中国科学技术大学
University of Science and Technology of China

GAMES102

GAMES 102在线课程

几何建模与处理基础

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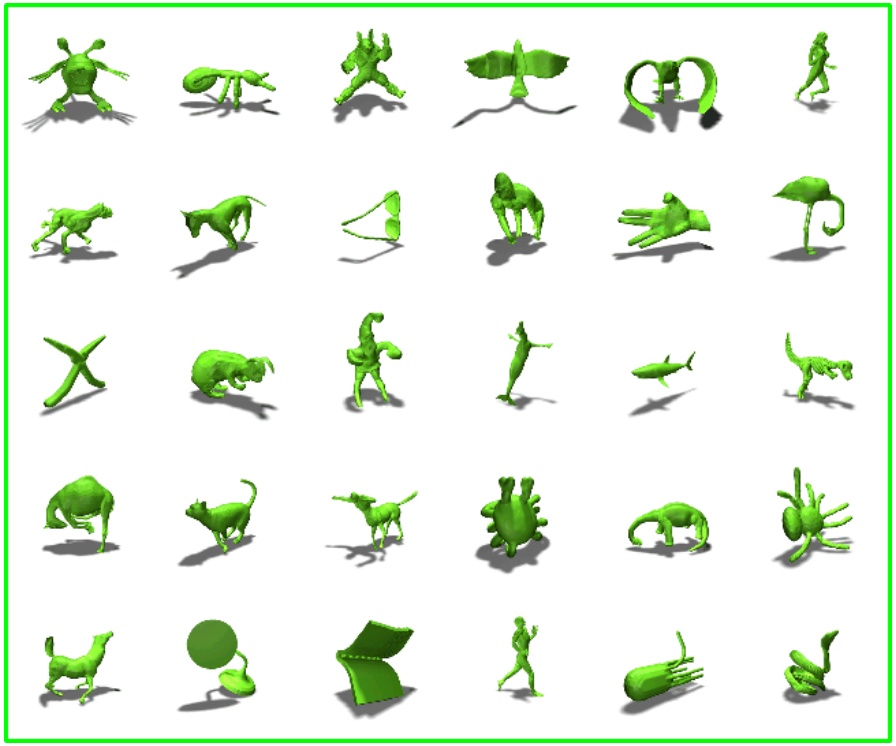
GAMES102

GAMES 102在线课程：几何建模与处理基础

形状分析与理解

Recap: 3D Content Creation

- Surface reconstruction
- Geometric modeling
- Geometry processing
- Creative generation
- …



There are lots of 3D models available…

Princeton Shape Benchmark

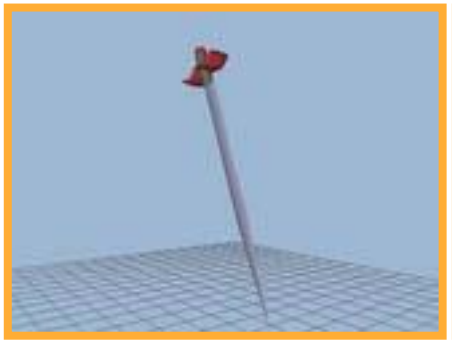
- 900+ models, 90 classes

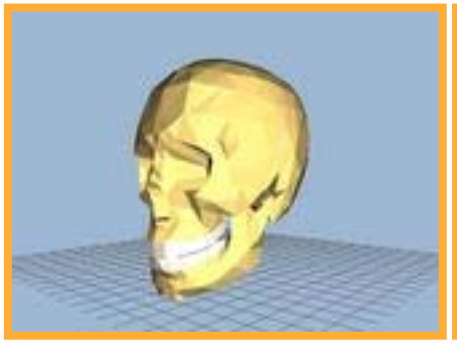

14 biplanes


50 human bipeds


7 dogs


17 fish


16 swords

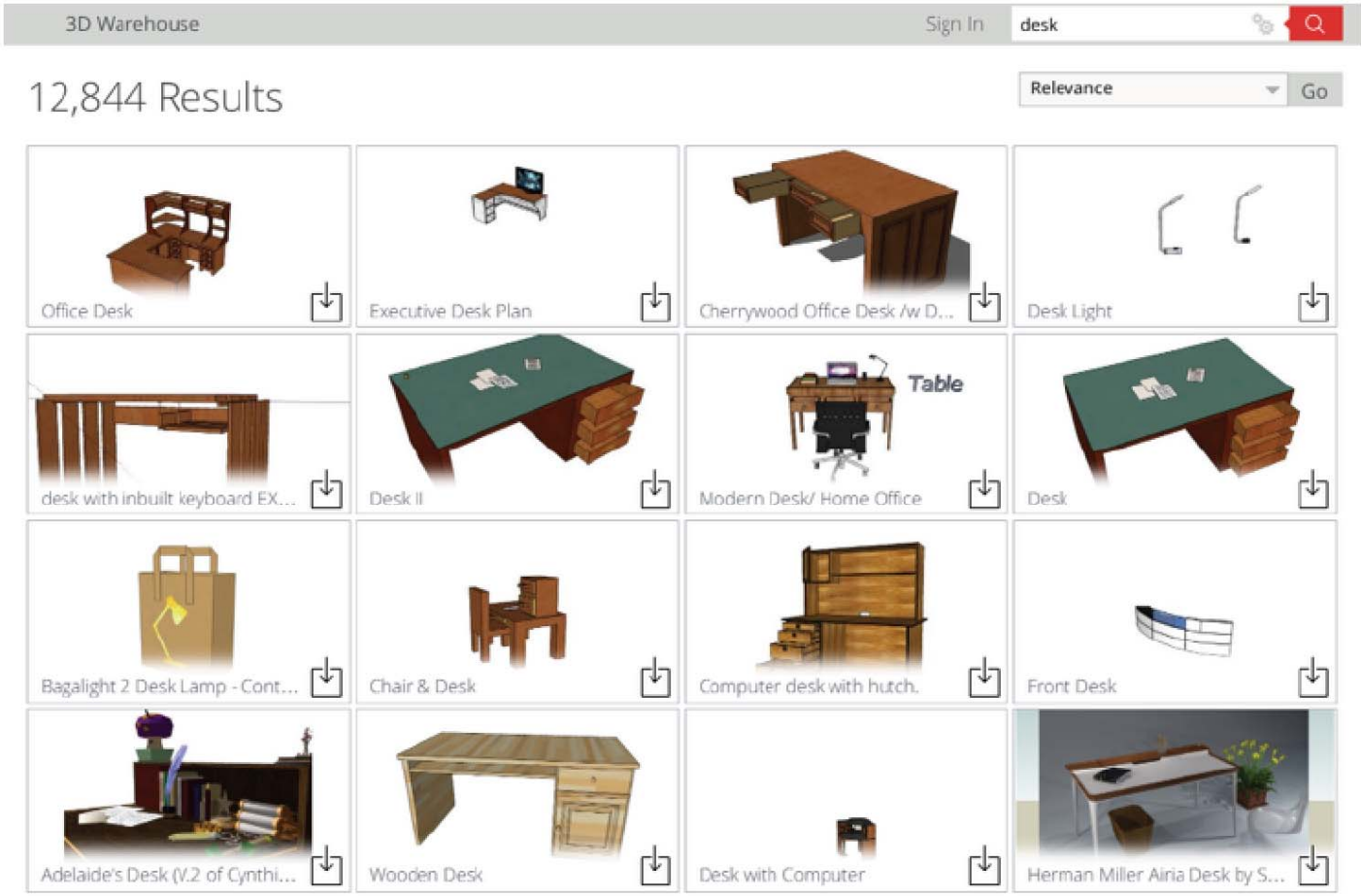

6 skulls


15 desk chairs


13 electric guitars

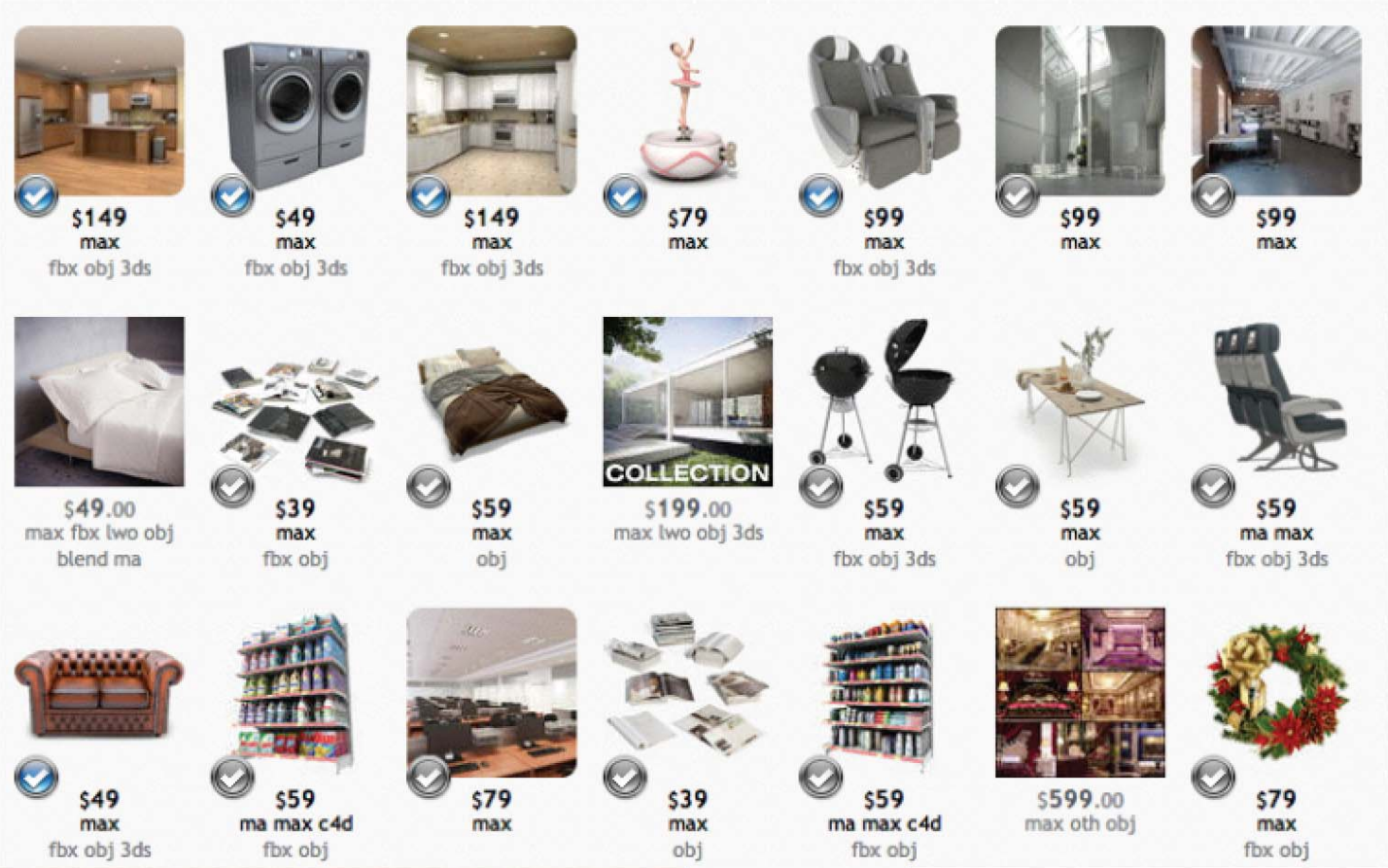
http://www.shape.cs.princeton.edu/benchmark/

Repositories of 3D Models



Trimble 3D Warehouse

Repositories of 3D Models

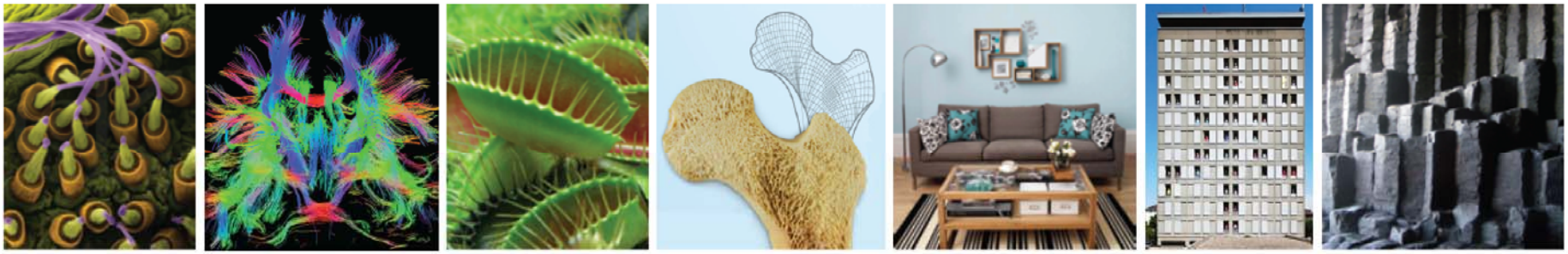


TurboSquid

Digimation

Analyzing and Understanding 3D Contents

- Organize Geometric Data
- Understand Structure and Relationships
- Understand Semantics and Functionality
- Synthesizing New Shapes
- …

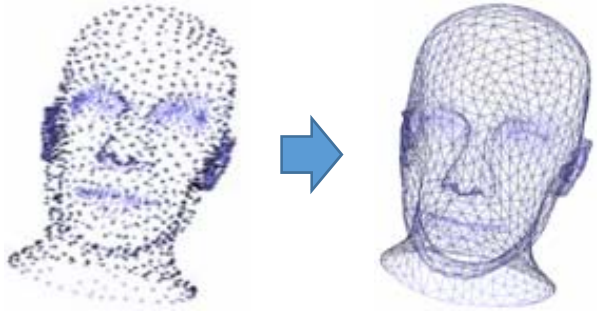


structures in nature

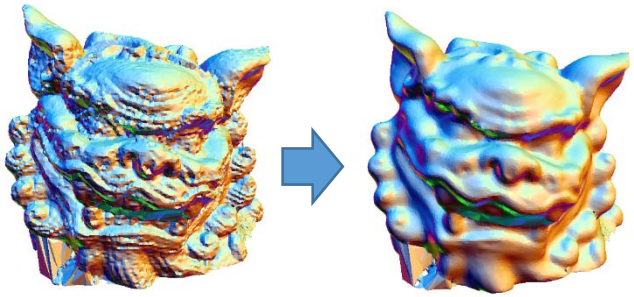
三维几何处理：从局部到全局

局部处理

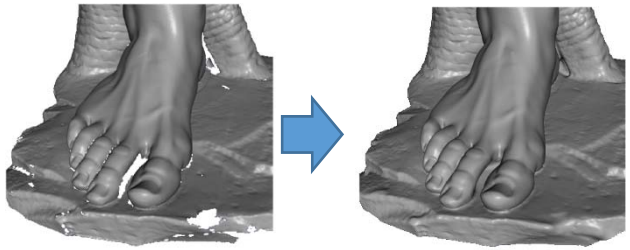
曲面重建



曲面去噪

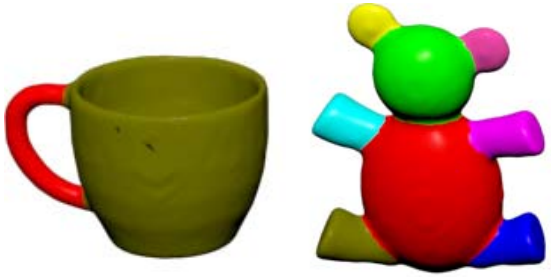


曲面修复

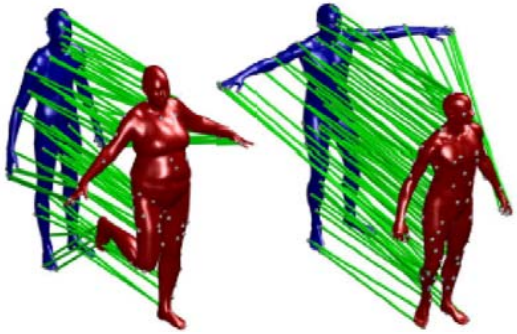


全局理解

语义分割



语义对应



形状检索

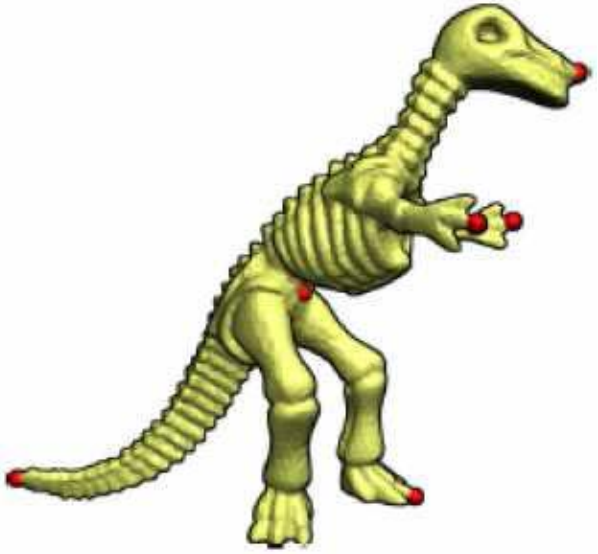
From low- to high-level processing

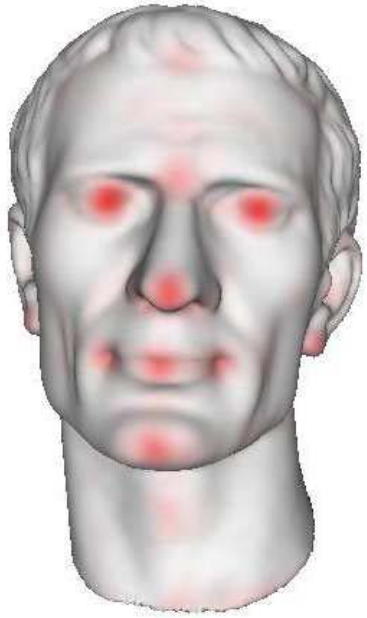
- Local level analysis
  - purely geometry/content-driven
  - mathematical formulation of objectives
  - Examples: curvature and normal estimation, mesh smoothing, simplification, remeshing, parameterization…
- High level analysis
  - non-local analysis
  - not easy to formulate objectives mathematically
  - Semantics is hard!

