# Modeling and Recognition of Regular Structures in Images

## demo

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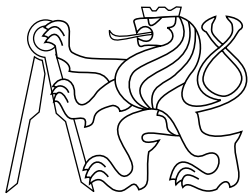
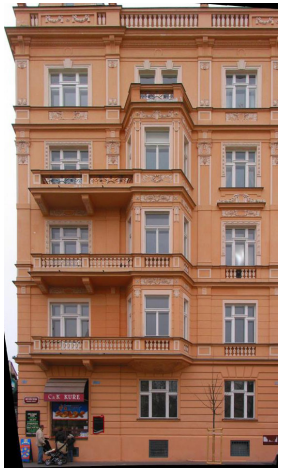
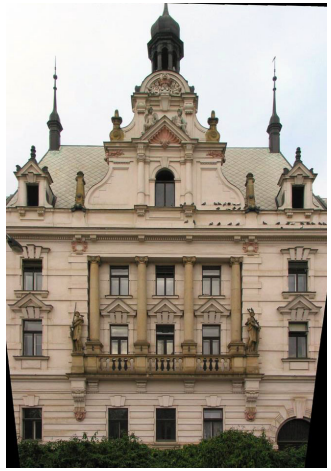


# Interpretation of Facade Images



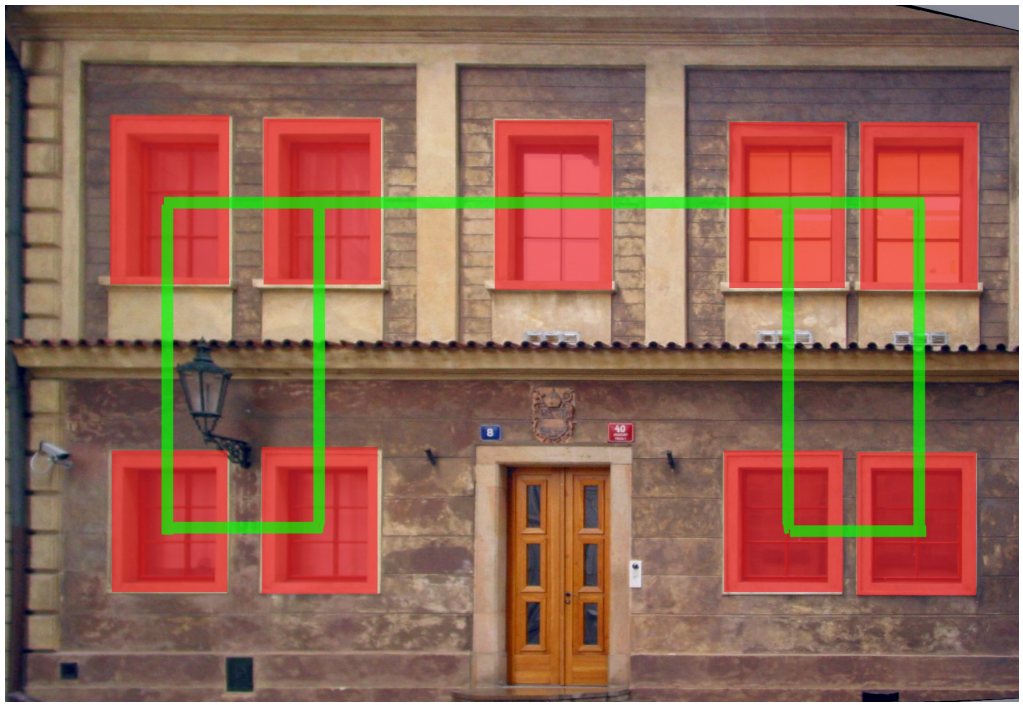
- **Objects of interest:**
  Images of scenes with strong regular structure
- **Goal:** Recognize image elements and their relationship
- **Problem:**
  How to combine image model with structural knowledge?
- **Playground:** Houses, facades, windows...
- **Applications:** 3D modeling of facades, buildings, cities

# Interpretation of Facade Images

## Goals:

1. Recognize facade **elements** (windows) and their **relationship**
2. Build **joint** structure and image models and combine them for **recognition**

