THE UNIVERSITY OF TEXAS AT DALLAS

Deep Optical Flow Networks and Applications

CS 6384 Computer Vision

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Optical Flow is the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer and a scene

Lucas-Kanade Method for Optical Flow Estimation

- Brightness Constancy: the intensity or brightness of a pixel remains constant while moving from one frame to another
- Small Motion: the motion between consecutive frames is small
- Spatial Coherence: neighboring pixels have similar motion

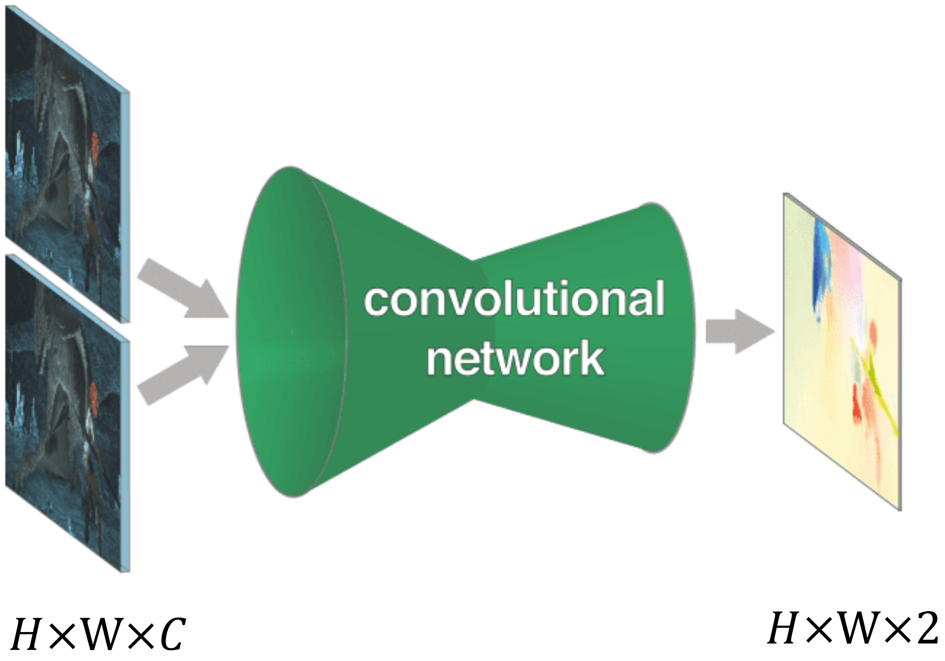
$$I_x u + I_y v + I_t = 0$$

$$\underset{\substack{A \\ 25\times2}}{\begin{bmatrix} I_x(\mathbf{p}_1) & I_y(\mathbf{p}_1) \\ I_x(\mathbf{p}_2) & I_y(\mathbf{p}_2) \\ \vdots & \vdots \\ I_x(\mathbf{p}_{25}) & I_y(\mathbf{p}_{25}) \end{bmatrix}} \underset{\substack{d \\ 2\times1}}{\begin{bmatrix} u \\ v \end{bmatrix}} = - \underset{\substack{b \\ 25\times1}}{\begin{bmatrix} I_t(\mathbf{p}_1) \\ I_t(\mathbf{p}_2) \\ \vdots \\ I_t(\mathbf{p}_{25}) \end{bmatrix}}$$

Can we use deep nets to estimate optical flow?

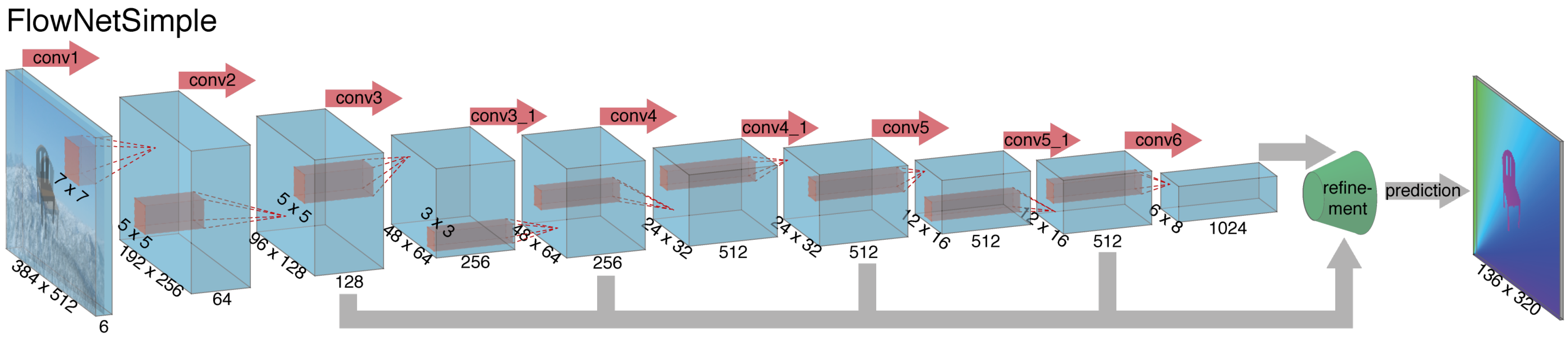
Estimating Optical Flow using Deep Networks

- Given two consecutive image frames: I_t and I_{t+1}, we aim to estimate the motion field (u, v) between them for each pixel



