Object Tracking

Computer Vision
Fall 2018
Columbia University

Homework 5

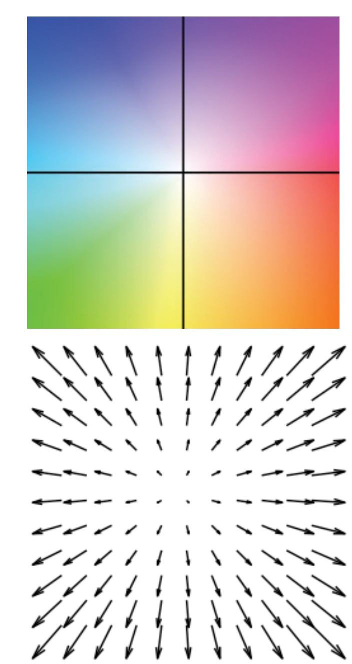
- Released last night
- Due November 26th
- Start it today— no extensions!

Optical Flow

- Optical flow field: assign a flow vector to each pixel
- Visualize: flow magnitude as saturation, orientation as hue

Input two frames

Ground-truth flow field



Visualization code [Baker et al. 2007]

Optical Flow Constraint

$$I_x u + I_y v + I_t = 0$$

- Brightness/color is constant
- Small motions
- Also assume neighboring pixels have same motion

Solving the aperture problem

- How to get more equations for a pixel?
- **Spatial coherence constraint:** pretend the pixel's neighbors have the same (u,v)
- If we use a 5x5 window, that gives us 25 equations per pixel

$$0 = I_t(\mathbf{p_i}) + \nabla I(\mathbf{p_i}) \cdot [u \;\; v]$$

$$\begin{bmatrix} I_x(\mathbf{p_1}) & I_y(\mathbf{p_1}) \\ I_x(\mathbf{p_2}) & I_y(\mathbf{p_2}) \\ \vdots & \vdots \\ I_x(\mathbf{p_{25}}) & I_y(\mathbf{p_{25}}) \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} = - \begin{bmatrix} I_t(\mathbf{p_1}) \\ I_t(\mathbf{p_2}) \\ \vdots \\ I_t(\mathbf{p_{25}}) \end{bmatrix}$$

$$\underset{25\text{x}2}{A} \;\; \underset{2\text{x}1}{d} = \underset{25\text{x}1}{b}$$

Slide credit: Steve Seitz

Solving the aperture problem

Problem: we have more equations than unknowns

$$\underset{25\times2}{A}\ \underset{2\times1}{d} = \underset{25\times1}{b} \longrightarrow \text{minimize } \|Ad - b\|^2$$

Slide credit: Steve Seitz

Solving the aperture problem

Problem: we have more equations than unknowns

$$\underset{25\times2}{A}\ \underset{2\times1}{d} = \underset{25\times1}{b} \longrightarrow \text{minimize } \|Ad - b\|^2$$

Solution: solve least squares problem

- minimum least squares solution given by solution (in d) of:

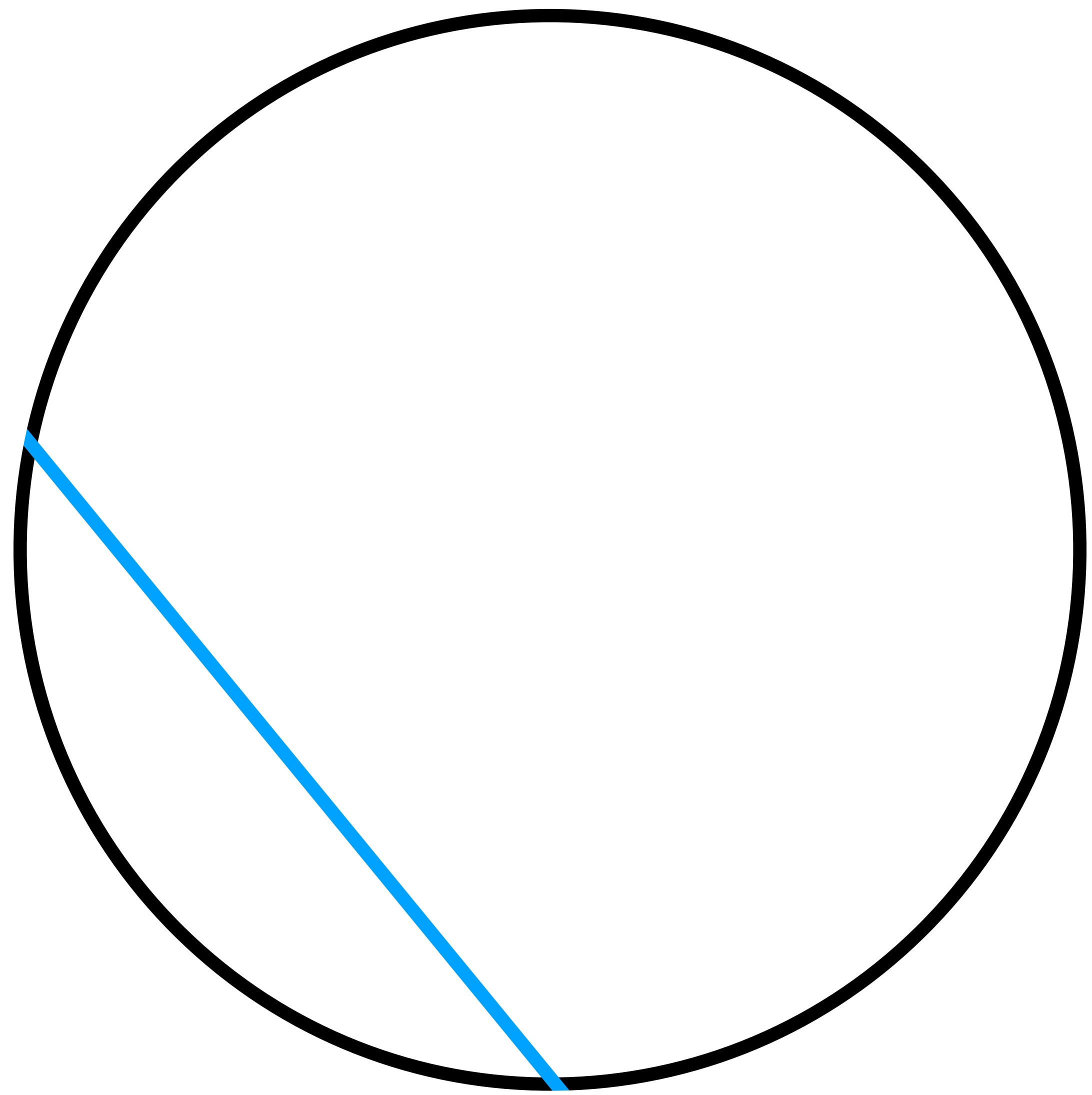
$$\underset{2\times2}{(A^T A)}\ \underset{2\times1}{d} = \underset{2\times1}{A^T b}$$

$$\underbrace{\begin{bmatrix} \sum I_x I_x & \sum I_x I_y \\ \sum I_x I_y & \sum I_y I_y \end{bmatrix}}_{A^T A} \begin{bmatrix} u \\ v \end{bmatrix} = - \underbrace{\begin{bmatrix} \sum I_x I_t \\ \sum I_y I_t \end{bmatrix}}_{A^T b}$$

- The summations are over all pixels in the K x K window
- This technique was first proposed by Lucas & Kanade (1981)

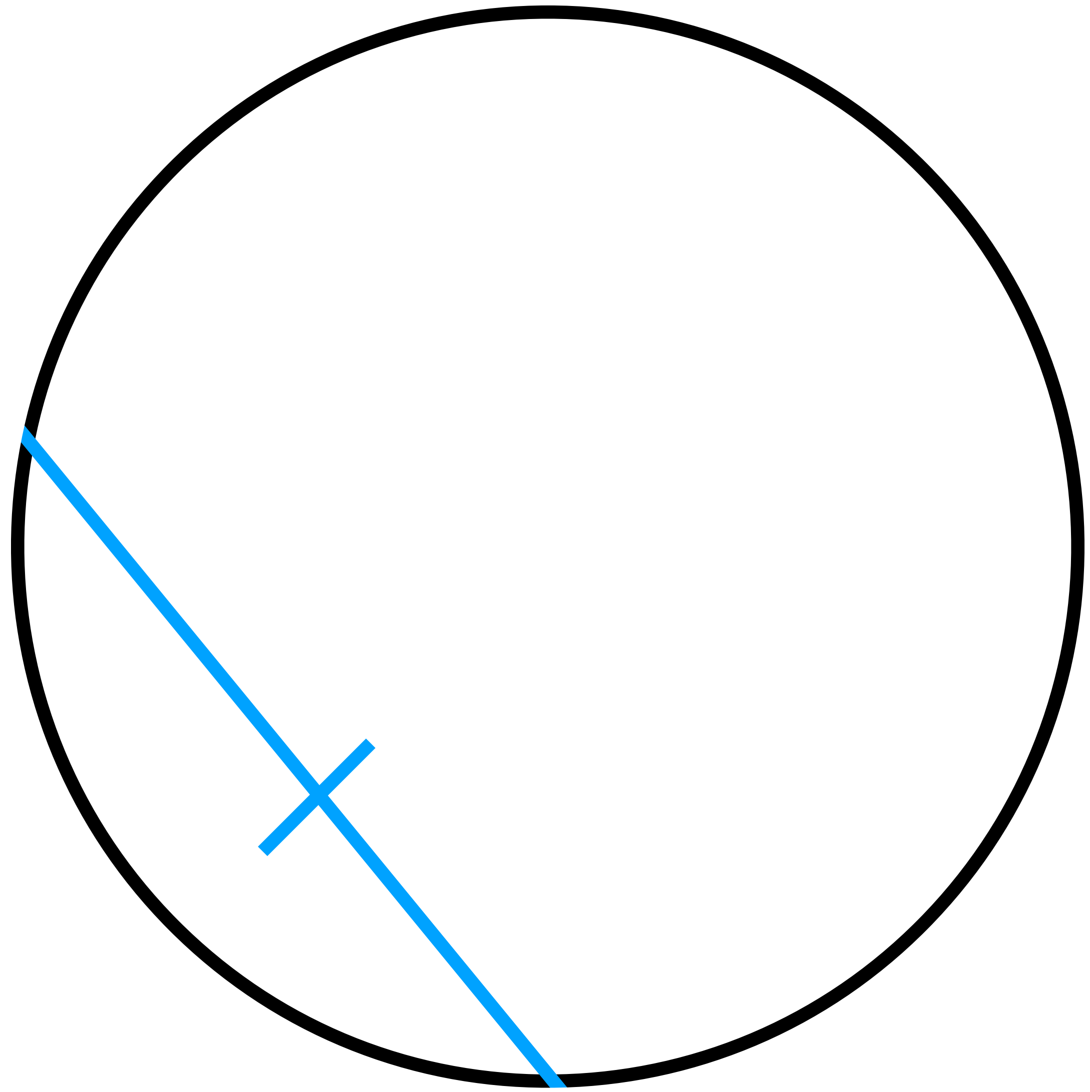
Slide credit: Steve Seitz

Aperture Problem



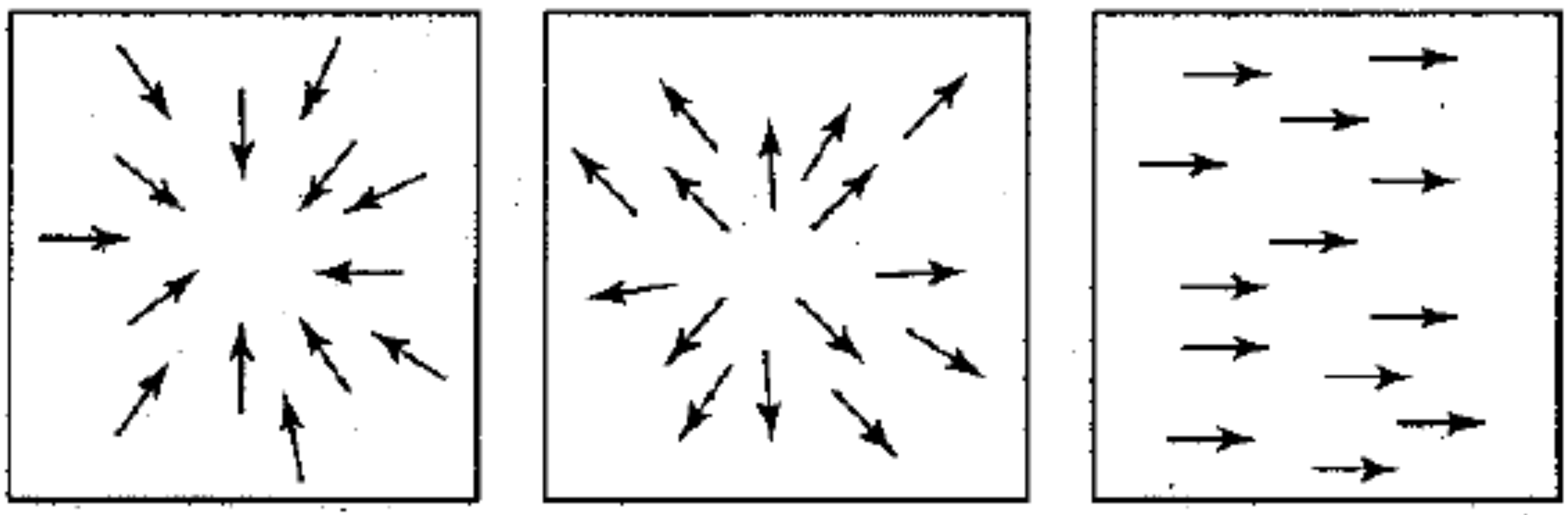
Which way did
the line move?

