Dynamic 3D Gaussian Splatting

Part of a Tutorial on 3D Gaussian Splatting at 3DV 2024

Jonathon Luiten

Dynamic 3D Gaussian Splatting

Dynamic Gaussian Splatting has Exploded!

First paper on ArXiv 18th Aug 2023. 7 Months later ~50 papers.

Dynamic 3D Gaussians: Tracking by Persistent Dynamic View Synthesis

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[1] Carnegie Mellon University, USA [2] RWTH Aachen University, Germany [3] Inria & Université Côte d'Azur, France
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4D Gaussian Splatting: Towards Efficient Novel View Synthesis for Dynamic Scenes

Yuanxing Duan[1]* Fangyin Wei[2]* Qiyu Dai[1,4] Yuhang He[1] Wenzheng Chen[3†] Baoquan Chen[1,4†]
[1]Peking University [2]Princeton University [3]NVIDIA [4]National Key Lab of General AI, China

REAL-TIME PHOTOREALISTIC DYNAMIC SCENE REPRESENTATION AND RENDERING WITH 4D GAUSSIAN SPLATTING

Zeyu Yang, Hongye Yang, Zijie Pan, Li Zhang*
Fudan University
https://fudan-zvg.github.io/4d-gaussian-splatting

Deformable 3D Gaussians for High-Fidelity Monocular Dynamic Scene Reconstruction

Ziyi Yang[1,2] Xinyu Gao[1] Wen Zhou[2] Shaohui Jiao[2] Yuqing Zhang[1] Xiaogang Jin[1†]
[1]State Key Laboratory of CAD&CG, Zhejiang University [2]ByteDance Inc.

4D Gaussian Splatting for Real-Time Dynamic Scene Rendering

Guanjun Wu[1*], Taoran Yi[2*], Jiemin Fang[3†], Lingxi Xie[3], Xiaopeng Zhang[3], Wei Wei[1], Wenyu Liu[2], Qi Tian[3], Xinggang Wang[2†‡]
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GauFRe: Gaussian Deformation Fields for Real-time Dynamic Novel View Synthesis

Yiqing Liang[‡], Numair Khan, Zhengqin Li, Thu Nguyen-Phuoc, Douglas Lanman, James Tompkin[‡], Lei Xiao
Meta [‡]Brown University

MD-Splatting: Learning Metric Deformation from 4D Gaussians in Highly Deformable Scenes

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An Efficient 3D Gaussian Representation for Monocular/Multi-view Dynamic Scenes

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DynMF: Neural Motion Factorization for Real-time Dynamic View Synthesis with 3D Gaussian Splatting

Agelos Kratimenos Jiahui Lei Kostas Daniilidis
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Gaussian-Flow: 4D Reconstruction with Dynamic 3D Gaussian Particle

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Spacetime Gaussian Feature Splatting for Real-Time Dynamic View Synthesis

Zhan Li[1,2*] Zhang Chen[1†] Zhong Li[1†] Yi Xu[1]
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https://oppo-us-research.github.io/SpacetimeGaussians-website/

Dynamic 3D Gaussians

Dynamic 3D Gaussians:
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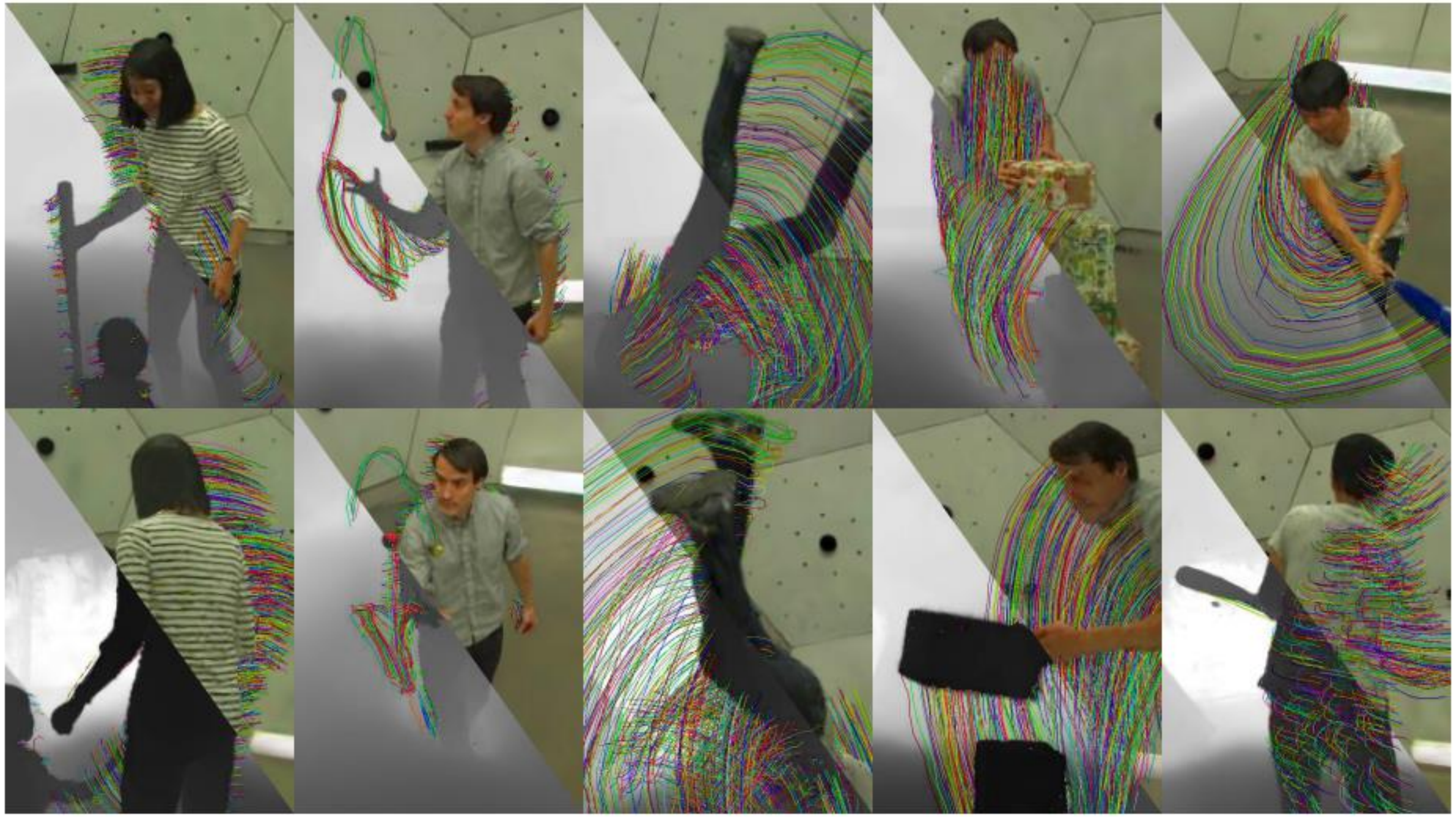


Analysis-by-Synthesis for Tracking and Dynamic 3D?

A Good Representation

Gaussians?

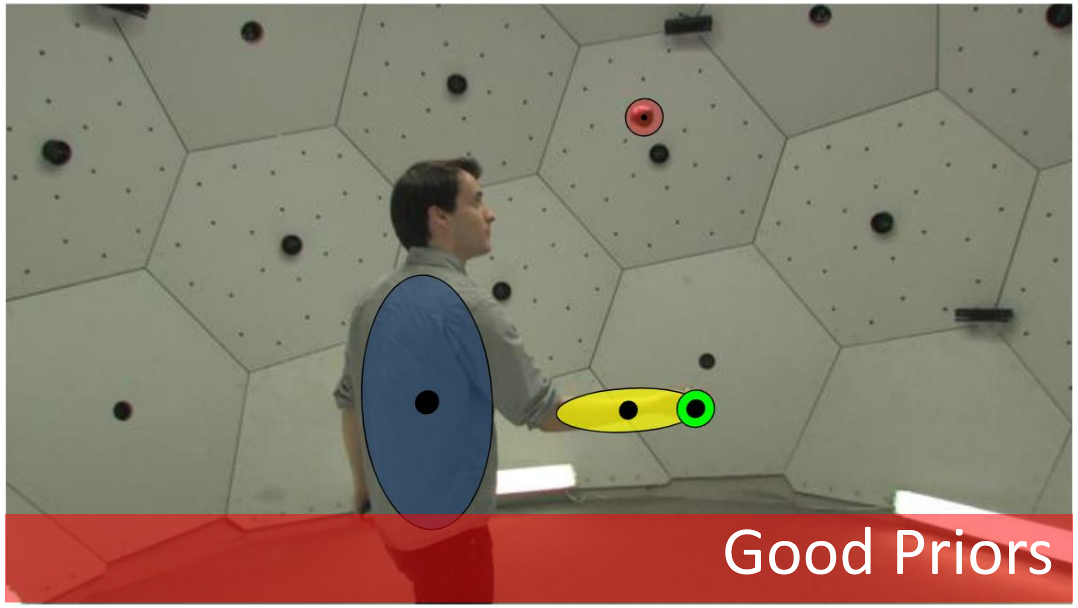
BANMo

Fuzzy Metaballs

3D Gaussian Splatting

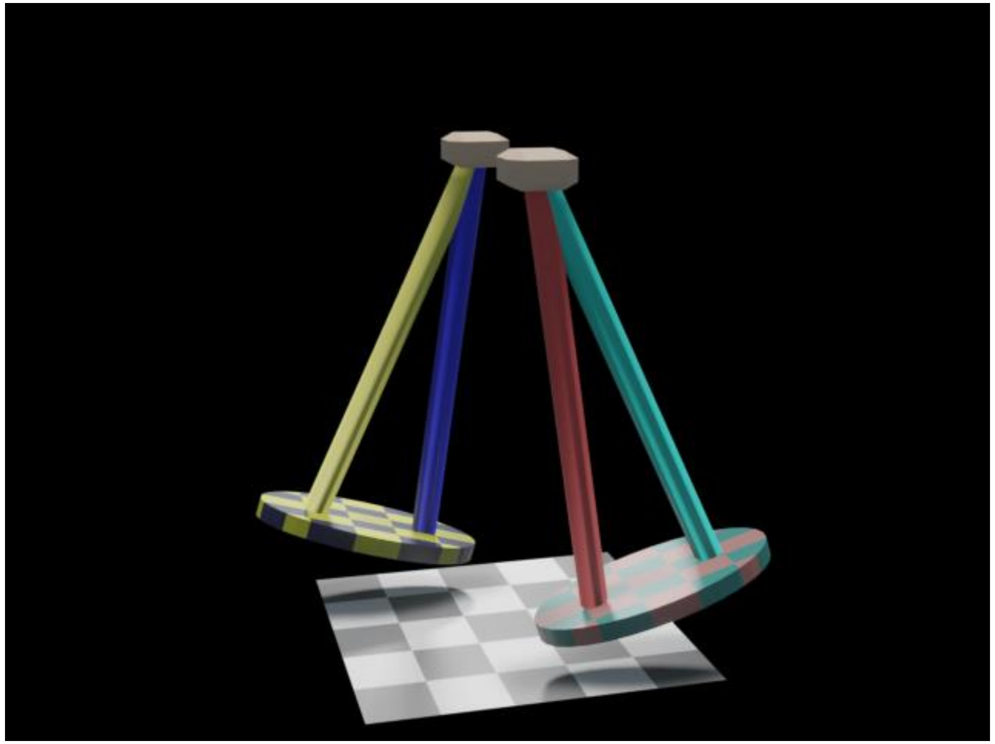
Dynamic 3D Gaussian Splatting?

What is needed?

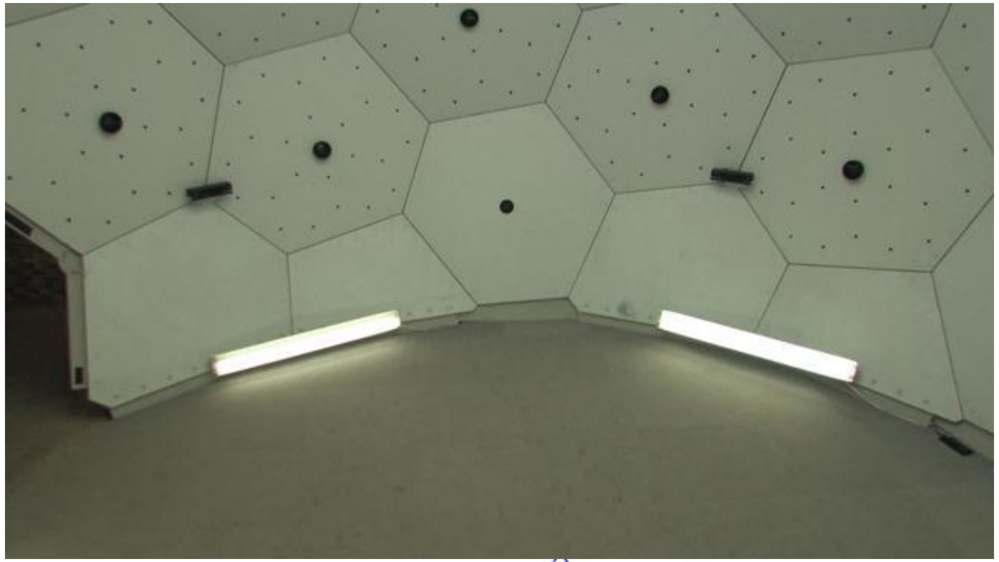


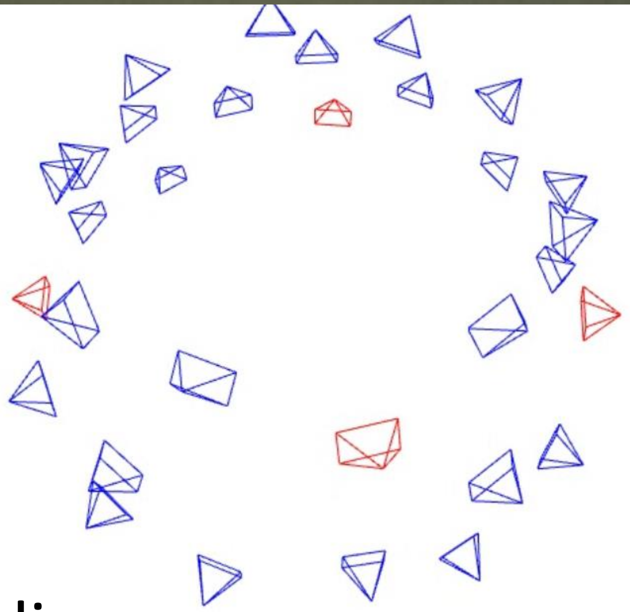
What is needed?

Good Data



Pixel NeRF





Panoptic Studio

Good Data

D-Nerf

Neural 3D Video

What is needed?

