Local Regularity-driven City-scale Facade Detection from Aerial Images

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PENNSTATE
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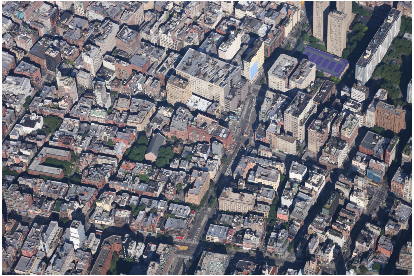
Acknowledgments

- NSF grant IIS-1248076
- NSF grant IIS-1144938
- Data provided by Google

The problem



- Unsupervised detection
- 200+ facades per image

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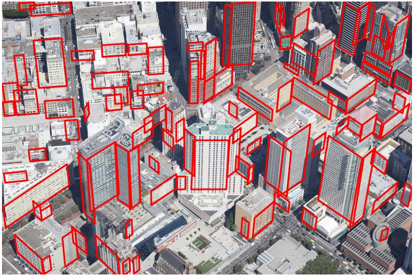

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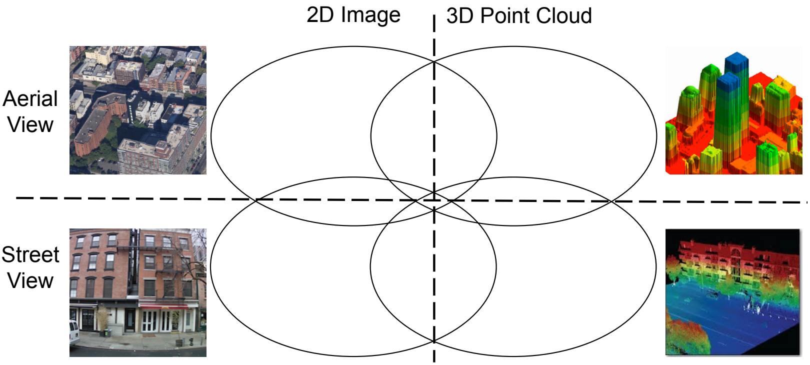
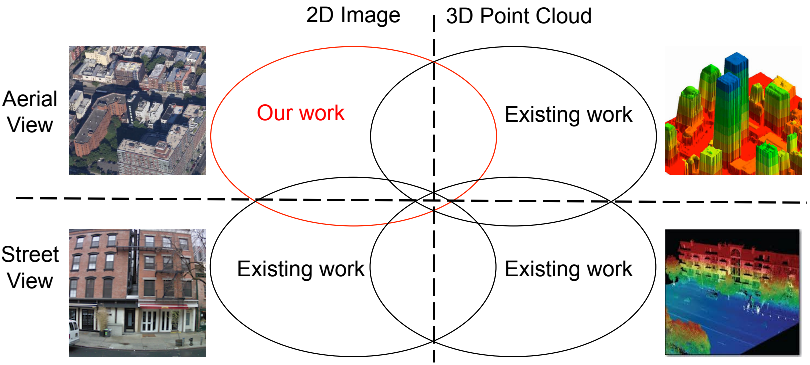
- 200+ facades per image

Motivation



- Huge amount of multi-modal, multi-dimensional data

Motivation



- Huge amount of multi-modal, multi-dimensional data
- Existing work only extracts a handful of facades from street-views
- Single-view facade detection helps matching / SfM
- Broad applications (geo-coding, SLAM, scene understanding)

