FlowWeb:
Joint Image Set Alignment by Weaving Consistent, Pixel-wise Correspondences

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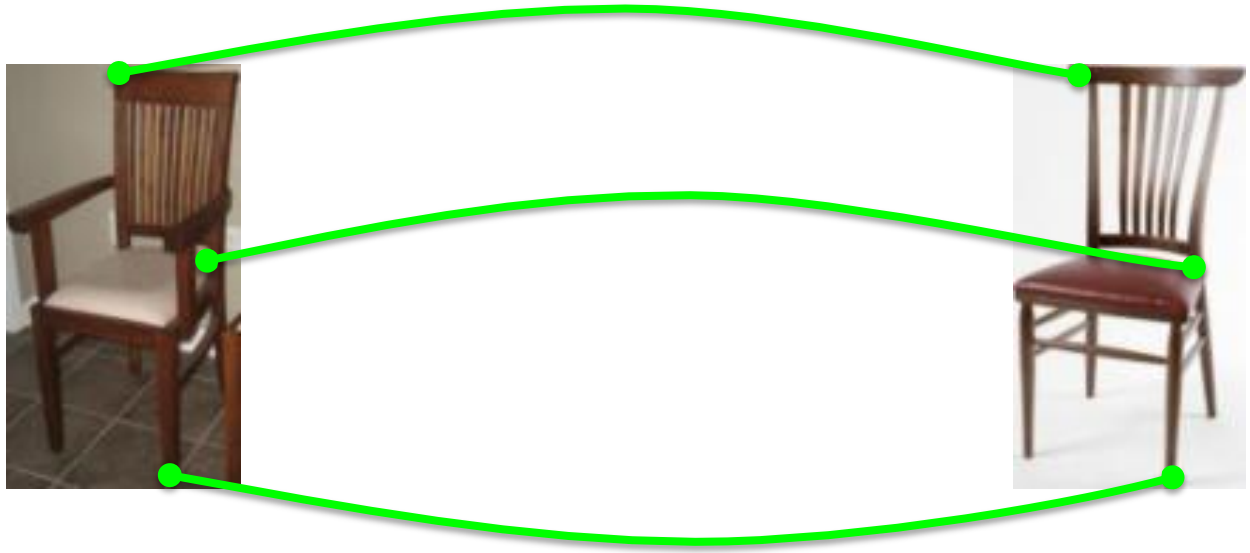
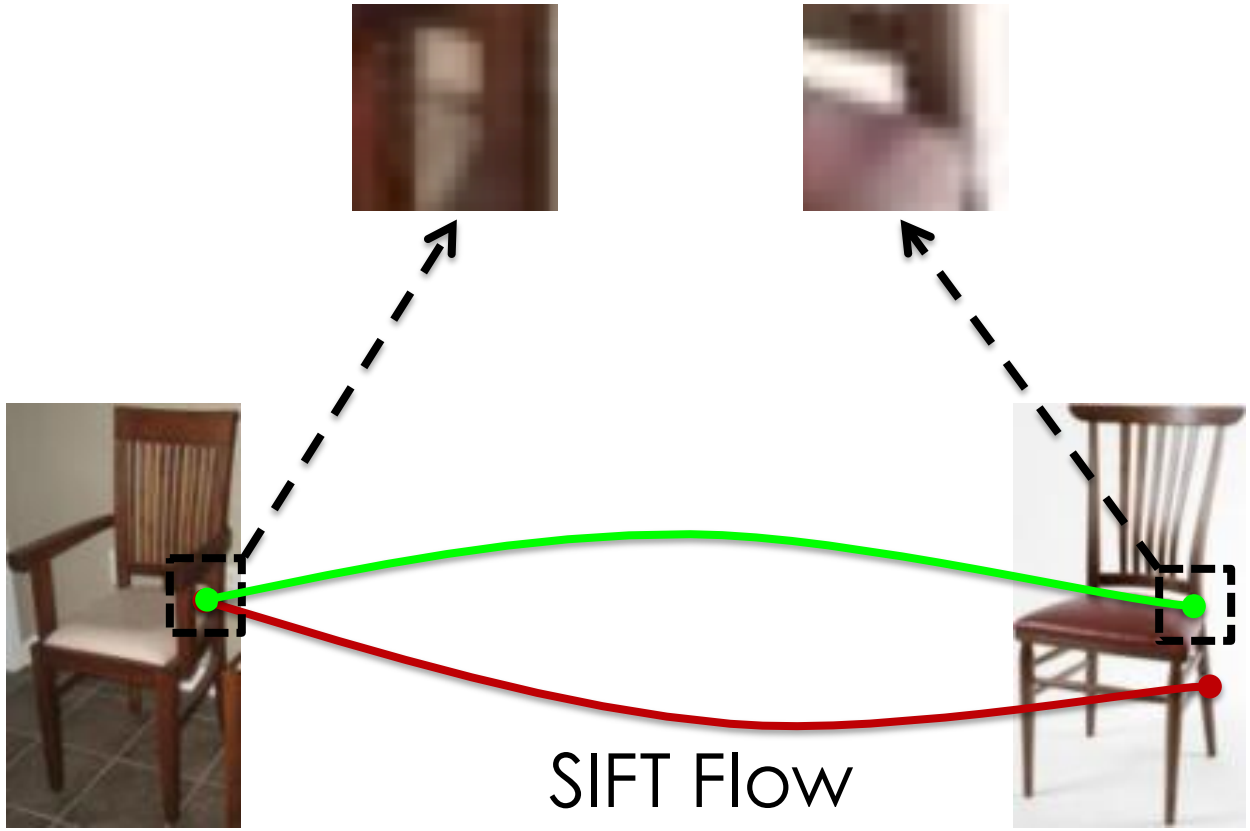
UC Berkeley[1] *UC Davis[2]* *ICSI[3]*