Aperture Problem



Which way did
the line move?

Motion Fields

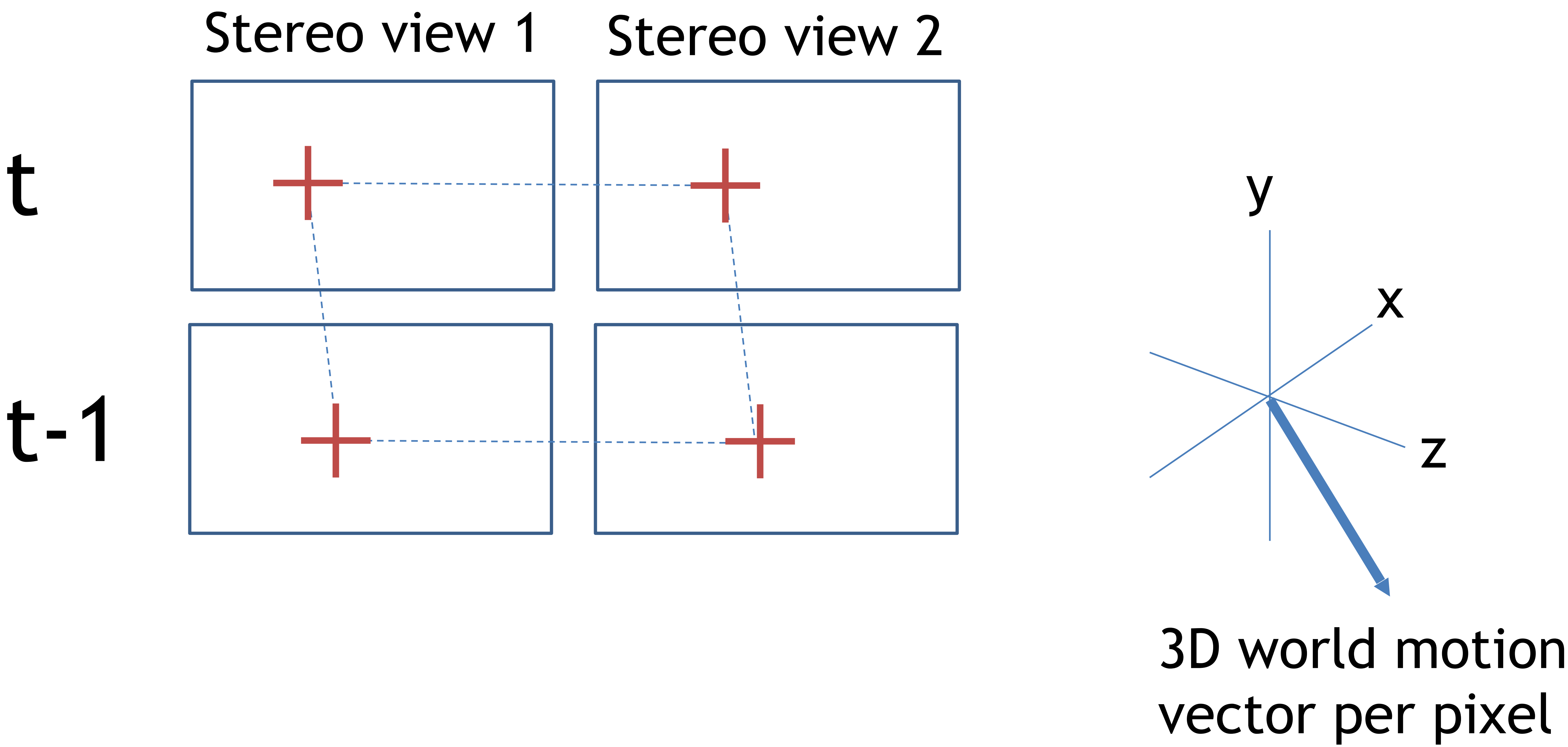


Zoom out **Zoom in** **Pan right to left**

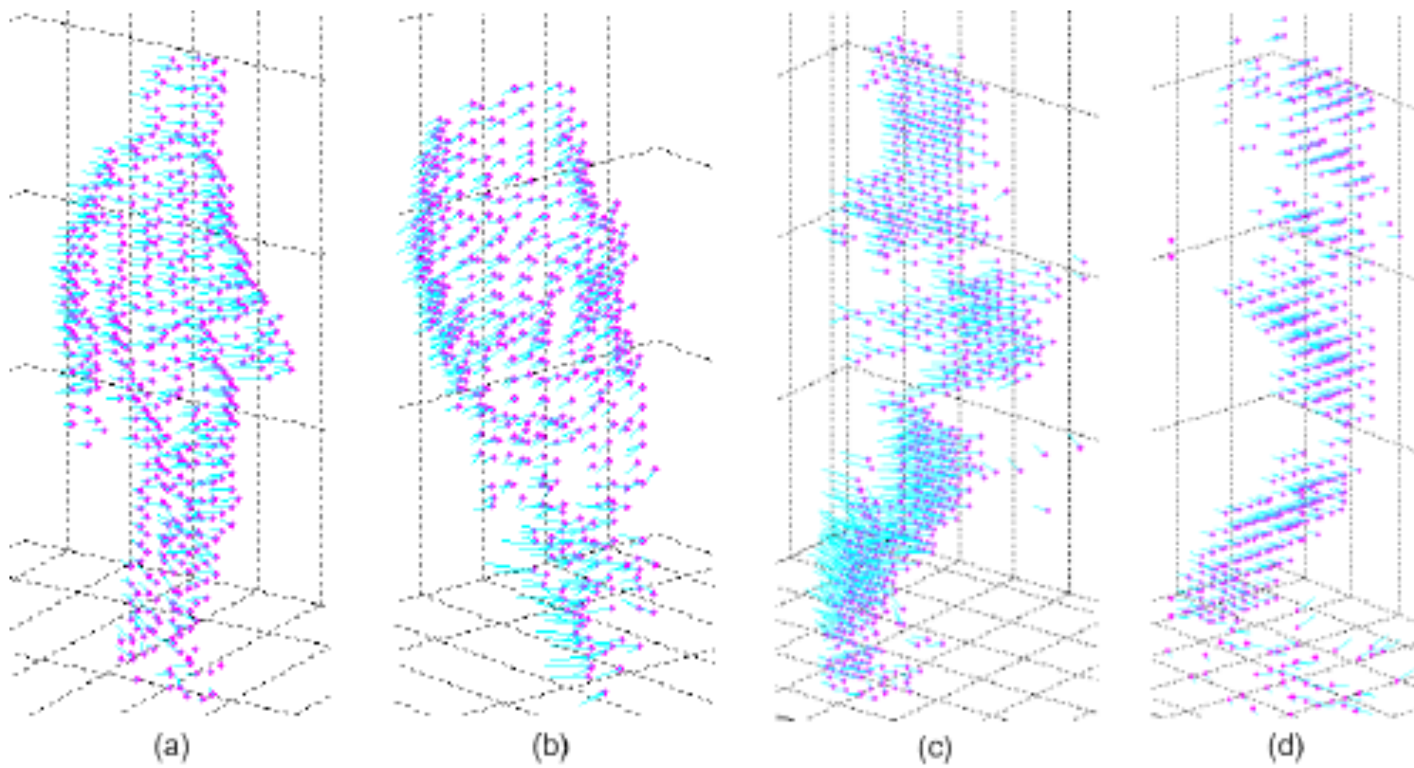
Can we do more? *Scene flow*

Combine spatial stereo & temporal constraints

Recover 3D vectors of world motion



Scene flow example for human motion



Estimating 3D Scene Flow from Multiple 2D Optical Flows, Ruttle et al., 2009

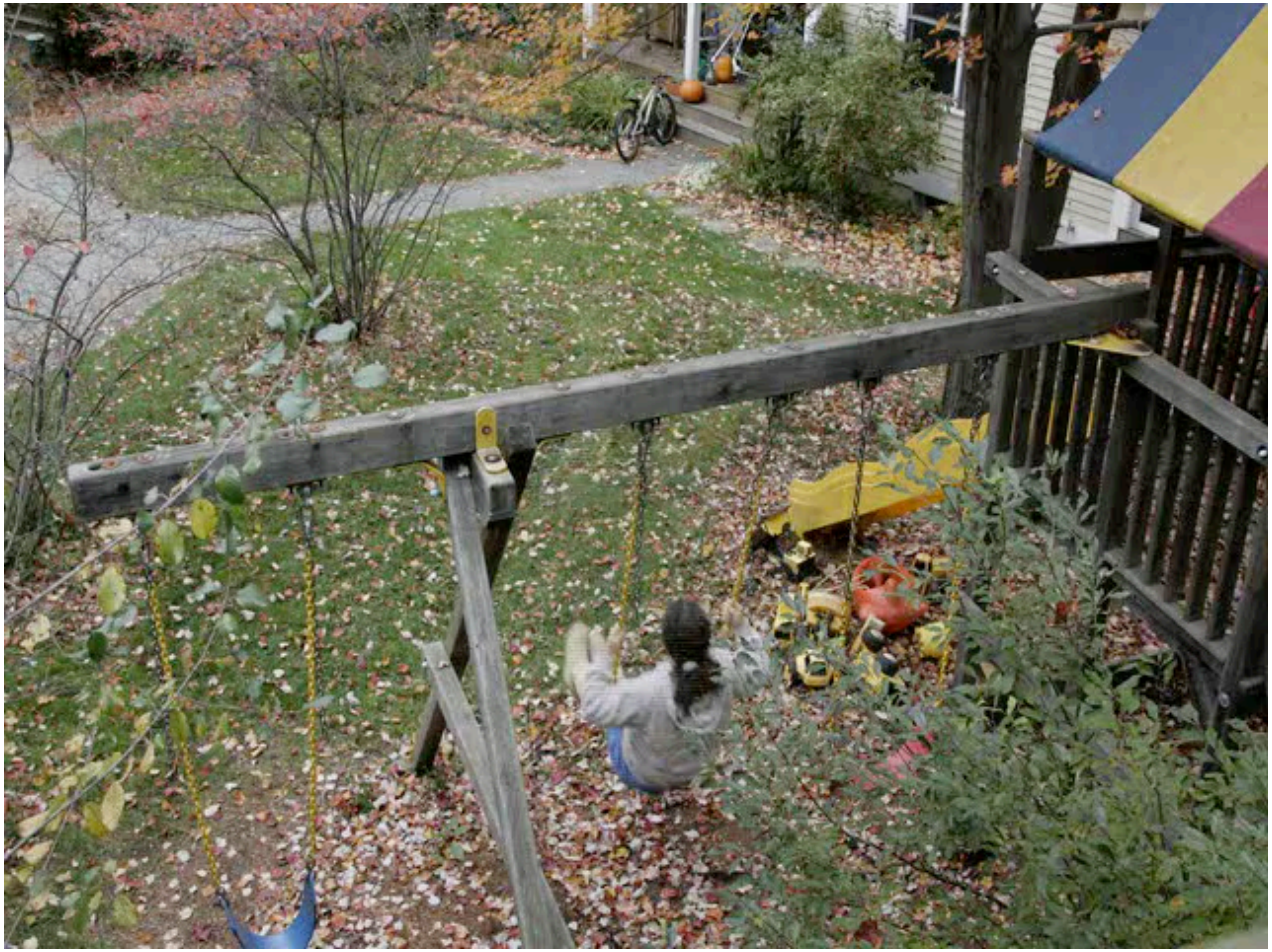
Scene Flow

https://www.youtube.com/watch?v=RL_TK_Be6_4

https://vision.in.tum.de/research/sceneflow

[Estimation of Dense Depth Maps and 3D Scene Flow from Stereo Sequences, M. Jaimez et al., TU Munchen]

Motion Analysis

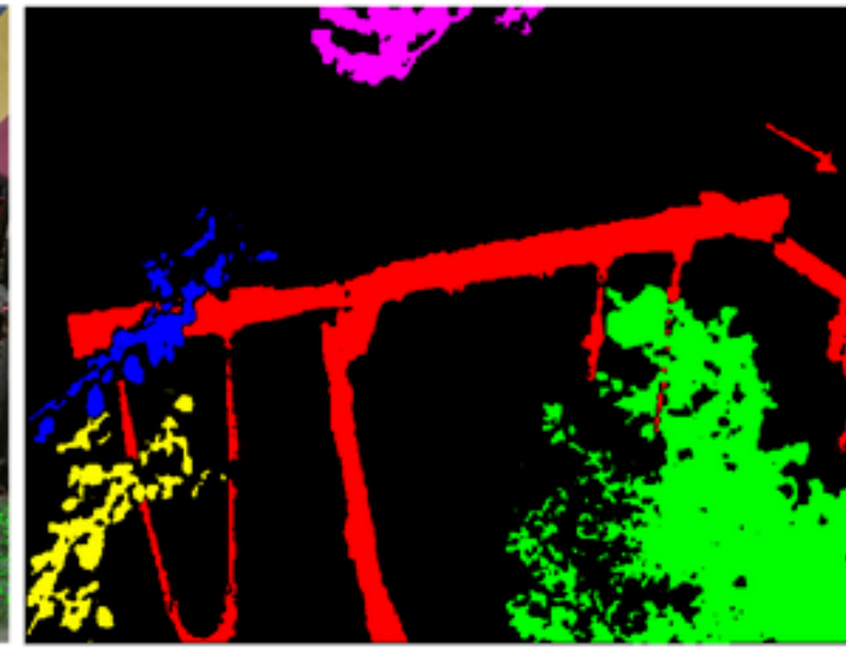


Motion Magnification

Motion Magnification

(a) Registered input frame

(b) Clustered trajectories of tracked features



(c) Layers of related motion and appearance

(d) Motion magnified, showing holes

(e) After texture in-painting to fill holes

(f) After user's modification to segmentation map in (c)

