

Object Scene Flow

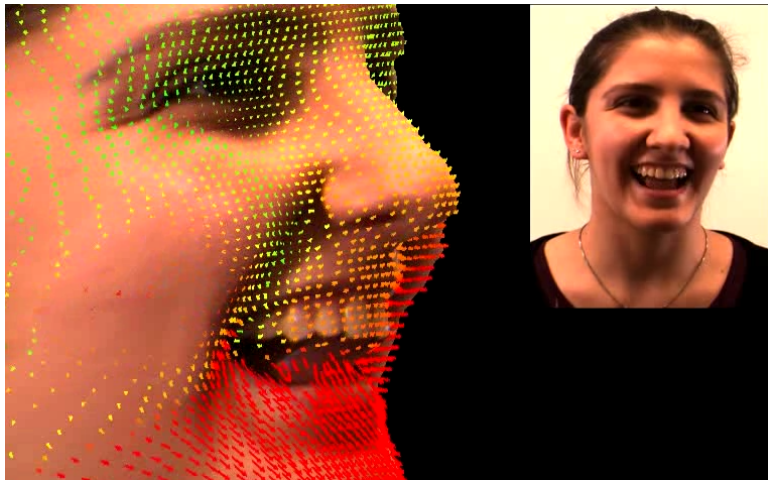


Andreas Geiger
MPI Tübingen

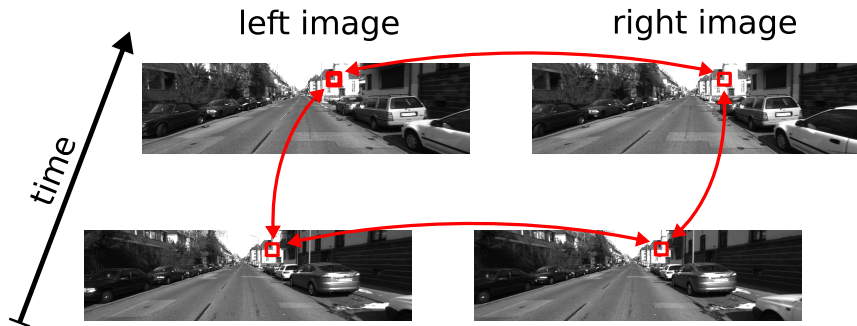
Moritz Menze
University of Hannover

What is Scene Flow?

“Scene flow is a dense three-dimensional vector field defined for each point on every surface in the scene” [Vedula et al. 2005]



Scene Flow



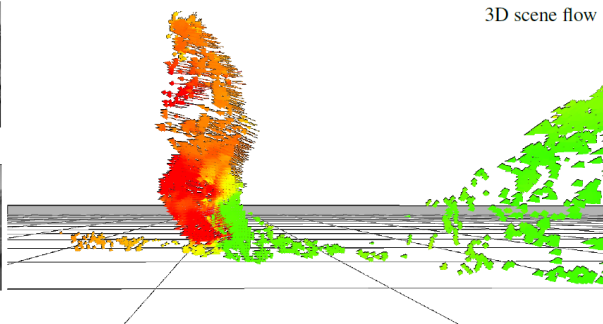
Application: Autonomous Driving



left image at time t



left image at time $t + 1$



[Wedel et al. 2010]

Related Work: Methods

Variational Methods

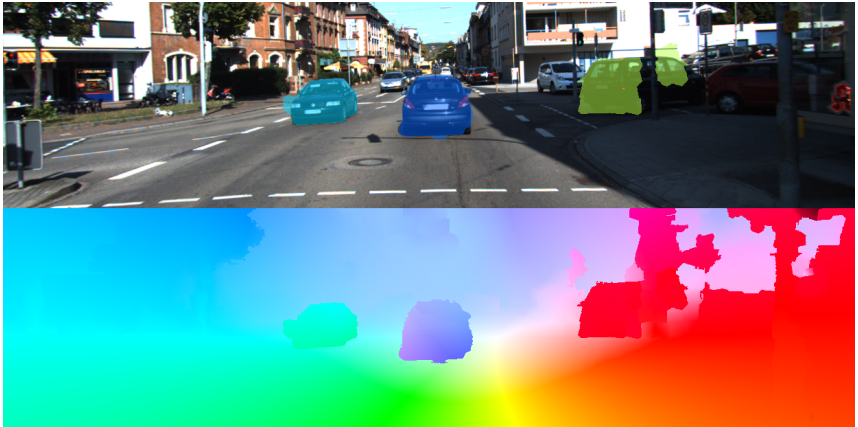
- S. Vedula, P. Rander, R. Collins, and T. Kanade.
Three-dimensional scene flow. PAMI, 2005.

Segment Based (Local Rigidity)

- C. Vogel, K. Schindler, and S. Roth.
Piecewise rigid scene flow. ICCV, 2013.



“Most of the **structures** in the visual world are rigid or at least nearly so.” [David Marr]



This Work

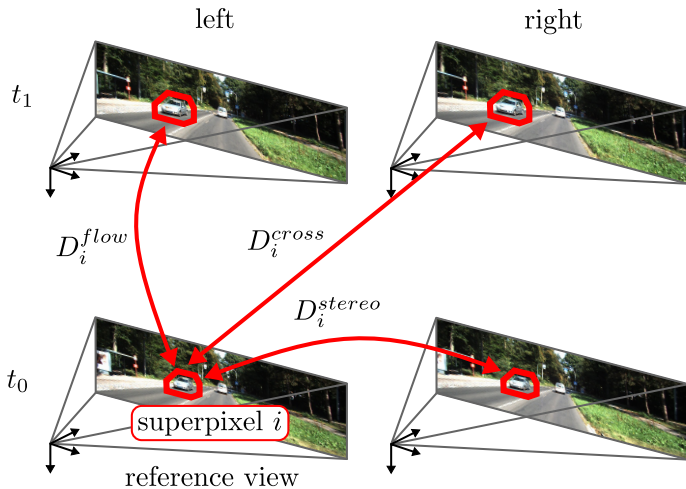
Observation:

- Many scenes decompose into small number of rigid objects
- Objects can be described by their shape and rigid motion
- Dramatic reduction in the number of parameters:

$$4 \times N_{\text{Superpixels}} + 6 \times N_{\text{Objects}} \ll 9 \times N_{\text{Superpixels}}$$