Problems of Shape Analysis

Understanding Shapes

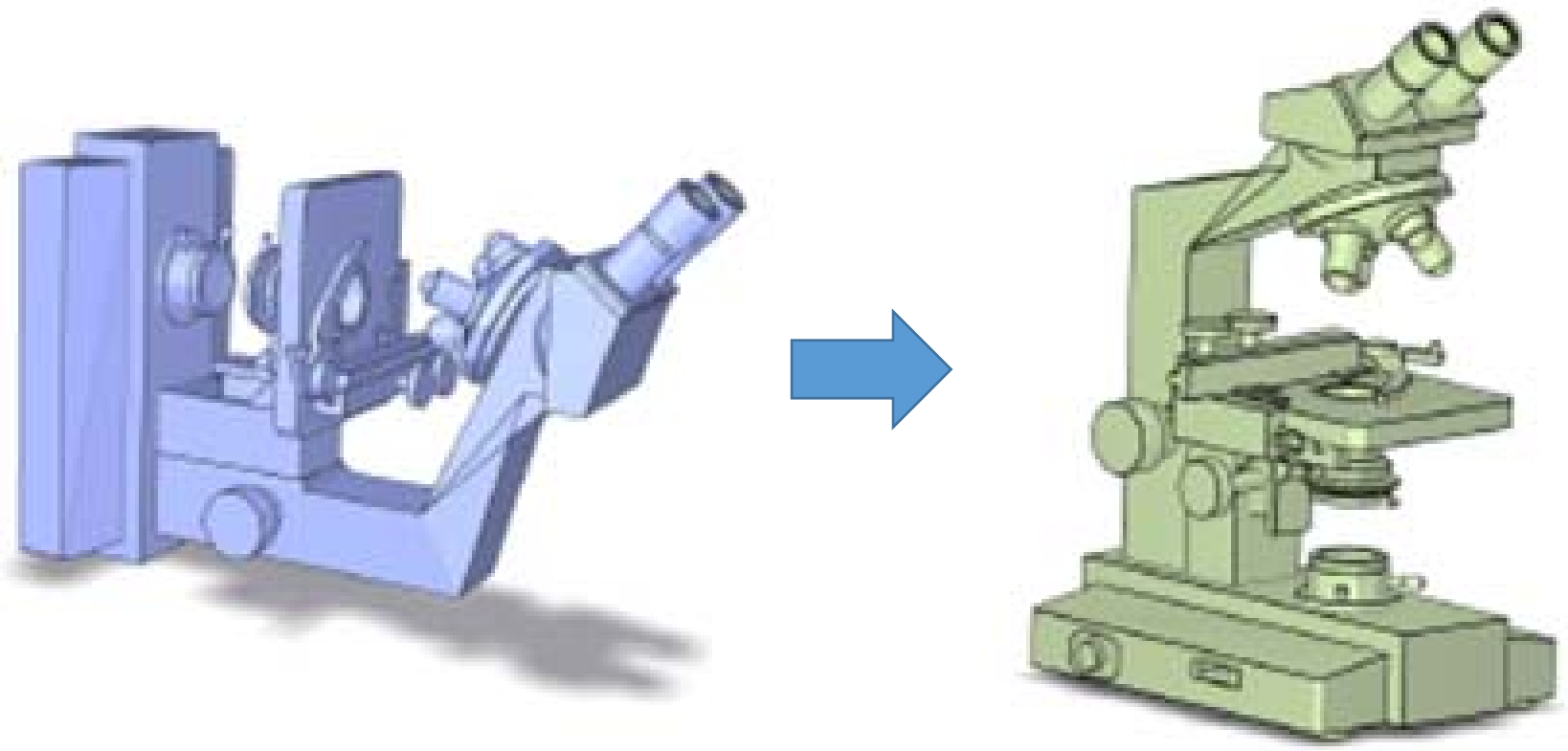
- Shape features
  - Feature points
  - Feature lines
  - Saliency





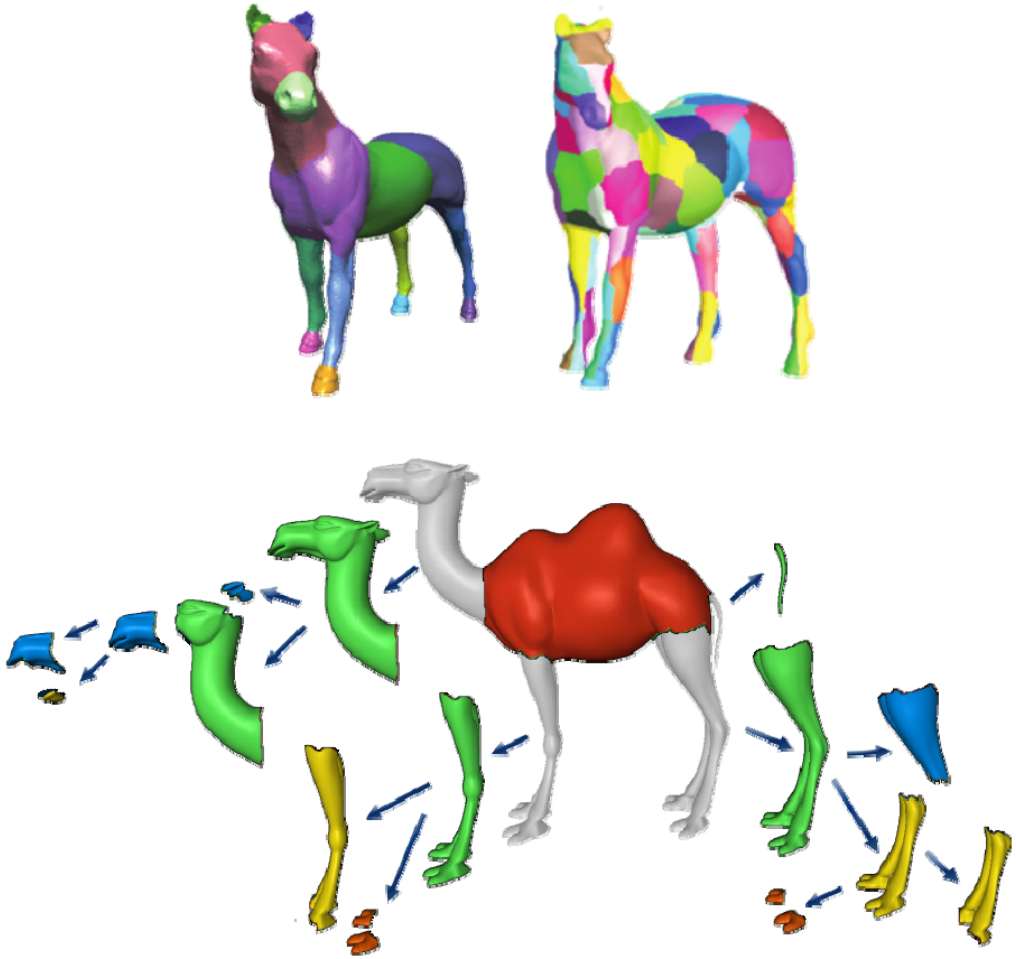
Understanding Shapes

- Alignment (upright)



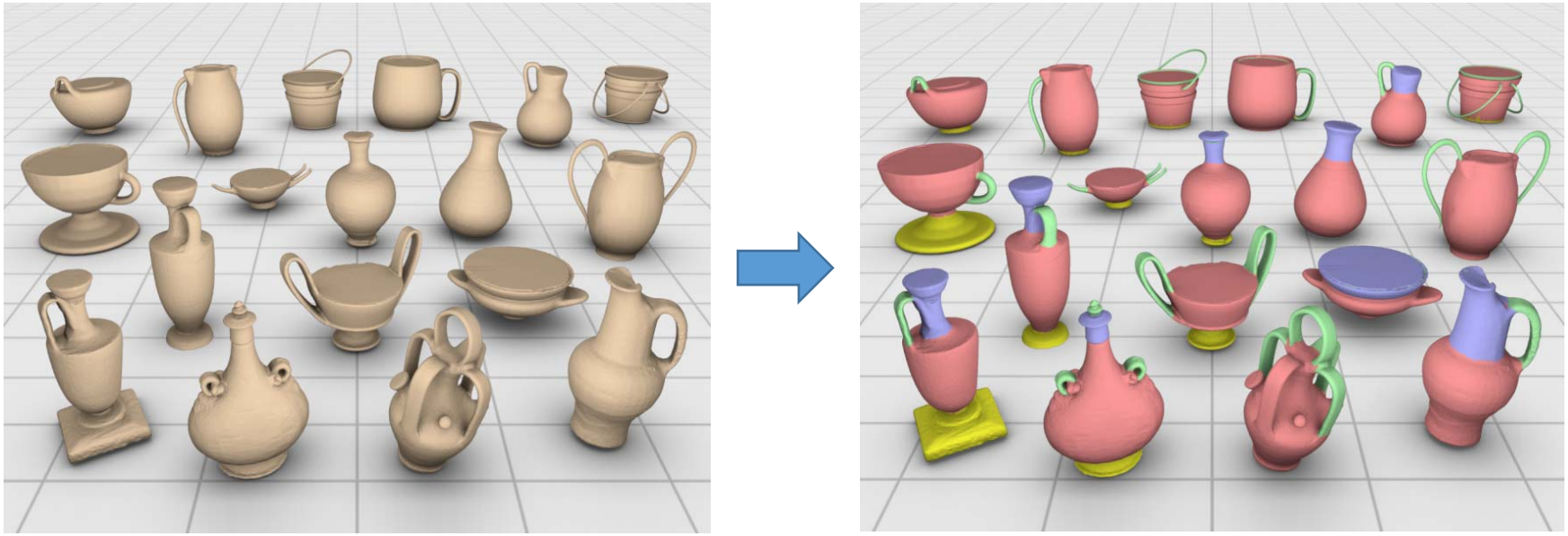
Understanding Shapes

- Shape segmentation (components)



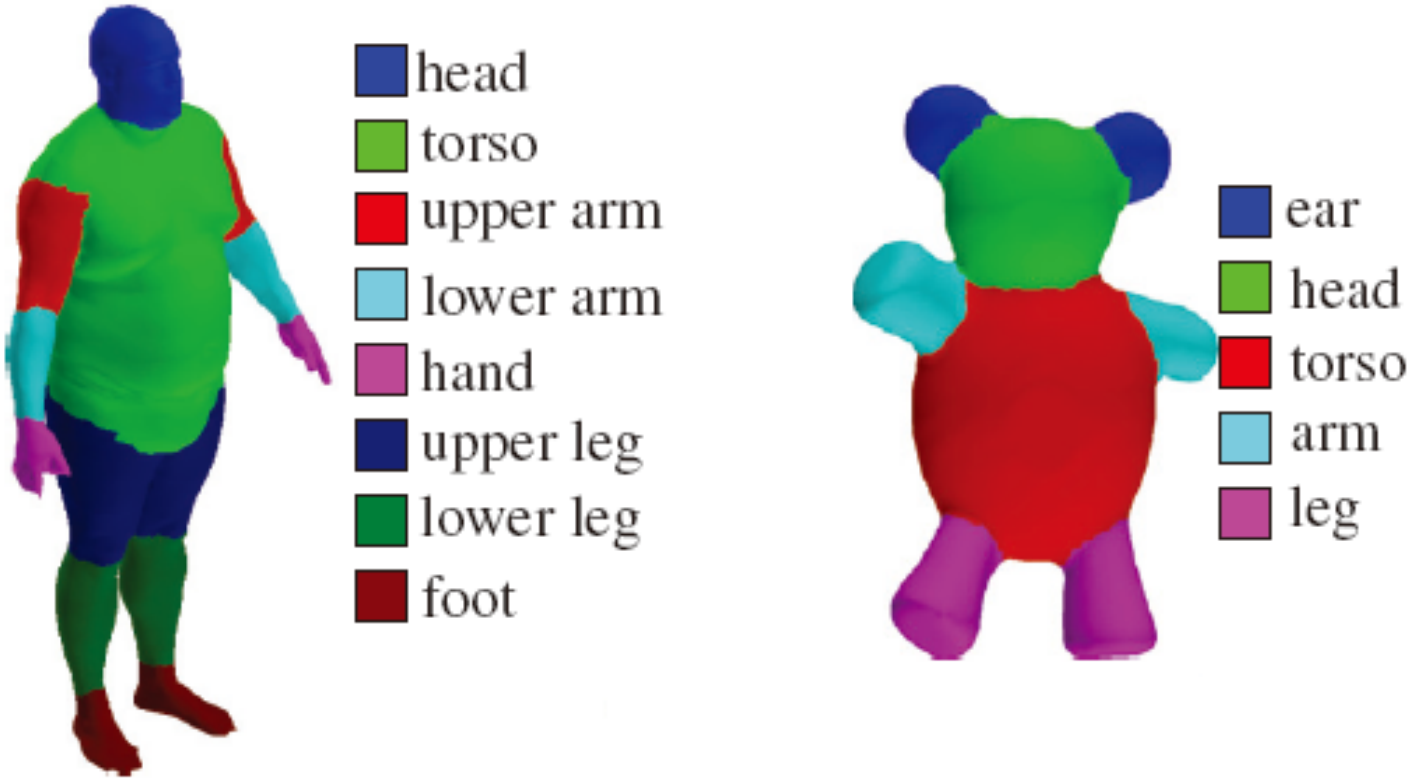
Understanding Shapes

- Co-segmentation of a set of shapes
  - More knowledge can be inferred from multiple shapes rather than an individual shape