- Complexity
- Element attributes
  - Size
  - Position
  - Shape
- Structure
  - Relationship
  - Regularity
  - Exceptions

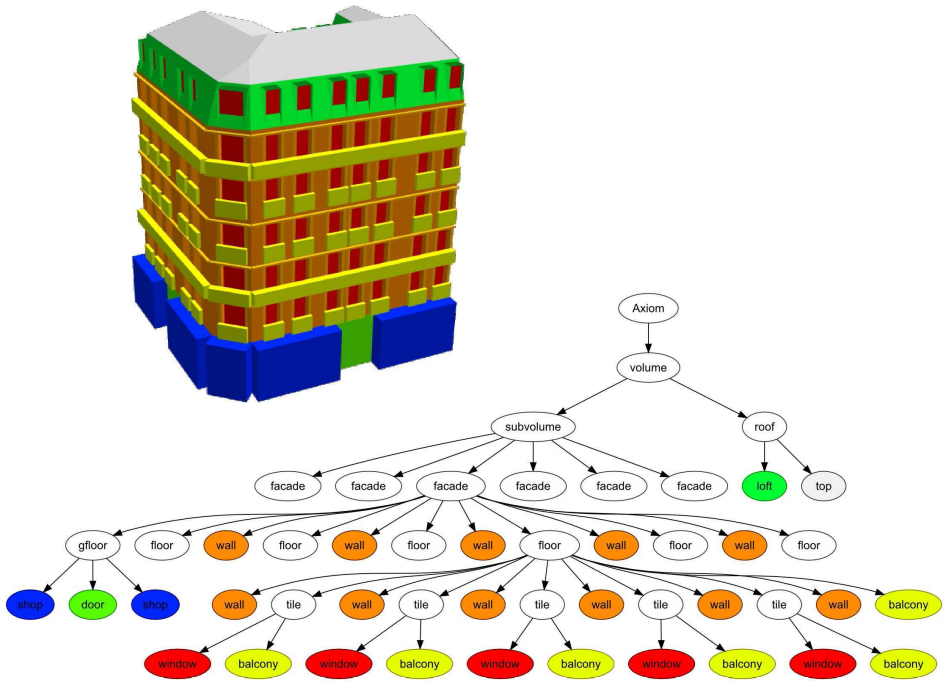


# Facade Structure Modeling

**Very strong model:** Grammar-based Procedural Modeling

## Properties

- rich semantics
- hand design of grammar
- split-based limitation
- overfitting




*O. Teboul et al. Segmentation of building facades using procedural shape prior. CVPR 2010.*

# Facade Structure Modeling

**General model:** Near Regular Texture Lattice

## Properties

- uninterrupted repetition
- hard to implement other rules

*J.Hays et al. Discovering texture regularity as a higher-order correspondence problem. Proc. ECCV, 2006*

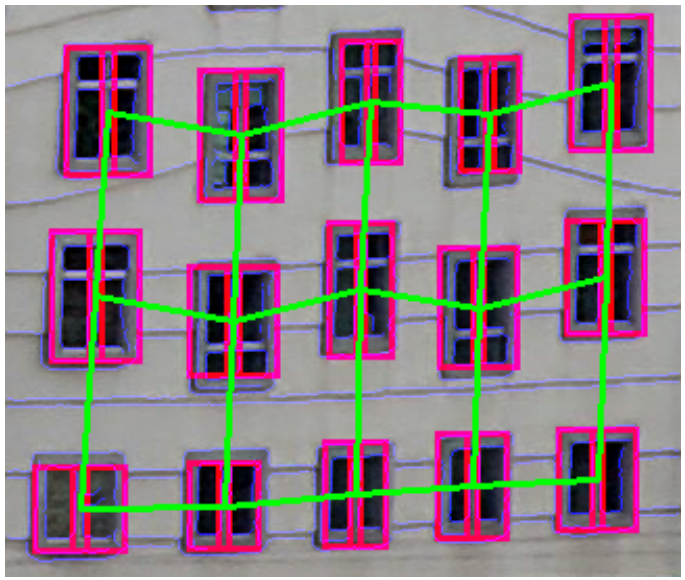
# Facade Structure Modeling

**Weak model:** Pair-wise neighborhood

**Idea:**

- Attribute constraints act *locally* on neighbors
- We search for the neighborhood relations

