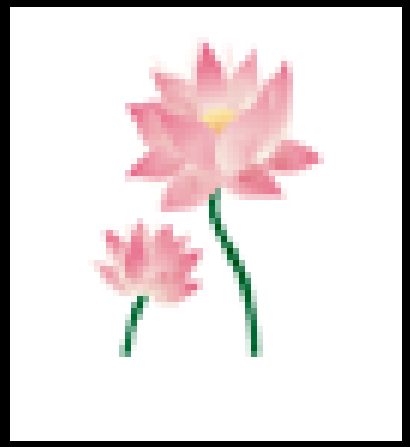
Example 7： Mirror Art

[Ongoing]

Mirror Cup Art

Reflection Art

问 题

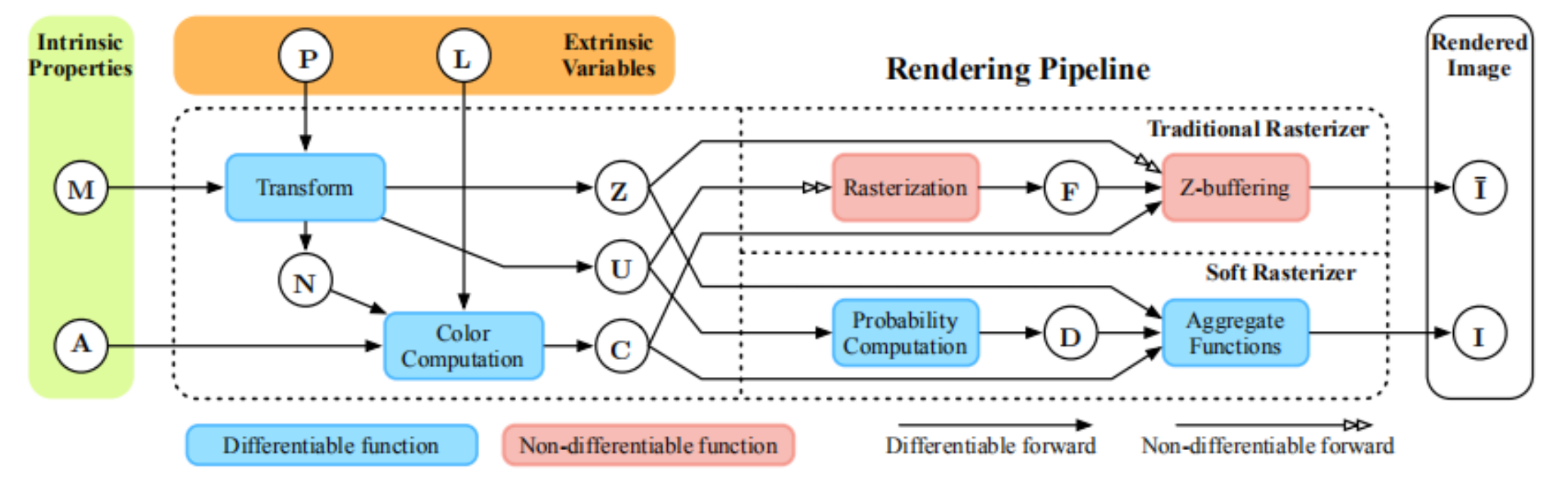


输入：两幅图片

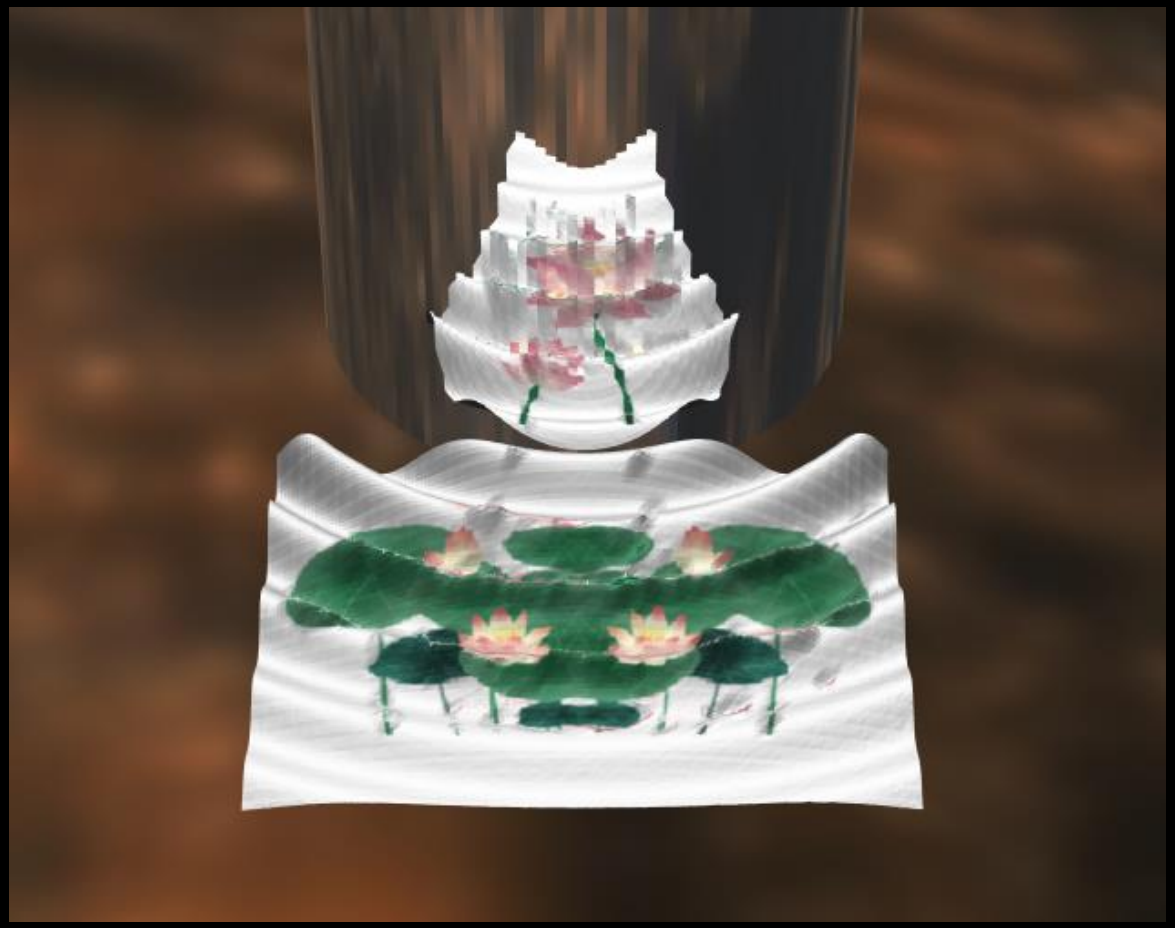
输出：反射曲面

实物产品

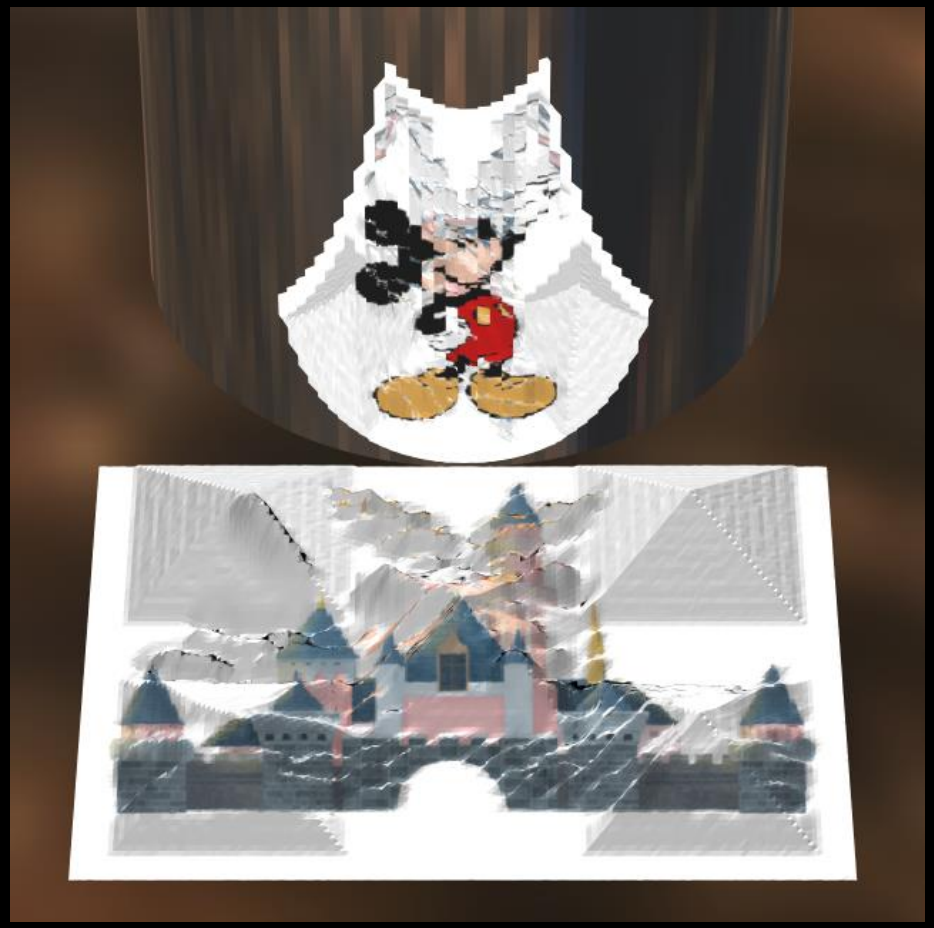
思路：可微渲染


Intrinsic Properties