Regression Loss: L2, L1, …

FlowNet



Stack two images

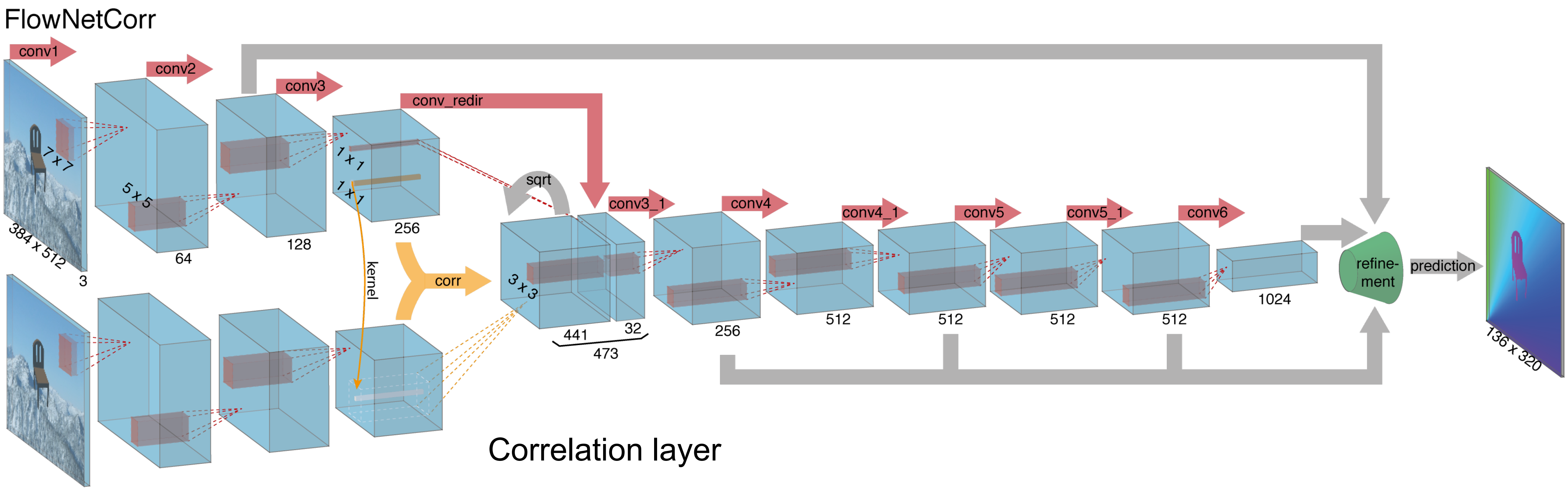
x-y flow fields

The architecture is similar to FCN for semantic segmentation

$$\frac{dx}{dt}, \frac{dy}{dt} = (\mathrm{u}, \mathrm{v})$$

FlowNet: Learning Optical Flow with Convolutional Networks. Fischer et al., ICCV, 2015

FlowNet



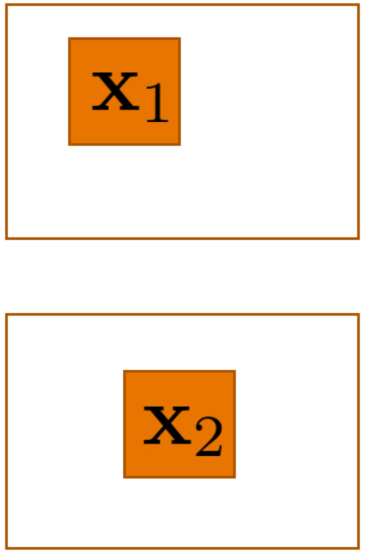
Correlation layer

FlowNet: Learning Optical Flow with Convolutional Networks. Fischer et al., ICCV, 2015

FlowNet

Correlation layer: multiplicative patch comparison between two feature maps

$$c(\mathbf{x}_1, \mathbf{x}_2) = \sum_{\mathbf{o} \in [-k,k] \times [-k,k]} \langle \mathbf{f}_1(\mathbf{x}_1 + \mathbf{o}), \mathbf{f}_2(\mathbf{x}_2 + \mathbf{o}) \rangle$$

