ICLR

Cameras as Rays:
Pose Estimation via Ray Diffusion

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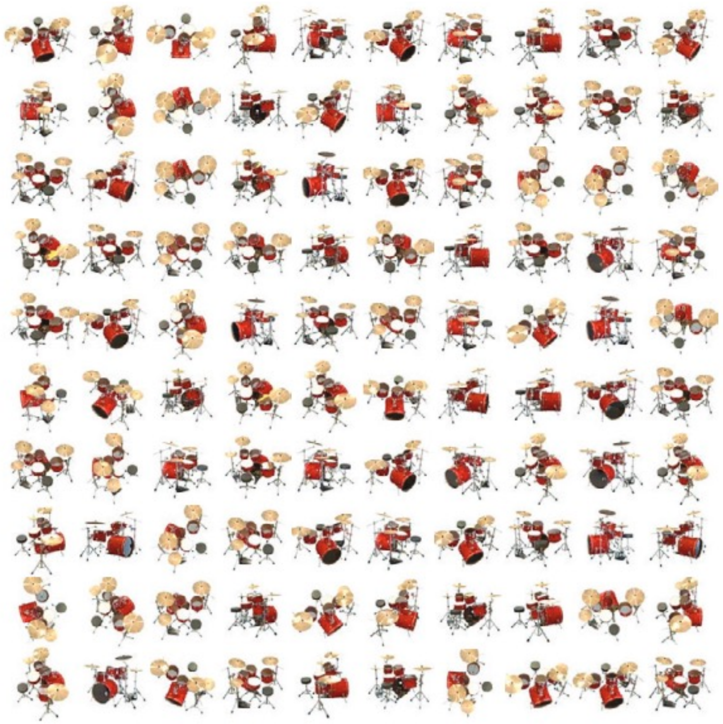
(* denotes equal contribution)

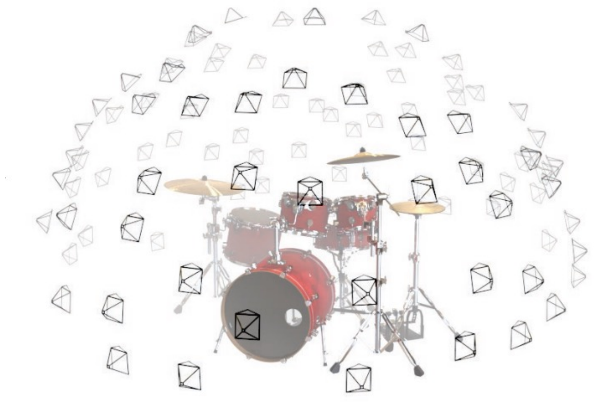
Lots of Progress in Novel-view Synthesis

Input Images



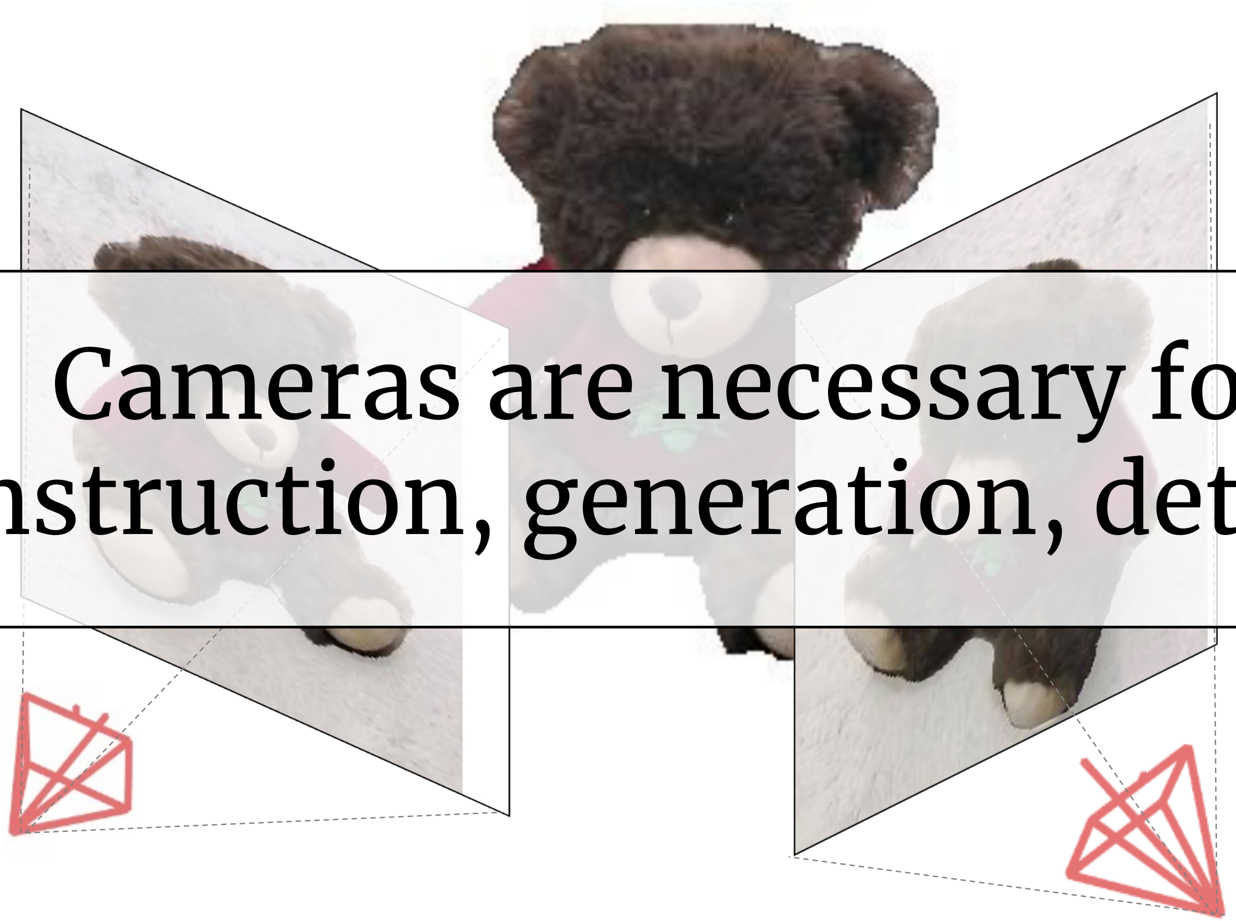
Rendered Views

Requirement:
Cameras



Mildenhall et al. *NeRF.* (ECCV 2020)

Recovering Cameras is a Pre-requisite for 3D Computer Vision



Cameras are necessary for:
3D reconstruction, generation, detection, etc.

