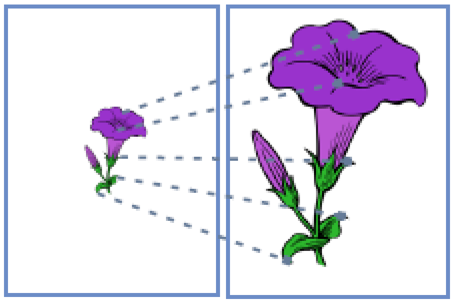
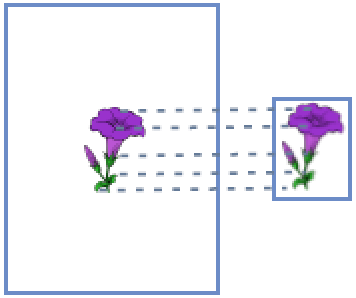


# Scale Invariant Optical Flow

Li Xu, Zhenlong Dai, Jiaya Jia
Department of Computer Science and Engineering
The Chinese University of Hong Kong

Milestones and Advances in Image Analysis Seminar
Presenter: Banafsheh Sadry



# Outline:

1. Introduction
2. Optical Flow Model with Scale Variables
3. Experiments
4. Concluding Remarks

# Introduction:

- What is the Optic Flow Problem?

  Given: Two consecutive images of an image sequence (one camera, different time).

  Wanted: Motion field between both frames.

- Applications;