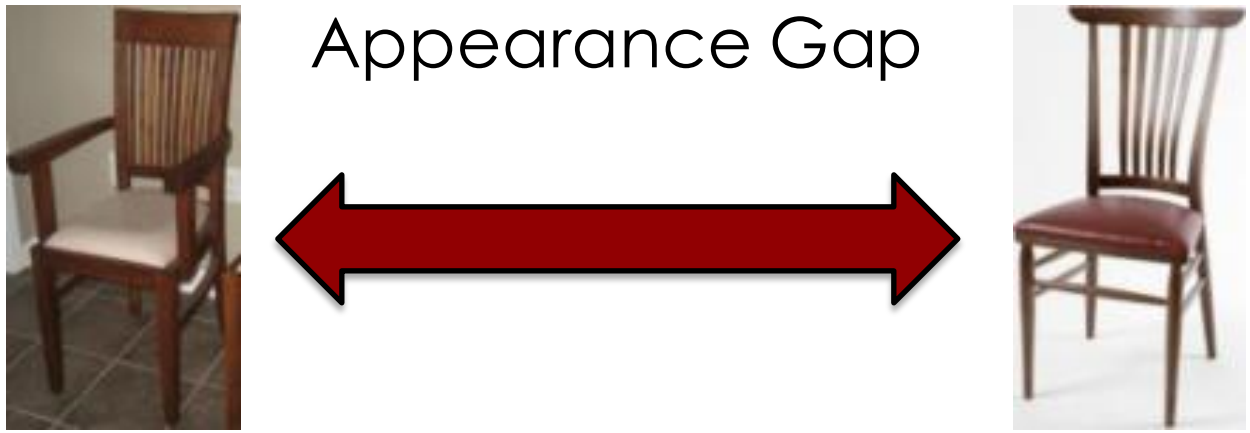
Match pixels between two chairs



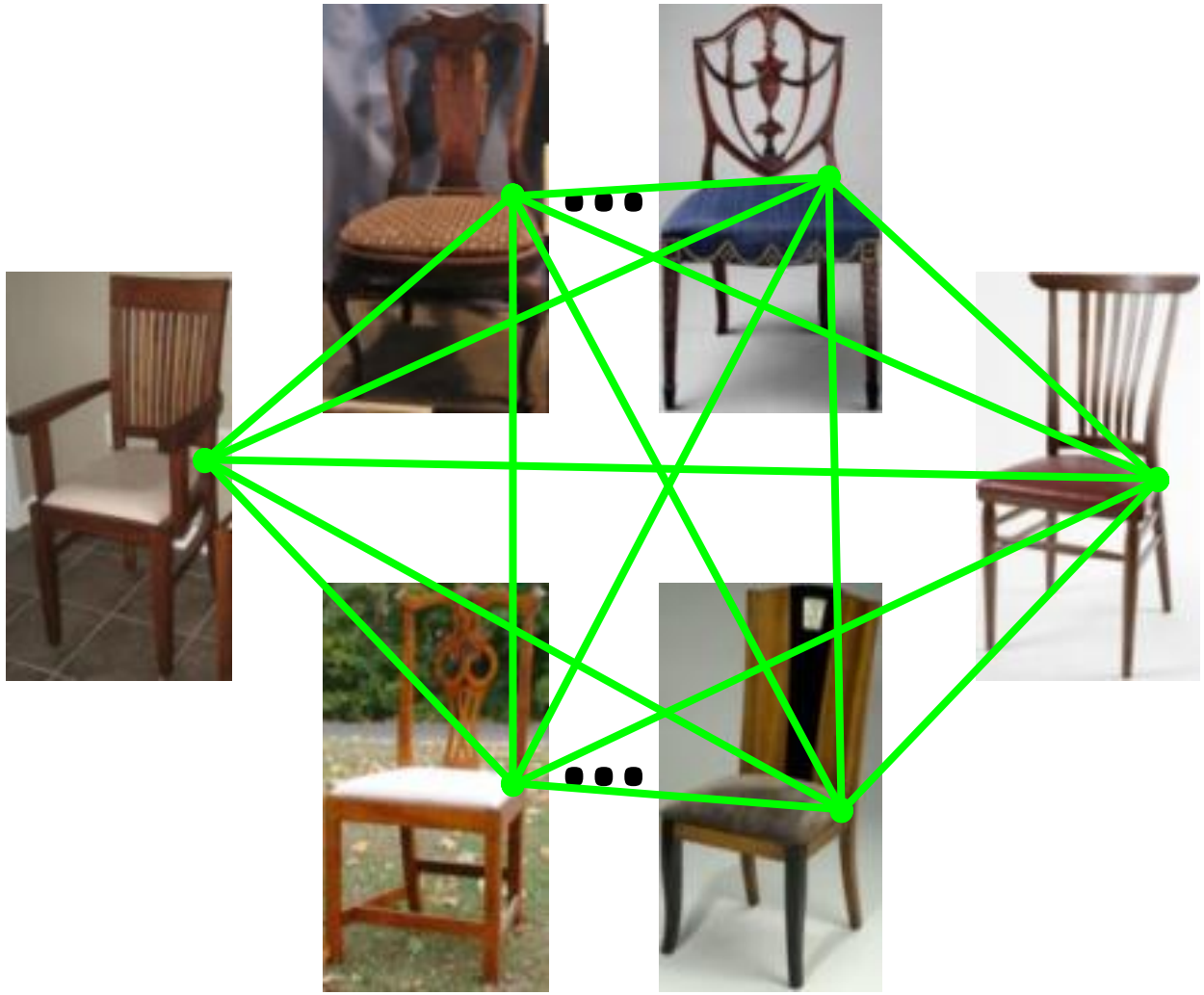
Match pixels between two chairs



Match pixels between two chairs

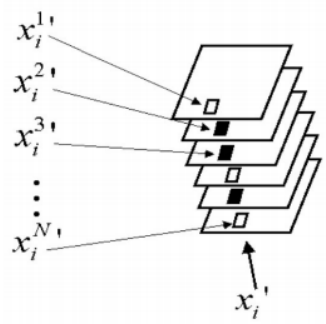


Bridging the appearance gap

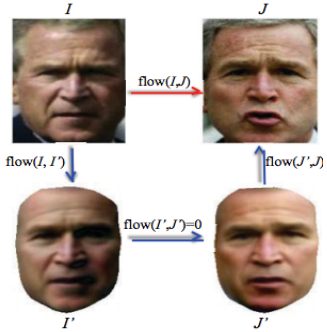


Prior Work on Joint Image Alignment

- **Congealing** (*Learned-Miller, PAMI'06*): Minimize pixel entropy with a parametric transformation per image

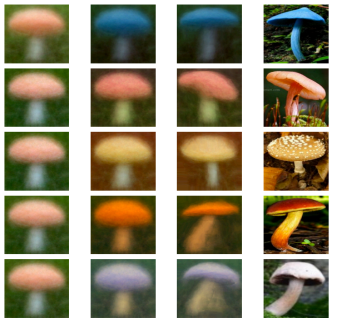


- **Collection Flow** (*Kemelmacher-Shlizerman et al., CVPR'12*): Low-rank + Optical flow



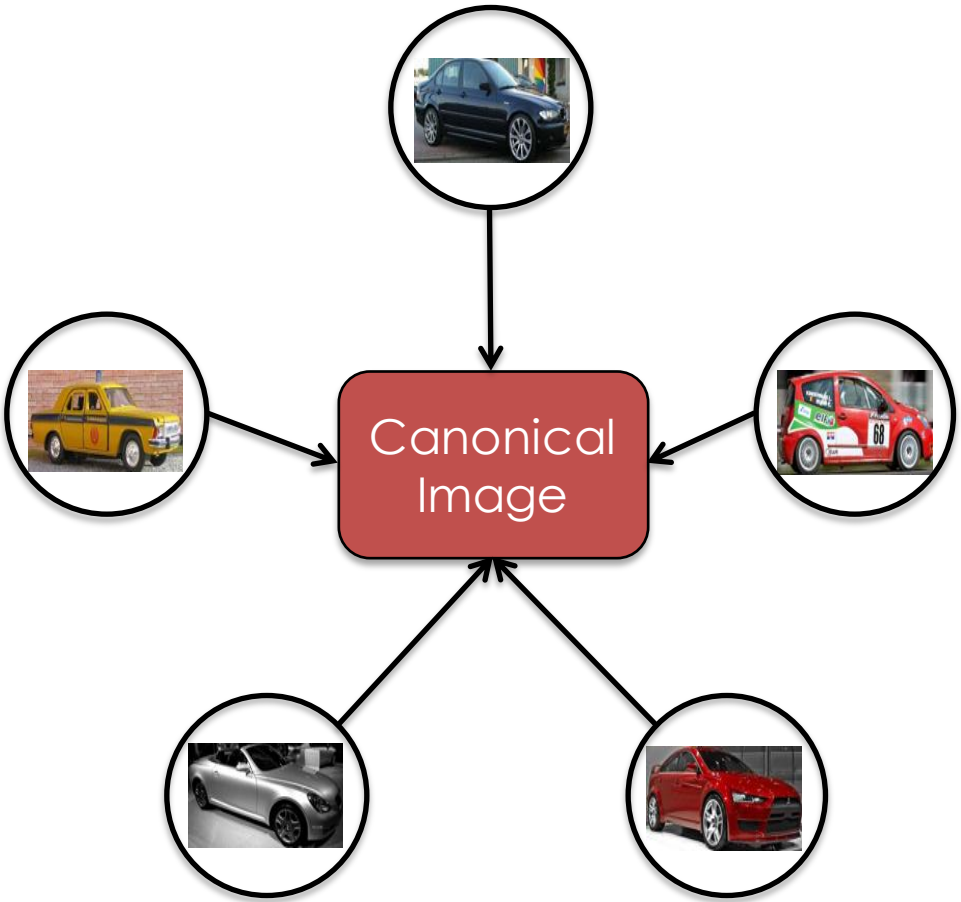
- **RASL** (*Peng et al., PAMI'12*): Low-rank + parametric transformation

