Slanted Stixels: Representing San Francisco's Steepest Streets

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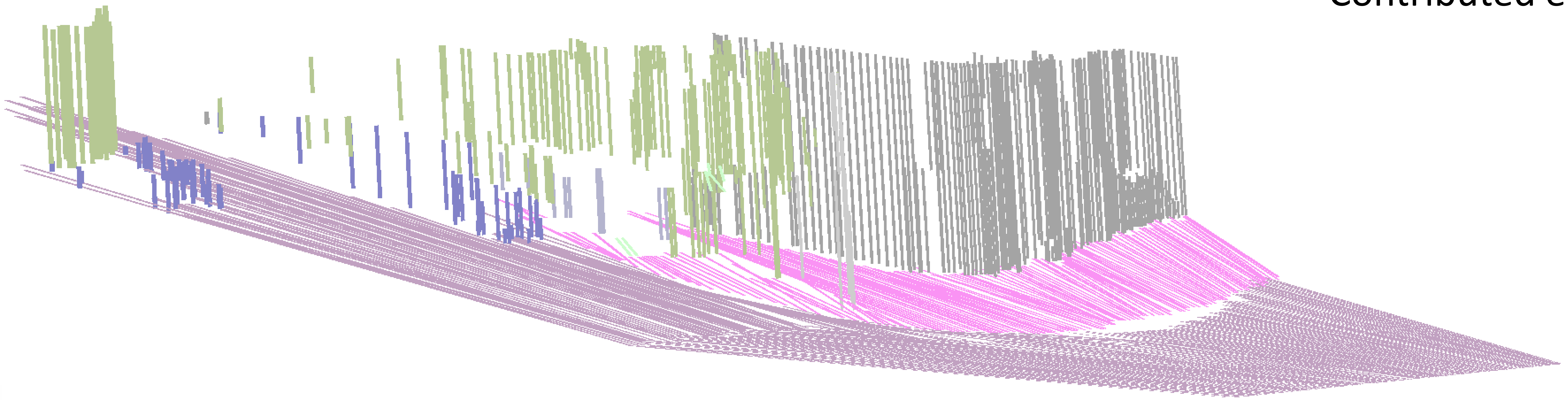
* Contributed equally



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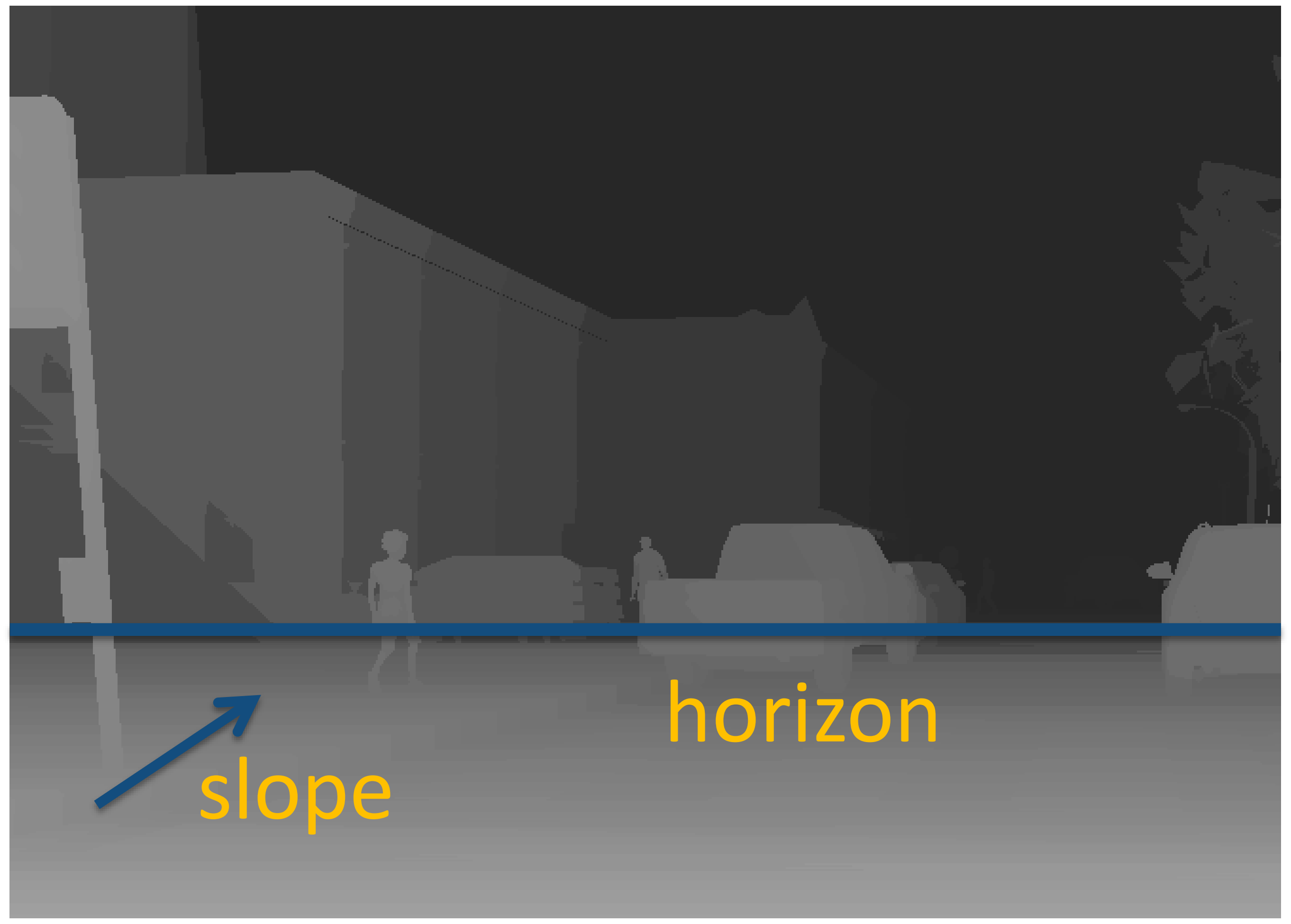
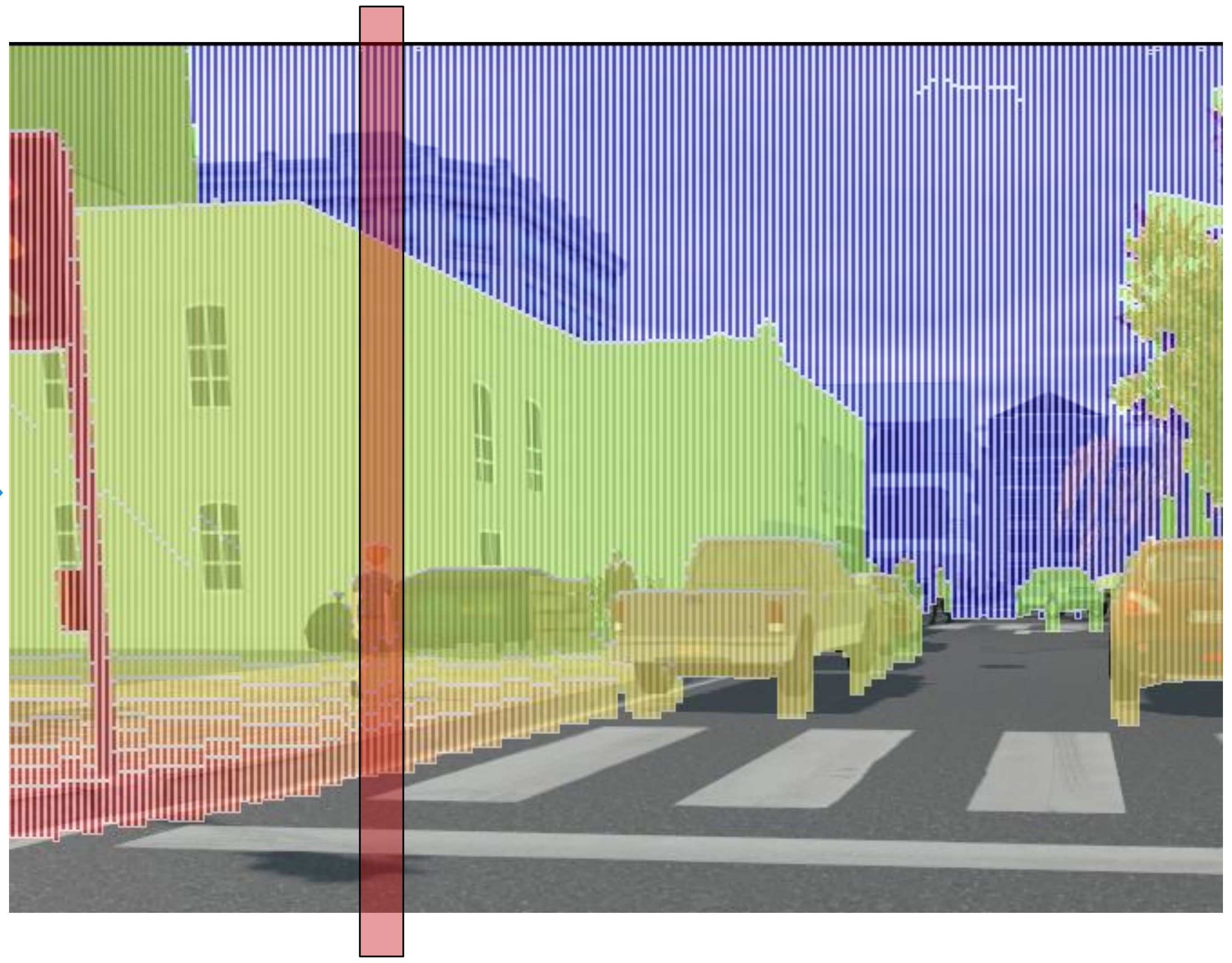
Stixel World: Compact representation of the world