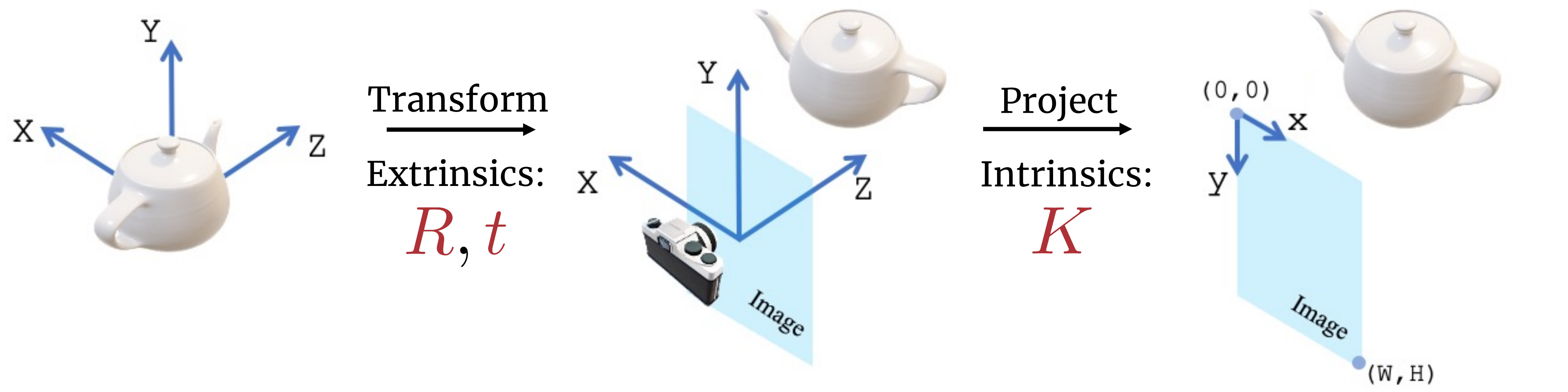
How are Cameras Typically Represented?

A camera describes how points in world coordinates project to pixel coordinates

World Coordinates

Camera Coordinates

Pixel Coordinates



Transform $\xrightarrow{\quad}$

Extrinsics:

R, t

Project $\xrightarrow{\quad}$

Intrinsics:

K

$$x$$

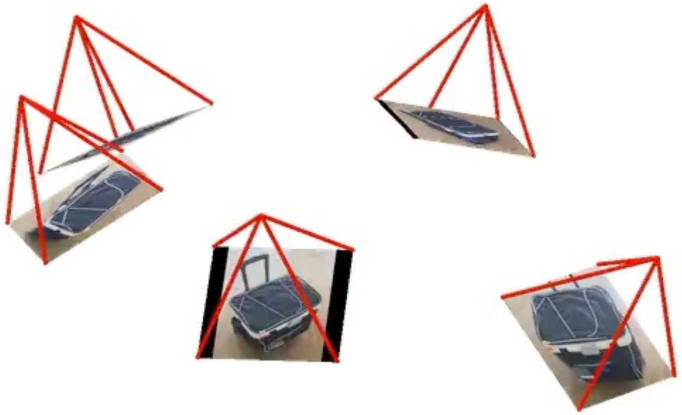
$$Rx + t$$

$$K(Rx + t)$$

Task: Sparse-view Camera Estimation

Input: Sparse Images (N≤8)

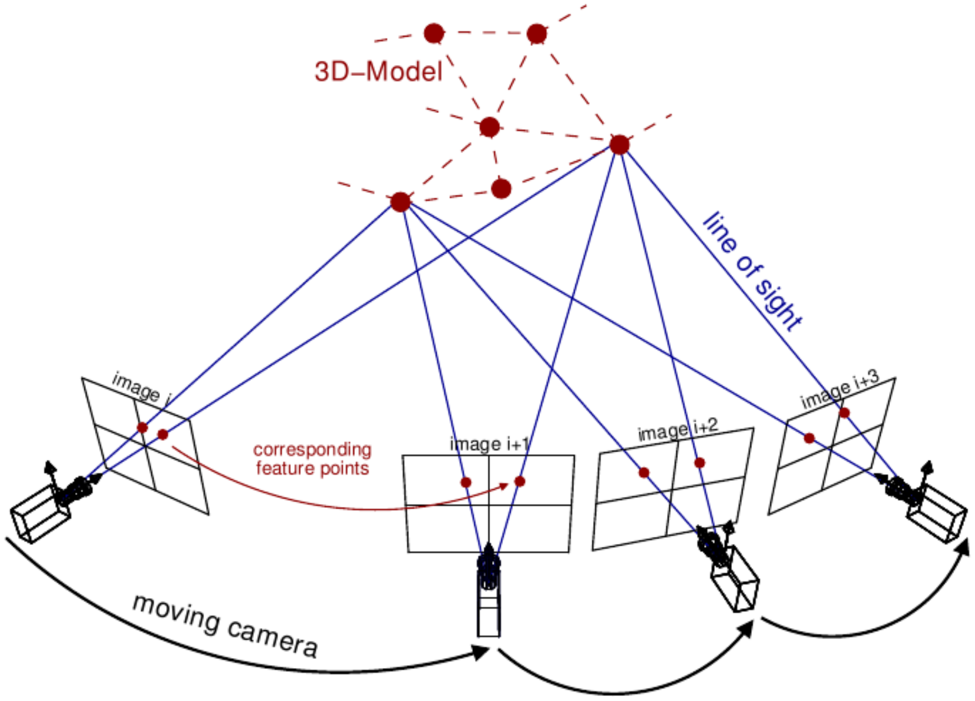
Output: Cameras



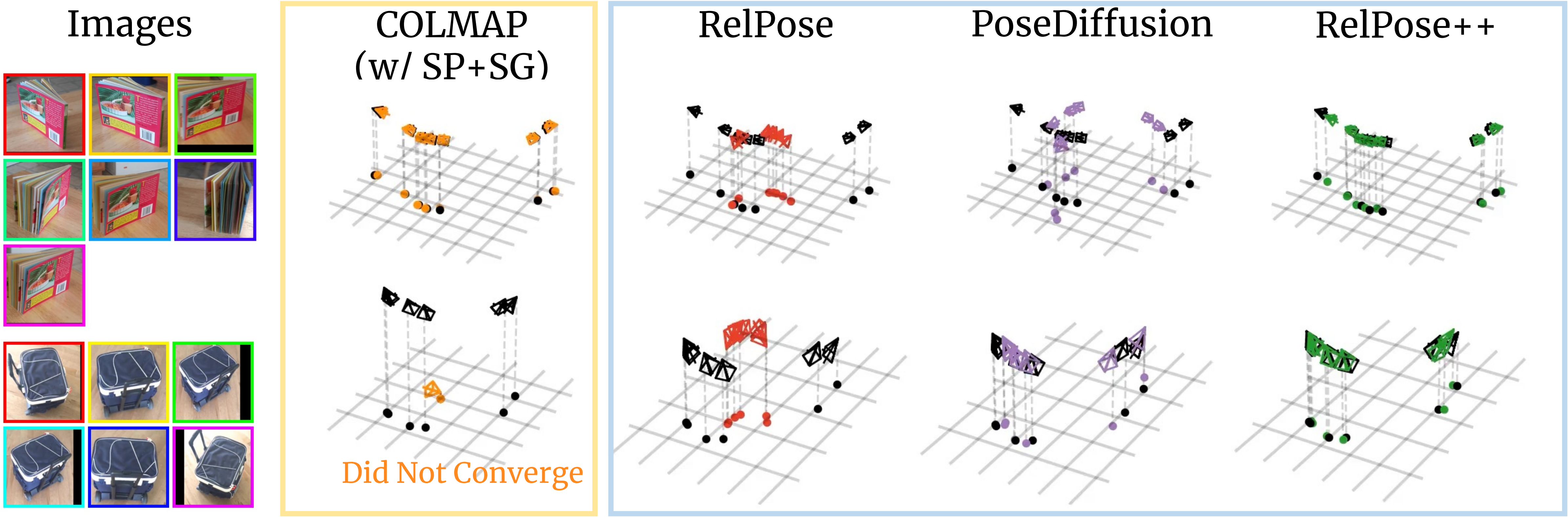
Structure-from-Motion:
Classical Pipeline for Recovering Cameras

Very challenging for sparse views!