✓ Tracking

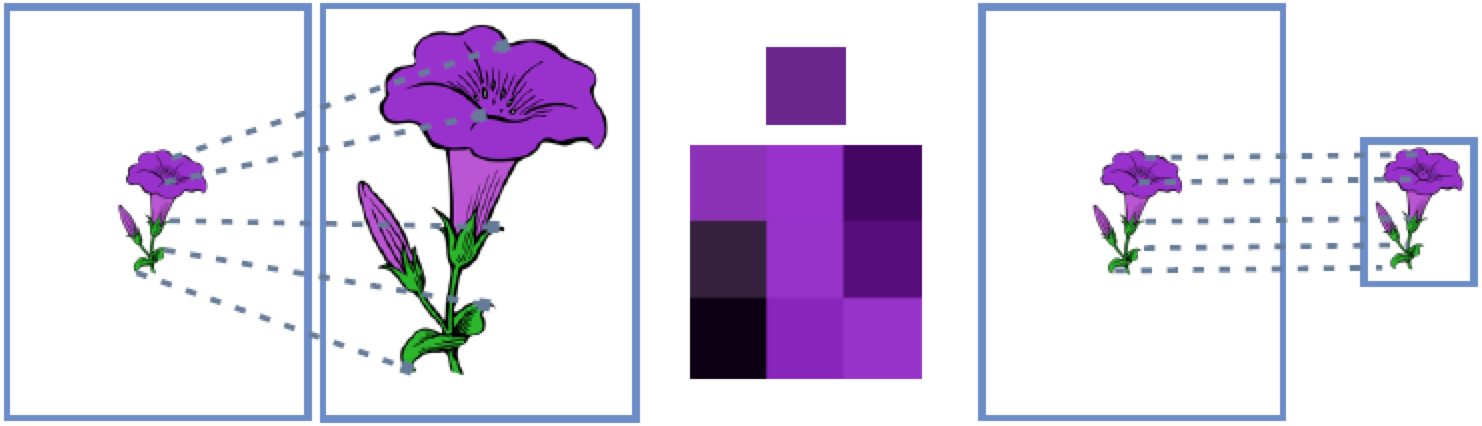
✓ Video editing

✓ View interpolation

✓ Scene understanding

# Introduction:

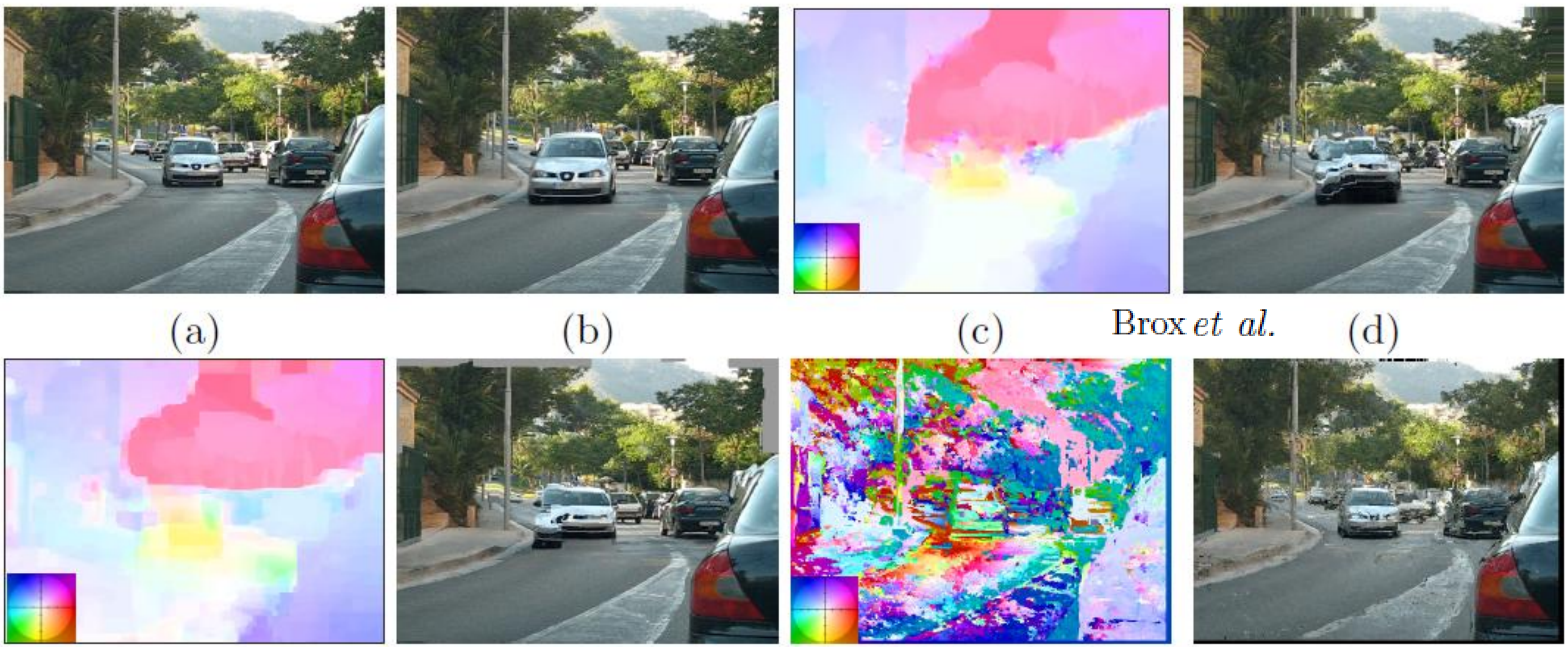
One to many or many to one mapping:



(a) (b) (c)

# Introduction:

## Limitation of current methods:



(a) (b) (c) Brox *et al.* (d)

(e) Sift flow (f) (g) Barnes *et al.* (h)

# Optical Flow Model with Scale Variables:

Common optical flow model:

$$\int \phi(|\mathbf{I}_2(\mathbf{x}+\mathbf{u}) - \mathbf{I}_1(\mathbf{x})|^2) + \alpha\phi(|\nabla u|^2 + |\nabla v|^2)\mathrm{d}\mathbf{x},$$

$\mathbf{x} = (x, y)$ indexes the 2D coordinates.

$\mathbf{I}_1$ and $\mathbf{I}_2$ are input image pairs.

$\mathbf{u} = (u, v)$ is the unknown optical flow field.

$\phi(a^2) = \sqrt{a^2 + \epsilon^2}$ is the robust function to deal with outliers

# Optical Flow Model with Scale Variables:

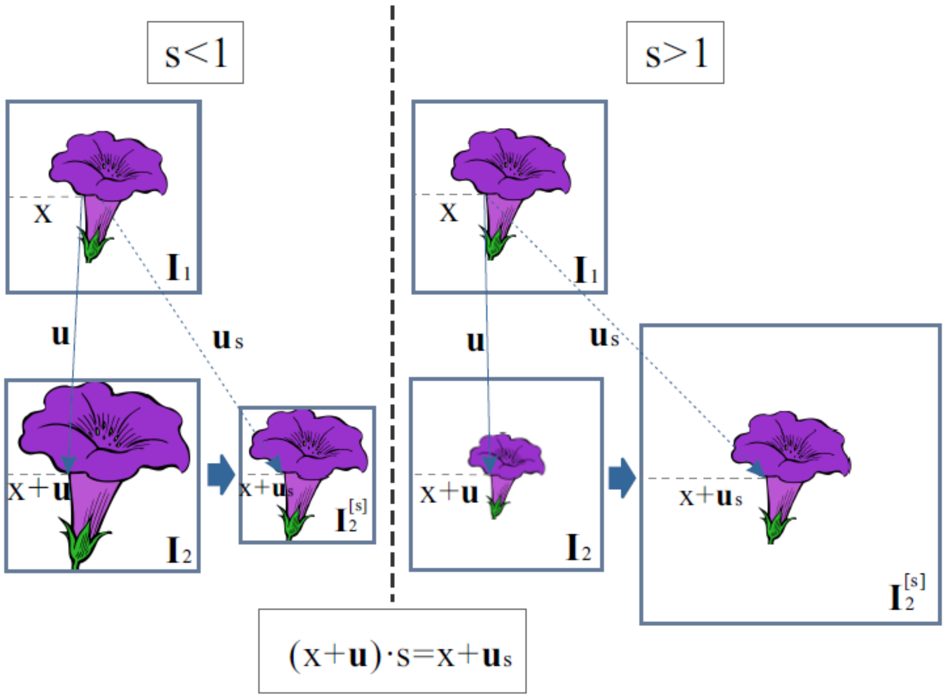
Commonly optical flow model:

$$\int \underbrace{\phi(|\mathbf{I}_2(\mathbf{x}+\mathbf{u}) - \mathbf{I}_1(\mathbf{x})|^2)}_{\text{Data term}} + \alpha \underbrace{\phi(|\nabla u|^2 + |\nabla v|^2)}_{\text{smoothness term}} \mathrm{d}\mathbf{x},$$