Object Scene Flow

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- Let $\mathcal{S}$ and $\mathcal{O}$ denote the set of superpixels and objects
- Superpixel $i \in \mathcal{S}$: $\mathbf{s}_i = (\mathbf{n}_i, k_i)^T$
 - Normal $\mathbf{n}_i$ ($\mathbf{n}_i^T \mathbf{x} = 1$)
 - Object index k_i
- Object $i \in \mathcal{O}$: $\mathbf{o}_i \in SE(3)$
 - Rigid motion parameters
- Discrete-Continuous CRF Energy:

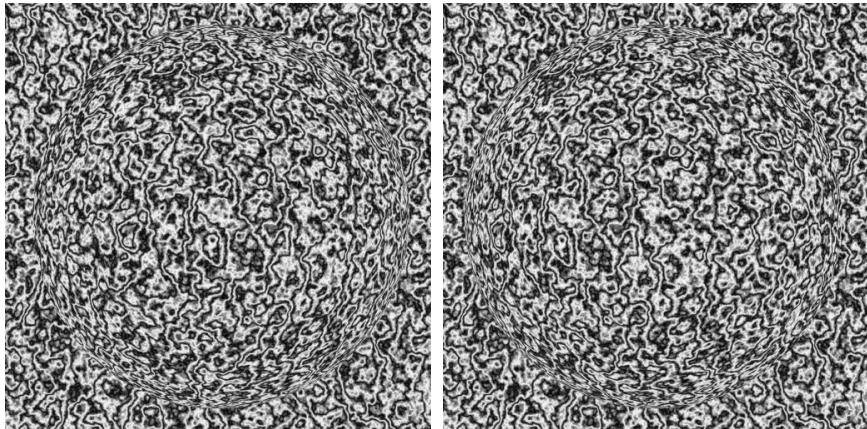
$$E(\mathbf{s}, \mathbf{o}) = \sum_{i \in \mathcal{S}} \underbrace{\varphi_i(\mathbf{s}_i, \mathbf{o})}_{\text{data}} + \sum_{i \sim j} \underbrace{\psi_{ij}(\mathbf{s}_i, \mathbf{s}_j)}_{\text{smoothness}}$$

- superpixel variables $\mathbf{s} = \{\mathbf{s}_i | i \in \mathcal{S}\}$
- object variables $\mathbf{o} = \{\mathbf{o}_i | i \in \mathcal{O}\}$
- Minimize $E(\mathbf{s}, \mathbf{o})$ using MP-PBP

Scene Flow Dataset

Related Work: Datasets with Ground Truth

Sphere Sequence [Huguet et al., ICCV 2007]



Related Work: Datasets with Ground Truth

Auckland Synthetic Street Scene [Vaudrey et al., IVCNZ 2008]



Related Work: Datasets with Ground Truth

Middlebury Stereo Dataset [Scharstein et al., IJCV 2002]



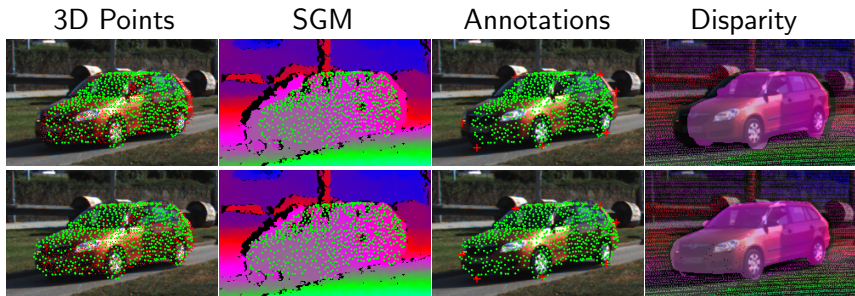
Related Work: Datasets with Ground Truth

KITTI Stereo and Optical Flow [Geiger et al., CVPR 2012]



Scene Flow Dataset

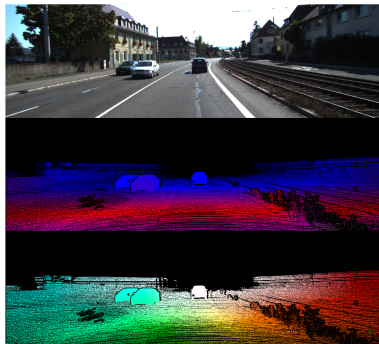
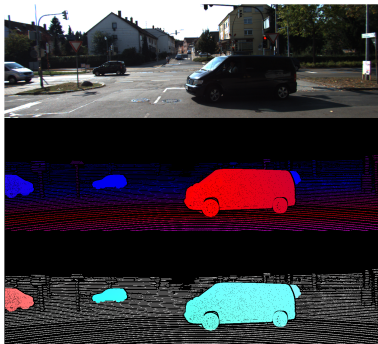
- Accumulate static background from 7 laser scans (ICP+GPS)
- Fit a 3D CAD model to each moving object ...



- ... using non-linear least squares minimization:

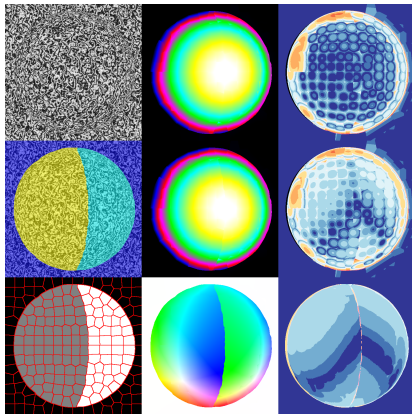
$$E(\xi) = \sum_{t \in \{1,2\}} E_t^{3D} + E_t^{SGM} + E_t^{2D}$$

Scene Flow Dataset



Experimental Results

Results on Synth. Sphere [Huguet et al., ICCV 2007]



	Valgaerts	Huguet	Wedel	Vogel	Ours
RMSE 2D Flow	0.63	0.69	0.77	0.63	0.55
RMSE Disparity	3.8	3.8	10.9	2.84	2.58
RMSE Scene Flow	1.76	2.51	2.55	1.73	0.75