3D Gaussians

$$f_{i,t}(p) = \text{sigm}(o_i) \exp\left(-\frac{1}{2}(p - \mu_{i,t})^T \Sigma_{i,t}^{-1} (p - \mu_{i,t}) \right)$$

$$\Sigma_{i,t} \quad = \quad R_{i,t} S_i S_i^T R_{i,t}^T$$

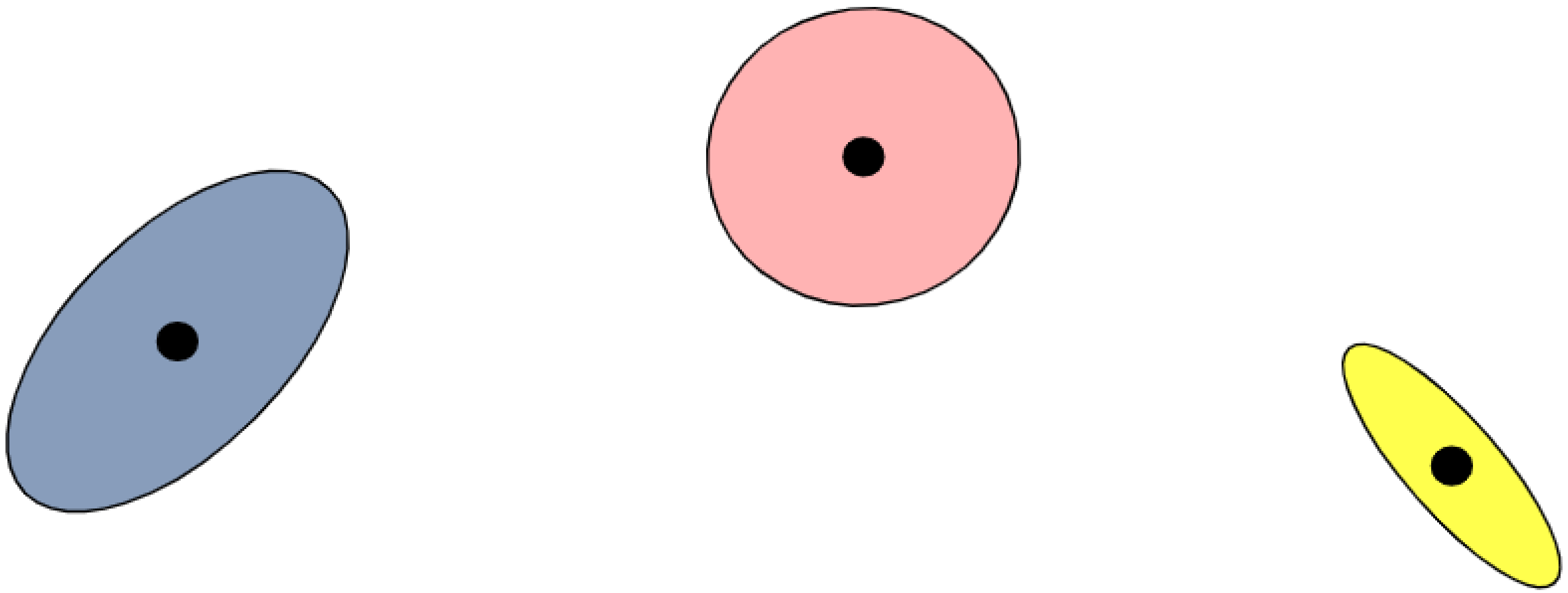
3D Center

3D Size

3D Rotation

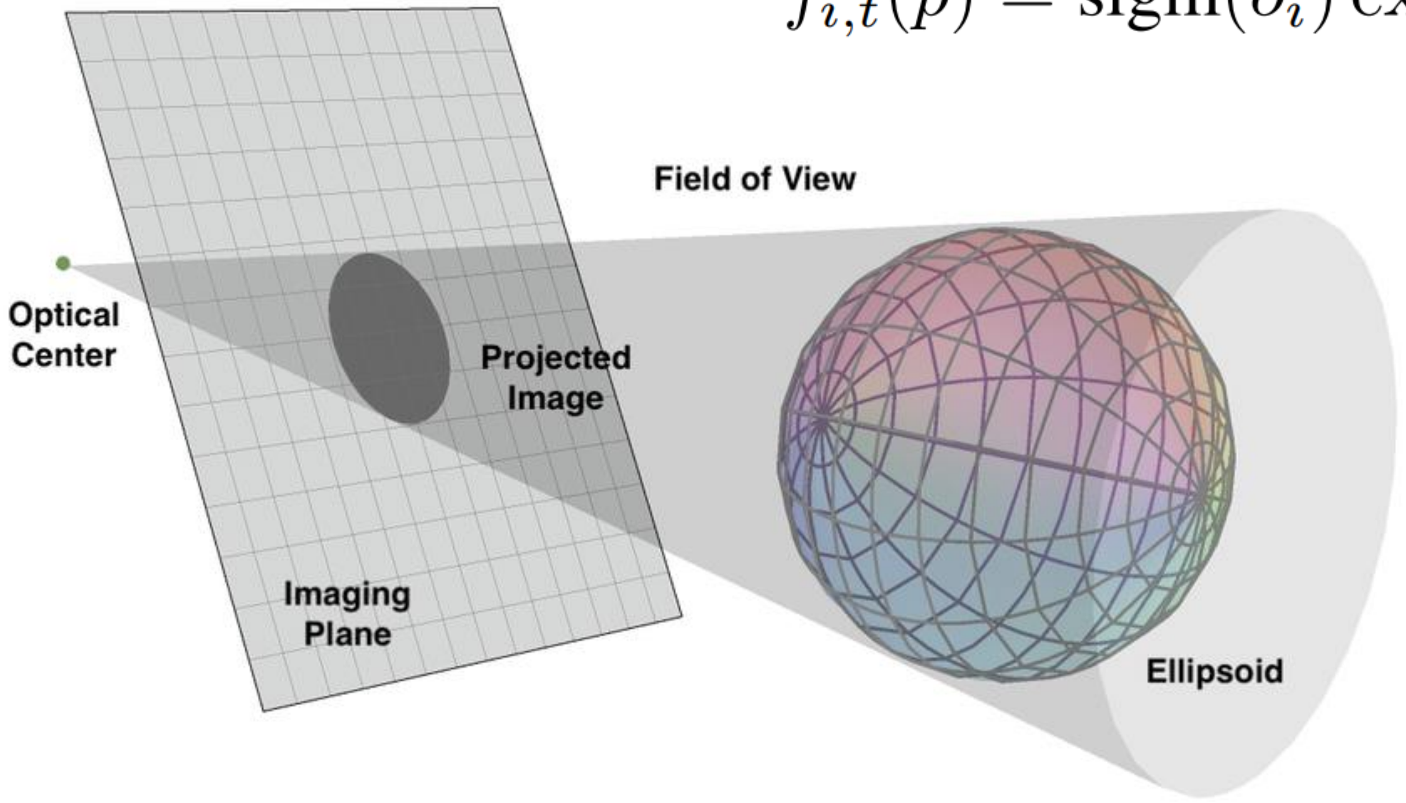
Color

Opacity



Rendering 3D Gaussians

$$f_{i,t}(p) = \mathrm{sigm}(o_i) \exp\left(-\frac{1}{2}(p - \mu_{i,t})^T \Sigma_{i,t}^{-1} (p - \mu_{i,t})\right)$$

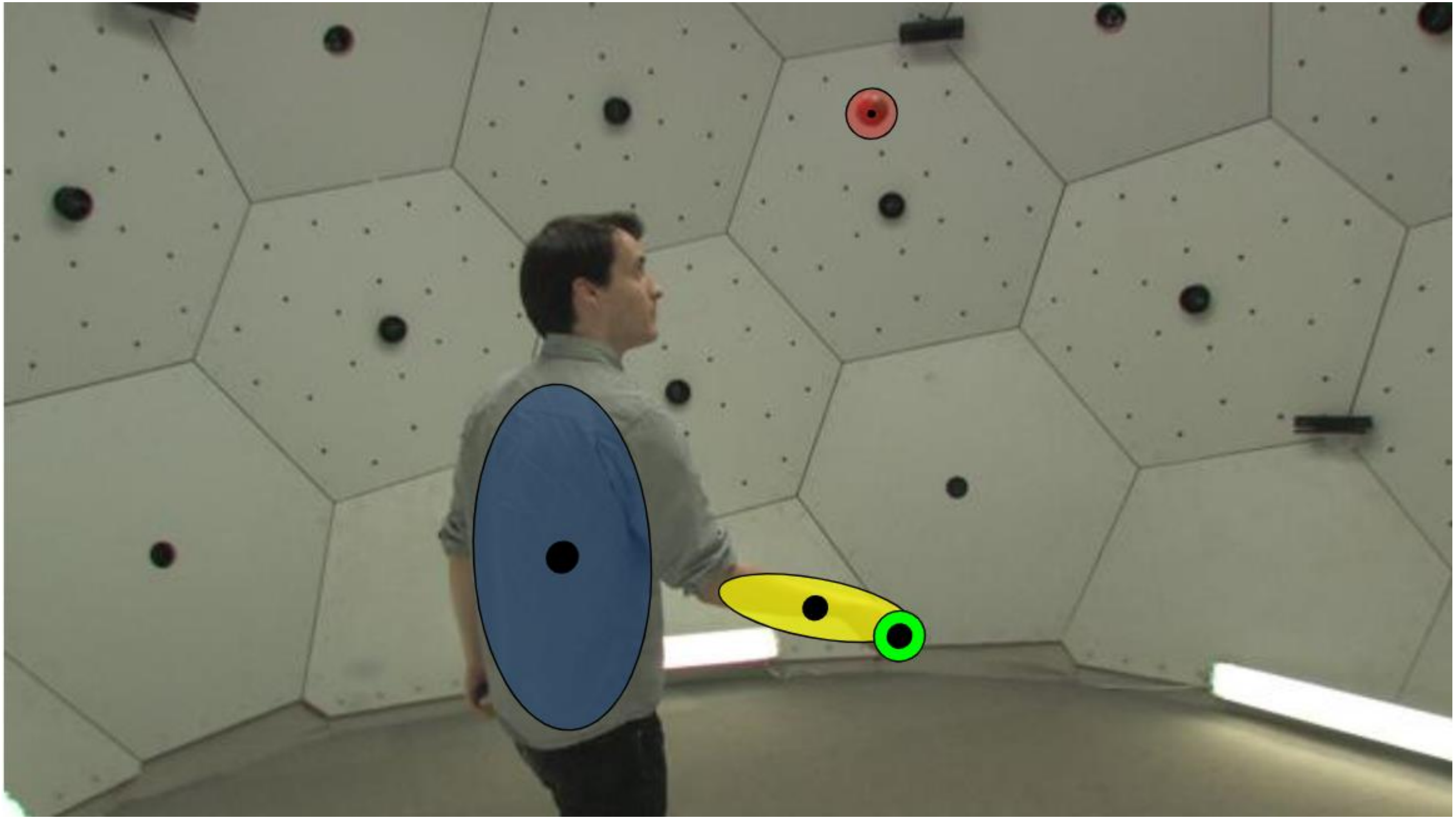


$$\mu^{\mathrm{2D}} = K\left((E\mu)/(E\mu)_z\right)$$

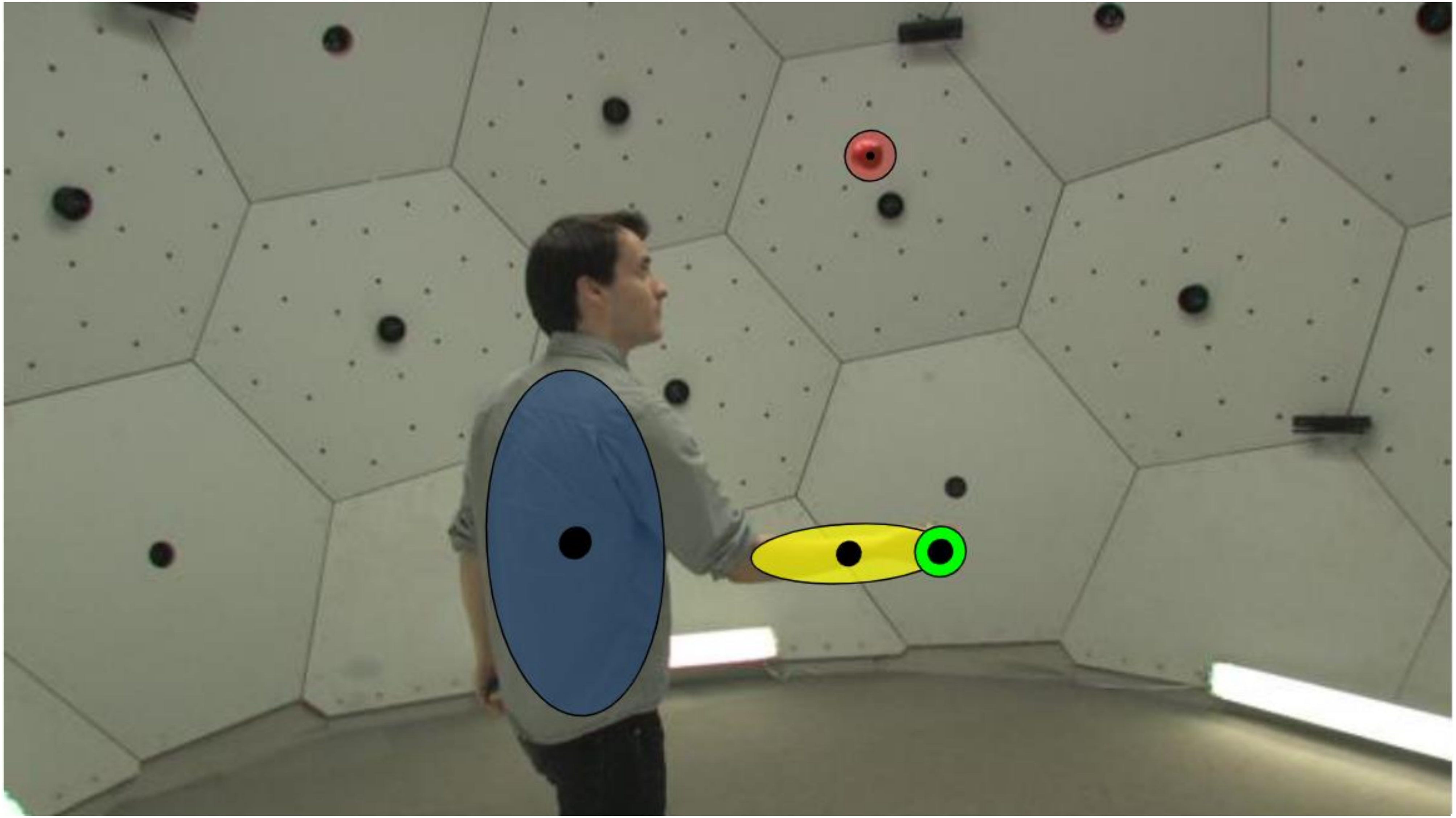
$$\Sigma^{\mathrm{2D}} = JE\Sigma E^T J^T$$

$$C_{\mathrm{pix}} = \sum_{i \in \mathcal{S}} c_i f_{i,\mathrm{pix}}^{\mathrm{2D}} \prod_{j=1}^{i-1} (1 - f_{j,\mathrm{pix}}^{\mathrm{2D}})$$

Making 3D Gaussians Move



Making 3D Gaussians Move



Making 3D Gaussians Move

Fixed / Consistent over time:

3D Size

Color

Opacity

Changing over time (per timestep):

3D Center

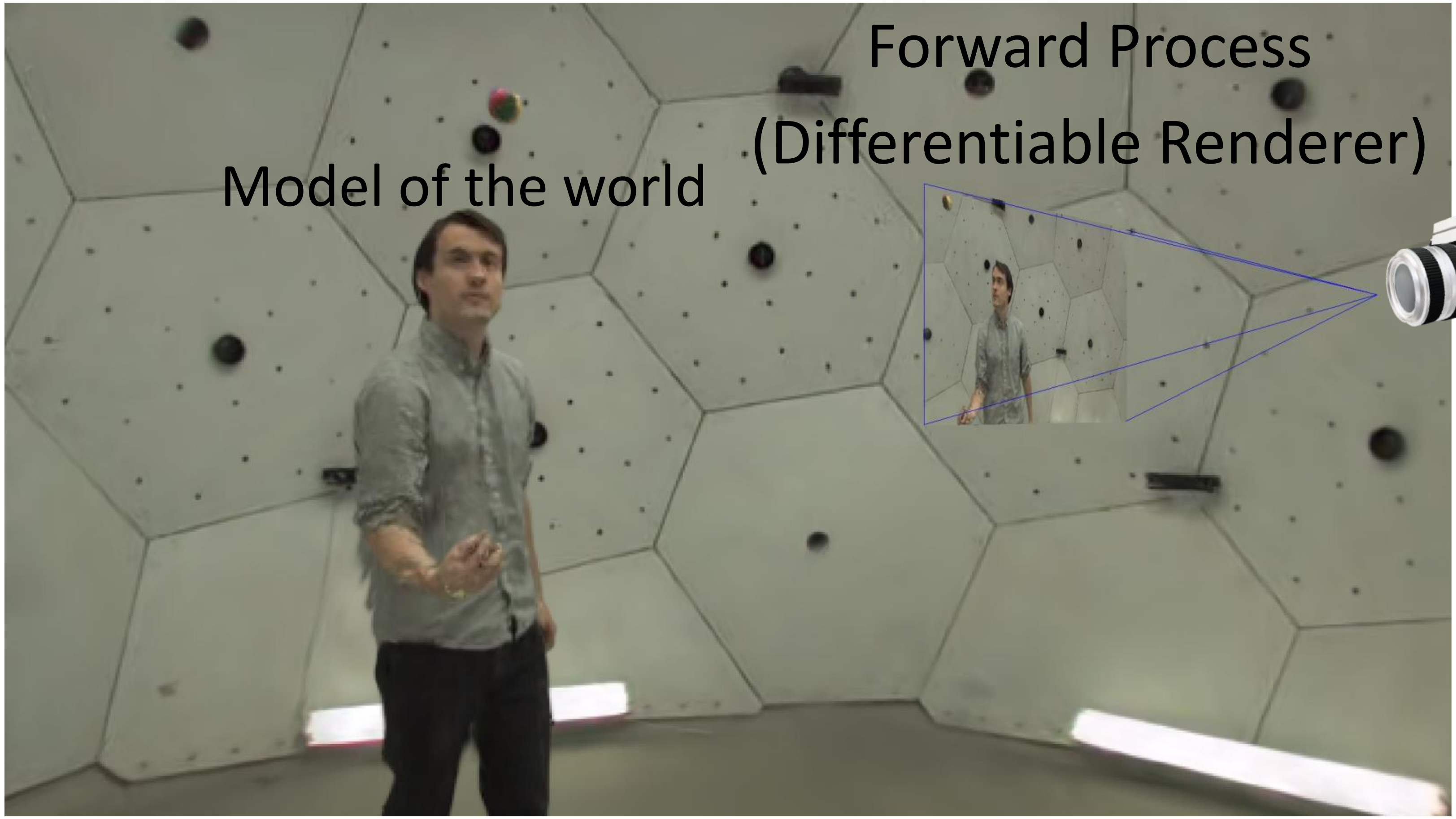
3D Rotation

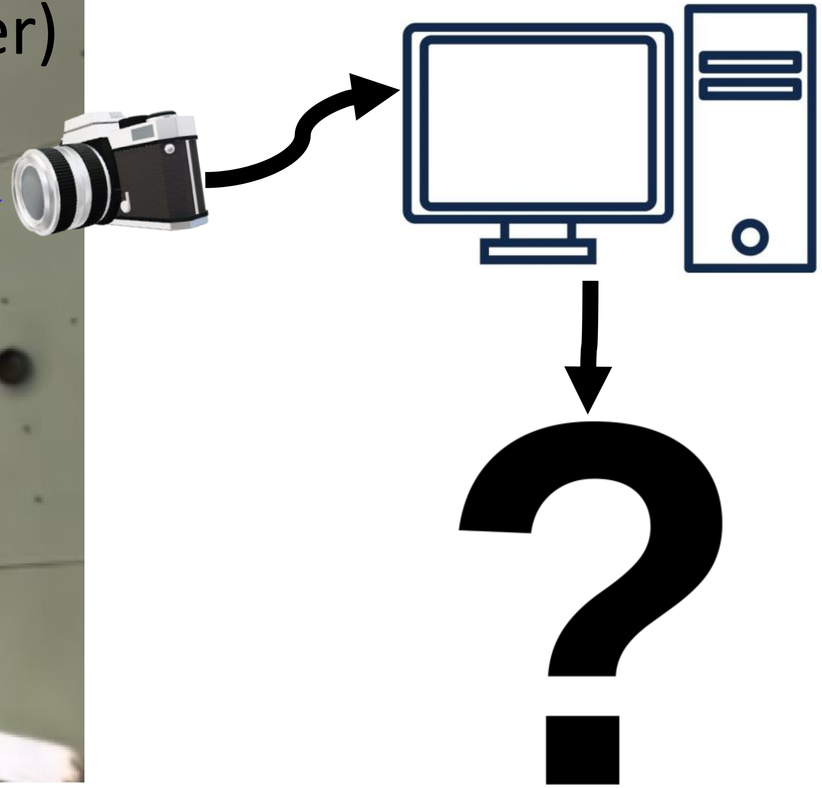
What is needed?