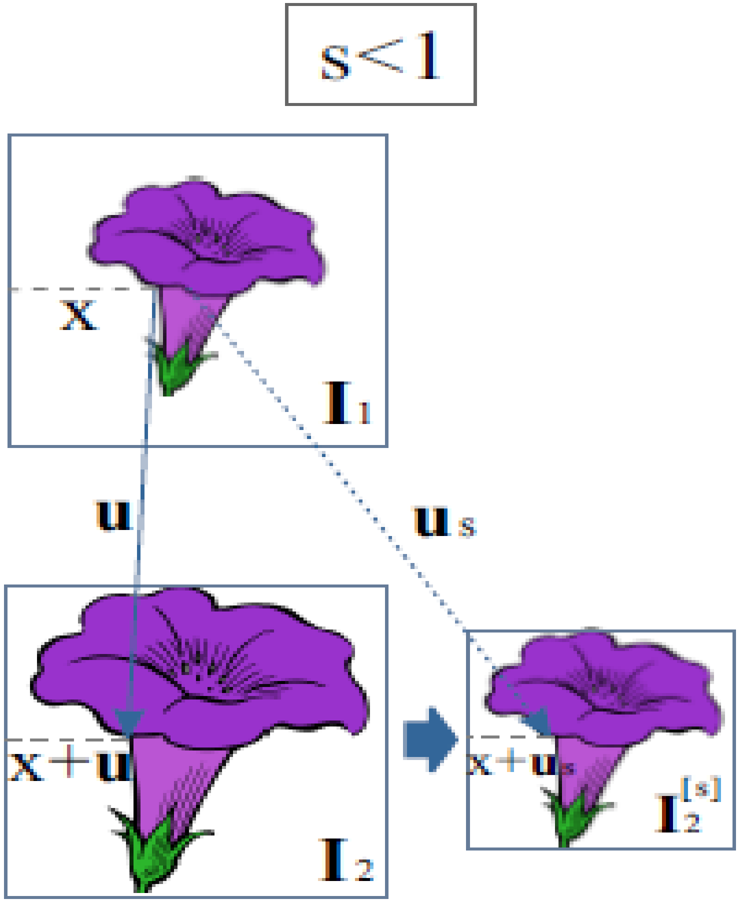
# Optical Flow Model with Scale Variables:

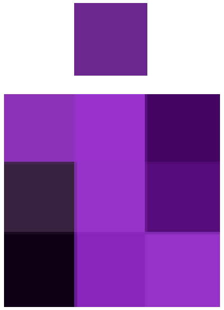
- For each pixel,

$$\phi(|\mathbf{I}_2^{[s]}(\mathbf{x}+\mathbf{u}_s(\mathbf{x})) - \mathbf{I}_1^{[s]}(\mathbf{x})|^2),$$