Stereo Images



Stereo + Horizon Line + Road Slope



Stixels

Fixed width stixels, **variable** number of stixels per column

Widespread in stereo vision for automotive industry

Stixel = Stick + Pixel

Motivation & Objectives

Left Image | Original Stixels

Previous work:

- Stixel World [Pfeiffer 2011]
- Semantic Stixels [Schneider 2016]

Problem:

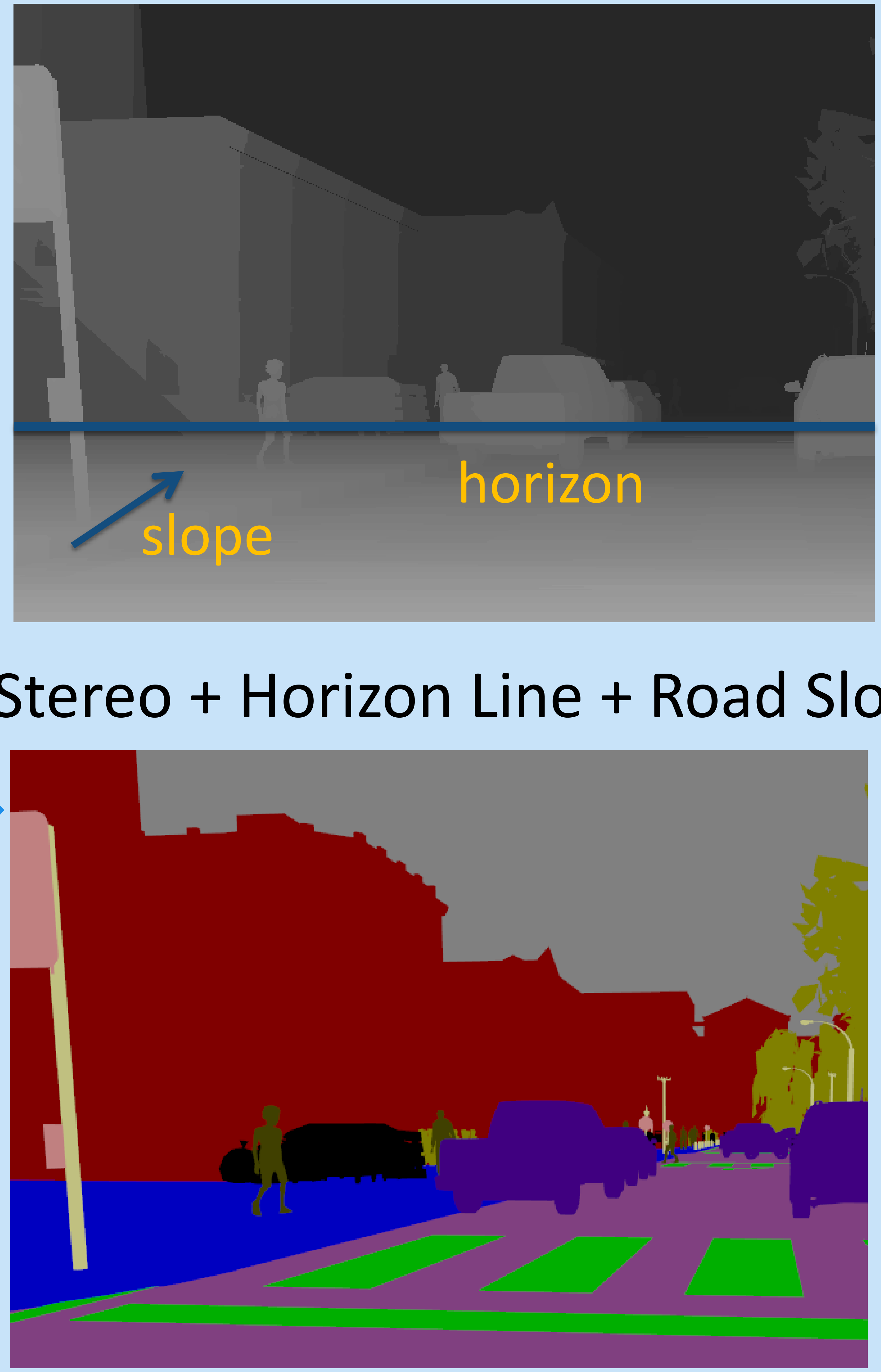
- Slanted roads not well modeled

Contribution:

- New model to represent slanted roads
- Proposal to reduce computational work

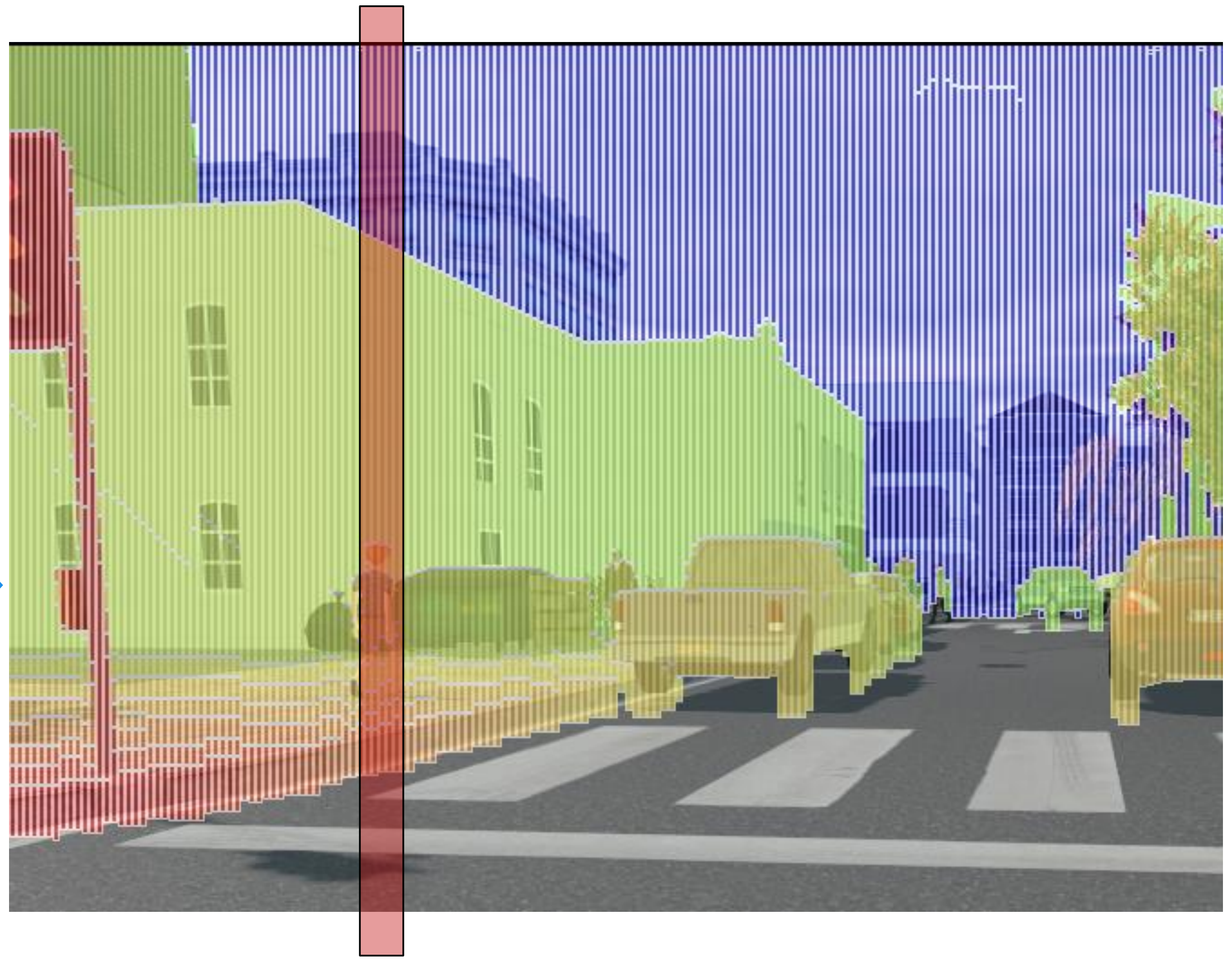
Semantic Stixels: Unified approach

Stereo Images

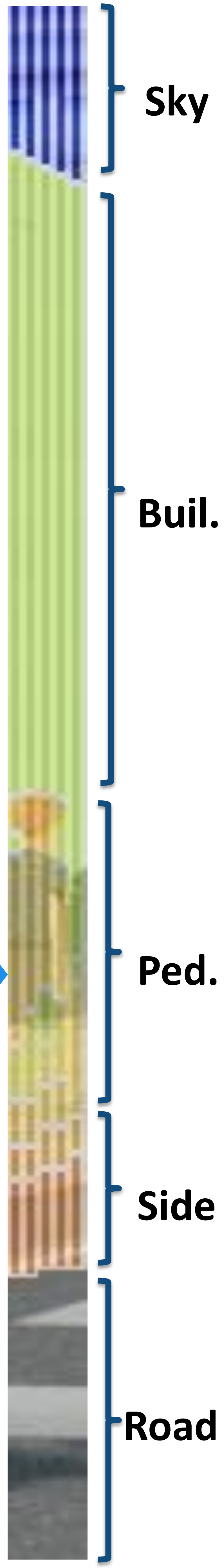


Stereo + Horizon Line + Road Slope

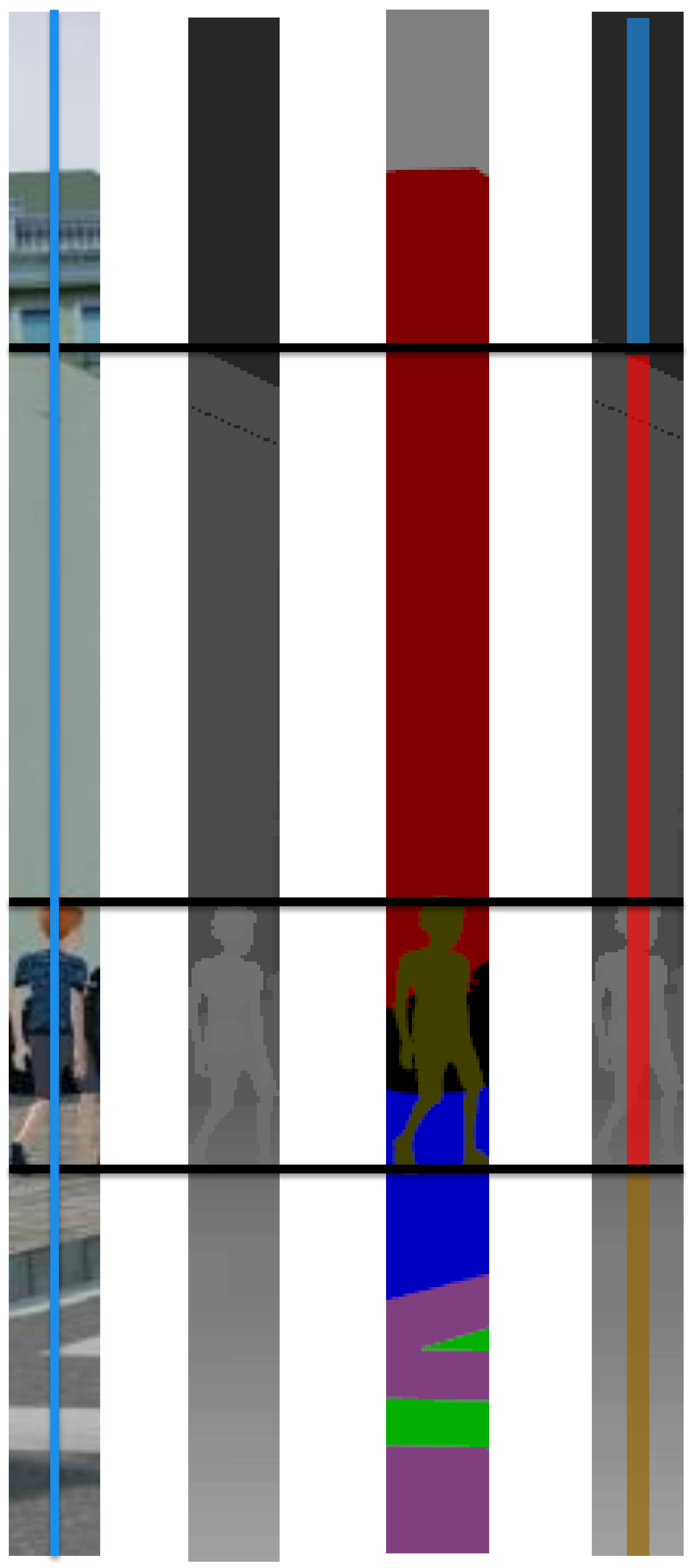
Semantic segmentation



Semantic Stixels



Stixels: Original Model



Stixel models:

Sky:	0 disparity	Assumption: Far away
