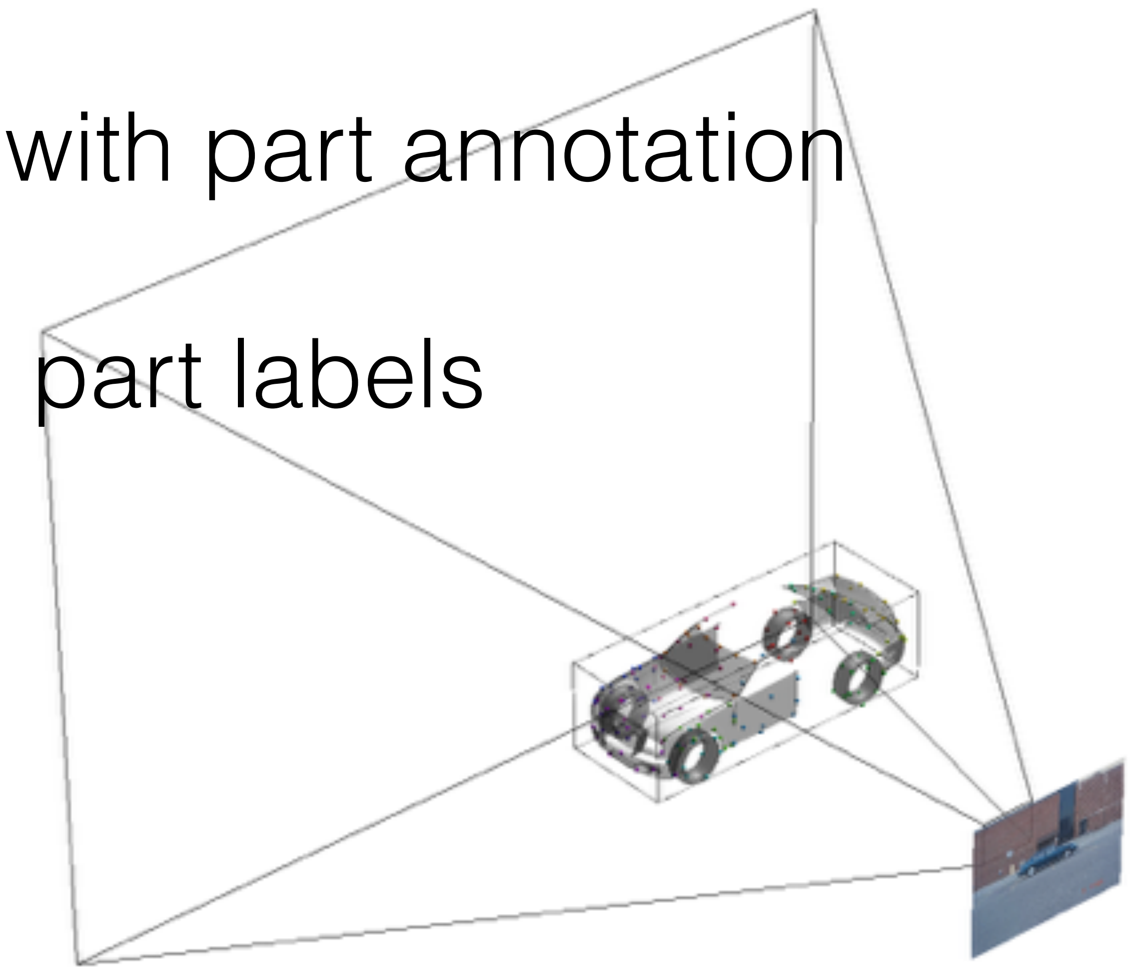
Semantic Reconstruction From Single RGB Image Using Part Priors

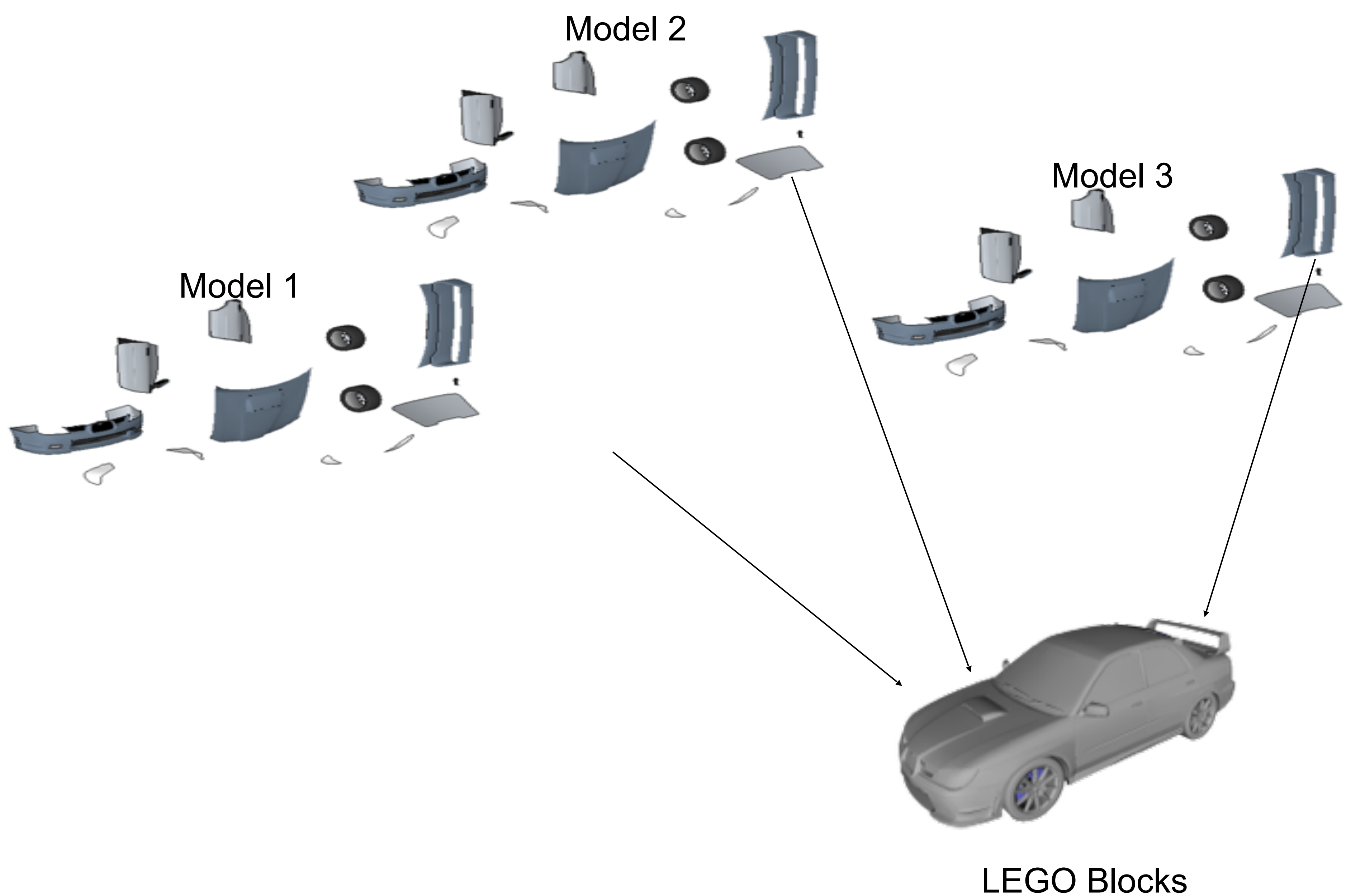
Christopher B. Choy, Ziang Xie, Michael Stark, Silvio Savarese