- ***Mobahi et al.*** *(CVPR'14)*: Low rank compositional model + Optical flow

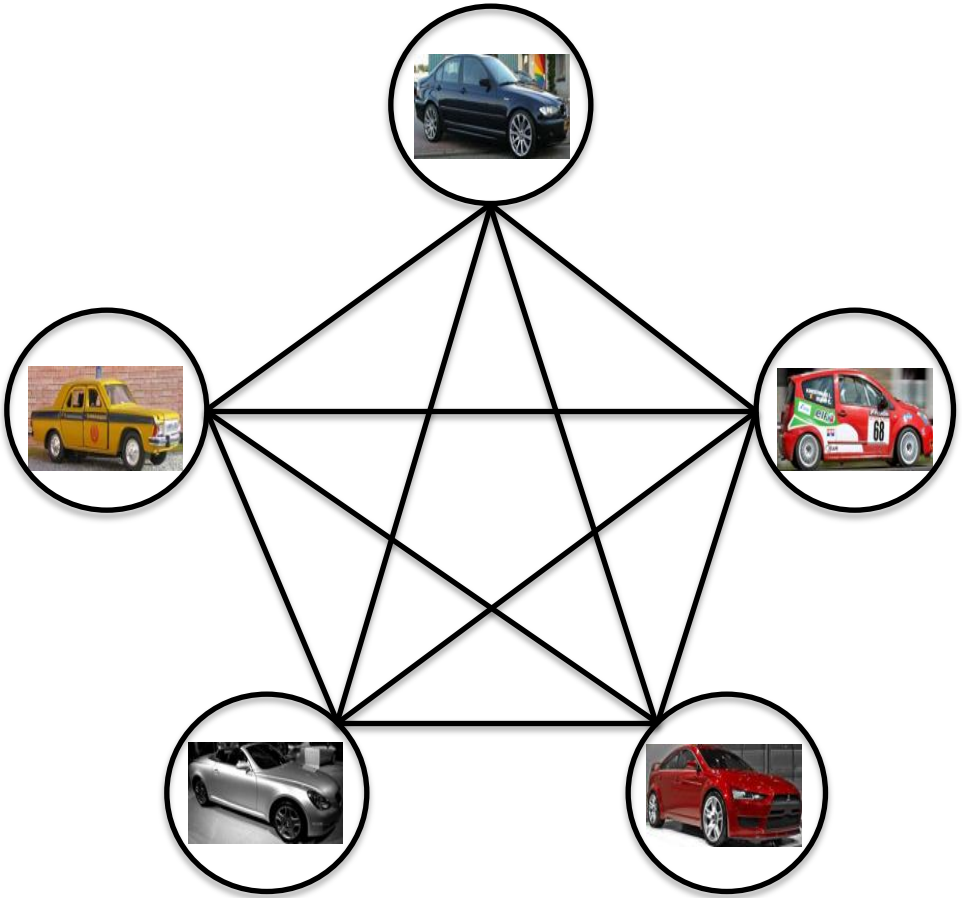


Star vs. Peer-to-Peer

Congealing, Collection Flow, RASL, Mobahi et al.

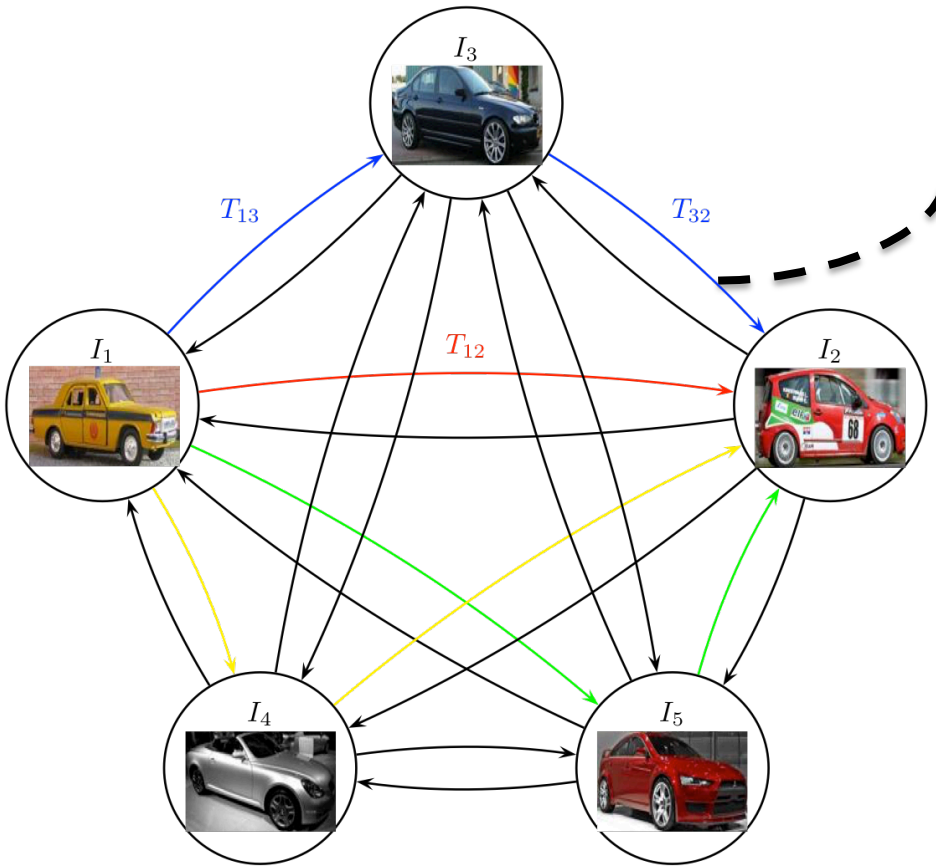


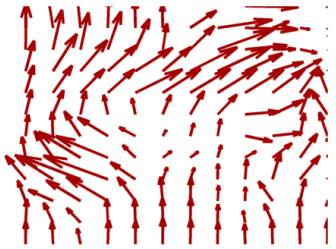
Ours



FlowWeb Representation

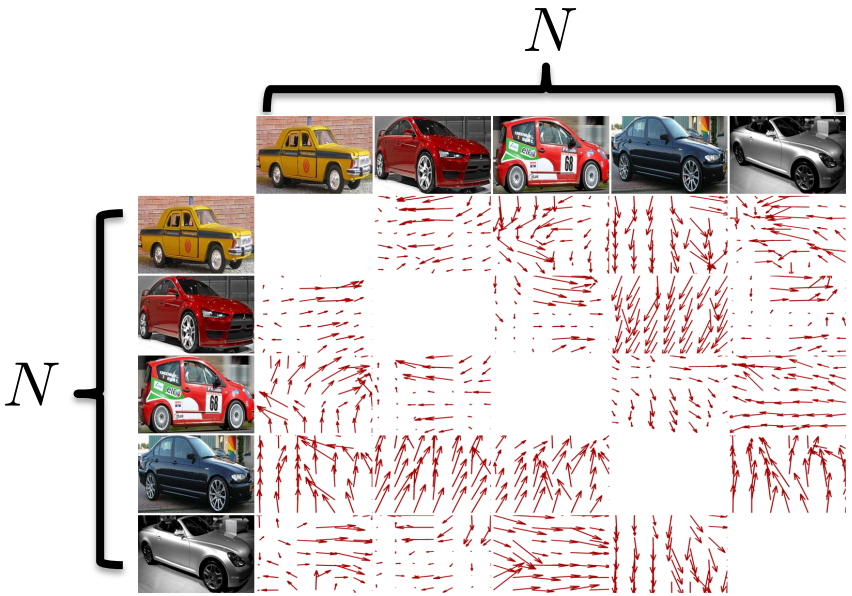
- A complete, bi-directed graph of *N* image nodes
- Each edge = flow field relating two images
- #Correspondences = $\mathcal{O}(N^2M)$