Find point correspondences between images, triangulate them in 3D, solve for cameras parameters using Bundle Adjustment



Prior Work for Sparse-view Cameras

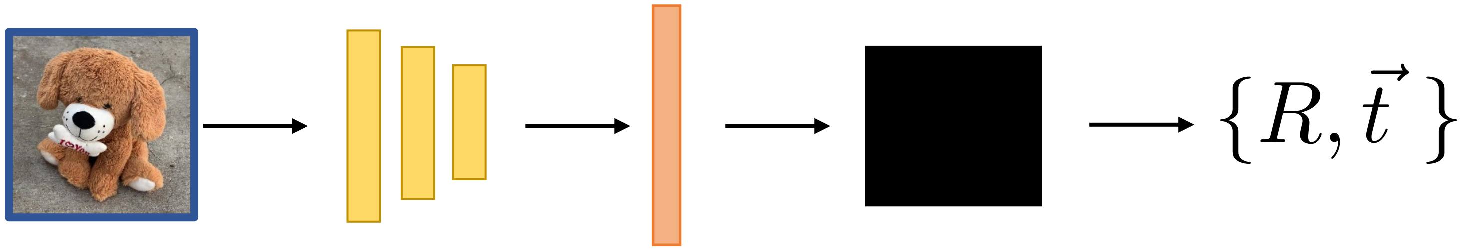


Classical Methods
+ Precise
- Lacks Robustness

Learning-based Methods
+ Robust
- Insufficient Precision

Schönberger et al. *COLMAP*. (CVPR 16, ECCV 16); Zhang et al. *RelPose*. (ECCV 22);
Wang et al. *PoseDiffusion*. (ICCV 23); Lin et al. *RelPose++*. (3DV 24)

Challenge: Global Features are a Bottleneck for Precision



Image

Encoder

(ResNet, DINO)

Feature

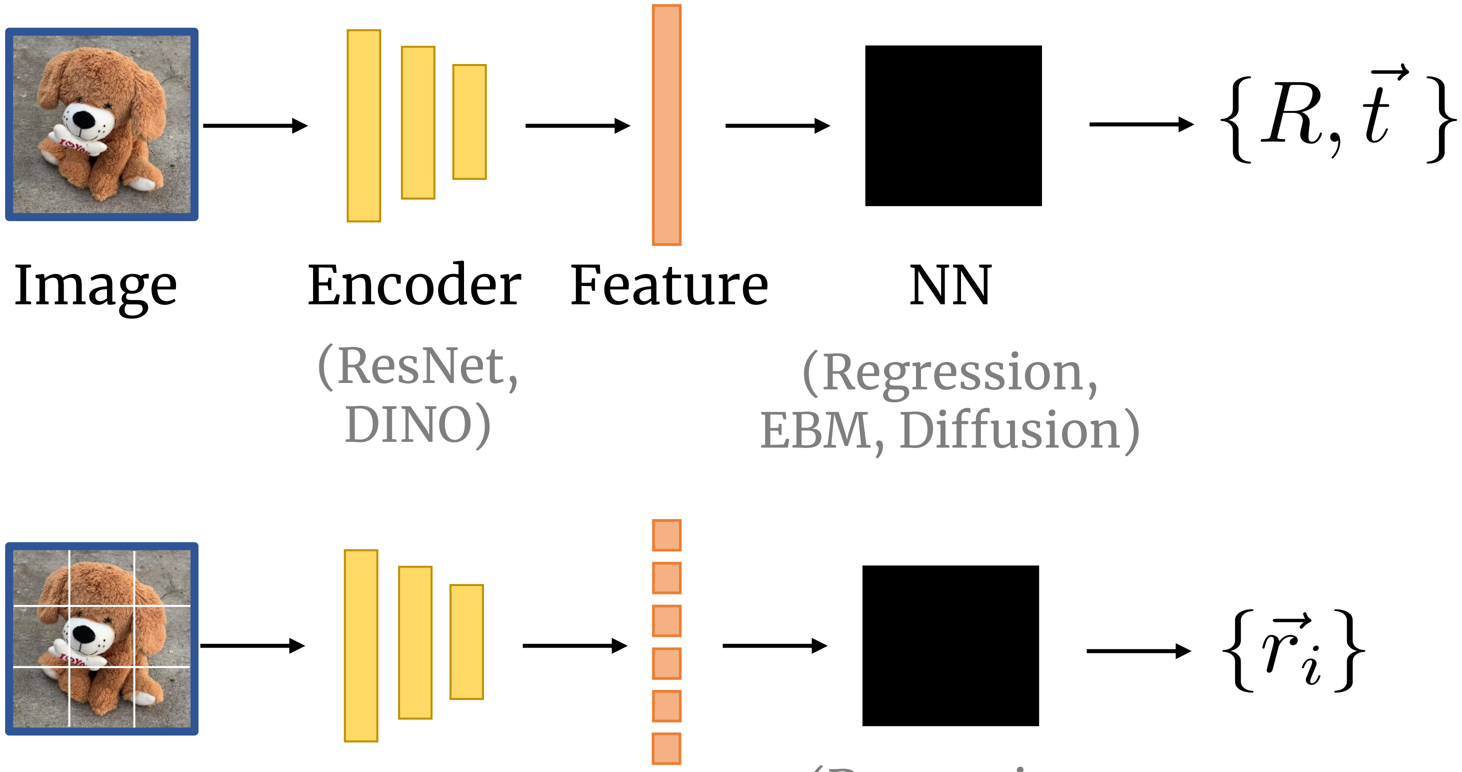
NN

(Regression, EBM, Diffusion)

$\{R, \vec{t}\}$

Cannot reason about low-level information (e.g., correspondences)

Challenge: Global Features are a Bottleneck for Precision



Image

Encoder

(ResNet, DINO)

Feature

NN

(Regression, EBM, Diffusion)