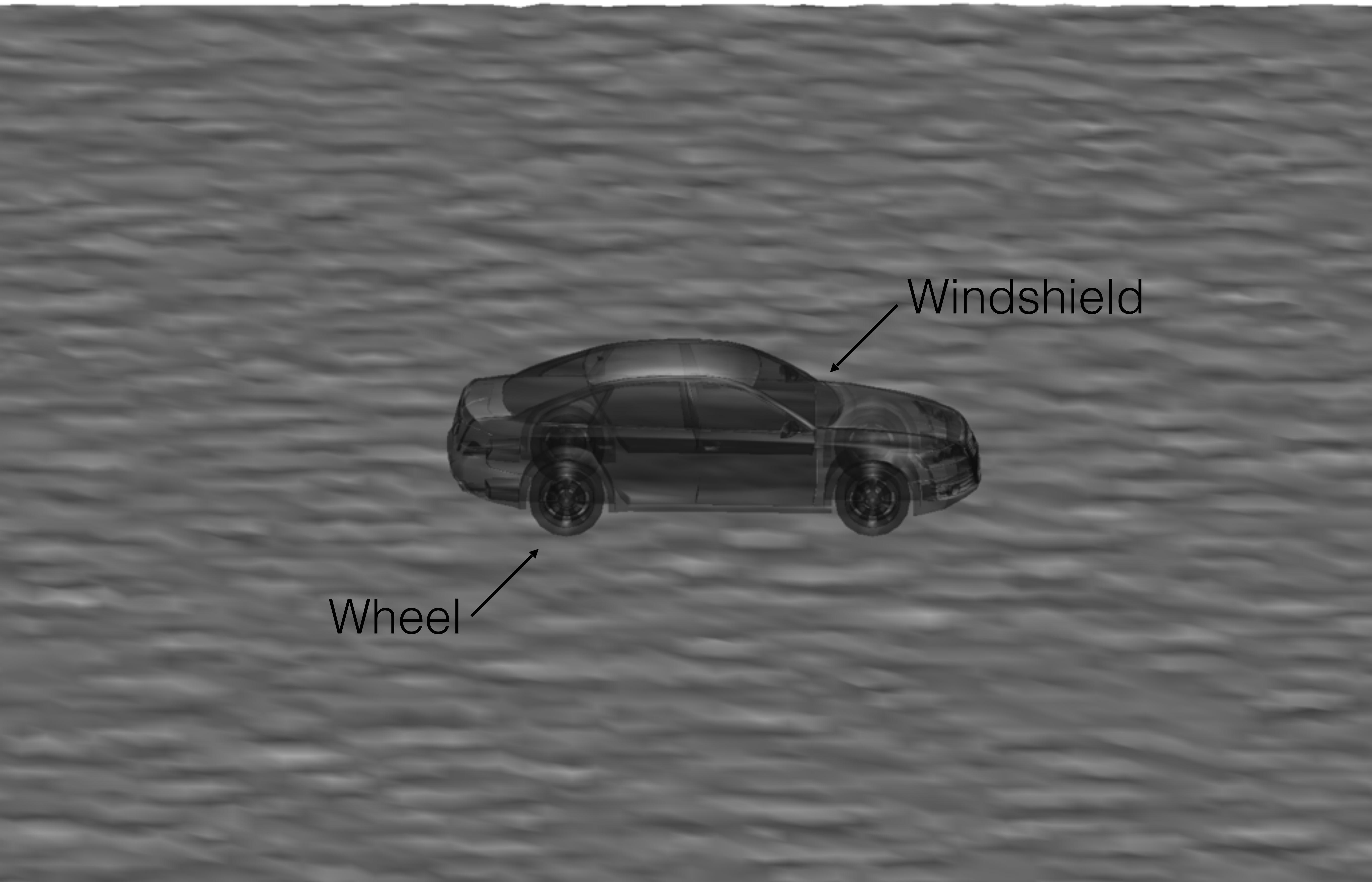
Problem

- Reconstruct an image
  - Input : RGB Image, Meshes with part annotation
  - Output : Reconstruction with part labels



Dictionary

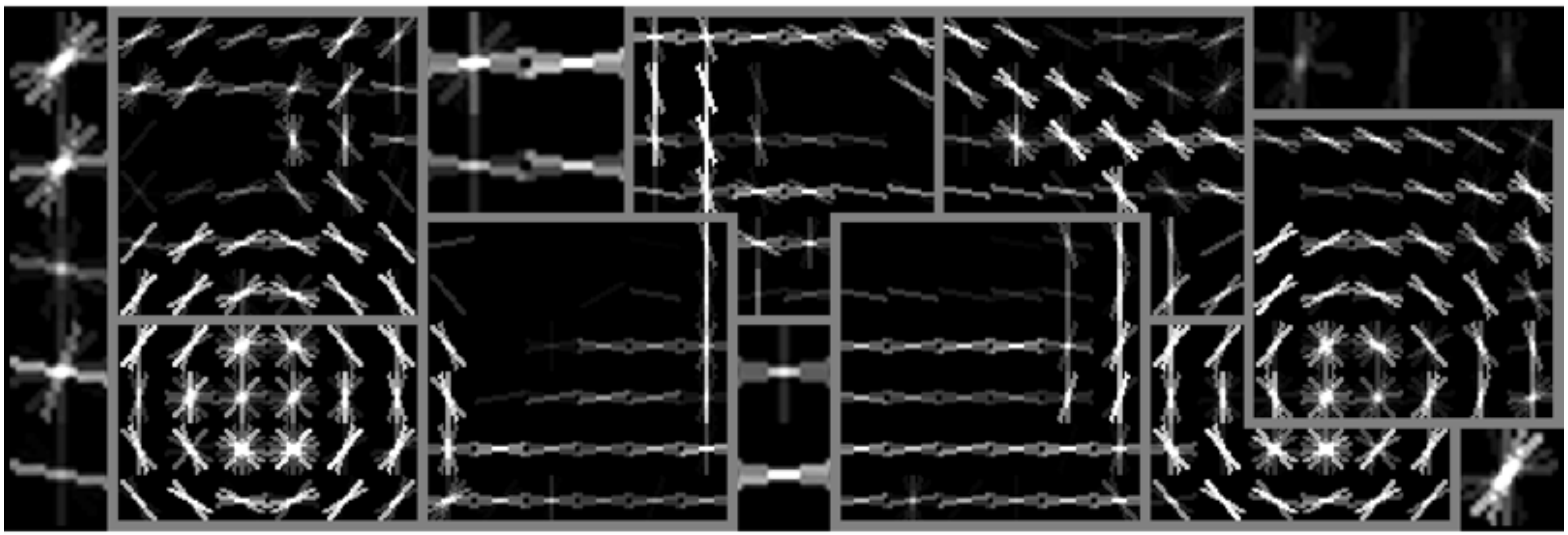



Windshield
Wheel

Where is the object on the image?

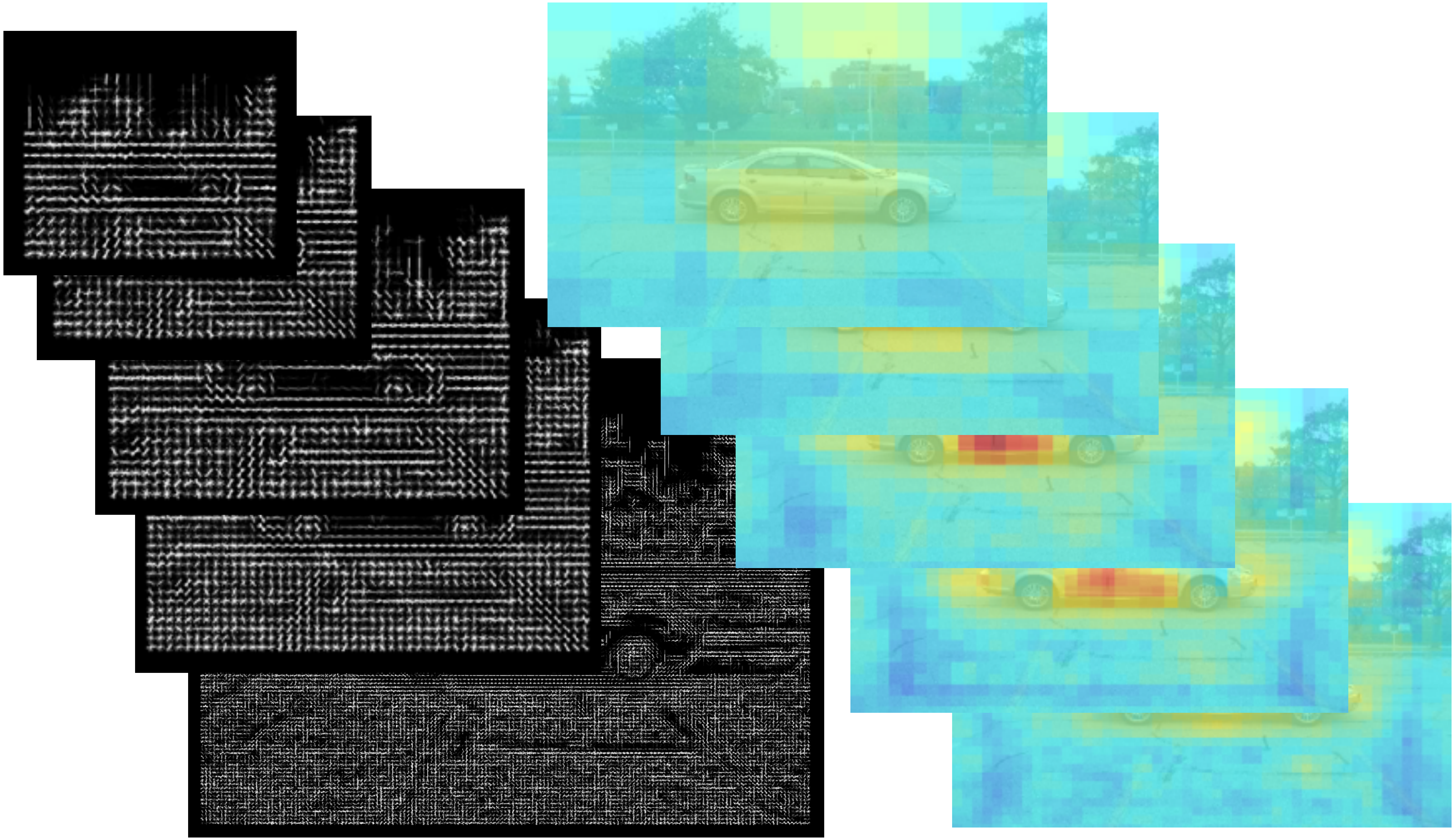
- x-y coord of object
- scale of the object (z-coord)
- rotation of the object

