# Superquadrics Revisited: Learning 3D Shape Parsing beyond Cuboids

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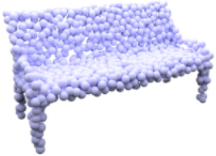
[Paschalidou, Ulusoy & Geiger, CVPR 2019]

# 3D Representations

Voxels



Points

Meshes

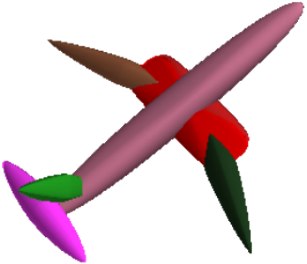
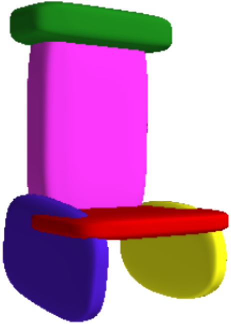
Implicit

**Limitations of existing 3D representations:**

- Large number of unstructured geometric elements
- Do not convey semantic information (parts, functionality, etc.)

What is a **useful** 3D representation?

# 3D Primitives


**Primitive-based 3D Representations:**

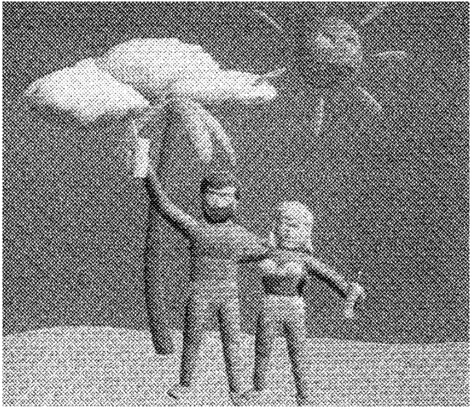
- Few primitives required to represent a 3D object
- Convey semantic information (parts, functionality, etc.)
- Challenges: Variable number of primitives, few annotated datasets

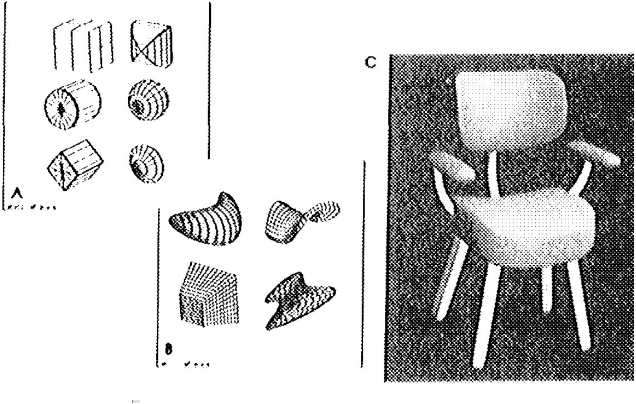
# 3D Shape Abstraction

**Goal of this work:**

- Learn 3D shape abstraction
- Infer number of primitives
- No supervision at primitive level
- Input: points/volumes/images

# Pentland's Superquadrics Revisited



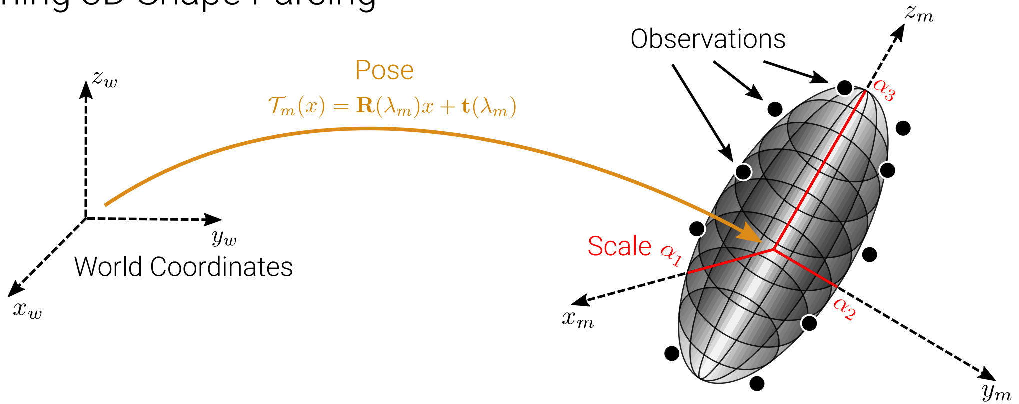



- 1 superquadric = 11 parameters $\Rightarrow$ scene on the left stored in only 1000 bytes!
- However, early fitting-based approaches did not work robustly

Pentland: Parts: Structured descriptions of shape. AAAI, 1986.

Can we **learn** to parse 3D shapes?