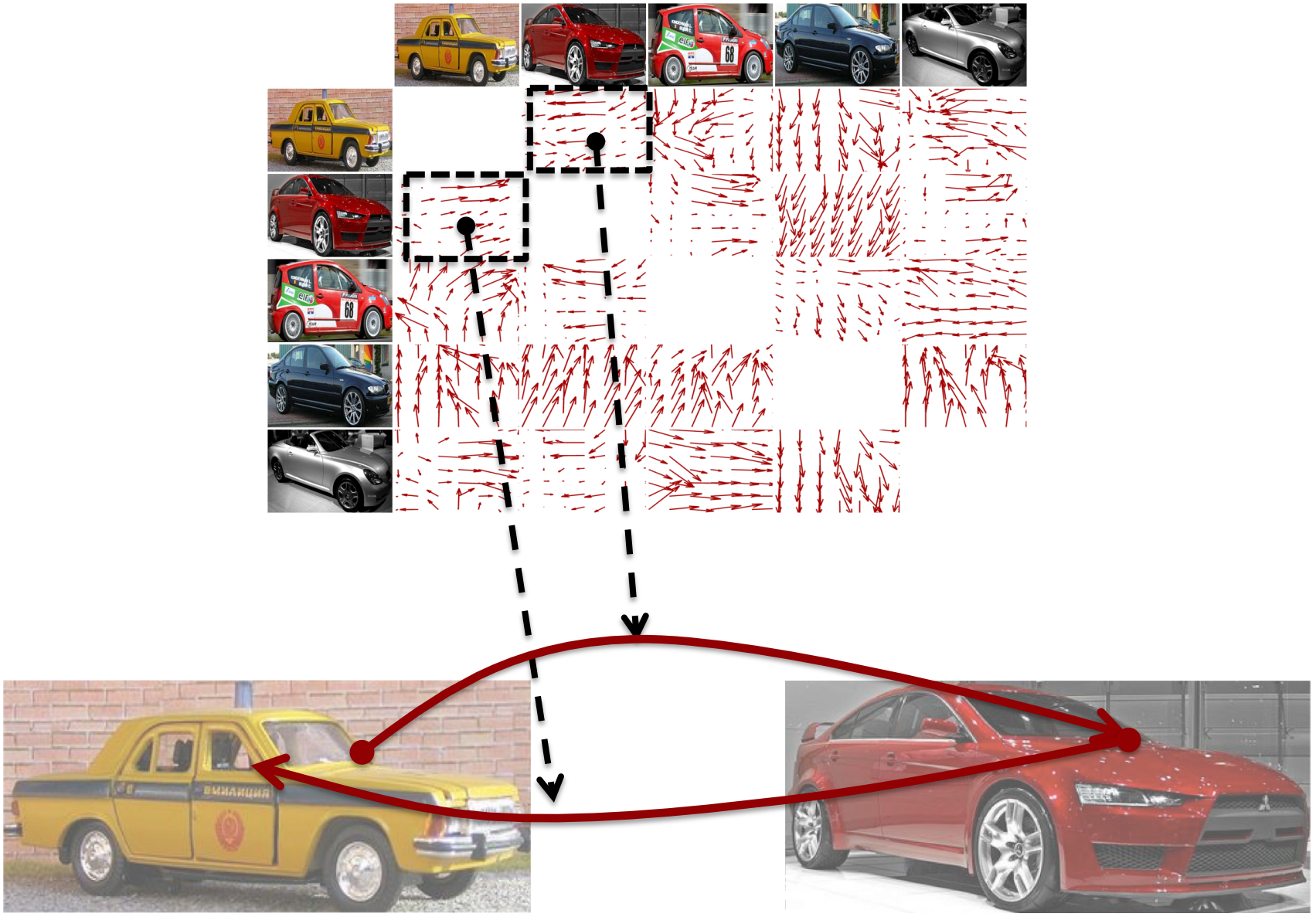


M vectors

Flow field

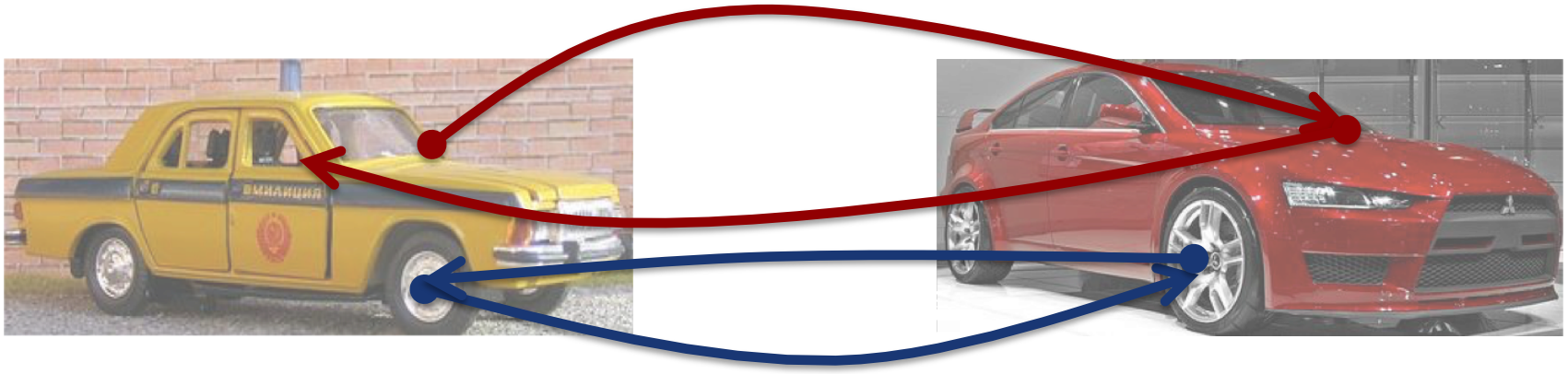


FlowWeb could be inconsistent



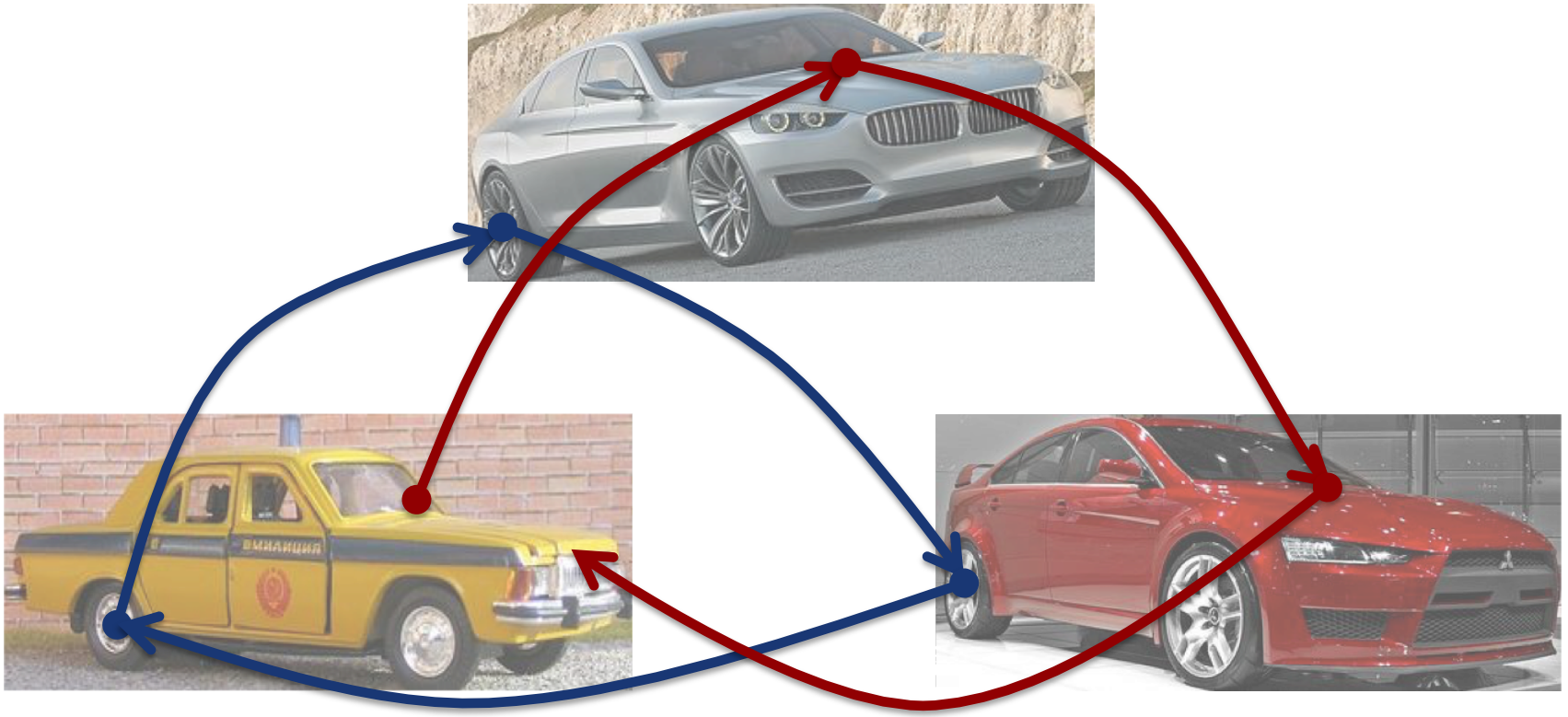
Cycle consistency

- Composite flows along cycles are zero
- 2-cycle consistency: $T_{ij} \circ T_{ji} = 0$



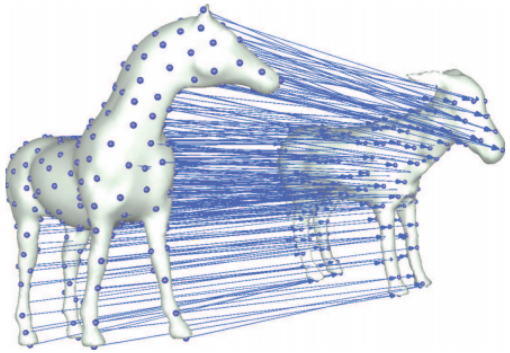
Cycle consistency

- Composite flows along cycles are zero
- 2-cycle consistency: $T_{ij} \circ T_{ji} = 0$
- 3-cycle consistency: $T_{ik} \circ T_{kj} \circ T_{ji} = 0$
- 2 and 3 cycles are sufficient (*Nguyen et al., SGP'11*)