Viewpoint Dependent Filters



Rendered Images for Training

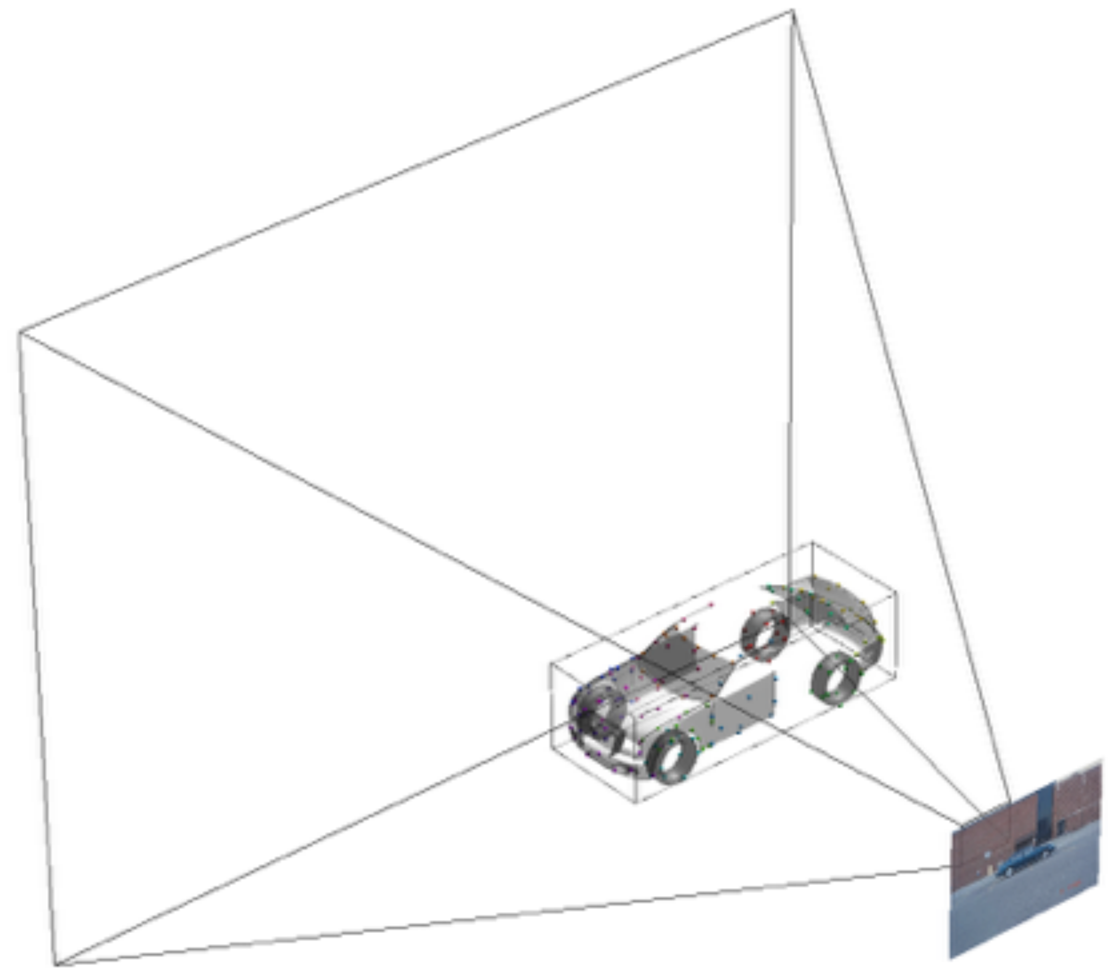
Convolution



Size increase by factor of $2^{\frac{1}{k}}$

2D to 3D

- Reconstruction
  - Position in 3D
  - Rotation



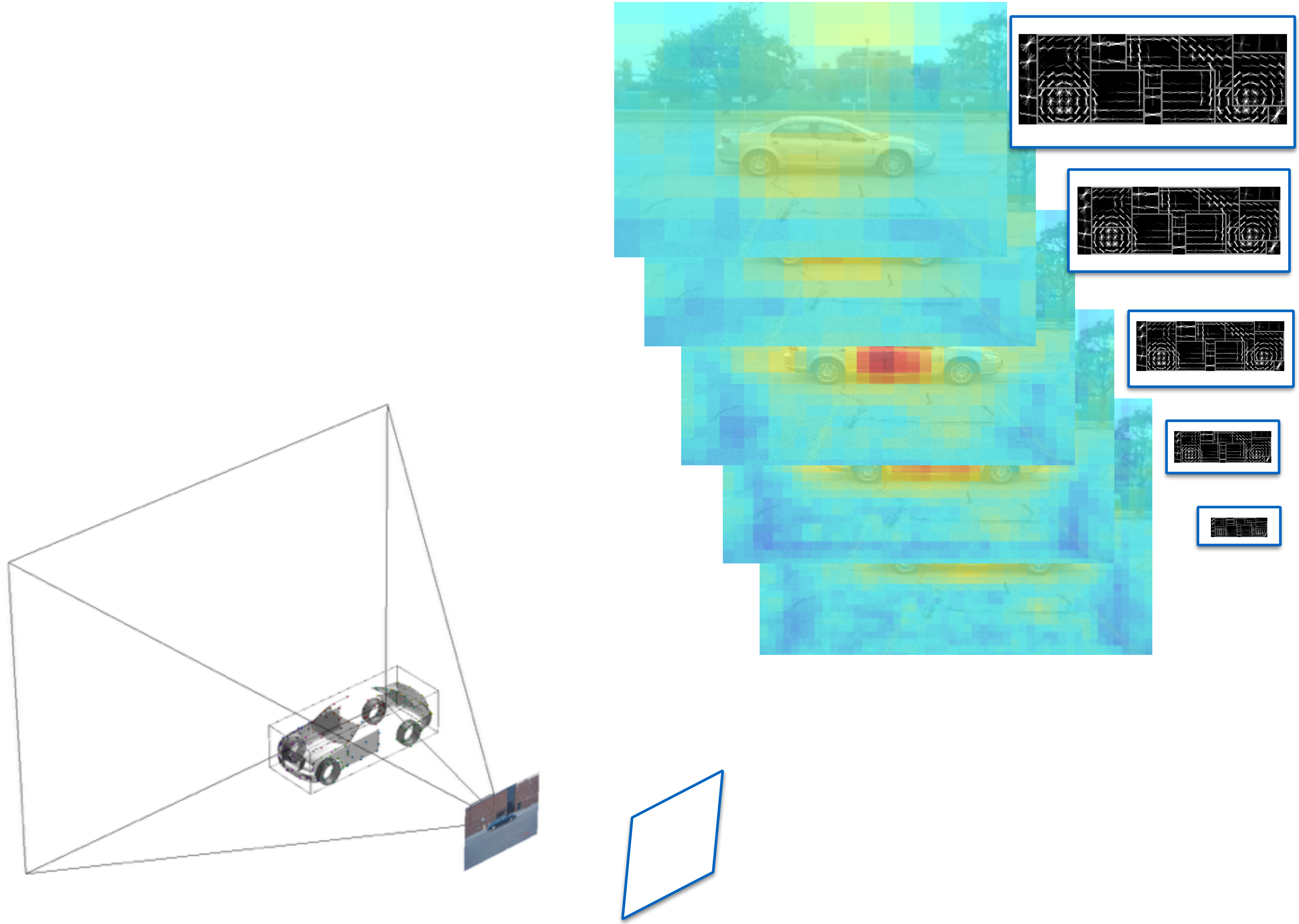
1. UV Coord

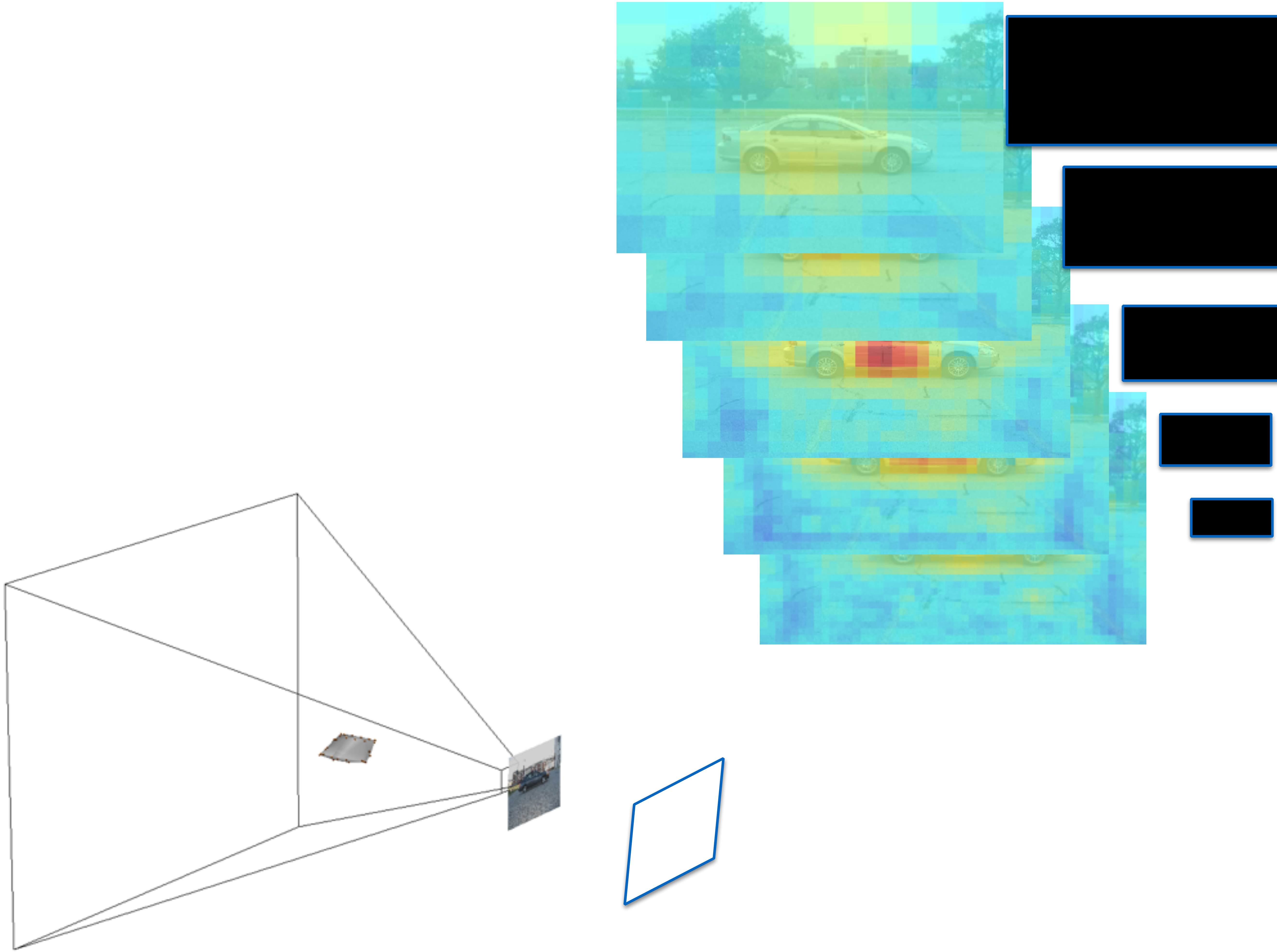
2. Scale

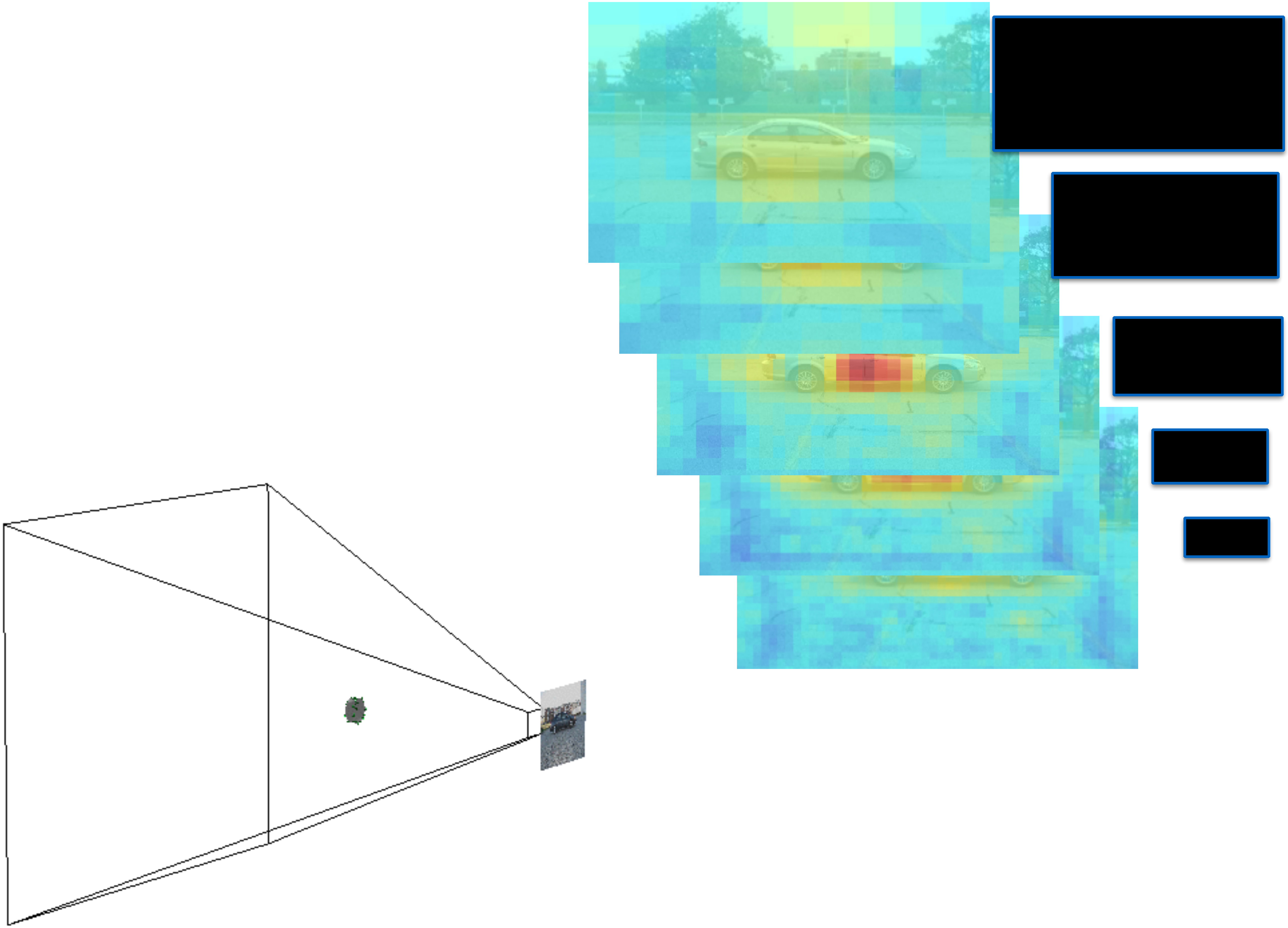
- Prior knowledge about the size
  - Depth