Motion Magnification

Motion Magnification

Massachusetts Institute of Technology

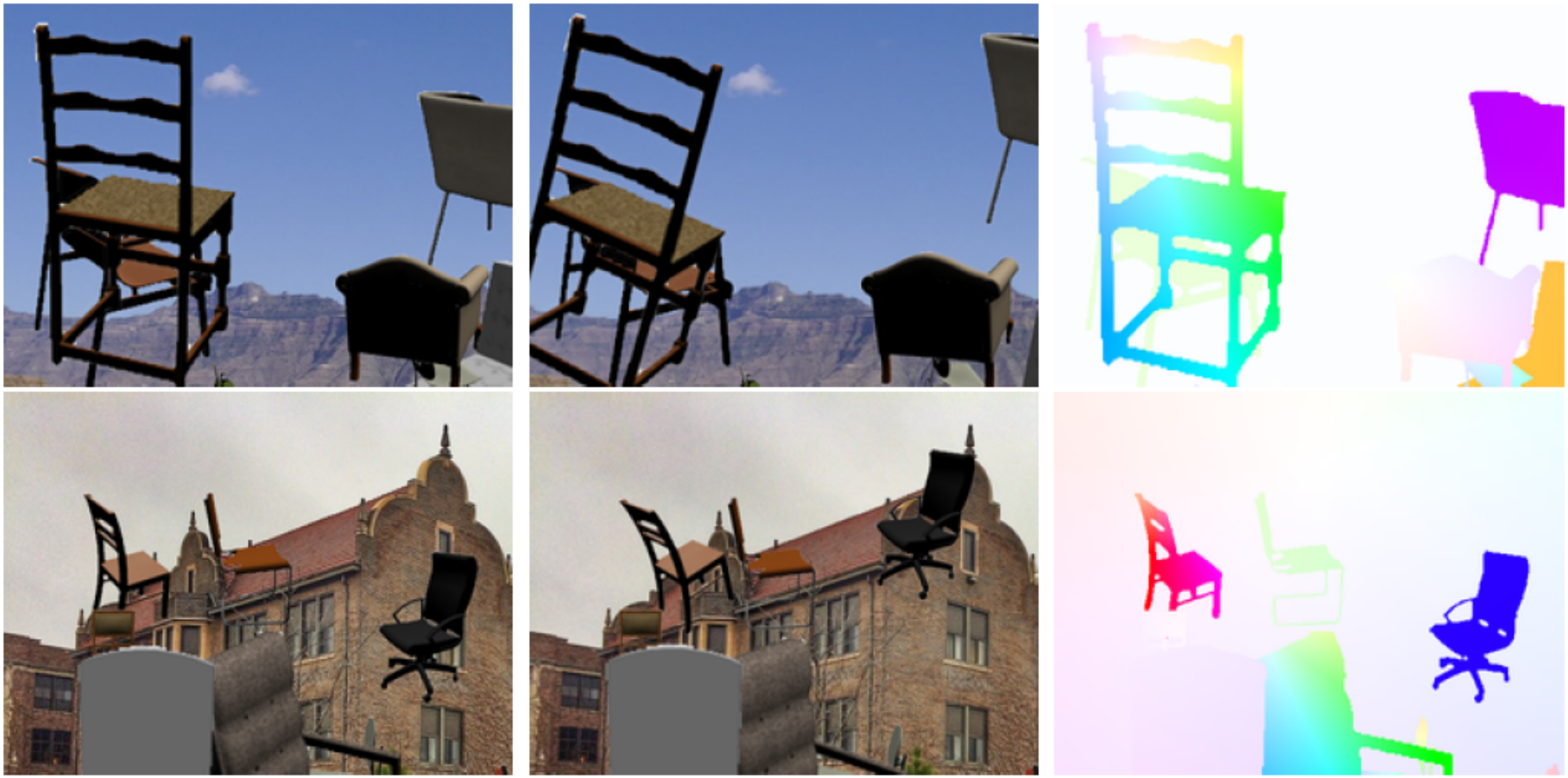
CSAIL

Revealing Invisible Changes In The World

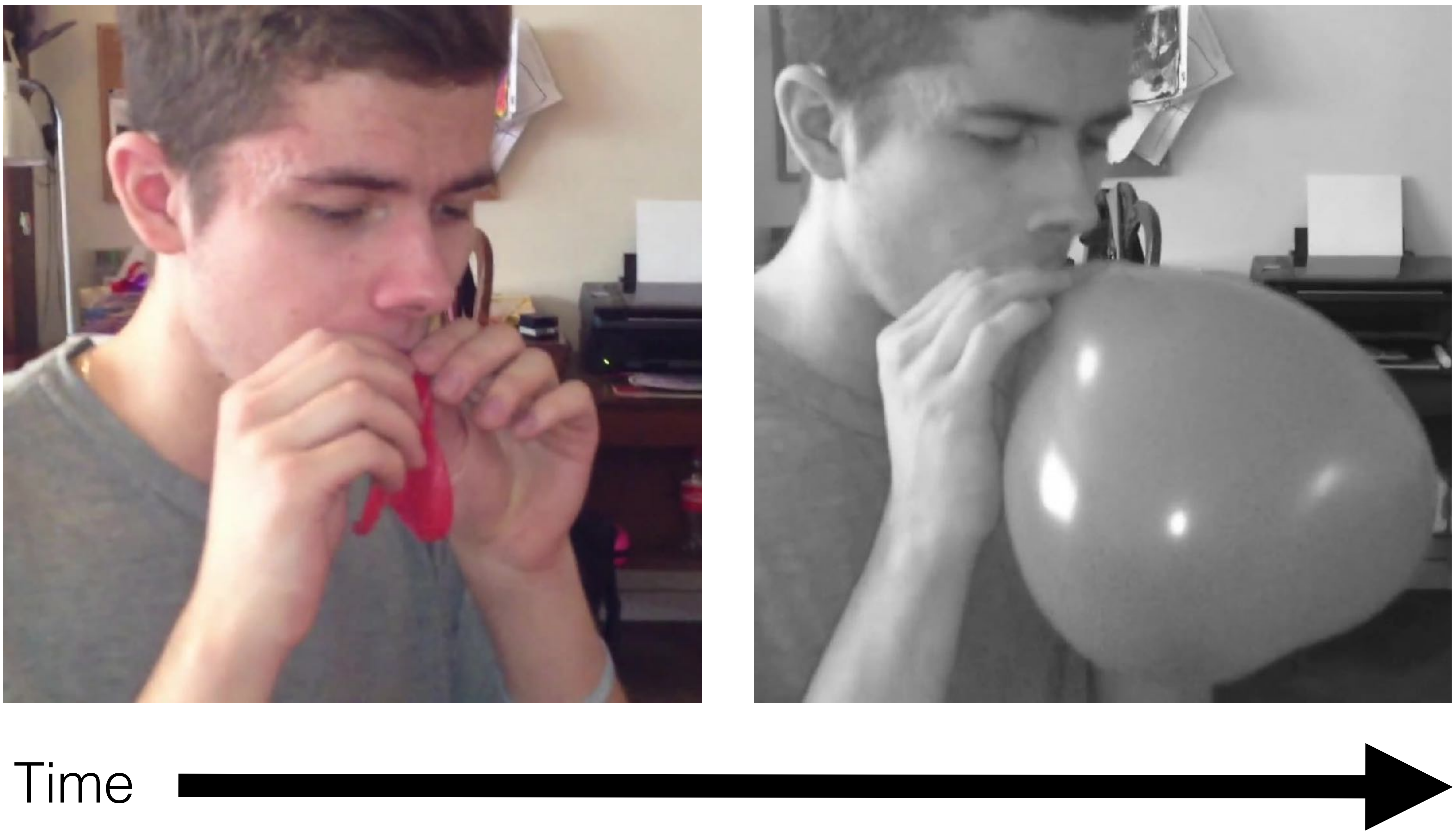
Created for the NSF International Science & Engineering