Using Cycle Consistency

Shape matching

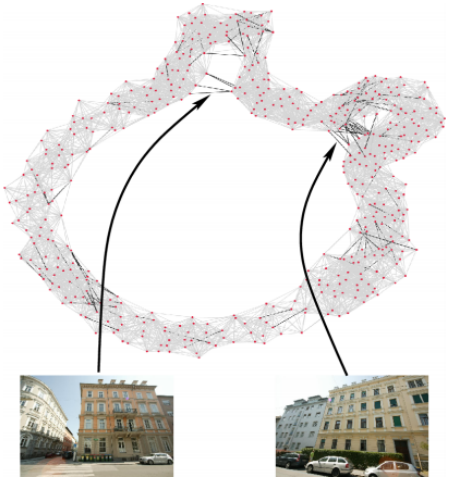


Huang et al,
SGP'13

Co-segmentation

Wang et al,
ICCV'13

Structure from Motion



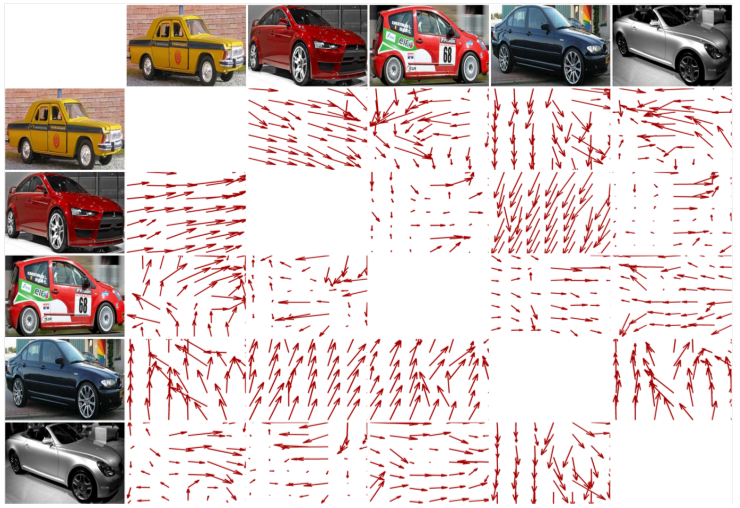
Zach et al,
CVPR'10

Our work: using cycle consistency for joint image alignment

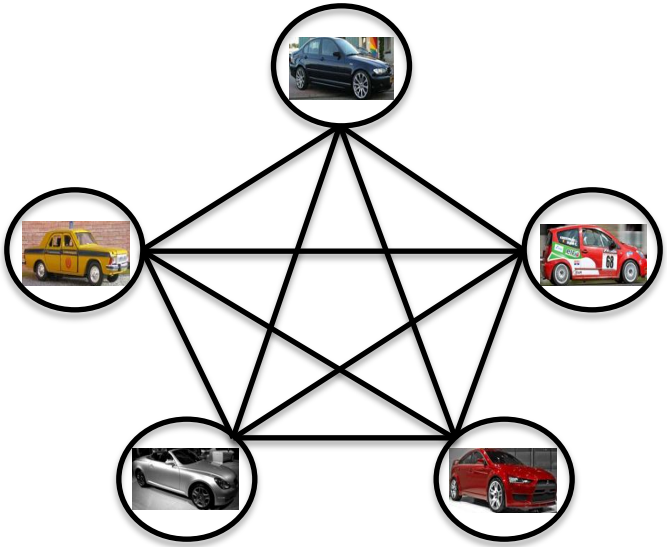
Approach Pipeline

Image Collection

Initial Pairwise Flow (e.g. SIFT Flow)



Joint Alignment

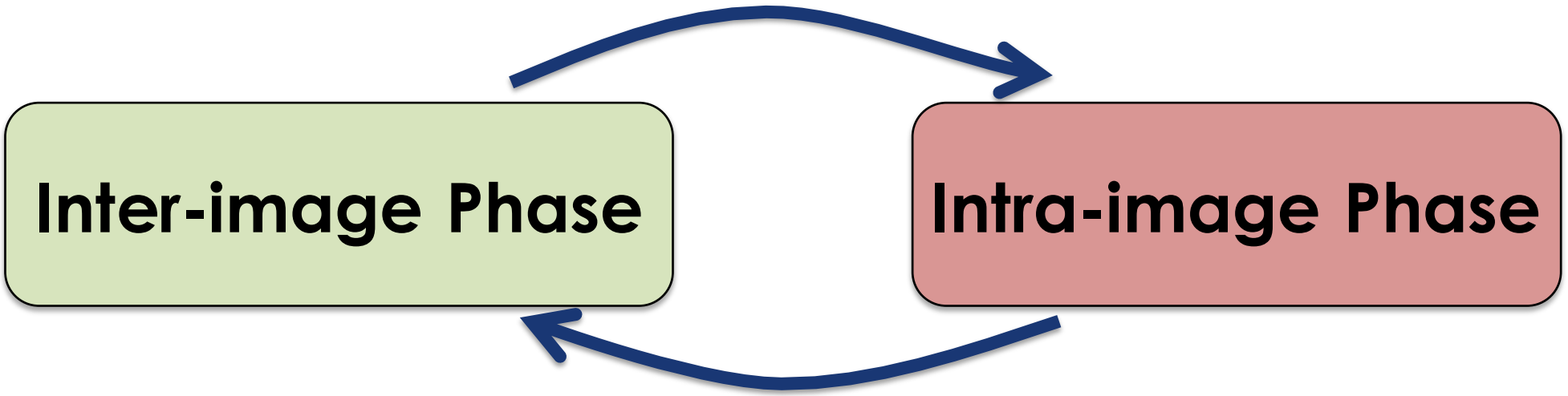


Final output

Wisdom of the Crowd

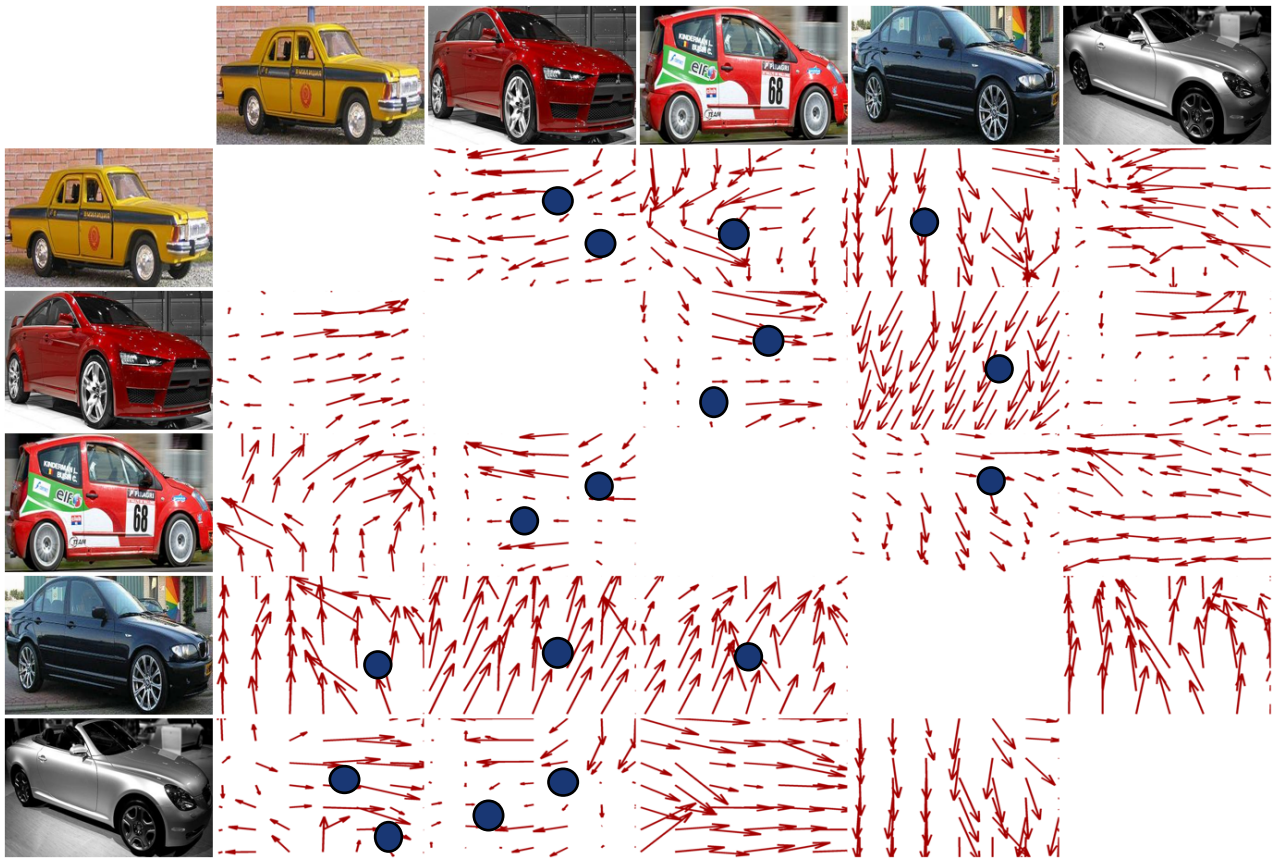
- Good correspondences are consistent
- Cycle-consistency ≈ flow quality
- Use consistent flows to guide inconsistent ones