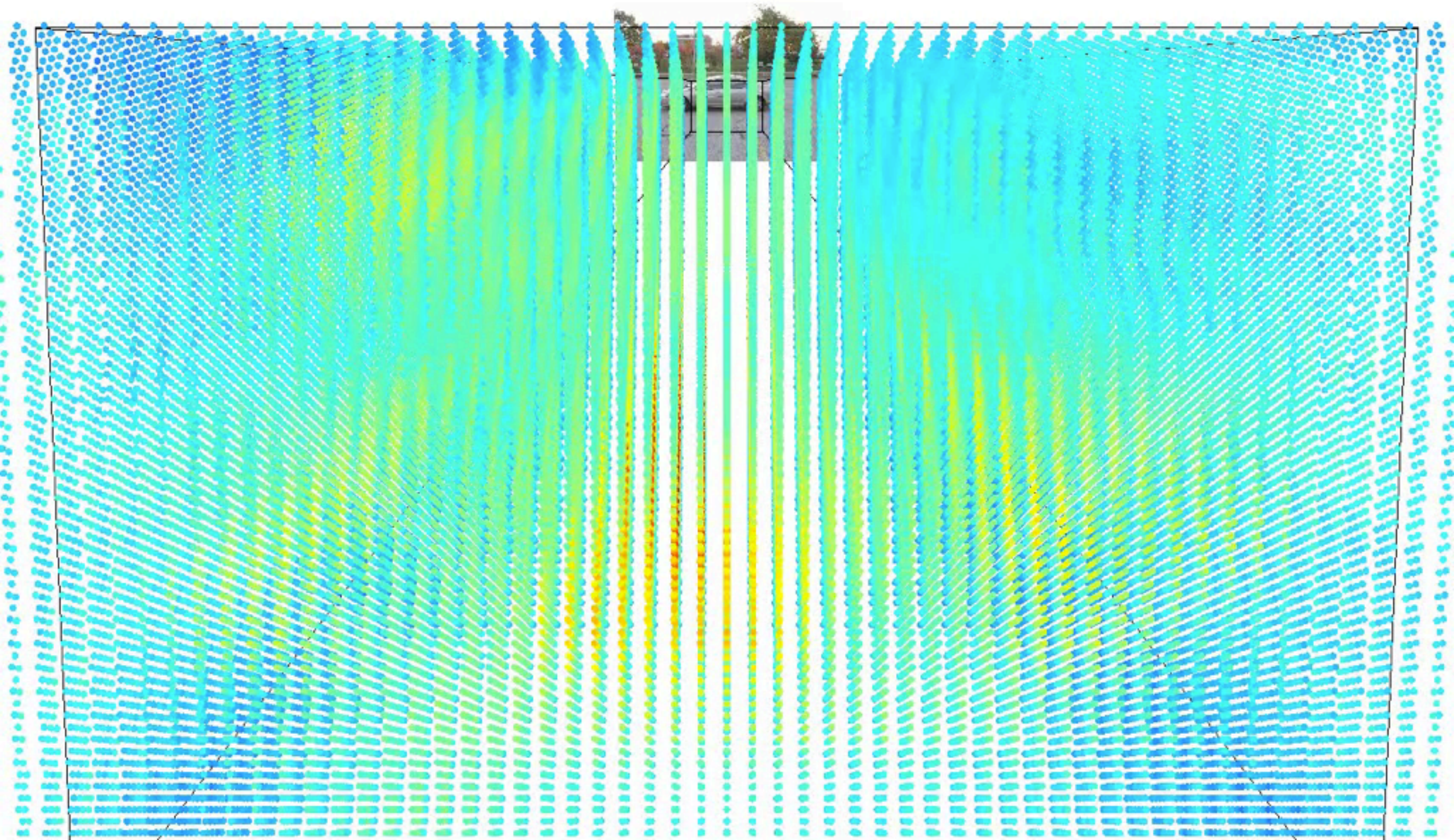
3. Rotation

- Independent Viewpoint Detectors







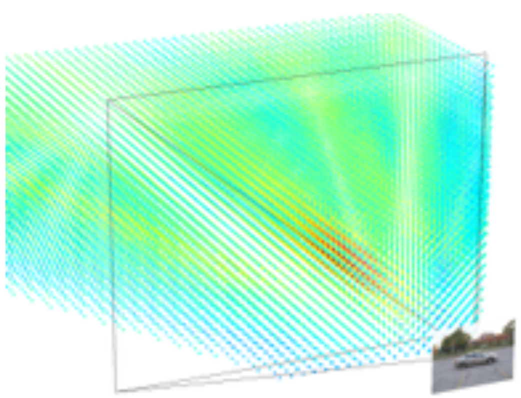


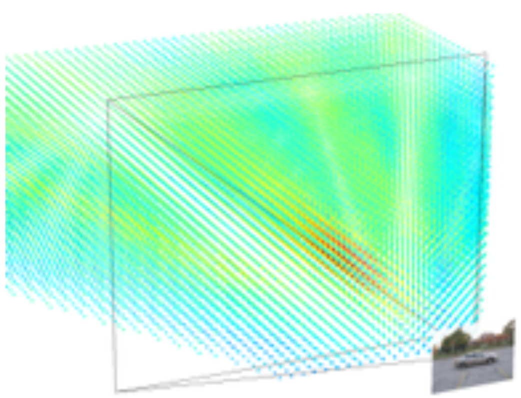
Optimization

$$\min_x f(x)$$

$$f(x) = \boxed{\phi_o(x)} + \sum_i \boxed{\phi_i(x)} + \boxed{f_{reg}(x)}$$

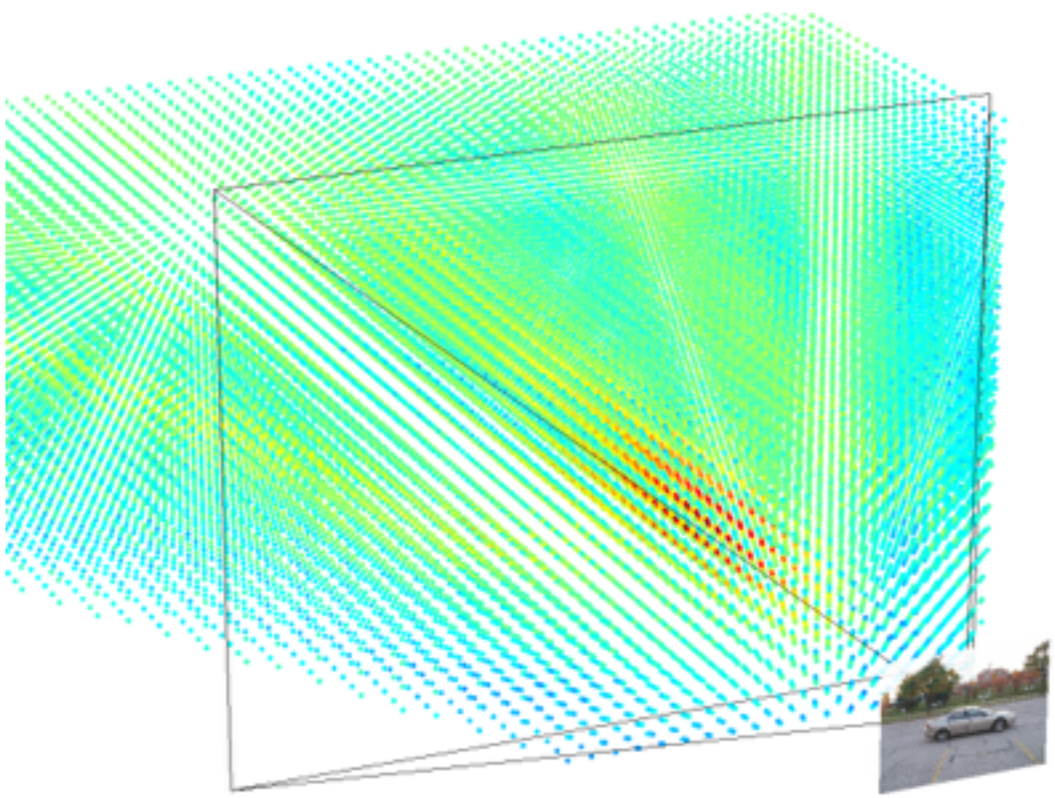
Object Parts Regularization





$$-\frac{1}{2}(x-\mu)^T \Sigma^{-1} (x-\mu)^T$$

$$x = [p, s, r, p_1, ..., p_k]$$



- for all viewpoint
- for all parts

- no cache

Every time it queries

- Project the mesh 10k vertices

$$\tilde{p} = PVp$$

$\tilde{p}$ Homogeneous Image Coordinate

p Homogeneous Space Coordinate

Projection

- Query point, project a mesh
- Project all vertices ?
- Minimal vertices
- Convex still convex

Sample Vertex

- Random Sample
- Exact Convex Hull
- Approximate Convex Hull
    - sample vertices that represent the mesh