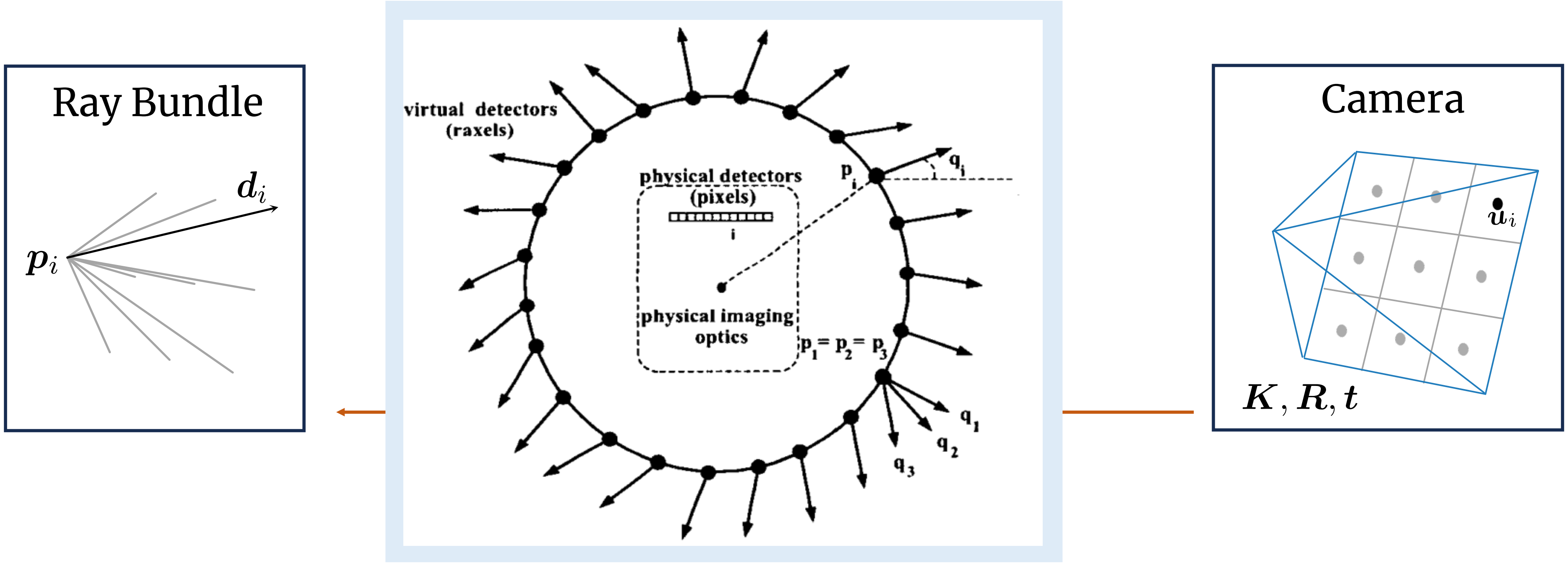
$\{R, \vec{t}\,\}$

Cannot reason about low-level information (e.g., correspondences)

$\{\vec{r}_i\}$

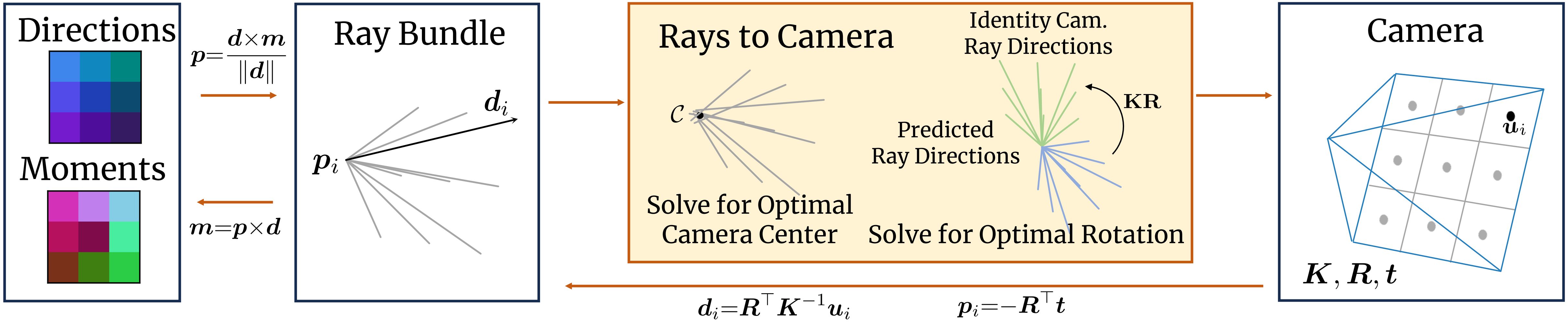
(Regression, Diffusion)

Representing Cameras via Ray Bundle



Grossberg & Nayar. *Raxel Imaging Model.* (IJCV 2005)

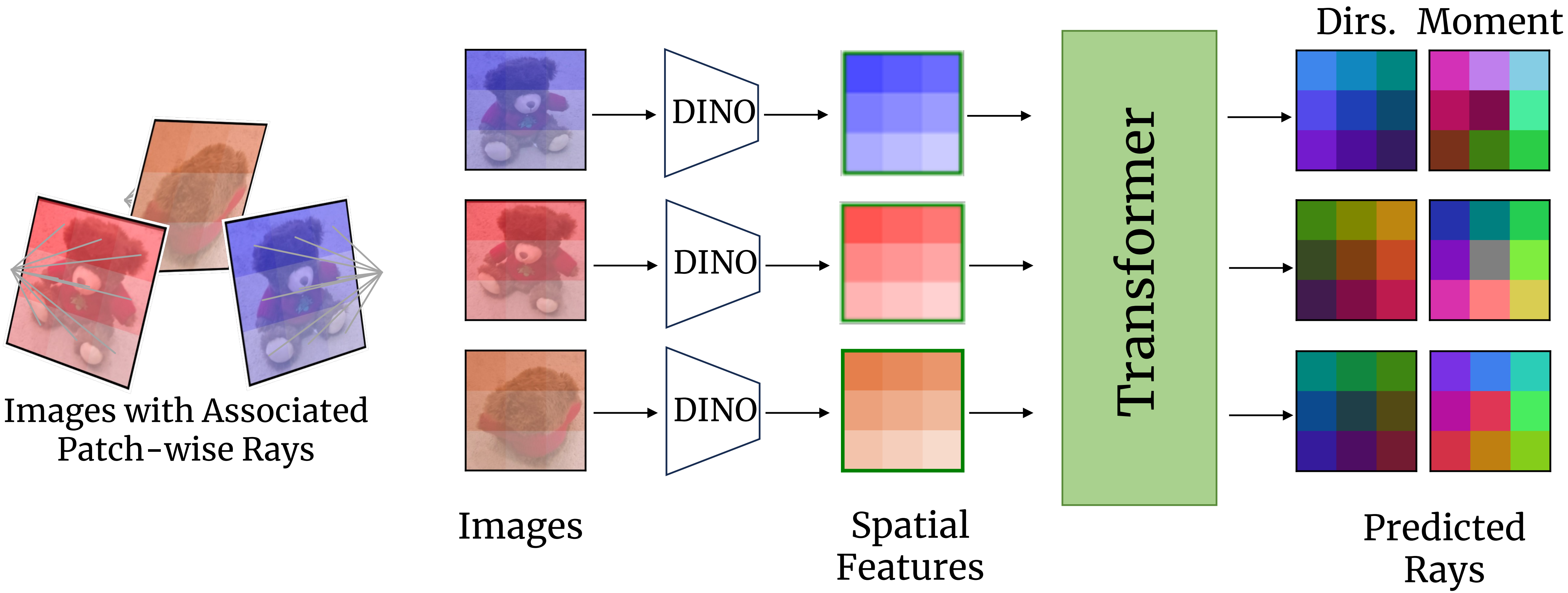
Representing Cameras via Ray Bundle


Directions
Moments
$p=\frac{\boldsymbol{d}\times\boldsymbol{m}}{\|\boldsymbol{d}\|}$
$\boldsymbol{m}=\boldsymbol{p}\times\boldsymbol{d}$
Ray Bundle
$\boldsymbol{d}_i$
$\boldsymbol{p}_i$
Rays to Camera
Identity Cam.
Ray Directions
$\mathcal{C}$
KR
Predicted
Ray Directions
Solve for Optimal
Camera Center
Solve for Optimal Rotation
Camera
$\boldsymbol{u}_i$
$\boldsymbol{K}, \boldsymbol{R}, \boldsymbol{t}$
$\boldsymbol{d}_i = \boldsymbol{R}^\top \boldsymbol{K}^{-1}\boldsymbol{u}_i$
$\boldsymbol{p}_i = -\boldsymbol{R}^\top \boldsymbol{t}$