P
L
Extrinsic Variables
Rendering Pipeline
Rendered Image
Traditional Rasterizer
M
Transform
Z
Rasterization
F
Z-buffering
Ī
N
U
Soft Rasterizer
A
Color Computation
C
Probability Computation
D
Aggregate Functions
I
Differentiable function
Non-differentiable function
Differentiable forward
Non-differentiable forward

试验结果-1



试验结果-2

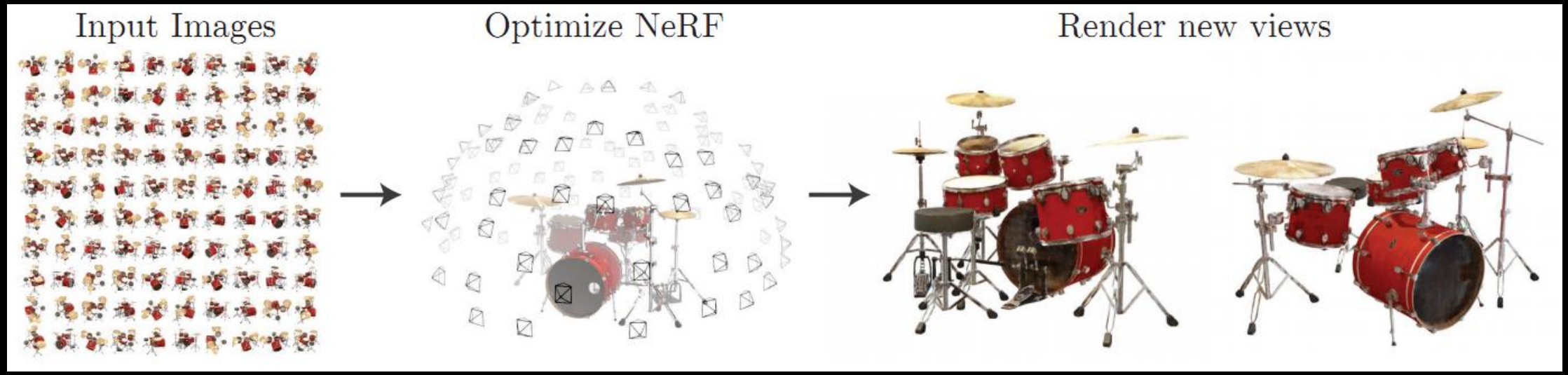


试验结果-3

NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis

Ben Mildenhall[1⋆] Pratul P. Srinivasan[1⋆] Matthew Tancik[1⋆]
Jonathan T. Barron[2] Ravi Ramamoorthi[3] Ren Ng[1]