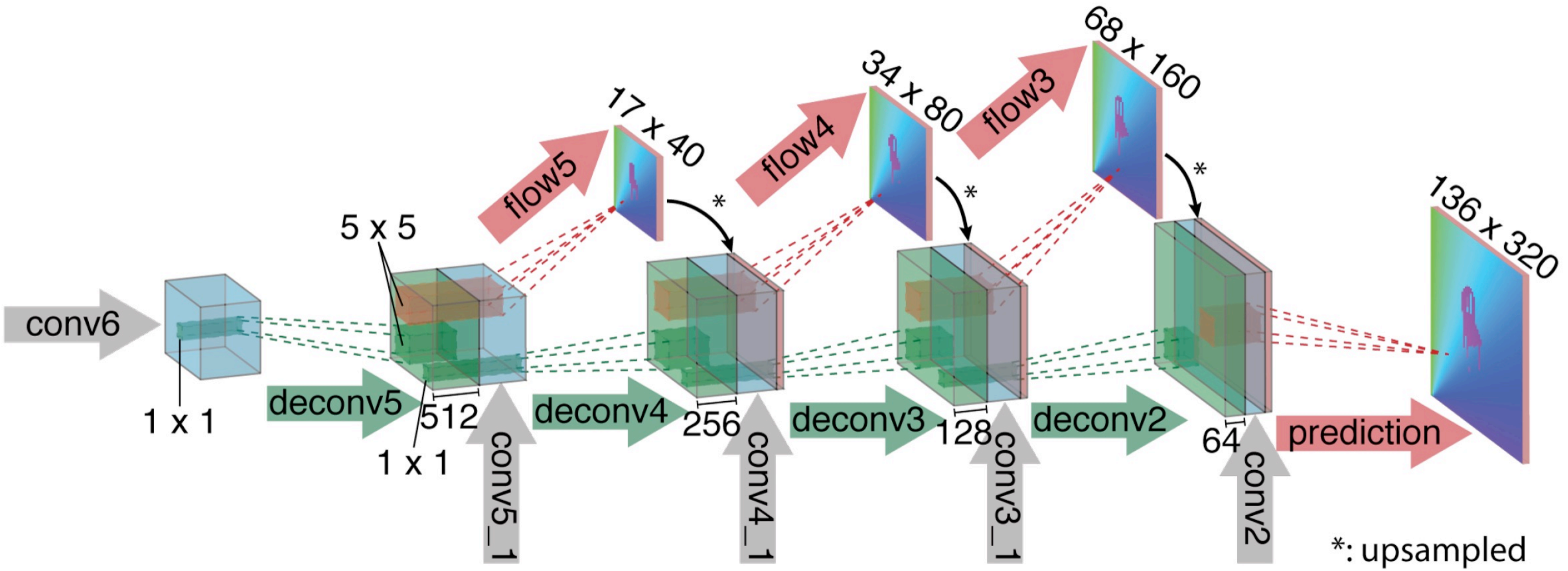


- Two patches centered at x1 and x2, with size K = 2k + 1
- Convolve data with another data
- Limit the patches for comparison with maximum displacement d
- Only compare patches in a neighborhood with size D = 2d + 1
- Output size $(w \times h \times D^2)$

FlowNet: Learning Optical Flow with Convolutional Networks. Fischer et al., ICCV, 2015

FlowNet

Refinement

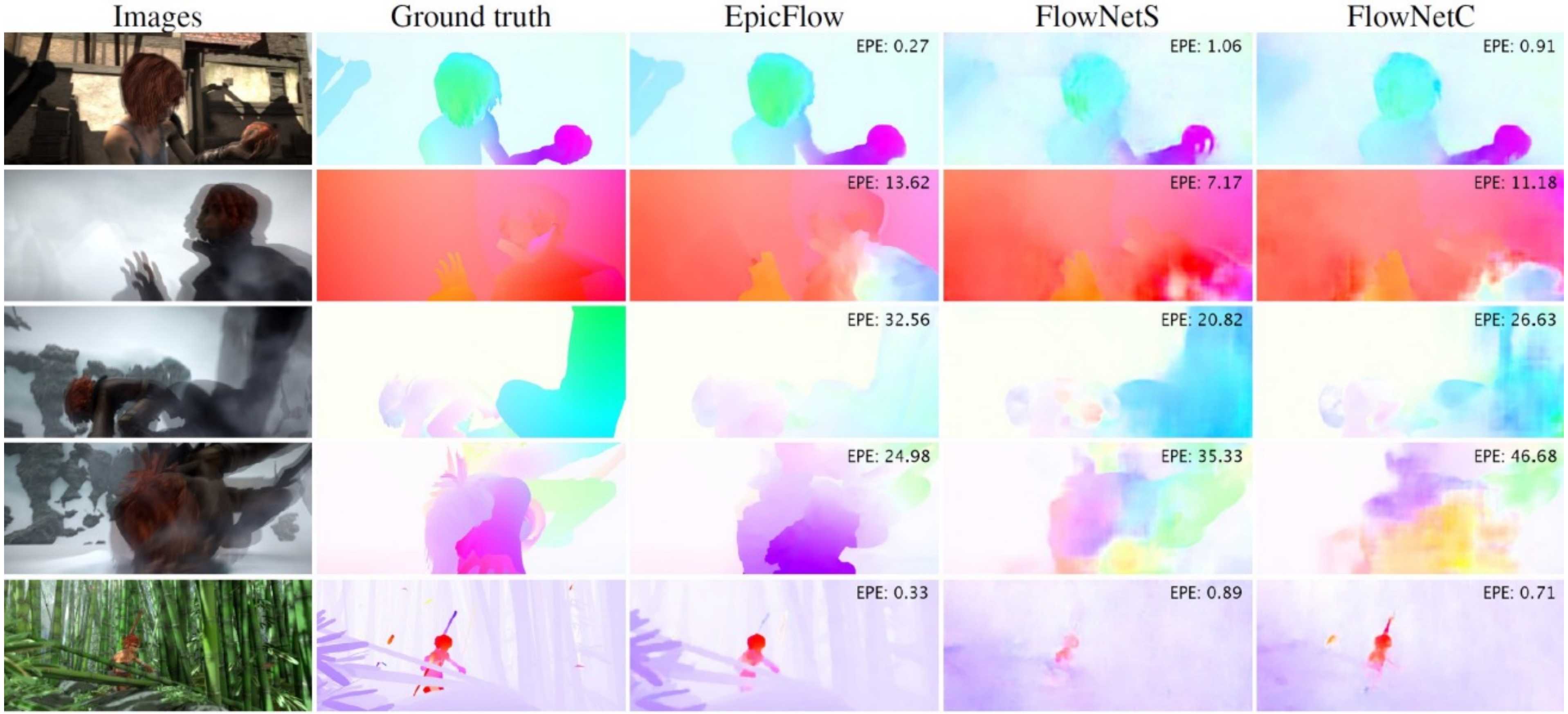


FlowNet: Learning Optical Flow with Convolutional Networks. Fischer et al., ICCV, 2015

Training Data

Flying Chairs Dataset

Deep Optical Flow Results



Results on Sintel (standard benchmark)