Overview – Edge based Regularity Analysis

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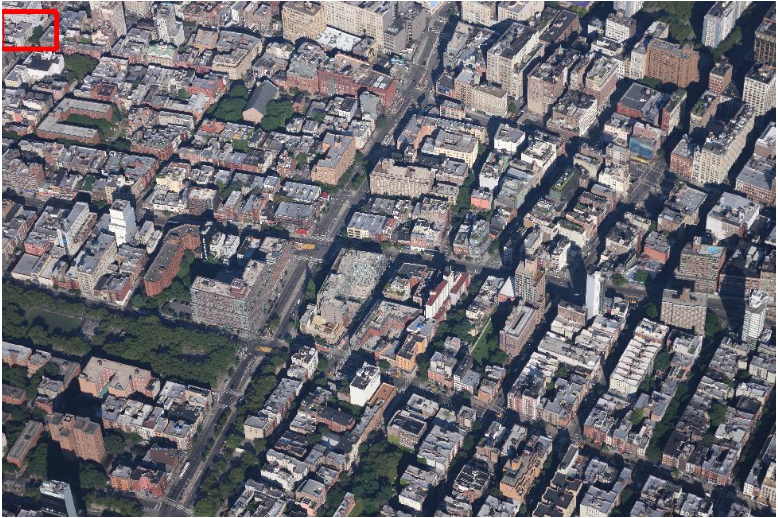
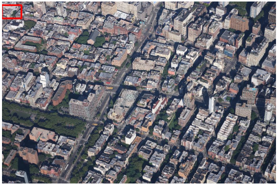
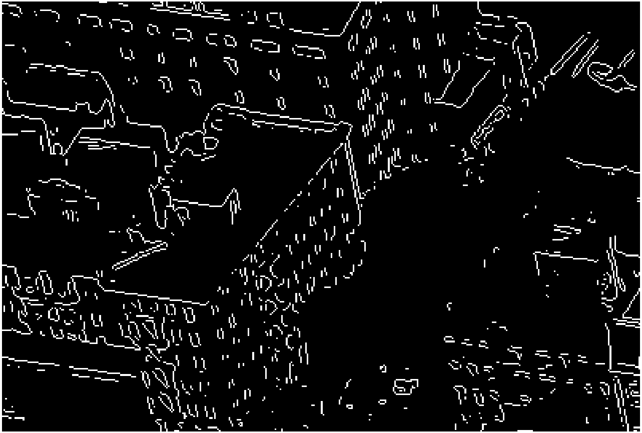


- Facade region has higher regularity
- Edge images are sufficient to capture such regularities





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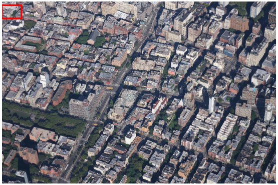
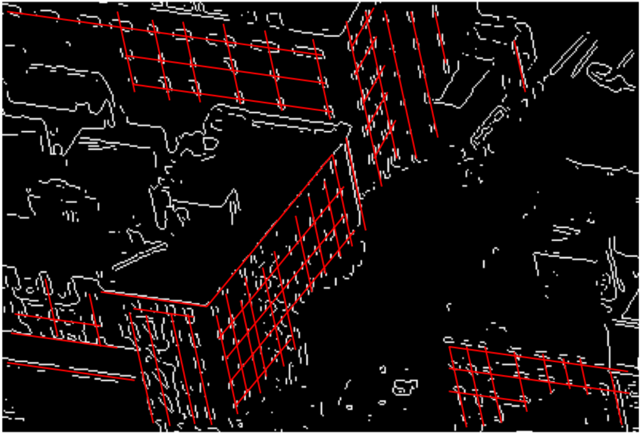
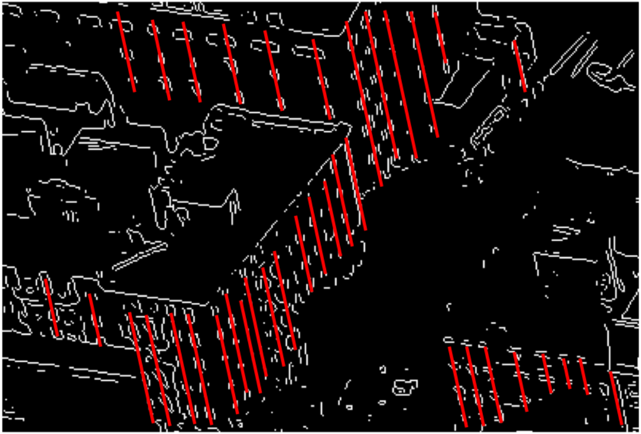




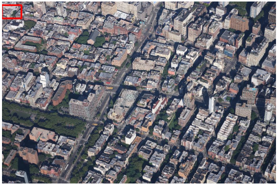
Determine the vertical and horizontal facade orientation

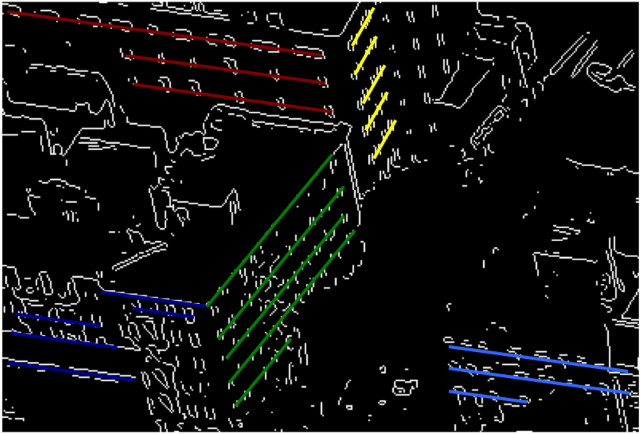
- Vertical orientation known from vanishing point