Object:	Disparity mean	Assumption: Constant distance
Ground:	Precomputed model	Assumption: Constant height

Unified probabilistic approach:

Disparity term considers the accordance of measurements to model

Semantic energy favors classes that fit to the observed input

Enforces constraints:

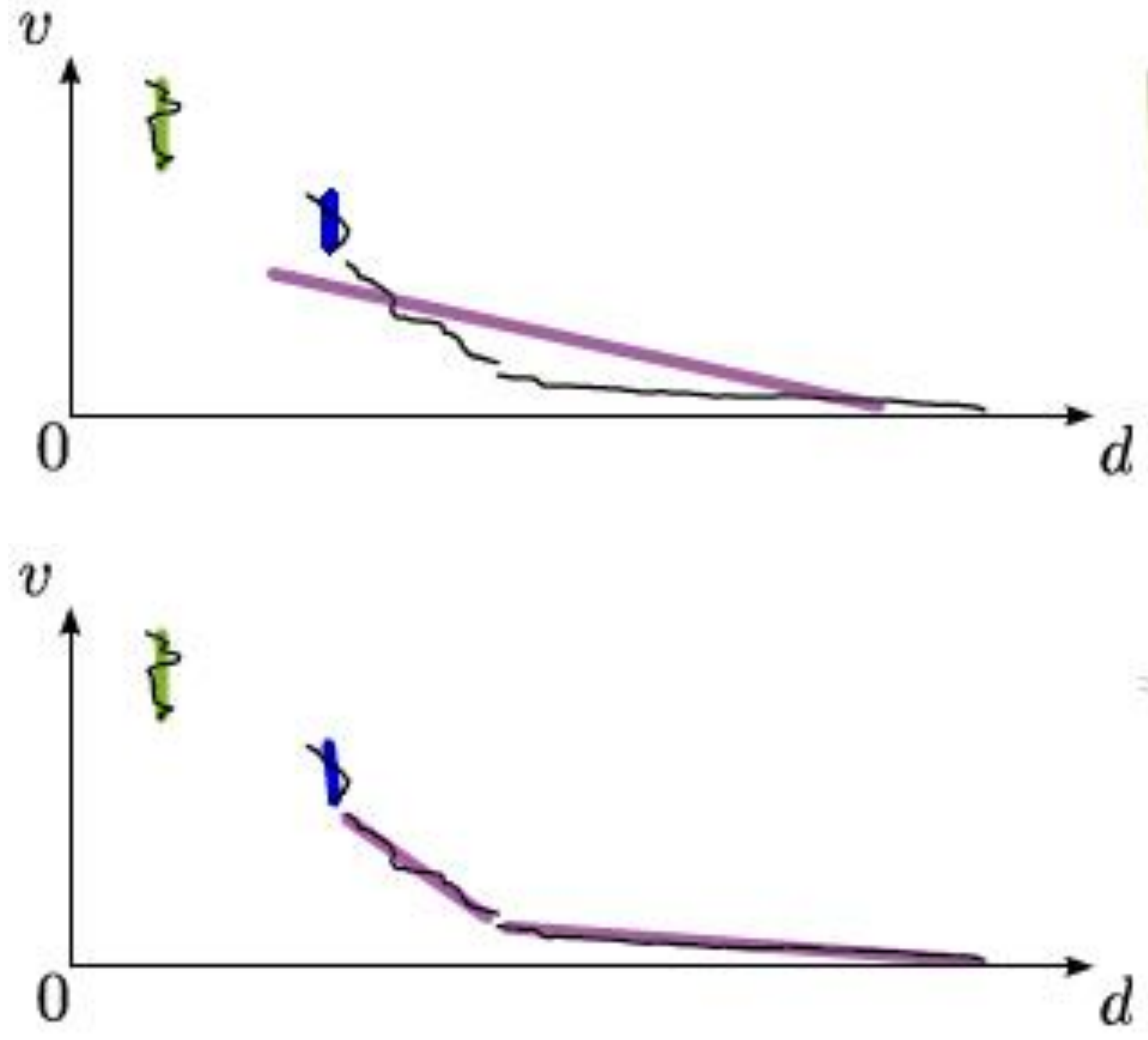
no sky below horizon, no neighbors objects at same disparity …