# Optical Flow Model with Scale Variables:



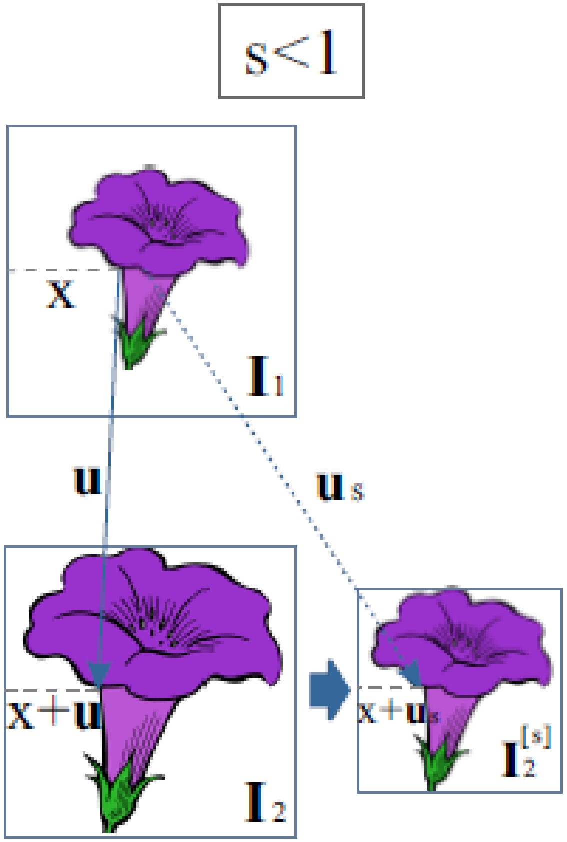



# Optical Flow Model with Scale Variables:

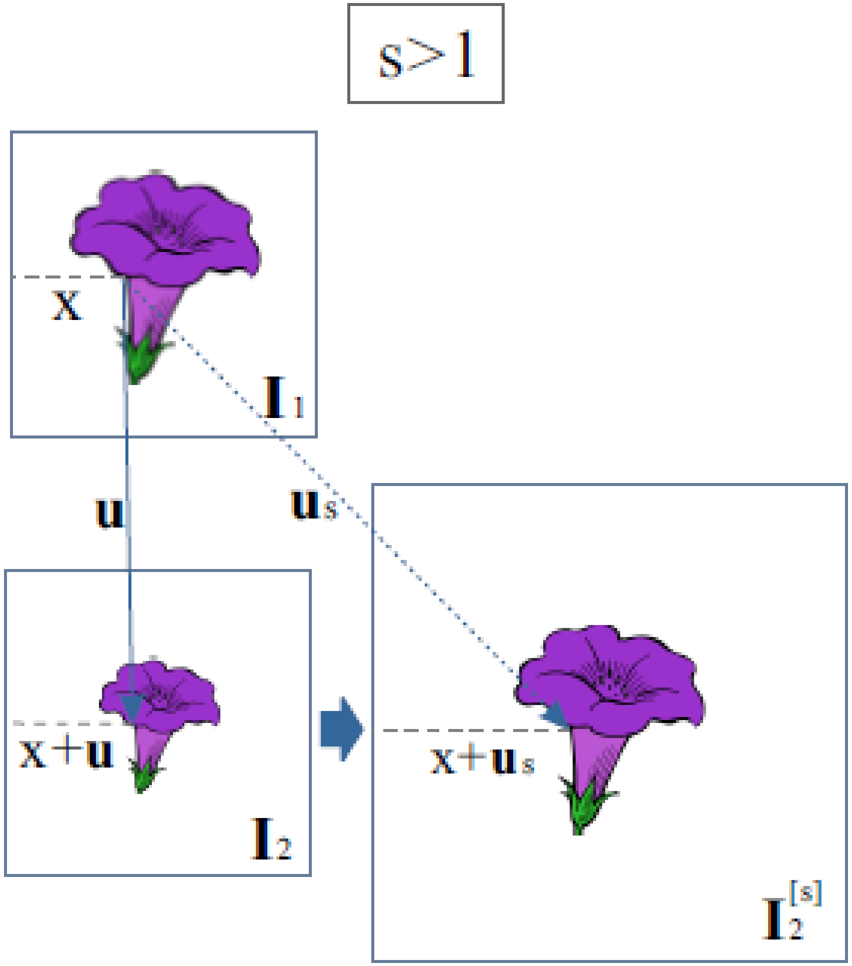
If $s < 1$,

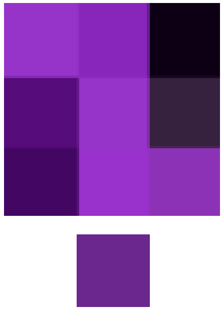
build correspondence by locally smoothing $\mathbf{I}_2$ by a Gaussian filter with standard deviation $\sigma = (1/s - 1)$ and downsampling it with scale $1/s$, obtaining $\mathbf{I}_2^{[s]}$.

$$\boxed{\mathbf{x} + \mathbf{u}_s(\mathbf{x}) = (\mathbf{x} + \mathbf{u}(\mathbf{x})) \cdot s.}$$