- **Attribute constraints:**
  alignment, spacing, similarity
- **Structural regularity:**
  neighborhood configurations
- **Representation:**
  planar graph with labels

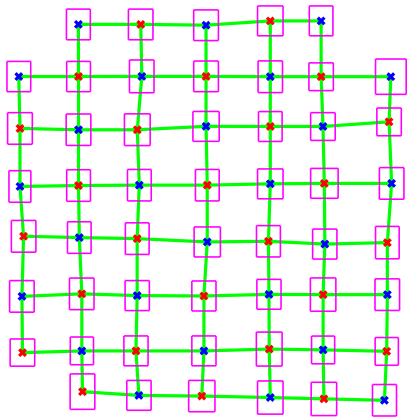


*R.Tylecek, R.Sara: Stochastic Recognition of Regular Structures in Facade Images. IPSJ T. Computer Vision and Applications, 2012*

# Weak Structure Model

**Structure Representation:**
fairly general to support most real structures
attributed neighborhood graph $G = \{V, D, C, N\}$

- $V$ ... vertices = elements (windows)
- $D$ ... edges $(uv)$ of complete graph,
- $C$ ... binary 'color' labels $c_i$ on $V$ for *Bipartite Graph* constraints
- $N$ ... binary edge labels $l_{uv}$ on $D$ indicate active edges in the neighborhood



*random sample from the structure model*

# Image Modeling

**The simplest model:** Color

## Color likelihood

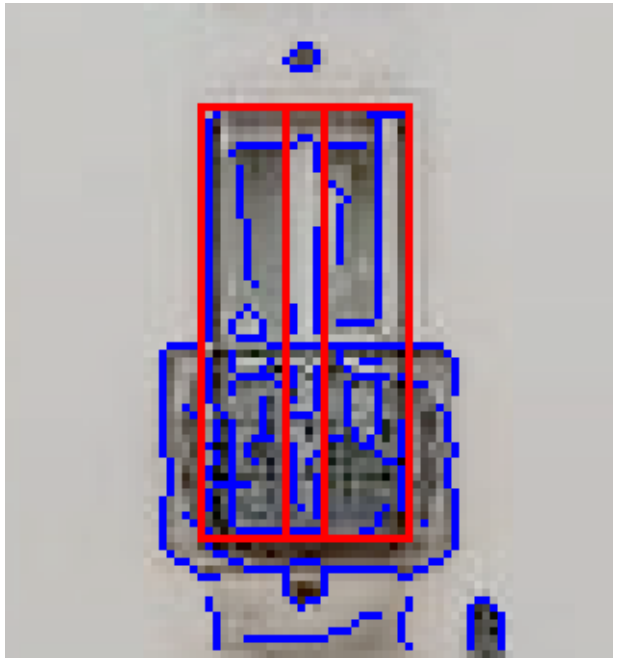
- Regions of interest
- Background
  - Flat Gaussian distribution
- Foreground
  - Gaussian mixture
- Integral image
  - Allows fast evaluation

# Image Modeling

**The simplest features:** Edges

## Edge likelihood

- Accurate localization
- Image edges detected i.e. by Canny detector
- Window template edge matching
  - Oriented images edges
  - Using distance transform
  - Penalty for orientation mismatch
- Integral image
  - Needs rectification