A Good Optimization Procedure

Gradient-based
Optimization

(+ Physics-based Priors)





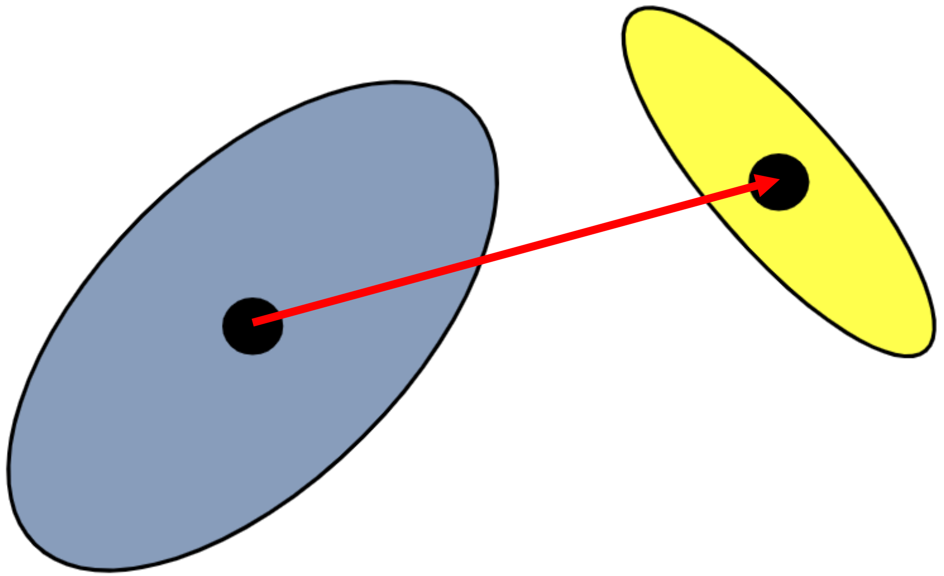
Analysis-by-Synthesis

A Good Optimization Procedure

What is needed?

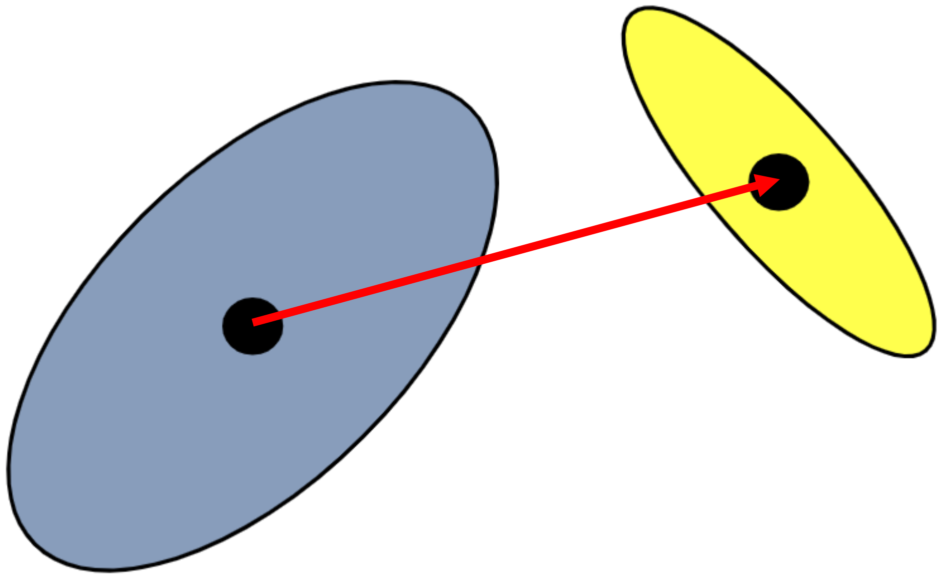
Good Priors

$$w_{i,j} = \exp\left(-\lambda_w \left\|\mu_{j,0} - \mu_{i,0}\right\|_2^2\right)$$



Good Priors

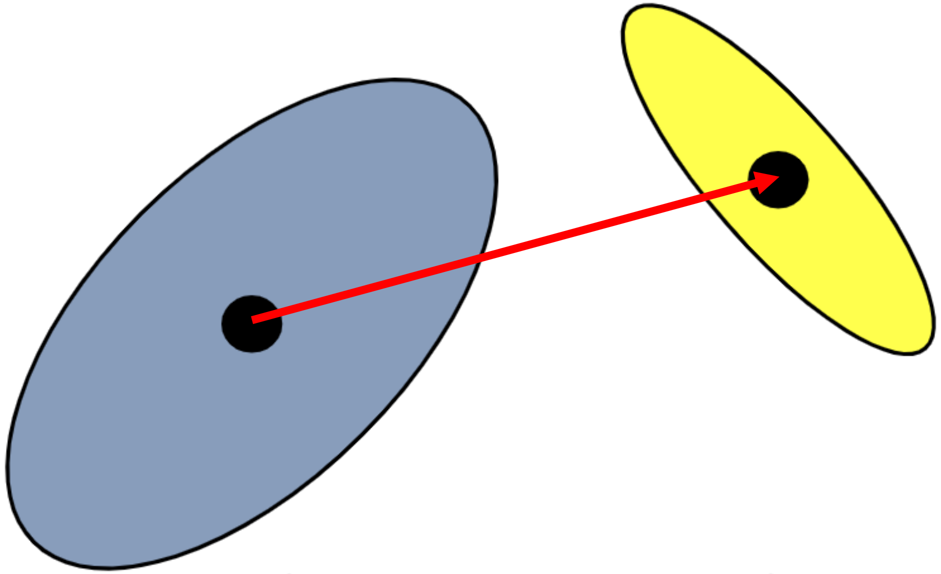
$$t-1$$



$$(\mu_{j,t-1} - \mu_{i,t-1})$$

Good Priors

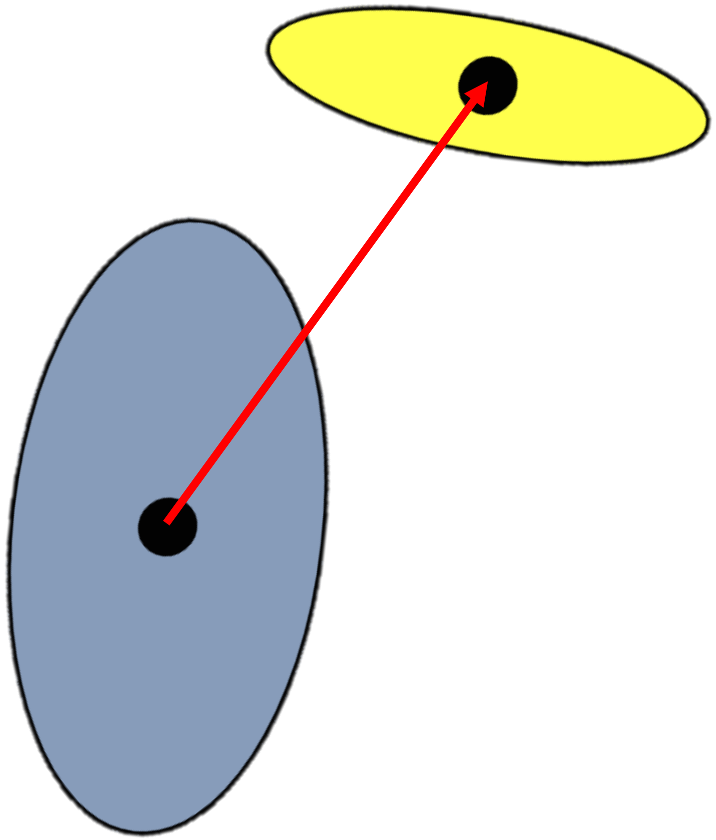
t



$$(\mu_{j,t} - \mu_{i,t})$$

Good Priors

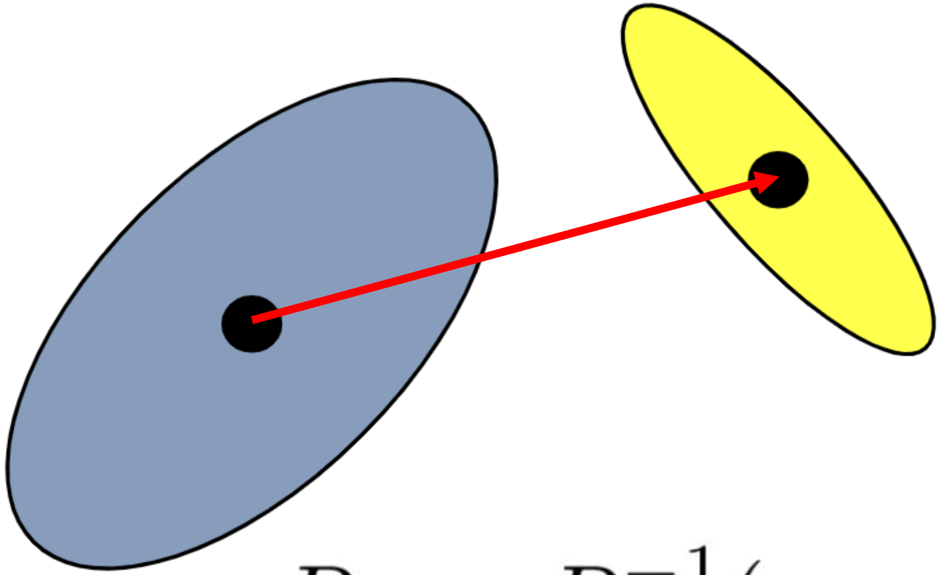
t



$$(\mu_{j,t} - \mu_{i,t})$$

Good Priors

t



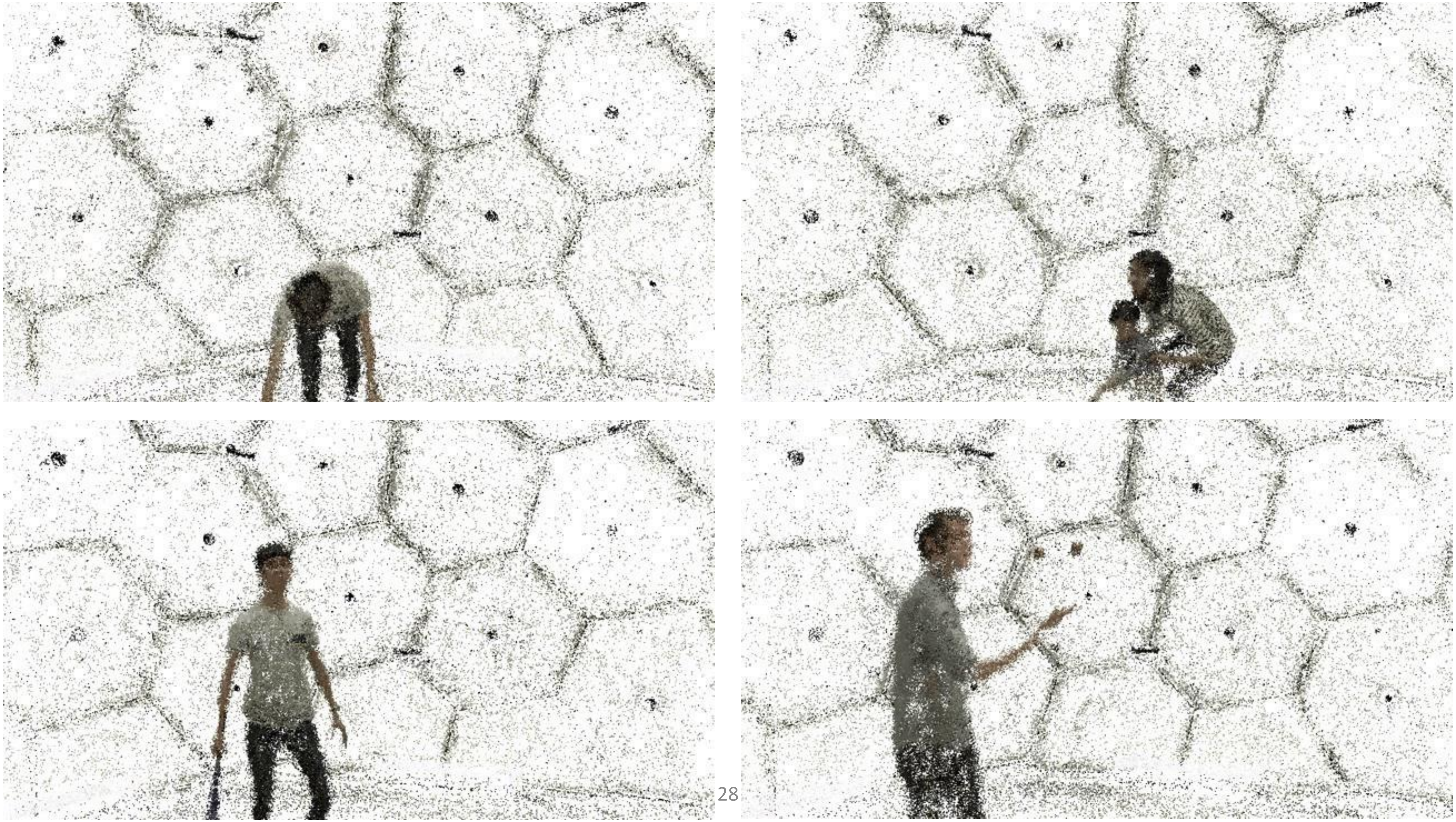
$$R_{i,t-1}R_{i,t}^{-1}(\mu_{j,t} - \mu_{i,t})\|_2$$