Results on Proposed Scene Flow Dataset

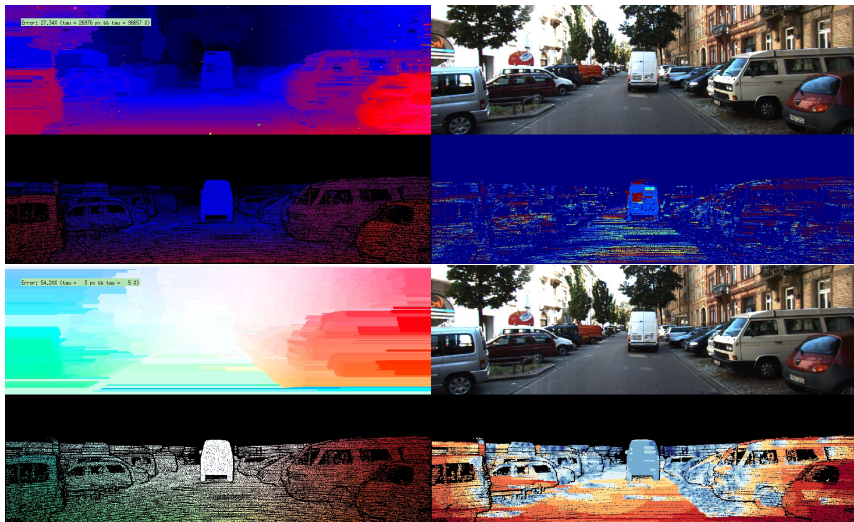
	<i>bg</i>	<i>fg</i>	<i>bg+fg</i>
Huguet et al.	67.94	69.63	68.25
GCSF (Cech et al.)	53.20	66.39	55.57
SGM + LDOF (Brox et al.)	44.38	54.77	46.25
SGM + Classic+NL (Sun et al.)	38.65	60.72	42.62
SGM + Sphere Flow (Hornacek)	23.51	50.48	28.36
PRSF (Vogel et al.)	14.07	48.49	20.26
Object Scene Flow	7.44	45.30	14.25

- Percentage of bad pixels
- D1/D2: disparity error, Fl: flow error, SF: scene flow error
- bg: background, fg: foreground, bg+fg: all image regions

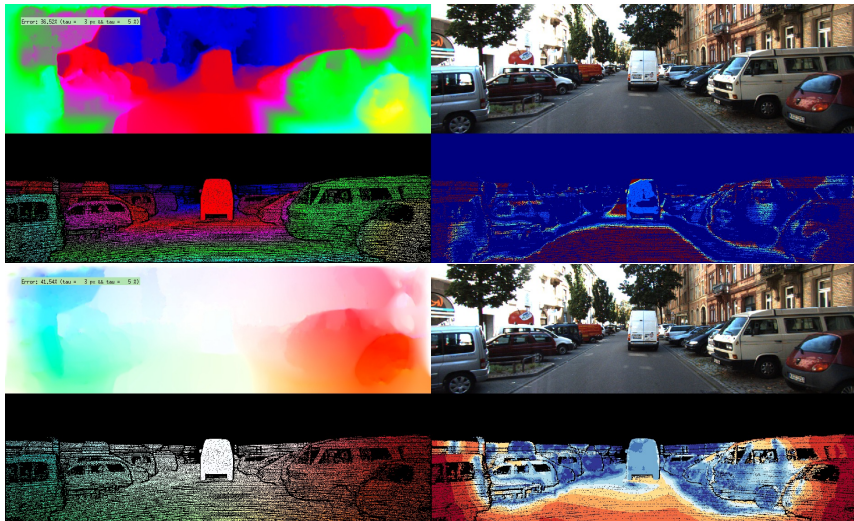
Qualitative Results

- GCSF [Cech et al., CVPR 2011]
- Variational Scene Flow [Huguet et al., ICCV 2007]
- SGM + LDOF [Brox et al., PAMI 2011]
- SphereFlow [Hornacek et al., CVPR 2014]
- PRSF [Vogel et al., ICCV 2013]
- Object Scene Flow

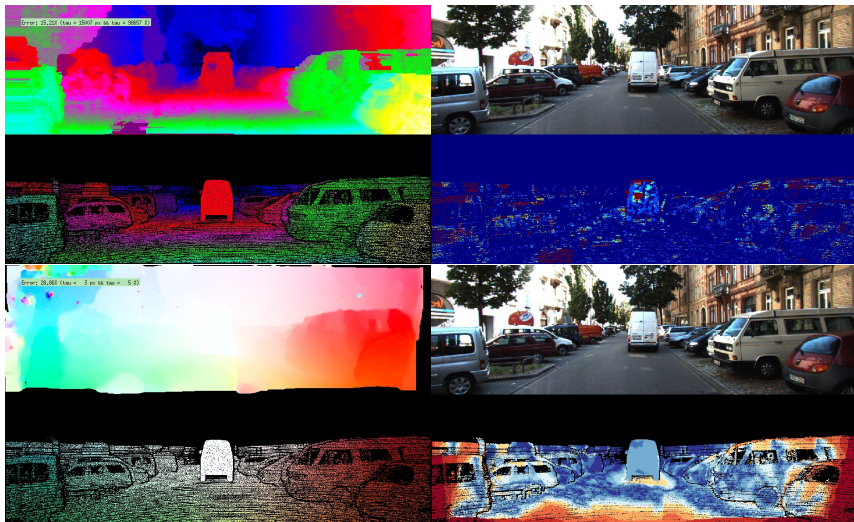
GCSF [Cech et al., CVPR 2011]



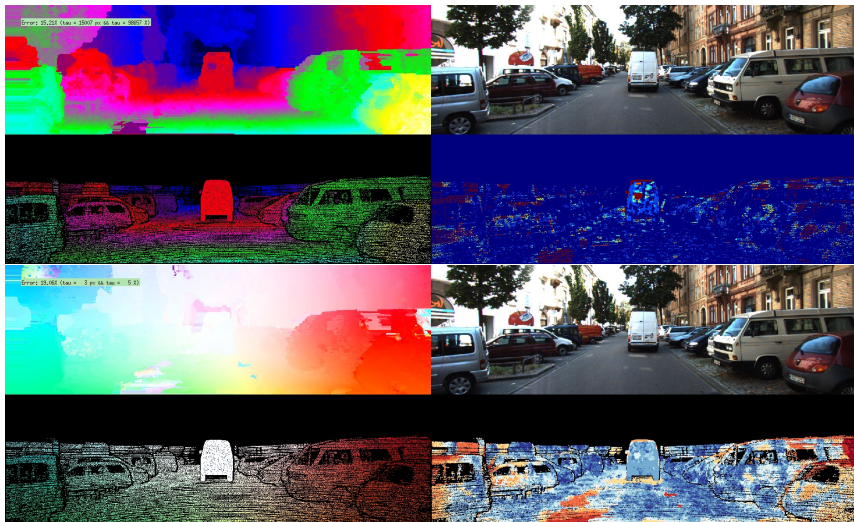
Variational Scene Flow [Huguet et al., ICCV 2007]