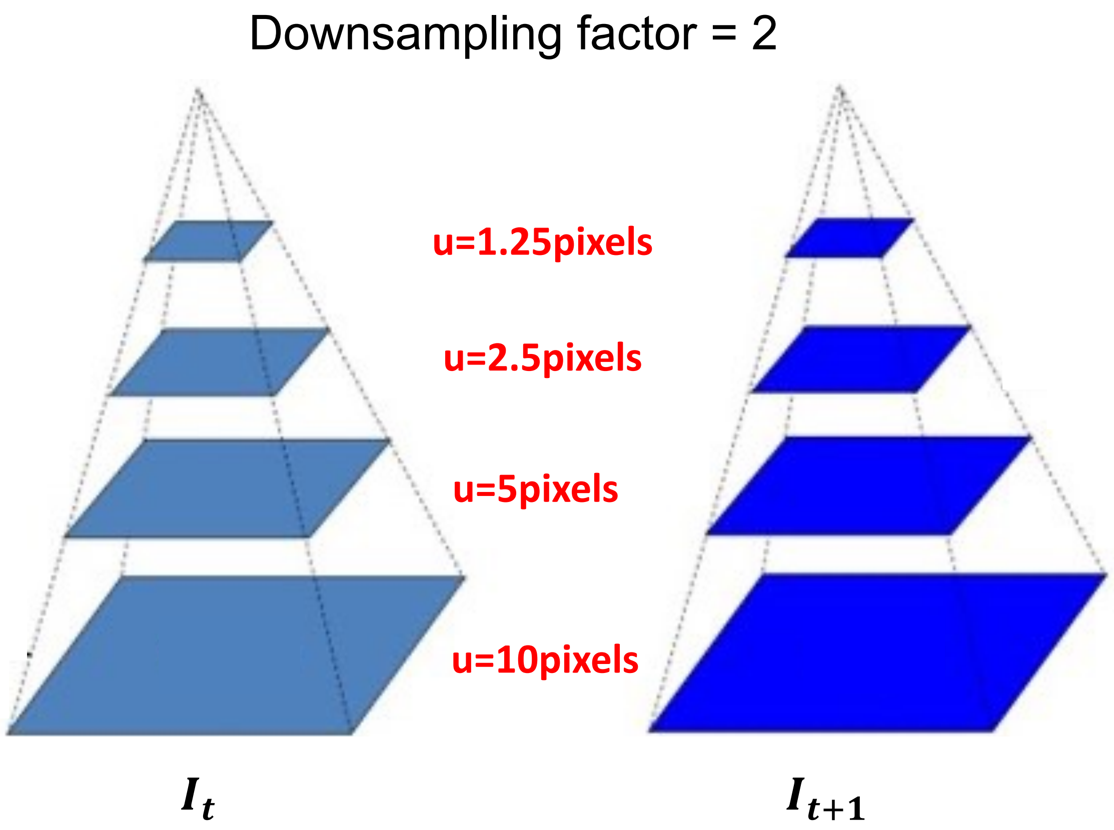
Revisiting the Small Motion Assumption

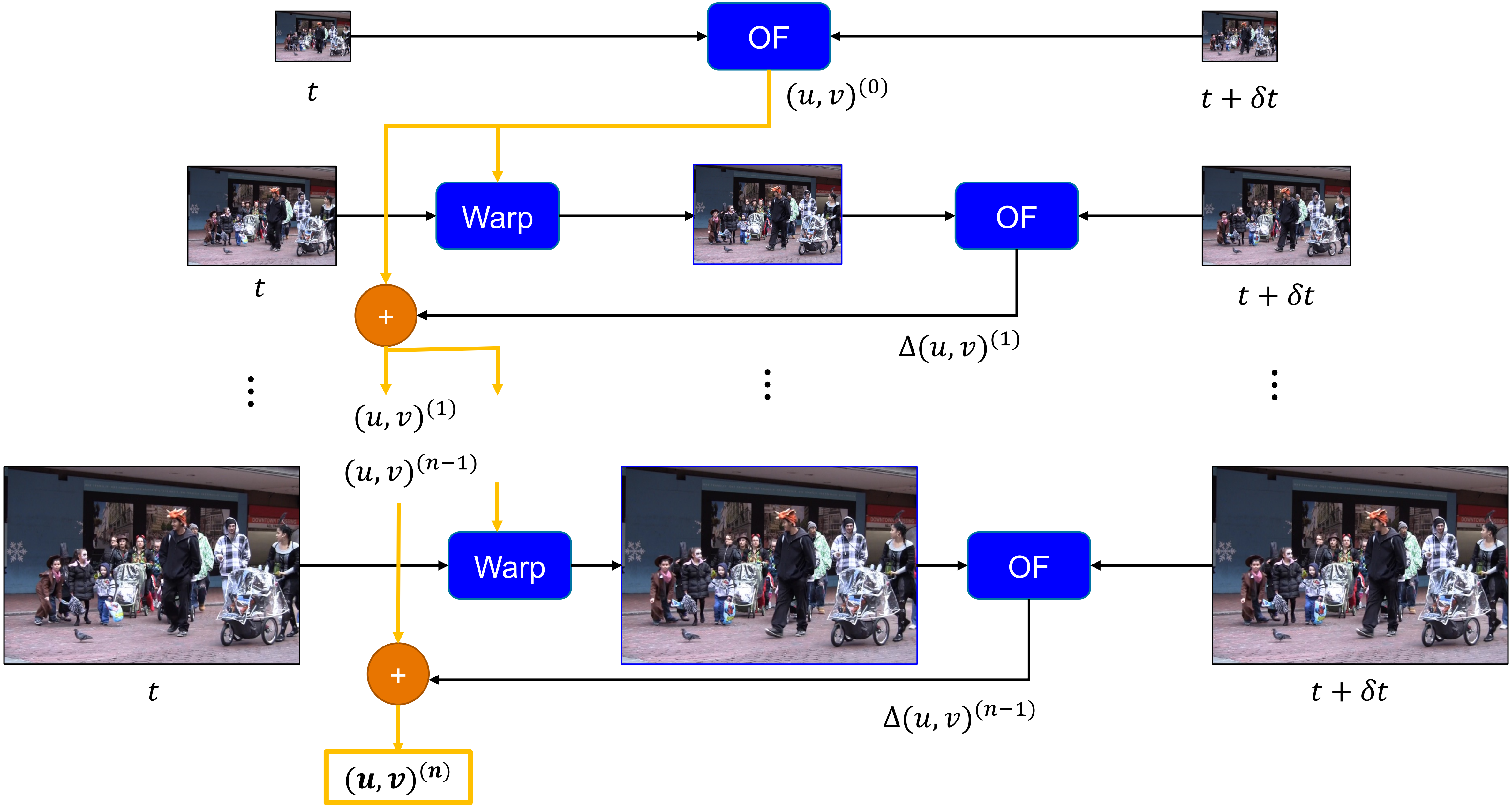
- Is this motion small enough?
  - Probably not—it's much larger than one pixel (2nd order terms dominate)
  - How to solve this problem?