Farthest Point Sampling

- Sample Vertex
- Farthest Point Sampling
    - Pairwise distance $O(n^2)$
- Sample parts and make convex hull
- Farthest point from the set on a mesh

Fast Marching

- Numerical Method to solve Boundary Value Problem
- Dijkstra Algorithm

1. Propagate boundary from initial sample points

   - min propagation time to max-heap

2. new sample = max from the heap
3. propagate boundary for the new sample
4. halt propagation if it meets smaller propagation time
5. update the max-heap

Path initialization: FM2

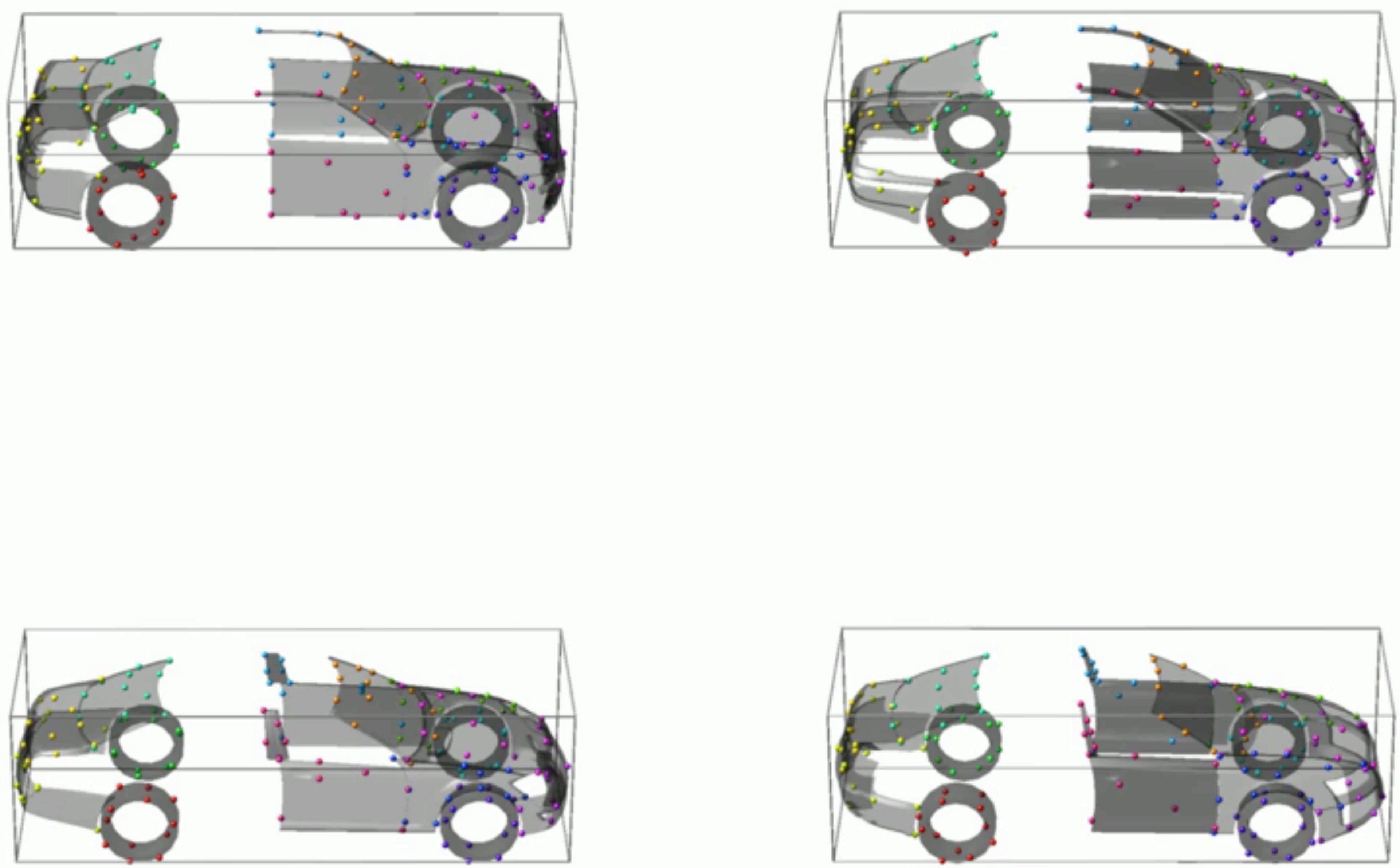
Map of velocities

Sampling

- For all models of the same category
- For all parts
- Exact Convex Hull
- Fast Marching Farthest Point Sampling
- Exact Convex Hull

Sample Vertex Per Part

Sample Vertex Per Part



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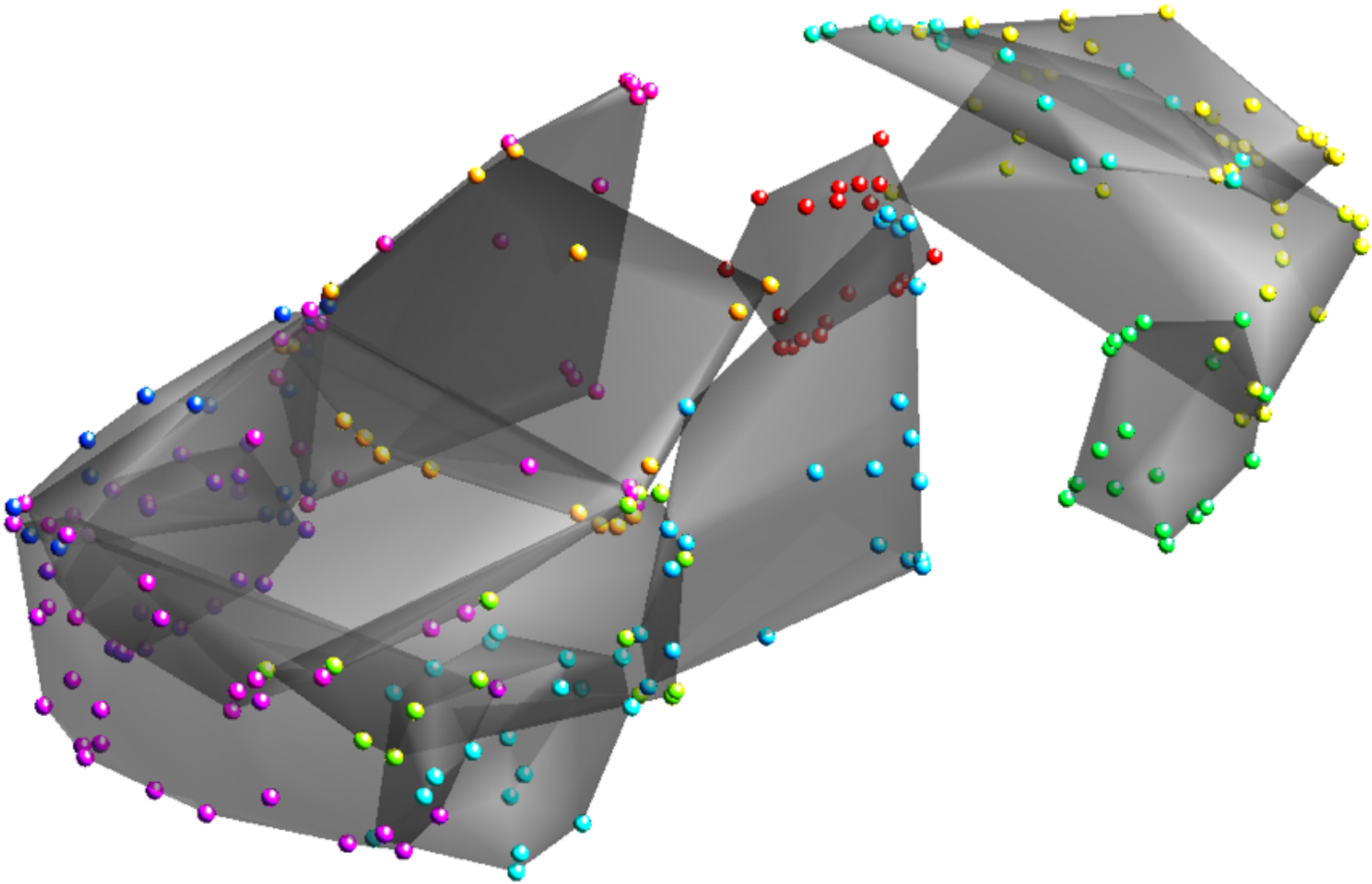