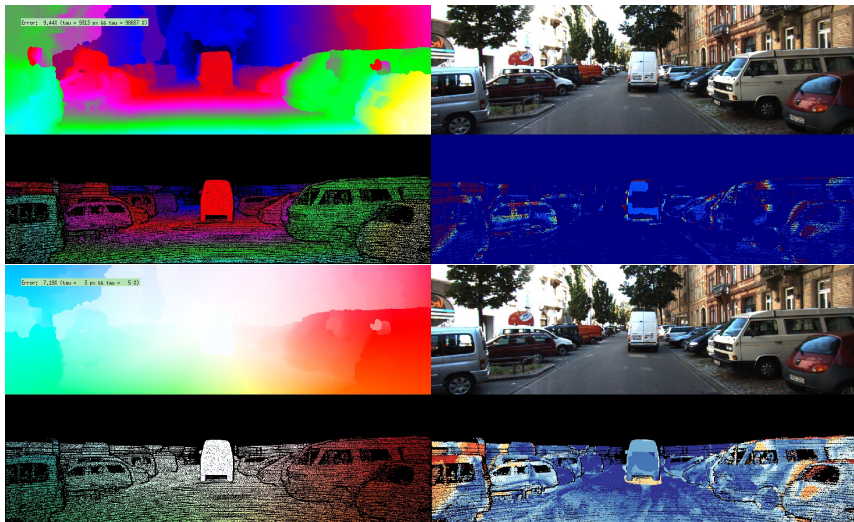
SGM + LDOF [Brox et al., PAMI 2011]



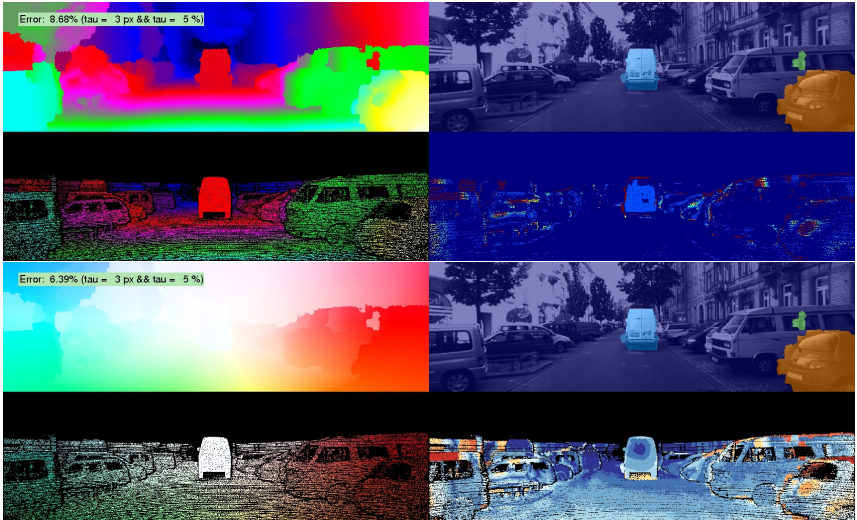
SphereFlow [Hornacek et al., CVPR 2014]



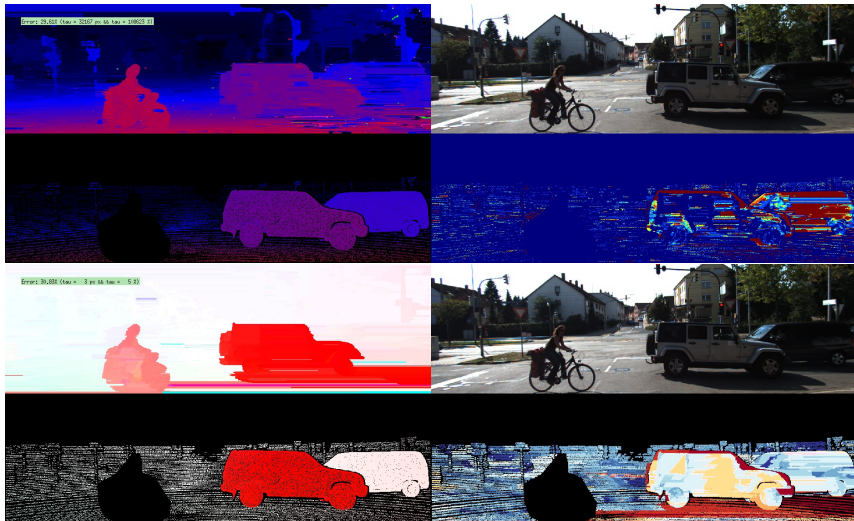
PRSF [Vogel et al., ICCV 2013]



