Parametric Models
Representing Shape Variations

Allen’03

Fish’14

Wu’14
Space of Human Bodies
Variance in human bodies

-20 kg
-20 cm
-40 kg
-20 kg
original
+20 kg
+40 kg
+20 kg
+20 cm
Variance in human bodies

Traditional anthropometry

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<th>Sitting Height (mm)</th>
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Variance in human bodies

Leverage new technology
Variance in human bodies

template

scan

Allen'03
Variance in human bodies

Statistical analysis (PCA) on vertex positions

average male
Variance in human bodies

Correlate principal components with known attributes
Future Reads

Geodesics in shape space
Shape Grammars
Shape Grammar for a Building

Extract a set of algebraic constraints

(a) input  (b) regular patterns  (c) degrees of freedom
Shape Grammar for a Building

a) regular patterns
Shape Grammar for a Building

(a) regular patterns

(a) rigid patch  (b) descr. line patch  (c) descr. area patch

Bokeloh'12
Shape Grammar for a Building

- a) regular patterns
  - (a) rigid patch
  - (b) descr. line patch
  - (c) descr. area patch
  - (d) cont. line patch
  - (e) cont. area patch
  - (f) mixed-case patch
Shape Grammar for a Building

a) regular patterns

b) representation
Shape Grammar for a Building

- **a)** regular patterns
- **b)** representation
- **c)** links
Shape Grammar for a Building

a) regular patterns
b) representation
c) links

\[
\begin{align*}
o_0 + t_0 l_0 & \rightarrow o_1 = \Delta_{0,1} \\
o_1 + t_1 l_1 & \rightarrow o_2 = \Delta_{1,2} \\
o_2 + t_2 l_2 & \rightarrow o_0 = \Delta_{2,0}
\end{align*}
\]
d) equations
Shape Grammar for a Building

a) regular patterns

b) representation

c) links

\[
\begin{align*}
\mathbf{o}_0 + t_0 l_0 - \mathbf{o}_1 &= \Delta_{0,1} \\
\mathbf{o}_1 + t_1 l_1 - \mathbf{o}_2 &= \Delta_{1,2} \\
\mathbf{o}_2 + t_2 l_2 - \mathbf{o}_0 &= \Delta_{2,0}
\end{align*}
\]

d) equations

e) null space analysis

\[
\begin{pmatrix} A \\ \vdots \\ l_2 \end{pmatrix} \begin{pmatrix} \mathbf{o}_0 \\ \Delta_{0,1} \\ \Delta_{1,2} \\ \Delta_{2,0} \end{pmatrix} = x(\lambda) = x_0 + \text{Ker}(A) \lambda
\]
Shape Grammar for a Building
Part Arrangements
Collections of 3D shapes

1000s of models!
Understand Variations

Seats vary in width

OR

1000s of models!

Kim’13
Need Joint Analysis

The problems are inter-related:
- Correspondences
- Consistent Segmentations
- Shape Variations
Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations

Smaller search space
Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations

Smaller search space

Kim’13
Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations

Smaller search space
More accurate search space

Kim ’13
Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations

Smaller search space
More accurate search space
Man-made object vary w.r.t. parts

Kim’13
Box-like Templates

Deformable Template
Box-like Templates

- variance in scale
- variance in positions

Deformable Template
Box-like Templates

Deformable Template
Box-like Templates

Deformable Template
Box-like Templates

Deformable Template
Box-like Templates

Deformable Templates
Box-like Templates

Deformable Templates
Box-like Templates

Deformable Templates
Algorithm Overview

Shapes
Algorithm Overview

Shapes

Templates

Template Initialization
Algorithm Overview

Shapes

Fitting Set

Templates

Template Initialization

Template Fitting
Algorithm Overview

Template Initialization

Template Fitting

Fitting Set

Shapes

Templates

Shapes

Templates
Algorithm Overview

Template Initialization

Template Fitting

Learning Set
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement

Learning Set
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement

repeat until convergence
Algorithm Overview

Template Initialization

repeat until convergence

Template Fitting

Template Refinement
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement

repeat until convergence
Template Initialization

Manual initialization

○ The user aligns boxes to semantic parts (≈ 5 min)
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement
Fitting Parameters

Rigid alignment

Per part deformations
- Existence
- Centroid position
- Anisotropic scale

Labeling of points in the shape

Shape $\leftrightarrow$ template mapping
Fitting Energy

\[ E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}} \]