# Optical Flow Model with Scale Variables:



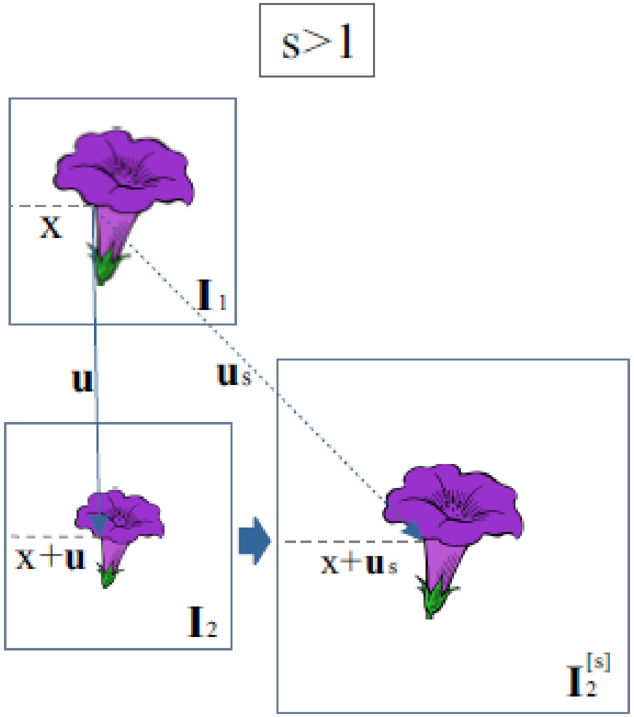



# Optical Flow Model with Scale Variables:

if $s > 1$,

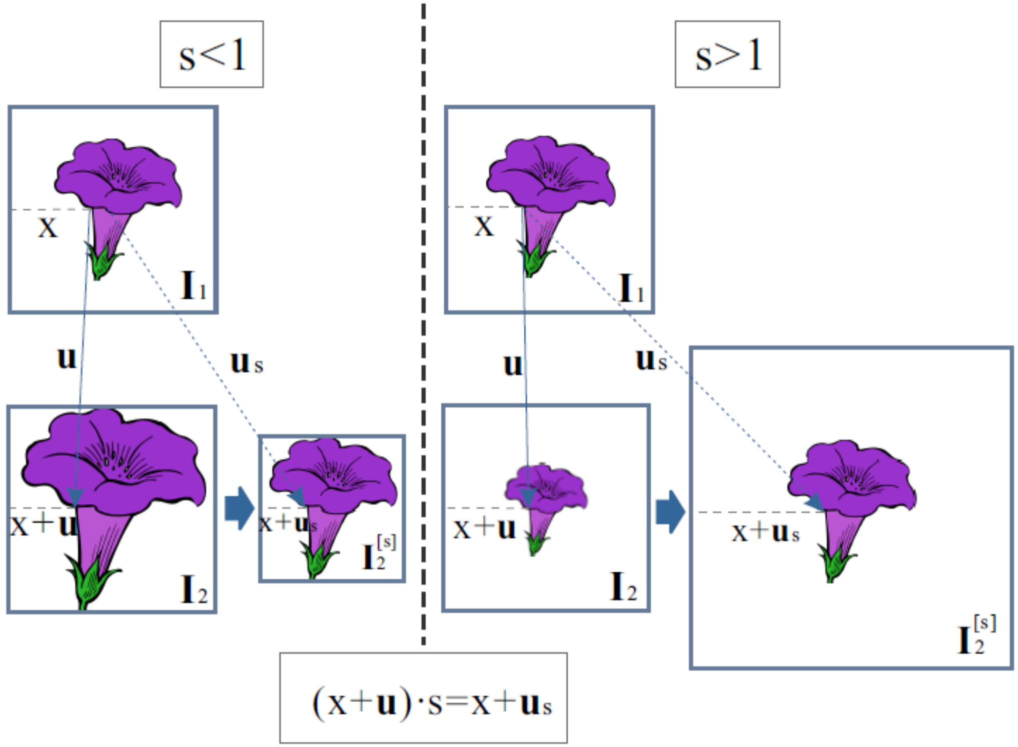
need to locally Gaussian filter $\mathbf{I}_1$ and then match $\mathbf{x}$ to a pixel in an upsampled version of $\mathbf{I}_2$ with scale $s$, i.e., $\mathbf{I}_2^{[s]}$.

$$\boxed{\mathbf{x} + \mathbf{u}_s(\mathbf{x}) = (\mathbf{x} + \mathbf{u}(\mathbf{x})) \cdot s.}$$



# Optical Flow Model with Scale Variables:

$$\begin{cases} (x + u(x,y)) \cdot s = x + u_s(x,y) \\ (y + v(x,y)) \cdot s = y + v_s(x,y) \end{cases}$$

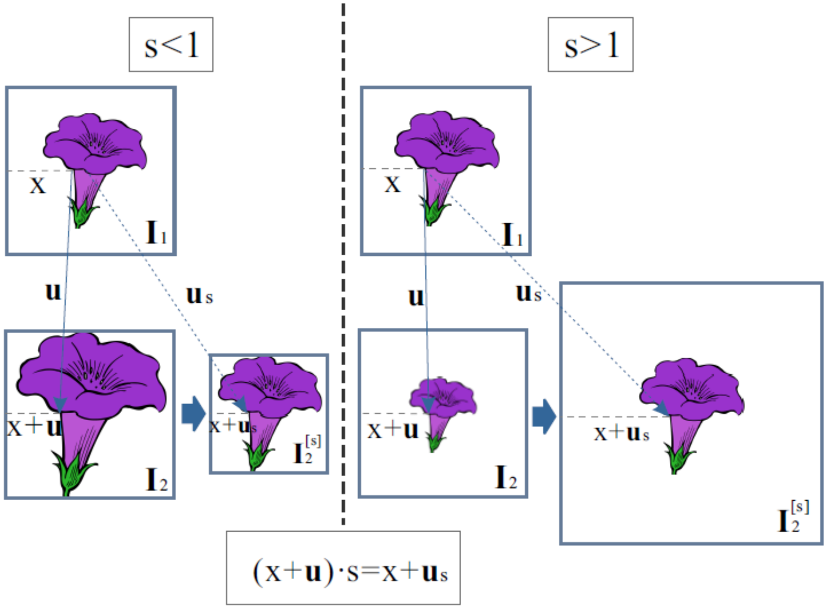


# Optical Flow Model with Scale Variables:

- For each pixel,

$$\phi(|\mathbf{I}_2^{[s]}(\mathbf{x} + \mathbf{u}_s(\mathbf{x})) - \mathbf{I}_1^{[s]}(\mathbf{x})|^2),$$

$$\phi_d(\mathbf{u}, s) = \phi(|\mathbf{I}_2^{[s]}(((\mathbf{x} + \mathbf{u}(\mathbf{x})) \cdot s) - \mathbf{I}_1^{[s]}(\mathbf{x})|^2),$$