$$I(x+\Delta x, y+\Delta y, t+\Delta t) = I(x,y,t) + \frac{\partial I}{\partial x}\Delta x + \frac{\partial I}{\partial y}\Delta y + \frac{\partial I}{\partial t}\Delta t + \text{higher-order terms}$$

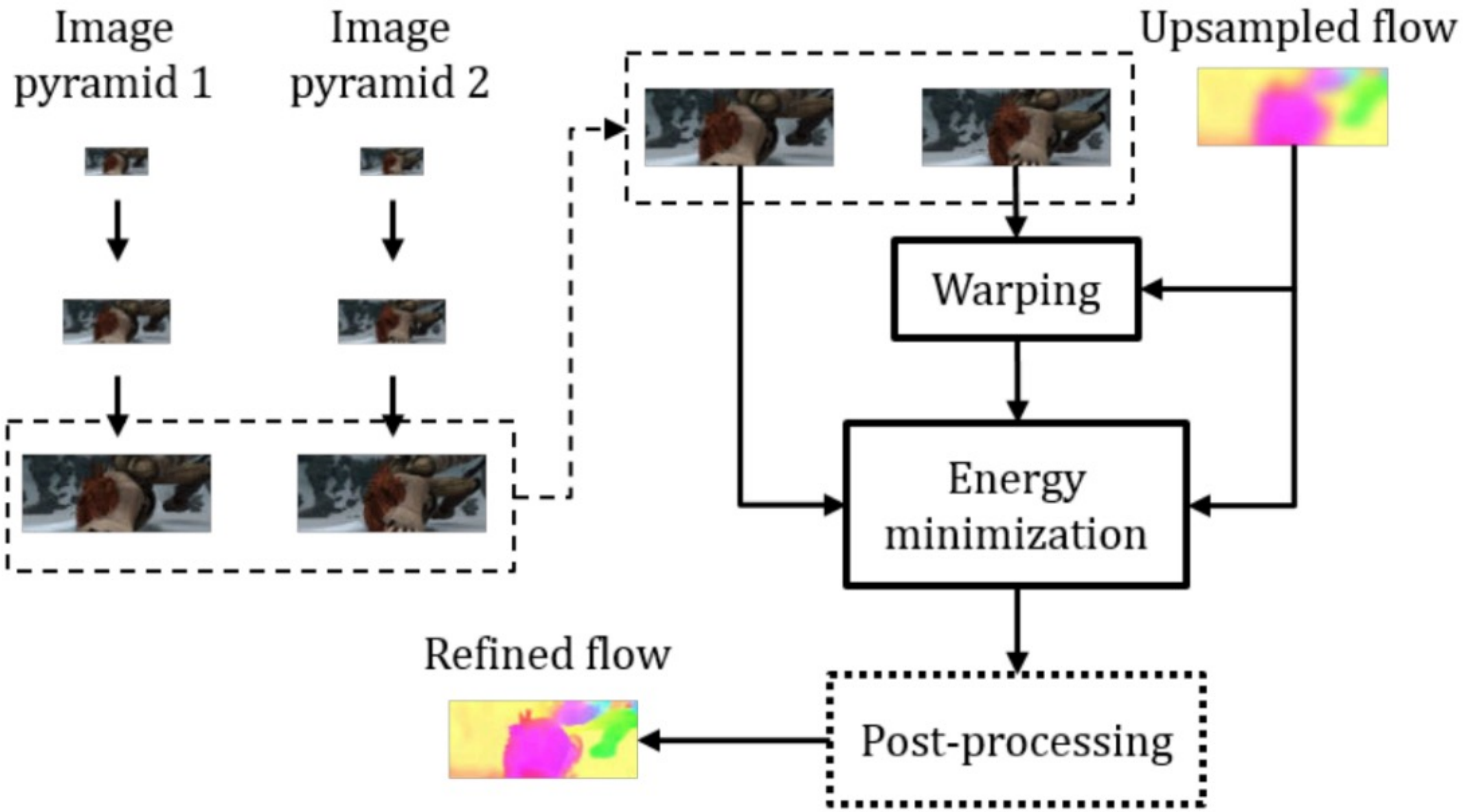
High-order terms will have large values for large motion