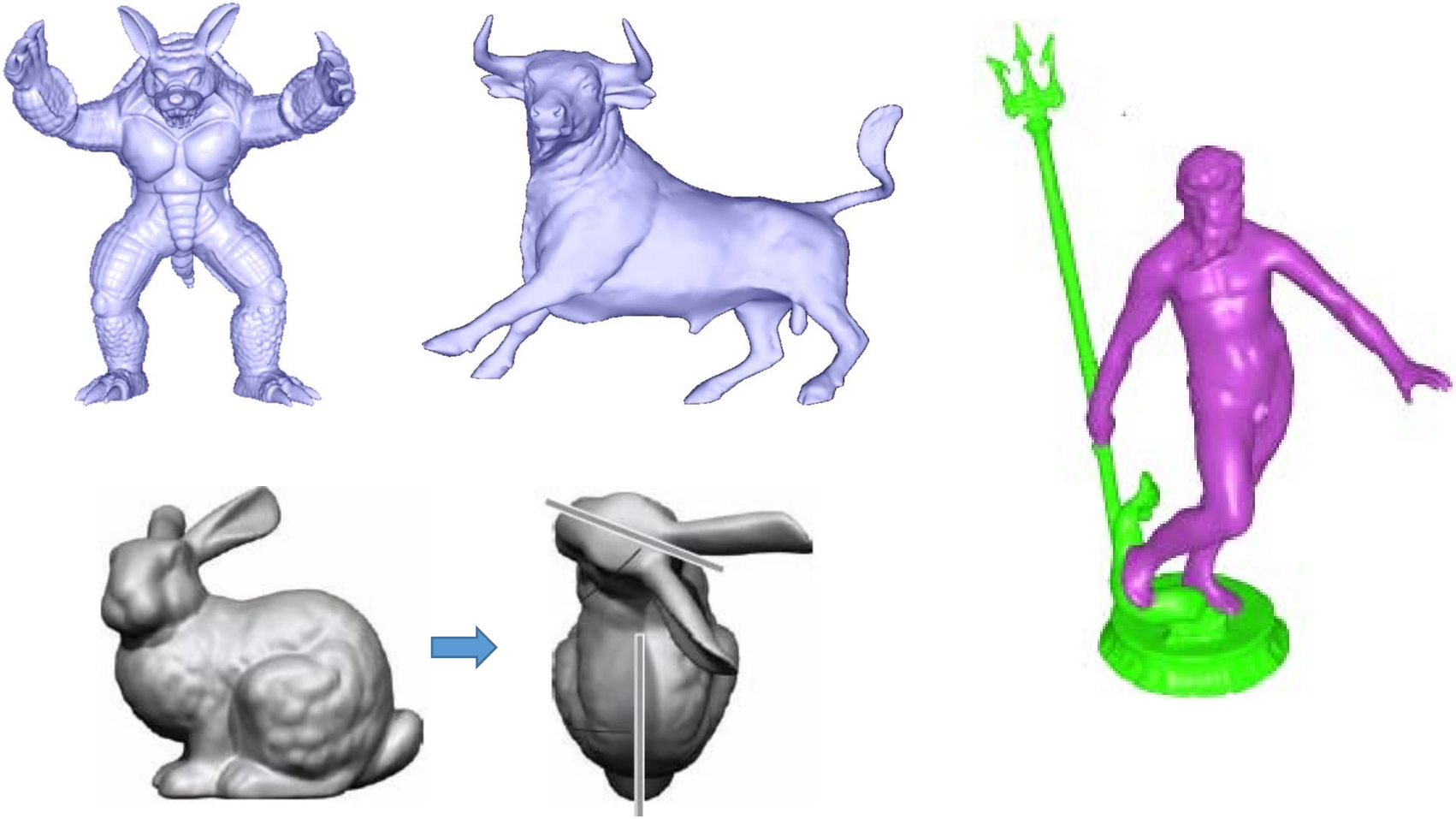
Understanding Shapes

- Labeling



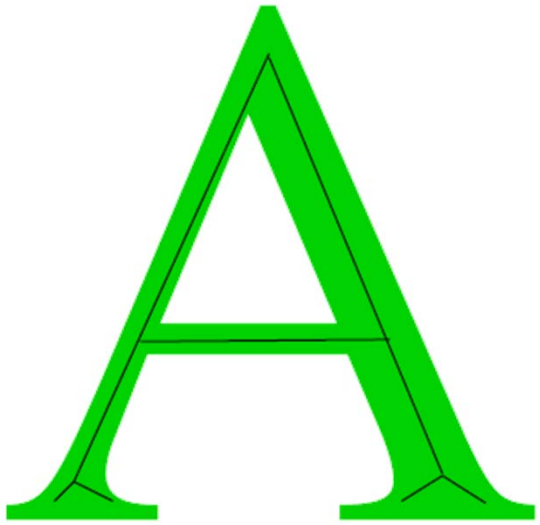
Understanding Shapes

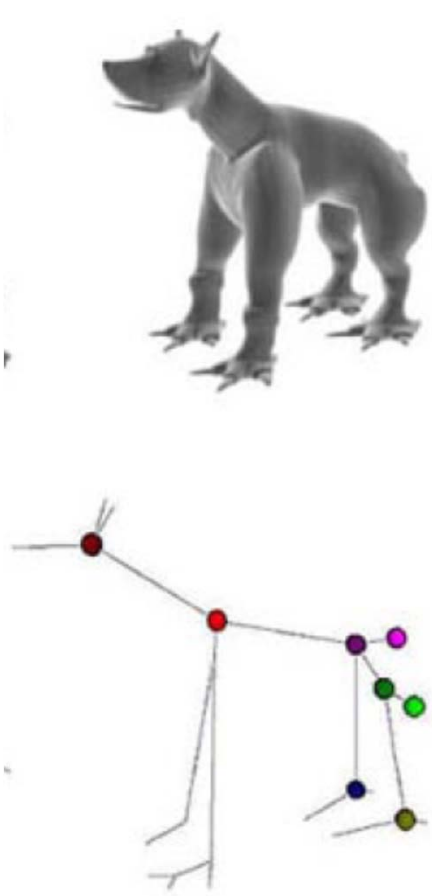
- Symmetries

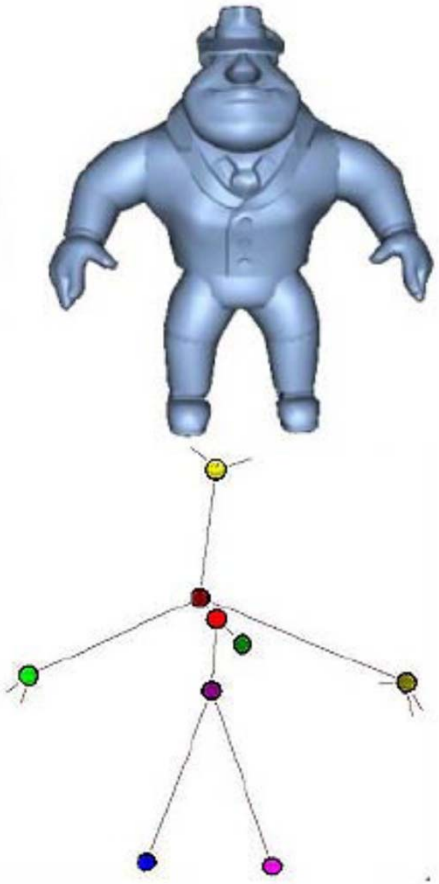


Understanding Shapes

- Skeleton

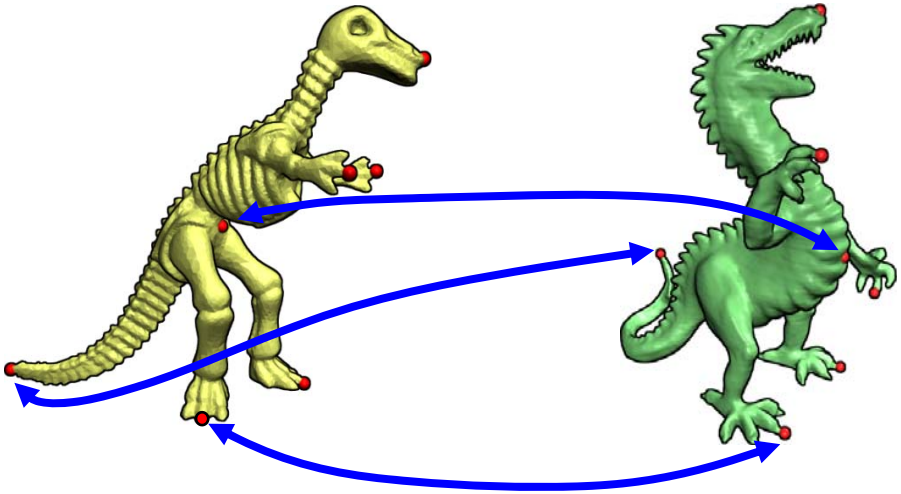






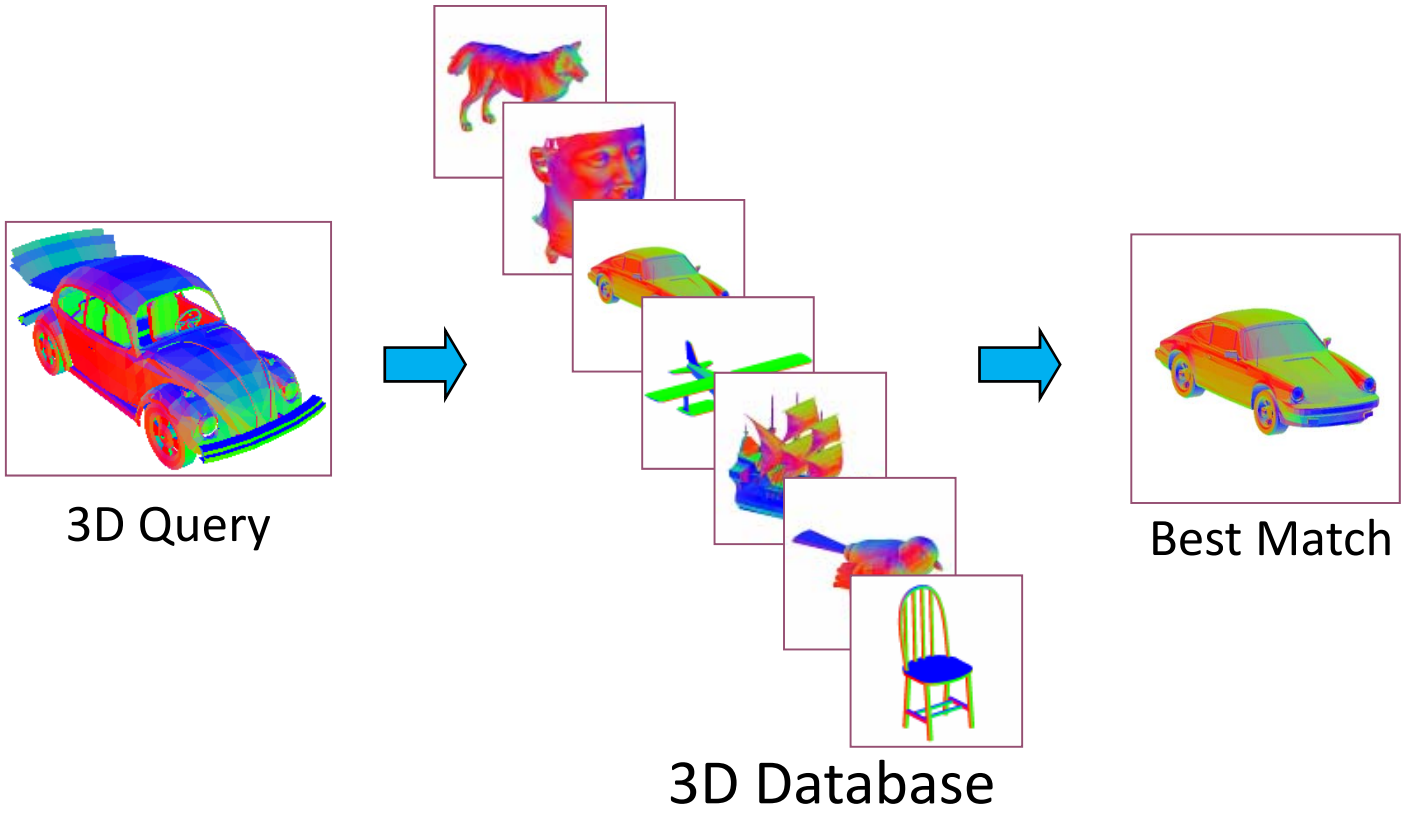
Understanding Shapes

- Shape matching
  - Similarity
  - Correspondences



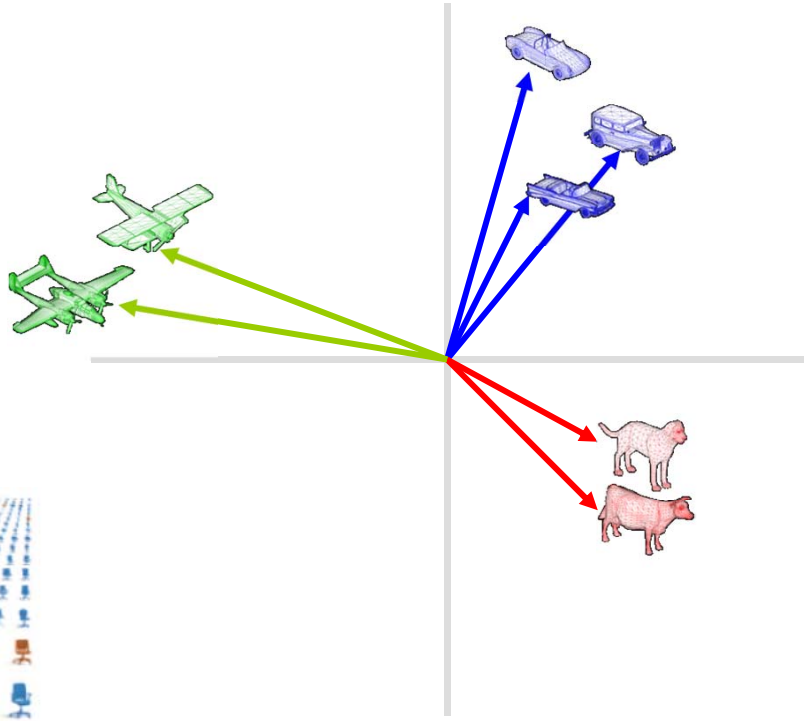
Understanding Shapes

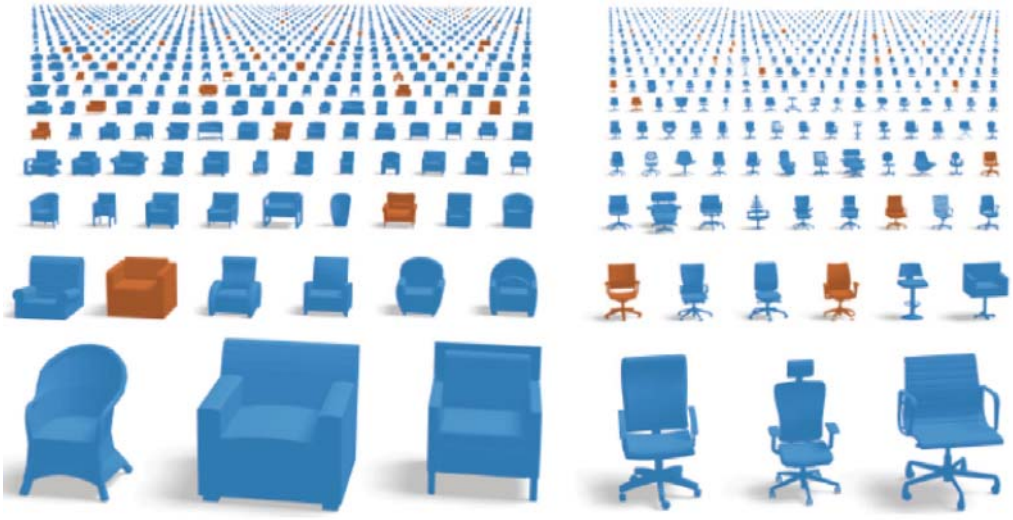
- Shape retrieval



Understanding Shapes

- Classification



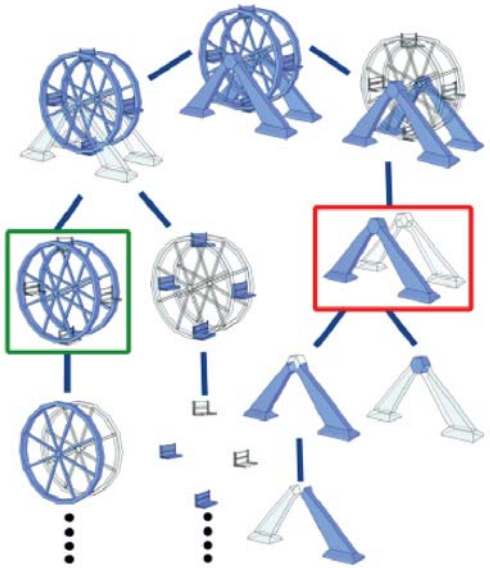


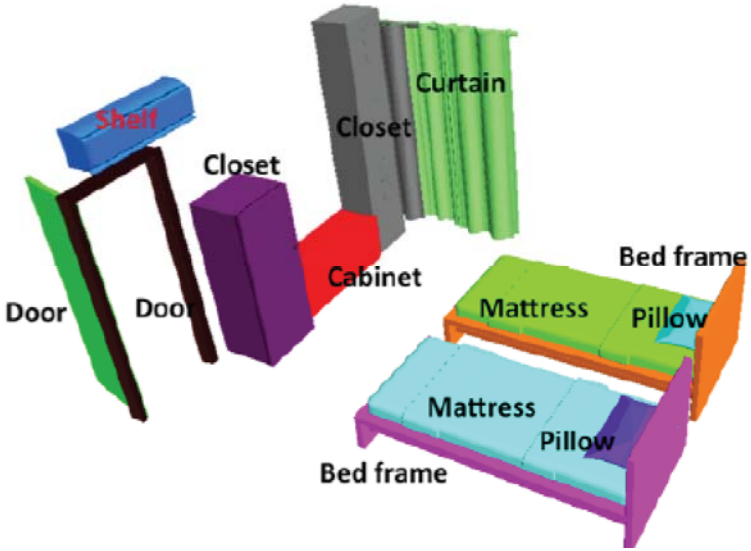
Club

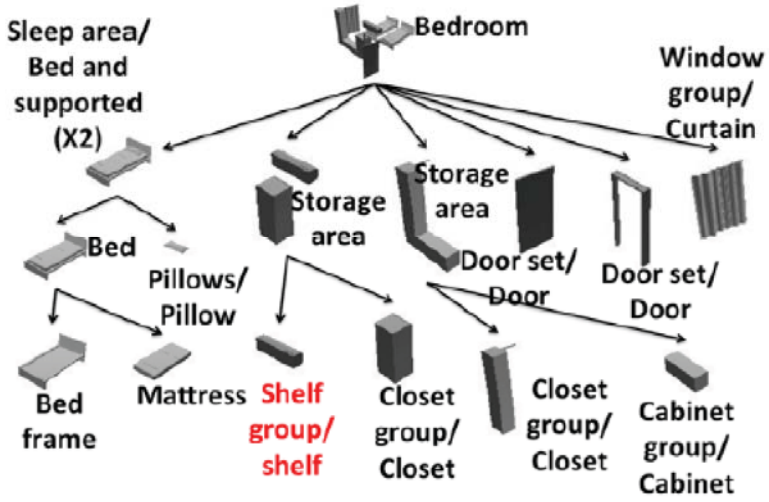
Swivel

Understanding Shapes

- Structures
- Hierarchical structures

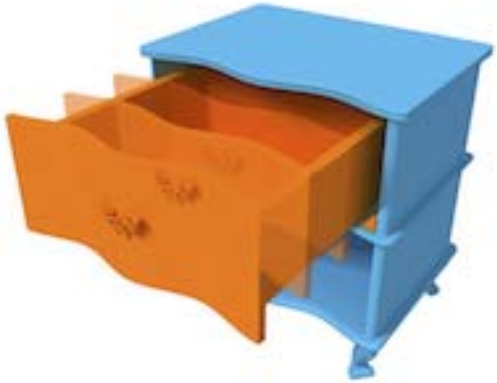


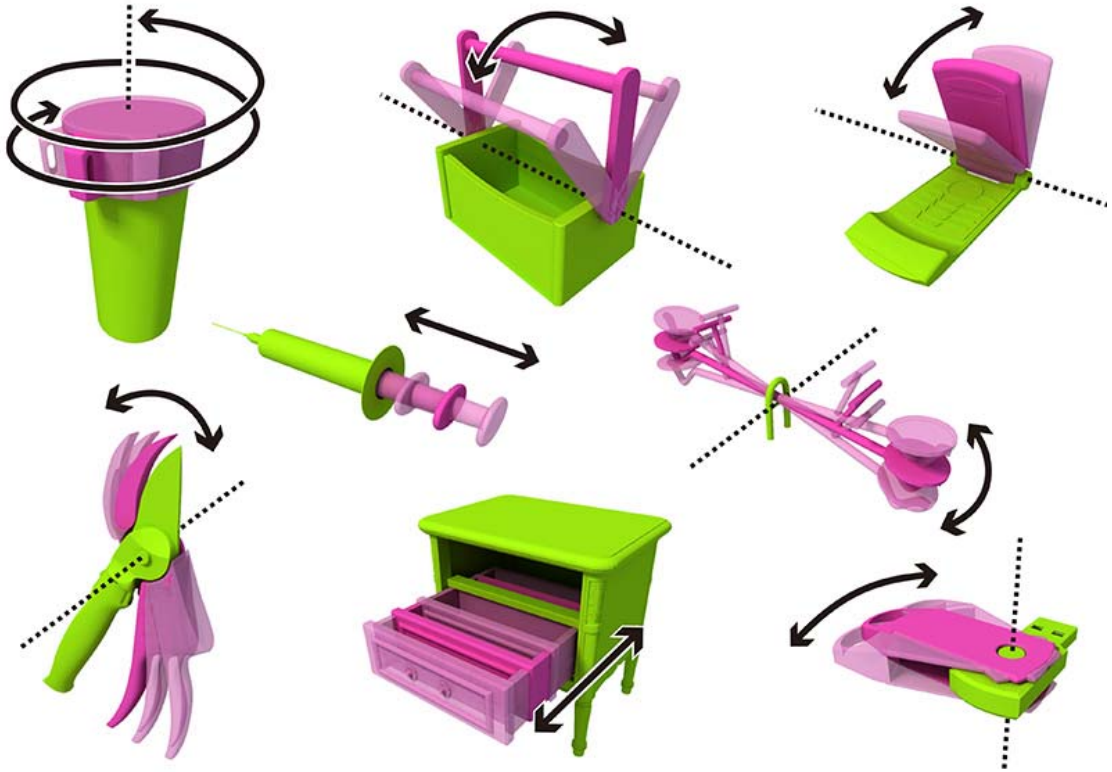




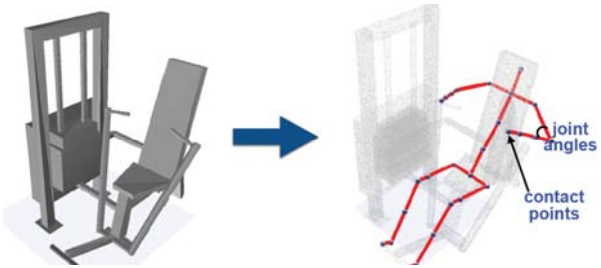
Understanding Shapes

- Functionality

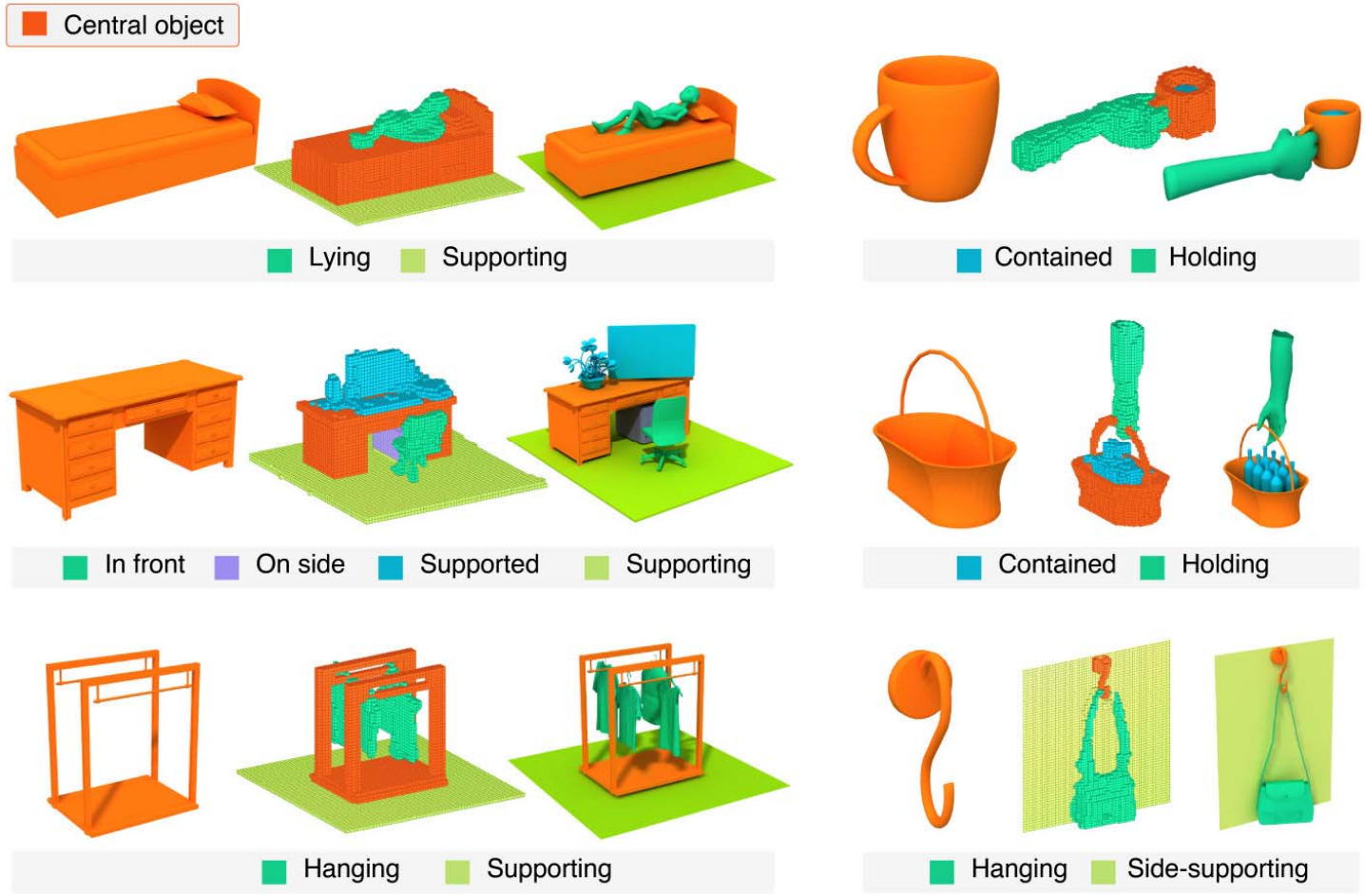




Understanding Shapes

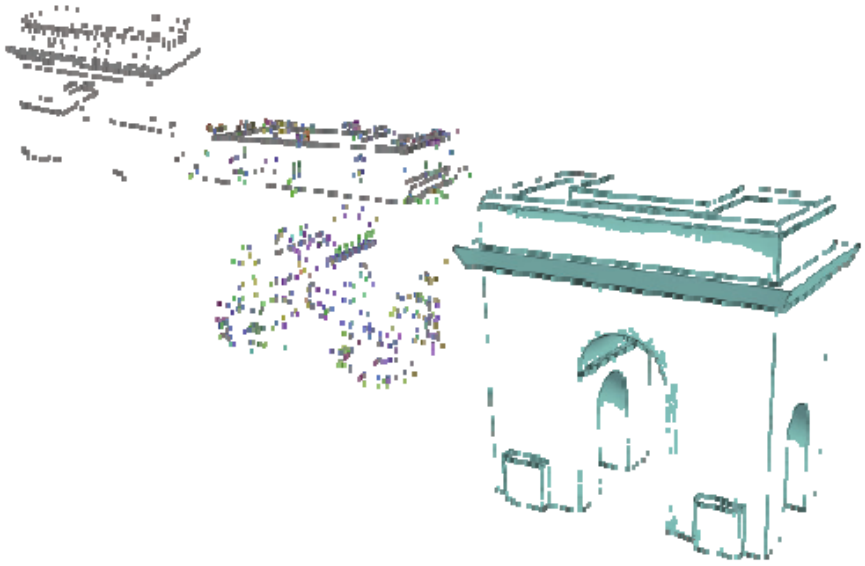