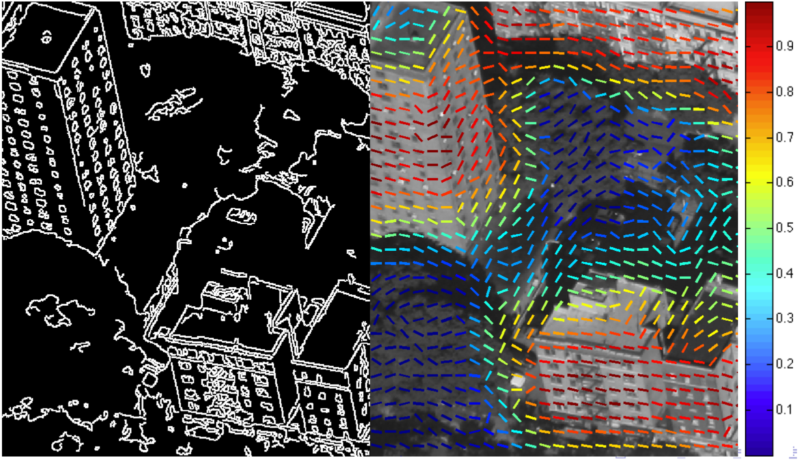
Determine the vertical and horizontal facade orientation

- Vertical orientation known from vanishing point
- Horizontal orientation to be detected





- Dense local regularity computation (facade likelihood)
- Dense dominant local horizontal orientation estimation



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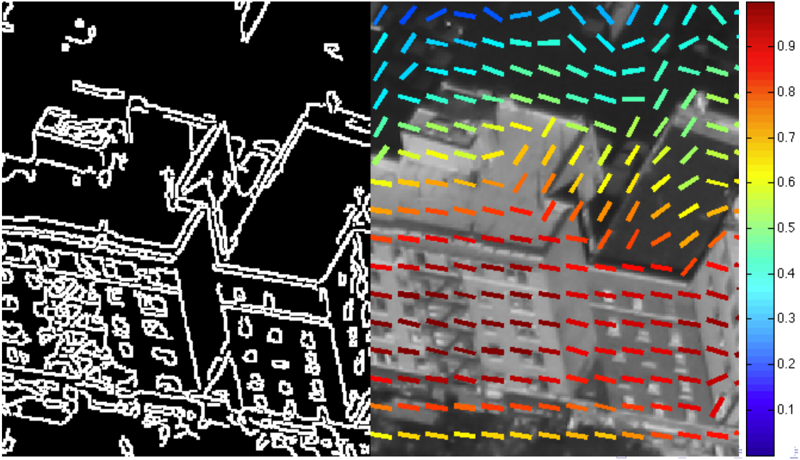

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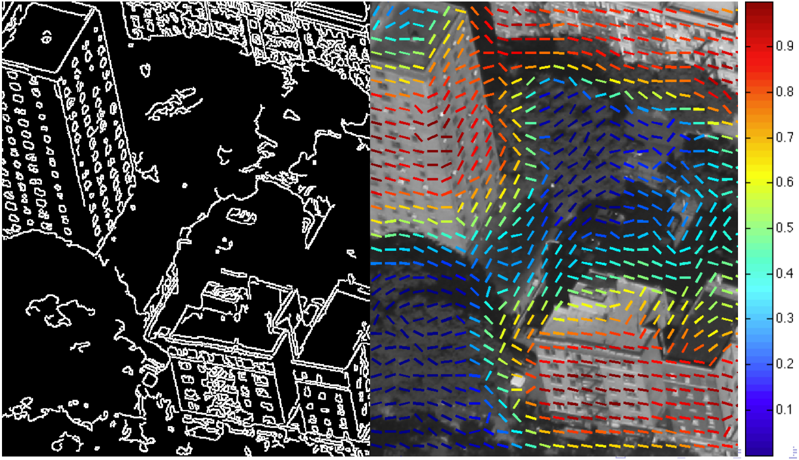