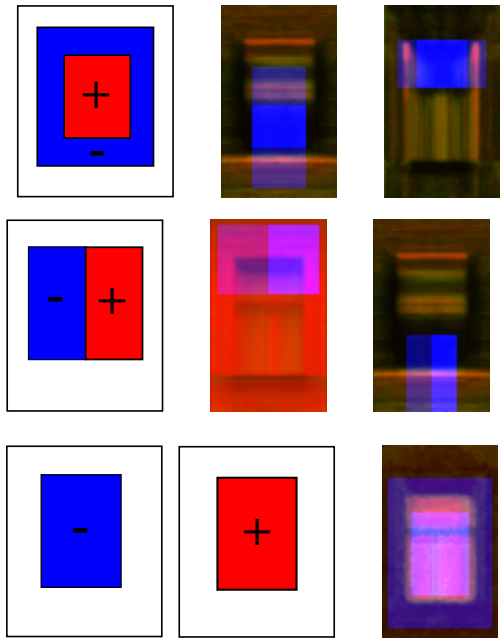
# Image Modeling

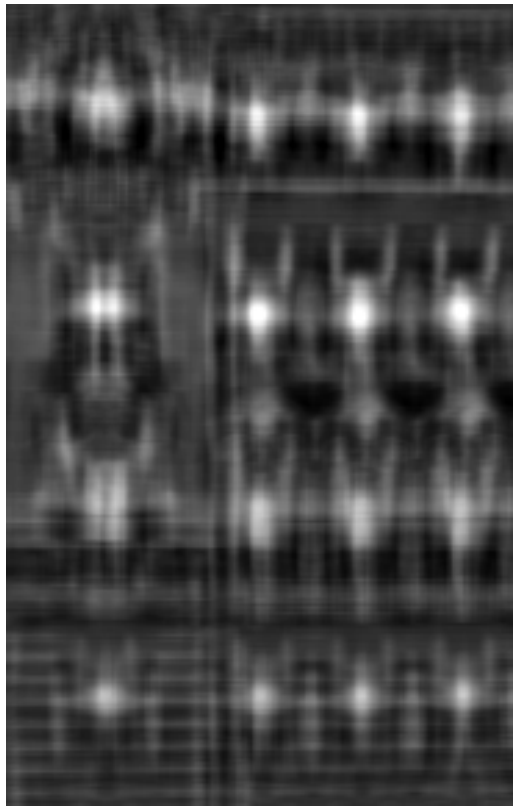
**Specific features: Detectors**

- Detectors trained for given class of objects
- Scale problem, multi scale detection

**Mixture of Haar-like features + AdaBoost**

- *Differential:*
- *Symmetric:*
- *Similarity:*



# Recognition Methods

## Model design:

1. Choose parameters $\theta$
2. Choose an image model $p(I|\theta)$
3. Choose a structure model $p(\theta)$

## Maximum Likelihood:

Find interpretation with best data fit

$$\theta^* = \arg\max_{\theta} p(I|\theta) \;\; \text{s.t. } p(\theta) > 0 \tag{1}$$

## Maximum Aposterior Probability:

Find the most probable interpretation (Bayes)

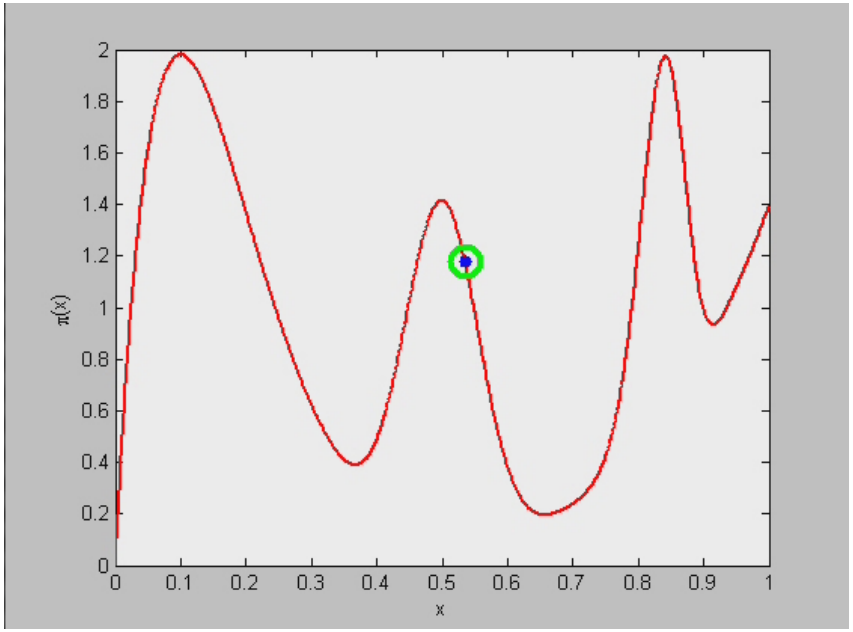
$$\theta^* = \arg\max_{\theta} p(I,\theta) = \arg\max_{\theta} p(I|\theta)p(\theta) \tag{2}$$