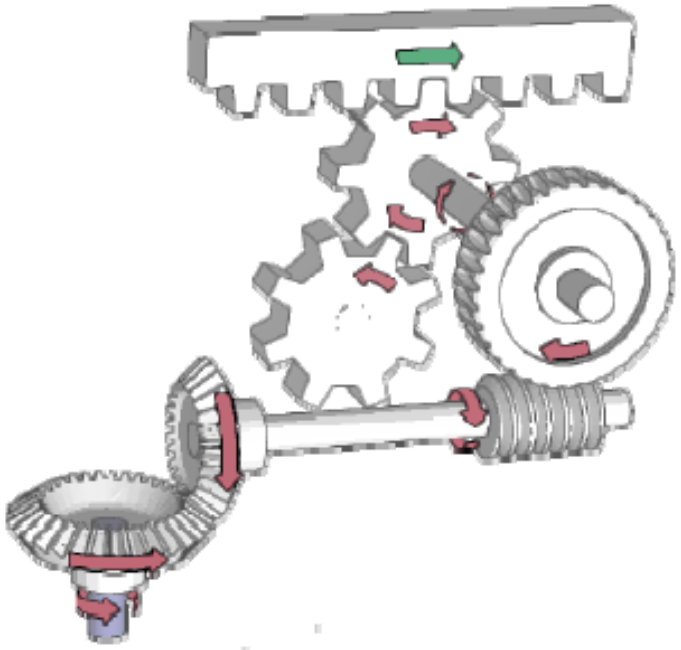
- Object affordance



Understanding Shapes

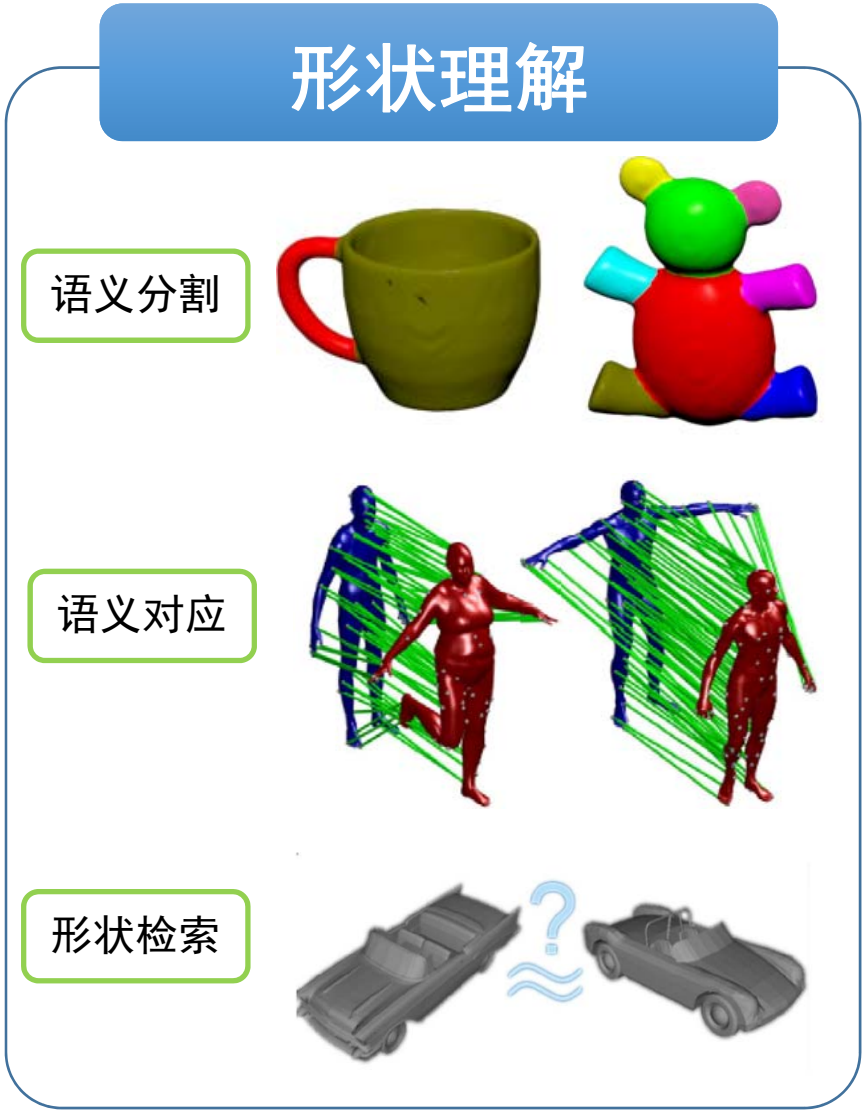
- Abstraction of shapes
  - [Mehra et al. SIGAsia 2009]
- Understanding assemblies
  - [Mitra et al. SIG 2010]



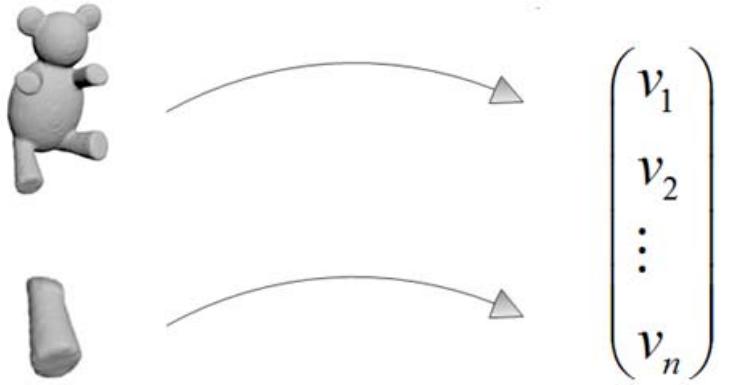


Shape Descriptors

核心问题：形状表征（描述子、特征）(Shape representation/descriptor/feature)

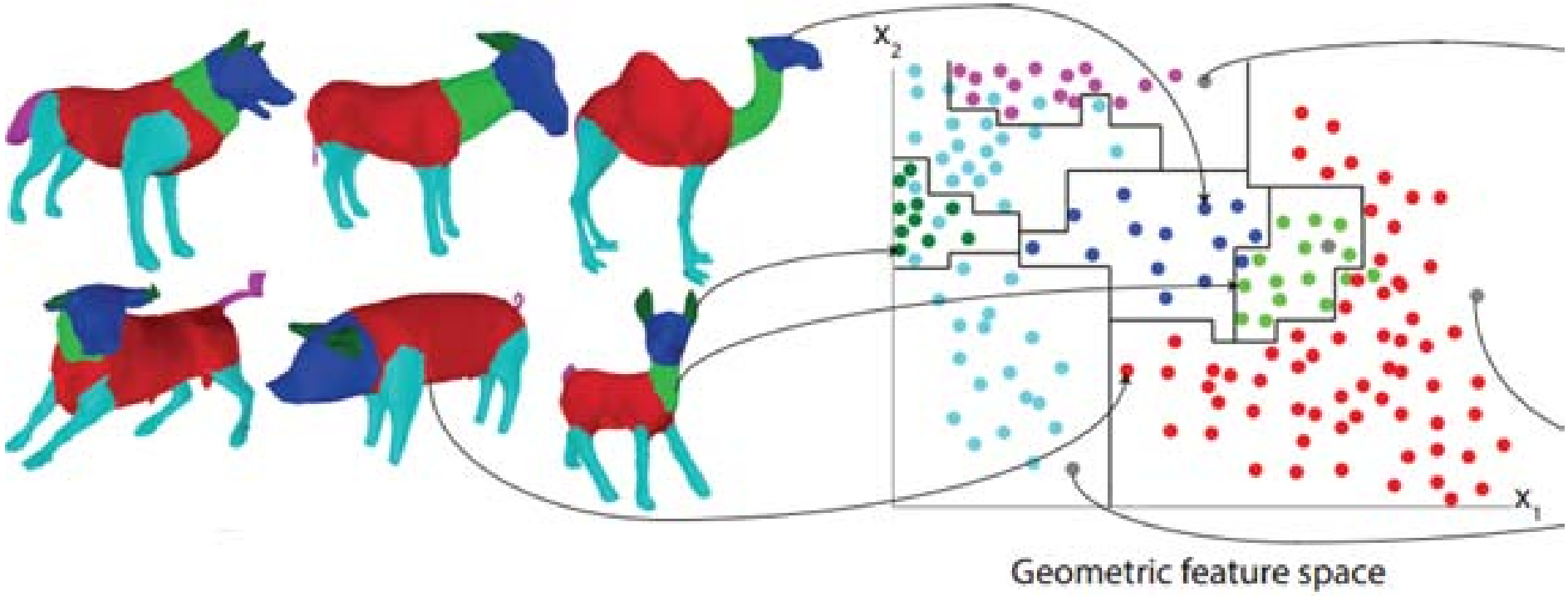


- 如何度量两个三维元素的相似性？
  - 整体形状
    - 全局描述子
  - 局部形状
    - 局部描述子

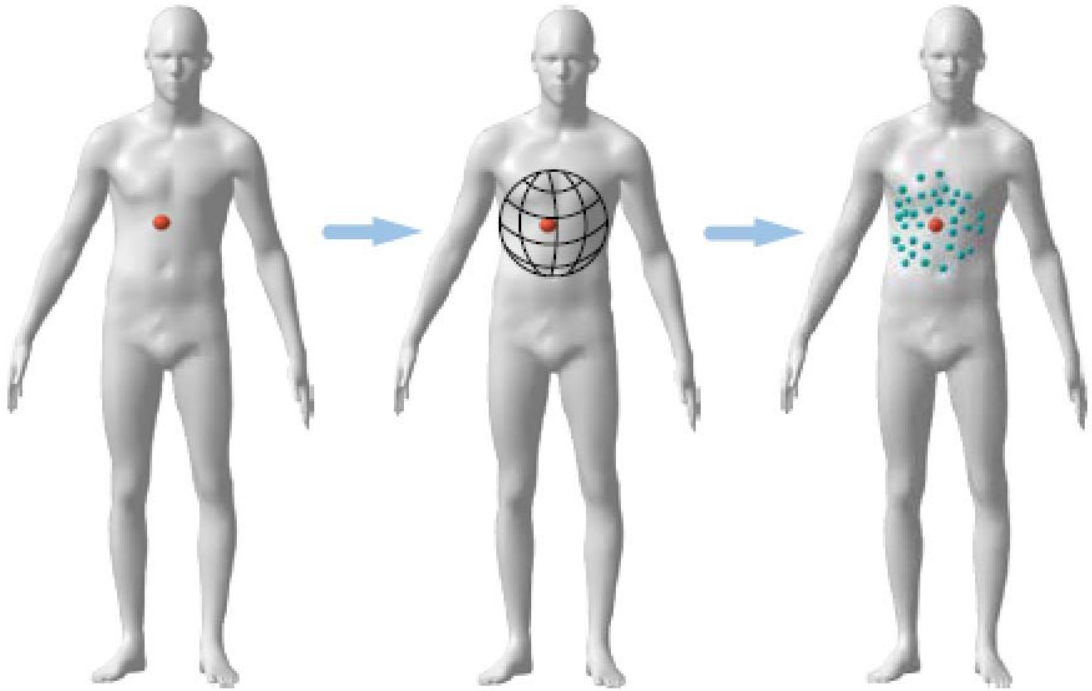


Feature vector

例子：模型分割-根据特征的聚类 (Clustering/Labeling)



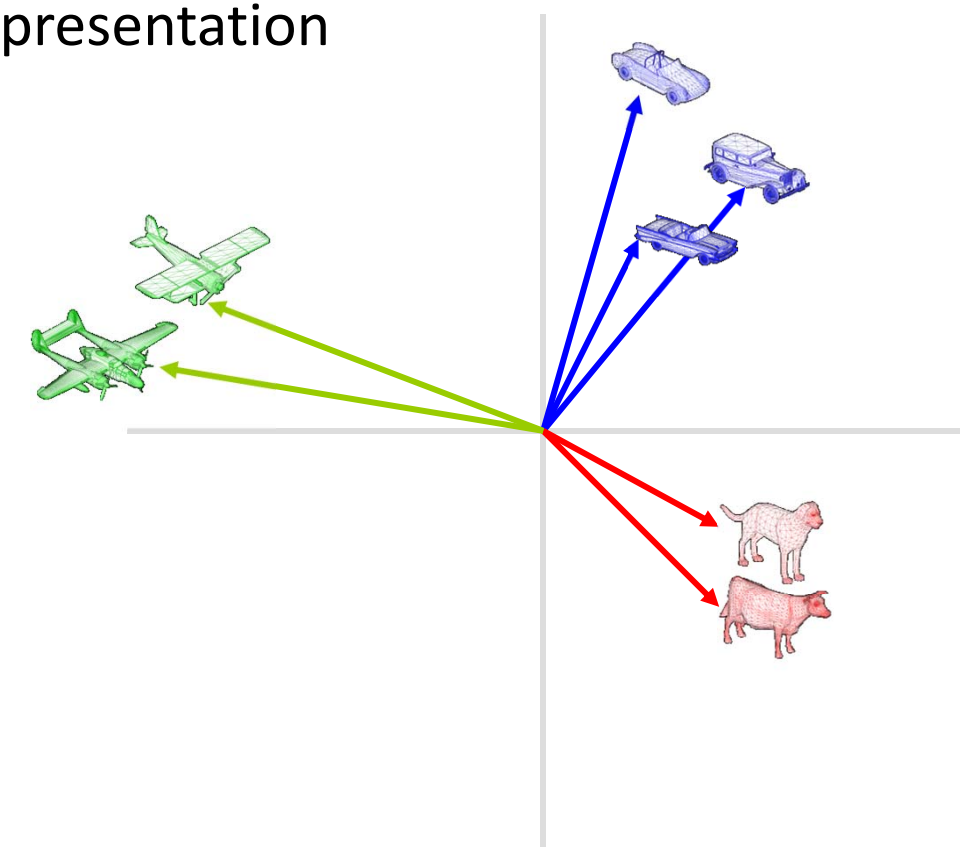
三维数据的信息



- 点坐标(x,y,z)
- 几何量
  - 长度、角度、面积、体积
- 微分量
  - 法向量
  - 曲率
- 拓扑量
  - 连接关系
  - Laplace谱
- 映射度量
  - 雅可比（变形量）
  - 共形比
- …

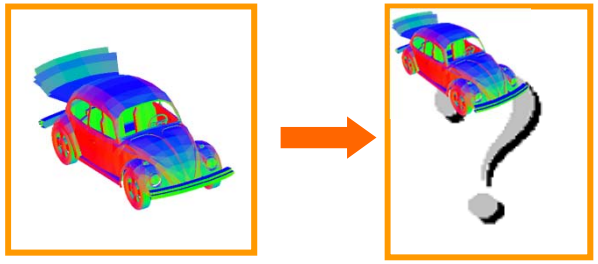
Shape Descriptors

- Shape Descriptors
  - Fixed dimensional vector
  - Independent of model representation
  - Easy to match



Shape Descriptors

- Representation:
  - What can you represent?
  - What are you representing?
- Matching:
  - How do you align?
  - Part or whole matching?