- Dense local regularity computation (facade likelihood)
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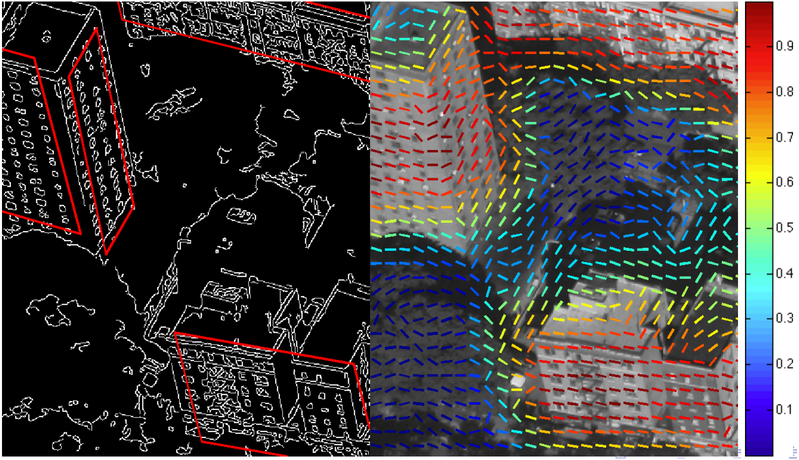
- Group local regions with high regularity and consistent orientation



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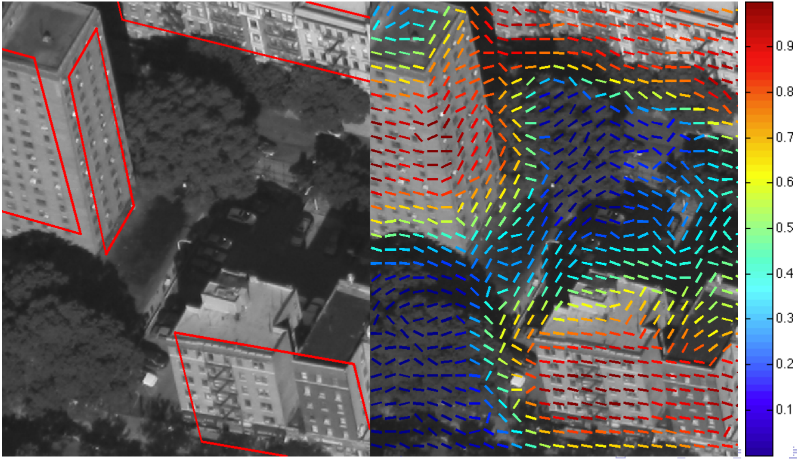
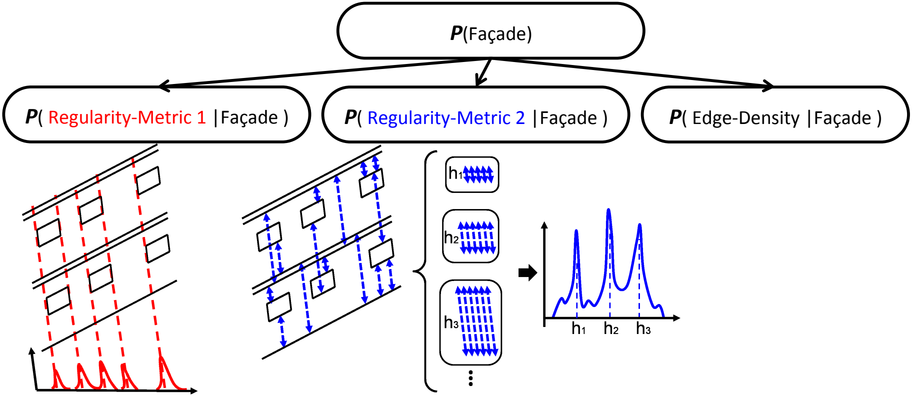
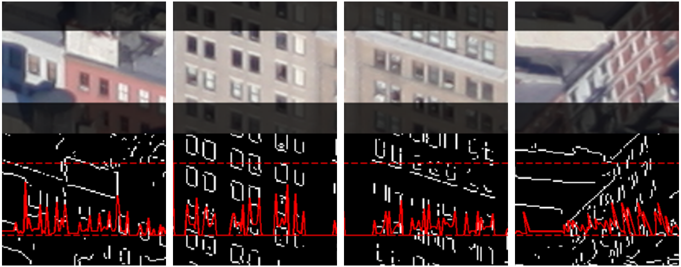


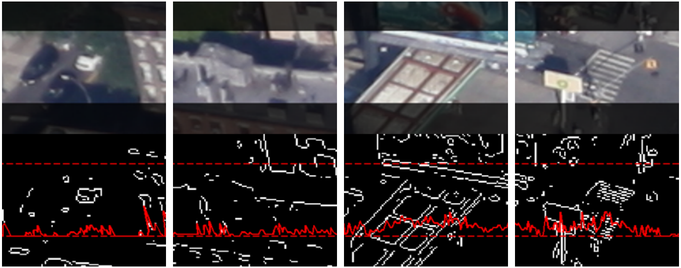
- Vertical Edge alignment regularity
- Vertical Edge distance regularity