- \( E_{\text{data}} \) (template \( \leftrightarrow \) shape distance + local shape features)
- \( E_{\text{deform}} \) (plausibility of template deformation)
- \( E_{\text{smooth}} \) (close & similar regions should get the same label)
Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
- Correspondences
- Deformation
Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
- Correspondences
- Deformation
Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
  - Correspondences
  - Deformation

\[ E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}} \]

**Method:** Graph cut [Boykov et al. 2001]
Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
- Correspondences
- Deformation

\[ E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}} \]

**Method:** Part-aware closest points
Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
- Correspondences
- Deformation

\[ E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}} \]

**Method:** Solve for critical points.

- **position:** \[ \frac{\partial (E_{\text{data}} + E_{\text{deform}})}{\partial b_p} = 0 \]
- **scale:** \[ \frac{\partial (E_{\text{data}} + E_{\text{deform}})}{\partial b_s} = 0 \]
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement
Template Refinement

Update template set from deformations in Learning Set

- Update current
- Spawn new
- Reject outliers
Template Refinement

Update template set from deformations in Learning Set

- Update current
  - Spawn new
  - Reject outliers
Template Refinement

Update template set from deformations in Learning Set

- Update current
- Spawn new
  - Reject outliers

Current Template Set

Learning Set
Template Refinement

Update template set from deformations in Learning Set

- Update current
- Spawn new
- Reject outliers
Algorithm Overview

Template Initialization

Template Fitting

Template Refinement

repeat until convergence
3D Warehouse: 3113 airplanes

Initial Template:
3D Warehouse: 3113 airplanes

Initial Template:

Final Templates:

1508

1605
3D Warehouse: 3113 airplanes

1508

1605
3D Warehouse: 3113 airplanes

1508

1605

Failure
3D Warehouse: 471 bikes

Initial Template:
3D Warehouse: 471 bikes

Initial Template:

Final Templates:

378

63

23

7
3D Warehouse: 471 bikes

378

63
3D Warehouse: 471 bikes

Failure
Structural Part Relations
Structural Part Relations

- support SFARR
- embed SFARR
- placement SFARR

Zheng'13
Structural Part Relations

Zheng'13
Structural Part Relations

Groups of structural arrangements
Probabilistic Part Relations

Pairwise co-variability
Probabilistic Part Relations

Pairwise co-variability

Unary Terms, I-label, U-relationship

$$PDF_{l_i,U_k}(r) : \mathbb{R} \rightarrow \mathbb{R}$$

Binary Terms, B-relationship

$$PDF_{l_i,l_j,B_k}(r) : \mathbb{R} \rightarrow \mathbb{R}$$
Probabilistic Part Relations

Binary Terms, B-relationship

$$PDF_{l_i, l_j, B_k}(r) : \mathbb{R} \rightarrow \mathbb{R}$$
Probabilistic Part Relations

All pairwise & unary probabilities define joint probability
Discrete Probabilistic Part Relations
Discrete Probabilistic Part Relations
Discrete Probabilistic Part Relations

Shape style $\in \mathbb{Z}^+$
Discrete Probabilistic Part Relations

Shape style $\in \mathbb{Z}^+$

Part style $\in \{0\} \cup \mathbb{Z}^+$

Kalogerakis'12
Discrete Probabilistic Part Relations

Number of parts from a category $\in \{0\} \cup \mathbb{Z}^+$

Shape style $\in \mathbb{Z}^+$

Part style $\in \{0\} \cup \mathbb{Z}^+$

Kalogerakis'12
Discrete Probabilistic Part Relations

Number of parts from a category $\in \{0\} \cup \mathbb{Z}^+$

Shape style $\in \mathbb{Z}^+$

Part style $\in \{0\} \cup \mathbb{Z}^+$

Continuous feature vector $\in \mathbb{R}^n$

Kalogerakis'12
Discrete Probabilistic Part Relations

Number of parts from a category $\in \{0\} \cup \mathbb{Z}^+$

Shape style $\in \mathbb{Z}^+$

Part style $\in \{0\} \cup \mathbb{Z}^+$

Continuous feature vector $\in \mathbb{R}^n$

Discrete feature vector $\in \mathbb{Z}^m$
Discrete Probabilistic Part Relations

\[ P(X) = P(R) \prod_{l \in L} \left[ P(S_l \mid R)P(N_l \mid R, \pi(N_l))P(C_l \mid S_l, \pi(C_l))P(D_l \mid S_l, \pi(D_l)) \right] \]
Discrete Probabilistic Part Relations
Shape Synthesis
Shape Synthesis
Shape Synthesis
Shape Synthesis
Shape Synthesis
Shape Synthesis
Shape Synthesis
Shape Synthesis
Shape Synthesis
References

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