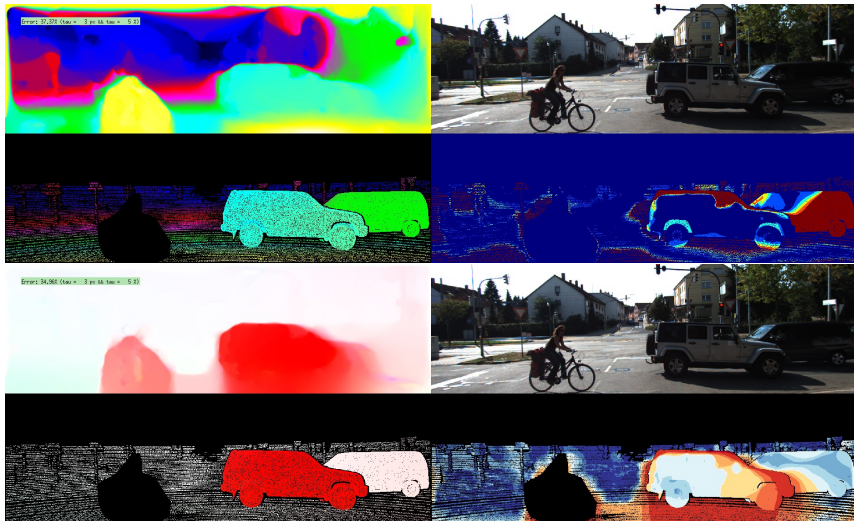
Object Scene Flow



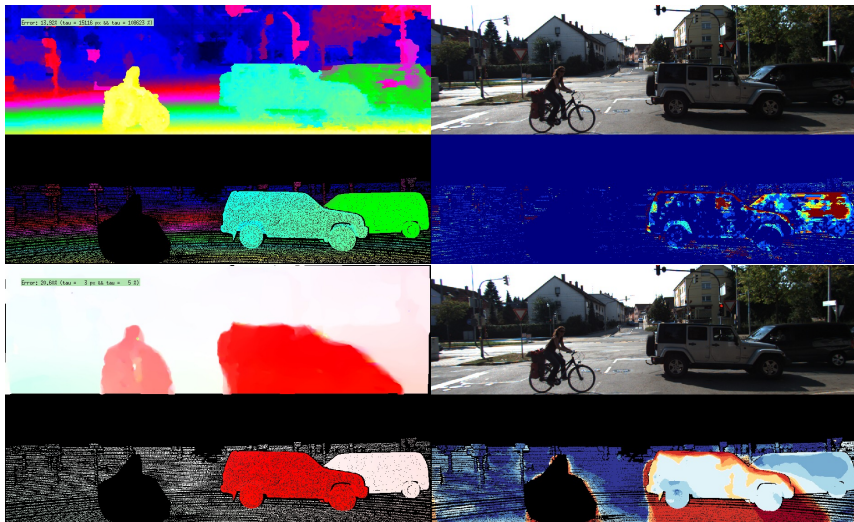
GCSF [Cech et al., CVPR 2011]



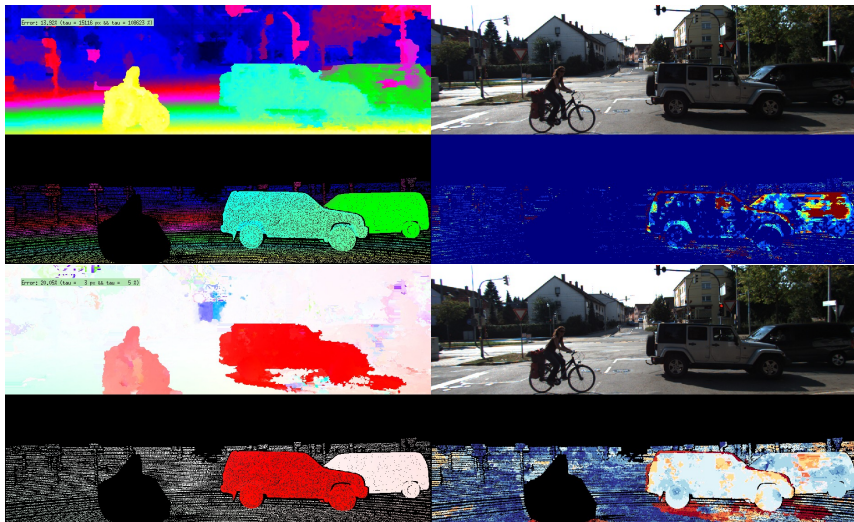
Variational Scene Flow [Huguet et al., ICCV 2007]



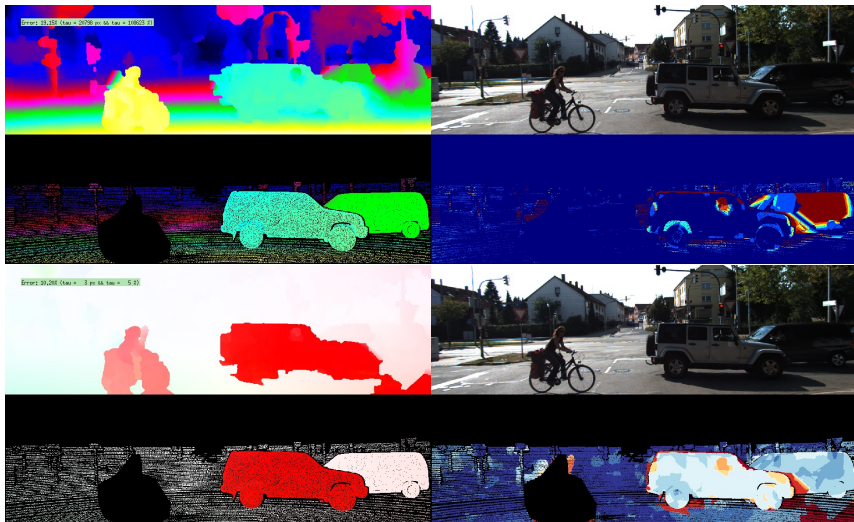
SGM + LDOF [Brox et al., PAMI 2011]



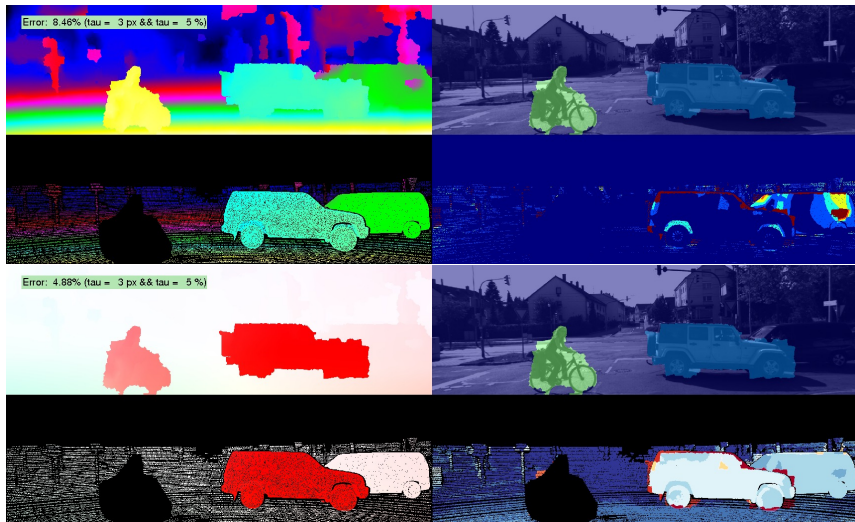
SphereFlow [Hornacek et al., CVPR 2014]