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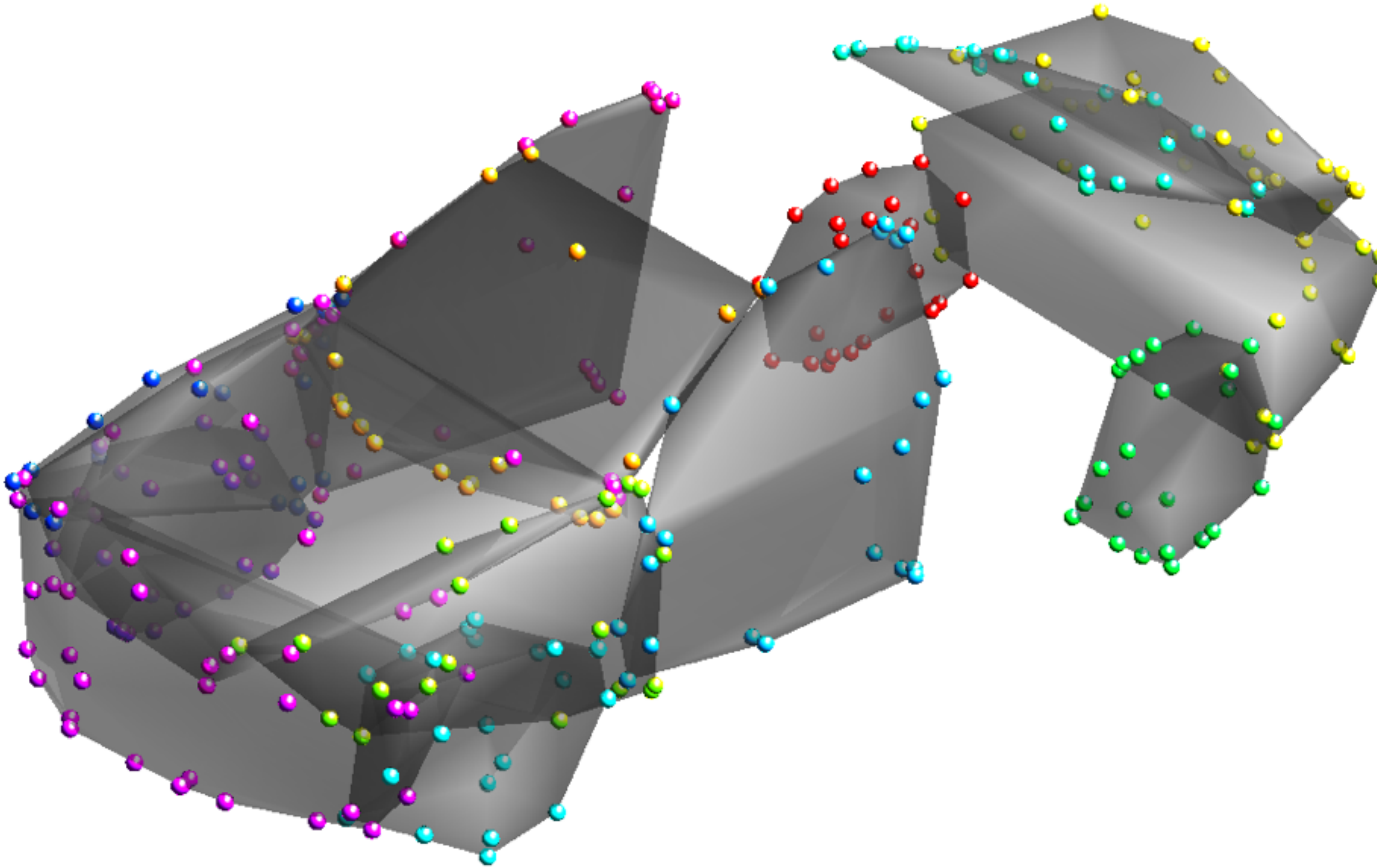
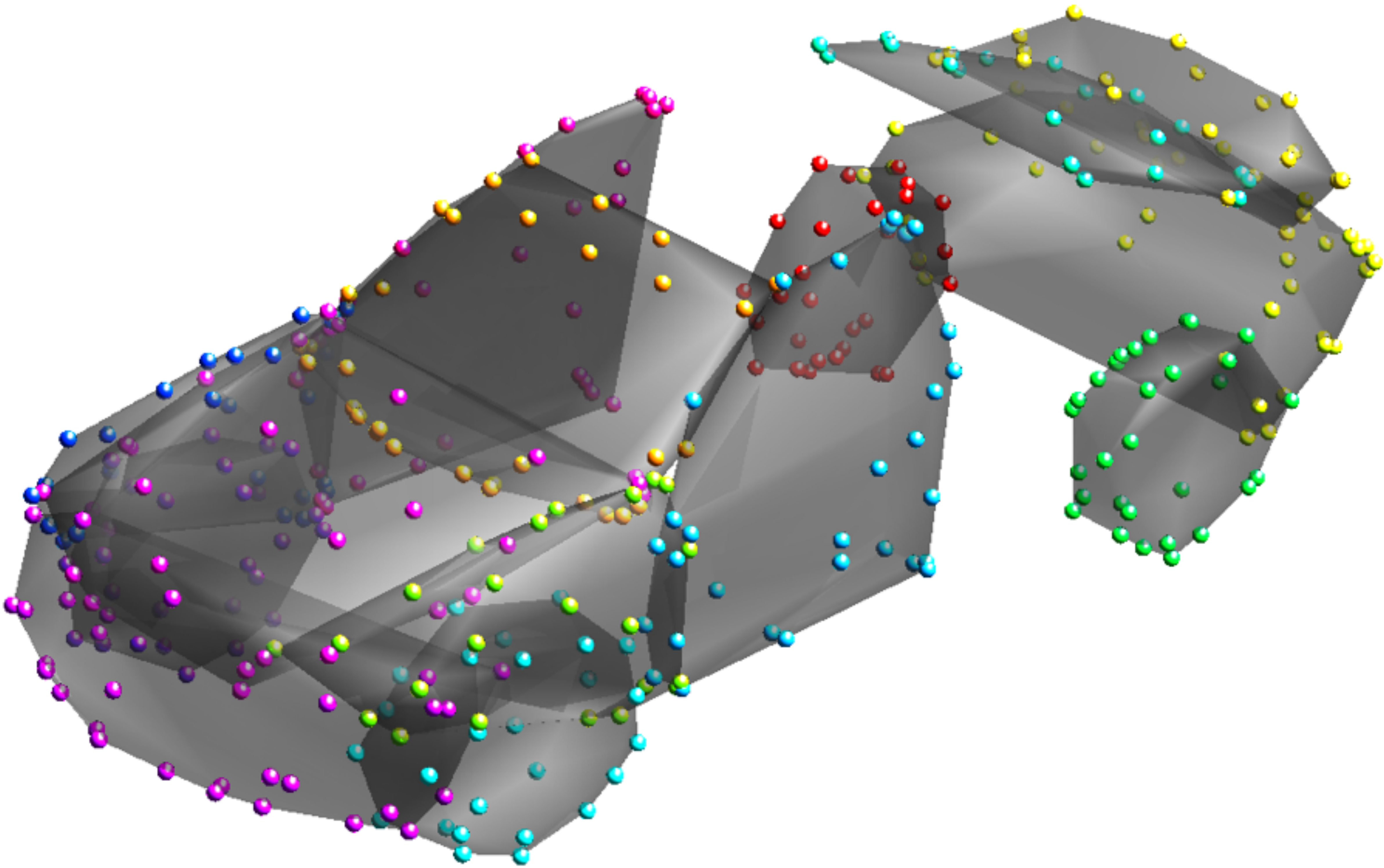
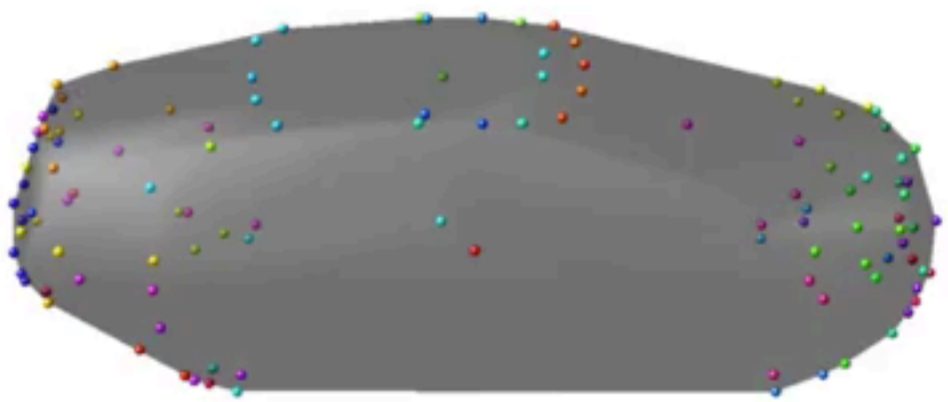
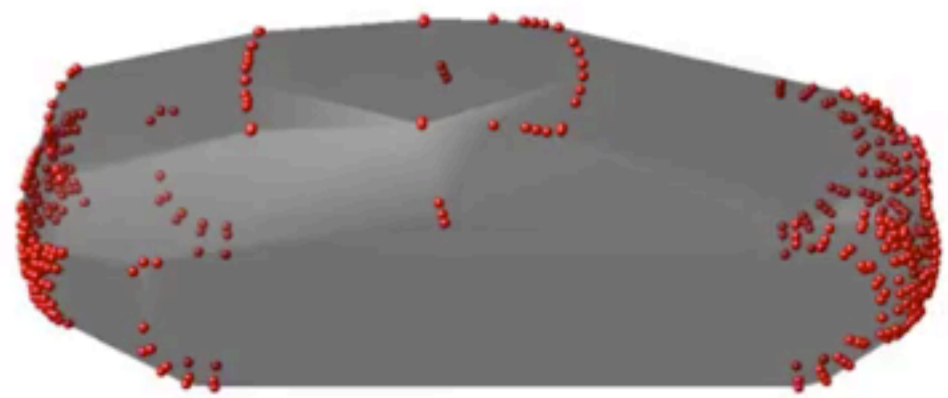