# Optical Flow Model with Scale Variables:

$$|\nabla u_s|^2 = |s \cdot u_x + (s-1)|^2 + |s \cdot u_y|^2$$

# Optical Flow Model with Scale Variables:

$$|\nabla u_s|^2 = |s \cdot u_x + (s-1)|^2 + |s \cdot u_y|^2$$

$\boxed{\text{This is } \textit{not} \text{ desirable.}}$

# Optical Flow Model with Scale Variables:

## Normalize Gradient

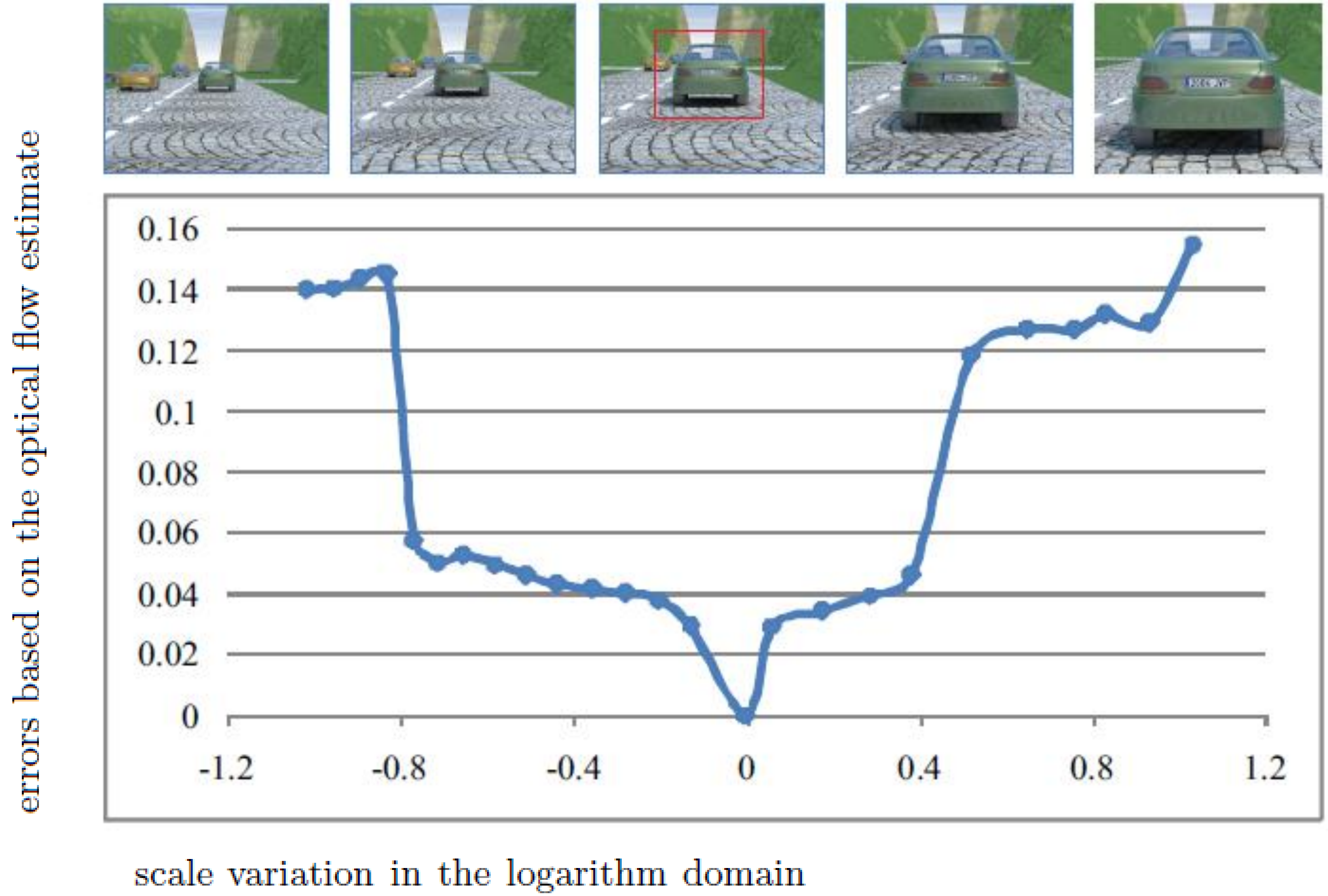
$$\phi_s(\mathbf{u}, s) = \phi(|\nabla u_s/s|^2 + |\nabla v_s/s|^2)$$
$$= \phi(|u_x + (s-1)/s|^2 + |u_y|^2 + |v_x|^2 + |v_y + (s-1)/s|^2),$$

# Optical Flow Model with Scale Variables:

$$\int \phi(|\mathbf{I}_2(\mathbf{x}+\mathbf{u}) - \mathbf{I}_1(\mathbf{x})|^2) + \alpha\phi(|\nabla u|^2 + |\nabla v|^2)\mathrm{d}\mathbf{x},$$

$$E(\mathbf{u}, s) = \int \phi_d(\mathbf{u}, s) + \alpha\phi_s(\mathbf{u}, s)\mathrm{d}\mathbf{x}.$$

# Optical Flow Model with Scale Variables:



# Optical Flow Model with Scale Variables:

set the scale range to $[1/2, 2]$ with interval $\sqrt{2}$.