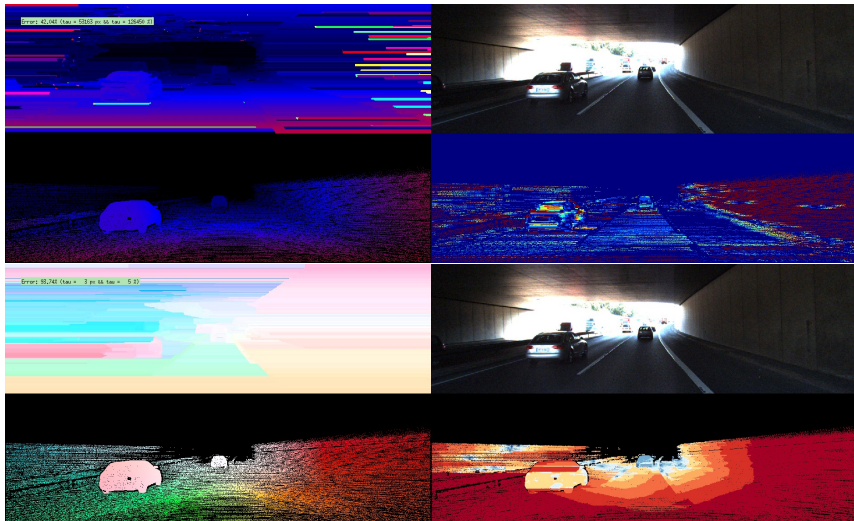
PRSF [Vogel et al., ICCV 2013]



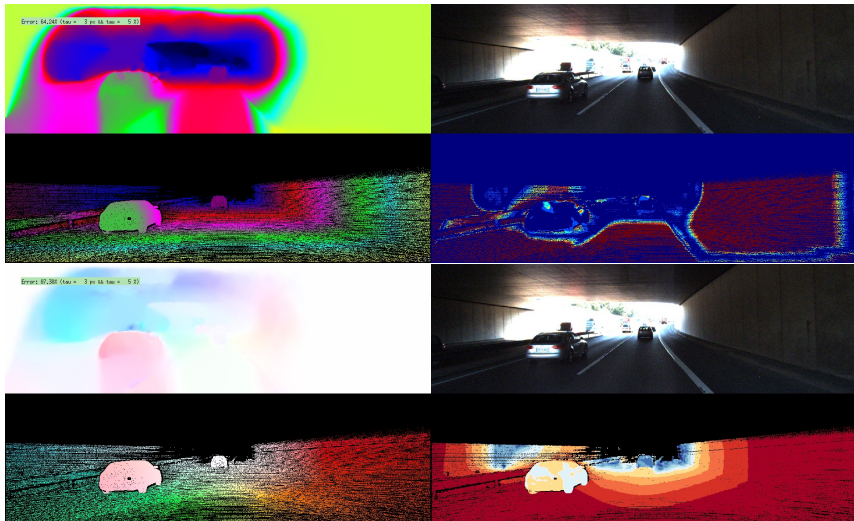
Object Scene Flow



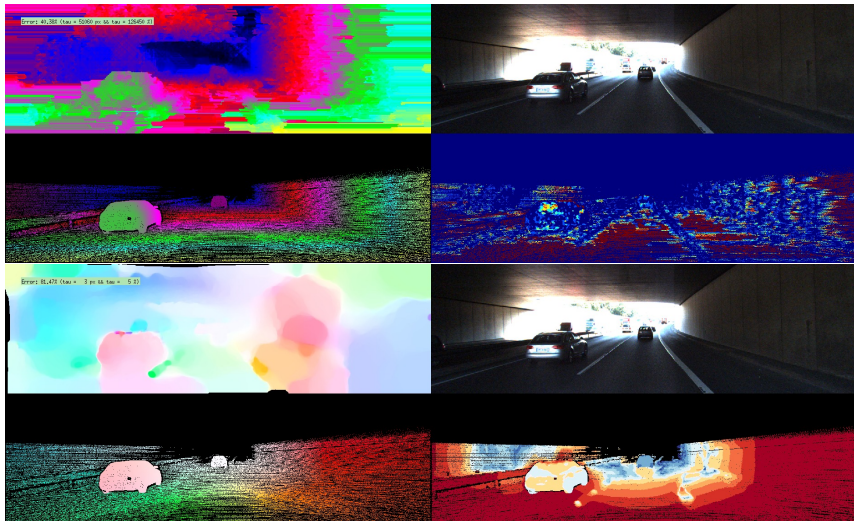
GCSF [Cech et al., CVPR 2011]



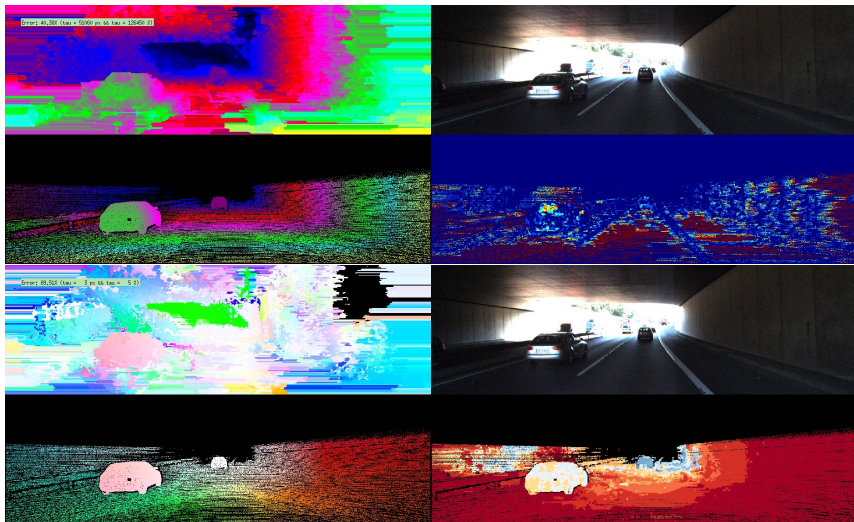
Variational Scene Flow [Huguet et al., ICCV 2007]