Coarse-to-fine Optical Flow Estimation



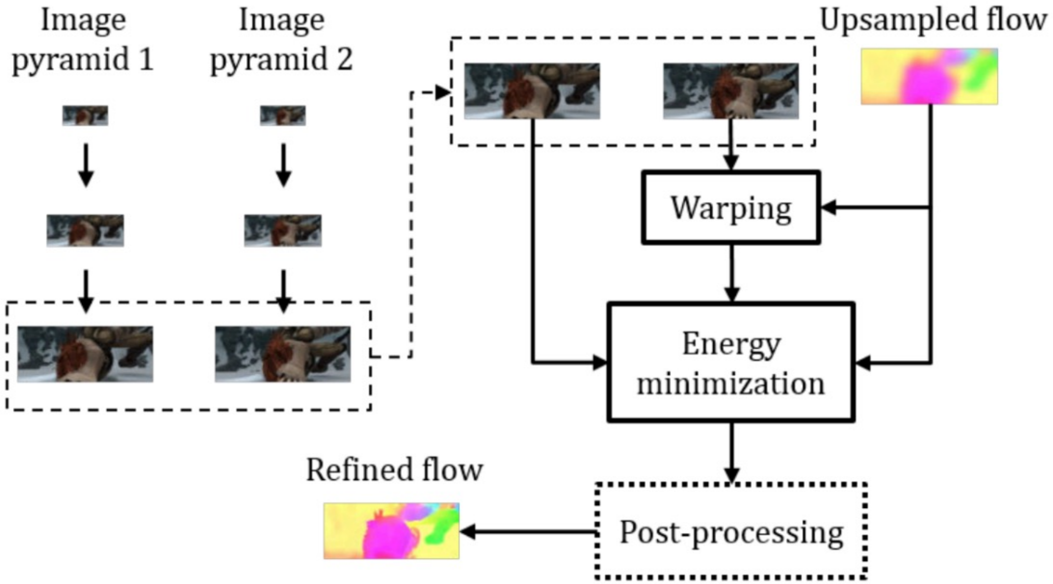

OF
t
$(u,v)^{(0)}$
$t+\delta t$
Warp
OF
t
+
$t+\delta t$
$\Delta(u,v)^{(1)}$
$(u,v)^{(1)}$
$(u,v)^{(n-1)}$
Warp
OF
+
t
$t+\delta t$
$\Delta(u,v)^{(n-1)}$
$(\boldsymbol{u},\boldsymbol{v})^{(\boldsymbol{n})}$