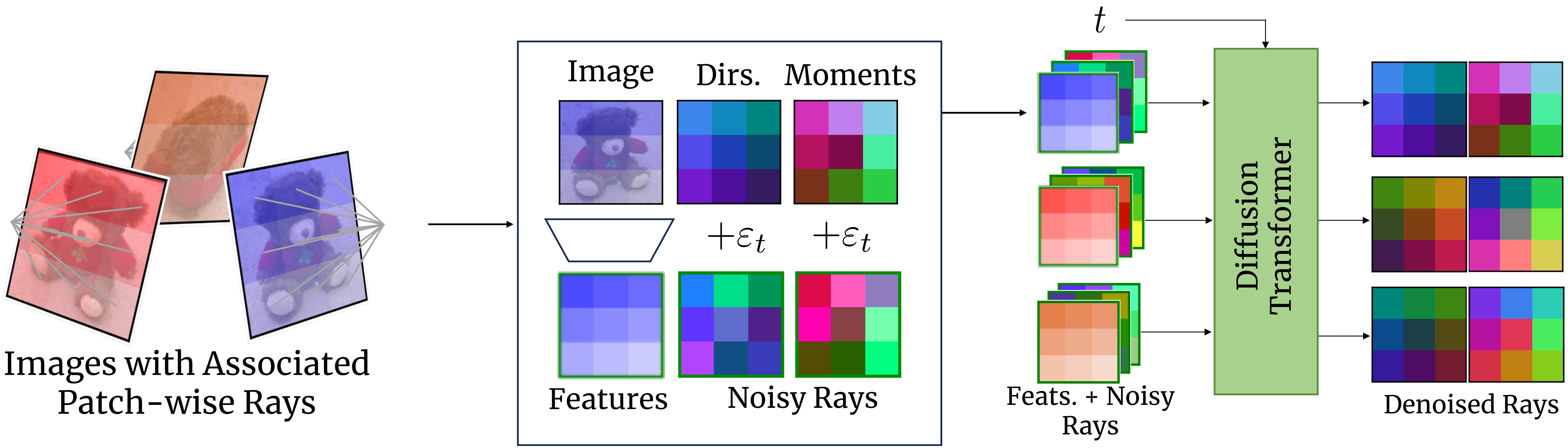
- Ray representation is distributed
- Ray representation is generic

Grossberg & Nayar. *Raxel Imaging Model.* (IJCV 2005)

Camera Estimation via Ray Regression



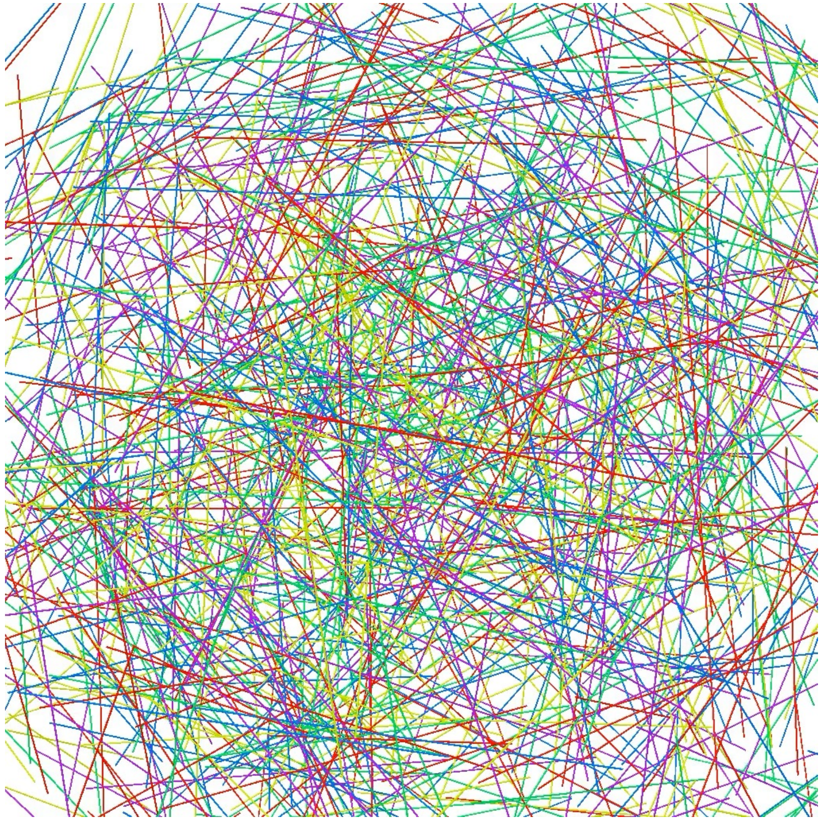
Camera Estimation via Ray Diffusion



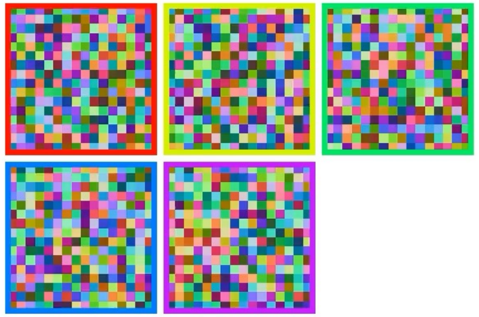
Backward Diffusion Process Visualization