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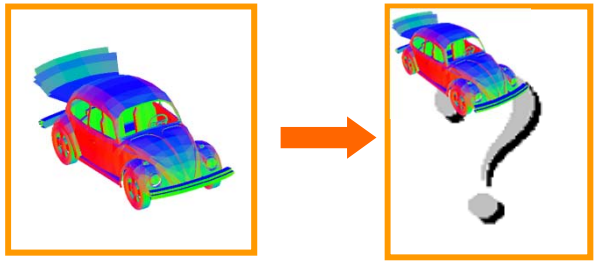
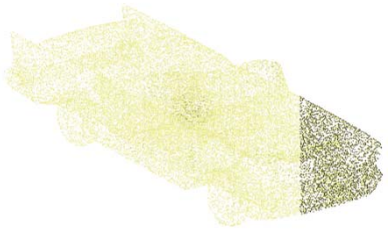
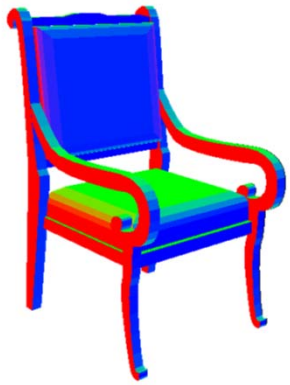




Point Clouds

Polygon Soups



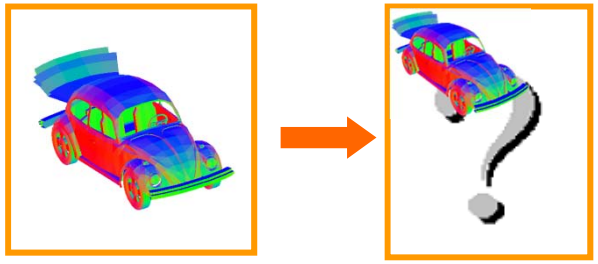
Closed Meshes

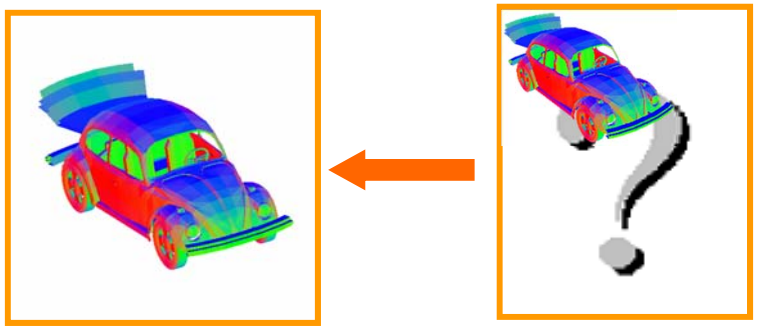
Genus-0 Meshes

Shape Spectrum

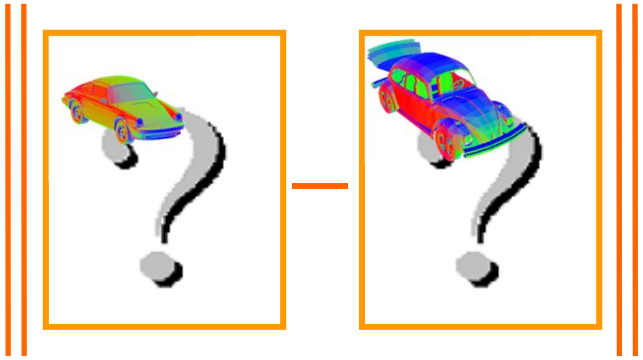
Shape Descriptors

- Representation:
  - What can you represent?
  - What are you representing?
- Matching:
  - How do you align?
  - Part or whole matching?





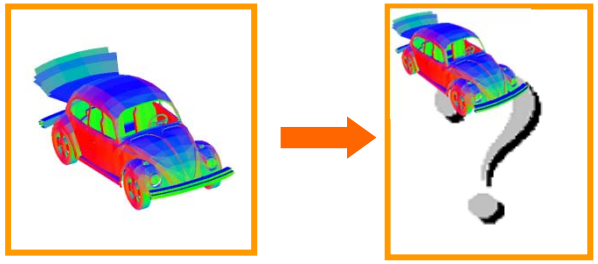
Is the descriptor invertible?

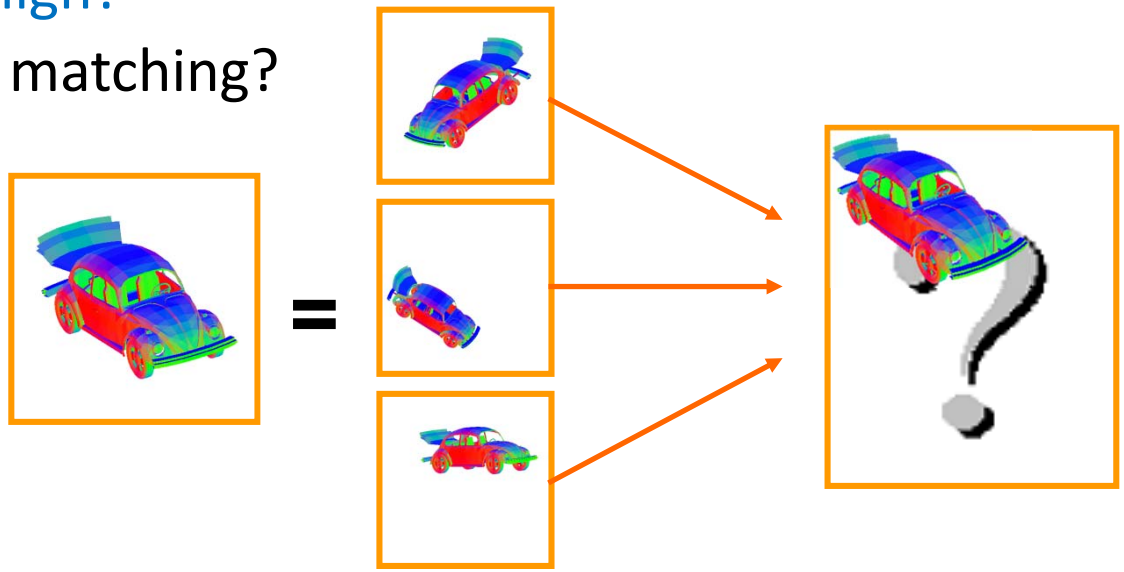


What is represented by the difference in descriptors?

Shape Descriptors

- Representation:
  - What can you represent?
  - What are you representing?
- Matching:
  - How do you align?
  - Part or whole matching?

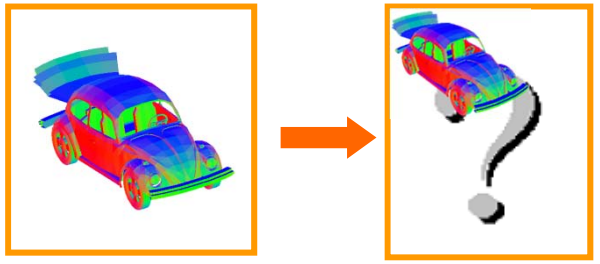


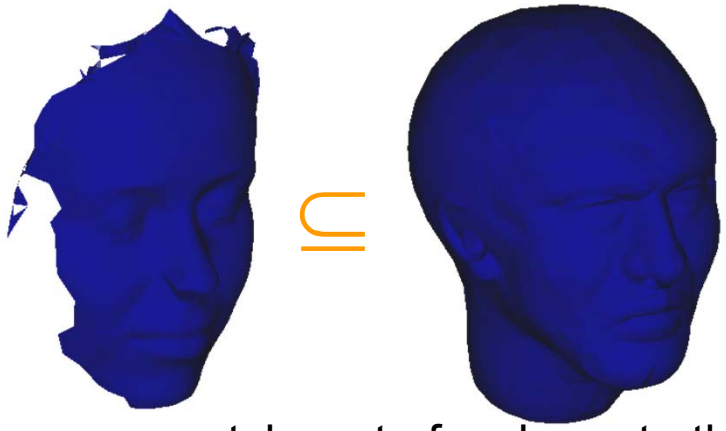


How do you represent models across the space of transformations that don't change the shape?

Shape Descriptors

- Representation:
  - What can you represent?
  - What are you representing?
- Matching:
  - How do you align?
  - Part or whole matching?



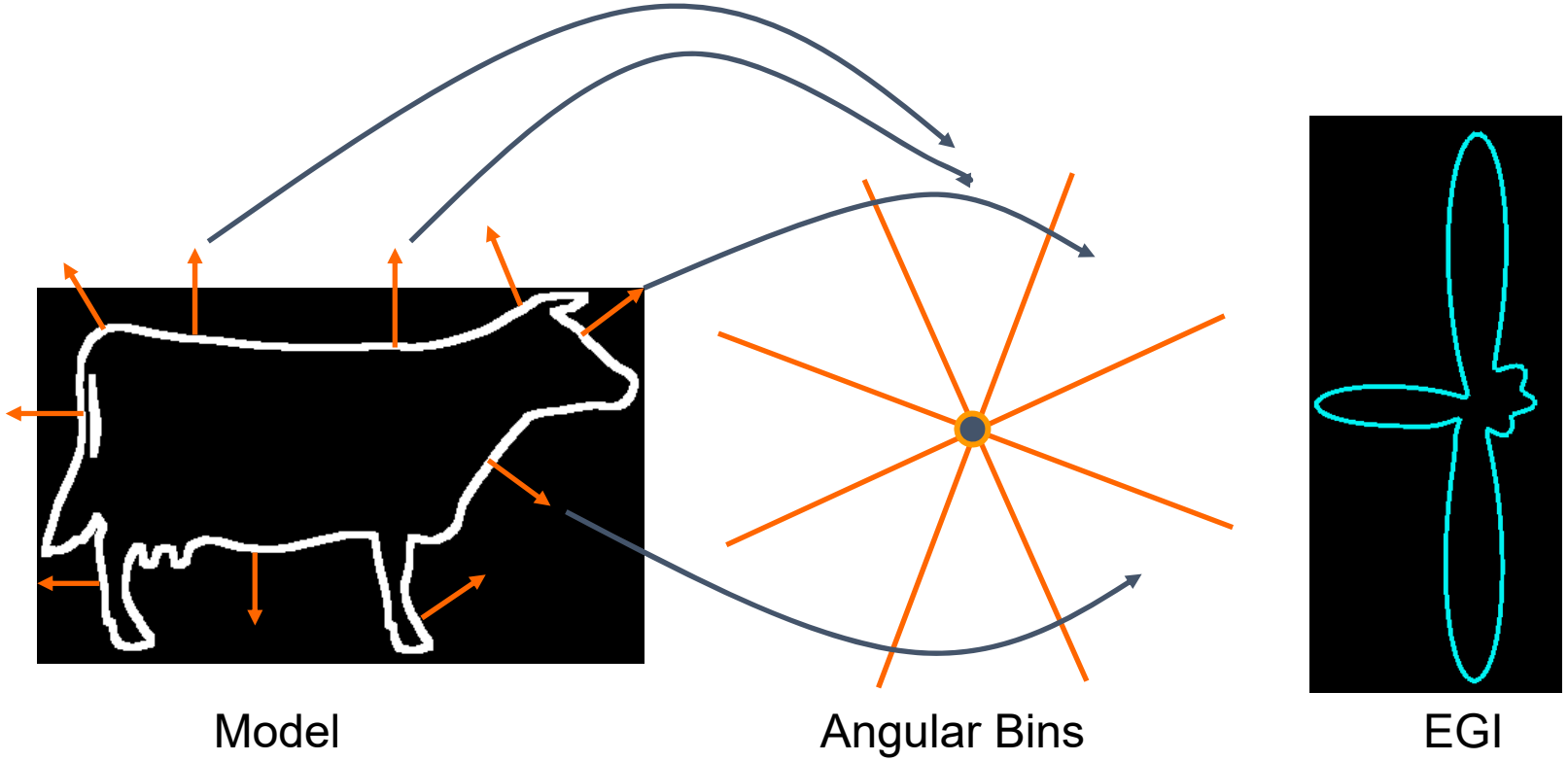


Can you match part of a shape to the whole shape?

Extended Gaussian Image

[Horn, 1984]

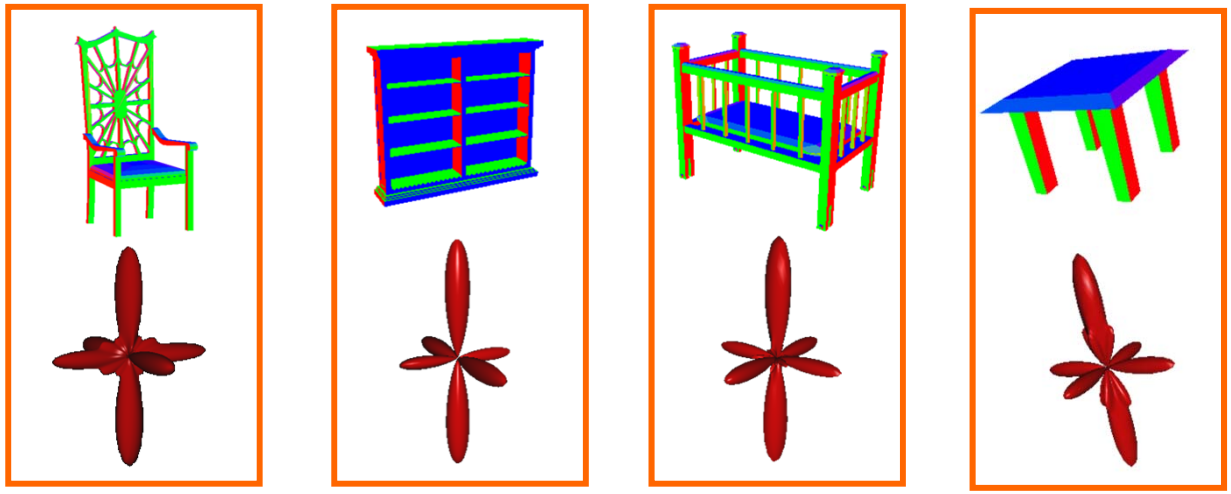
- Represent a model by a spherical function by binning surface normals



Extended Gaussian Image

[Horn, 1984]

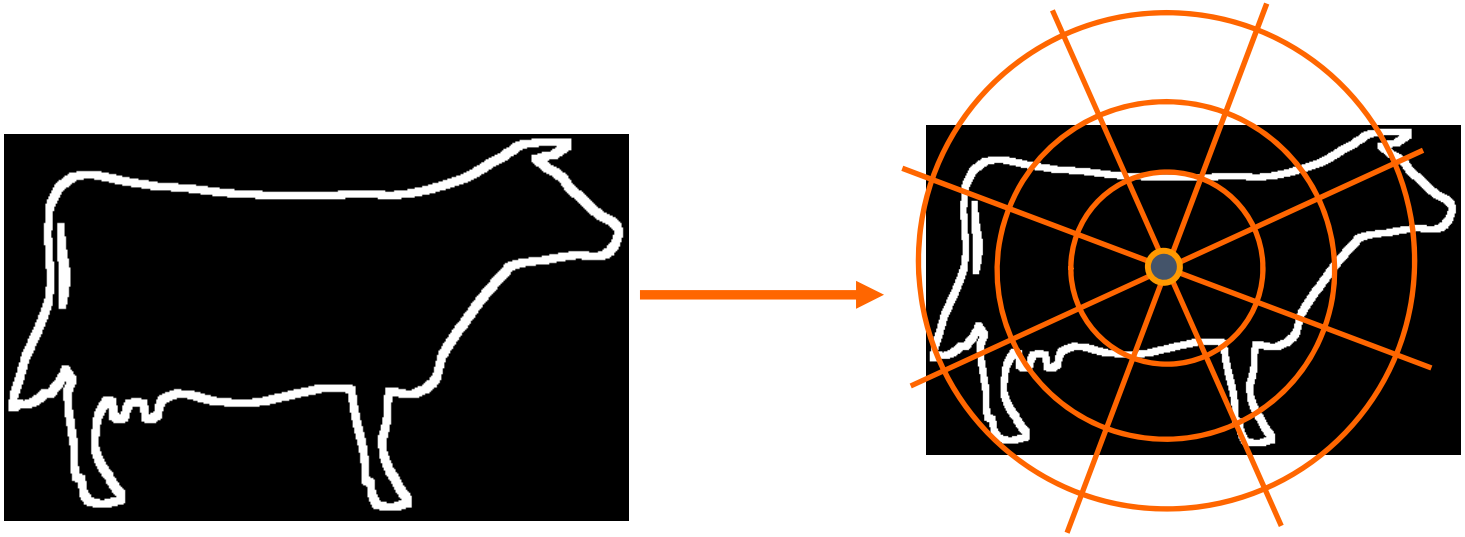
- Properties:
  - Invertible for convex shapes
  - 2D array of information
  - Can be defined for most models
- Limitations:
  - Too much information is lost
  - Normals are sensitive to noise



Shape Histograms

[Ankerst *et al.*, 1999]

- Shape descriptor stores a histogram of how much surface resides at different bins in space



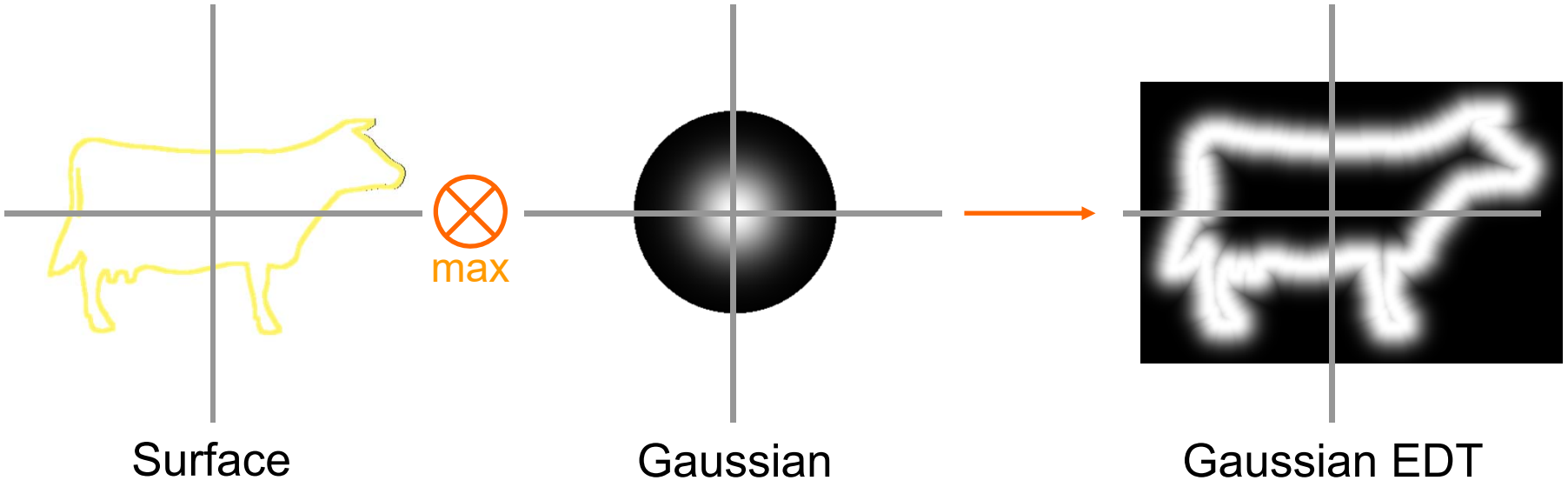
Model

Shape Histogram
(Sectors + Shells)