Visualization Challenge 2012

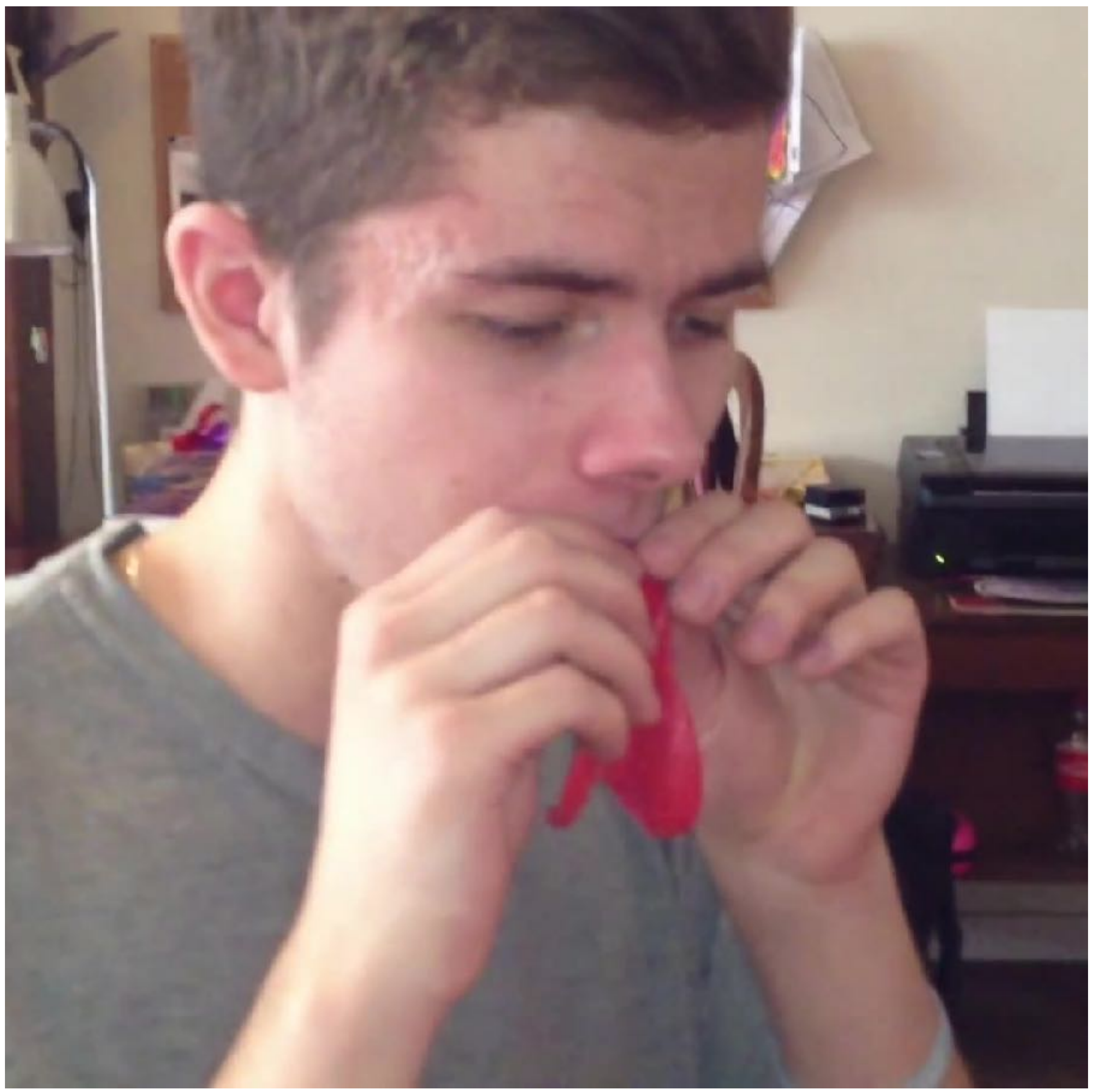
Learning optic flow



Fischer et al. 2015. https://arxiv.org/abs/1504.06852

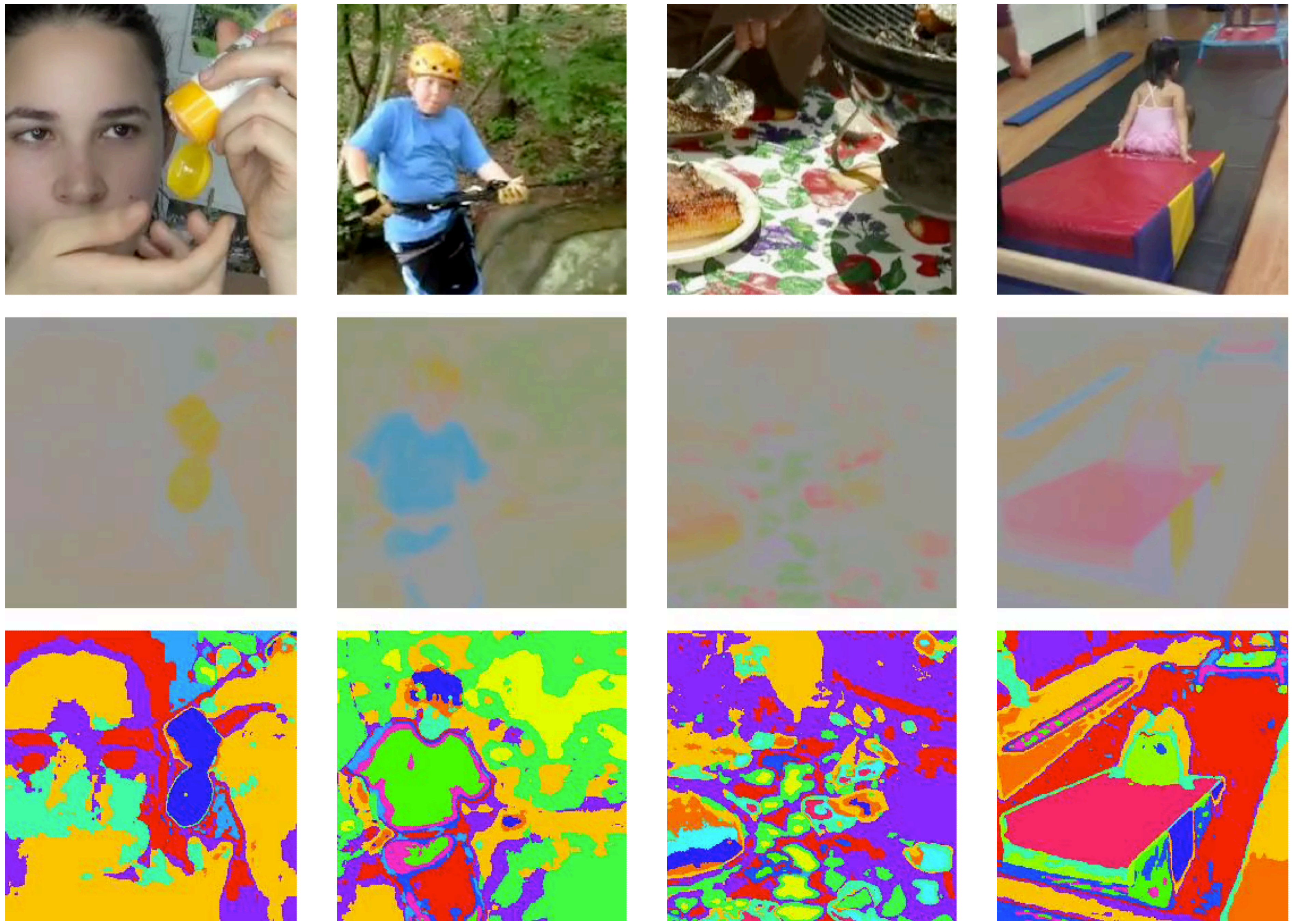

Time

What color is that pixel?



Time

Temporal Coherence of Color



RGB

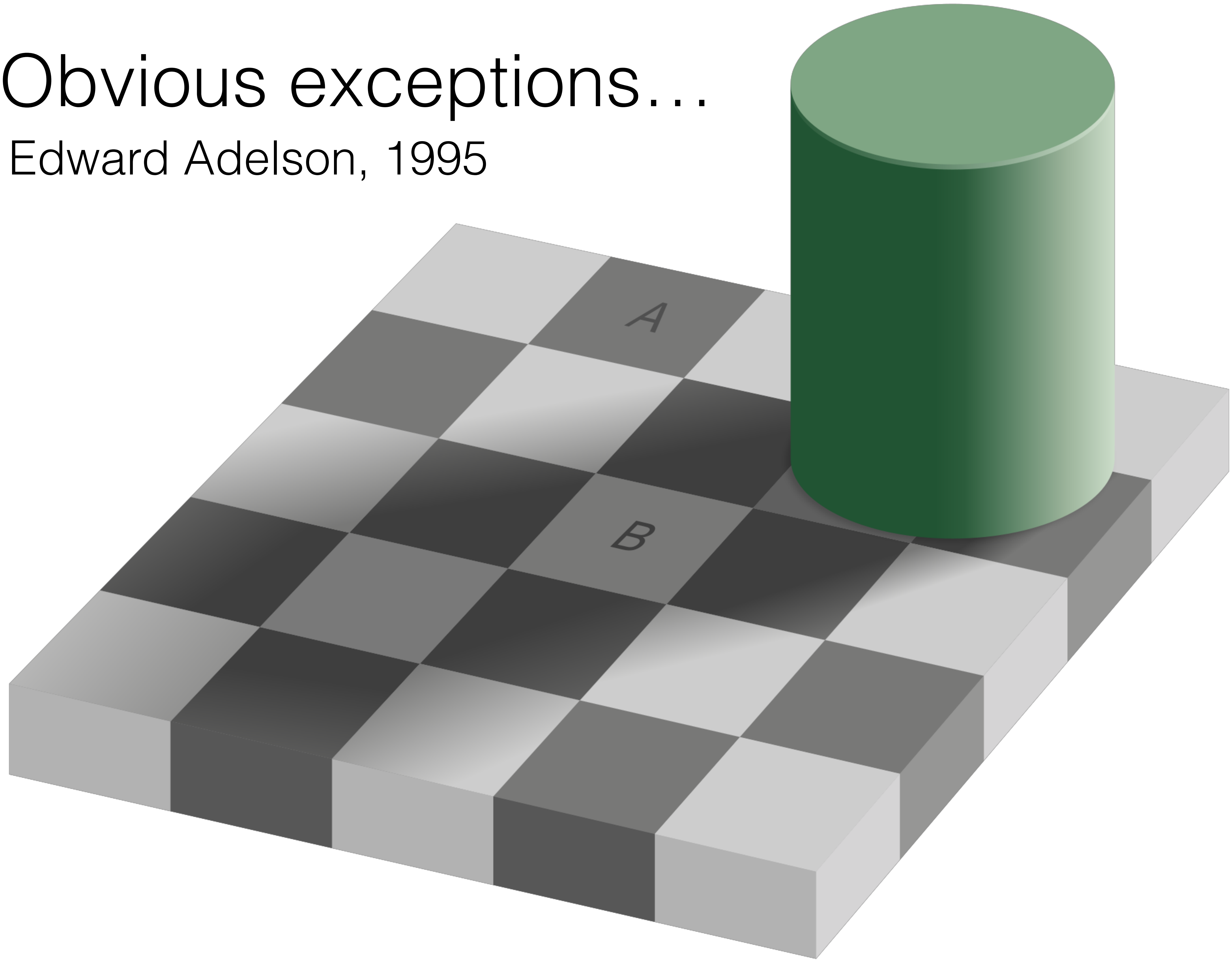
Color Channels

Quantized Color

Obvious exceptions…

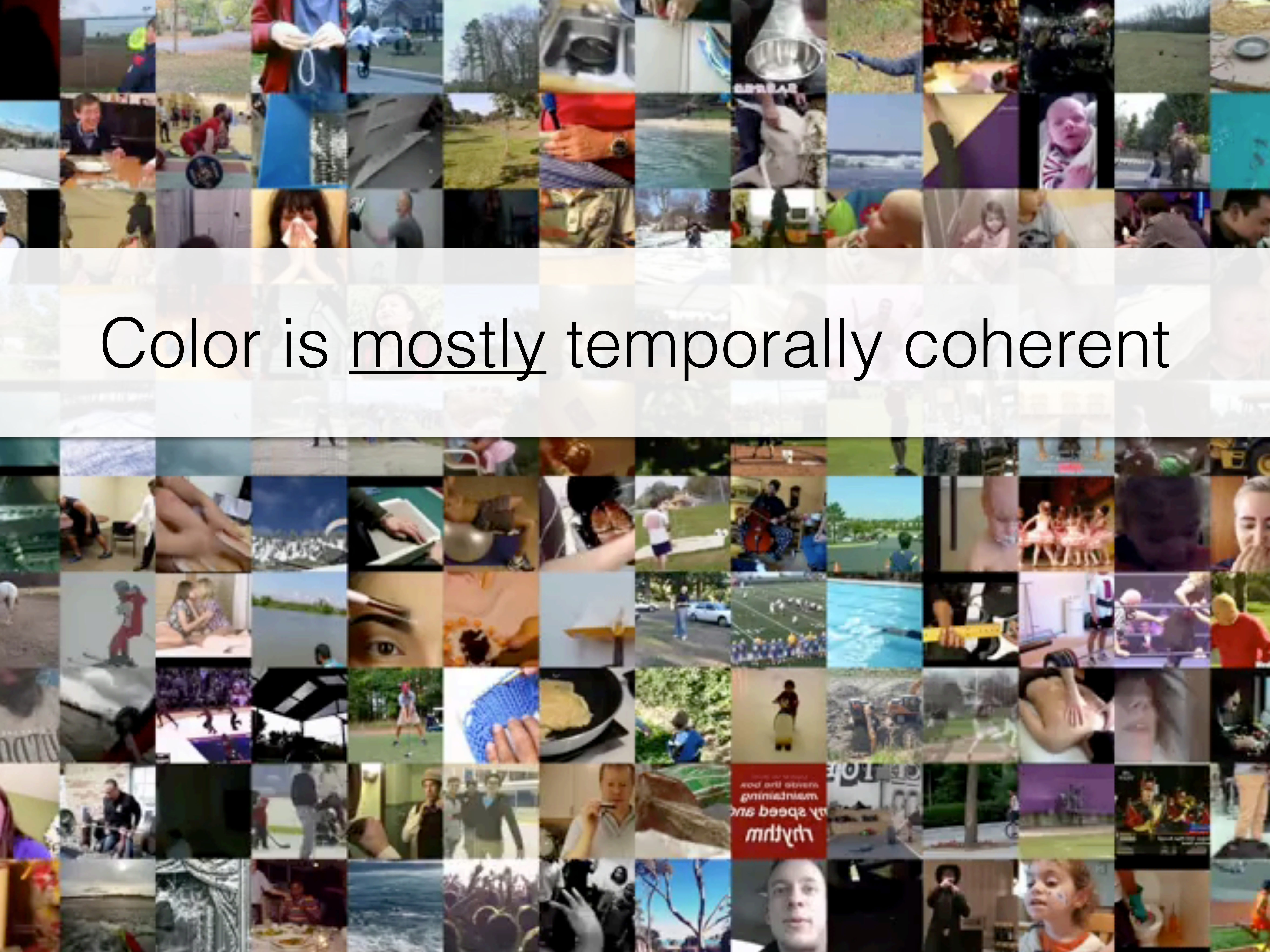
Obvious exceptions…

Edward Adelson, 1995



Obvious exceptions…

Color is mostly temporally coherent



Self-supervised Tracking

Reference Frame

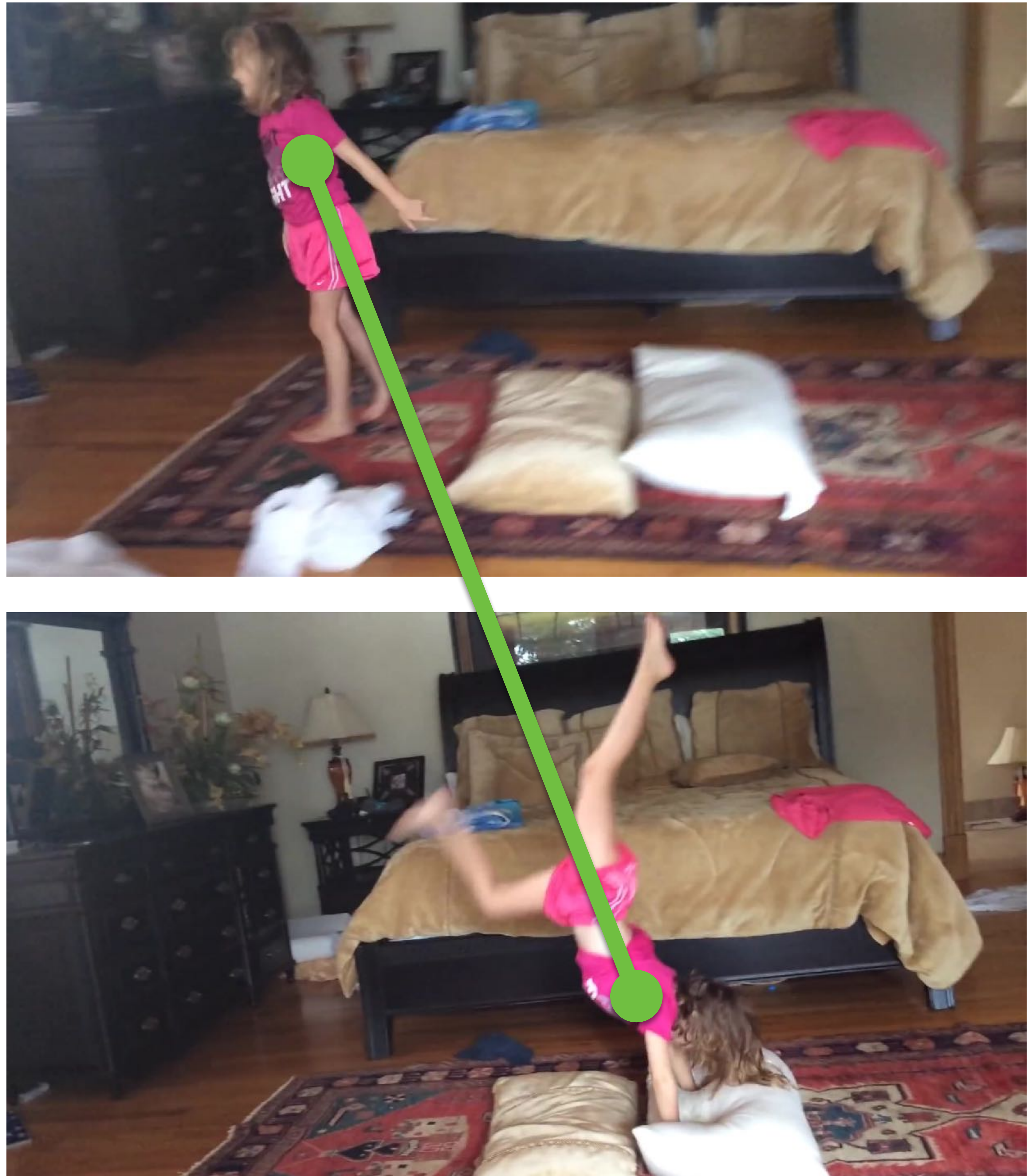
Gray-scale Video

Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

What color is this?