Good Priors

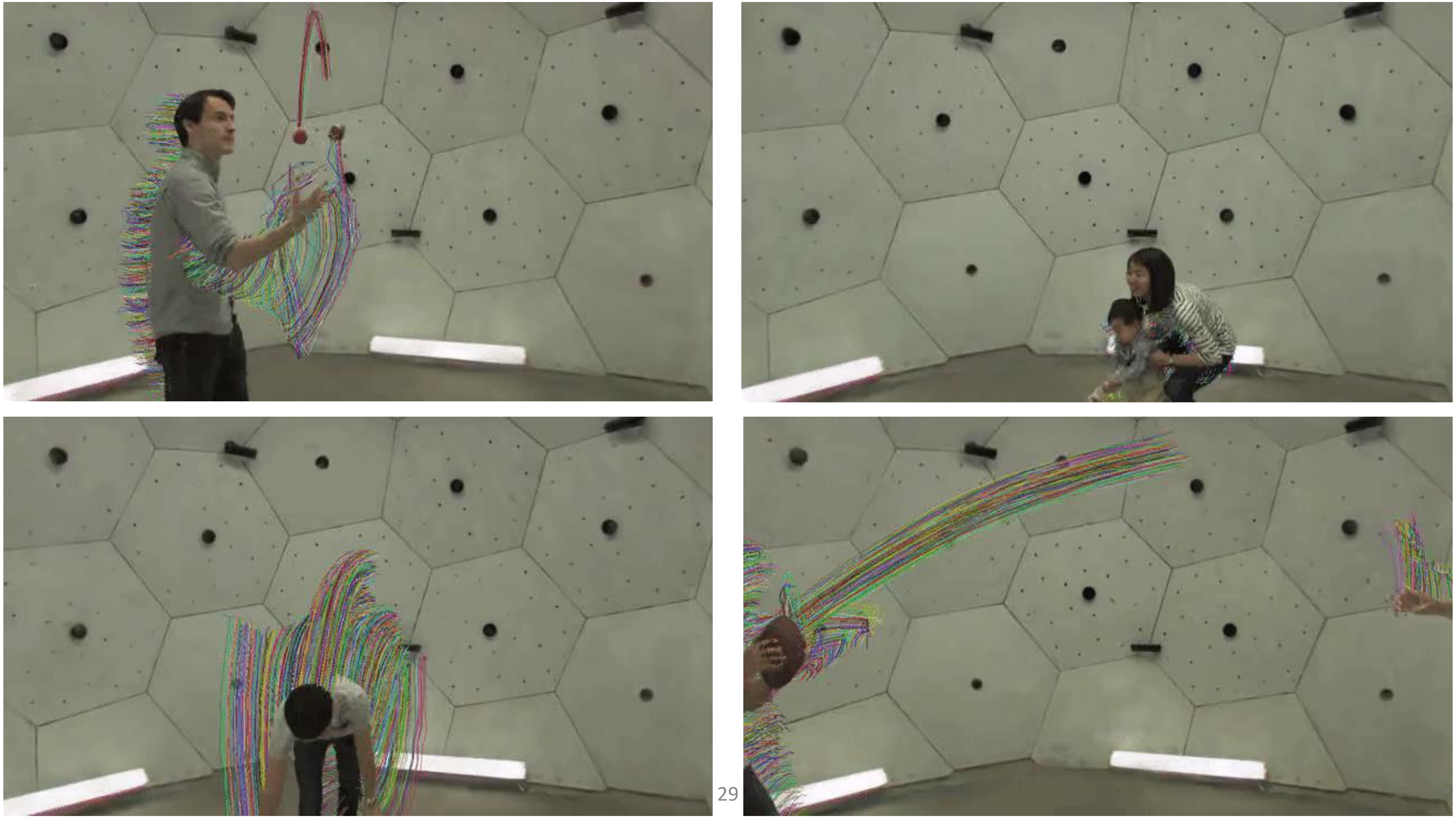
$$\mathcal{L}_{i,j}^{\text{rigid}} = w_{i,j} \left\| (\mu_{j,t-1} - \mu_{i,t-1}) - R_{i,t-1} R_{i,t}^{-1} (\mu_{j,t} - \mu_{i,t}) \right\|_2$$

$$\mathcal{L}^{\text{rigid}} = \frac{1}{k|\mathcal{S}|} \sum_{i \in \mathcal{S}} \sum_{j \in \text{knn}_{i;k}} \mathcal{L}_{i,j}^{\text{rigid}}$$

Making 3D Gaussians Move

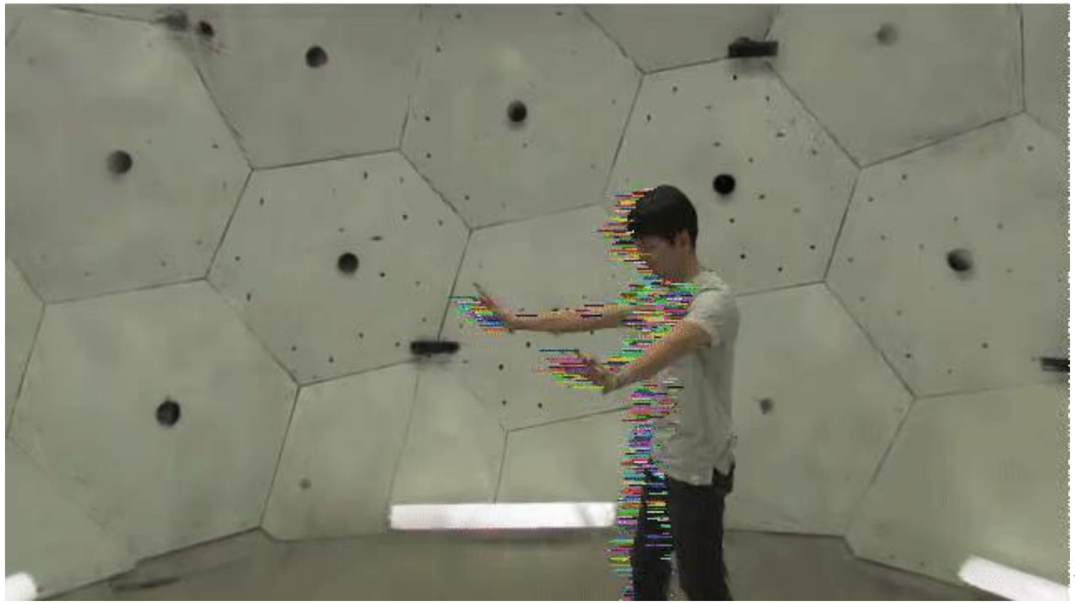


Making 3D Gaussians Move



Full 6-DoF Tracking





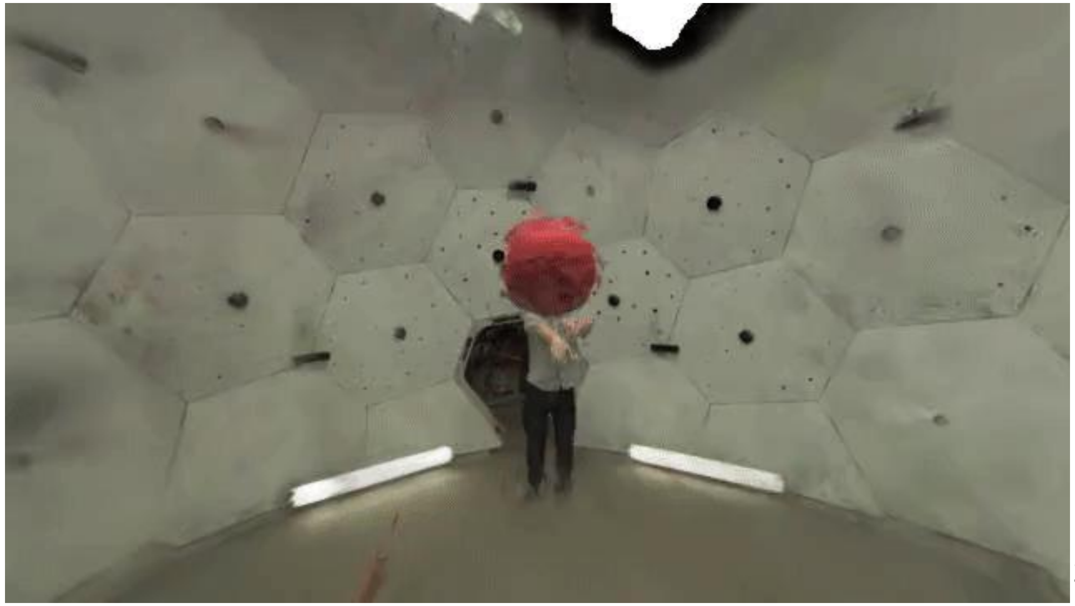

It works!

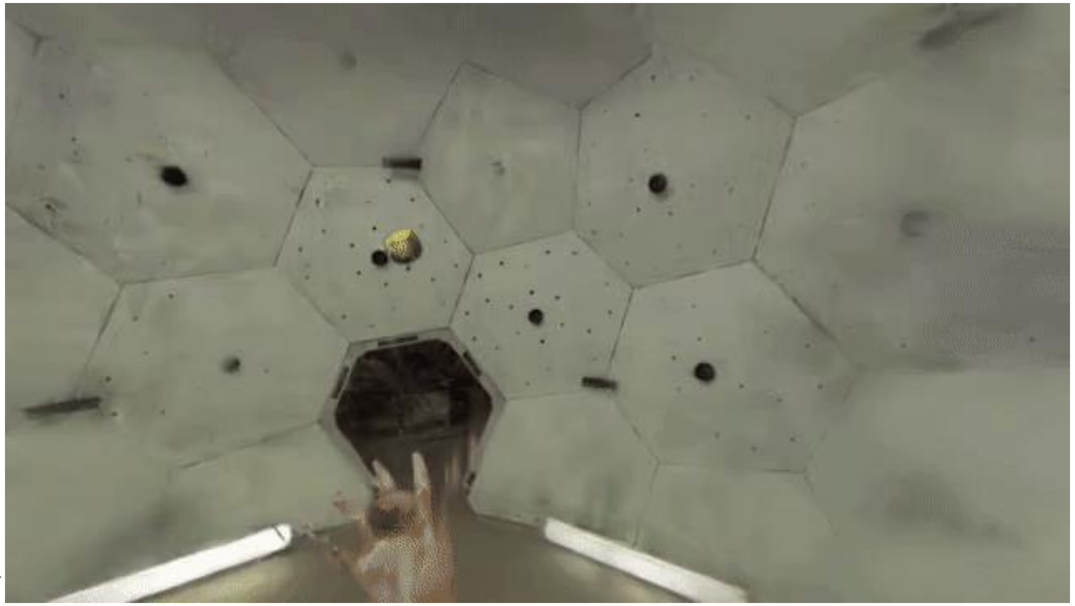
It works!

Median 3D Tracking Error:	1.90 cm
Median 2D Tracking Error:	1.54 pix
PSNR:	29.48 dB

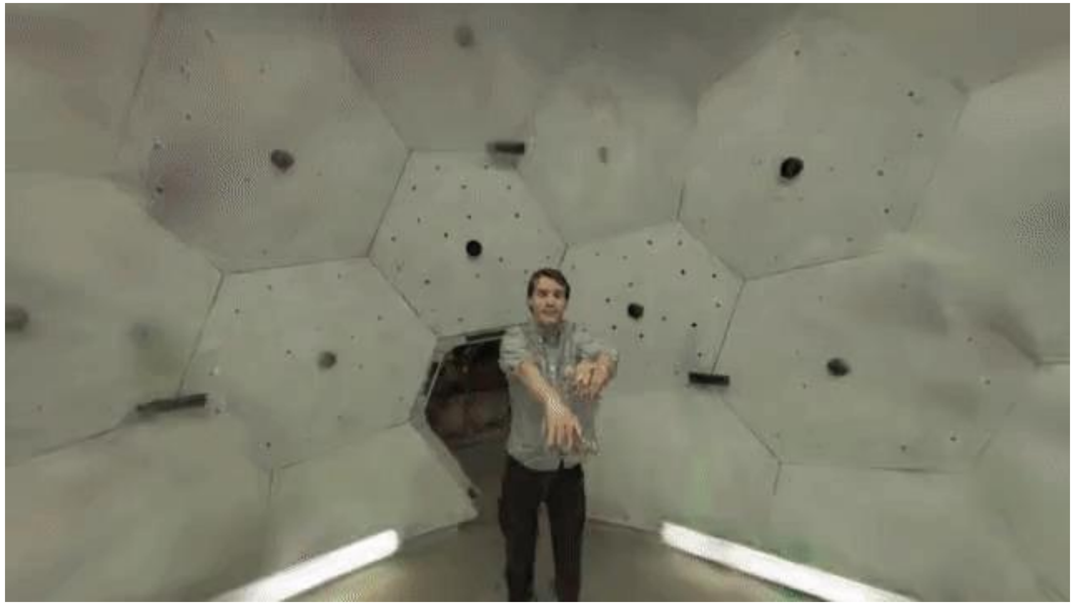
Dense Metric 3D Tracking

Creative Applications: Gaussian-eye view





Creative Applications: Gaussian-eye view



Creative Applications: Compositional Dynamic Scenes

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Dynamic 3D Gaussians

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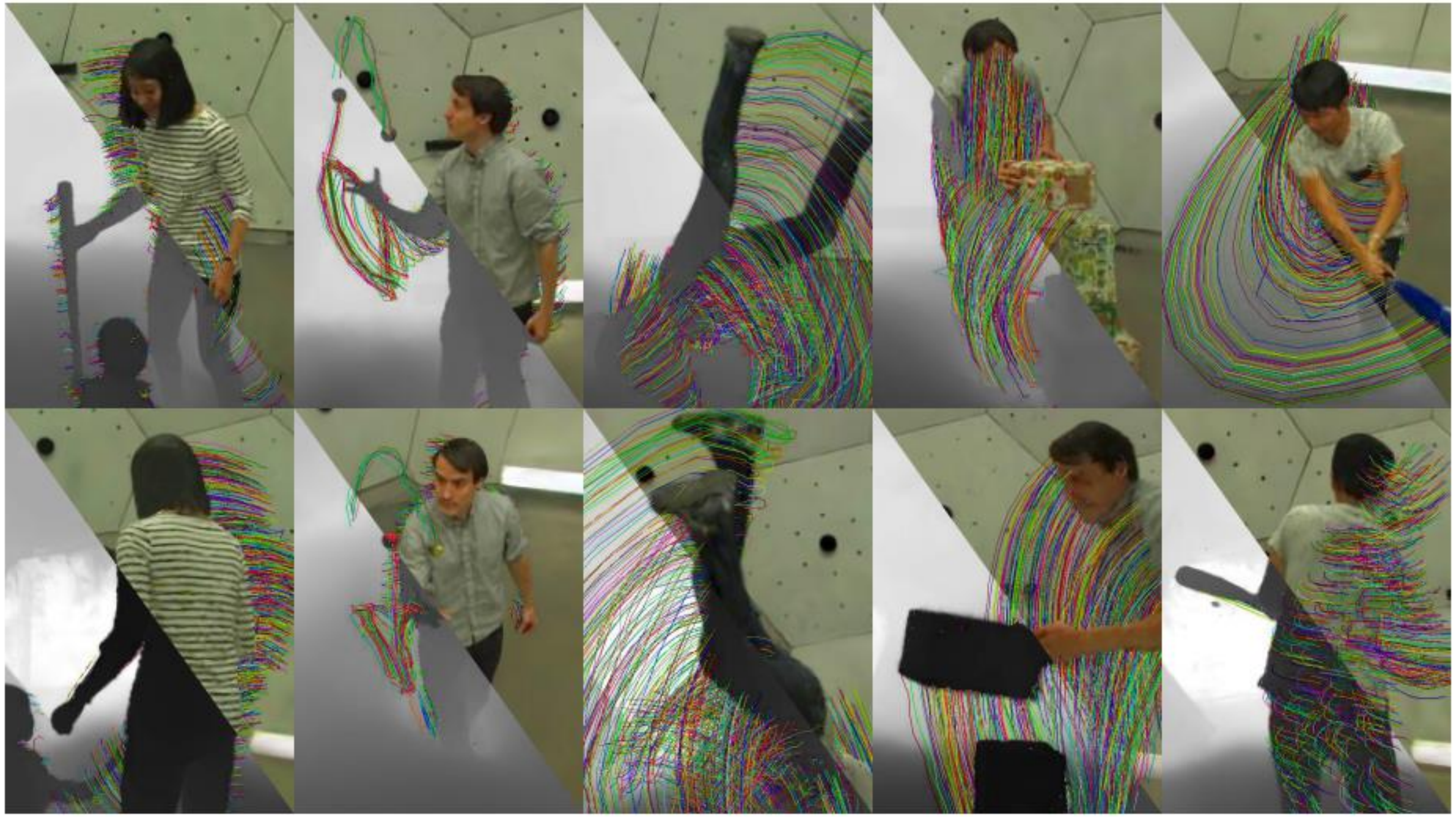

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Real-time Photorealistic Dynamic Scene Representation and Rendering with 4D Gaussian Splatting

Zeyu Yang, Hongye Yang, Zijie Pan, Li Zhang*
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https://fudan-zvg.github.io/4d-gaussian-splatting

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GauFRe 🍪: Gaussian Deformation Fields for Real-time Dynamic Novel View Synthesis