[1]UC Berkeley [2]Google Research [3]UC San Diego

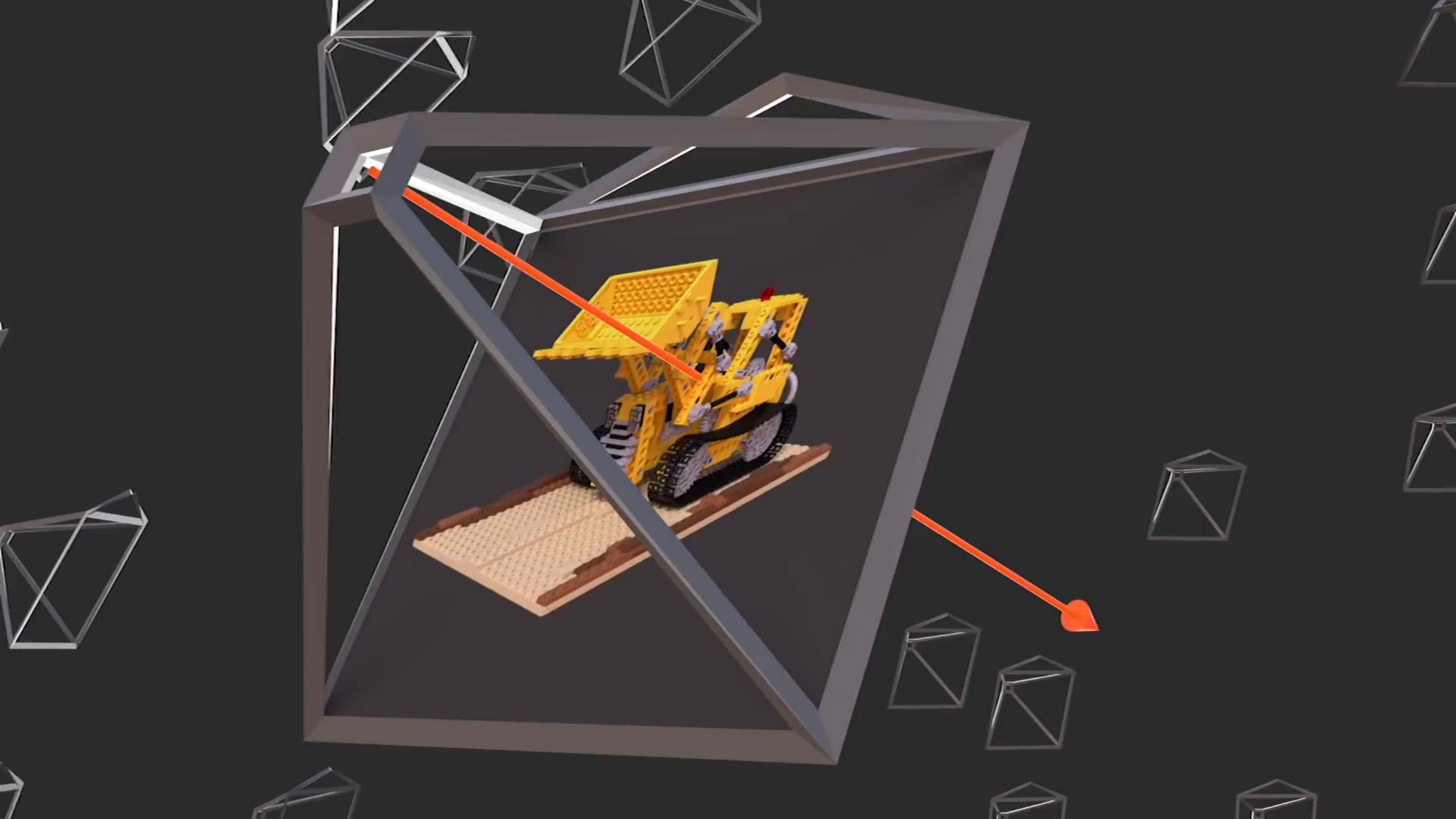


将传统渲染管线(体渲染)和神经网络相结合 (ECCV 2020)

效果展示

100 张图片作为输入

20-62 张图片作为输入



语音驱动的说话人

张举勇（中科大）

Audio Source

Audio Driven Results

背景与角度编辑

张举勇（中科大）

Original

Self-driven

Background Editing

Pose Editing

基于神经渲染的人脸参数化模型表示

张举勇（中科大）

- 主要优势：
  - 可解耦控制：身份，表情，光照，年龄等
  - 支持多视角一致的颜色渲染，且渲染结果具有高真实感
  - 可直接应用于人脸重建，全息通信，AR/VR等