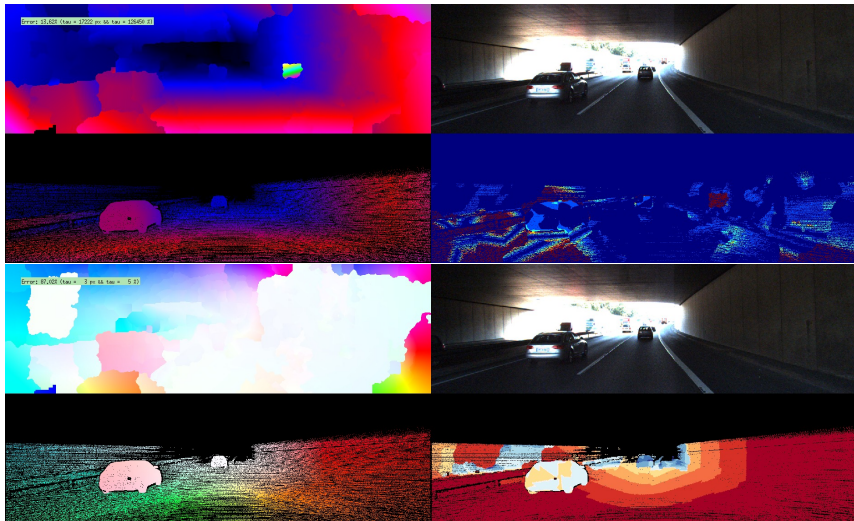
SGM + LDOF [Brox et al., PAMI 2011]



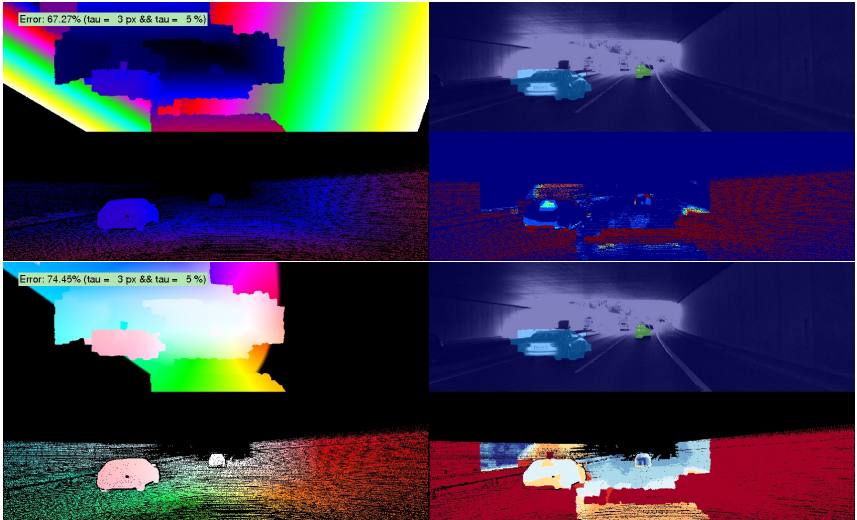
SphereFlow [Hornacek et al., CVPR 2014]



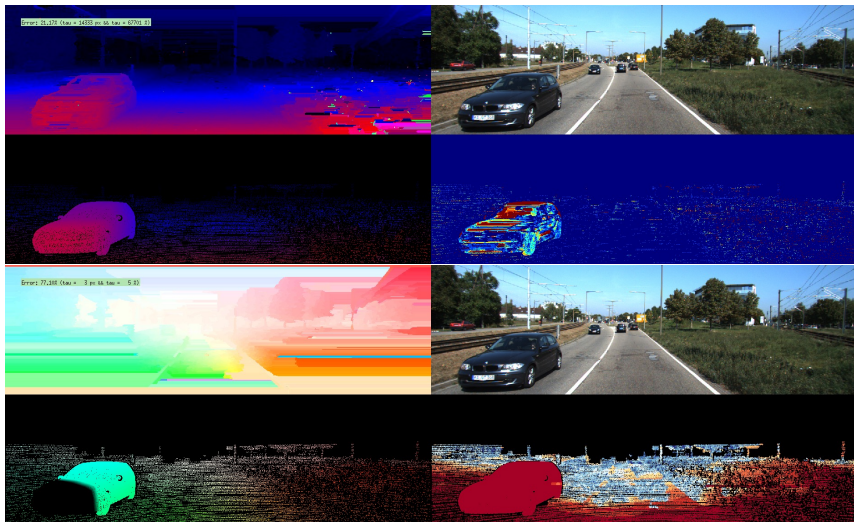
PRSF [Vogel et al., ICCV 2013]