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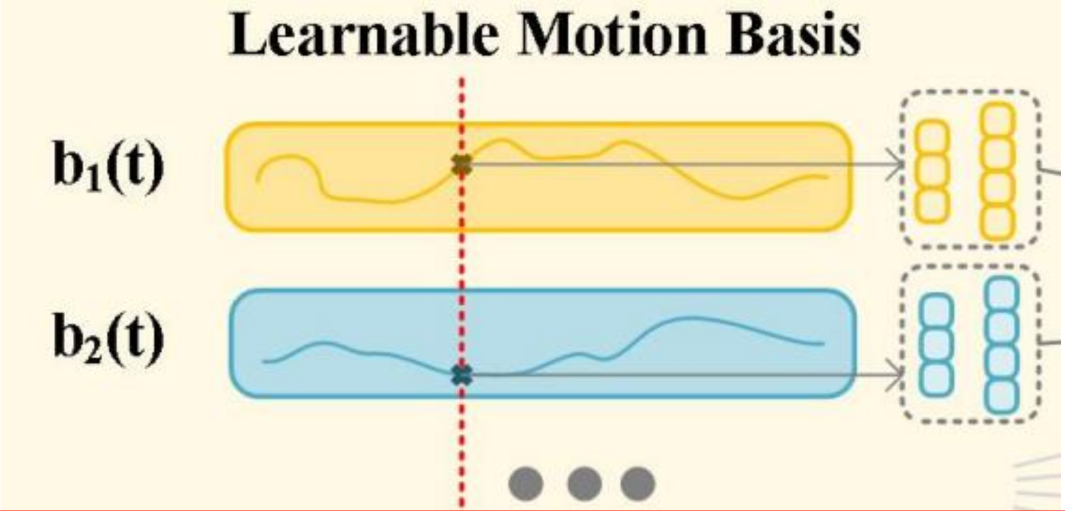
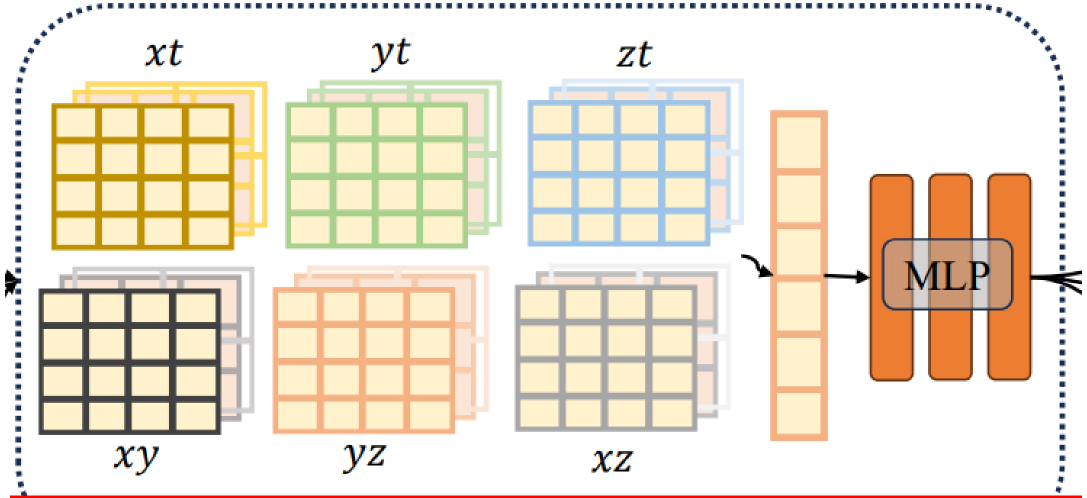
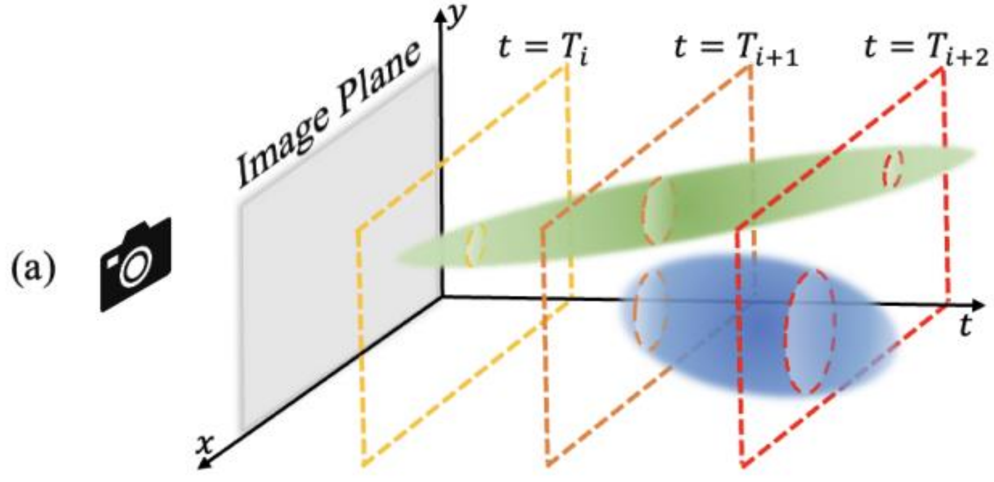
Alternative Dynamic Gaussian Representations



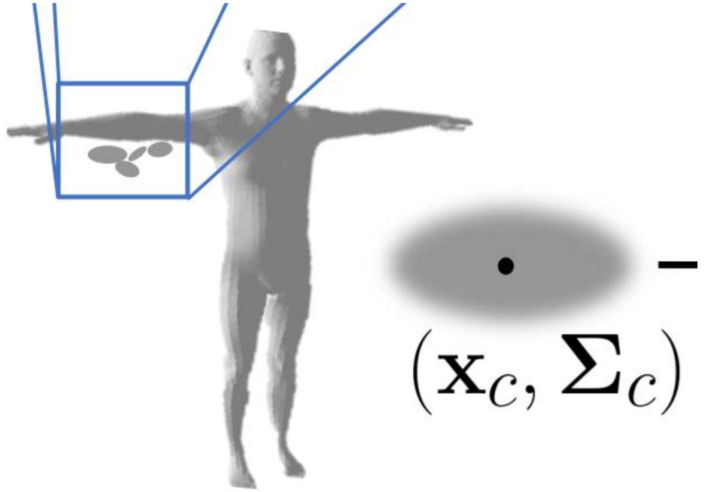
Motion Basis



Deformation Fields

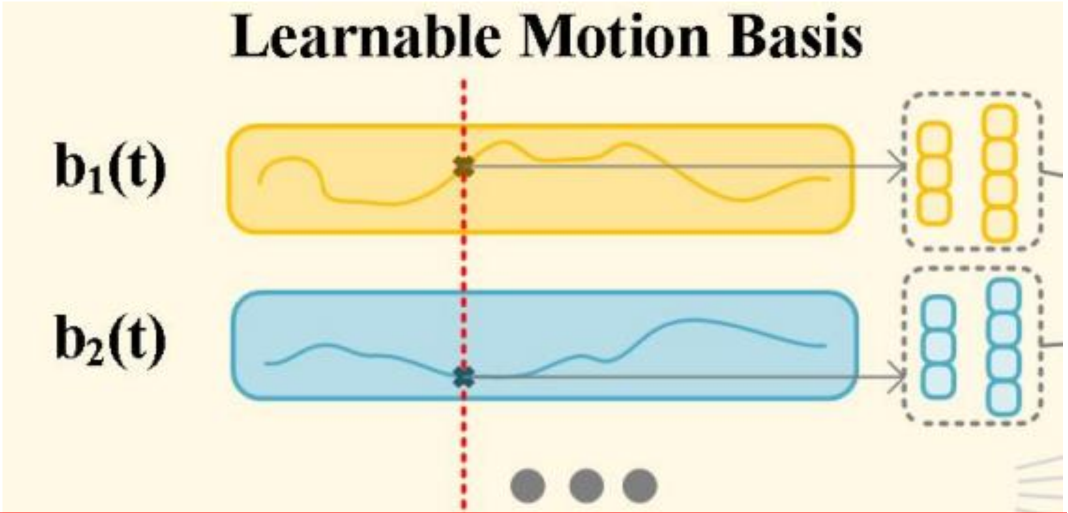


4D Gaussians

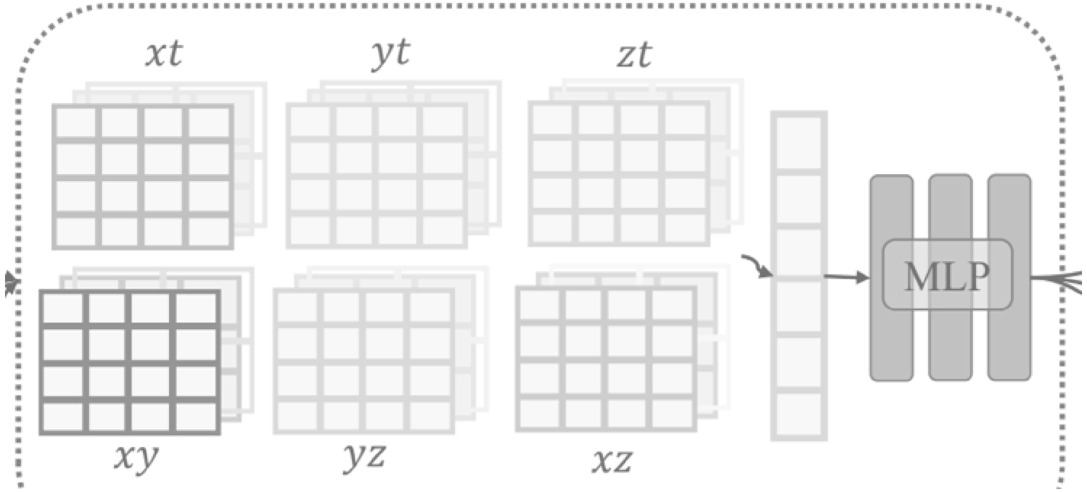


Shape Templates

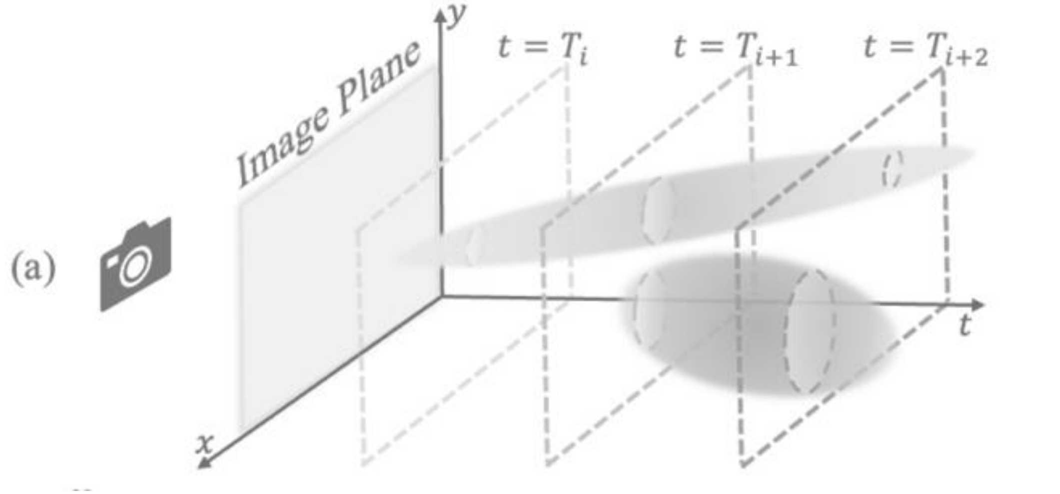
Alternative Dynamic Gaussian Representations



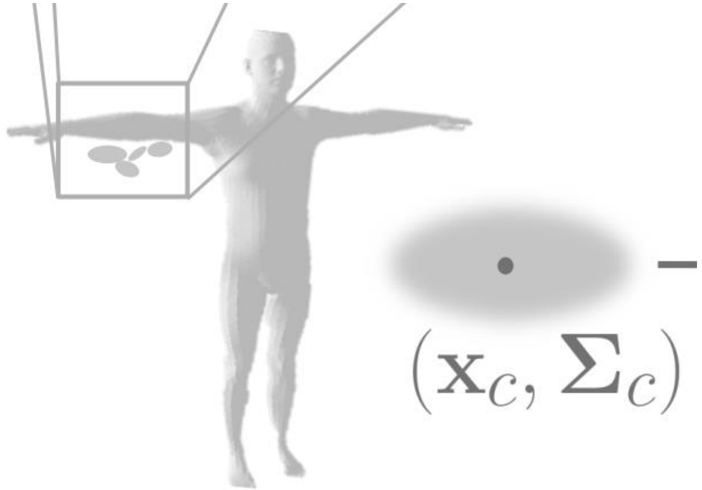
Motion Basis



Deformation Fields



4D Gaussians



Shape Templates

Motion Basis Representations

An Efficient 3D Gaussian Representation for Monocular/Multi-view Dynamic Scenes

Kai Katsumata   Duc Minh Vo   Hideki Nakayama
The University of Tokyo, Japan
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Motion as Fourier Coefficients / Optical Flow supervision

$$x(t) = w_{x,0} + \sum_{i=1}^{L} w_{x,2i-1} \sin(\pi t) + w_{x,2i} \cos(\pi t),$$

$$y(t) = w_{y,0} + \sum_{i=1}^{L} w_{y,2i-1} \sin(\pi t) + w_{y,2i} \cos(\pi t),$$

$$z(t) = w_{z,0} + \sum_{i=1}^{L} w_{z,2i-1} \sin(\pi t) + w_{z,2i} \cos(\pi t),$$

Motion Basis Representations

Spacetime Gaussian Feature Splatting for Real-Time Dynamic View Synthesis

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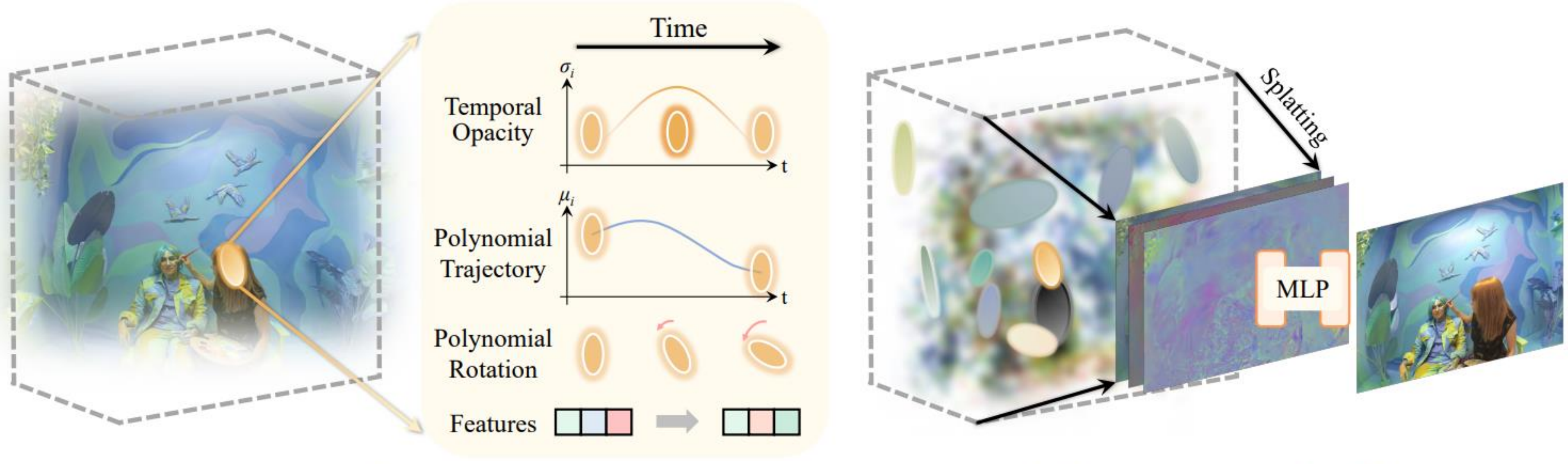
Motion as Polynomial Coefficients / Temporally Local Opacity / Splats Features instead of Colors.