控制身份

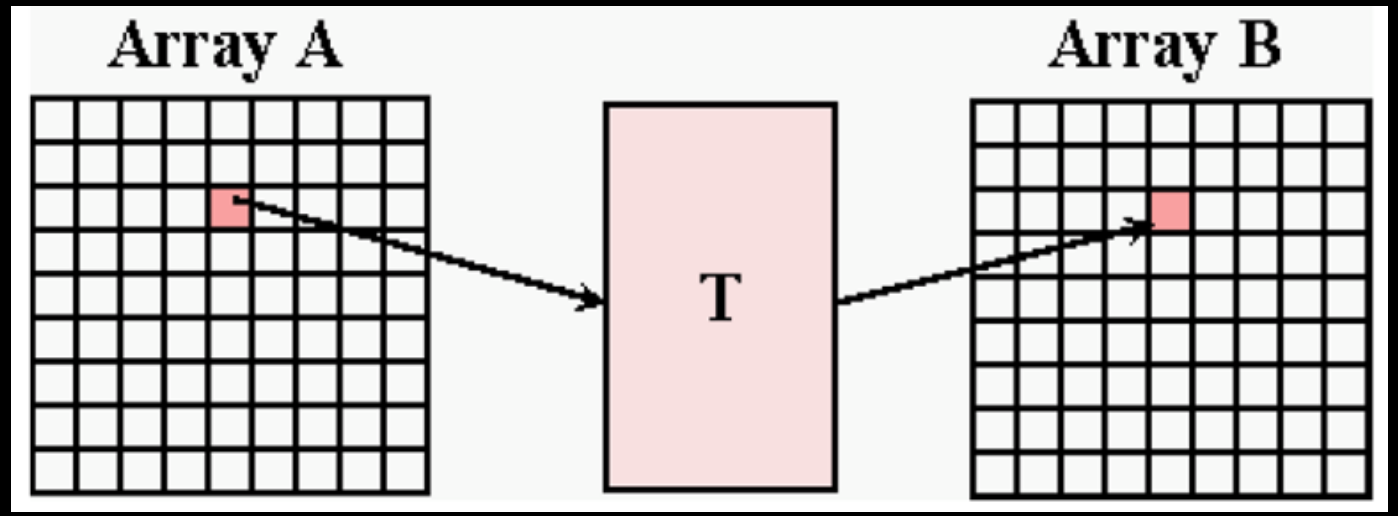
控制表情

控制光照

Summary

可视计算：图形+图像+视觉

- 利用图像中蕴含的三维几何信息来引导处理计算



3D几何模型计算

图形计算：再造平行世界、数字孪生世界

- 1. 图形计算：再造世界之“彩”--仿色彩之真，求美
- 2. 图形计算：再造世界之“动”--仿运动之真，求真
- 3. 图形计算：再造世界之“形”--仿几何之真，求精

GAMES: Graphics And Mixed Environment Symposium

图形学与混合现实在线平台

- 主页：**http://games-cn.org**
- 宗旨：图形学及相关领域交流的华人在线社区
- 隶属：中国计算机学会计算机辅助设计与图形学专委会
  - 线下活动：2016年4月创建（鲍虎军）
  - 线上活动：2017年6月创建（刘利刚）
    - 线上活动运营负责人：刘利刚（2017.6.-2018.12.），周晓巍（2019.1.-至今）
- 在线直播活动：所有资料（视频/PPT）云端保存，总观看 100+ 万人次
  - 每周四晚8:00-9:30的在线报告（166期）
  - 专题：几何、绘制、模拟、视觉、可视化…
  - 课程：101（闫令琪）、201（胡渊鸣）、102（刘利刚）、202（闫令琪）
    - 已规划：203（黄其兴）、103（王华明）
- 在线交流微信群：16个群（7600+人）

加入微信群的方法：在微信中搜索微信号gamesrobot3或扫描二维码，加gamesrobot3为好友；然后回复“GAMES”即可获取群聊邀请。

GAMES主页及资源
http://games-cn.org

相关专著书籍

连续几何

王国瑾、刘利刚
科学出版社
2015年2月

离散几何

鲍虎军、黄劲、刘利刚
科学出版社
2021年4月

近期学习和会议信息

- GAMES 2021 & CAD/Graphics 2021，5月14-16日，西安
  - http://event.icrp.xjtu.edu.cn/106149063
- 中国科学技术大学《计算机图形学前沿》暑期课程，7月5-9日，合肥
  - http://staff.ustc.edu.cn/~lgliu/Courses/SummerSchool/USTC-summer-school.html
- CCF CAD&CG 2021，8月19-22日，大连
  - http://cs.dlut.edu.cn/CADCG2021/CADCG2021sy.htm
- CSIAM GDC 2021，10月15-17日，长沙
  - http://gdc21.csiam-gdc.cn

谢 谢！