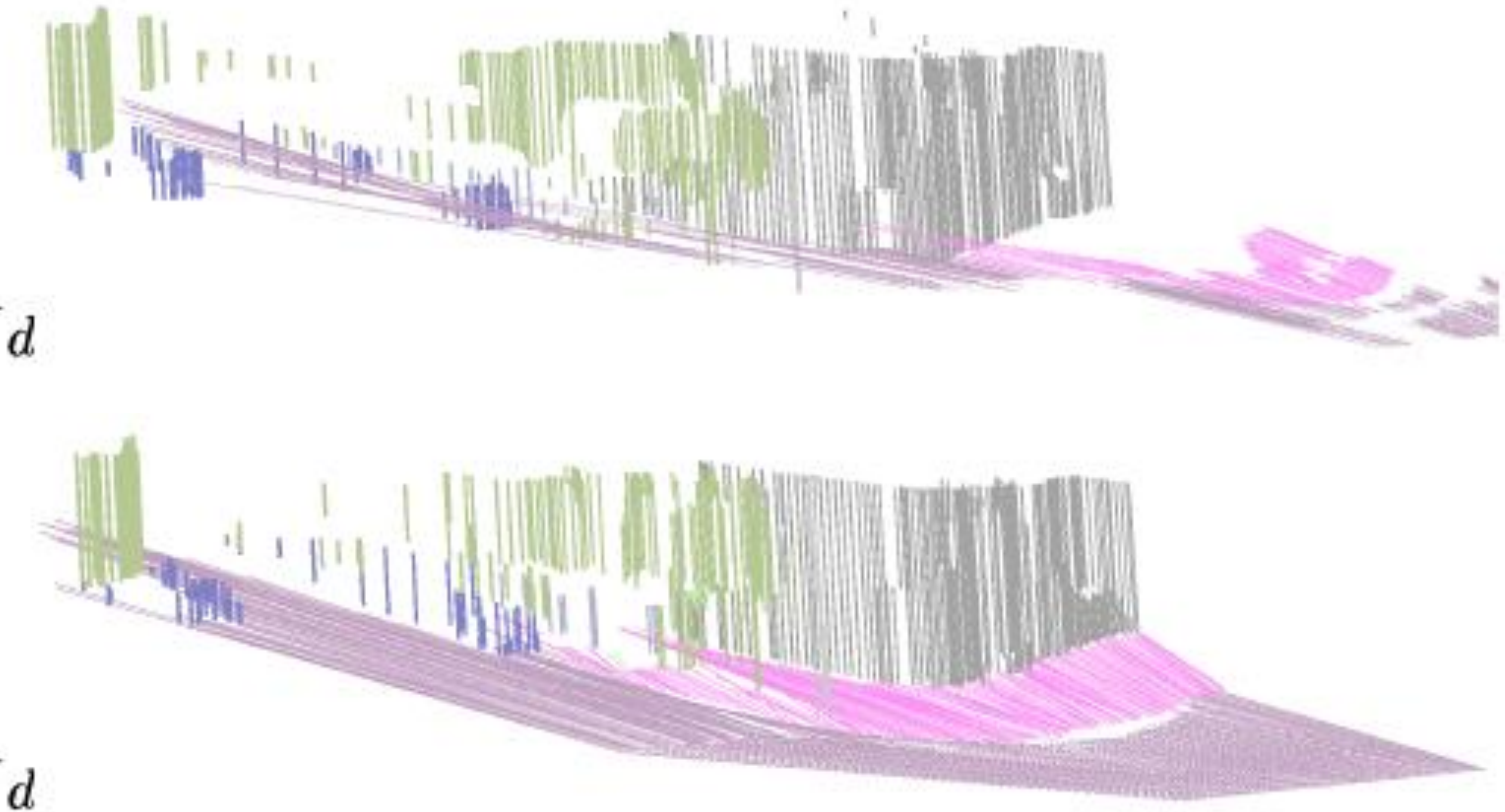
Computed independently for each column

New model: Slanted Stixels

Original Stixels

Slanted Stixels

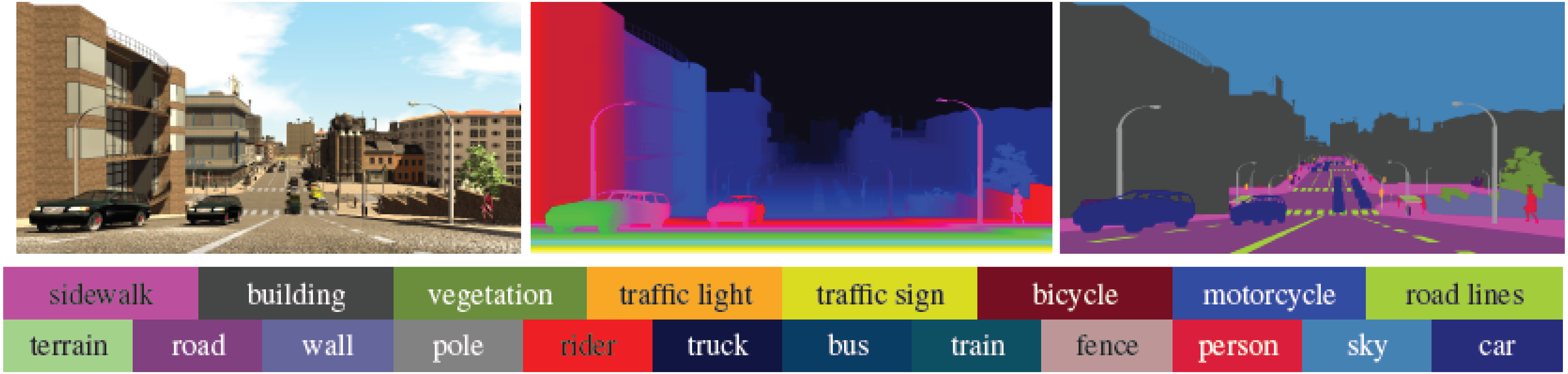




- New model to represent all classes: $\mu(s_i, v) = b_i * v + a_i$
- With priors according to the class: $E_{plane}(s_i) = \left(\frac{a-\mu^a_{c_i}}{\sigma^a_{c_i}}\right)^2 + \left(\frac{b-\mu^b_{c_i}}{\sigma^b_{c_i}}\right)^2 - \log(Z)$

- Each class has different parameters: slanted ground and objects and 0 disparity for sky
- Optimized jointly with Semantic Stixel probabilistic framework

New dataset: SYNTHIA-San Francisco



- Generated with SYNTHIA toolkit to evaluate our algorithm, features slanted roads
- Photorealistic virtual sequence (2224 images), pixel-level depth and semantic ground truth
- Expensive to generate equivalent real-data sequence

Results: Disparity Error

Metric	Dataset	Original	Ours
Disp Err (%)	Ladicky	17.3	16.9
	KITTI 15	10.9	11.0
	SYNTHIA-SF	30.9	**12.9**

Lower is better

- Much better accuracy for slanted road sequence, similar for others

Results: Semantic segmentation IoU

Metric	Dataset	Original	Ours
Disp Err (%)	Ladicky	17.3	16.9
	KITTI 15	10.9	11.0
	SYNTHIA-SF	30.9	**12.9**
IoU (%)	Ladicky	63.5	63.4
	Cityscapes	65.7	65.8
	SYNTHIA-SF	46.0	**48.5**