(a) Spacetime Gaussians (b) Feature Splatting and Rendering

Motion Basis Representations

Gaussian-Flow: 4D Reconstruction with Dynamic 3D Gaussian Particle

Youtian Lin[1] Zuozhuo Dai[2] Siyu Zhu[3] Yao Yao[1]✉
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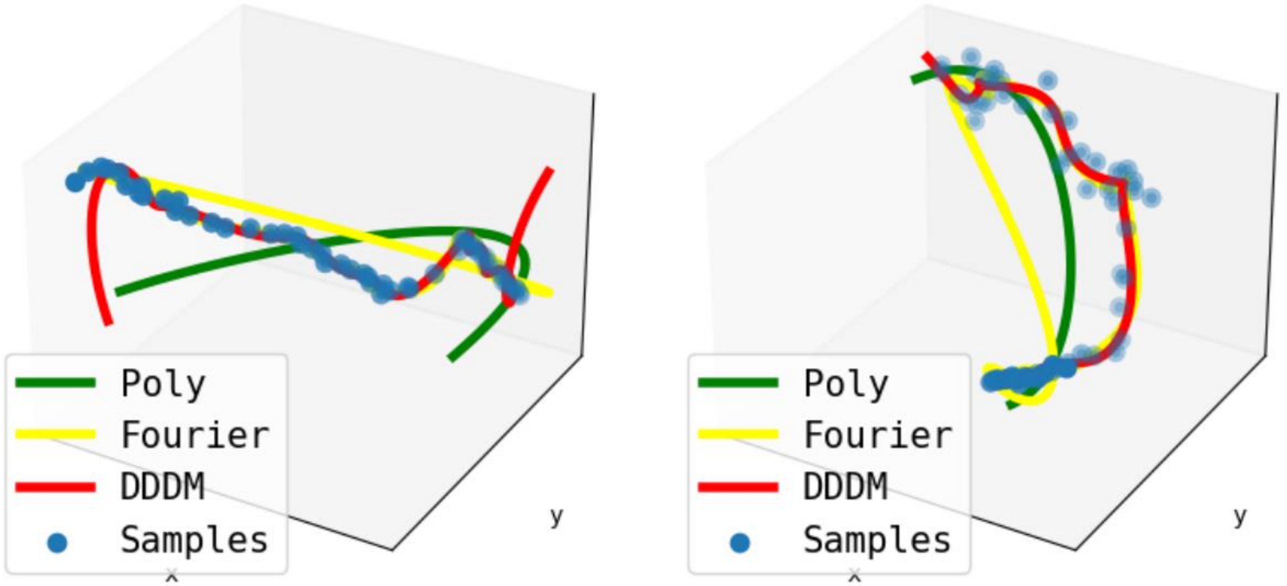
Combines Polynomial + Fourier Coefficients for modelling motion

$$D(t) = P_N(t) + F_L(t)$$



Motion Basis Representations

DynMF: Neural Motion Factorization
for Real-time Dynamic View Synthesis with 3D Gaussian Splatting

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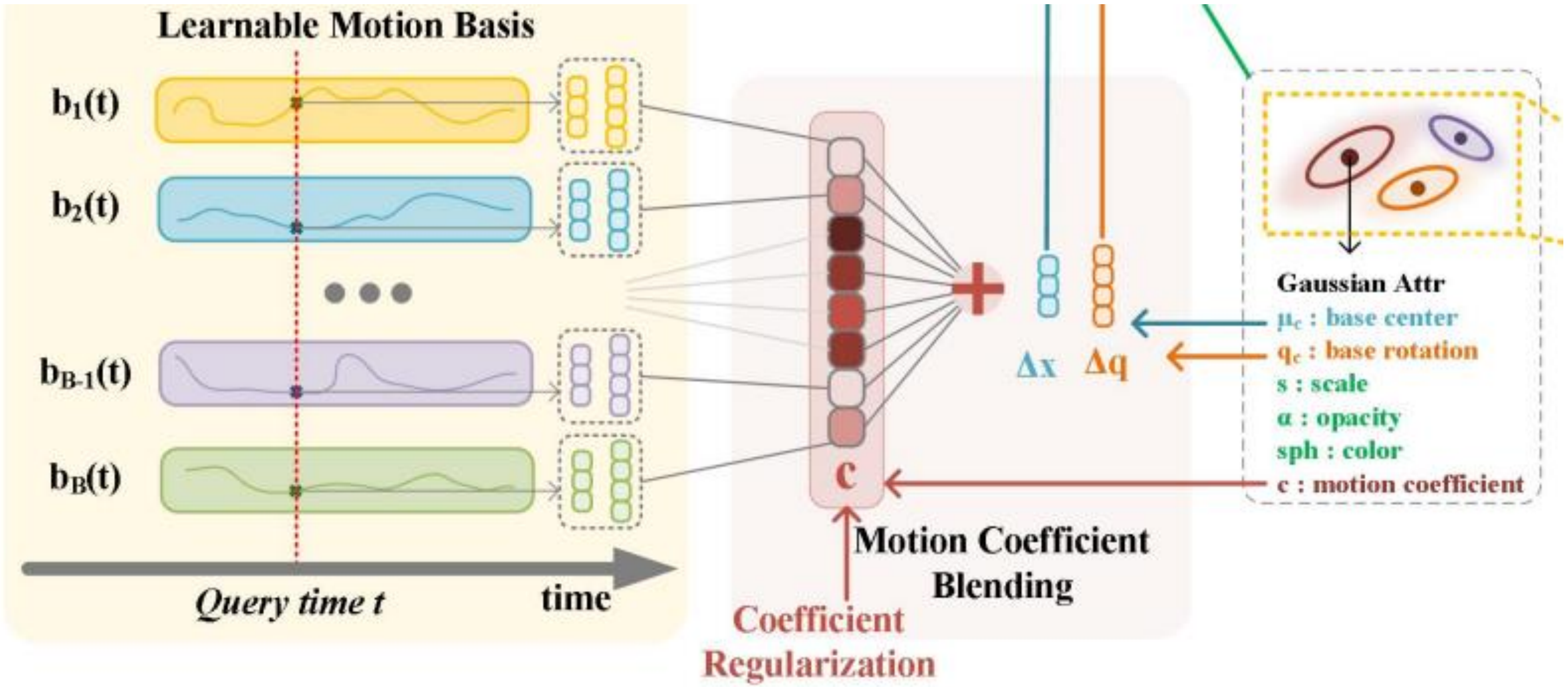
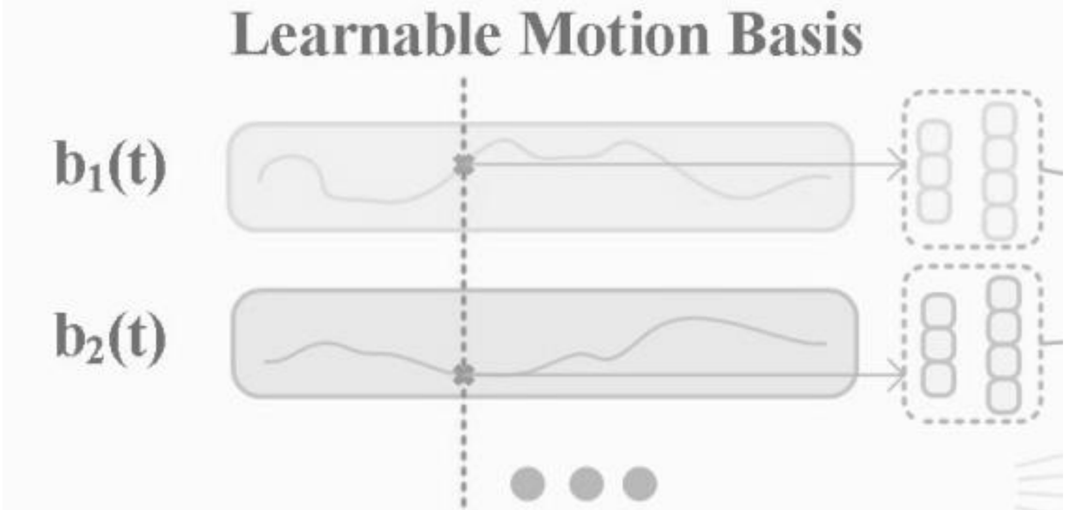
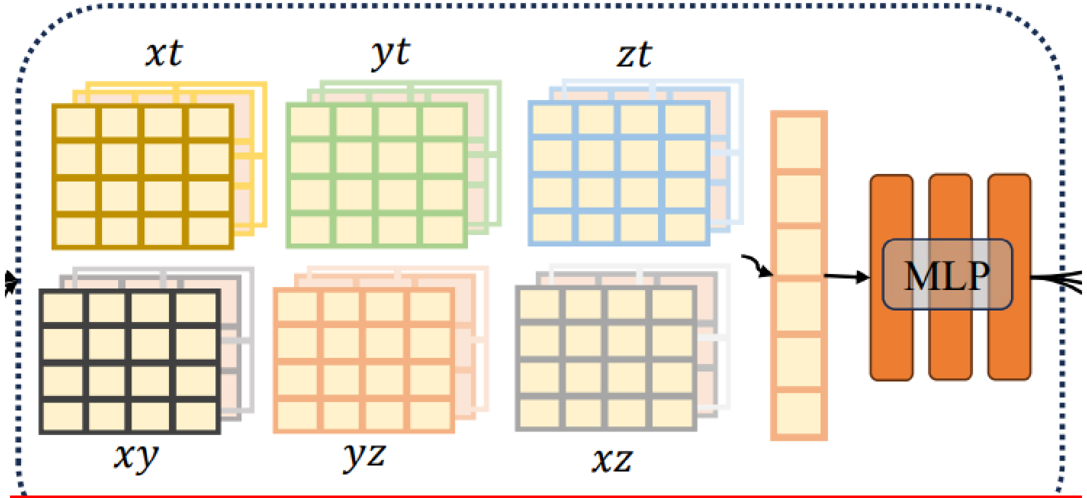
Uses MLPs to represent small basis set / Each Gaussians motion is linear combo of MLP bases. Bases can we sparse (10 or 16).



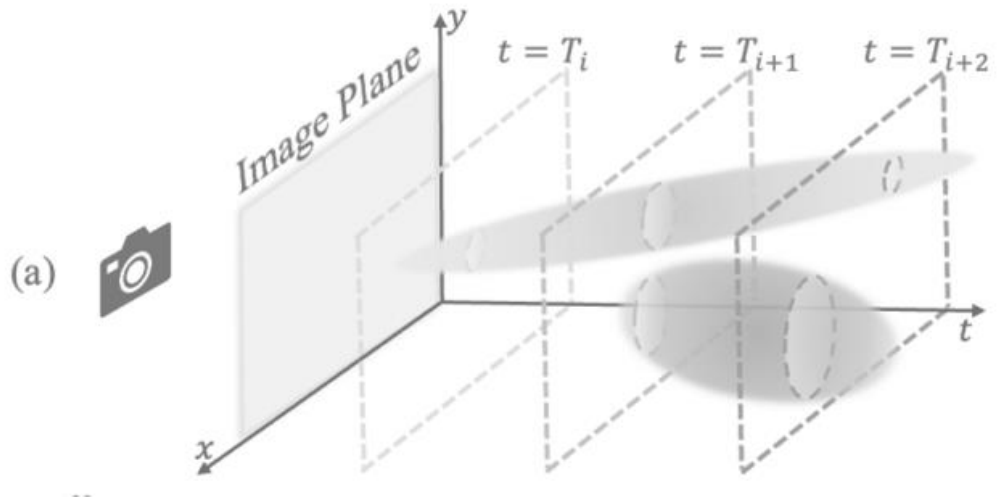
Alternative Dynamic Gaussian Representations



Motion Basis



Deformation Fields



4D Gaussians

Shape Templates

Deformation Field Representations

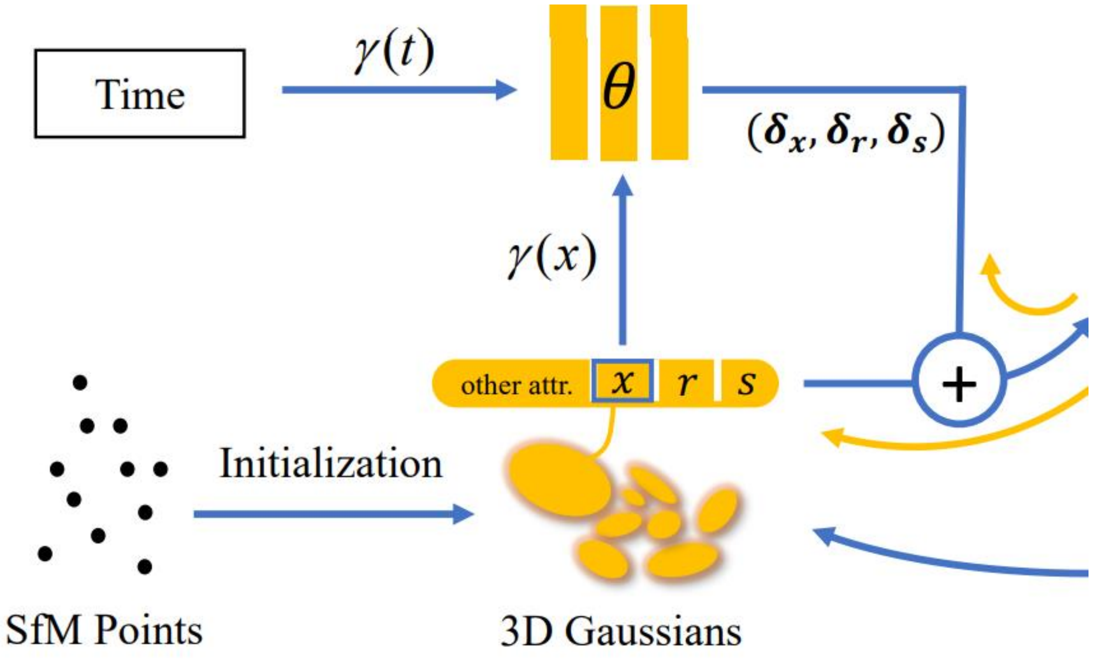
Deformable 3D Gaussians for High-Fidelity Monocular Dynamic Scene Reconstruction

Ziyi Yang[1,2] Xinyu Gao[1] Wen Zhou[2] Shaohui Jiao[2] Yuqing Zhang[1] Xiaogang Jin[1†]

[1]State Key Laboratory of CAD&CG, Zhejiang University [2]ByteDance Inc.

Dense MLP representation over space / time defining the push-forward deformation of Gaussians

$$(\delta \boldsymbol{x}, \delta \boldsymbol{r}, \delta \boldsymbol{s}) = \mathcal{F}_\theta(\gamma(\text{sg}(\boldsymbol{x})), \gamma(t)),$$

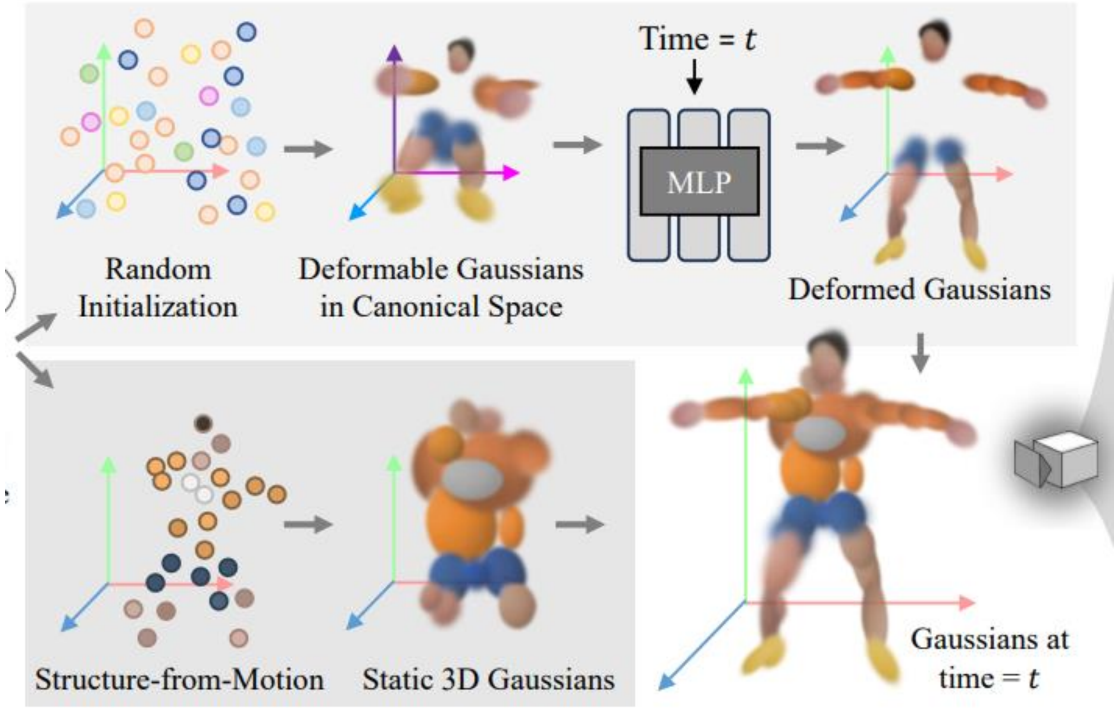


Deformation Field Representations

GauFRe : Gaussian Deformation Fields for Real-time Dynamic Novel View Synthesis

Yiqing Liang[‡], Numair Khan, Zhengqin Li, Thu Nguyen-Phuoc,
Douglas Lanman, James Tompkin[‡], Lei Xiao
Meta [‡]Brown University

Adds a set of static Gaussians that cannot move.