Flow Update Algorithm



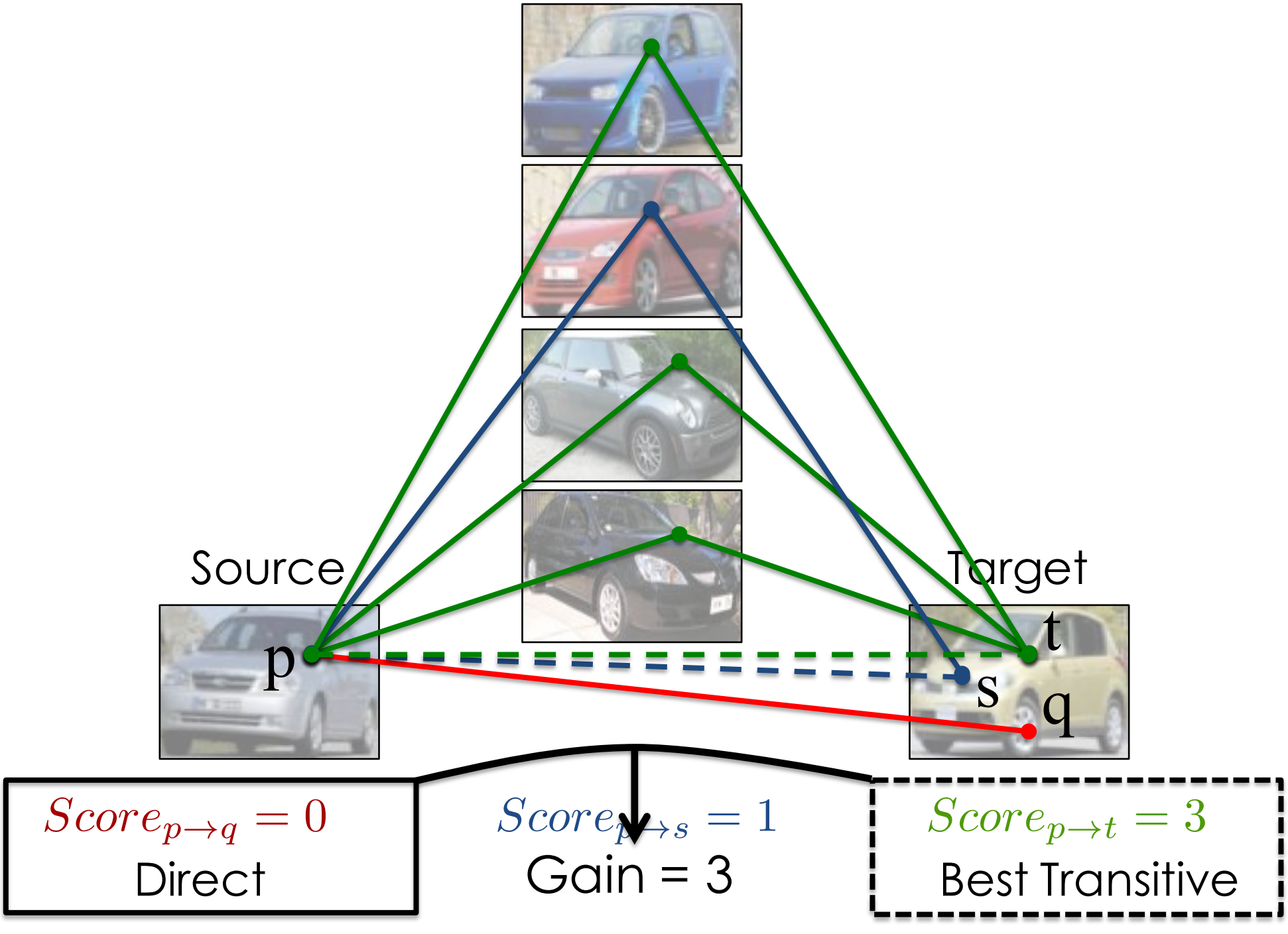
Inter-image Phase

- Update **inconsistent direct** flows with **consistent transitive** flows
- Prioritize by consistency gain



Top-ranked flows

Inter-image Phase

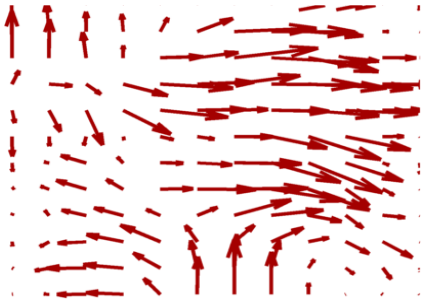


Intra-image Phase

Update flows lacking good transitive flows by **proximity** and **consistency**

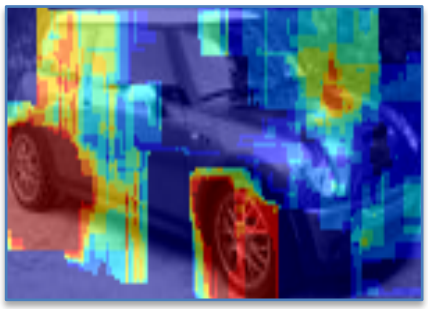
$$T_{ij}^{pq} \leftarrow \frac{1}{Z} \sum_{p' \in I_i} T_{ij}^{p'q'} g_{\sigma_s}(\|x_{p'} - x_p\|) h_{\sigma_c}(\mathcal{C}(T_{ij}^{p'q'}) - \mathcal{C}(T_{ij}^{pq}))$$

Intra-image flows



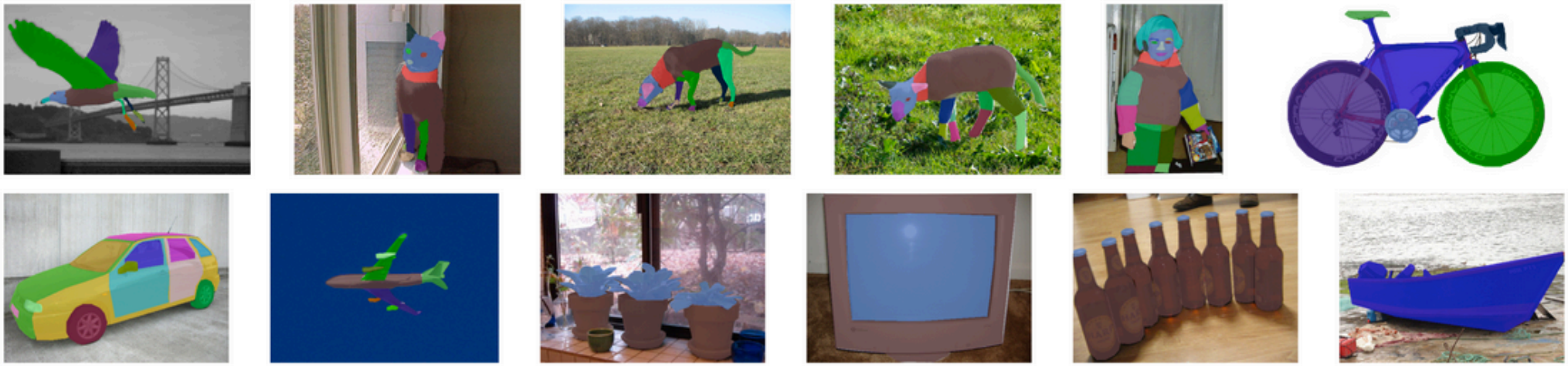
Spatial weight

Consistency weight



Evaluation: Part and Keypoint Matching

- **PASCAL-Part** (Chen et al., CVPR'14): Part segment annotations for PASCAL objects
- **PASCAL3D+** (Xiang et al., WACV'14): Keypoint annotations for 12 rigid categories