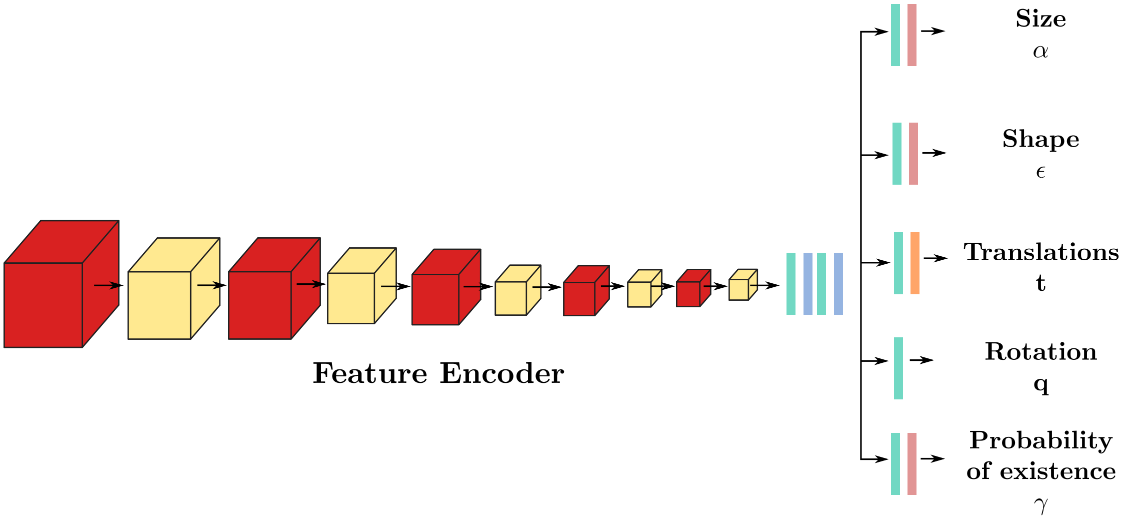
# Learning 3D Shape Parsing




**Predictions per primitive:**

- 11 parameters: 6 pose $(\mathbf{R}, \mathbf{t})$ + 3 scale $(\boldsymbol{\alpha})$ + 2 shape $(\boldsymbol{\epsilon})$
- Probability of existence: $\gamma \in [0, 1]$

# Network Architecture



# Loss Function

**Overall Loss:**

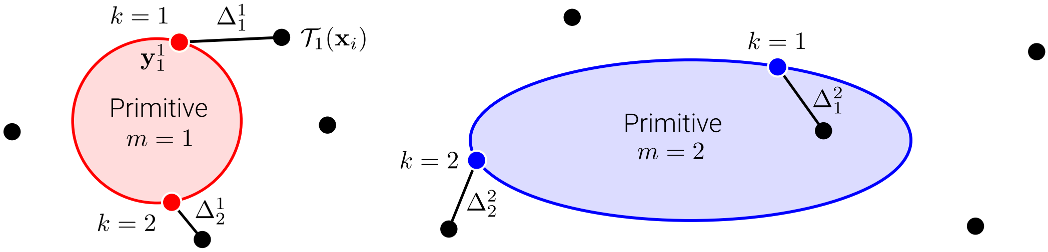
$$\mathcal{L}(\mathbf{P},\mathbf{X}) = \mathcal{L}_{P\rightarrow X}(\mathbf{P},\mathbf{X}) + \mathcal{L}_{X\rightarrow P}(\mathbf{X},\mathbf{P}) + \mathcal{L}_{\gamma}(\mathbf{P})$$

**Composed of:**

- $\mathcal{L}_{P\rightarrow X}(\mathbf{P},\mathbf{X})$: Primitive-to-Pointcloud Loss
- $\mathcal{L}_{X\rightarrow P}(\mathbf{X},\mathbf{P})$: Pointcloud-to-Primitive Loss
- $\mathcal{L}_{\gamma}(\mathbf{P})$: Existence and Parsimony Loss

Paschalidou, Ulusoy and Geiger: Superquadrics Revisited: Learning 3D Shape Parsing beyond Cuboids. CVPR, 2019.

# Primitive-to-Pointcloud Loss




$$\mathcal{L}_{P\to X}^m(\mathbf{P},\mathbf{X}) = \frac{1}{K}\sum_{k=1}^{K}\Delta_k^m$$

$$\Delta_k^m = \min_{i=1,..,N} \|\mathcal{T}_m(\mathbf{x}_i) - \mathbf{y}_k^m\|_2$$

$$\mathcal{L}_{P\to X}(\mathbf{P},\mathbf{X}) = \mathbb{E}_{p(\mathbf{z})}\left[\sum_{m|z_m=1}\mathcal{L}_{P\to X}^m(\mathbf{P},\mathbf{X})\right] = \sum_{m=1}^{M}\gamma_m\,\mathcal{L}_{P\to X}^m(\mathbf{P},\mathbf{X})$$