Approximate vs. Exact Convex Hull





Optimization

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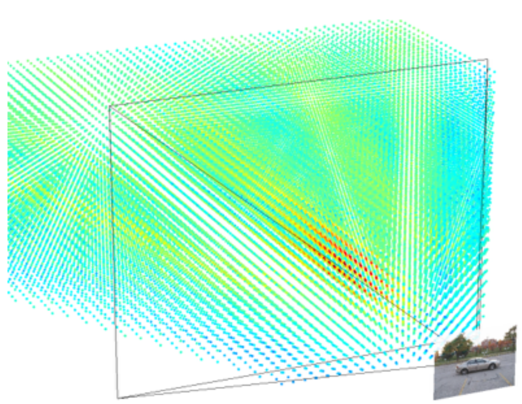
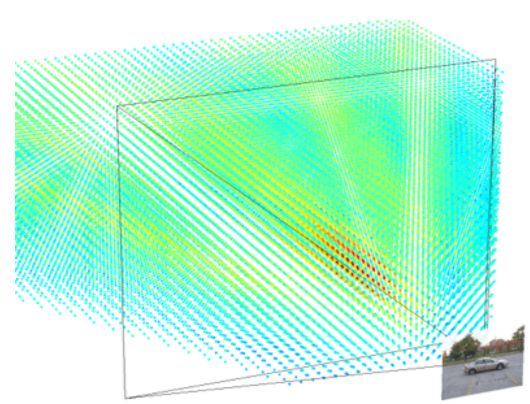
Object Parts Regularization





$$-\frac{1}{2}(x-\mu)^T\Sigma^{-1}(x-\mu)^T$$

$$x = [p, s, r, p_1, ..., p_k]$$

Optimization

$$f(x) = \phi_o(x) + \sum_i \phi_i(x) + f_{reg}(x)$$

- Convex?
- Continuous?
- Screwed?

Optimization

- Oracle Problem
  - Monte Carlo
  - Subgradient descent

Optimization

- Single Component-MCMC
  - $x = [p, s, r, p_1, ..., p_k]$
- Hand-Crafted MCMC Moves
  - 1. Local Jumps : $p(x^+) \sim \mathcal{N}(x, \sigma)$
  - 2. Global Jumps : $\phi_o(x) = \log p_o(x)$

Optimization

- Initialize Chains
  - Sample from the discretized space of possible combinations
- Burn in the chains
  - Local Jump/Global Jump choose randomly
- MCMC convergence/Optimality
  - Not guaranteed

24 chains for 5k iterations

Optimization

- Discontinuous
  - Linear Interpolation
- Non-convex
  - Initialization
- Quasi-Newton (BFGS)
  - Finite Difference

Broyden-Fletcher-Goldfarb-Shanno (BFGS)

$$\mathbf{x}_{n+1} = \mathbf{x}_n - [Hf(\mathbf{x}_n)]^{-1} \nabla f(\mathbf{x}_n), \ n \geq 0$$

- 2nd Order Finite Difference
    - $\sim \ O(k^2)$ Queries
- 1st Order Finite Difference and approximate

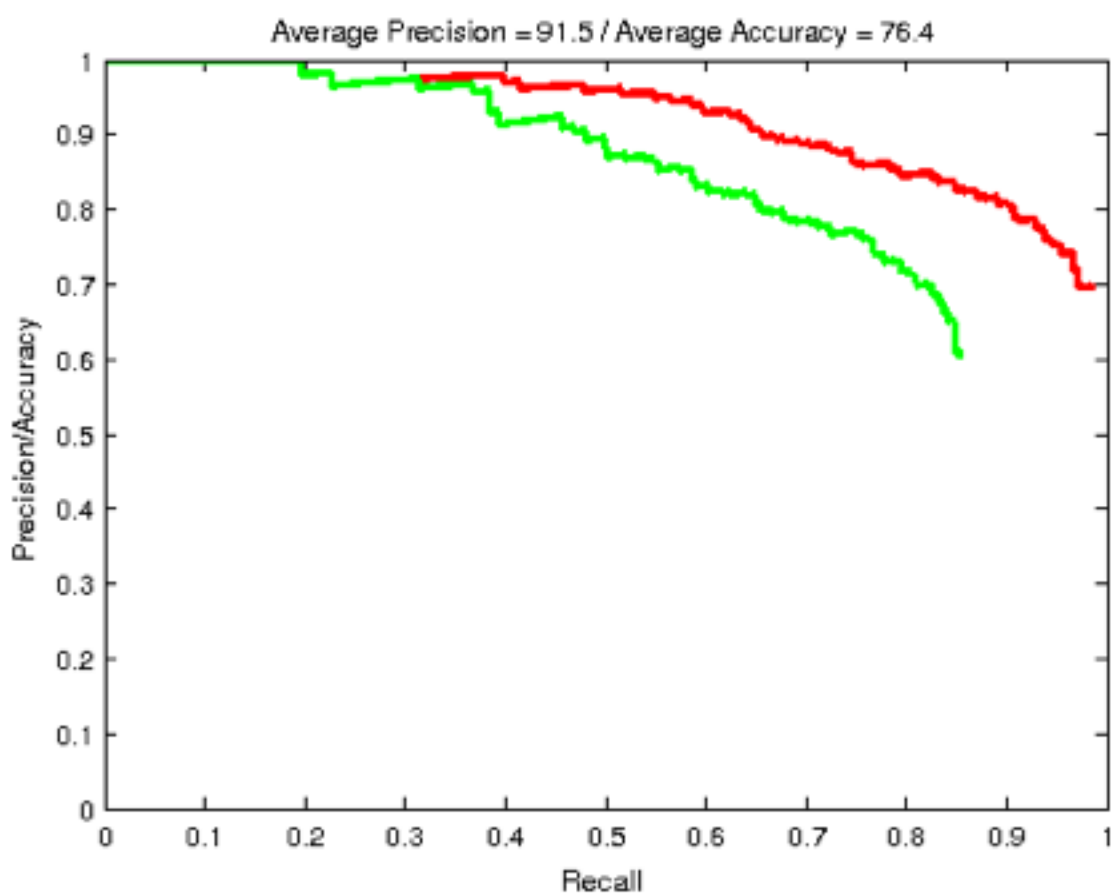
$$H_{k+1} = \left(I - \frac{y_k \Delta x_k^T}{y_k^T \Delta x_k} \right)^T H_k \left(I - \frac{y_k \Delta x_k^T}{y_k^T \Delta x_k} \right) + \frac{\Delta x_k \Delta x_k^T}{y_k^T \Delta x_k}$$