Part segment matching

Source Image

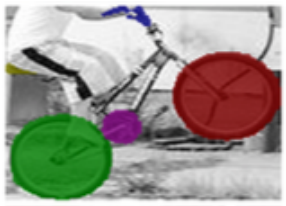
Target Image

Source Mask | Congeal | RASL | Col. Flow | DSP | Ours | Target Mask

Part segment matching

Source Image

Target Image



Source Mask

Congeal

RASL

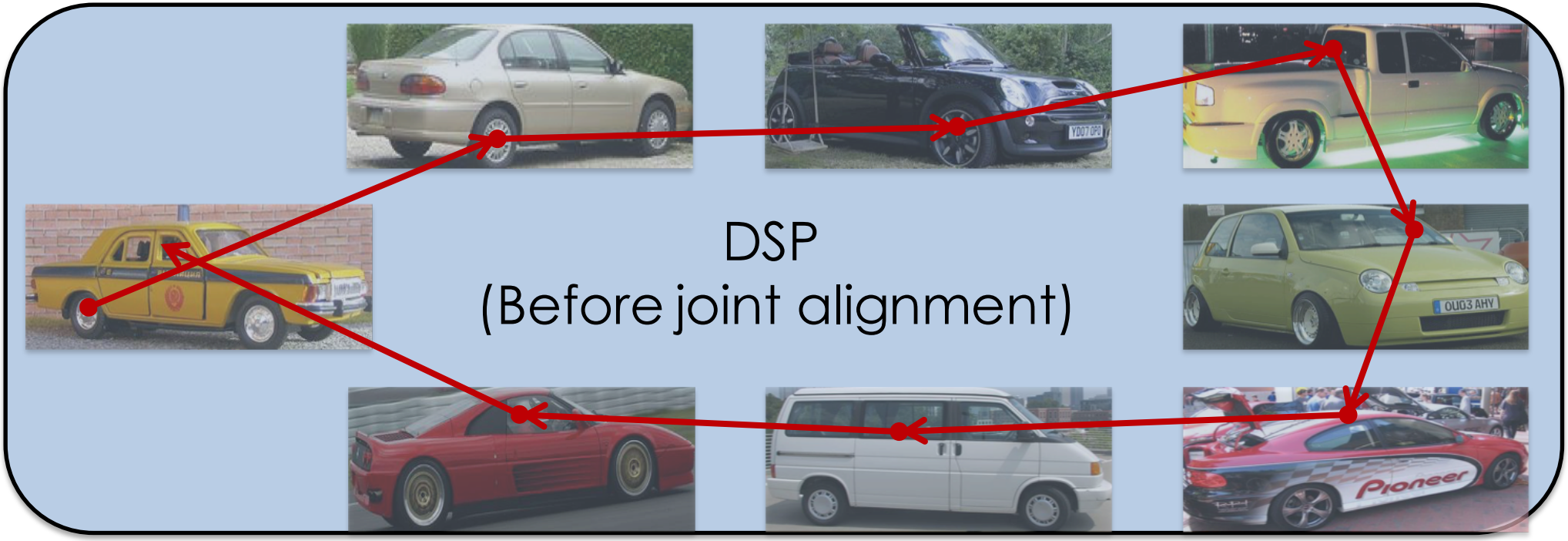
Col. Flow

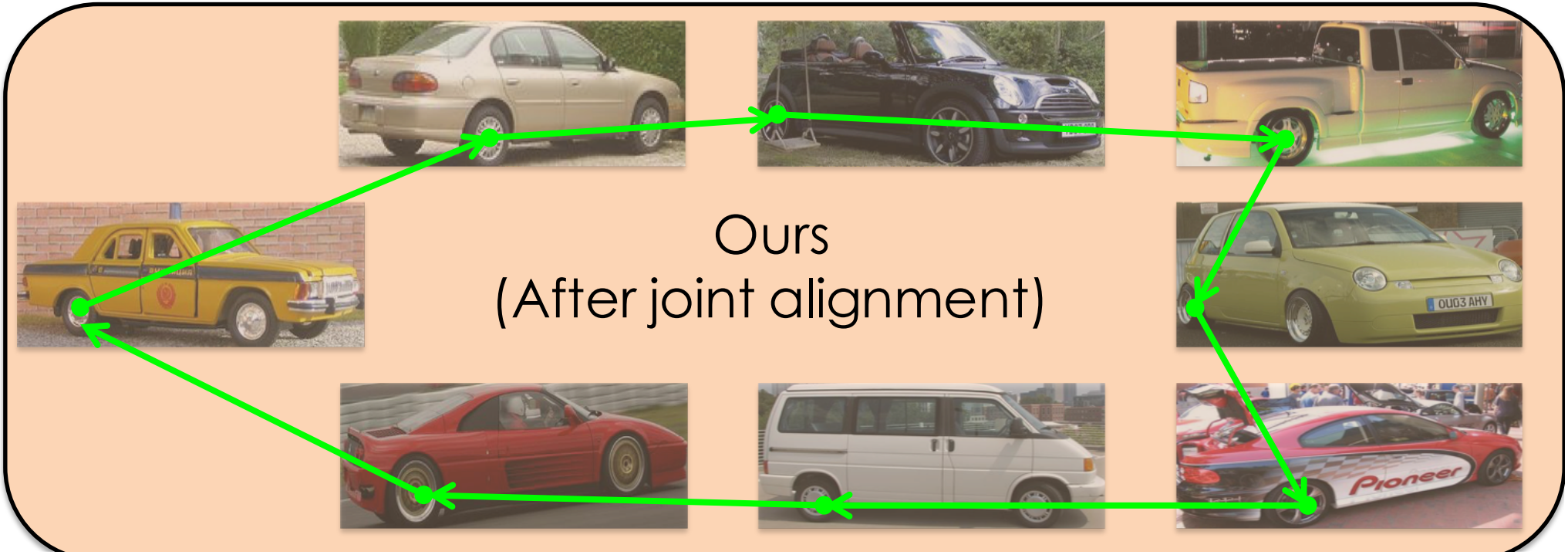
DSP

Ours

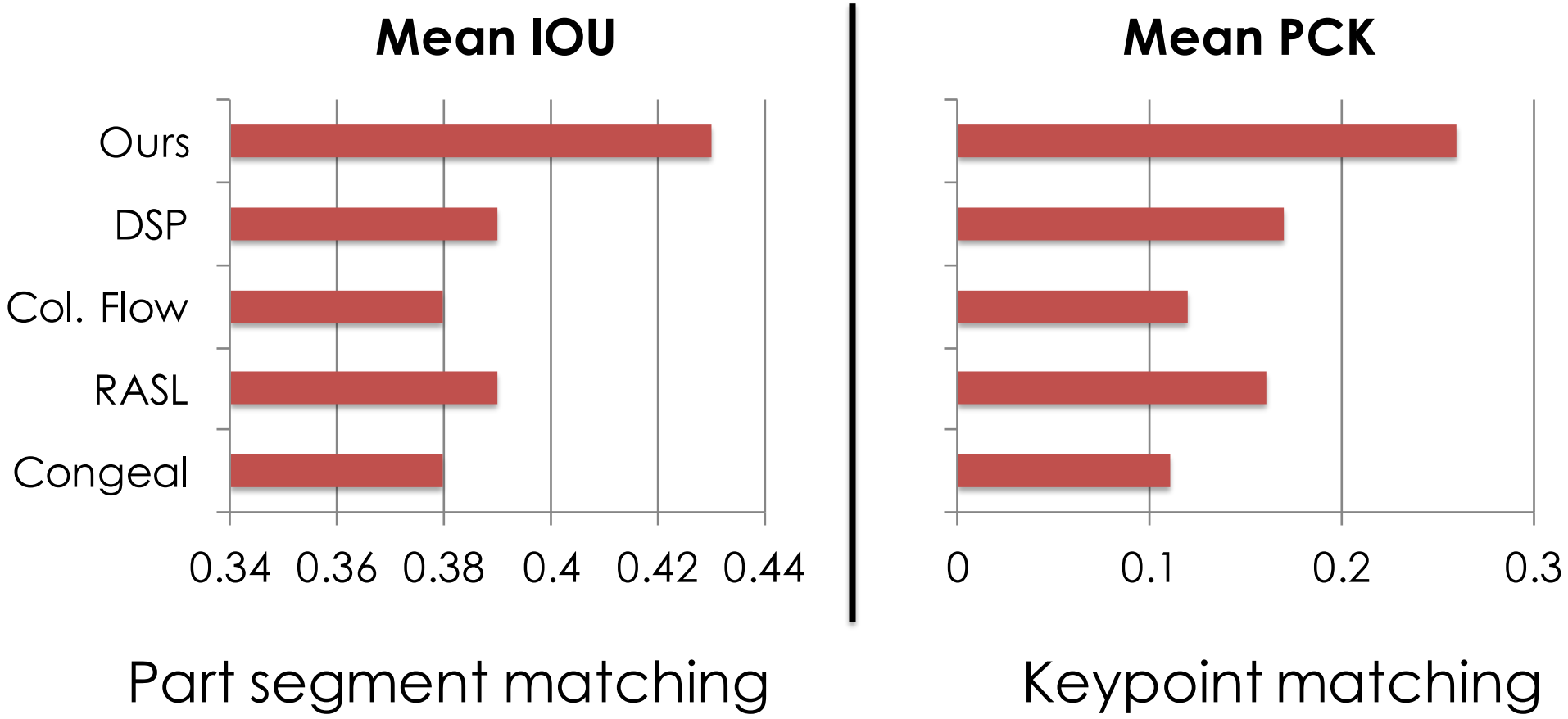
Target Mask

Keypoint Trajectories





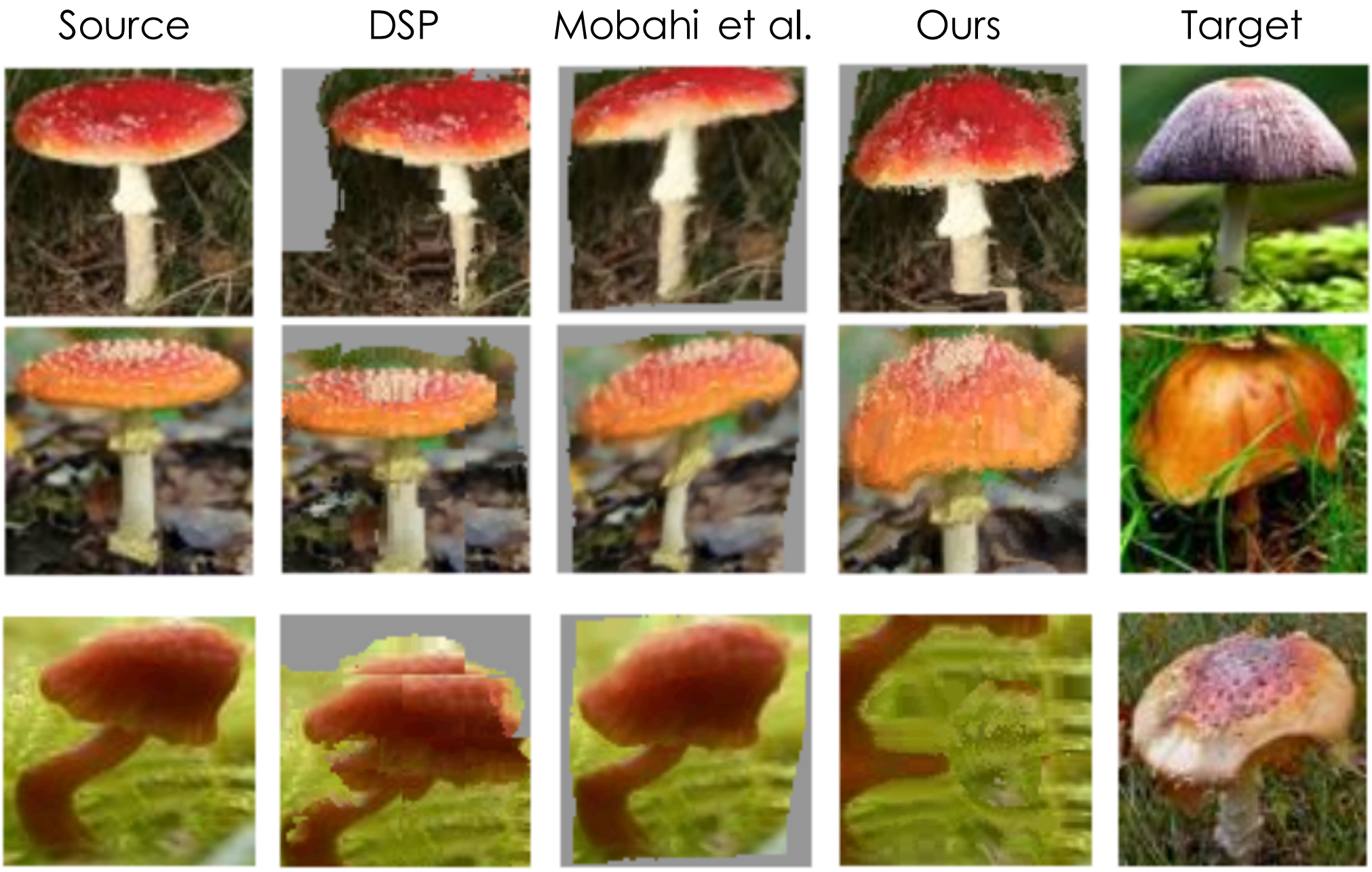
Quantitative Benchmark