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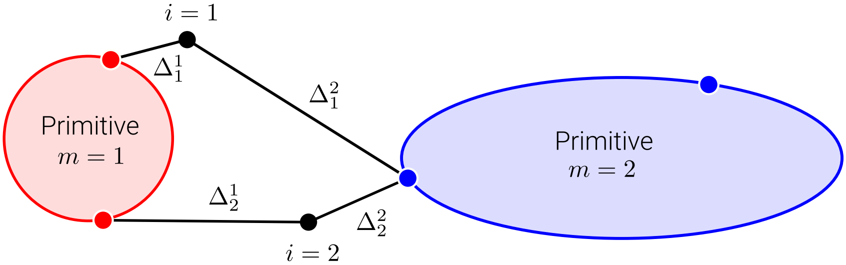
# Pointcloud-to-Primitive Loss




$$\mathcal{L}^i_{X \to P}(\mathbf{X}, \mathbf{P}) = \min_{m | z_m = 1} \Delta_i^m$$

$$\Delta_i^m = \min_{k=1,..,K} \| \mathcal{T}_m(\mathbf{x}_i) - \mathbf{y}_k^m \|_2$$

$$\mathcal{L}_{X \to P}(\mathbf{X}, \mathbf{P}) = \mathbb{E}_{p(\mathbf{z})} \left[ \sum_{\mathbf{x}_i \in \mathbf{X}} \mathcal{L}^i_{X \to P}(\mathbf{X}, \mathbf{P}) \right]$$

$$= \sum_{\mathbf{x}_i \in \mathbf{X}} \sum_{m=1}^{M} \Delta_i^m \, \gamma_m \prod_{\bar{m}=1}^{m-1} (1 - \gamma_{\bar{m}})$$

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# Existence and Parsimony Loss

$$\mathcal{L}_{\gamma}(\mathbf{P}) \;=\; \max\left(1-\sum_{m=1}^{M}\gamma_m, 0\right) \;+\; \beta\sqrt{\sum_{m=1}^{M}\gamma_m}$$

- First term: Enforces at least one primitive to exist
- Second term: Encourages parsimony

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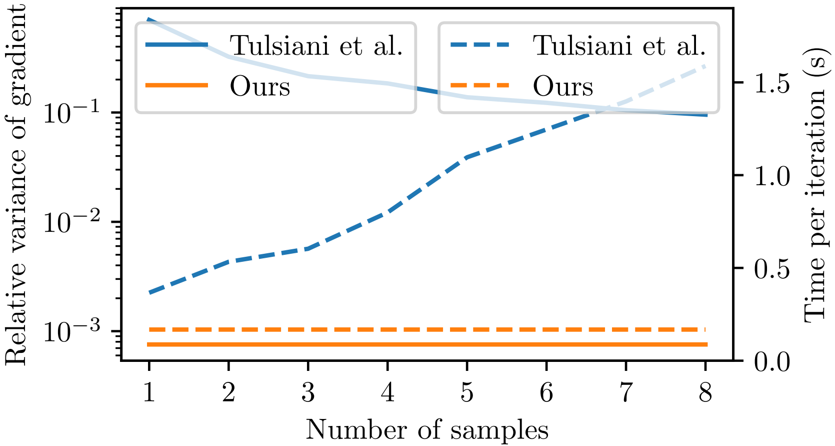
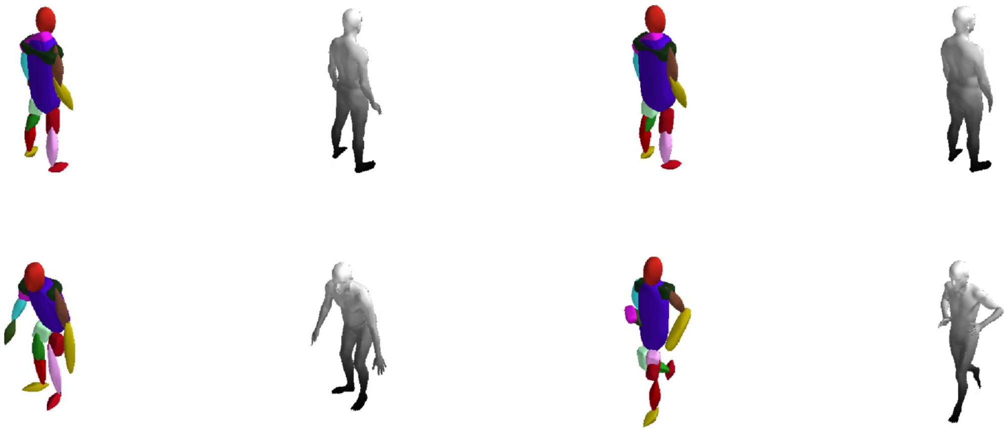
# Comparison to Tulsiani et al./ REINFORCE



# Results



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# Summary

# Thank you!

http://autonomousvision.github.io

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