Input Images

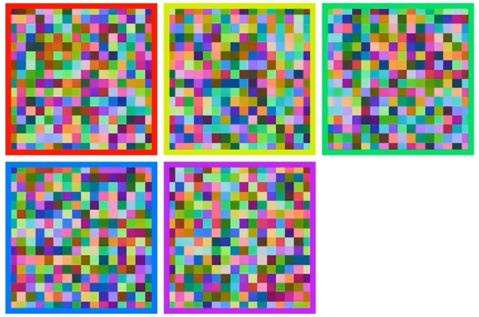
3D Rays



Directions



Moments



Backward Diffusion Process Visualization

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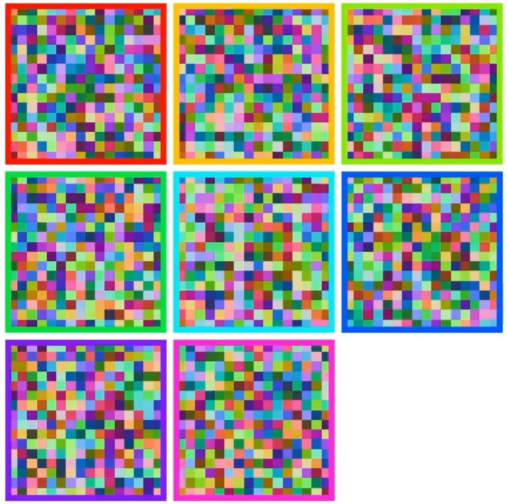
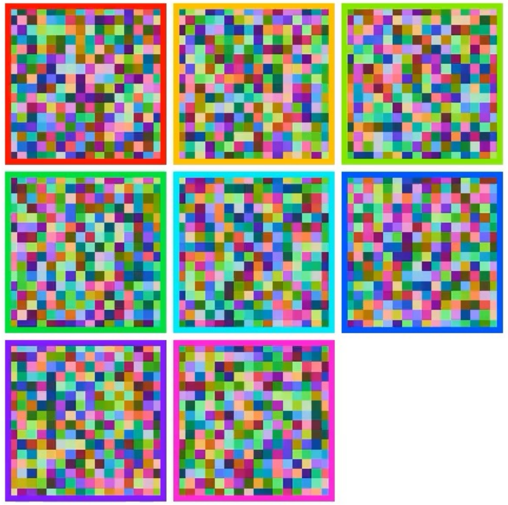
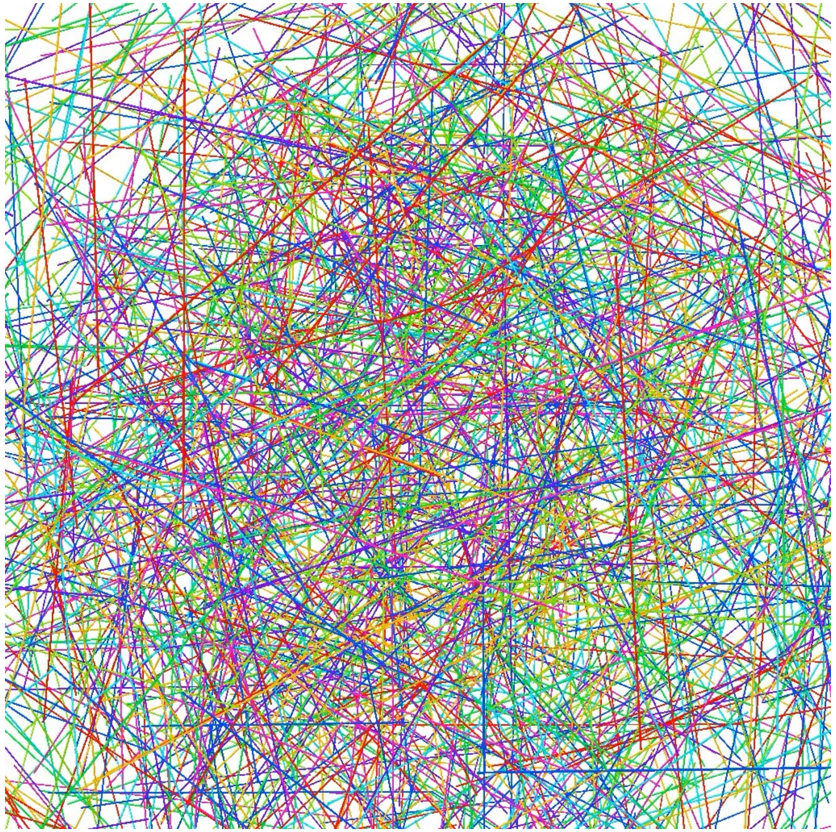
Directions