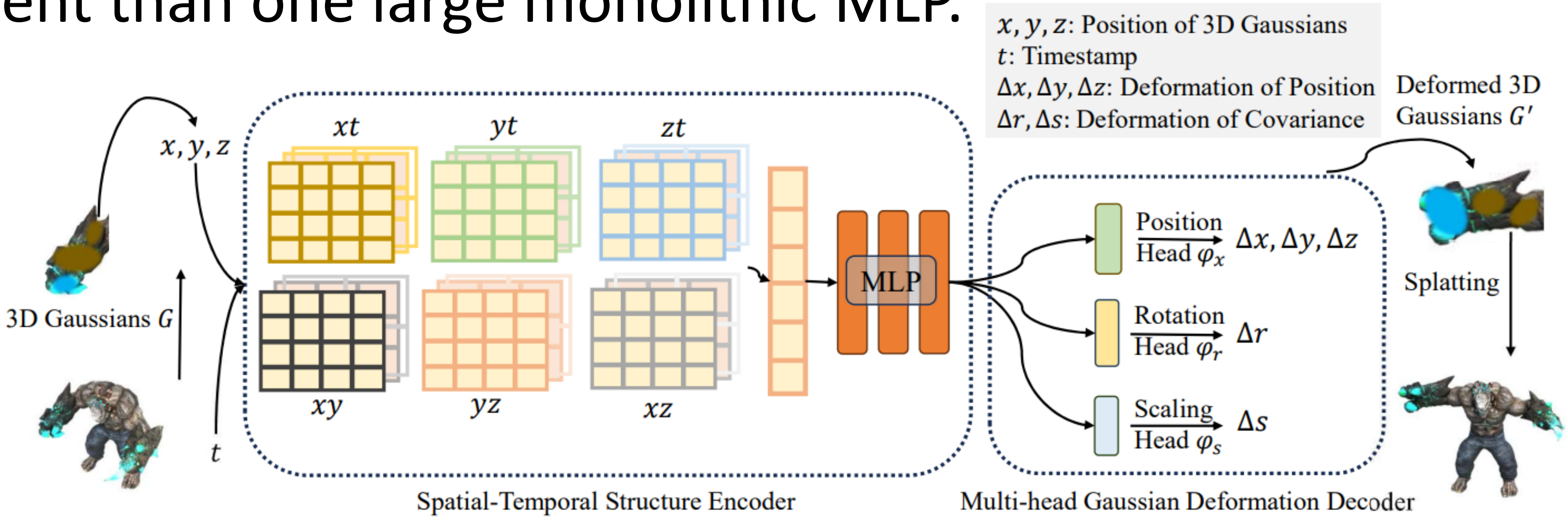


Deformation Field Representations

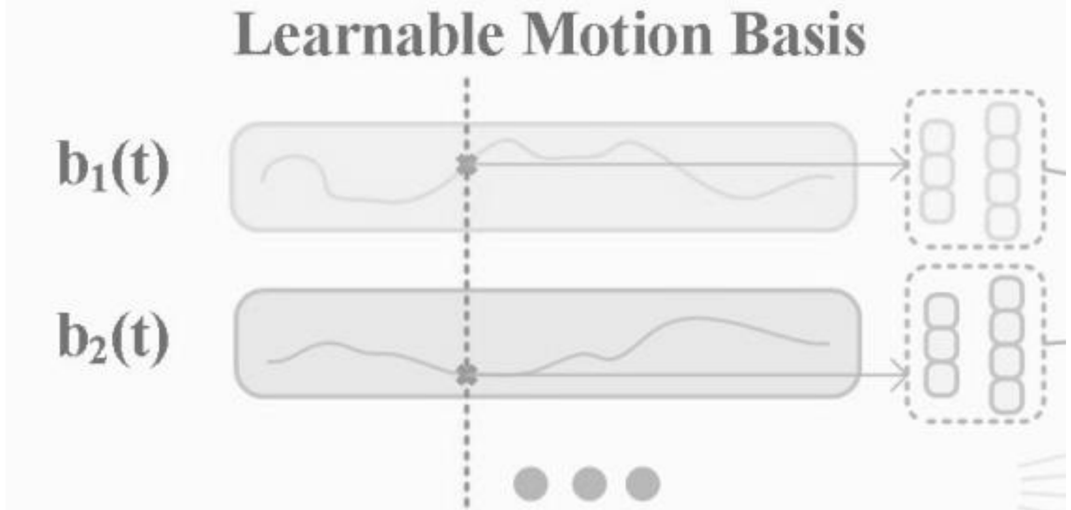
4D Gaussian Splatting for Real-Time Dynamic Scene Rendering

Guanjun Wu[1*], Taoran Yi[2*], Jiemin Fang[3†], Lingxi Xie[3], Xiaopeng Zhang[3],
Wei Wei[1], Wenyu Liu[2], Qi Tian[3], Xinggang Wang[2†‡]
[1]School of CS, Huazhong University of Science and Technology
[2]School of EIC, Huazhong University of Science and Technology [3]Huawei Inc.
{guajuwu, taoranyi, weiw, liuwy, xgwang}@hust.edu.cn
{jaminfong, 198808xc, zxphistory}@gmail.com tian.qi1@huawei.com

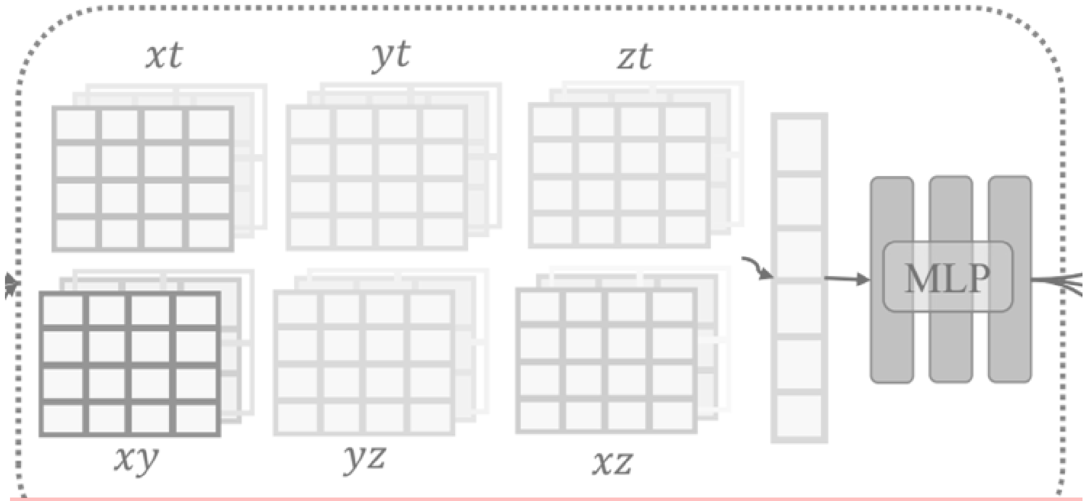
Using Multi-Res Hex-plane + tiny MLP for push-forward deformation is more efficient than one large monolithic MLP.



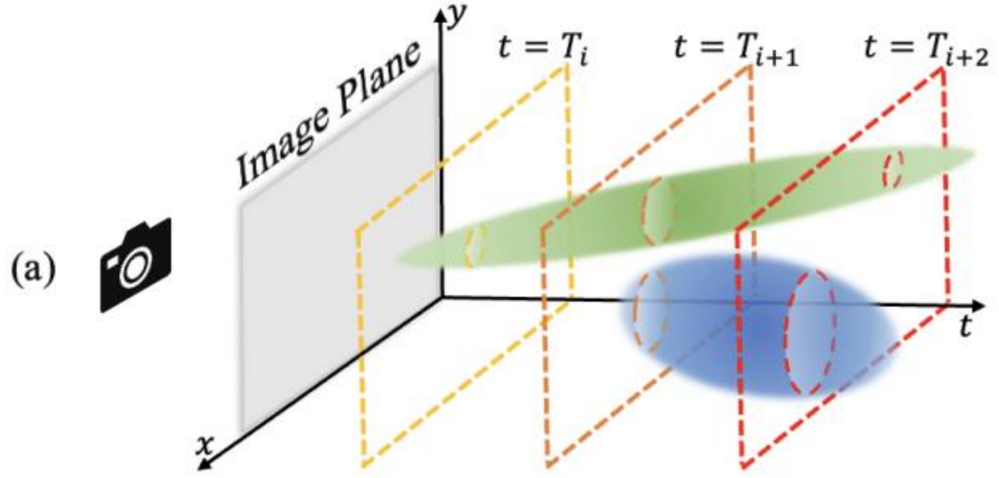
Alternative Dynamic Gaussian Representations



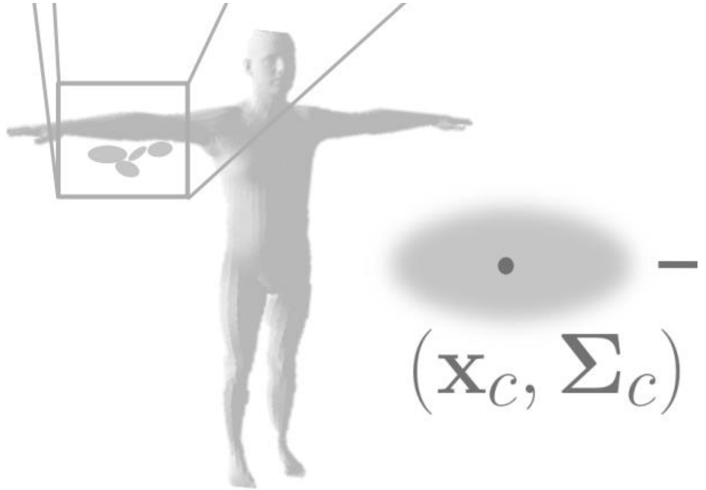
Motion Basis



Deformation Fields



4D Gaussians



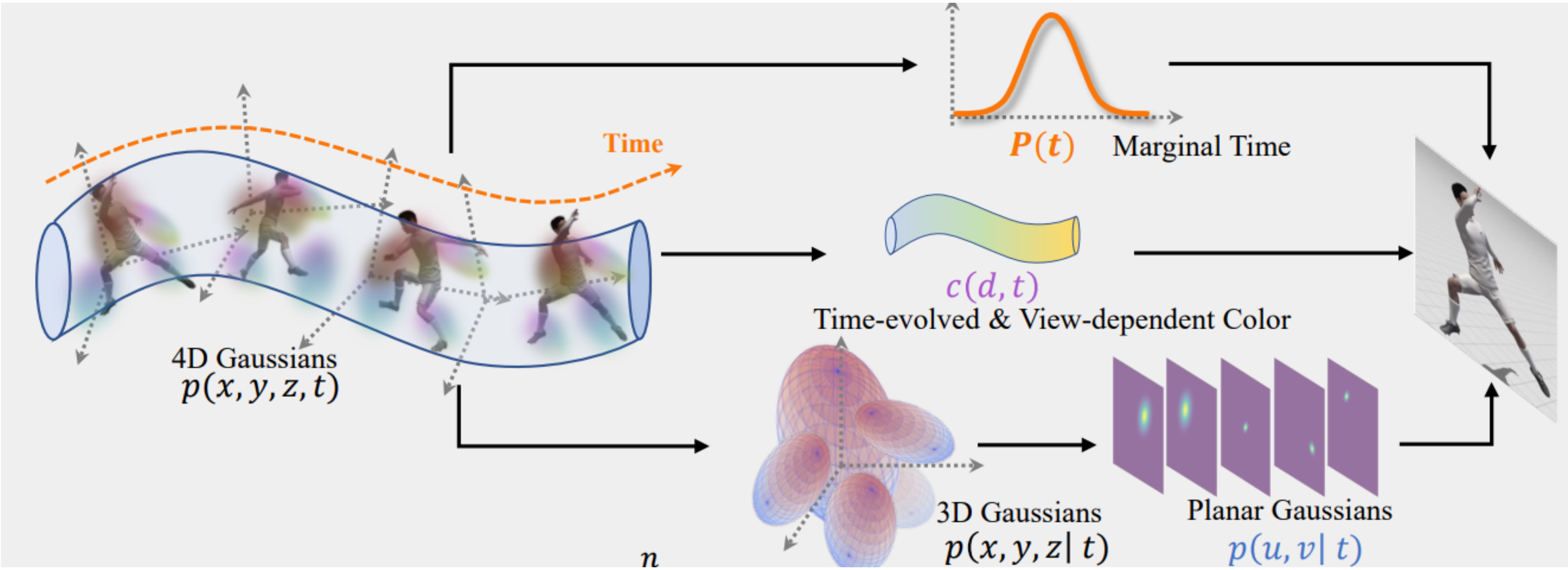
Shape Templates

4D Gaussian Representations

REAL-TIME PHOTOREALISTIC DYNAMIC SCENE REPRESENTATION AND RENDERING WITH 4D GAUSSIAN SPLATTING

Zeyu Yang, Hongye Yang, Zijie Pan, Li Zhang*
Fudan University

Represents scenes as actual 4D Gaussians, which are spliced into 3D Gaussians per timestep



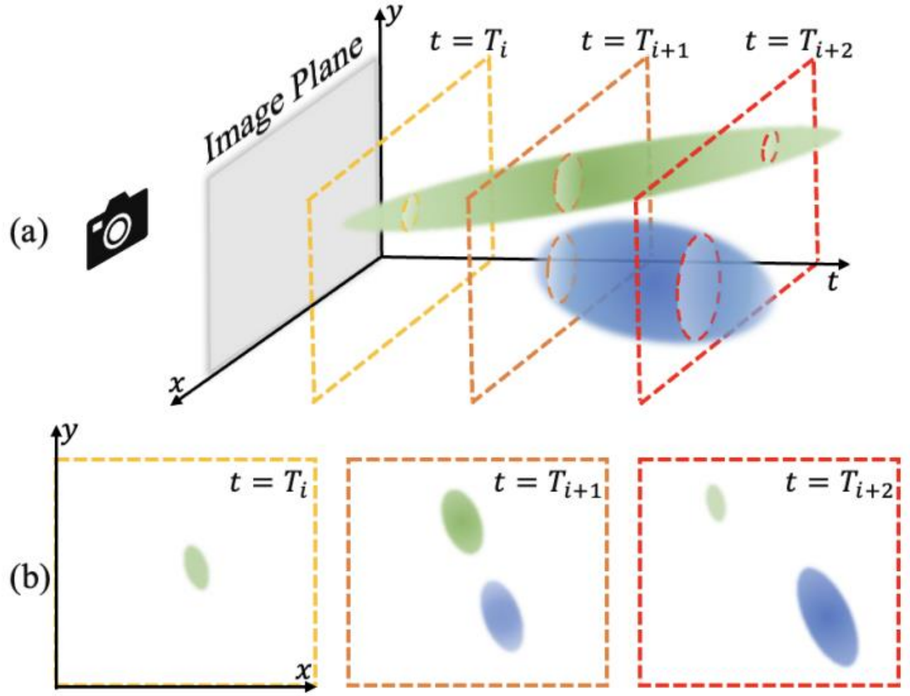
4D Gaussian Representations

4D Gaussian Splatting:
Towards Efficient Novel View Synthesis for Dynamic Scenes

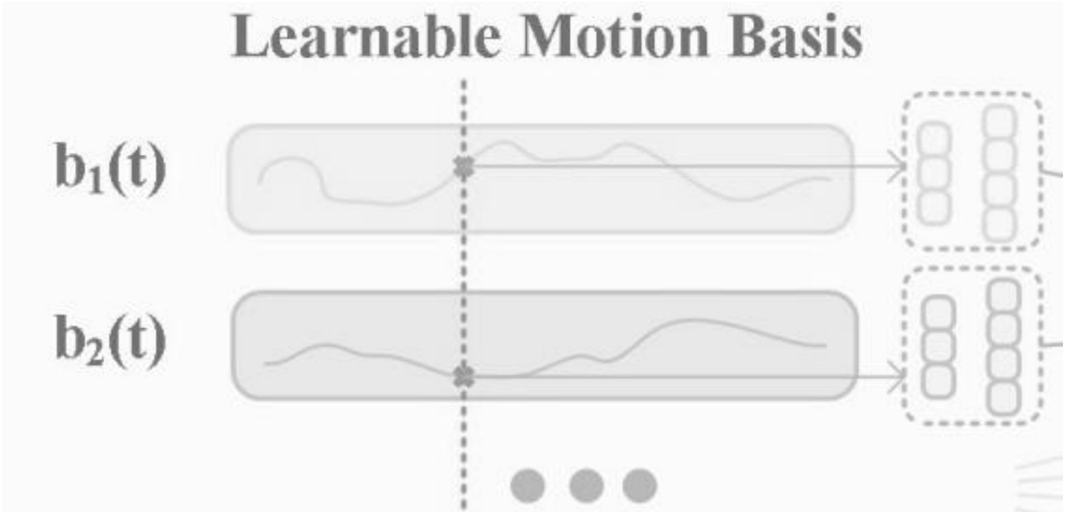
Yuanxing Duan[1]* Fangyin Wei[2]* Qiyu Dai[1,4] Yuhang He[1] Wenzheng Chen[3†] Baoquan Chen[1,4†]
[1]Peking University [2]Princeton University [3]NVIDIA [4]National Key Lab of General AI, China

Uses a different (rotor-based) 4D gaussian covariance representation.