Gaussian Euclidean Distance Transform

[Kazhdan *et al.*, 2003]

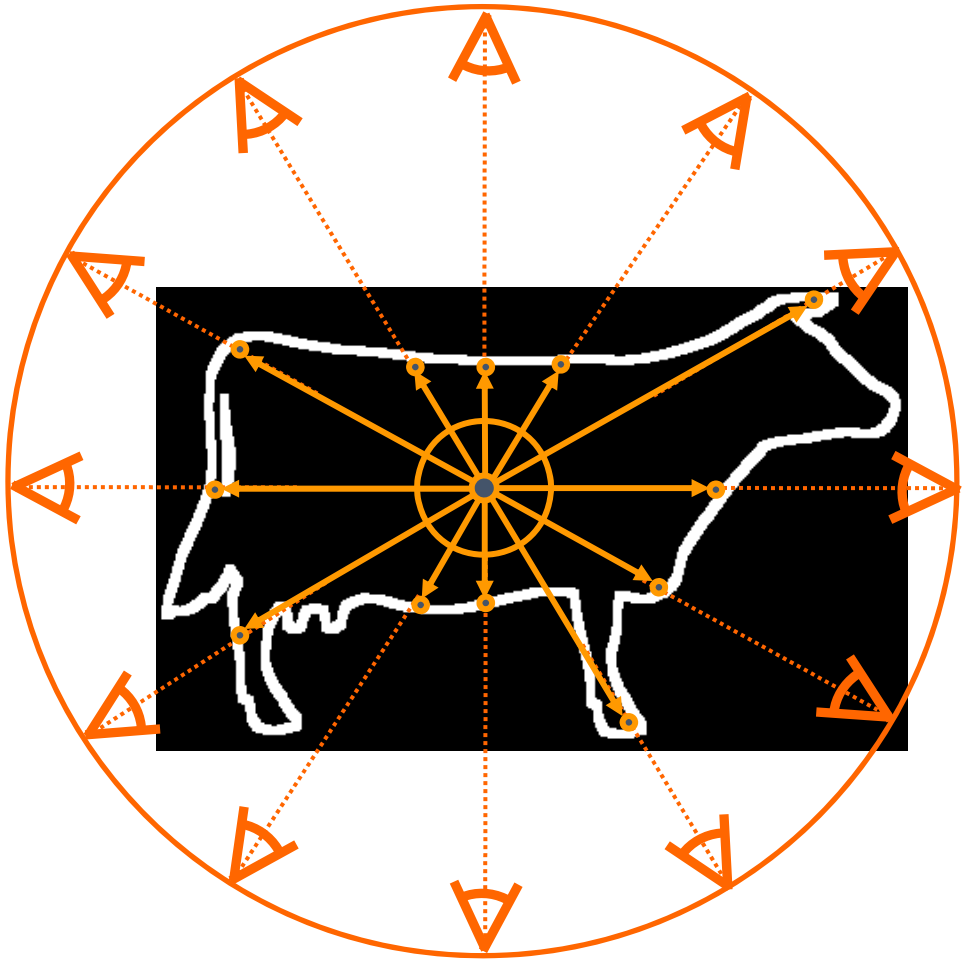
- The value at a point is obtained by summing the Gaussian of the closest point on the model surface.
  - ✓Distributes the surface into adjacent bins
  - ✓Maintains high-frequency information



Spherical Extent Function

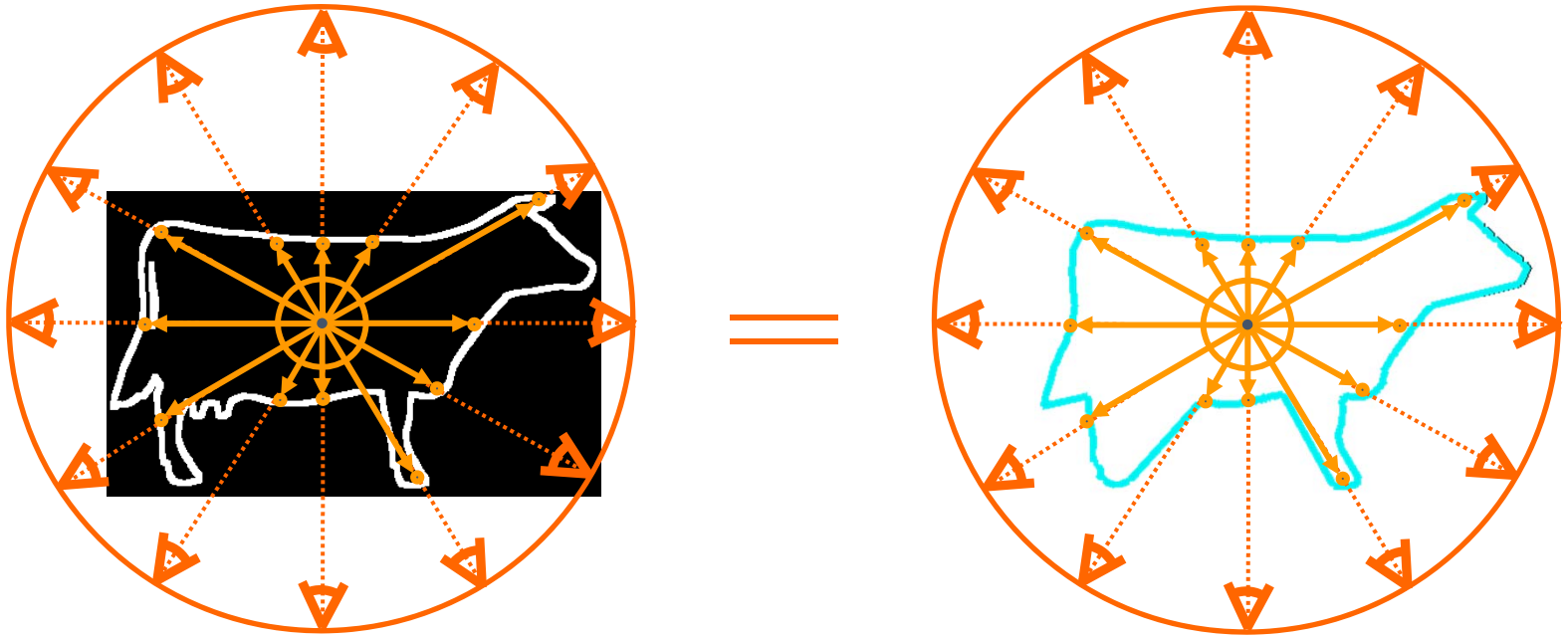
[Vranic *et al.* 2002]

- For every view direction, store the distance to the first point a viewer would see when looking at the origin.



Spherical Extent Function

- A model is represented by its star-shaped envelope:
  - The minimal surface containing the model with the property that the center sees every point on the surface
  - Transforms arbitrary genus models to genus-0 surfaces



Spherical Extent Function

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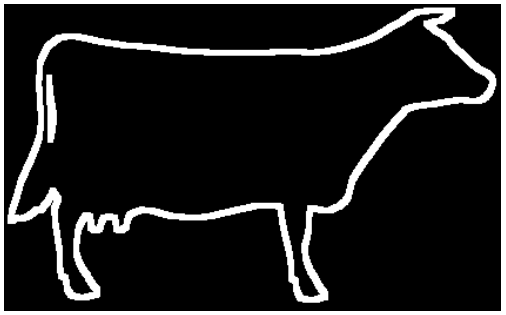
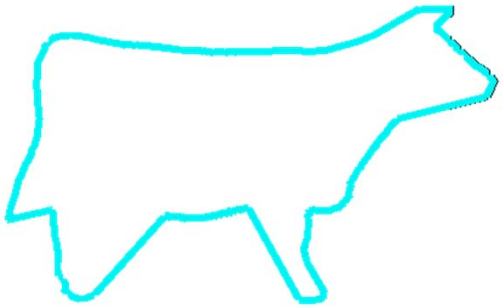


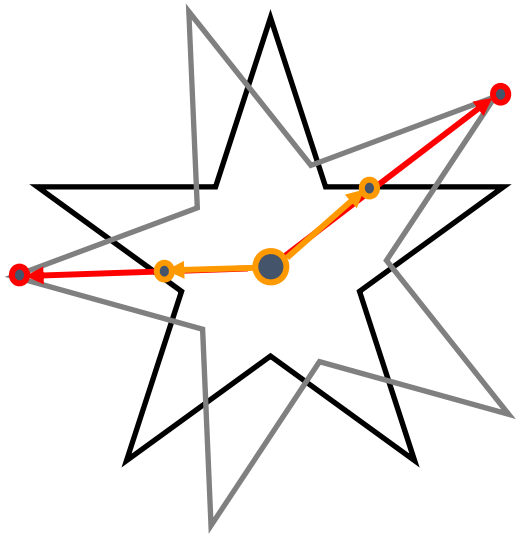
Model



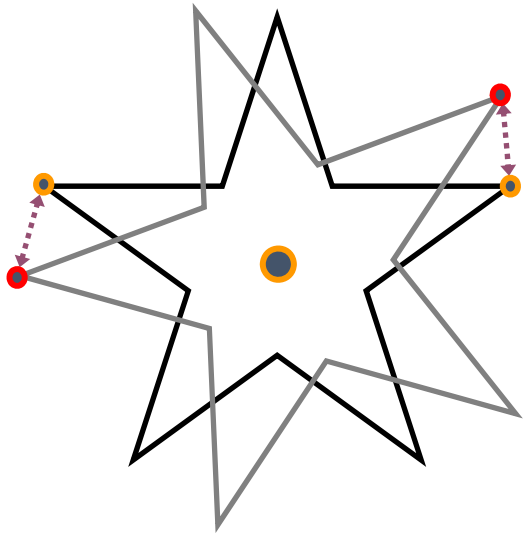
Star-Shaped Envelope

Spherical Extent Function

- Properties:
  - Can be defined for most models
  - Invertible for star-shaped models
  - 2D array of information
- Limitations:
  - Distance only measures angular proximity



Spherical Extent Matching

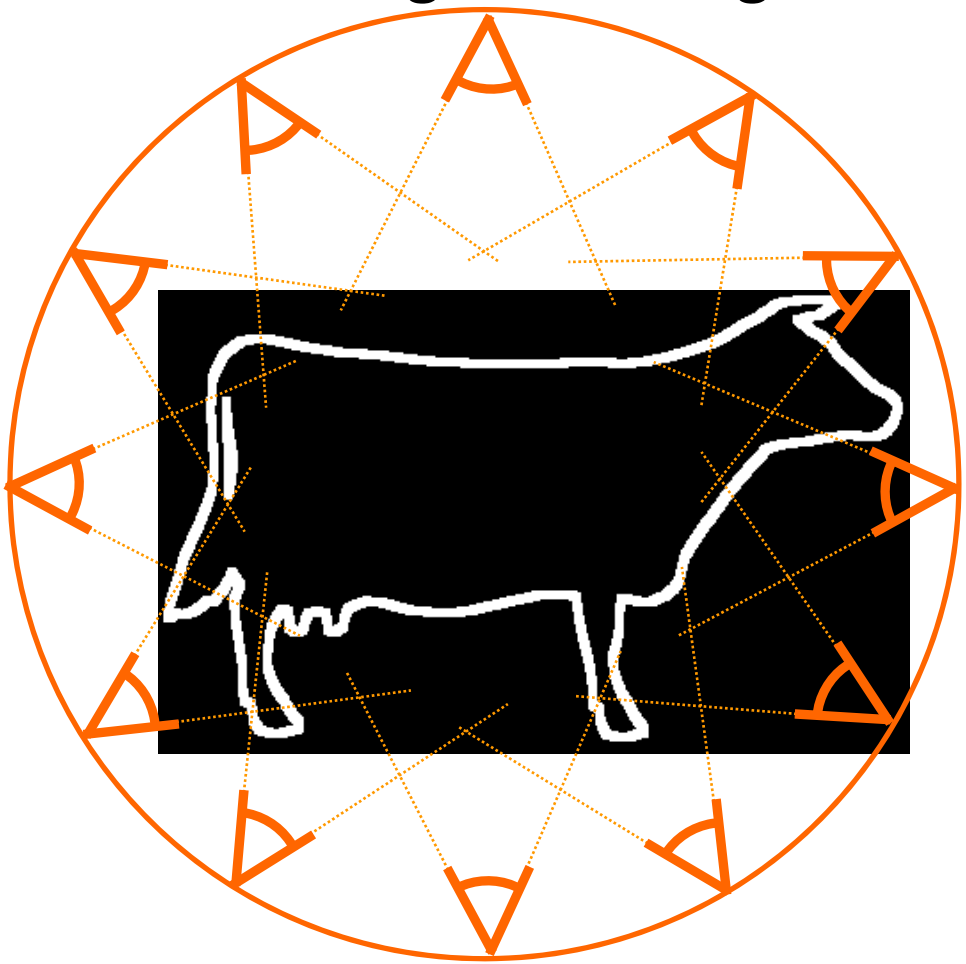


Nearest Point Matching

Light Field Descriptor

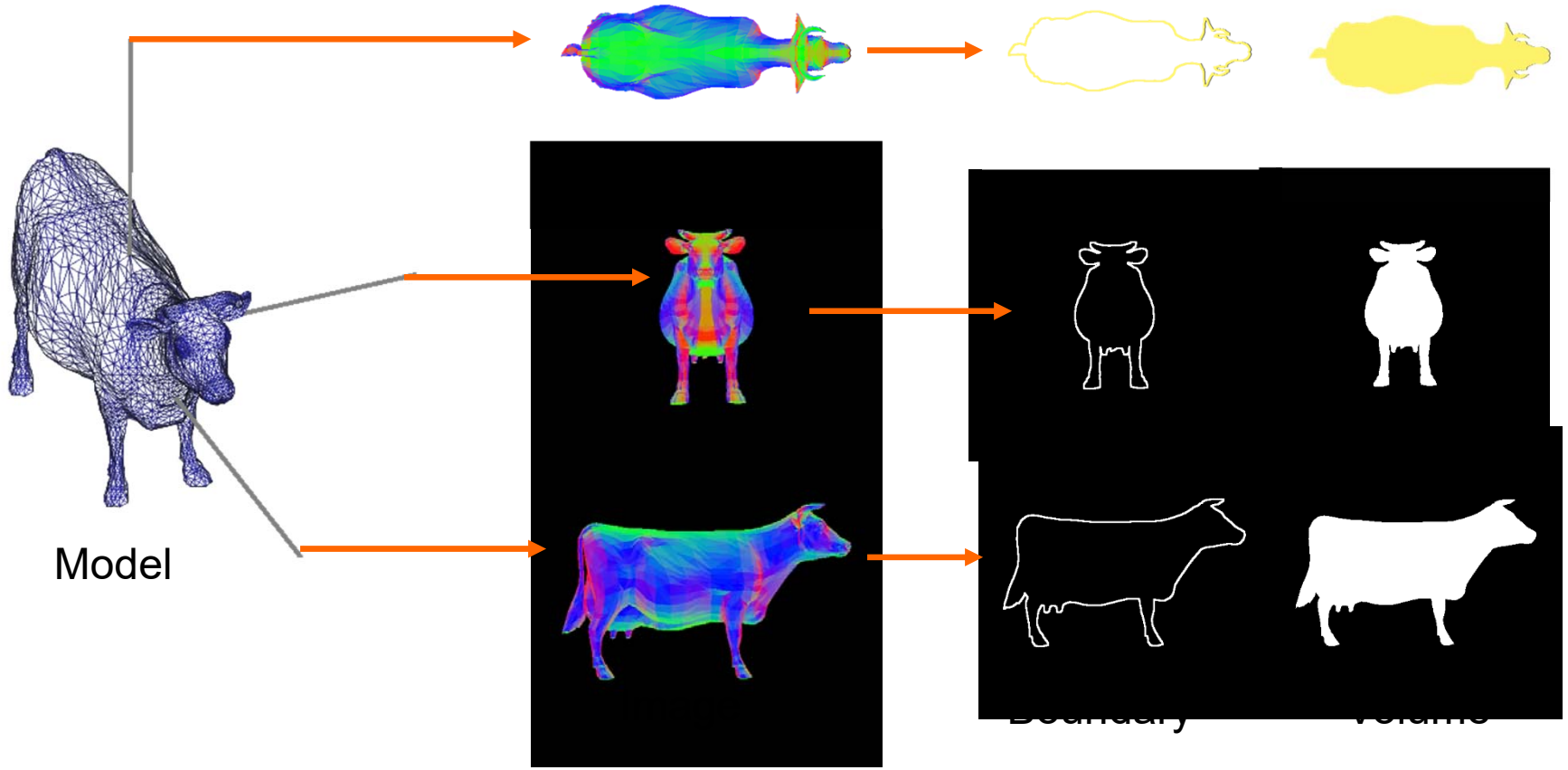
[Chen *et al.* 2003]

- For every view direction, store the image the viewer would see when looking at the origin.