# Recognition Methods

**Markov Chain Monte Carlo** (MCMC)
sampling for exploration of parameter space

## Metropolis-Hastings Algorithm

- Random Walk
- Sample new state $\theta'$ conditionally on the current state $\theta$ with proposal distribution $q(\theta'|\theta)$
- Proposals with probability ratio $< 1$ can be also accepted

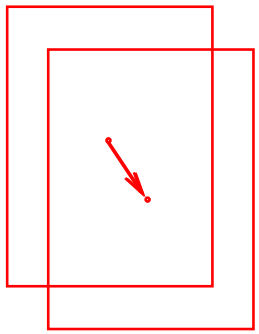


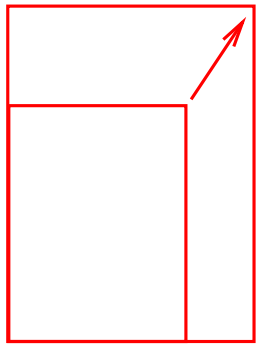
# Recognition Methods

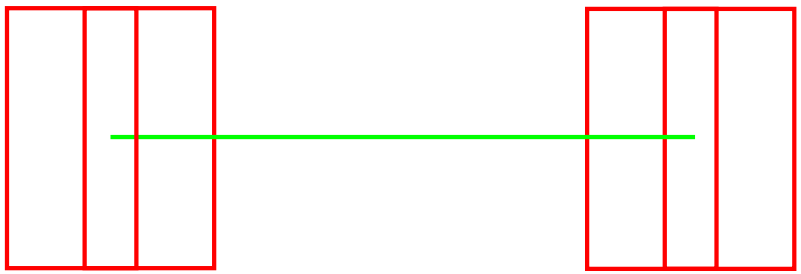
## Proposal Design

- Random initialization
- Proposals can be local and simple
- Proposals $q_m(\theta'|\theta)$ are chosen randomly from a set
  1. Attribute modification
  2. Complexity modification

  *Reversible Jump MCMC*







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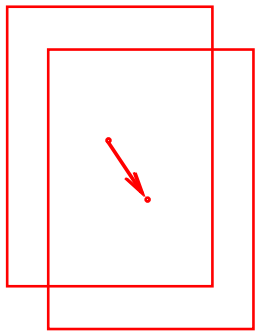
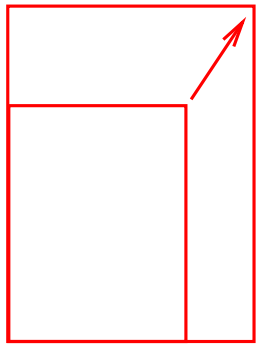
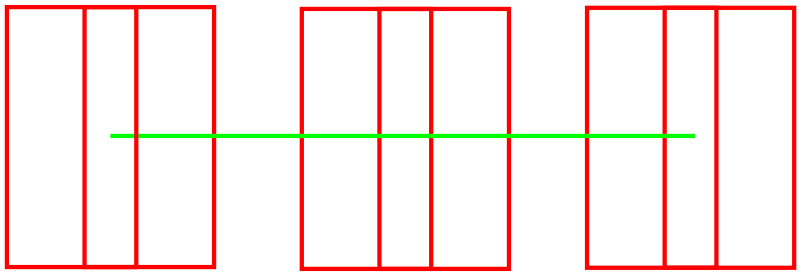