Vertical Edge Alignment Regularity



Facade regions → Sparse distribution



Non-facade regions

Desirable attributes of sparsity measurement [1]

- Robin Hood – stealing from rich giving to poor DECREASES sparsity

[1] Hurley and Rickard, “Compare Measures of Sparsity”, 2008

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Measure	Robin Hood	Rising Tide	Scaling	Cloning
$\|\mathbf{c}\|_0$			$\surd$	
$\|\mathbf{c}\|_2/\|\mathbf{c}\|_1$	$\surd$		$\surd$	
Gini	$\surd$	$\surd$	$\surd$	$\surd$

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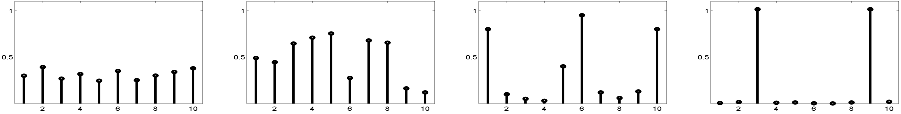
Gini	$\surd$	$\surd$	$\surd$	$\surd$

$$\text{Gini} = 1 - 2\sum_{k=1}^{N} \frac{c_{(k)}}{|\mathbf{c}|_1}\left(\frac{N-k+0.5}{N}\right), \text{ where } c_{(1)} \le c_{(2)} \le \ldots \le c_{(N)}$$



$Gini = 0.09$ $Gini = 0.25$ $Gini = 0.53$ $Gini = 0.78$

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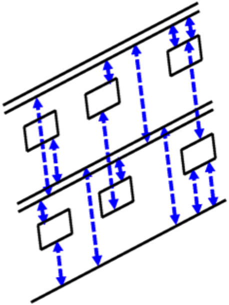
- Extract vertical distances between edges



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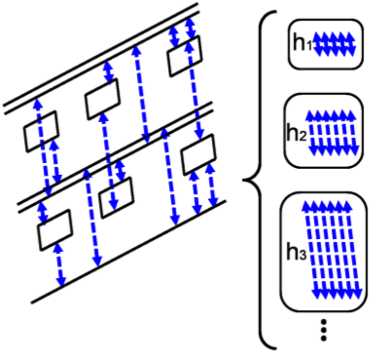
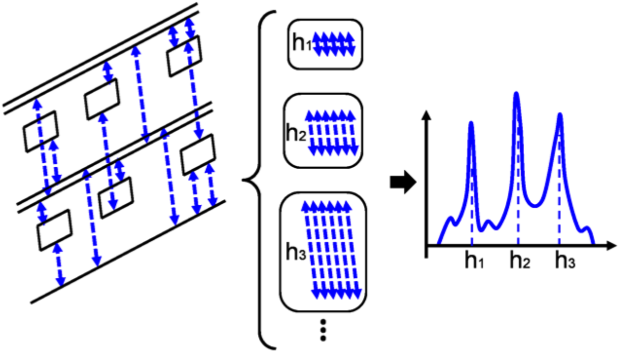
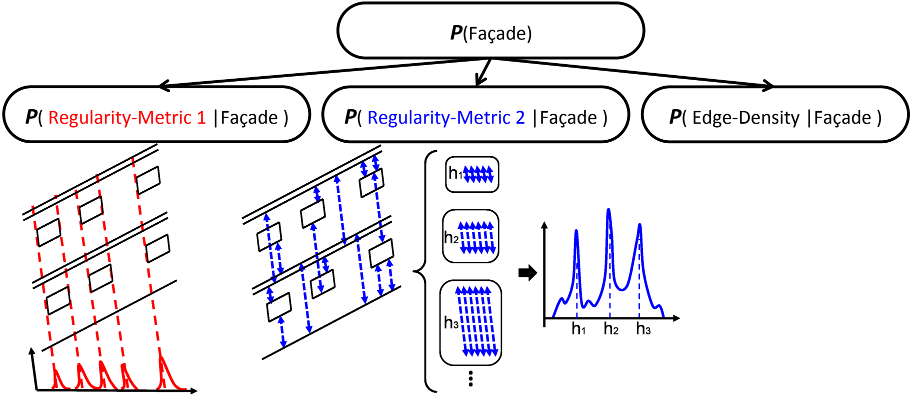