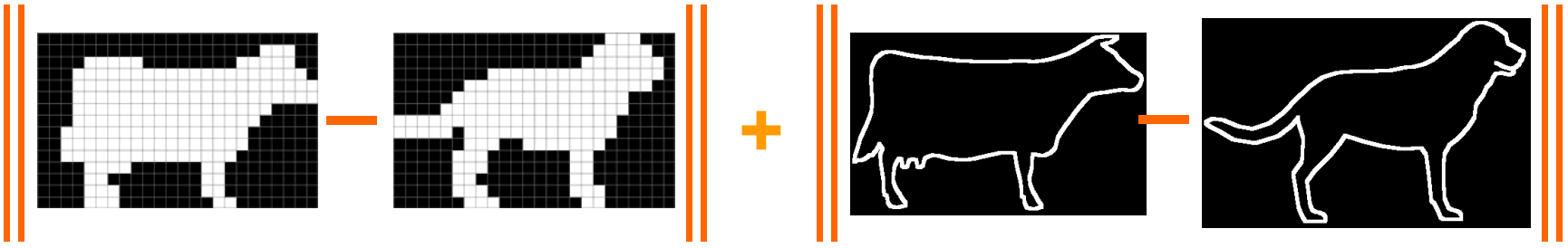
Light Field Descriptor

- Hybrid boundary/volume representation



Light Field Descriptor

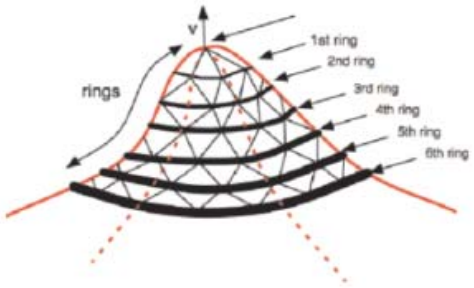
- Properties:
  - Can be defined for most models
  - Invertible for star-shaped models
  - 4D array of information
  - Similarity = sum of area and contour similarities
    - There is a well defined interior
    - Can parameterize contours in 2D



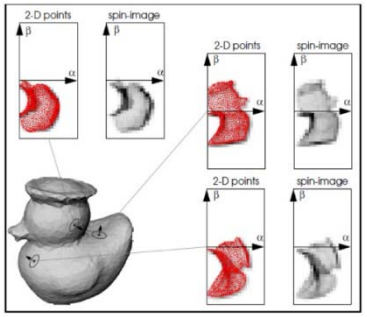
Area Comparison

Contour Comparison

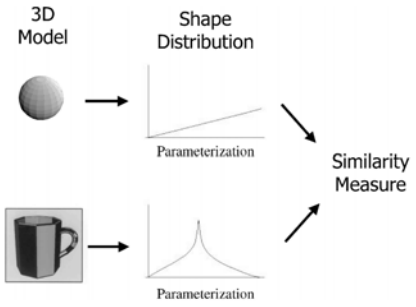
各种人工定义的3D形状特征



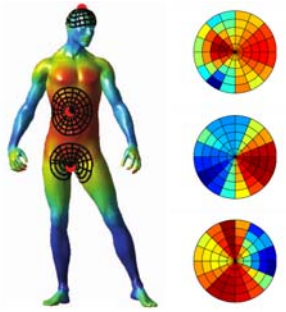
MeshHOG



Spin Image

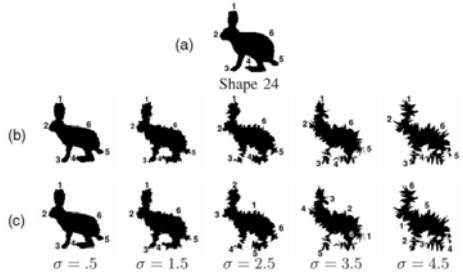


Shape Distributions



Shape Context

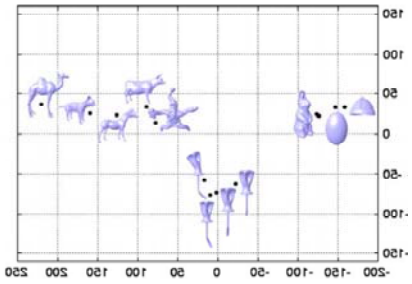
ShapeMSER



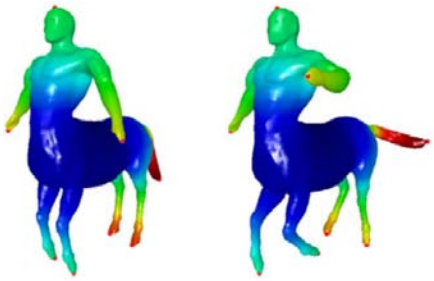
integral volume descriptors

HKS

WKS



Shape DNA



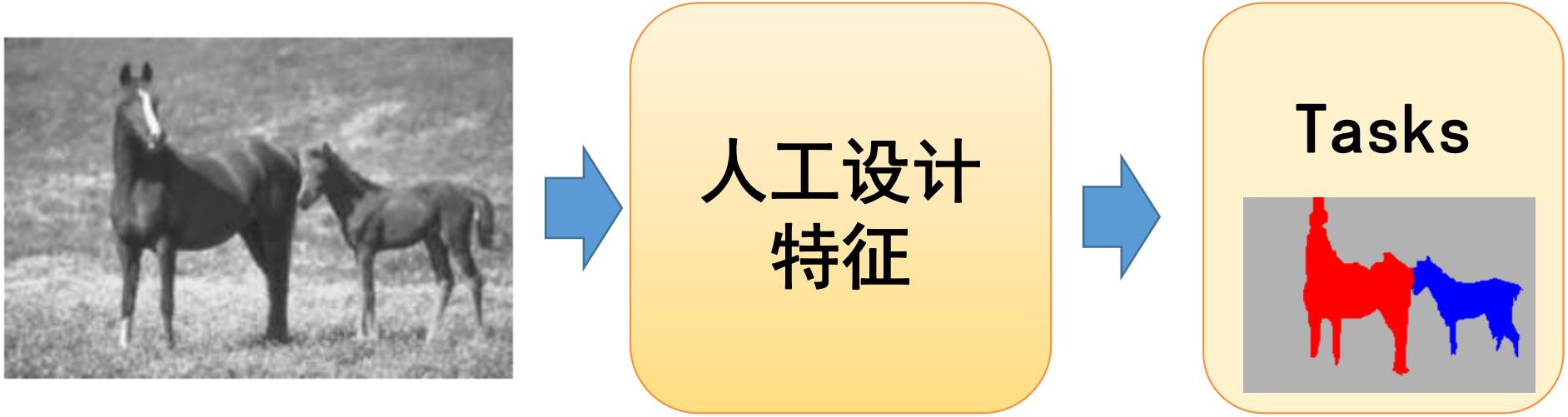
GPS

Geodesic Distance

Conformal Factors

Methodology

Traditional Methods



特征工程的两个主要问题

1. **特征抽取 (Feature Extraction)**
2. **特征选择(Feature Selection)**

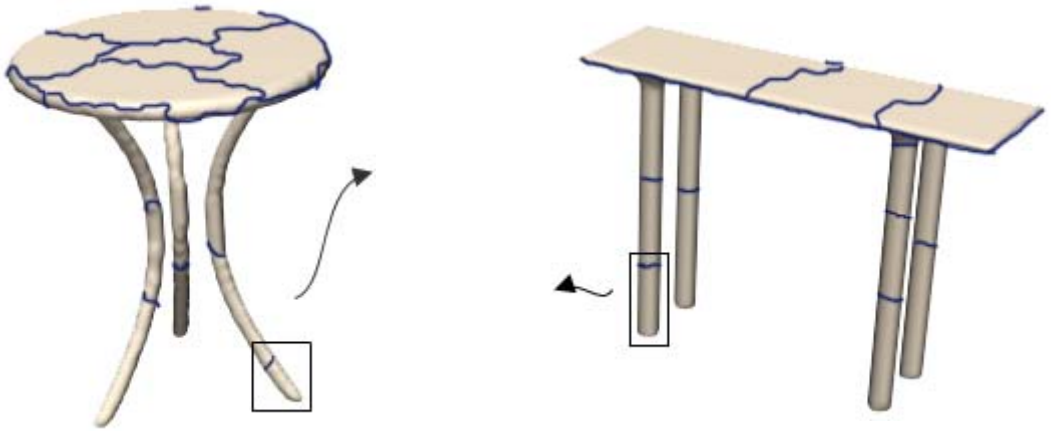
特征工程的两个主要问题

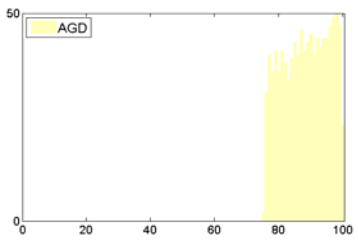
1. **特征抽取 (Feature Extraction)**
2. **特征选择(Feature Selection)**

特征并不是越多越好！

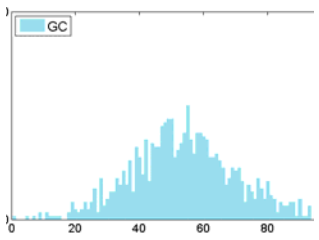
应根据需求来选择合适的特征

如何选择合适的特征?

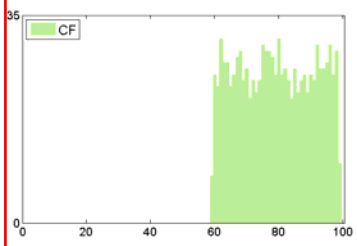




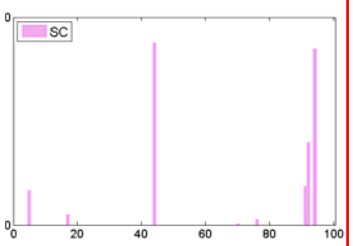
average geodesic distance (AGD) [HSKK01]



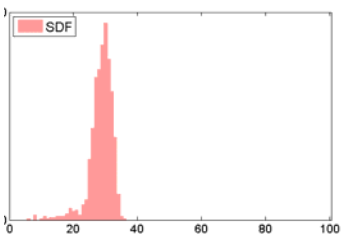
Gaussian curvature (GC) [GCO06]



conformal factor (CF) [BCG08]



shape contexts (SC) [BMP02]

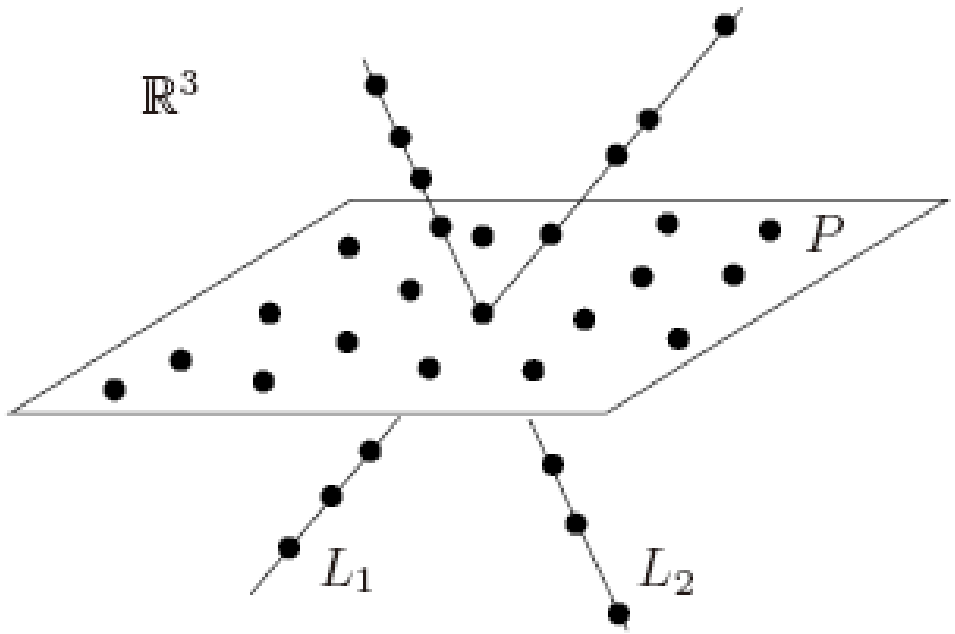


shape diameter function (SDF) [SSS10]

想法：稀疏学习选择合适的特征

[Hu et al. SGP 2012]

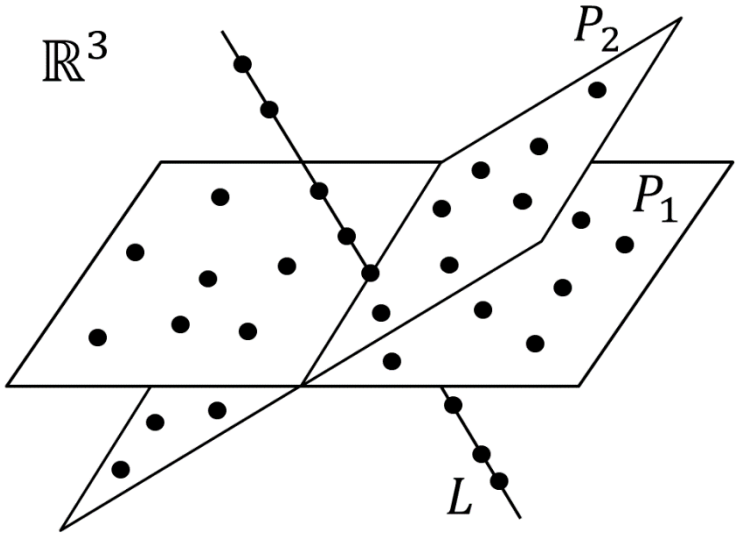
- 稀疏学习的本质：聚类
- 子空间聚类（Subspace clustering）



Subspace Clustering

[Vidal 2010]

- Input:
  - high dimensional datasets having low intrinsic dimensions
  - $\{x_j\}_{j=1,\ldots,N}, x_t \in \mathbb{R}^D$



- Output:
  - multiple low-dimensional linear subspaces
  - L, P_1, P_2

Formulation: Group Lasso

- Our solution:
  - apply subspace clustering in each feature space
  - add the consistent multi-feature penalty

$$\min_{W_1,\ldots,W_H} \quad \sum_{h=1}^{H} \mathcal{F}(W_h) + P_{cons}(W_1, W_2, \ldots, W_H)$$

$$\text{s.t.} \quad W_h \geq 0, \operatorname{diag}(W_h) = 0, \qquad h = 1,2,\ldots,H$$

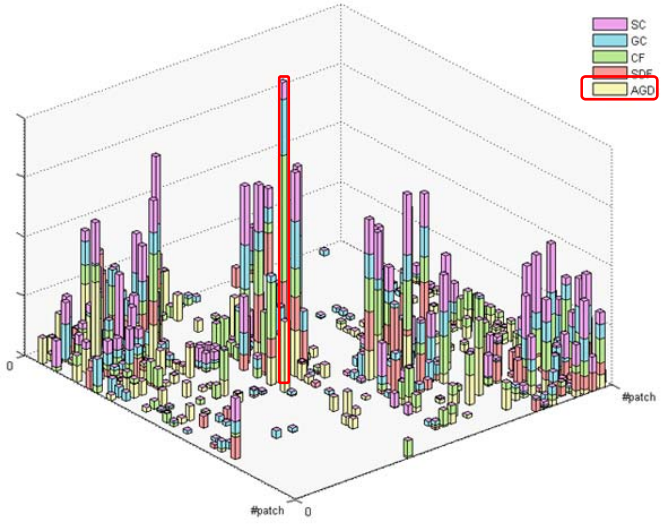
where $\mathcal{F}(W_h) = \|X_h W_h - X_h\|_F{}^2 + \lambda \|W_h{}^T W_h\|_{1,1}$

Consistent multi-feature penalty

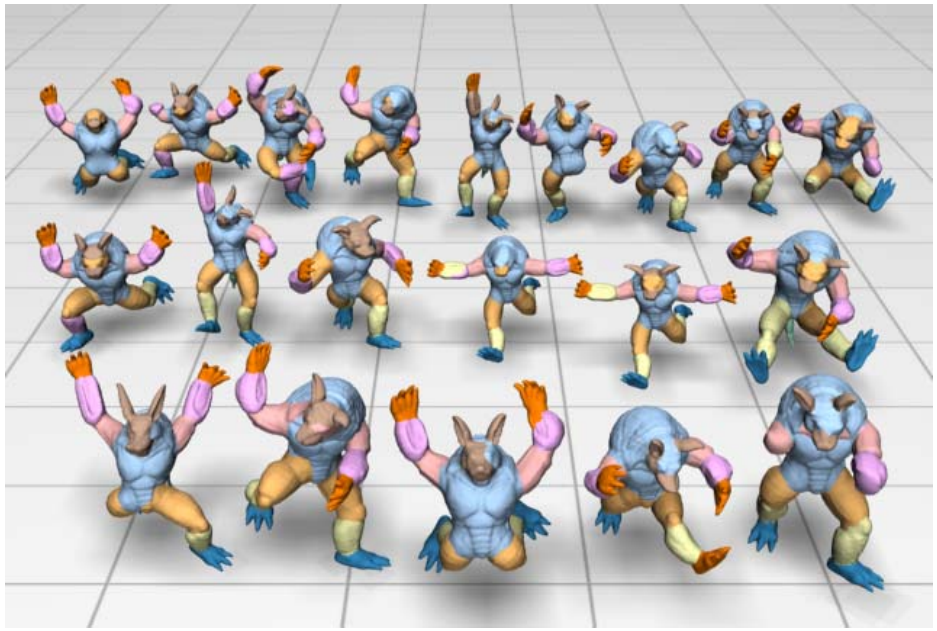
1. Find the most similar patch pairs
2. Corresponding patches need not be similar in all features

$$P_{cons}(W_1, W_2, \dots, W_H) = \alpha\|W\|_{2,1} + \beta\|W\|_{1,1}$$

$$W = \begin{pmatrix} (W_1)_{11} & (W_1)_{12} & \cdots & (W_1)_{N^2} \\ (W_2)_{11} & (W_2)_{12} & \cdots & (W_2)_{N^2} \\ \vdots & \vdots & \ddots & \vdots \\ (W_H)_{11} & (W_H)_{12} & \cdots & (W_H)_{N^2} \end{pmatrix}$$