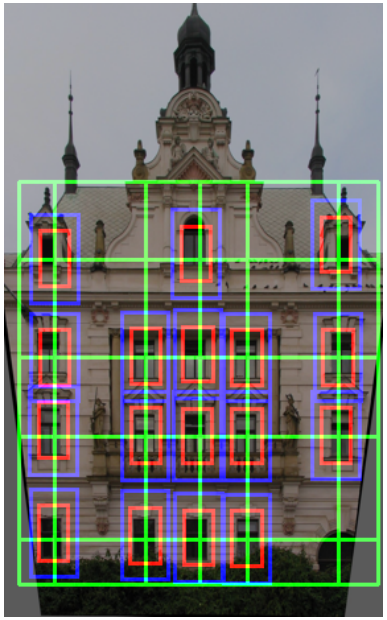


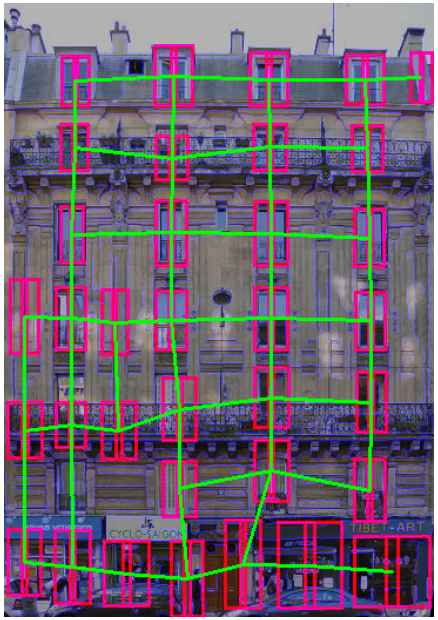
# Experimental Results

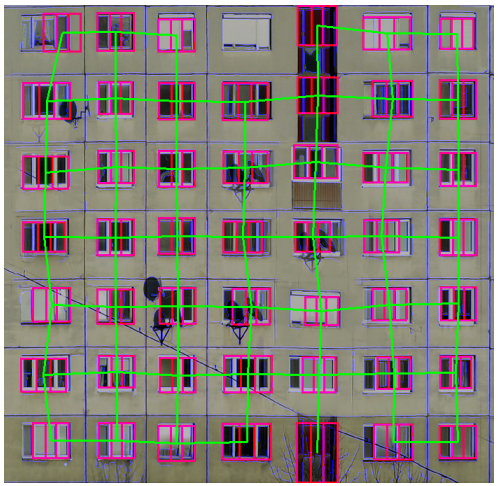
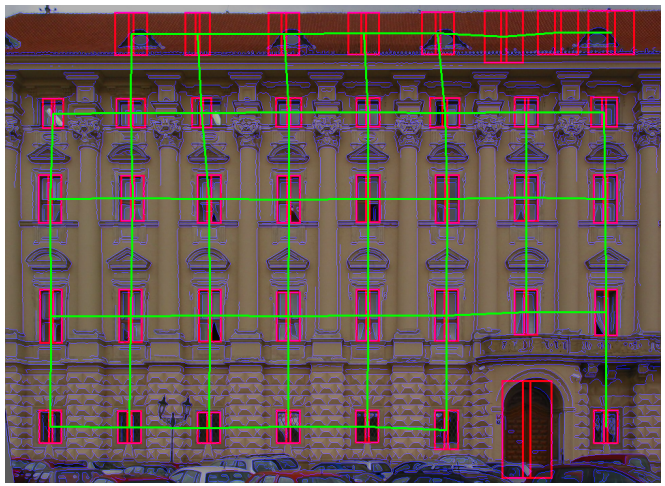
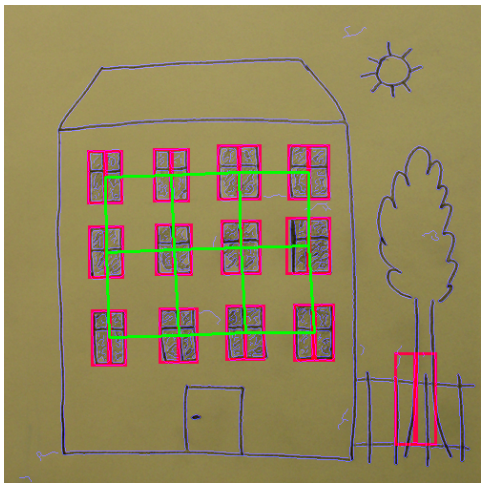
**Dancing House** (Prague)

- Only loosely regular
- Random initialization
- 3000 samples
- Only samples with increasing probability rendered
- Sampling rate shown in real-time

# Experimental Results





# Conclusion

## Structure

Implementation of structure model facilitates recognition even with simple and general image features

## Recognition

MCMC is effective and powerful way to combine structure with image information

## Outlook

Search for more efficient optimization algorithms applicable to regular structures. Use semantic information to constraint 3D reconstruction of facades.

# Thank you.


Website: `cmp.felk.cvut.cz`