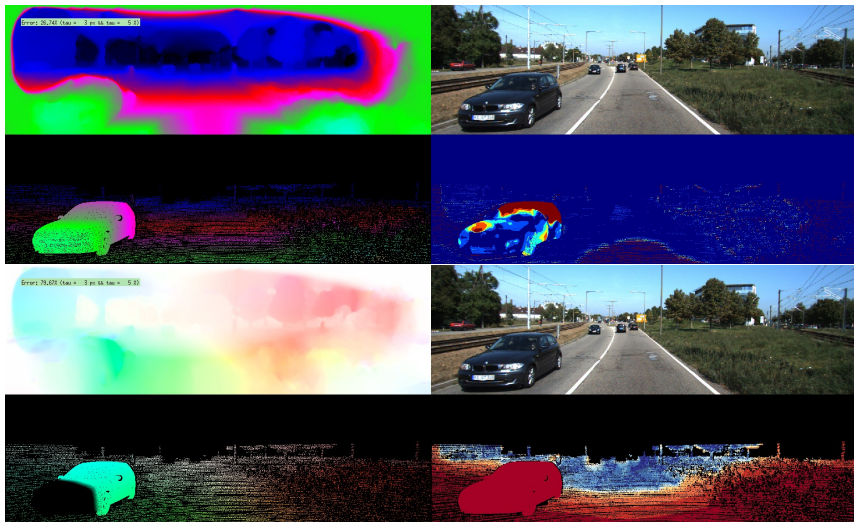
Object Scene Flow



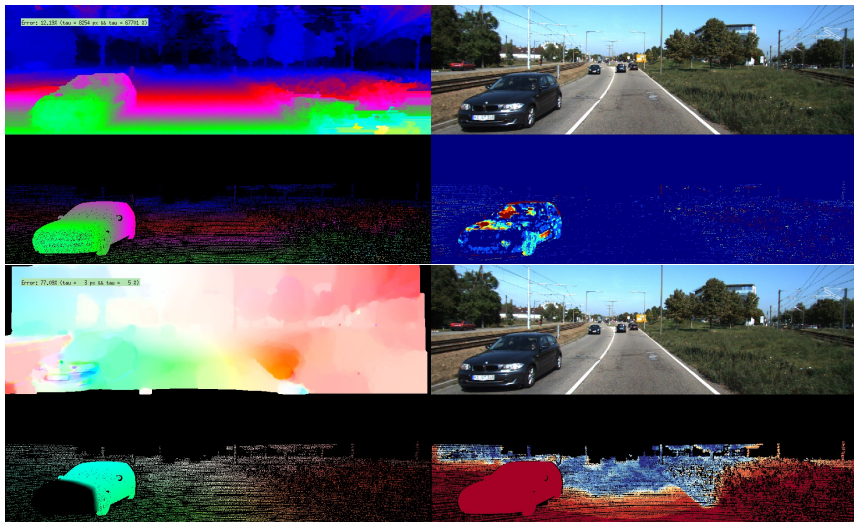
GCSF [Cech et al., CVPR 2011]



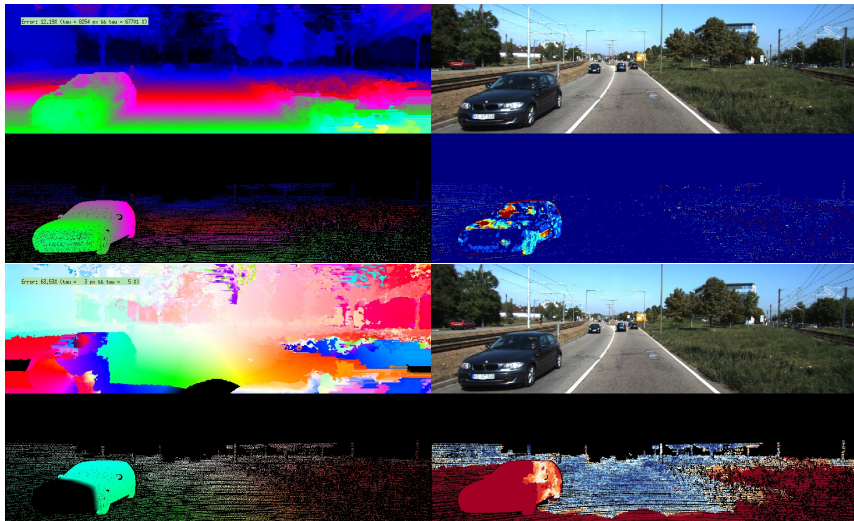
Variational Scene Flow [Huguet et al., ICCV 2007]



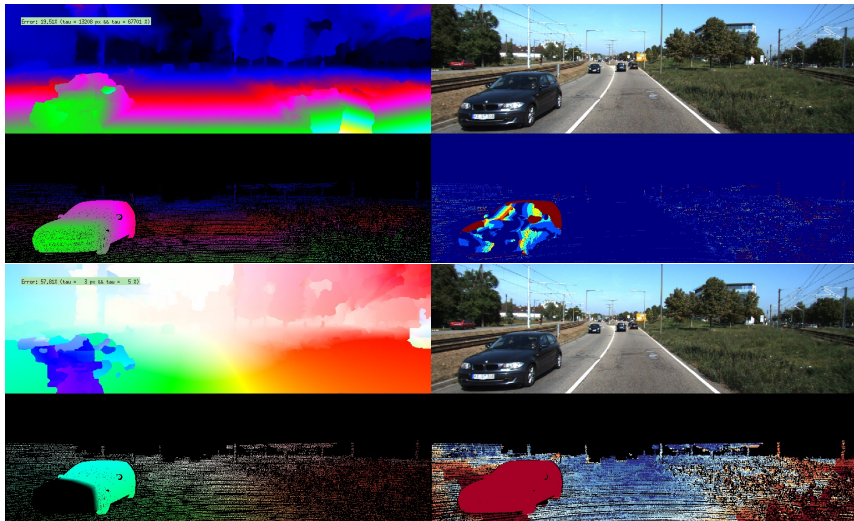
SGM + LDOF [Brox et al., PAMI 2011]



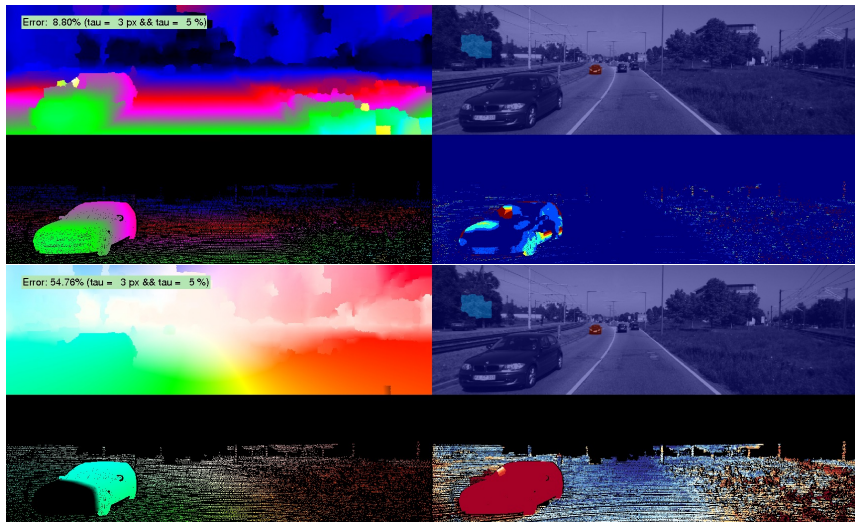
SphereFlow [Hornacek et al., CVPR 2014]



PRSF [Vogel et al., ICCV 2013]



Object Scene Flow



LIBVISO2 [Geiger et al.]