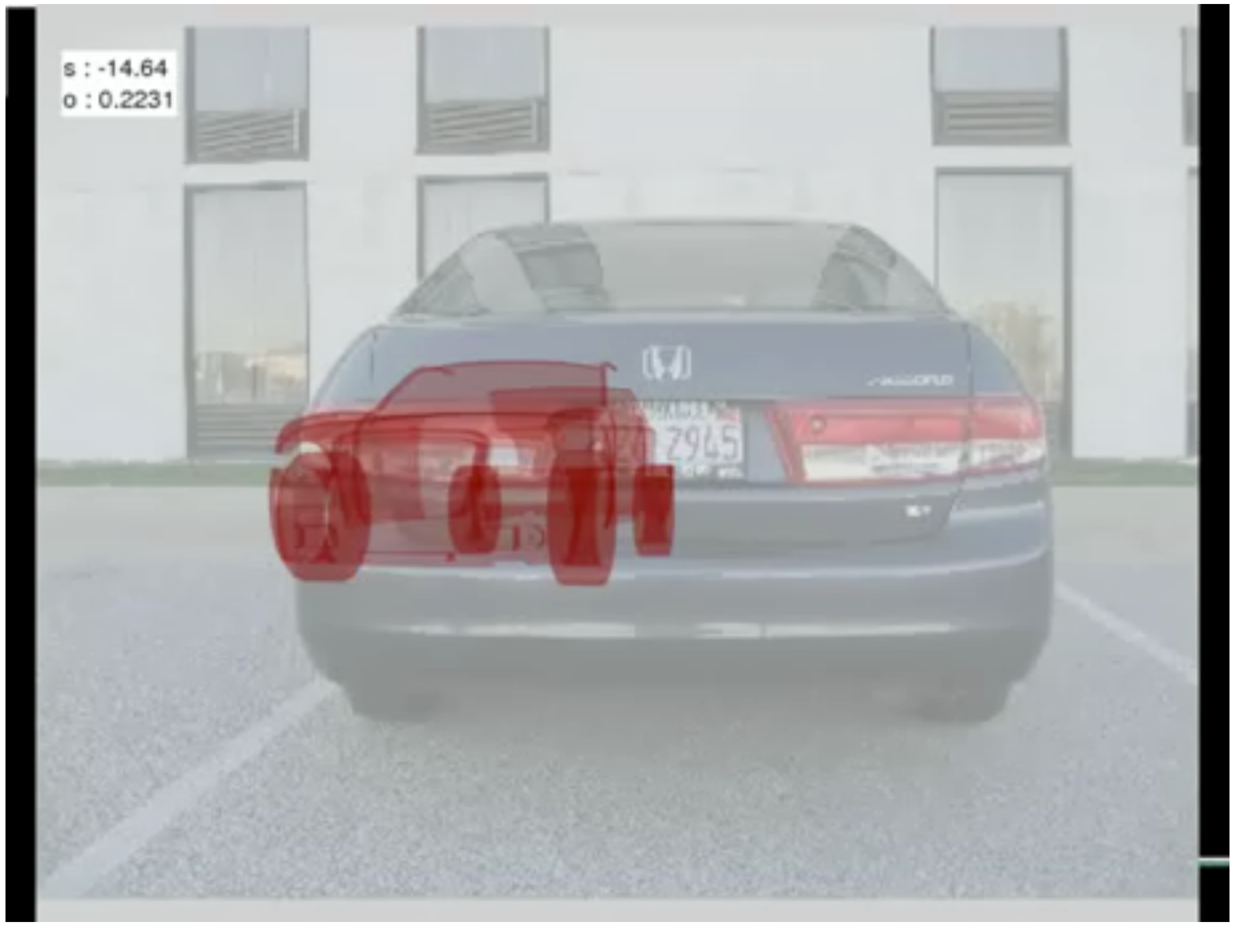
Optimization

- Initialize each optimization sub-problem
    - Threshold from the discretized space of possible combinations
- Sub-Optimization
- Convergence/Optimality < numerical error

How Fast?

- Quasi-Newton
  - Preprocessing 5 min
  - Optimization
    - 200k queries 2 sec
    - ~160 for optimization 2 min
- MCMC
  - Initialization Important
  - 24 chains for 5000 iterations
  - 2 min + 5min





S. Savarese and L. Fei-Fei, ICCV 2007

Optimization

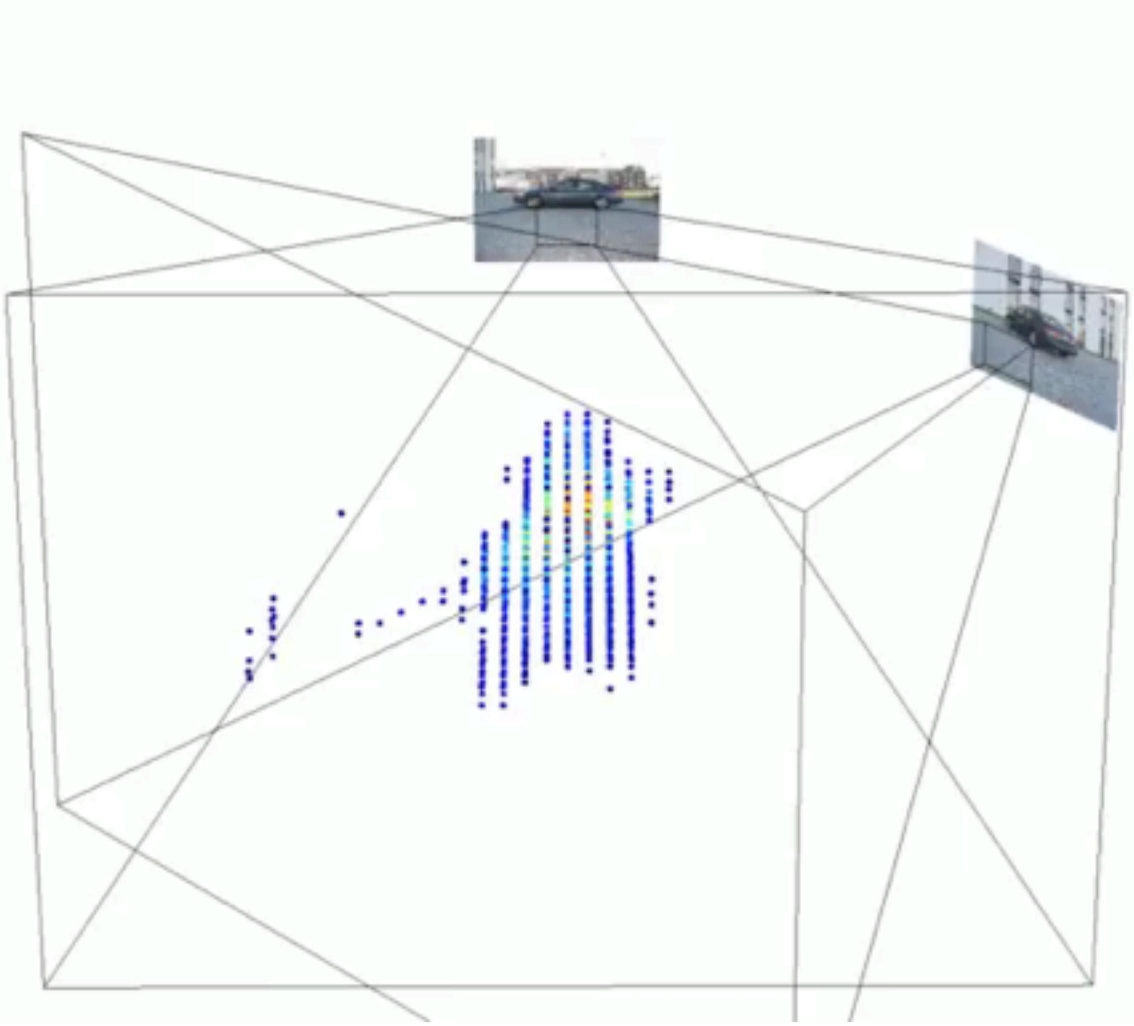
$$f(x) = \boxed{\phi_o(x)} + \sum_i \boxed{\phi_i(x)} + \boxed{f_{reg}(x)}$$

Object Parts Regularization

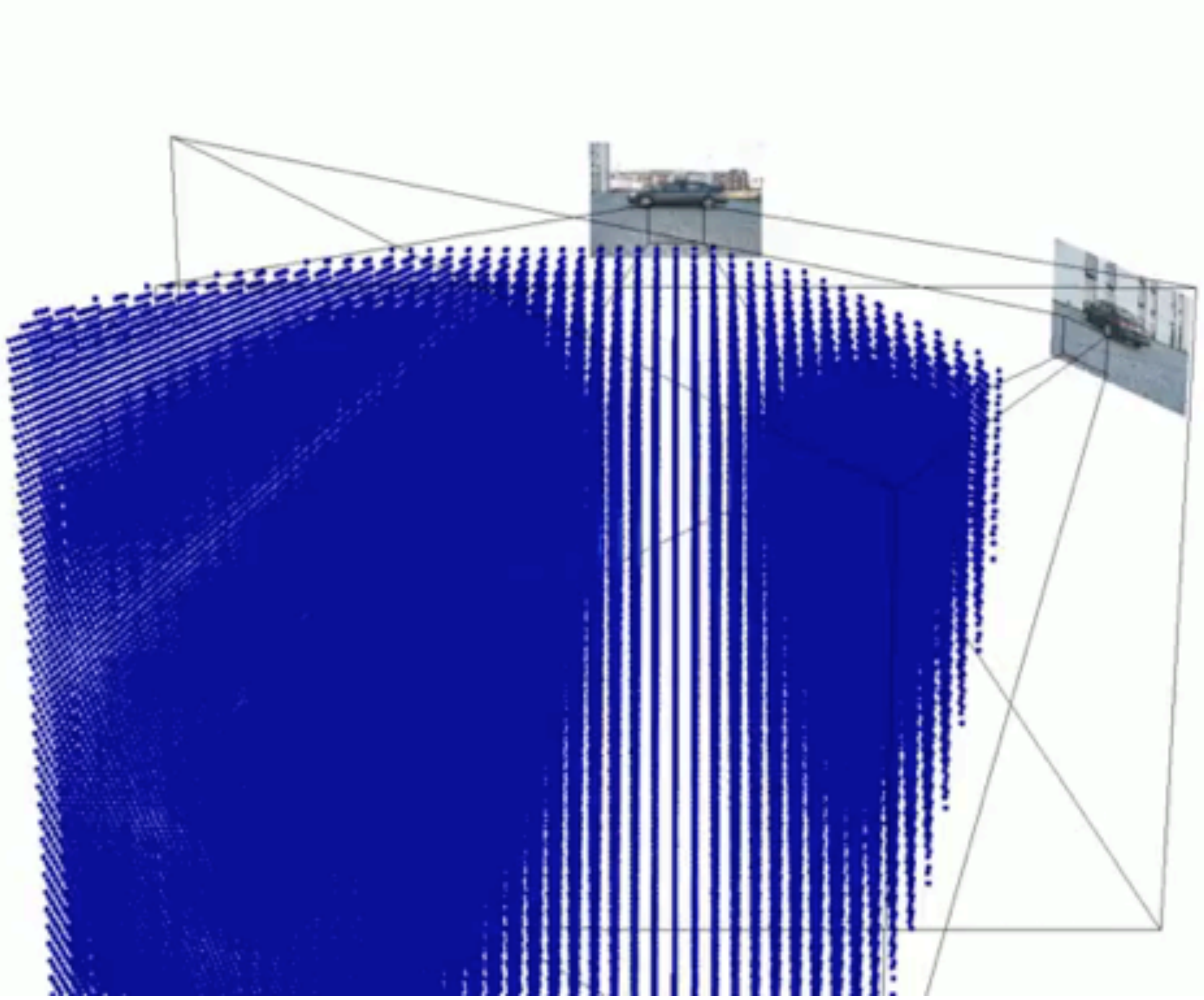
$$f(x) = \sum_v \phi_{ov}(x) + \sum_v \sum_i \phi_{iv}(x) + f_{reg}(x)$$

Future Work

- More words in the dictionary
- Viewpoint estimation
- Noisy observation
  - CNN features on sparse set of boxes
  - E-SVM convolution



Threshold = -1



Threshold = -5