- Extract vertical distances between edges
- High responses to parallel elements



- Naive Bayes assumption

$$P(f_1, f_2 \ldots, | x = \text{Facade}) = \prod_i P(f_i | x = \text{Facade})$$



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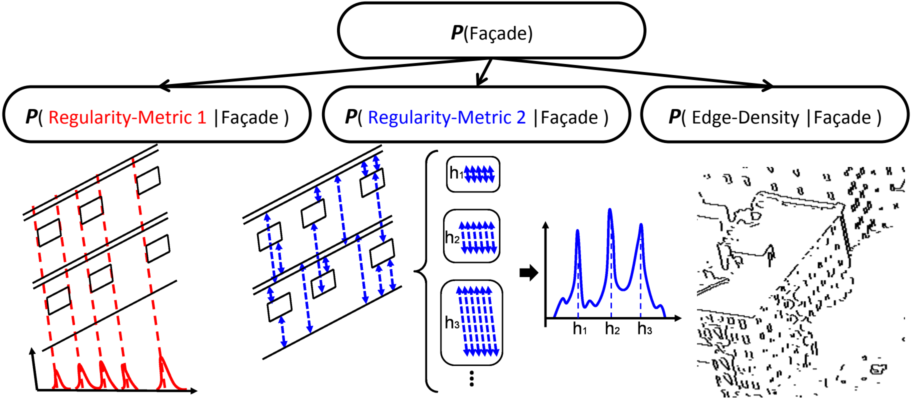
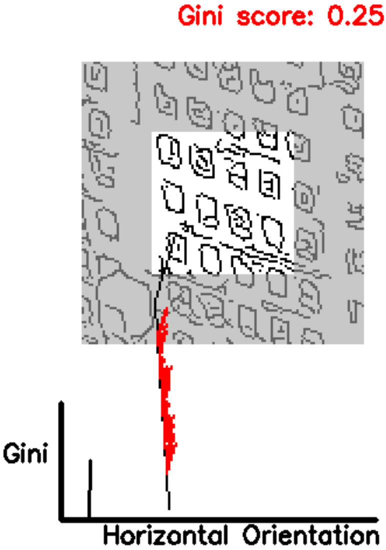


Discover the Horizontal Direction



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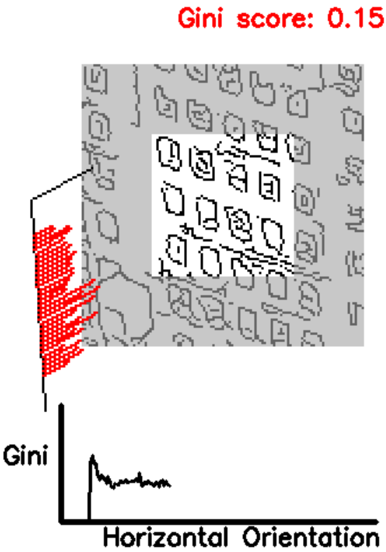
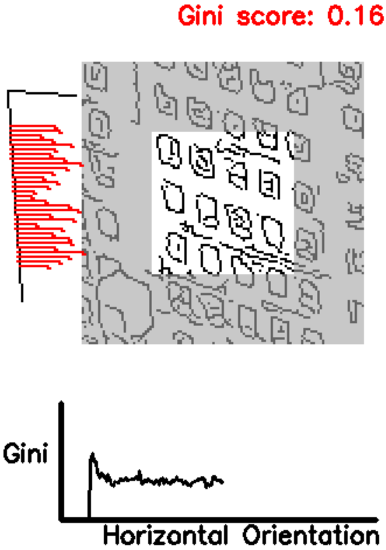
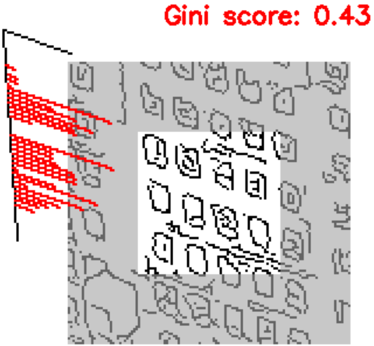