Coarse-to-fine Optical Flow Estimation

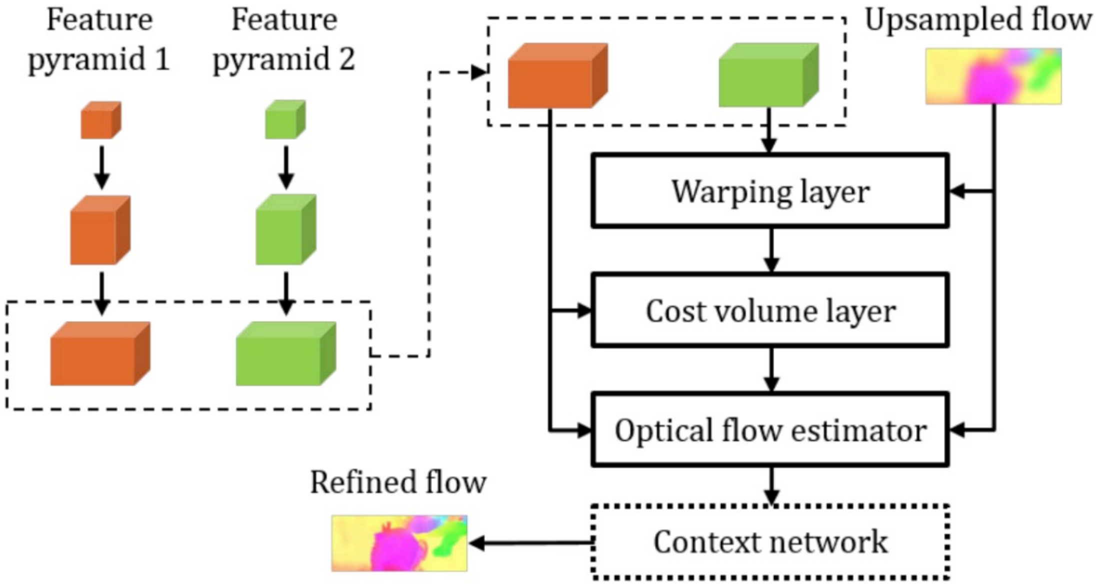


Simplified illustration

Coarse-to-fine Optical Flow Estimation



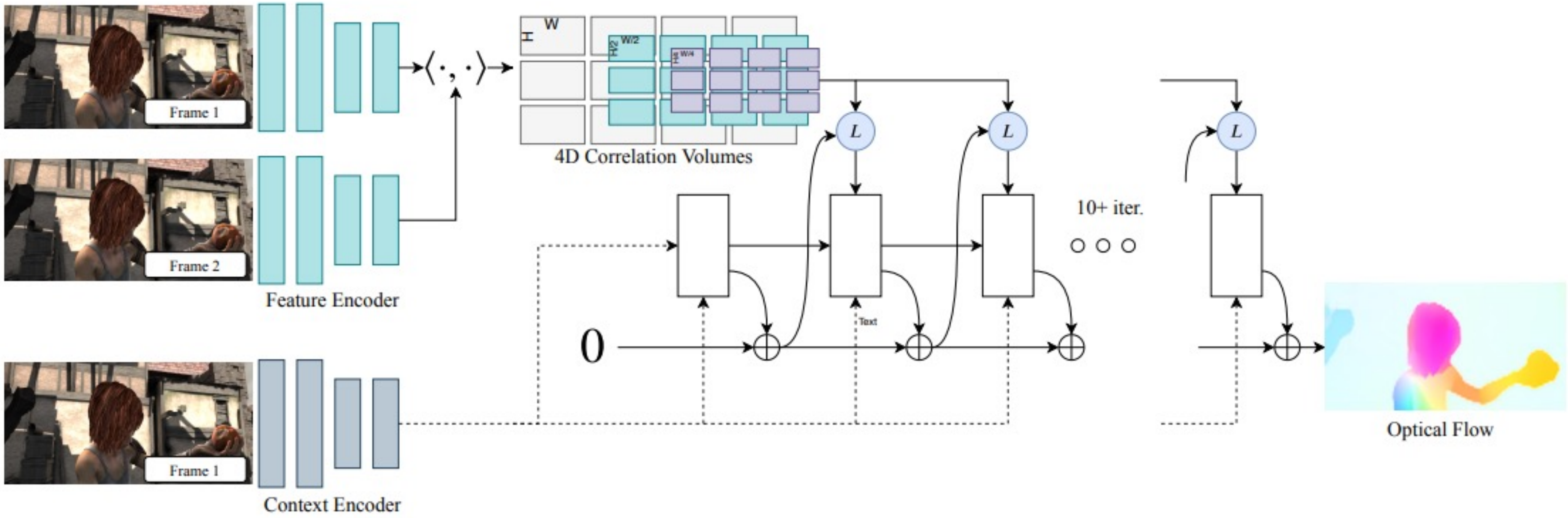
Traditional coarse-to-fine flow



PWC-net

[Sun et al., "PWC-Net", 2018]

RATF



Recurrent All-Pairs Field Transforms (RAFT), a new deep network architecture for optical flow

[Teed and Deng. “RATF”, 2020]

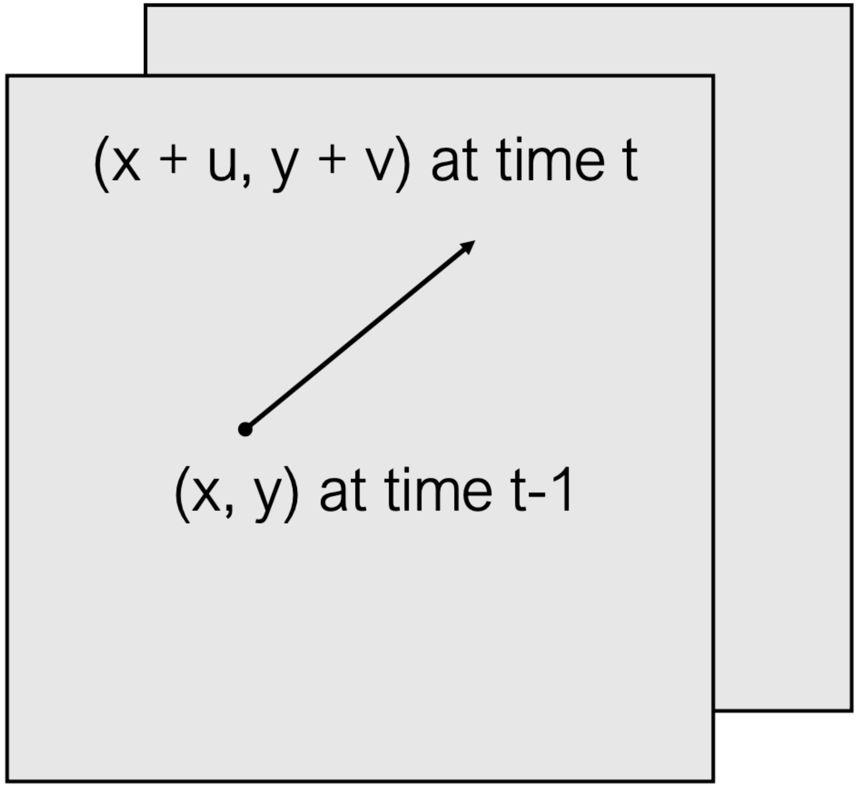
Applications

- Video Stabilization
- Video Frame Interpolation
- Action Recognition
- Video Restoration
- Visual Tracking
- …

Video Stabilization – Remove Camera Shake

https://cseweb.ucsd.edu/~ravir/jiyang_cvpr20.pdf [Yu and Ramamoorthi, 2020]