Higher is better

- Better accuracy for slanted road sequence, similar for others

Results: Frame-rate

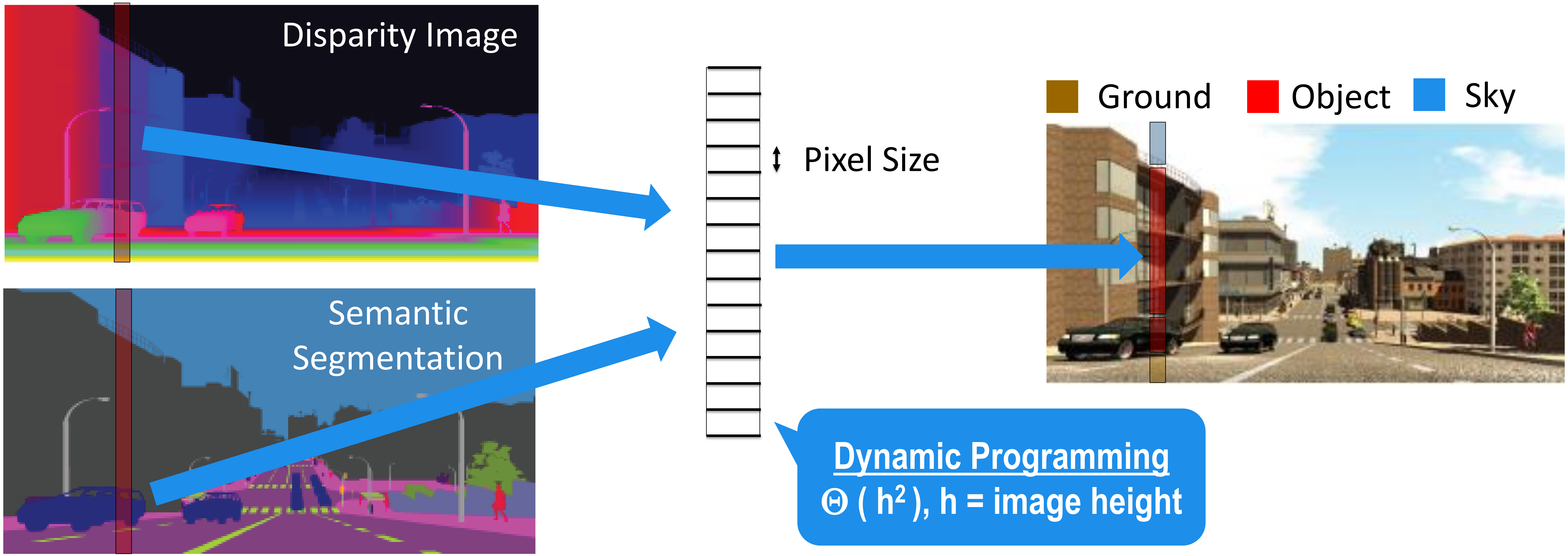
Metric	Dataset	Original	Ours
Disp Err (%)	Ladicky	17.3	16.9
	KITTI 15	10.9	11.0
	SYNTHIA-SF	30.9	**12.9**
IoU (%)	Ladicky	63.5	63.4
	Cityscapes	65.7	65.8
	SYNTHIA-SF	46.0	**48.5**
Frame-rate (Hz)	KITTI 15	**113**	61
	Cityscapes	**20.9**	6.6
	SYNTHIA-SF	**19.4**	4.7

Stixels time measured on 6-core Intel i7

Higher is better

- Our version is slightly slower because of the increased complexity

Stixel Computation Complexity: Dynamic Programming

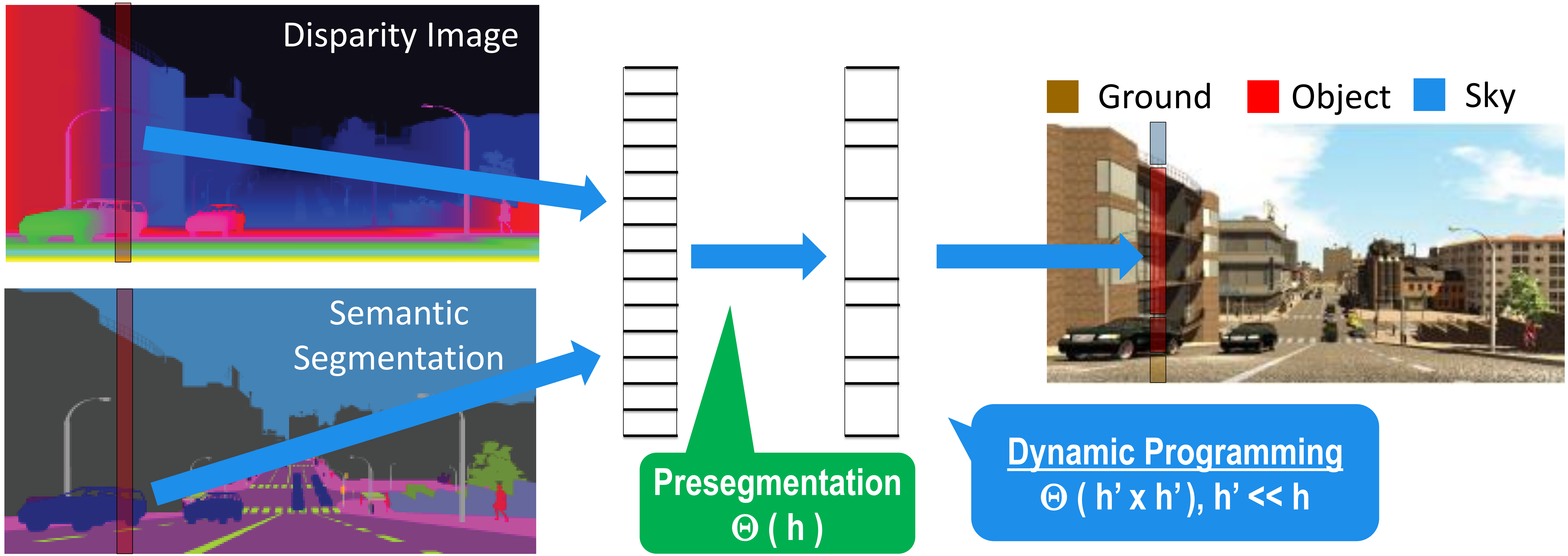


First-order Markov property: Only pair-wise Stixel relations are taken into account

Combinatorial explosion (of possible configurations):

Dynamic programming to evaluate efficiently

Stixel Computation Complexity: Presegmentation



- Infer possible Stixel cuts (presegmentation) from image
- Avoid checking all possible Stixel combinations
- If given the correct Stixel cuts, same accuracy (or better!)