Gini score: 0.16
Gini
Horizontal Orientation

Discover the Horizontal Direction



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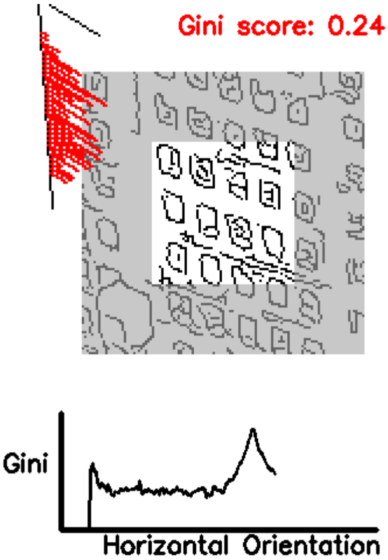
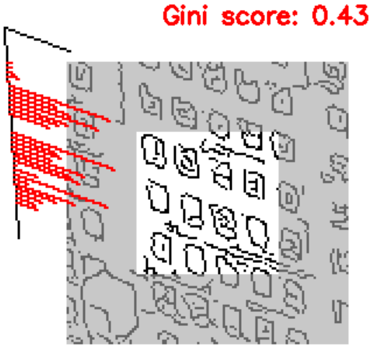
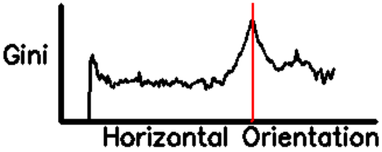


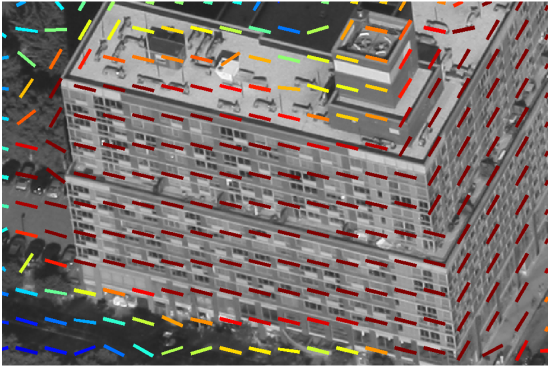

Gini score: 0.22


Gini
Horizontal Orientation

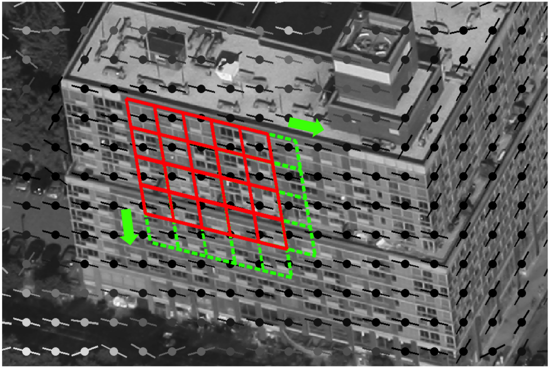
Discover the Horizontal Direction







$$\mathbf{F}^* \doteq (X_{Min}, X_{Max}, Y_{Min}, Y_{Max}, \dot{\theta}_h, \dot{\theta}_v) = \arg\max_{\mathbf{F}} \sum_{i=1}^{I} \sum_{j=1}^{J} s(x_{ij}, y_{ij}) \cdot a_{ij}$$



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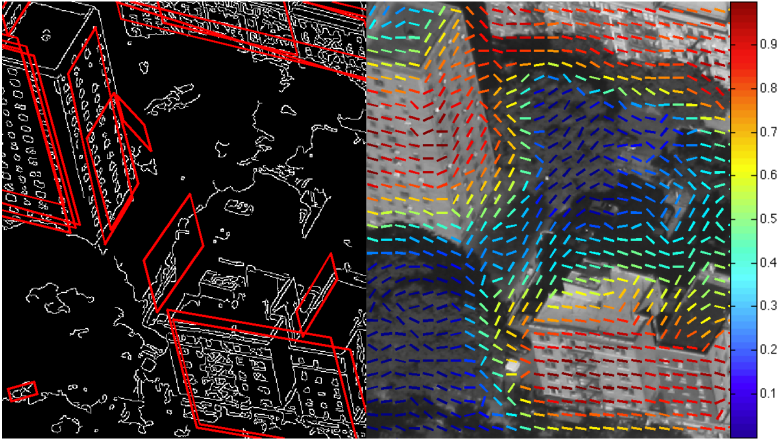
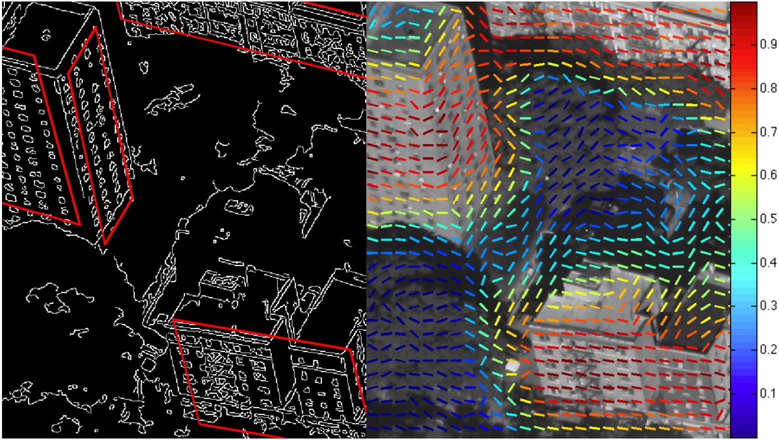
$$\sum_j s(x_{ij}, y_{ij}) a_{ij} > \tau_r \cdot \max_k \{\sum_j s(x_{kj}, y_{kj}) a_{kj}\}, \forall i = 1, \ldots I$$