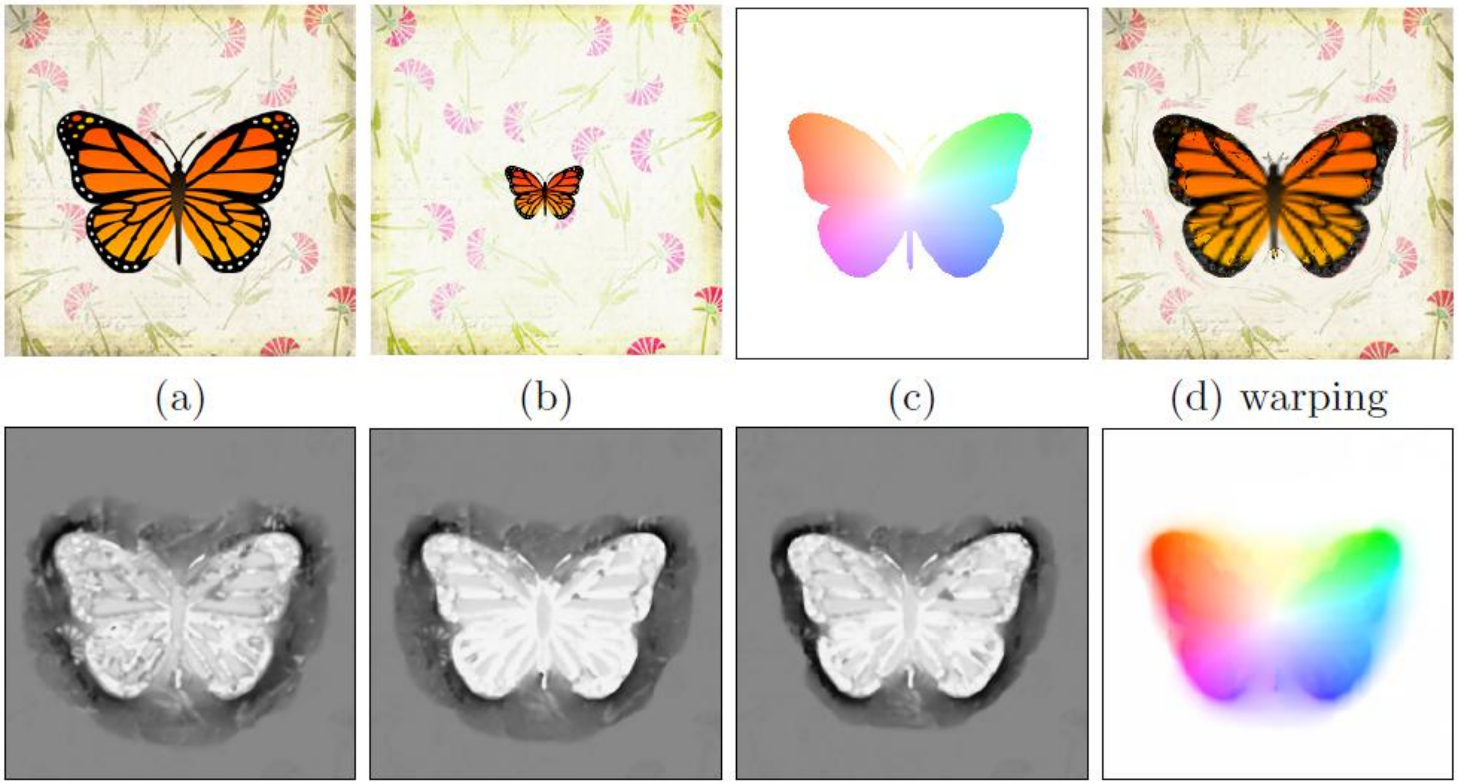
$$s \in S = \{1/2, 1/\sqrt{2}, 1, \sqrt{2}, 2\}.$$

# Optical Flow Model with Scale Variables:

$$E(\mathbf{u}, \mathbf{z}) = \int \sum_{i=1}^{5} z_i \cdot (\phi_d(\mathbf{u}, s_i) + \alpha \phi_s(\mathbf{u}, s_i)) \mathrm{d}\mathbf{x}.$$

# Experiments:

## Evaluation of Our Model to Handle Scales


(a) (b) (c) (d) warping
(e) (f) (g) (h)

# Experiments:

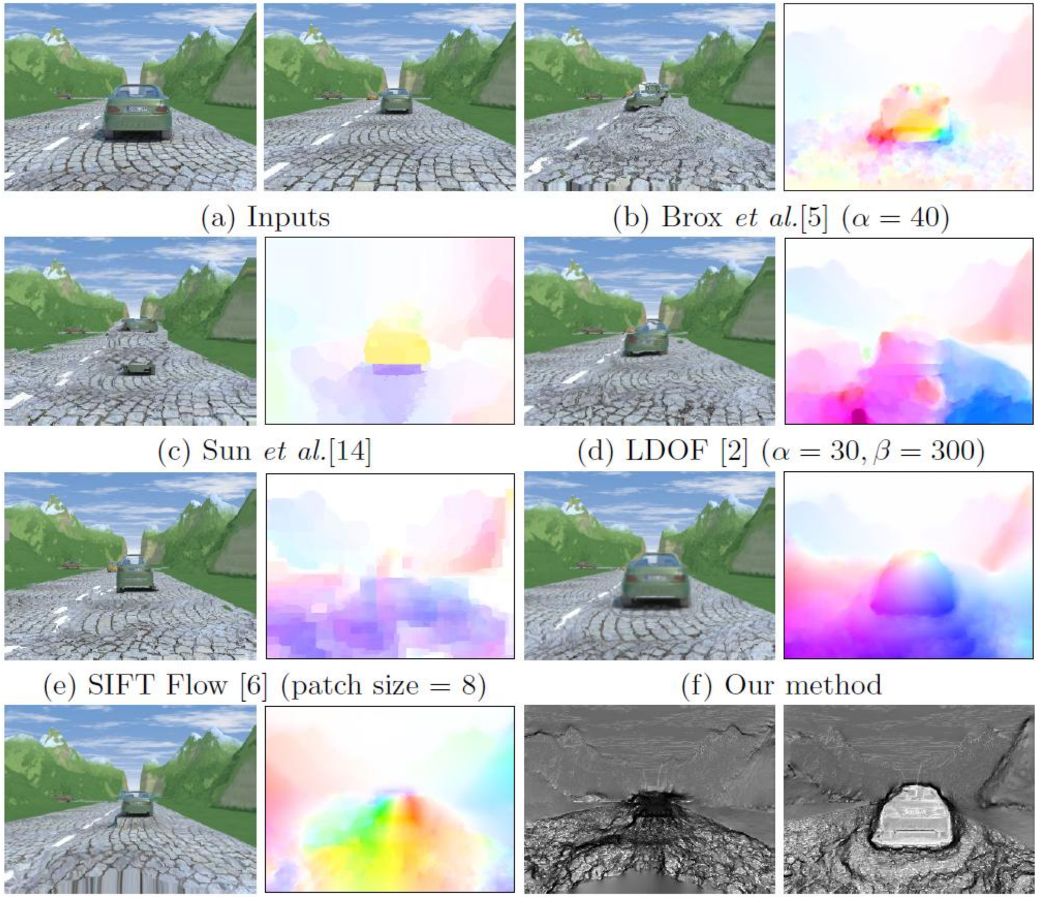
## Comparison with Other Optical Flow Methods