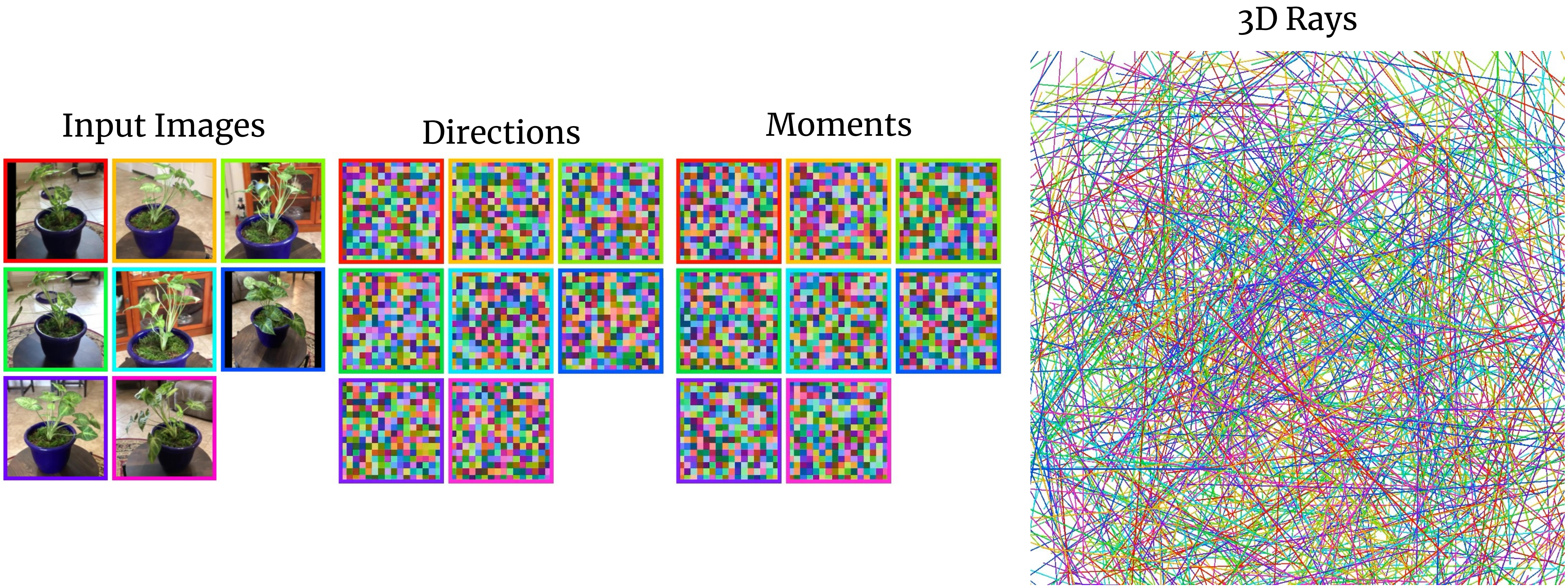
Moments



3D Rays



Backward Diffusion Process Visualization



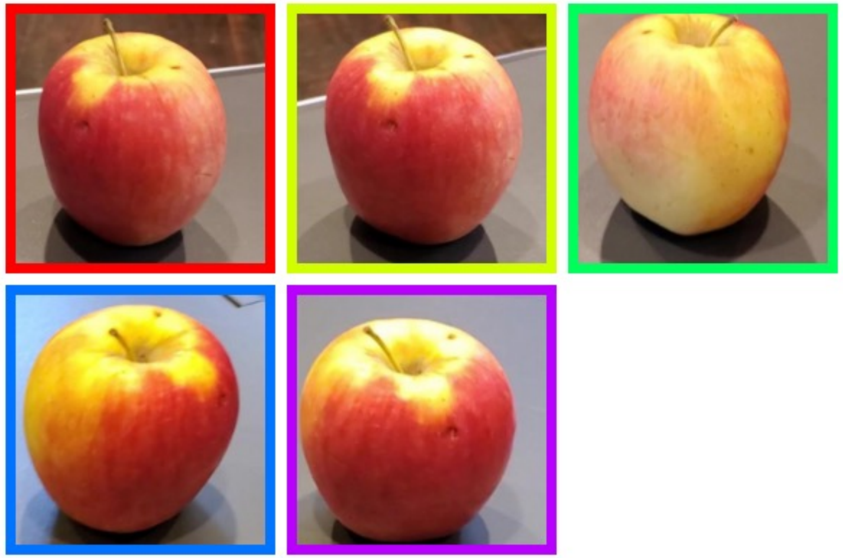
Input Images

Directions

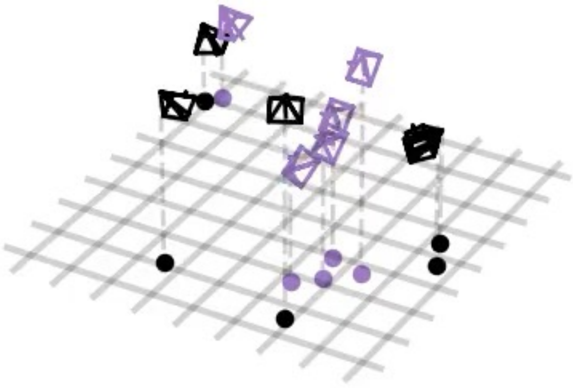
Moments

3D Rays

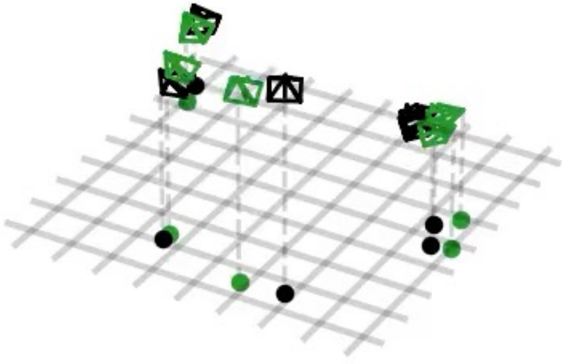
Qualitative Comparison



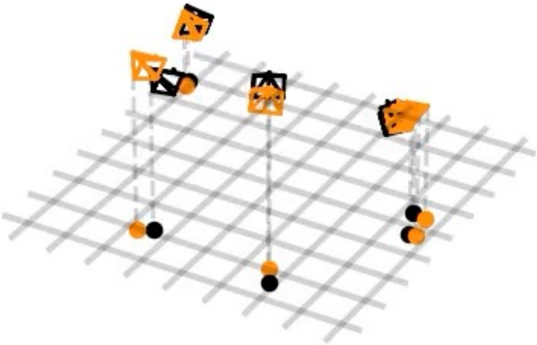
PoseDiffusion



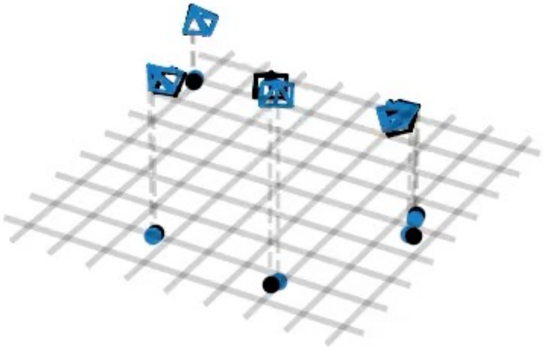
RelPose++



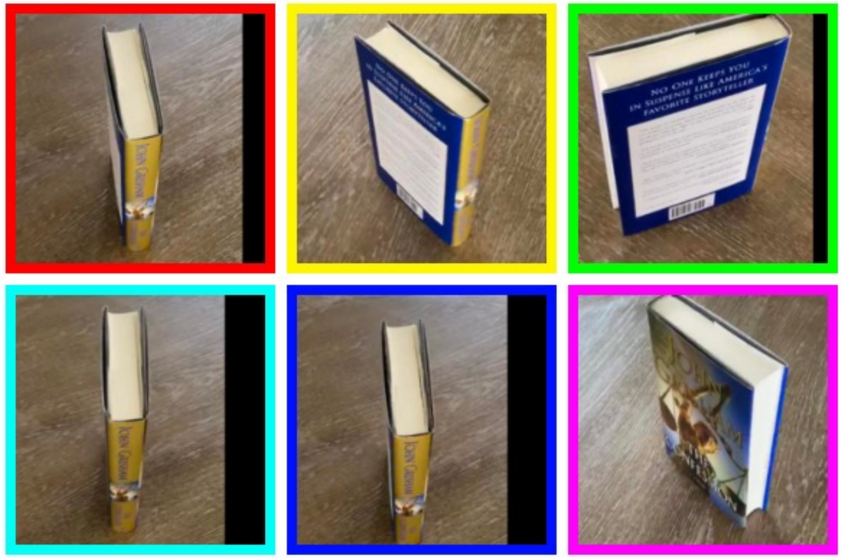
Ray Regression

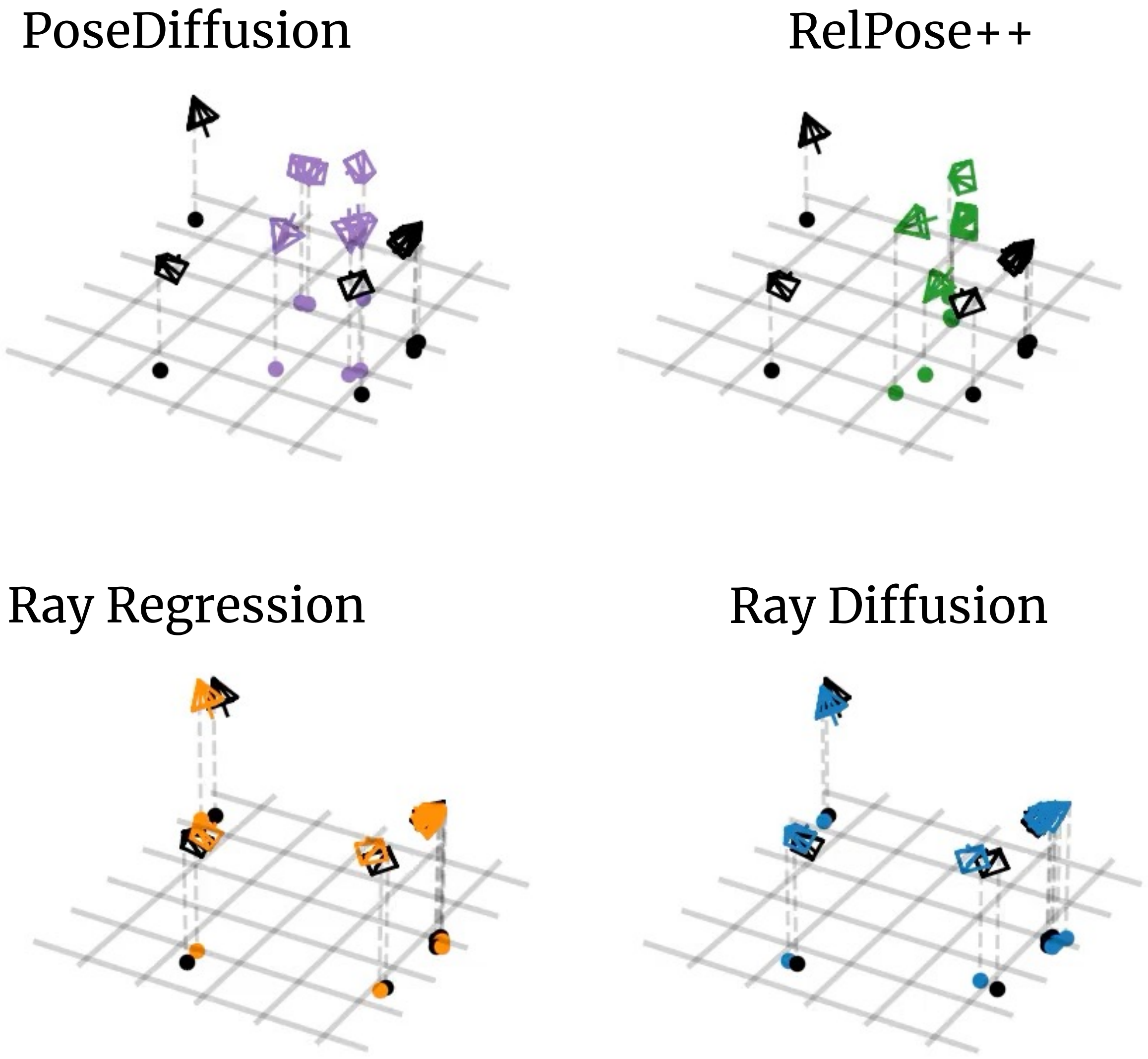


Ray Diffusion



Qualitative Comparison





PoseDiffusion

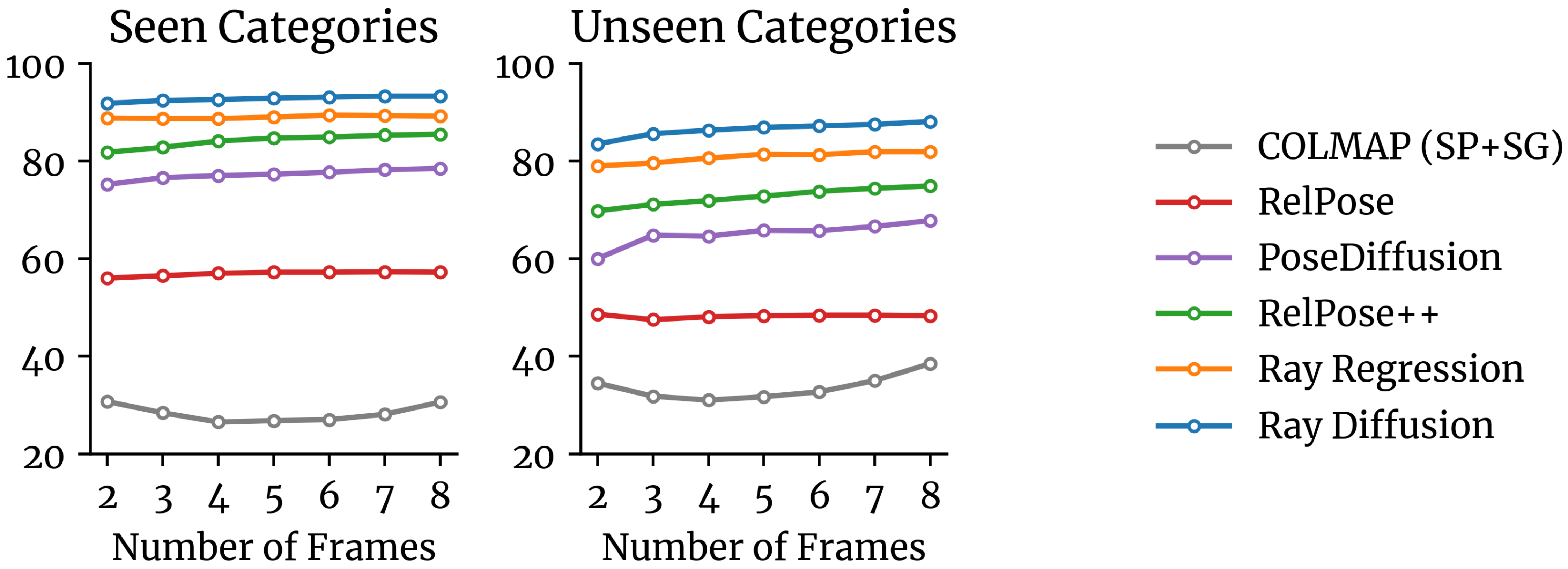