Where to copy color?

Want to be safe!



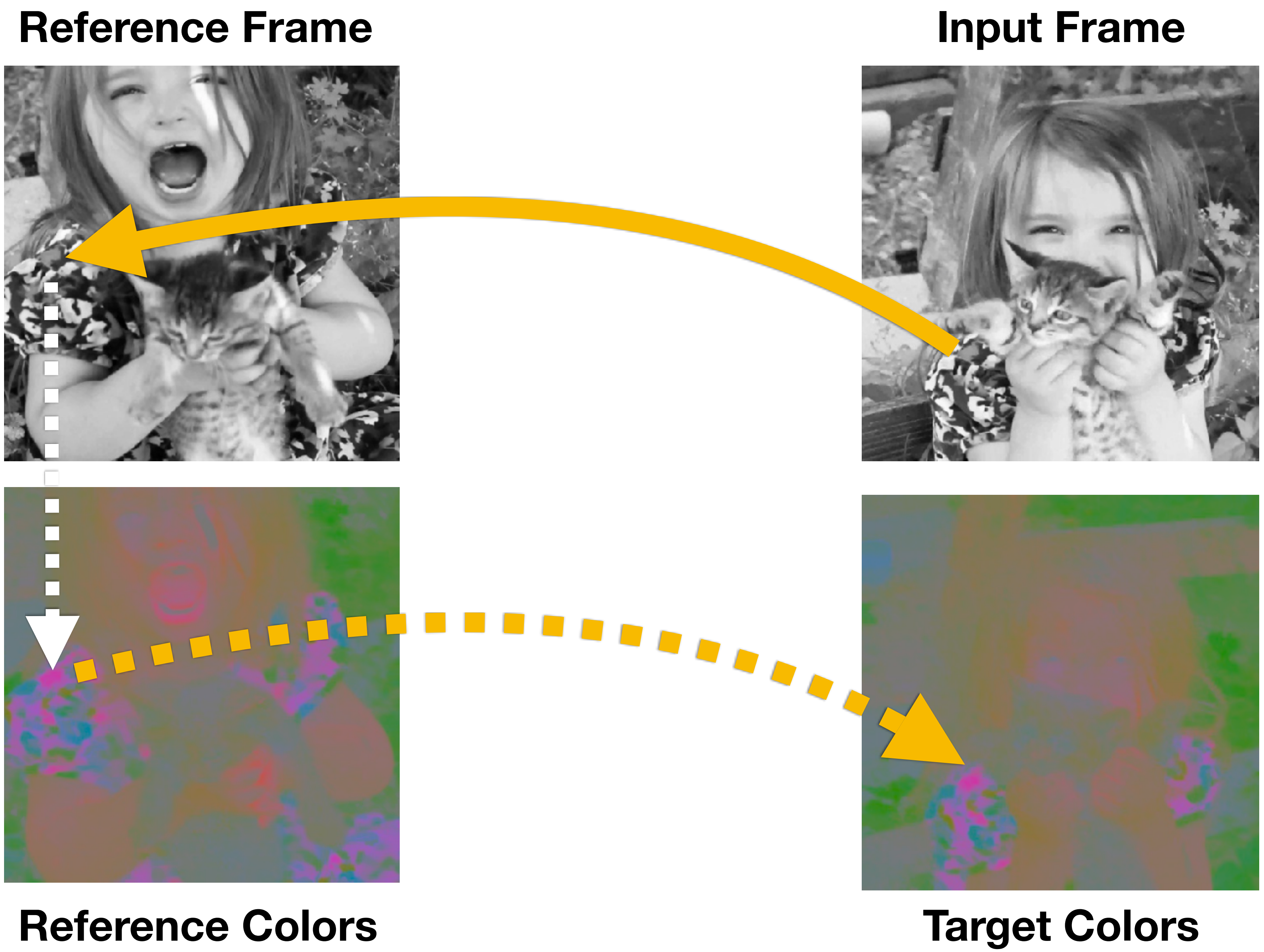
Where to copy color?