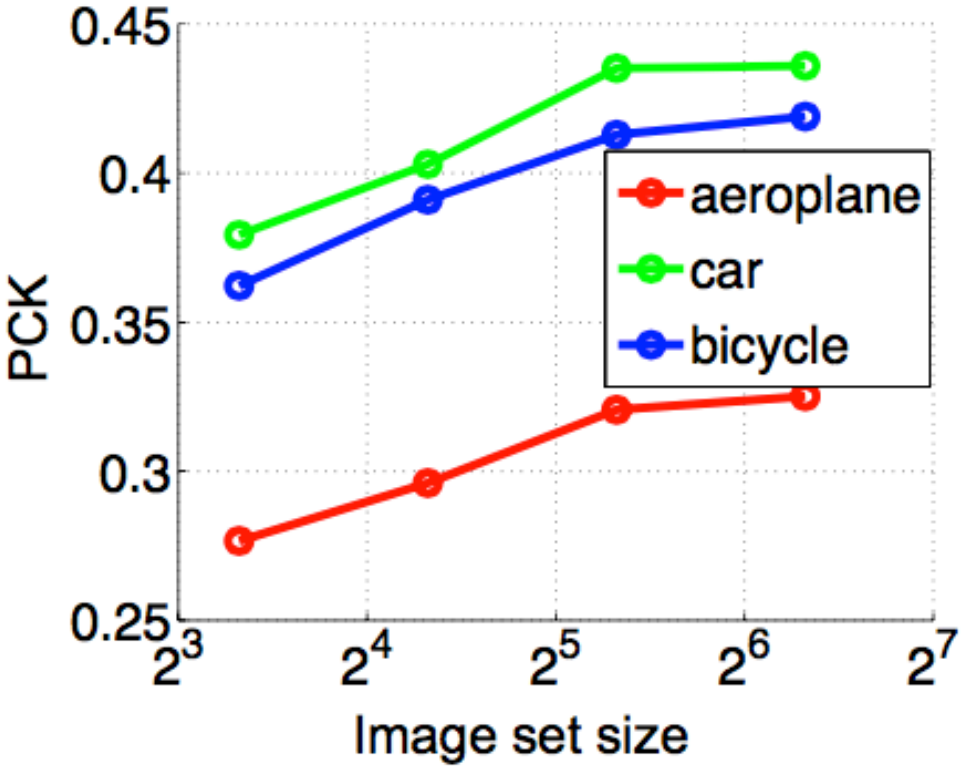
Part segment matching

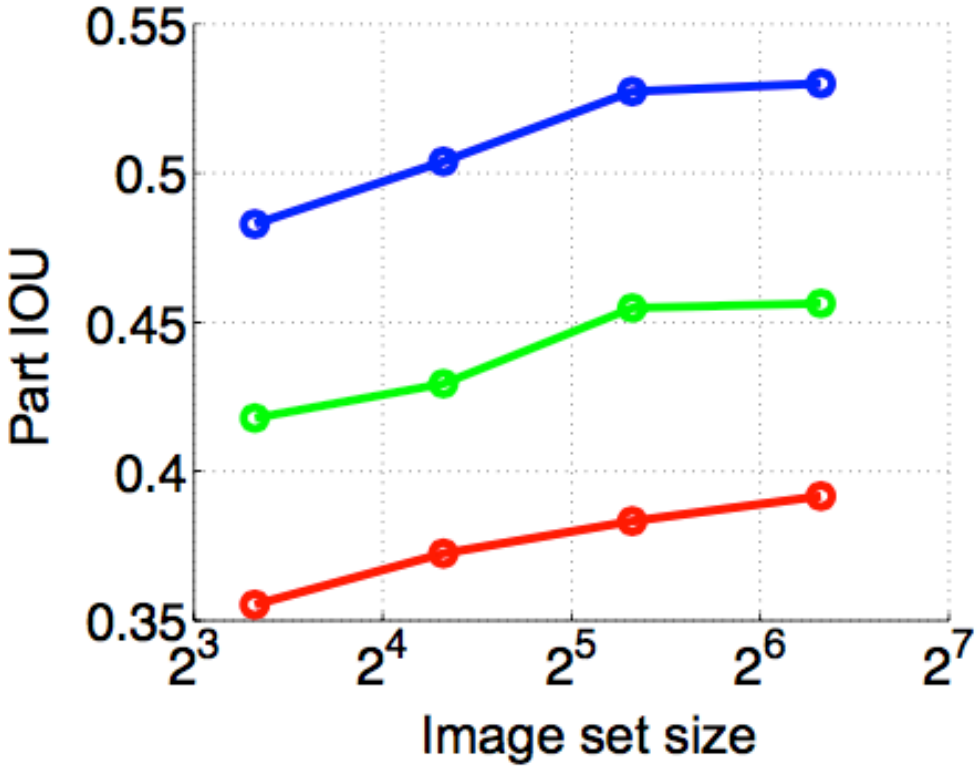
Keypoint matching

Evaluation: Shape Warping



More data $\Rightarrow$ better correspondences





Application: Image Edit Propagation

Take-home Message

- **More Data Wins:** Joint alignment better than Pairwise alignment

- **Consistency as supervision:** All good flows are consistent; each bad flow is bad in its own way.

- **Limitations:**
  - Not globally optimal
  - Slow