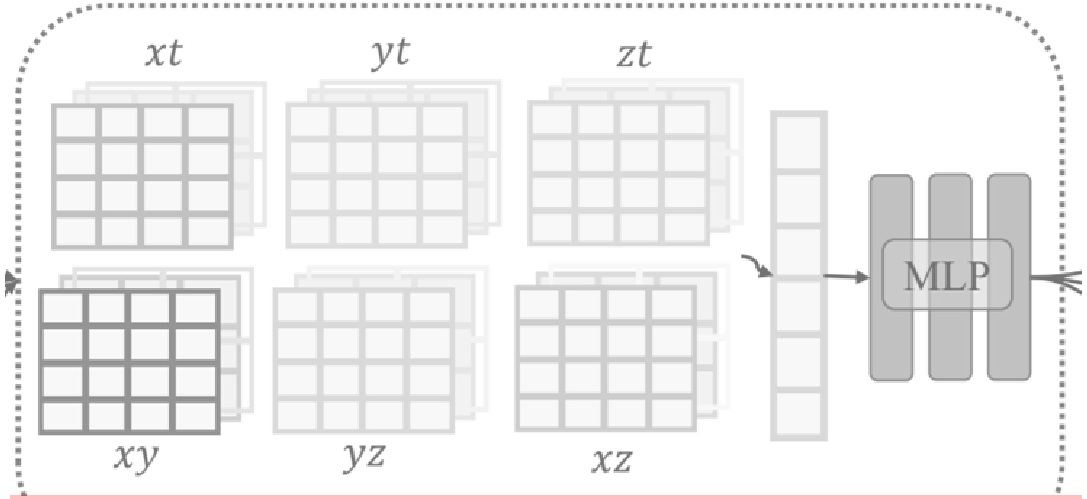
More naturally decomposes into 3D + 1D, also VERY fast CUDA impl.



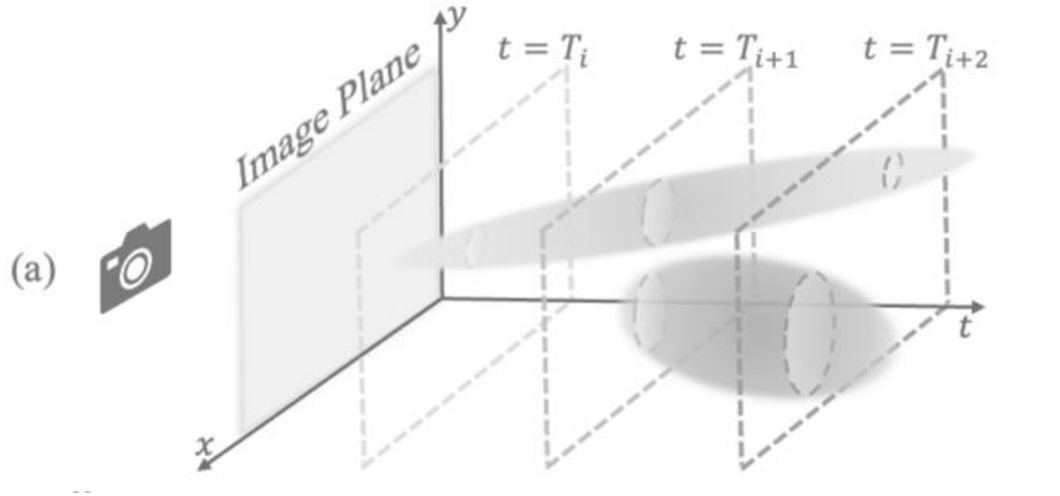
Alternative Dynamic Gaussian Representations



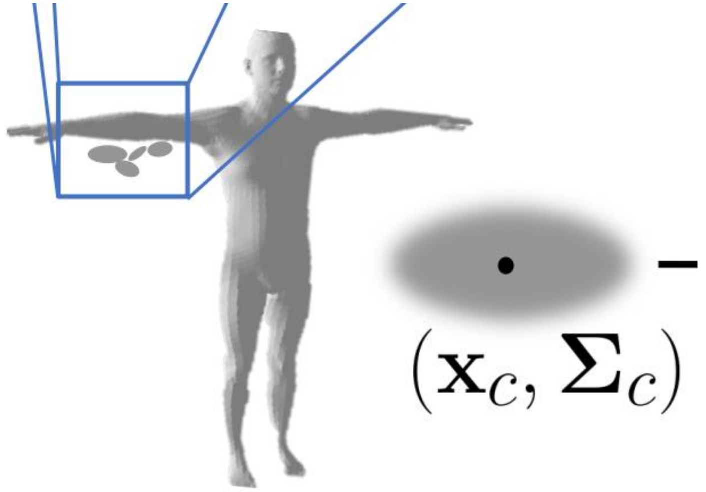
Motion Basis



Deformation Fields



4D Gaussians



Shape Templates

Shape Templates

Drivable 3D Gaussian Avatars

Wojciech Zielonka[3,1*], Timur Bagautdinov[1], Shunsuke Saito[1], Michael Zollhöfer[1], Justus Thies[2,3], Javier Romero[1]

[1]Meta Reality Labs Research [2]Technical University of Darmstadt
[3]Max Planck Institute for Intelligent Systems, Tübingen, Germany

https://zielon.github.io/d3ga/

Animatable Gaussians: Learning Pose-dependent Gaussian Maps for High-fidelity Human Avatar Modeling

Zhe Li[1], Zerong Zheng[2], Lizhen Wang[1], Yebin Liu[1]
[1] Department of Automation, Tsinghua University [2] NNKosmos Technology

https://animatable-gaussians.github.io/

SplatArmor: Articulated Gaussian splatting for animatable humans from monocular RGB videos

Rohit Jena[1*] Ganesh Iyer[2] Siddharth Choudhary[2] Brandon M. Smith[2]
Pratik Chaudhari[1] James C. Gee[1]
[1]University of Pennsylvania [2]Amazon.com, Inc

GART: Gaussian Articulated Template Models

Jiahui Lei[1] Yufu Wang[1] Georgios Pavlakos[2] Lingjie Liu[1] Kostas Daniilidis[1,3]
[1] University of Pennsylvania [2] UC Berkeley [3] Archimedes, Athena RC
{leijh, yufu, lingjie.liu, kostas}@cis.upenn.edu, pavlakos@berkeley.edu

Human Gaussian Splatting: Real-time Rendering of Animatable Avatars

Arthur Moreau* Jifei Song* Helisa Dhamo Richard Shaw Yiren Zhou
Eduardo Pérez-Pellitero
Huawei Noah's Ark Lab

HUGS: Human Gaussian Splats

Muhammed Kocabas[♘♖♗] Jen-Hao Rick Chang[♘] James Gabriel[♘] Oncel Tuzel[♘] Anurag Ranjan[♘]
[♘]Apple [♖]Max Planck Institute for Intelligent Systems [♗]ETH Zurich

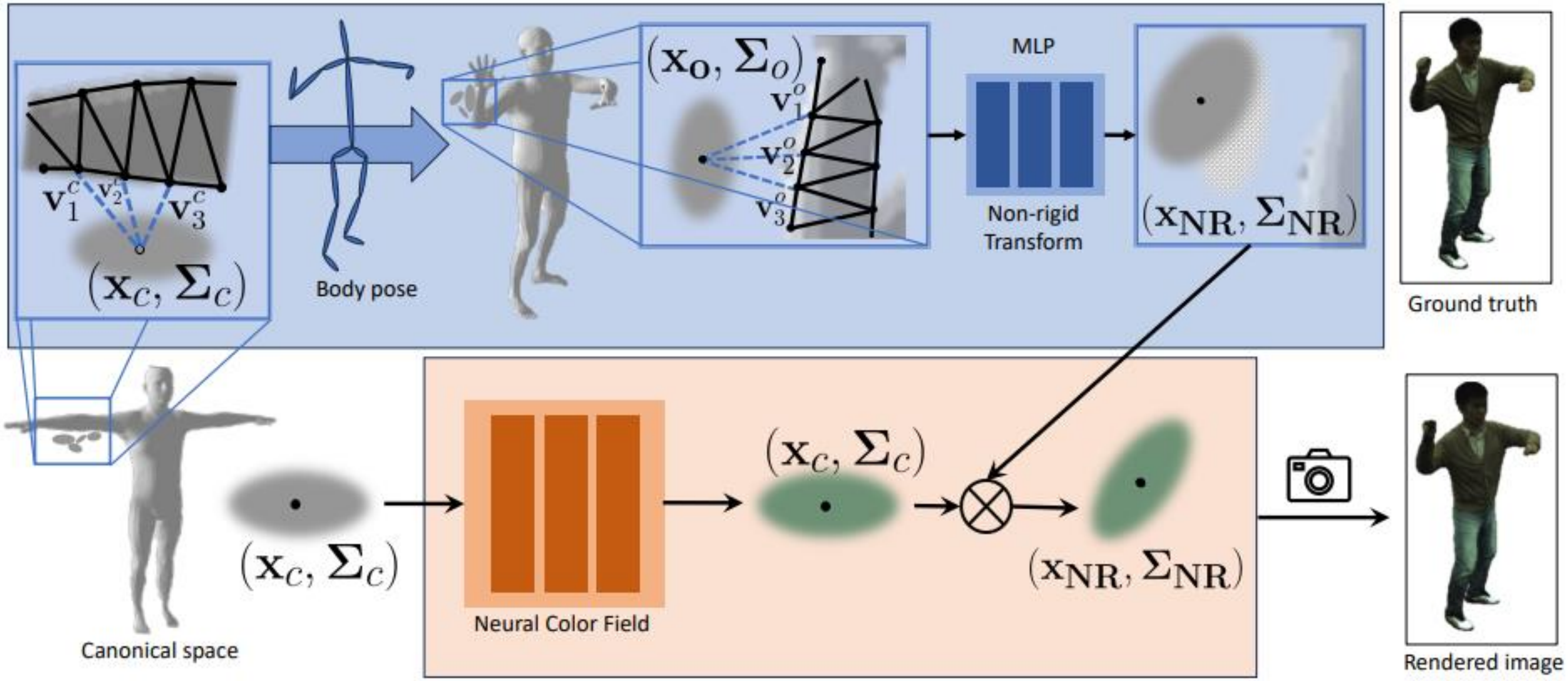
Gaussian Shell Maps for Efficient 3D Human Generation

Rameen Abdal[*1] Wang Yifan[*1] Zifan Shi[*†1,2] Yinghao Xu[1] Ryan Po[1] Zhengfei Kuang[1]
Qifeng Chen[2] Dit-Yan Yeung[2] Gordon Wetzstein[1]
[1]Stanford University [2]HKUST

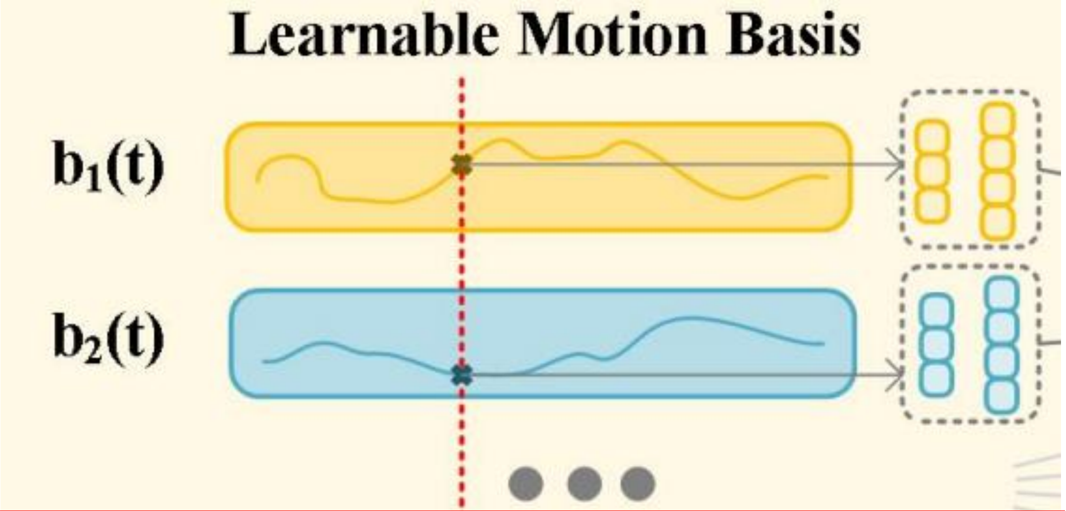
Shape Templates

SplatArmor: Articulated Gaussian splatting for animatable humans from monocular RGB videos

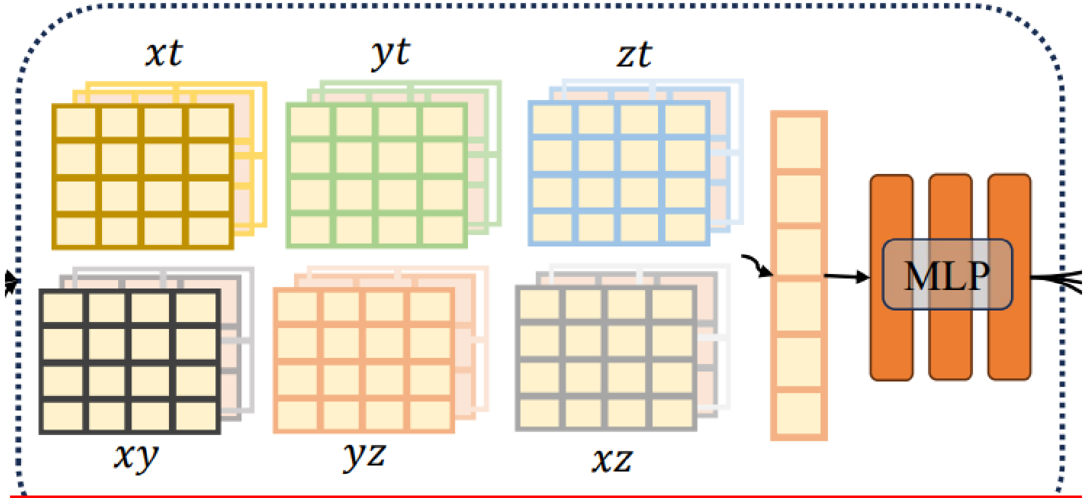
Rohit Jena[1*] Ganesh Iyer[2] Siddharth Choudhary[2] Brandon M. Smith[2]
Pratik Chaudhari[1] James C. Gee[1]
[1]University of Pennsylvania [2]Amazon.com, Inc



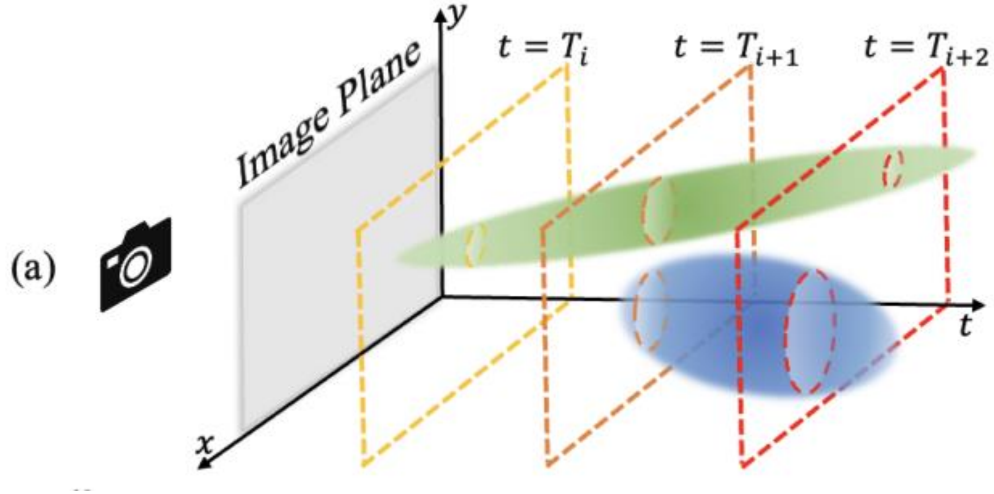
Alternative Dynamic Gaussian Representations



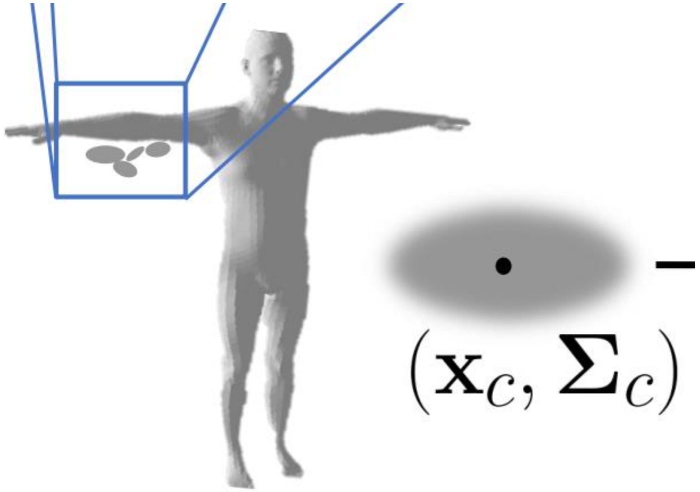
Motion Basis



Deformation Fields



4D Gaussians



Shape Templates

Thanks