Color can be robust to occlusion

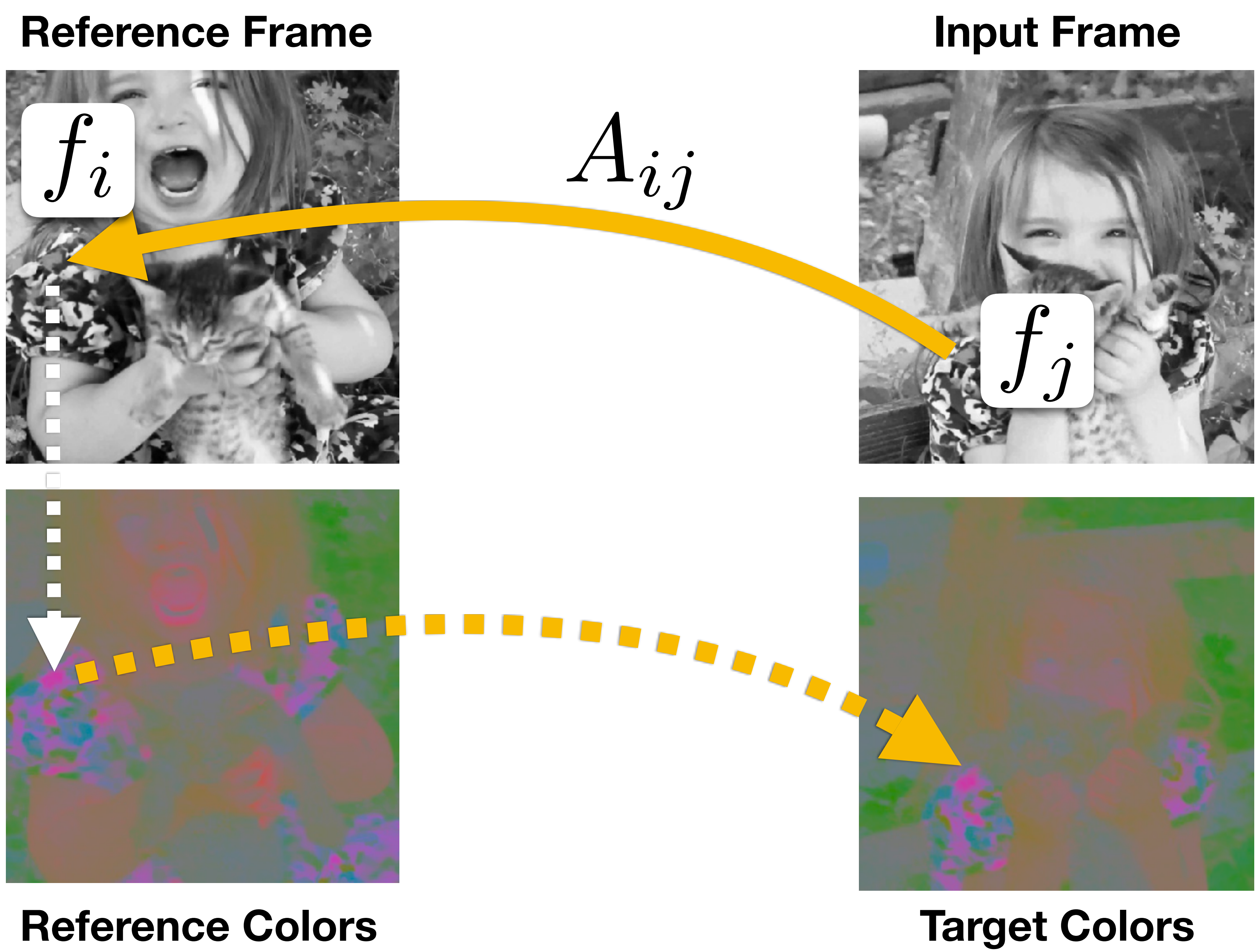
Input Frame

Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Colorize by Pointing

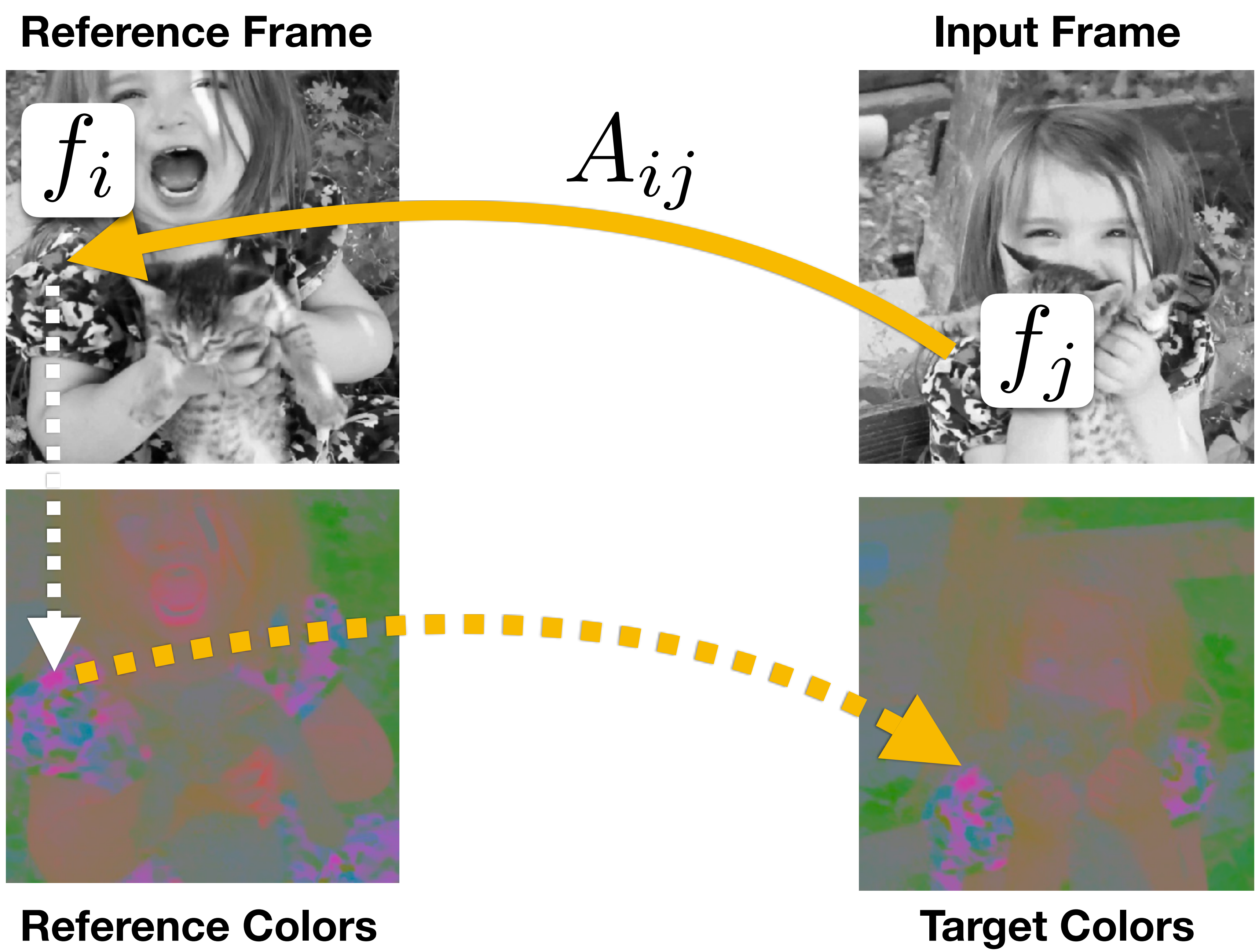


Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018



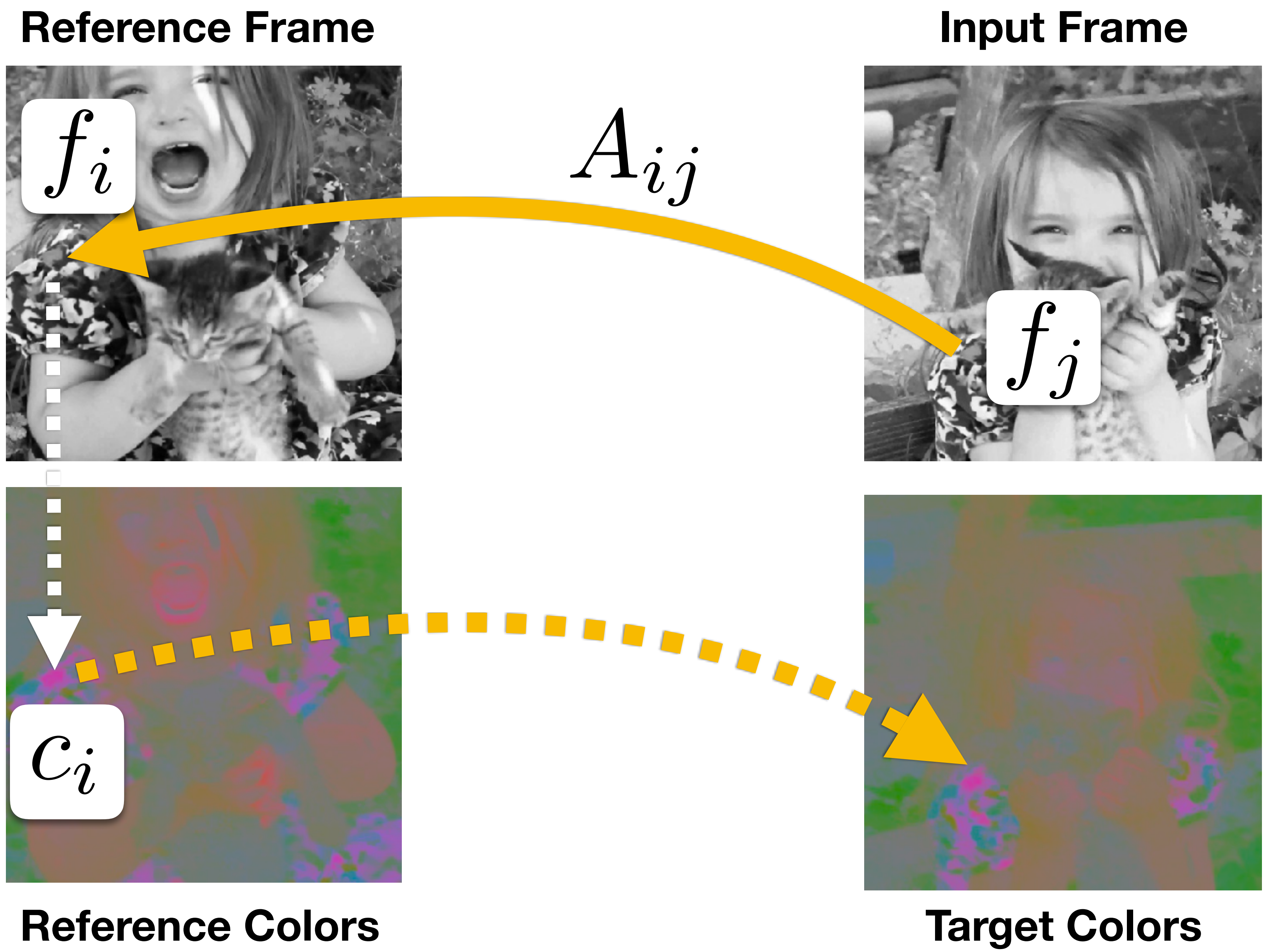
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

$$A_{ij} = \frac{\exp\left(f_i^T f_j\right)}{\sum_k \exp\left(f_k^T f_j\right)}$$



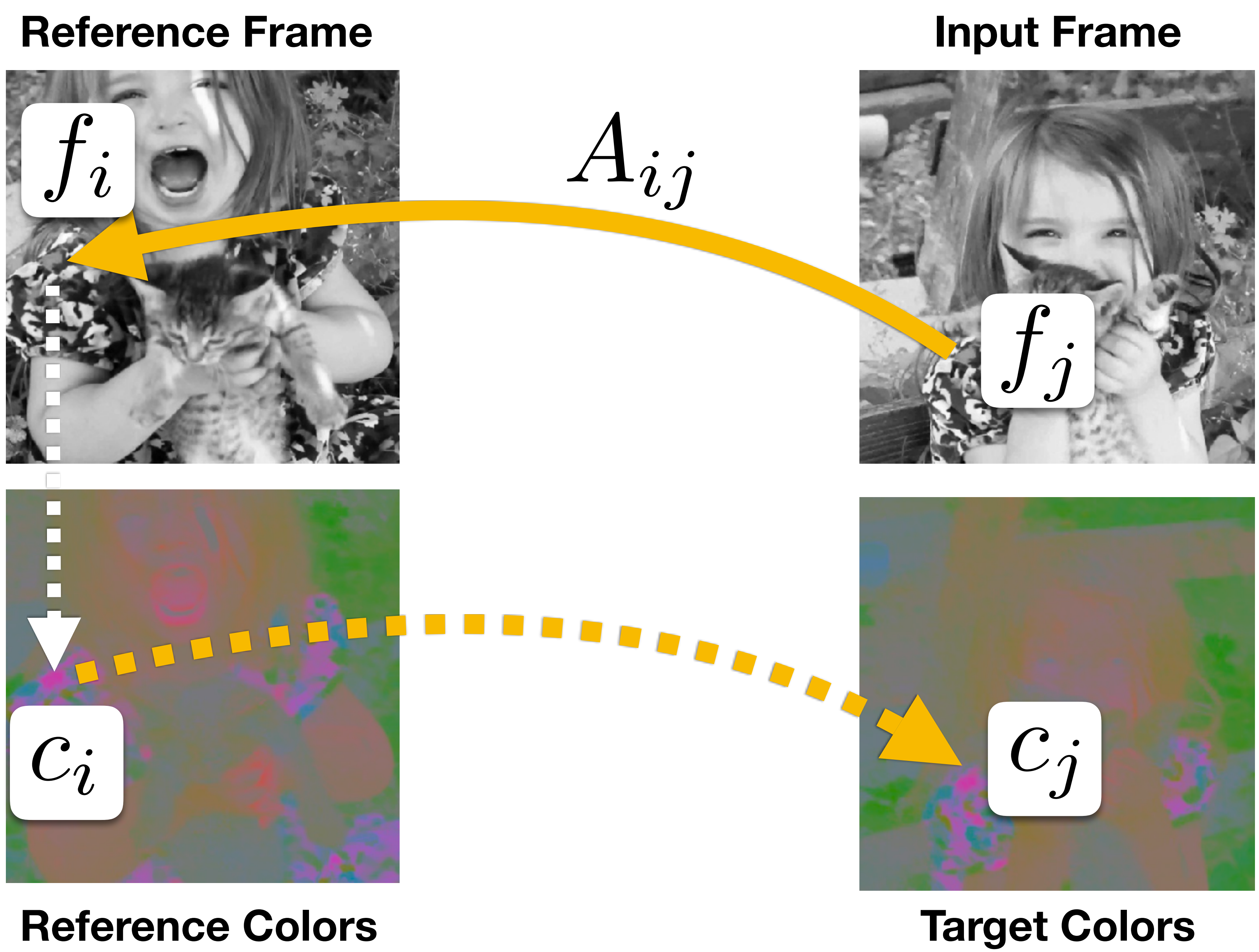
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

$$\hat{c}_j = \sum_i A_{ij} c_i \quad \text{where } A_{ij} = \frac{\exp\left(f_i^T f_j\right)}{\sum_k \exp\left(f_k^T f_j\right)}$$



Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

$$\min_f \mathcal{L}\left(c_j, \sum_i A_{ij} c_i\right) \text{ where } A_{ij} = \frac{\exp\left(f_i^T f_j\right)}{\sum_k \exp\left(f_k^T f_j\right)}$$



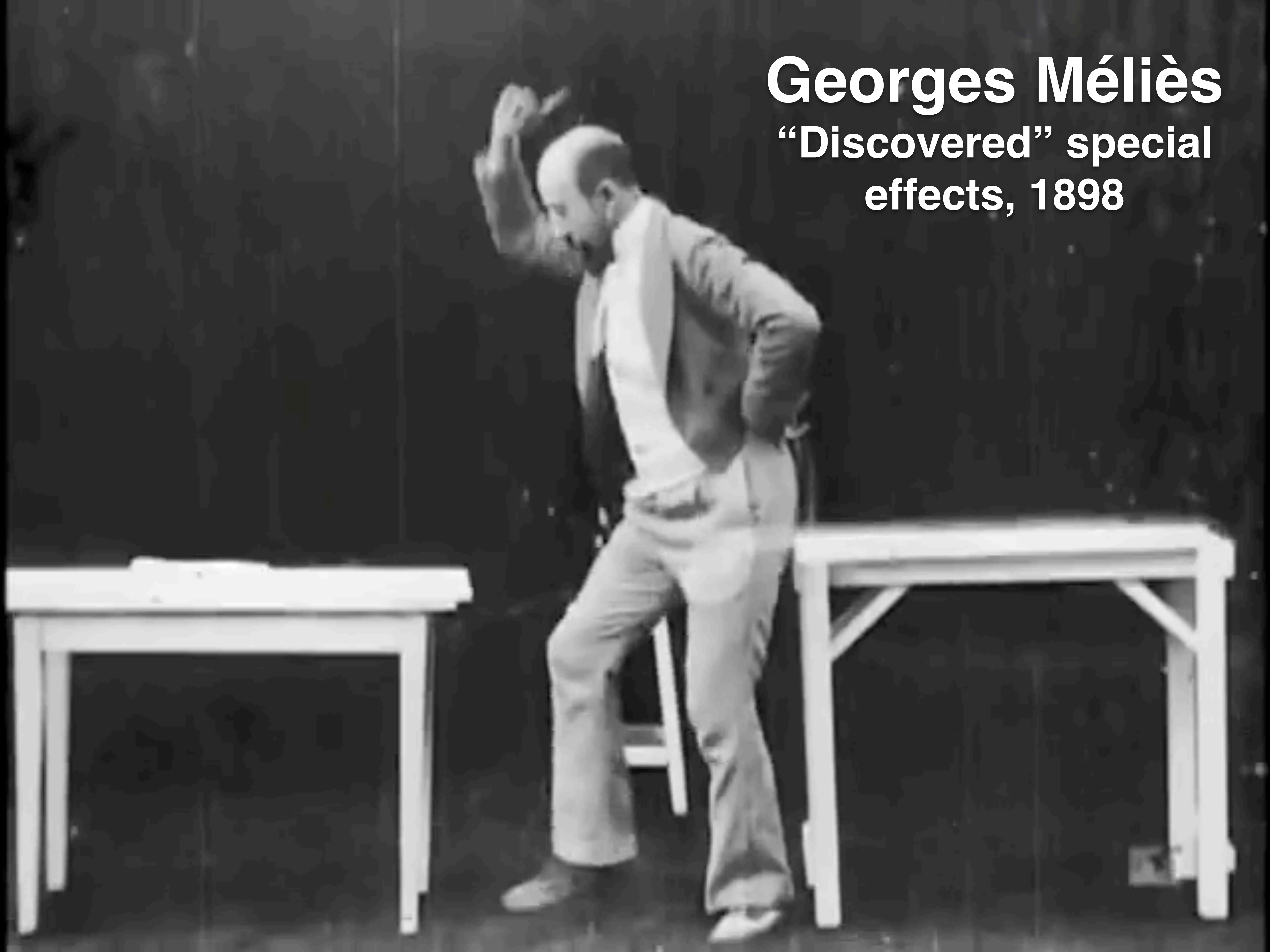
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018


‘ANNABELLE SERPENTINE DANCE’ (1895)