RelPose++

Ray Regression

Ray Diffusion

Quantitative Evaluation

Rotation Accuracy (% @ 15°)



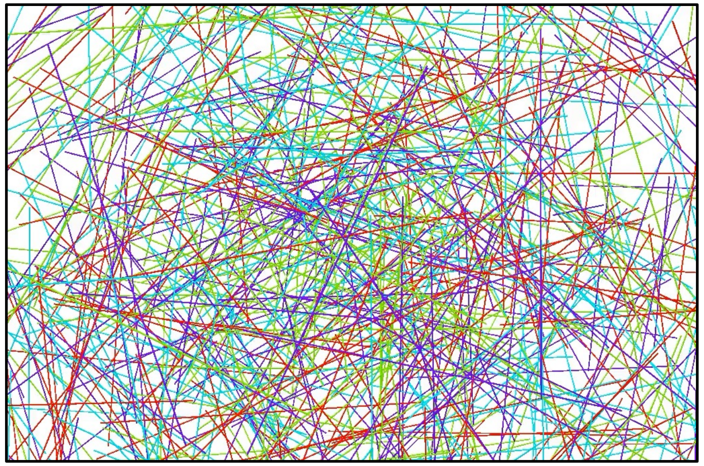
Takeaways

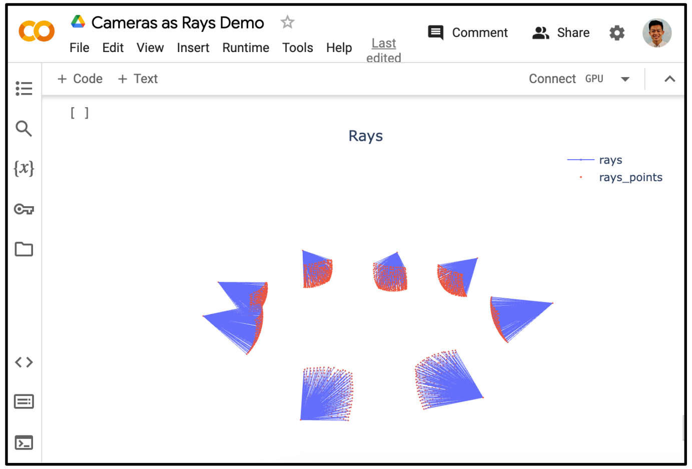
- We revisit the classical ray representation of cameras for learning-based pose estimation

- Present a diffusion-based model to predict the ray representation probabilistically

- **Future direction**: Train on all camera models jointly

Thank You for Listening!





Project Page (w/ Paper, Code, & More Results):

jasonyzhang.com/RayDiffusion

Join us at our poster: **Halle B #14**