Presegmentation Results: Disparity Error

				Presegmentation	
Metric	Dataset	Original	Ours	Original	Ours
Disp Err (%)	Ladicky	17.3	16.9	18.5	17.8
	KITTI 15	10.9	11.0	11.8	11.7
	SYNTHIA-SF	30.9	**12.9**	33.9	**15.4**

Lower is better

- Depth error is higher because we do not check all combinations

Presegmentation Results: Semantic segmentation IoU

				Presegmentation	
Metric	**Dataset**	**Original**	**Ours**	**Original**	**Ours**
Disp Err (%)	Ladicky	17.3	16.9	18.5	17.8
	KITTI 15	10.9	11.0	11.8	11.7
	SYNTHIA-SF	30.9	**12.9**	33.9	**15.4**
IoU (%)	Ladicky	63.5	63.4	63.9	63.7
	Cityscapes	65.7	65.8	65.7	65.8
	SYNTHIA-SF	46.0	**48.5**	46.9	**48.5**

Higher is better

- The same semantic segmentation accuracy is maintained

Presegmentation Results: Frame-rate

				Presegmentation	
Metric	**Dataset**	**Original**	**Ours**	**Original**	**Ours**
Disp Err (%)	Ladicky	17.3	16.9	18.5	17.8
	KITTI 15	10.9	11.0	11.8	11.7
	SYNTHIA-SF	30.9	**12.9**	33.9	**15.4**
IoU (%)	Ladicky	63.5	63.4	63.9	63.7
	Cityscapes	65.7	65.8	65.7	65.8
	SYNTHIA-SF	46.0	**48.5**	46.9	**48.5**
Frame-rate (Hz)	KITTI 15	113	61	120	116
	Cityscapes	20.9	6.6	36.6	27.5
	SYNTHIA-SF	19.4	4.7	38.9	33.1

Higher is better

- Presegmentation speeds up both original and Slanted Stixels

Presegmentation Results: Frame-rate

				Presegmentation	
Metric	**Dataset**	**Original**	**Ours**	**Original**	**Ours**
Disp Err (%)	Ladicky	17.3	16.9	18.5	17.8
	KITTI 15	10.9	11.0	11.8	11.7
	SYNTHIA-SF	30.9	**12.9**	33.9	**15.4**
IoU (%)	Ladicky	63.5	63.4	63.9	63.7
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Frame-rate (Hz)	KITTI 15	113	61	120	116
	Cityscapes	20.9		36.6	27.5
	SYNTHIA-SF	19.4	4.7	38.9	33.1

Up to 2x

Higher is better

Presegmentation Results: Frame-rate

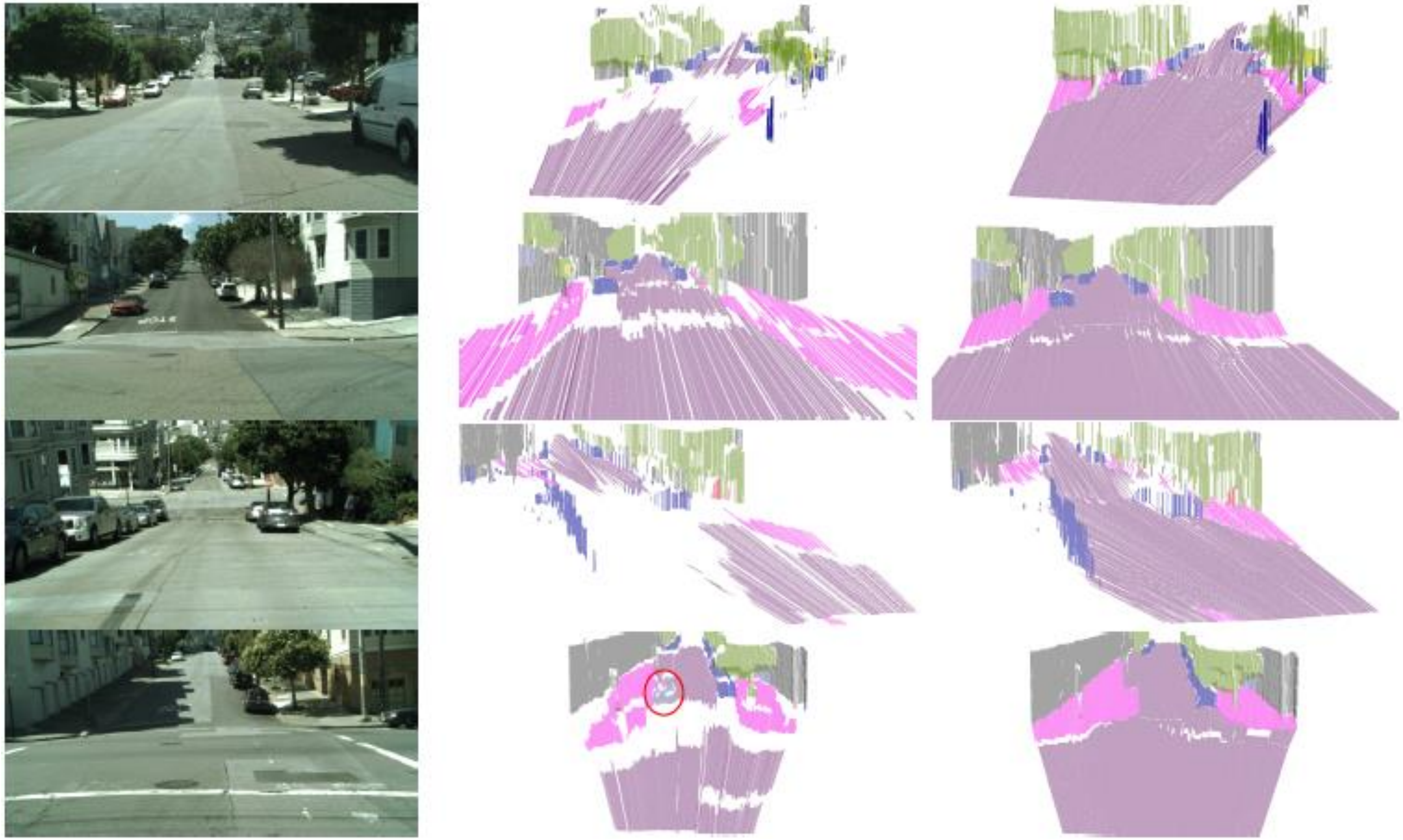
				Presegmentation	
Metric	**Dataset**	**Original**	**Ours**	**Original**	**Ours**
Disp Err (%)	Ladicky	17.3	16.9	18.5	17.8
	KITTI 15	10.9	11.0	11.8	11.7
	SYNTHIA-SF	30.9	**12.9**	33.9	**15.4**
IoU (%)	Ladicky	63.5	63.4	63.9	63.7
	Cityscapes	65.7	65.8	65.7	65.8
	SYNTHIA-SF	46.0	**48.5**	46.9	**48.5**
Frame-rate (Hz)	KITTI 15	113	61	120	116
	Cityscapes	20.9	6.6	27.5	27.5
	SYNTHIA-SF	19.4	4.7	38.9	33.1