Results



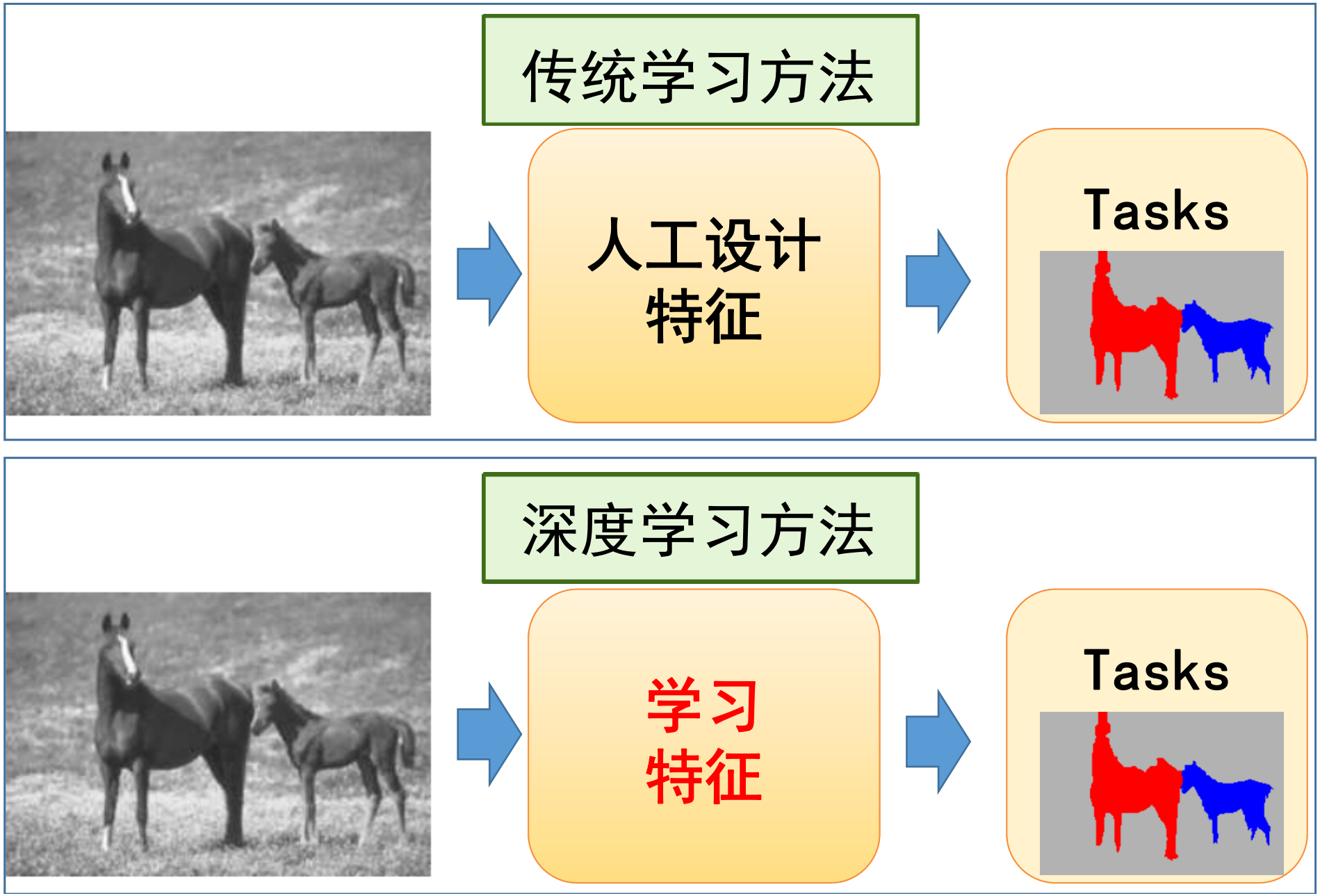
Deep Learning based Methods

Hand-crafted Features are not Enough

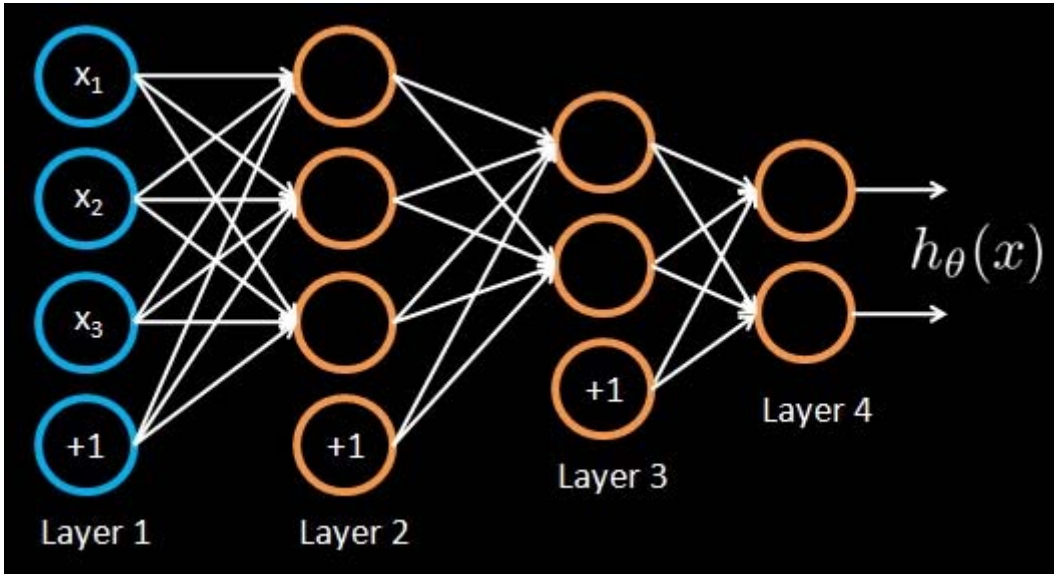
- “Hand-crafted” feature descriptor need domain knowledge
- Too many feature descriptor, which is the best?
- Concatenation of the features may result in over-fitting in feature space

Use deep leaning to extract good feature descriptors!

深度学习方法：端到端



Deep Neural Networks (DNN)



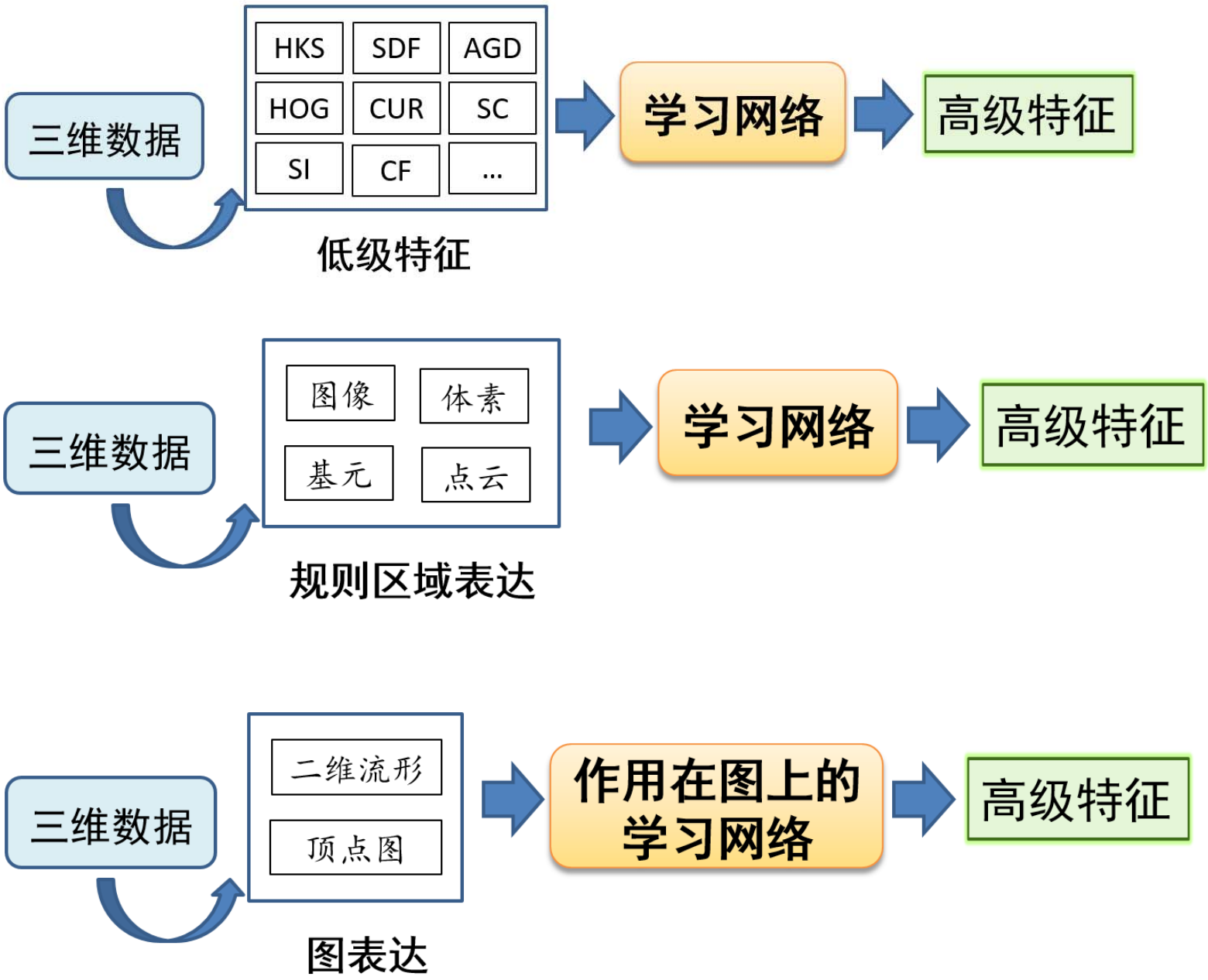
Regression problem:

Input: Given training set (x_1, y_1), (x_2, y_2), (x_3, y_3), ….

Output: Adjust parameters θ (for every node) to make:

$$h(x_i) \approx y_i$$

三维数据的深度学习的三种方法



关于深度学习

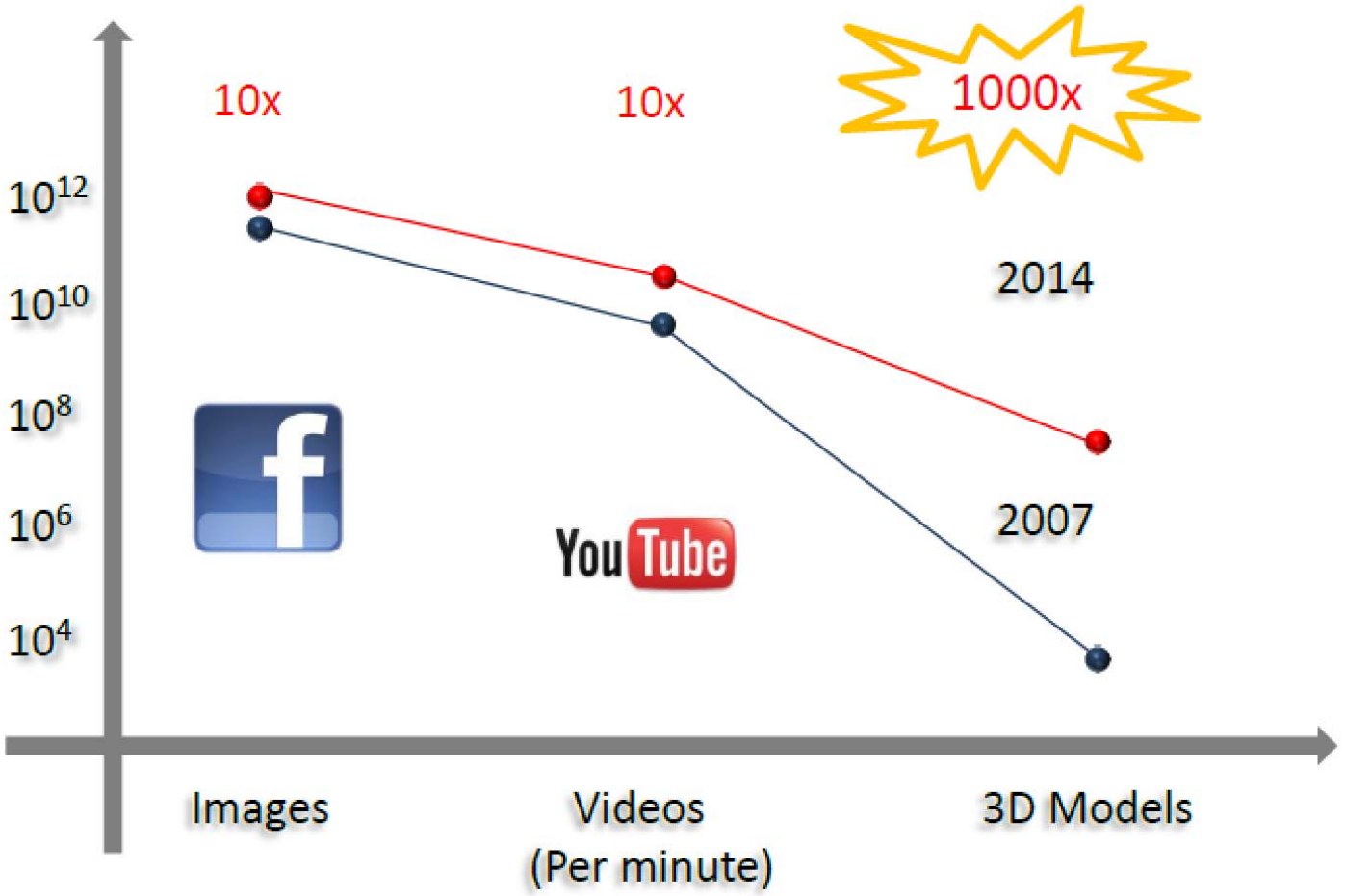
- 通用拟合器（较大的逼近函数空间）
  - 应用三部曲
    - 在哪找（网络构造）、哪个好（损失函数）、怎么找（优化）
  - 仅拟合了大量样本：可能只是“虚假关系”
  - 并没有“理解”或“认知”真正的规律
  - 不可解释性
- 性能依赖训练样本（数据集）
  - 当数据集足够密：近似“最近邻”算法
  - 训练数据集不够完备：缺乏泛化能力
  - 大部分是过拟合
- 基于深度神经网络的深度学习并不是真正的AI，离真正的“智能”仍很遥远

稀疏学习与深度学习：殊途同归

- 方法的不同性
  - 压缩感知：基于模型的，有很好的结构和数学模型；来自于数学理论的突破
  - 深度学习：基于实证的，模型灵活，须通过数据进行监督学习；来自于求解速度的突破
- 一致性
  - 目标：高维数据的信息(特征)提取
  - 结果：从局部信息来处理全局信息
  - 类似的网络结构：求解L1优化的IST (Iterative Soft-Thresholding)算法实质上是多层网络优化

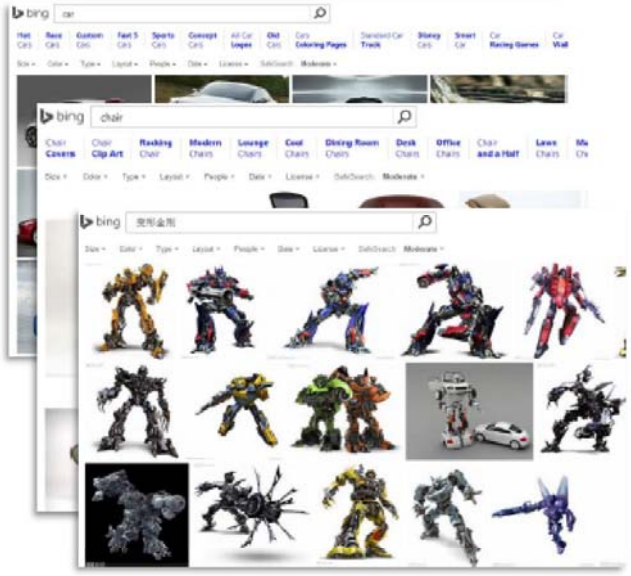
Trends

3D Data: Big Data Era?



Cross-Domain （跨模态）

Image world



Very big: Trillions

Rich labels

2D

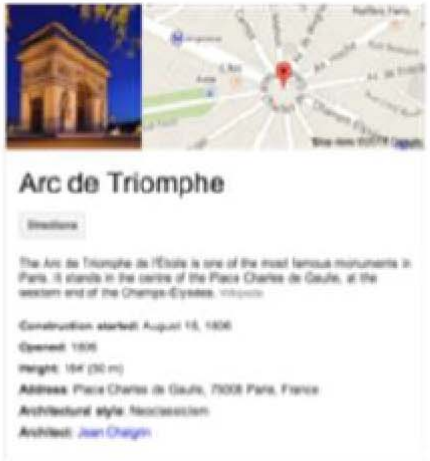
Shape world

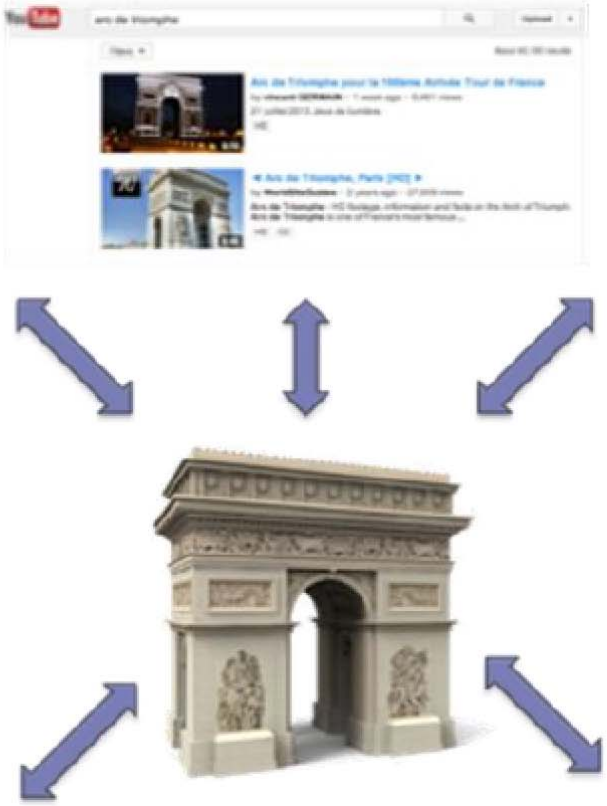
Big: Tens of millions

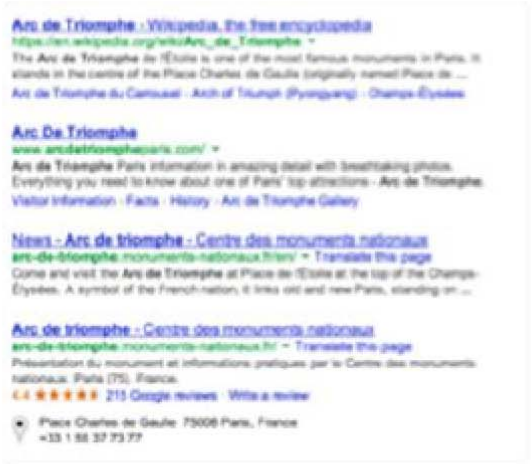
Sparse labels

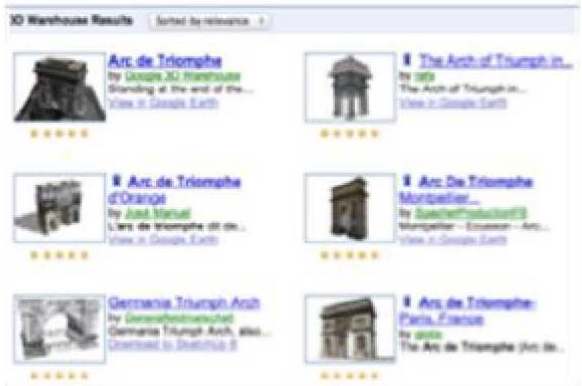
3D

多模态


Arc de Triomphe
Directions
The Arc de Triomphe de l'Étoile is one of the most famous monuments in Paris. It stands in the centre of the Place Charles de Gaulle, at the western end of the Champs-Élysées.
Construction started: August 15, 1806
Opened: 1836
Height: 164' (50 m)
Address: Place Charles de Gaulle, 75008 Paris, France
Architectural style: Neoclassicism
Architect: Jean Chalgrin


arc de triomphe


Arc de Triomphe - Wikipedia, the free encyclopedia
Arc De Triomphe
Arc de triomphe - Centre des monuments nationaux
215 Google reviews · Write a review


3D Warehouse Results
Arc de Triomphe
The Arch of Triumph in...
Arc de Triomphe d'Orange
Arc De Triomphe Montpellier...
Germania Triumph Arch
Arc de Triomphe-Paris, France

Creative Design

- How can computational tools support human creativity?
  - –What stimulates creative design?
  - –How can computers help?
  - –Requires something more than just structural/functional/semantic analysis of shapes
- 3D content creation is still far from solved!

中国科学技术大学

University of Science and Technology of China

谢　谢　！