Structure Completion of Facade Layouts

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Completing A Layout
Challenges

• We cannot only rely on observations.
• We need additional information.
This Work

• Two sources of information
  - Observation
  - Database

• A statistical model evaluates layouts.
• A planning algorithm generates candidates.
Related Work

• Structural image inpainting

Structure propagation
[Sun et al. 2005]

Statistics patch offsets
[He and Sun 2012]

Texture synthesis
[Dai et al. 2013]

Planar structure guidance
[Huang et al. 2014]

They cannot complete facade with large missing regions.
Related Work

• Facade modeling

Metropolis procedural modeling [Talton et al. 2011]

Single view reconstruction [Koutsourakis et al. 2011]

Structure-preserving retargeting [Lin et al. 2011]

Procedural facade variation [Bao et al. 2013]

Tiled patterns [Yeh et al. 2013]

They cannot generate facade layouts consistent with given observations.
Related Work

• Facade analysis

Procedural modeling [Müller et al. 2007]

Shape grammar parsing [Teboul et al. 2011]

Adaptive partitioning [Shen et al. 2011]

Rank-one approximation [Yang et al. 2012]

Symmetry maximization [Zhang et al. 2013]

Inverse procedural modeling [Wu et al. 2014]
Facade Representation

• Grid layout - $G$

Example Grid

$g$: $g.x_0 = 2.0; \ (g.x_i, e.y) \ldots; \ g.rows = 2; \ g.columns = 4; \ (e.w, e.h)$

$g.y_0 = 3.0; \ e.label \quad g.width = \ldots; g.height = \ldots$
Facade Dataset

• 100 facade images
• Box abstraction
• Statistics of elements and grids
Overview

Input

Statistical Model

Candidate Generation

Factor Graph
A Statistical Model for Facade Layouts
A Good Completion

• Criteria
  • It satisfies some constraints.
  • It is consistent with the observations and the layouts in database.

• Likelihood of a facade layout

\[ f_\alpha(G) = \ln p_\alpha(G) \]

\( P_\alpha \): distribution of the grid attributes in the database

\( G \): grid layout
Unary Grid Functions

- Element aspect ratio: $f_{as}(g)$
- Element spacing: $f_{ed}(g)$
- Grid regularity: $f_{gr}(g)$
- Grid completeness: $f_{gc}(g)$
Binary Grid Functions

• Pattern of interleaved grids
  - \( f_{gp}(g_i, g_j) \)

• Grid alignment
  - \( f_{ga}(g_i, g_j) \)
Global Grid Functions

- Element compatibility - $f_{ec}(G)$
- Grid coverage - $f_{gc}(G)$
- Facade border - $f_{fb}(G)$
- Facade symmetry - $f_{fs}(G)$
**Factor Graph**

- **Factors**

\[
\begin{align*}
\mathcal{F}_{\text{unary}}(g_i) &= \exp \left( w_{as}f_{as}(g_i) + w_{ea}f_{ea}(g_i) + w_{gr}f_{gr}(g_i) + w_{gc}f_{gc}(g_i) \right) \\
\mathcal{F}_{\text{binary}}(g_i, g_j) &= \exp \left( w_{gp}f_{gp}(g_i, g_j) + w_{ga}f_{ga}(g_i, g_j) \right) \\
\mathcal{F}_{\text{global}}(G) &= \exp \left( w_{ec}f_{ec}(G) + w_{gc}f_{gc}(G) + w_{fb}f_{fb}(G) + w_{fs}f_{fs}(G) \right)
\end{align*}
\]
Factor Graph

• The overall probability

\[ p(G|\mathbf{w}) = \frac{1}{Z(\mathcal{F}, \mathbf{w})} \prod_{\mathcal{F}} \mathcal{F}(\text{Scope}_\mathcal{F}(G)) \]

the partition function

variables connected to factor \( \mathcal{F} \)

• Weight learning - \( \mathbf{w} \)
  • Maximum likelihood parameter estimation
Structure Candidate Generation
Planning Algorithm

• Value of state $s$ using Bellman’s equation

$$V(s) = R(s) + \gamma \max_{a \in A} \sum_{s' \in S} T(s, a, s') V(s')$$

- **reward of $s$**
- **transition probabilities**

![Diagram](image)

- $a = \pi(s, \lambda)$

$S \rightarrow S'$
Planning Algorithm

• Optimal policy

\[ \pi^*(s) = \arg \max_{a \in A} \sum_{s' \in S} T(s, a, s') V(s') \]

• Actions consist of adding one single element.

\[ a = \pi(s, \lambda) \]
Policy Design

- Policy for adding an element: \( \pi(s, \lambda) \)

\[ \lambda = \{ \lambda_0, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8, \lambda_9, \lambda_{10} \} \]

- Seed element \((e_s)\) selection
- Extension direction
- Extension spacing
- Extension label
- Other parameters
  - Snapping
  - Symmetric copying
Policy Optimization

• For each facade

\[ \lambda^* = \arg \max_\lambda \sum_{s' \in S} T(s, \pi(s, \lambda), s') V(s') \]

• Genetic algorithm
• Initial policies are learnt from the database.

Crossover
\[ \lambda^a = \{ \ldots, \lambda^a_i, \ldots \} \]
\[ \lambda^b = \{ \ldots, \lambda^b_i, \ldots \} \]

Mutation
\[ \lambda = \{ \ldots, \lambda_j, \ldots \} \]
\[ \lambda_j \leftarrow \lambda_j + d, \quad d \sim \mathcal{N}(0, \sigma) \]
Policy Optimization

observation

a completion with a fixed specified policy

a completion using policy optimization
Results and Applications
Results

• Completion results influenced by the number of observed elements
Results

• Completions of incoherent observations.
An Application
Evaluation I: Structure Completion

• Completion ranking test

Which of two possible completions is more plausible?

1. A is more plausible.
2. B is more plausible.
3. They look the same.
Evaluation I: Structure Completion

• Ground truth data received 31.5%.
• Our completion received 40.2%.
• Both equally received 28.3% of all votes.
Evaluation II: Scoring functions

• Leave-one-out test

observation

all terms included

aspect ratio term excluded

spacing term excluded

regularity term excluded completeness term excluded

pattern term excluded

alignment term excluded

compatibility term excluded coverage term excluded

border term excluded
Evaluation III: Comparison

• Comparison to simulated annealing
Limitation

• Our statistical model only considers simple pattern.
Conclusions

• A framework for structure completion of facade layouts
  • Large missing regions!
  • A statistical model to evaluate layouts
  • A planning algorithm to generate candidate layouts

• An application in the area of urban reconstruction
Acknowledgement

• Anonymous reviewers

• Research grants
  • Visual Computing Center of KAUST
  • Austrian Science Funds
  • National Natural Science Foundation of China
  • One Hundred Talent Project of the Chinese Academy of Sciences
  • U.S. National Science Foundation
Thank you!

More details about this project are available at:
https://sites.google.com/site/lubinfan/publications/2014-facade-completion