Up to 7x

Higher is better

Visual examples

Left Image | Original Stixels | Slanted Stixels

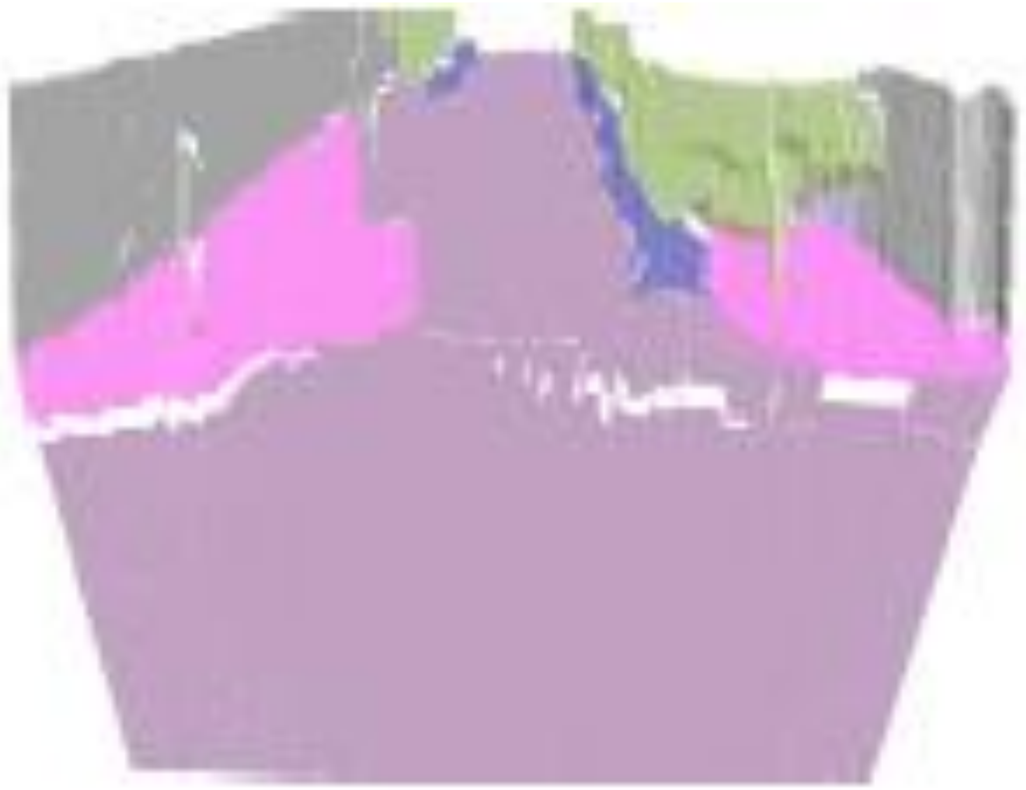


Visual example: Avoid emergency break

Left Image

Original Stixels

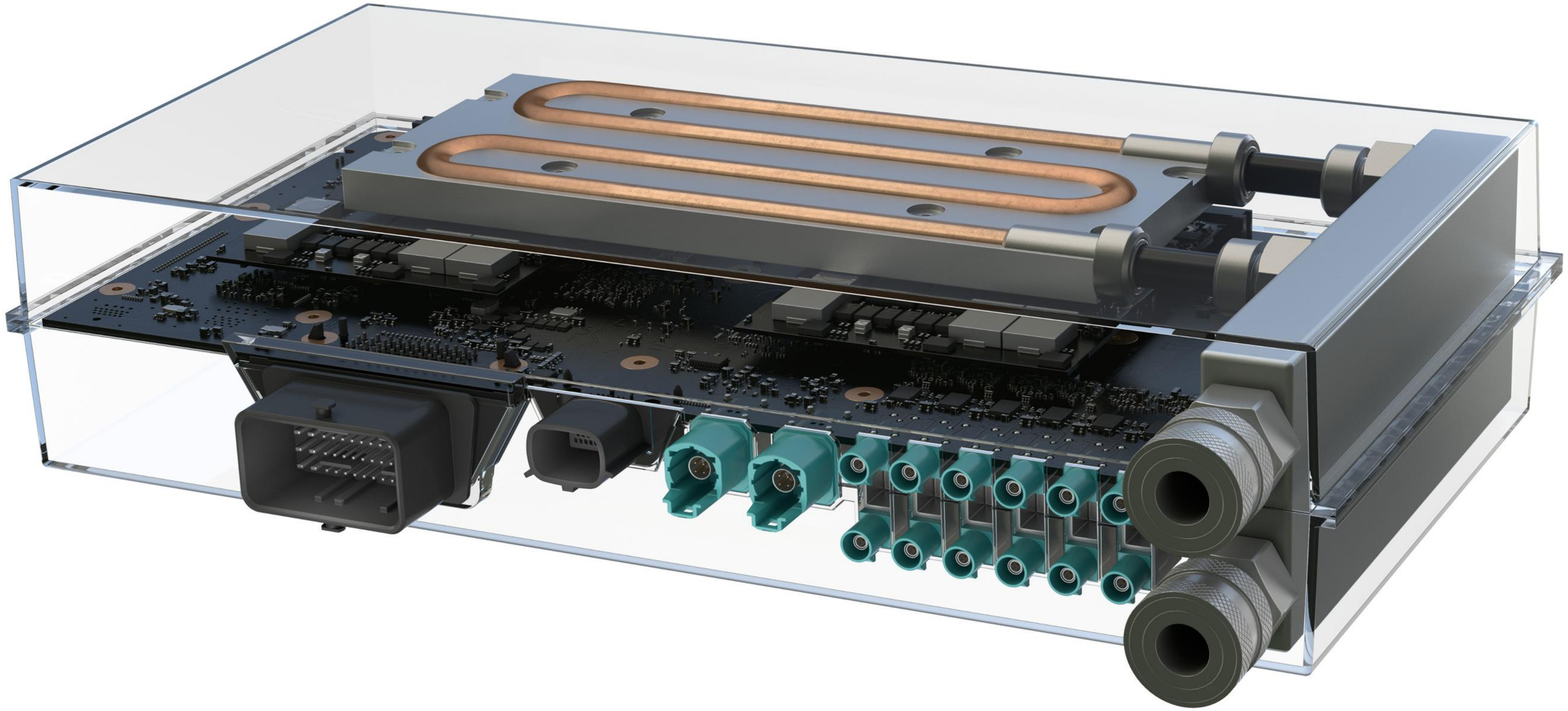
Slanted Stixels



Summary: Real sequence video

Future work

- Improve presegmentation for better accuracy using a CNN
- Embedded GPU version on NVIDIA Drive PX 2 for autonomous driving



Thank you

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