Video Frame Interpolation

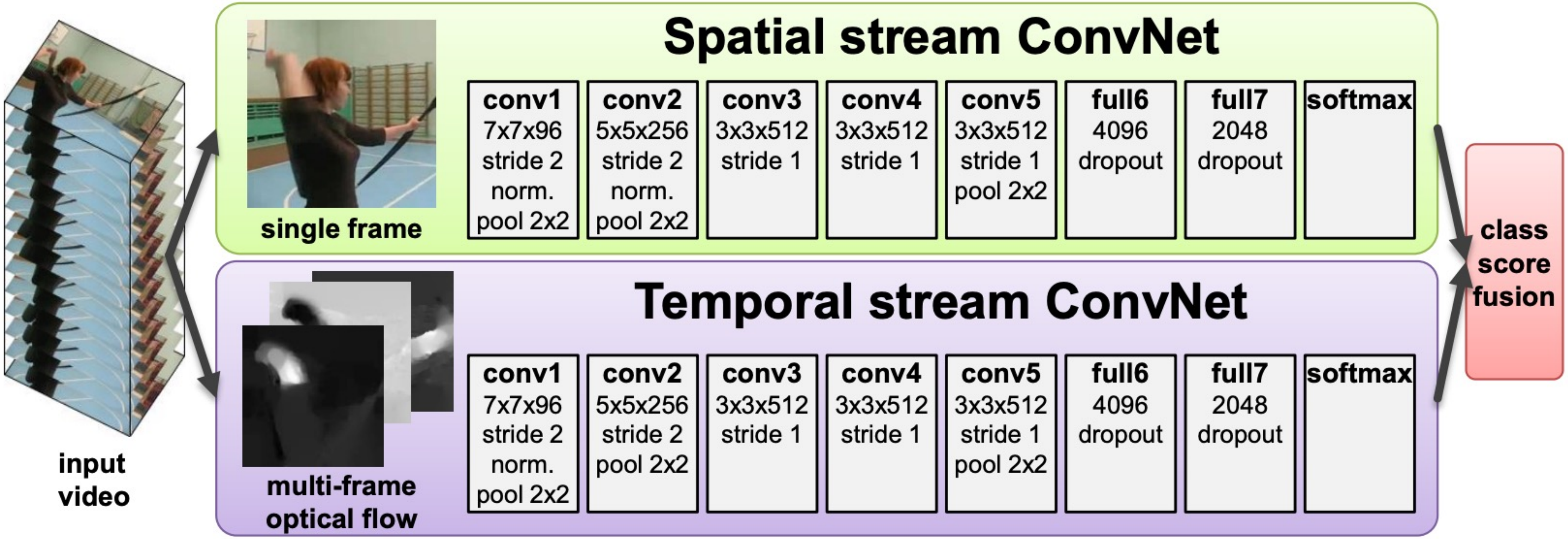


- use flow to estimate where pixel will be between two frames
- Synthesize intermediate frames to generate slow-motion videos

Credit: Shu Kong

https://www.youtube.com/watch?v=MjViy6kyiqs

Action Recognition

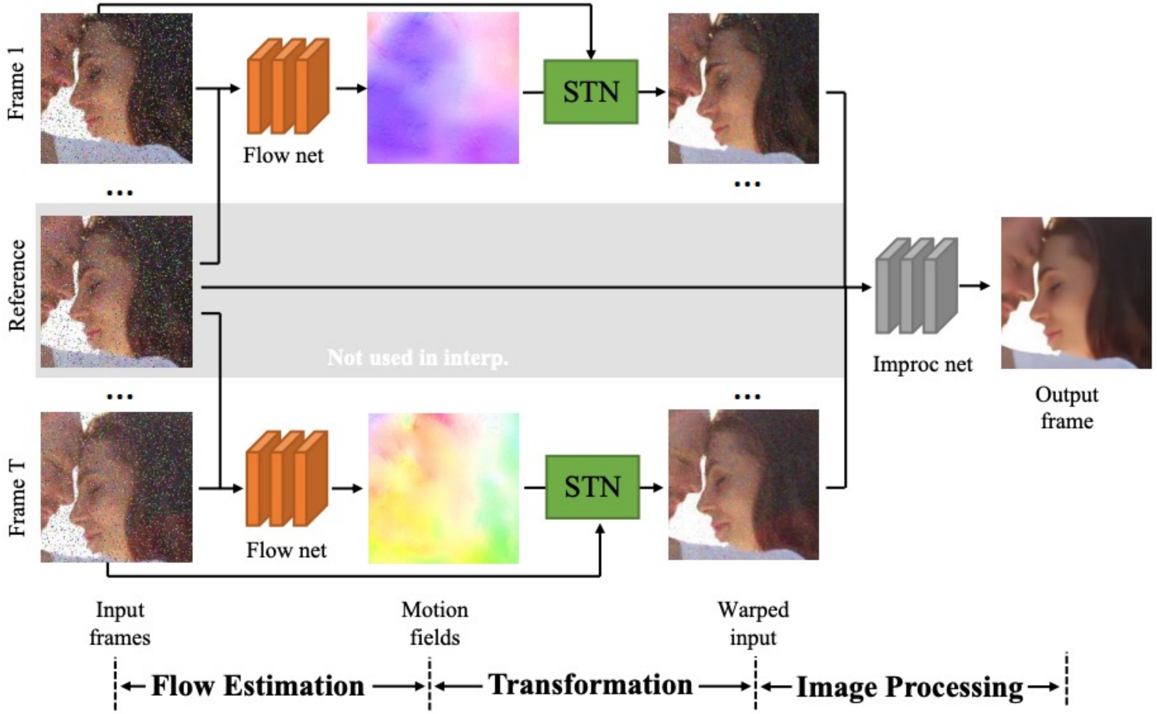


Two-stream architecture for video classification

[Simonyan and Zisserman, 2014]

Video Restoration

Optical flow can be used to address a series video restoration tasks, such as denoising, deblocking, and super-resolution



- Flow net to estimate motion field between neighboring frames
- Stack warped frames as input for the image processing network to predict the high-quality frame

Video Restoration

https://www.youtube.com/watch?v=msC5GK9aV9Q

Visual Tracking

https://nanonets.com/blog/optical-flow/

Further Reading

FlowNet: Learning Optical Flow with Convolutional Networks, 2015
https://arxiv.org/abs/1504.06852

PWC-Net: CNNs for Optical Flow Using Pyramid, Warping, and Cost Volume, 2018
https://arxiv.org/abs/1709.02371

RAFT: Recurrent All-Pairs Field Transforms for Optical Flow, 2020
https://arxiv.org/abs/2003.12039