(a) Brox *et al.* (b) Brox *et al.* (c) Sun, (d) Ours

**Fig. 7.** Warping results based on flow estimated by different methods.

# Experiments:

## Comparison with Other Optical Flow Methods



(a) Inputs
(b) Brox *et al.*[5] ($\alpha = 40$)
(c) Sun *et al.*[14]
(d) LDOF [2] ($\alpha = 30, \beta = 300$)
(e) SIFT Flow [6] (patch size = 8)
(f) Our method
(g) Our backward flow
(h) The pseudo scale map

# Experiments:

## Comparison with Other Optical Flow Methods

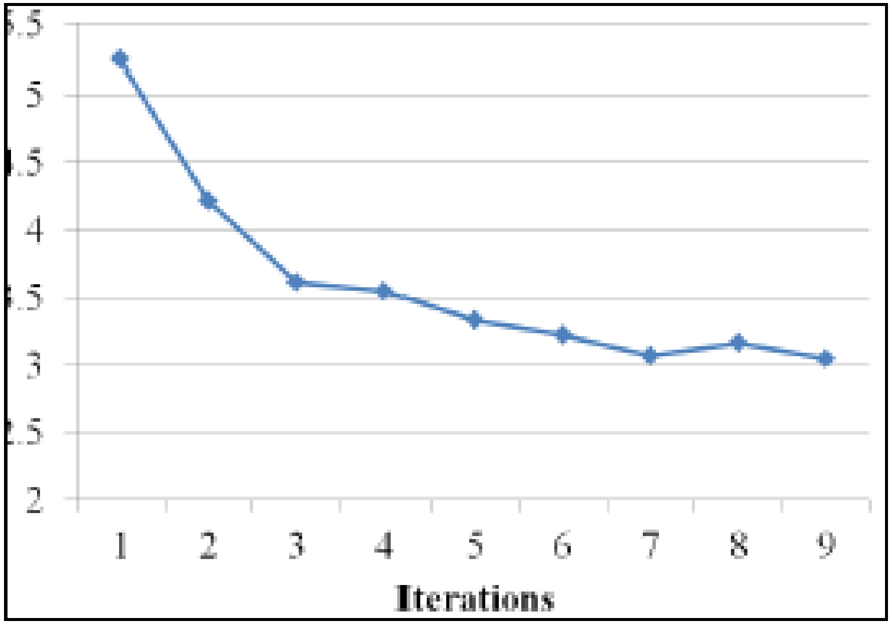


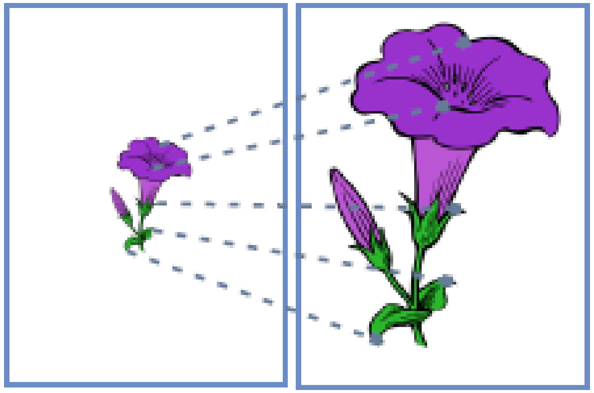

Fig. 8. Error statistics w.r.t. the number of iterations.

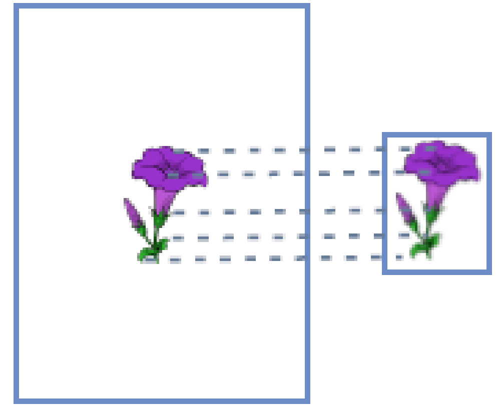
# Concluding Remarks:

- New optical flow framework
- Introduce a scale variable for each pixel
- Derive an effective numerical scheme to make it solvable

Future work:

- Integrating advanced edge-preserving techniques into the flow model.
- Speed up the current method using GPU





# Thanks for your attention!