Lumière Brothers

Inventors of
motion picture, 1895

Inventors of first practical
color camera, 1903

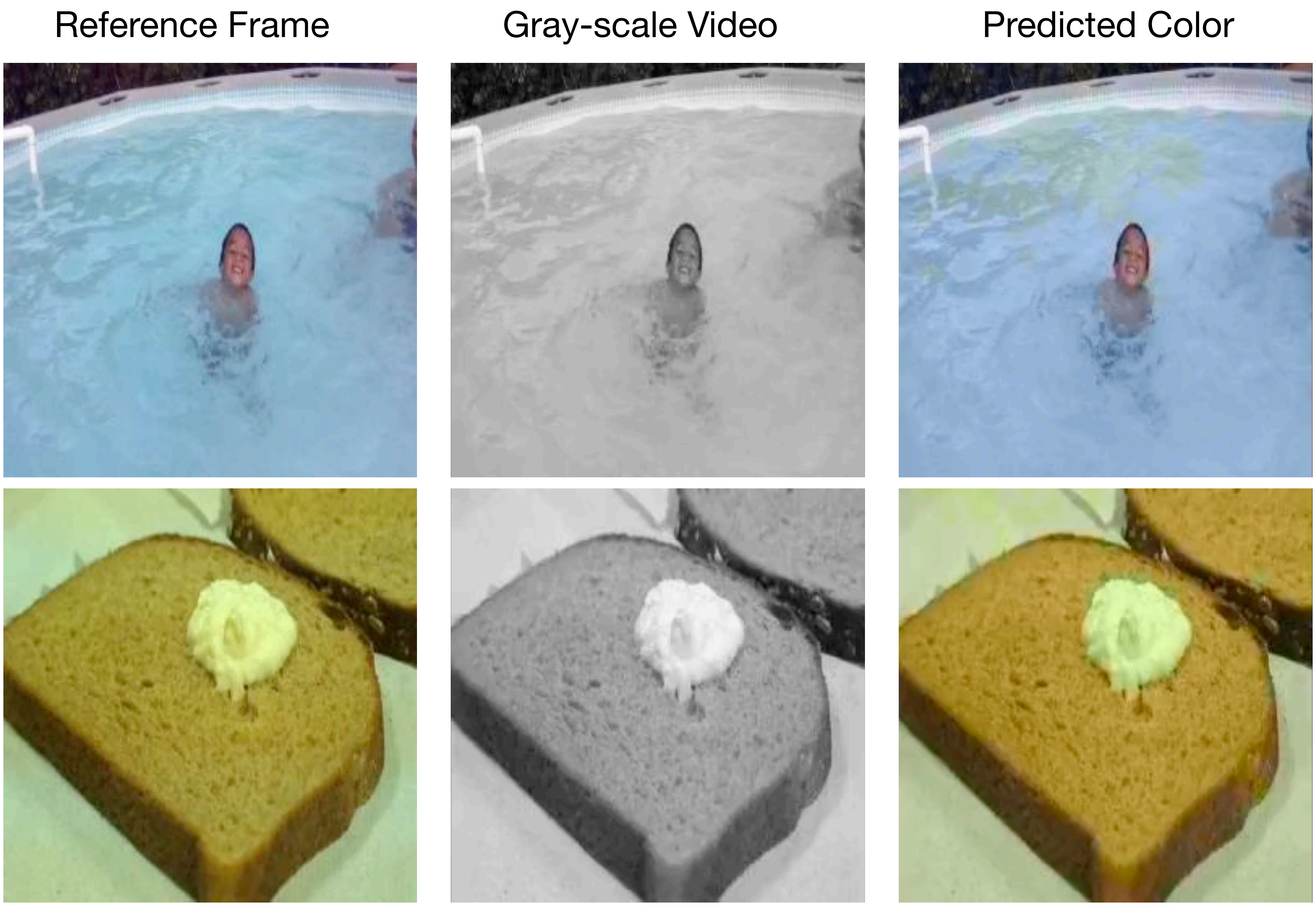

Georges Méliès
“Discovered” special
effects, 1898

Video Colorization

Reference Frame | Gray-scale Video | Predicted Color

Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Video Colorization



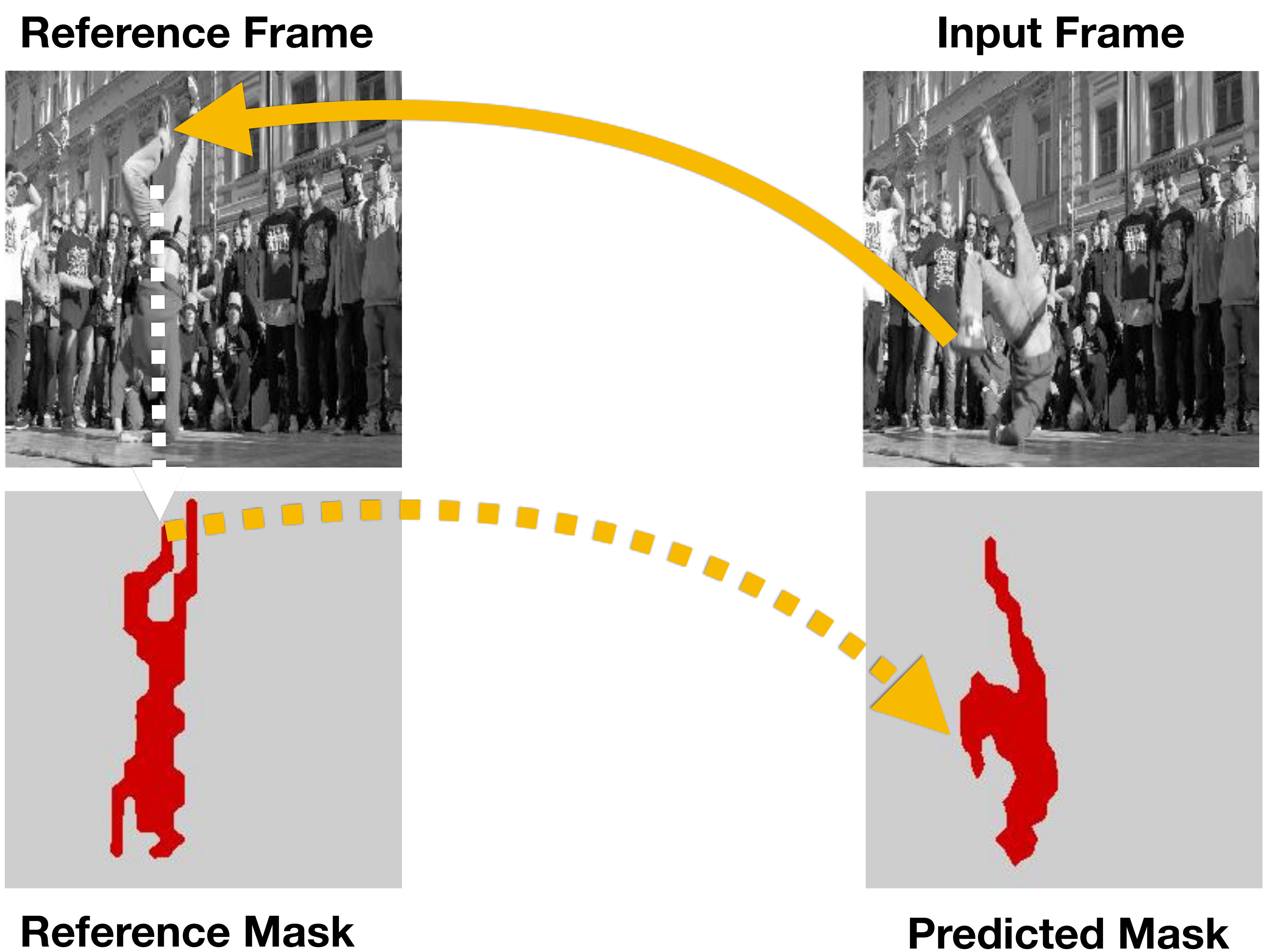
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Tracking Emerges!

Reference Frame **Input Frame**

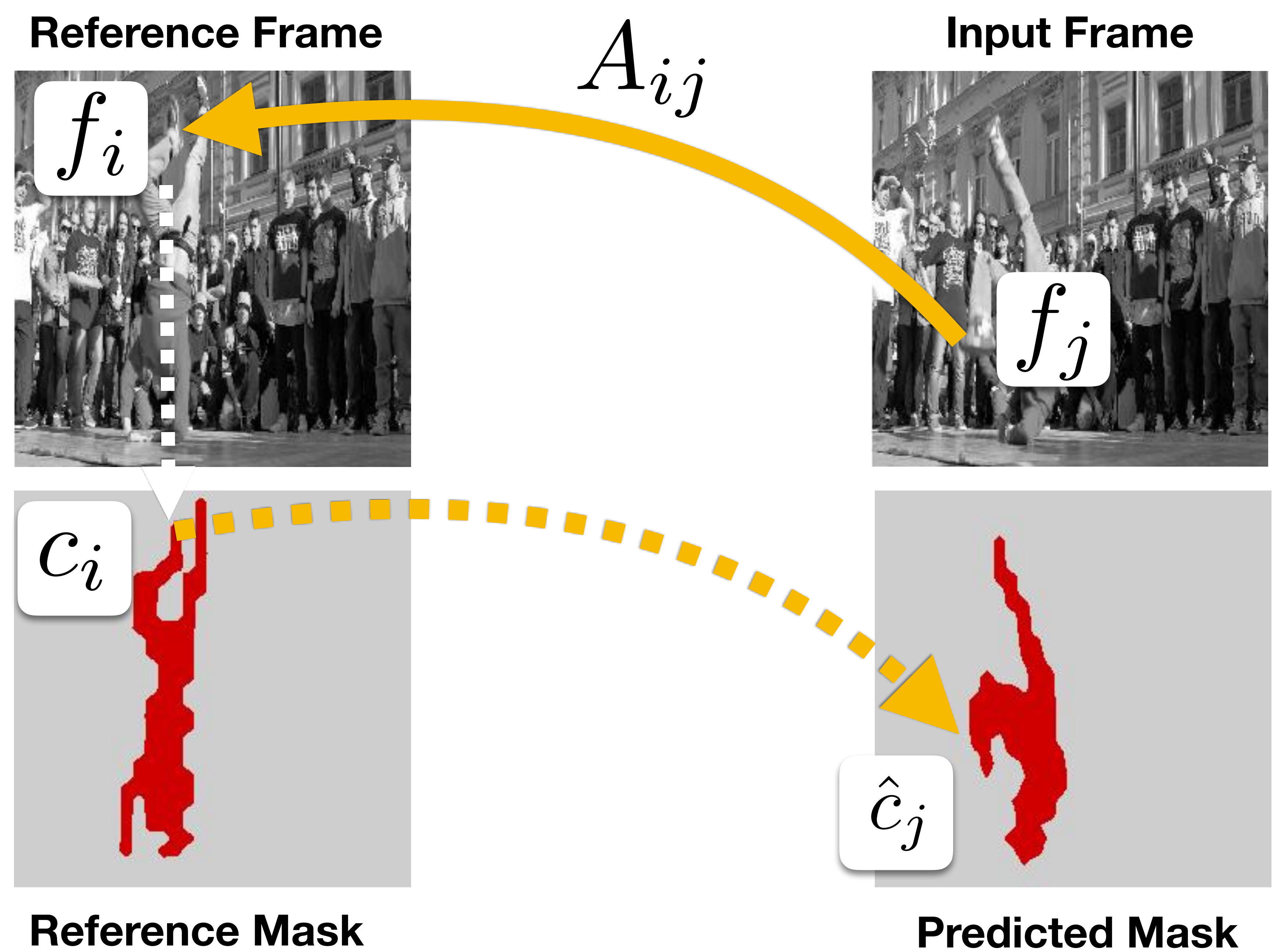
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Tracking Emerges!



Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

$$\hat{c}_j = \sum_i A_{ij} c_i \quad \text{where } A_{ij} = \frac{\exp\left(f_i^T f_j\right)}{\sum_k \exp\left(f_k^T f_j\right)}$$



Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Segment Tracking Results

Only the first frame is given. Colors indicate different instances.

Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

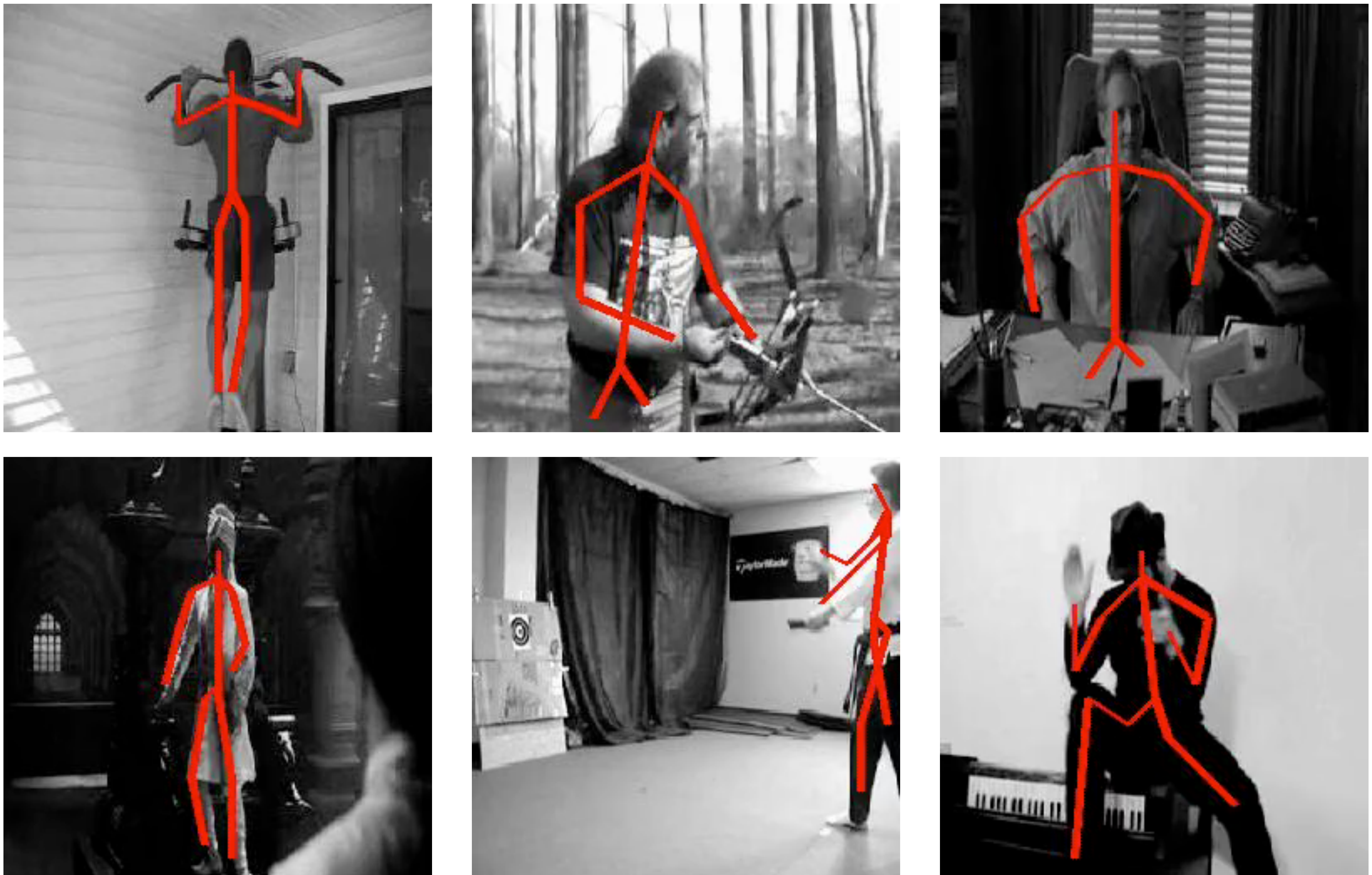
Segment Tracking Results

Only the first frame is given. Colors indicate different instances.

Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

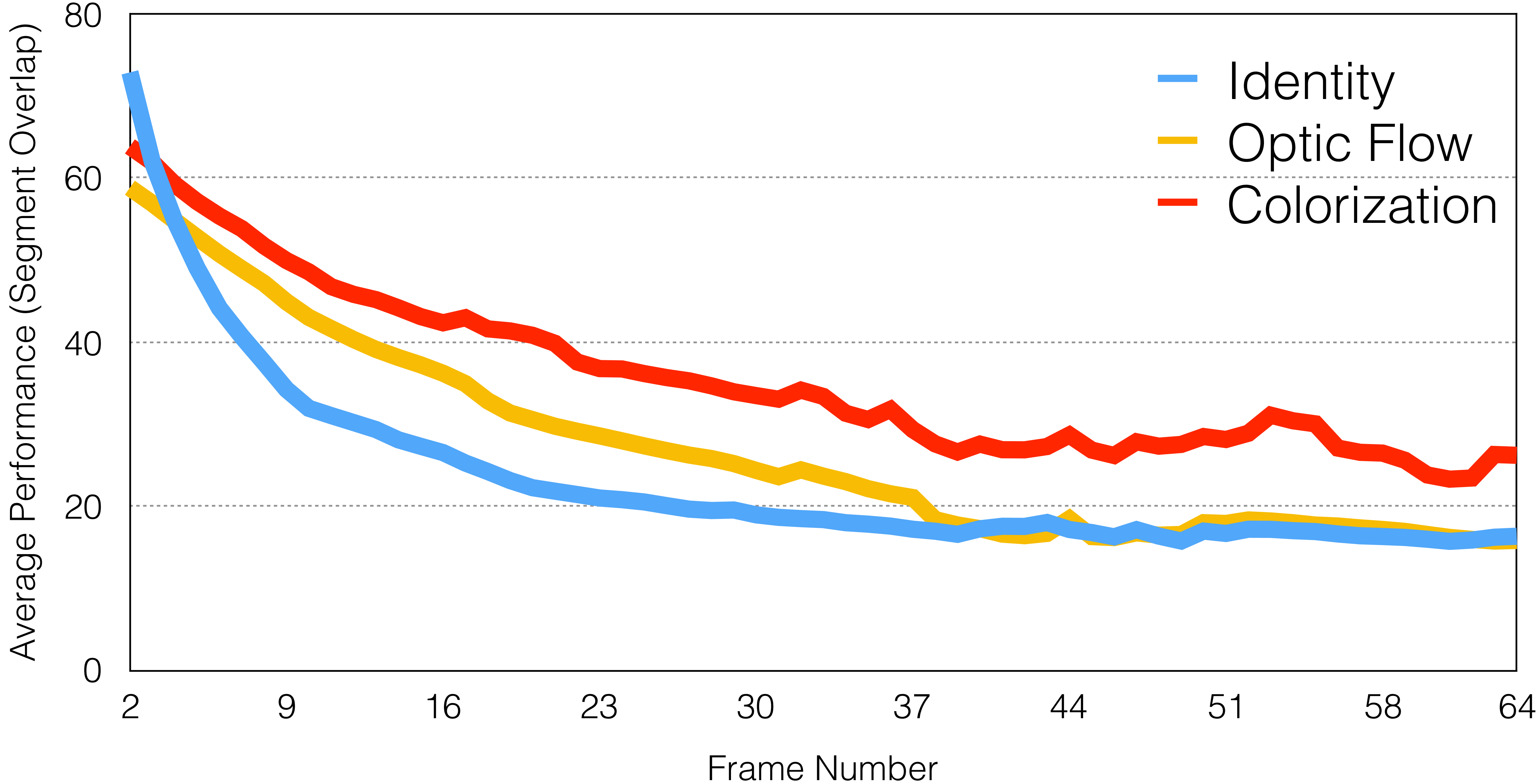
Pose Tracking Results

Only the skeleton in the first frame is given.



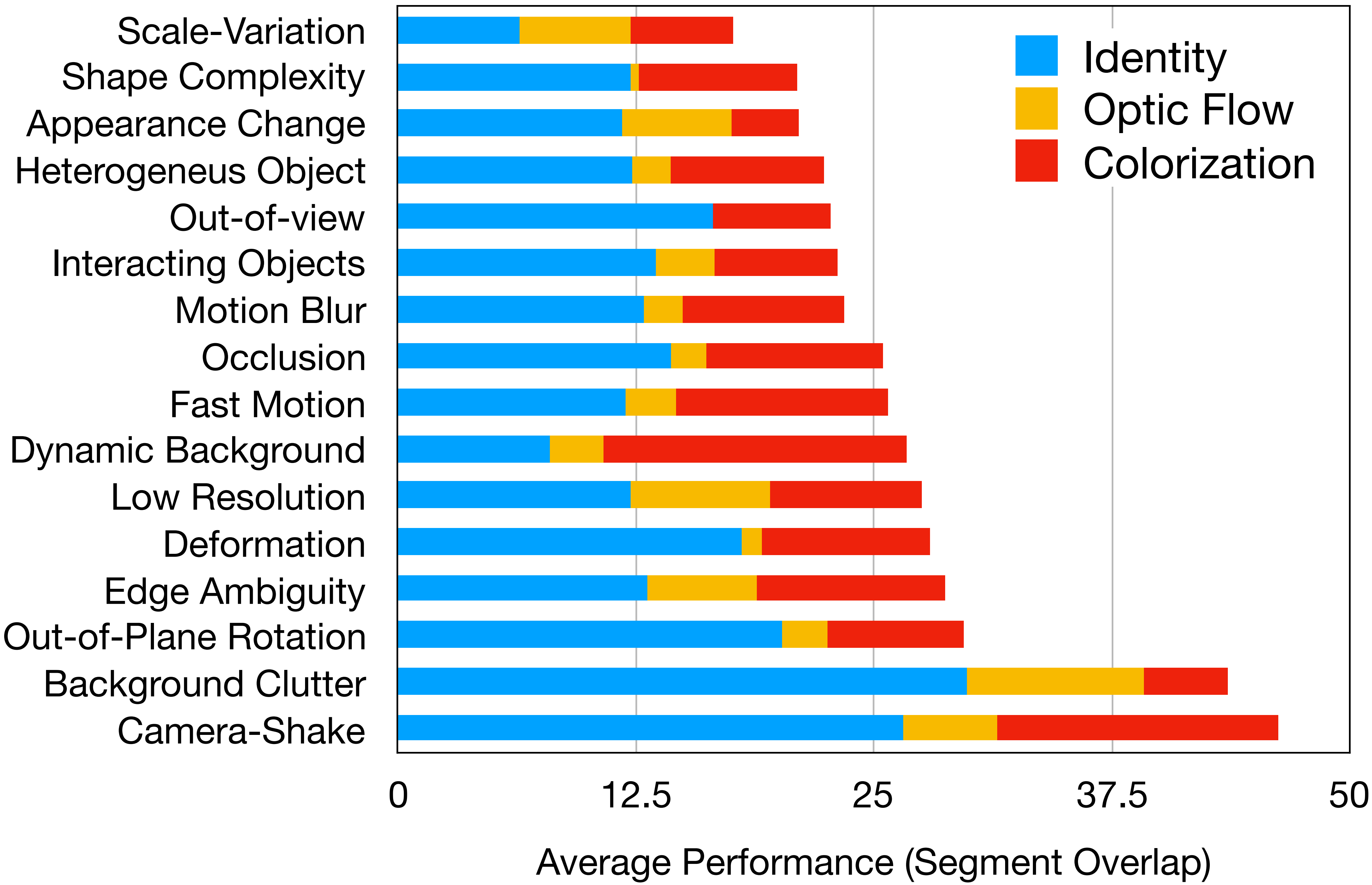
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Tracking Performance



Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Tracking Performance



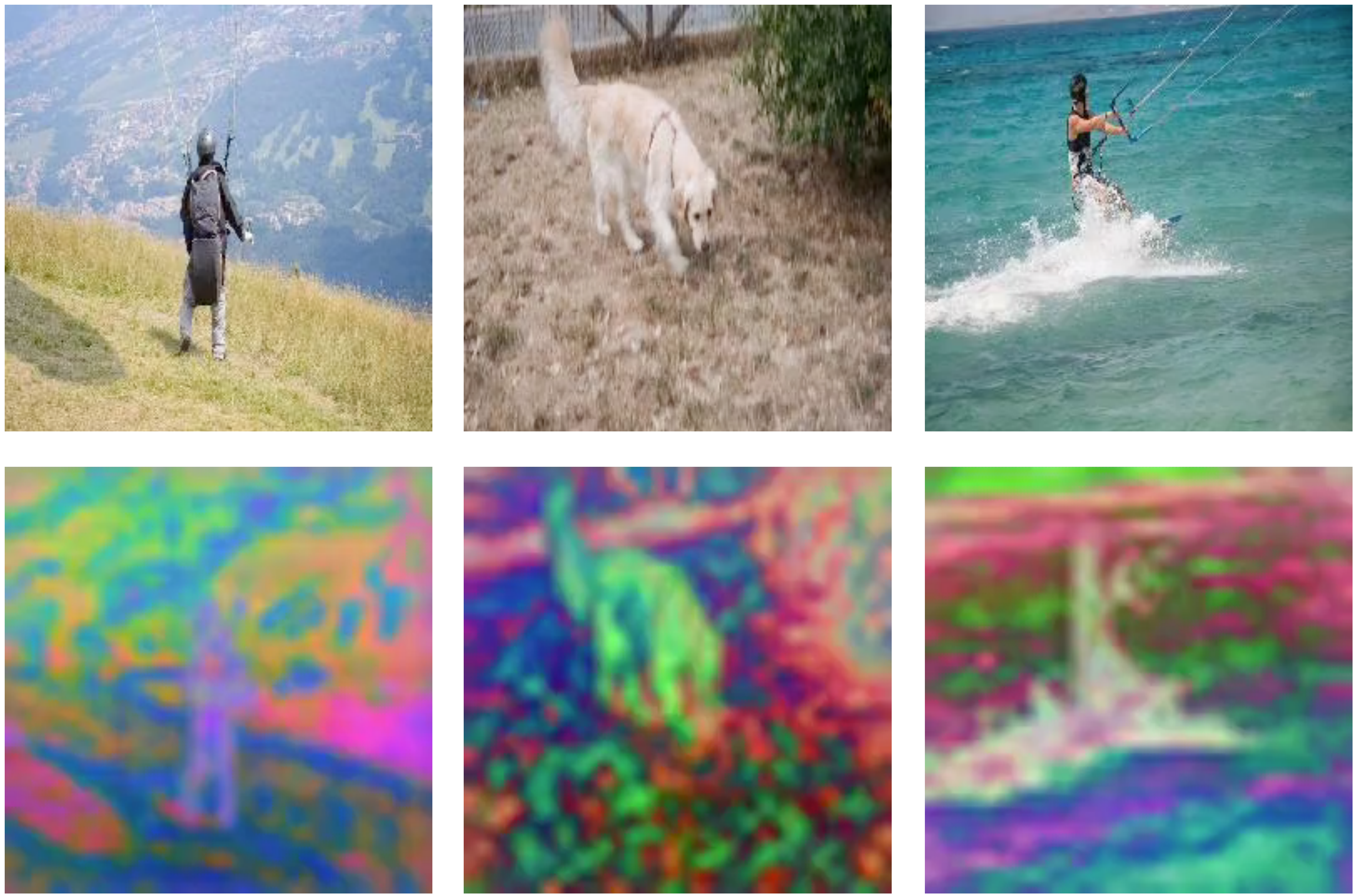
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Visualizing Embeddings

Project embedding to 3 dimensions and visualize as RGB

Original Video

Embedding Visualization



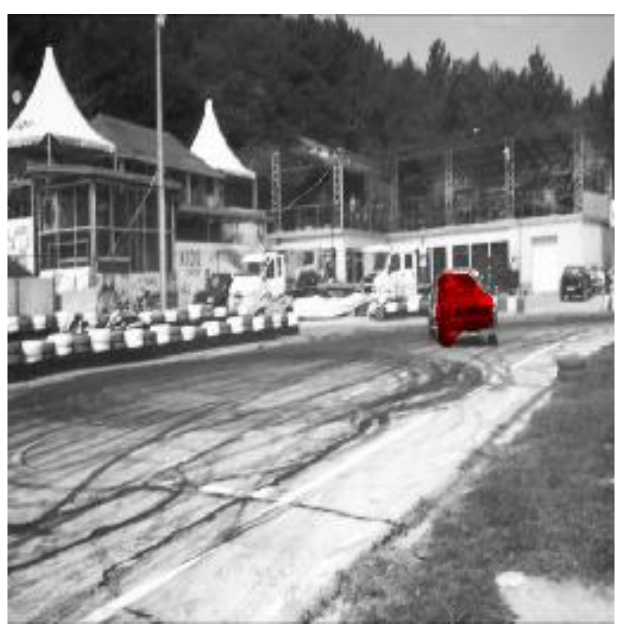
Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018

Colorization and tracking fail together

Reference Colors

Predicted Colors

Reference Mask



Predicted Mask

Vondrick, Shrivastava, Fathi, Guadarrama, Murphy. ECCV 2018