$$\sum_i s(x_{ij}, y_{ij}) a_{ij} > \tau_r \cdot \max_k \{\sum_i s(x_{ik}, y_{ik}) a_{ik}\}, \forall j = 1, \ldots J$$

Facade Detection via Regional Expansion (Demo Video)



- Multiple random initialization followed by iterative expansion to maximize local regularity



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- IQP to remove overlapping: $\arg\max_x x'Mx, \quad x \in \{0,1\}^n$

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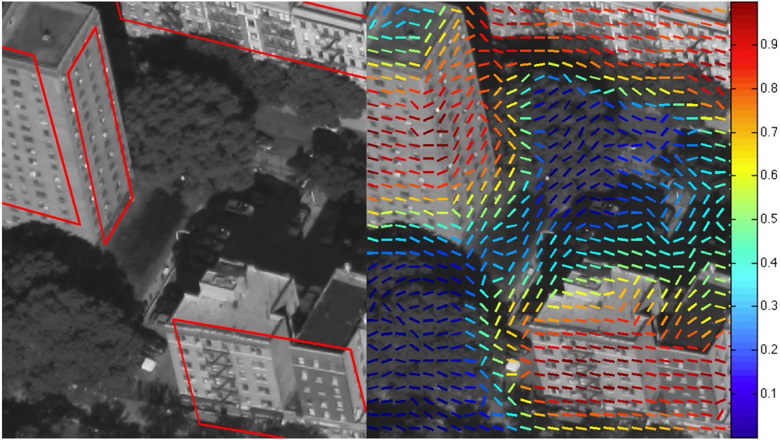

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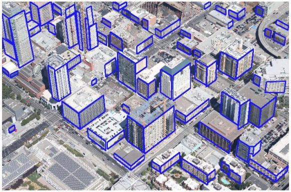
Experiments

- Images from NYC, Rome and SF
- 3000+ facades

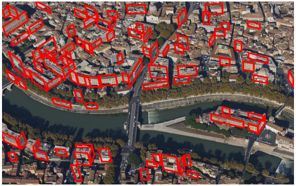
NYC (GT)

Rome (GT)

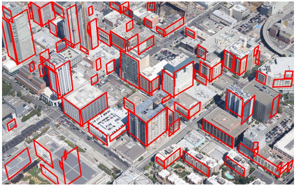


SF (GT)

NYC (result)

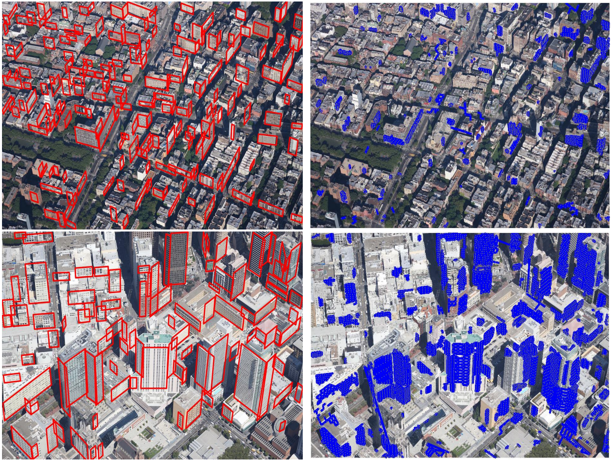


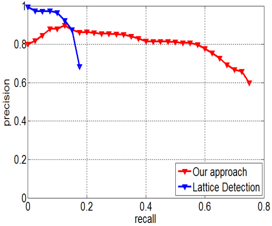
Rome (result)

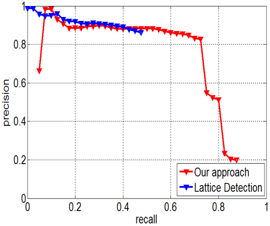


SF (result)

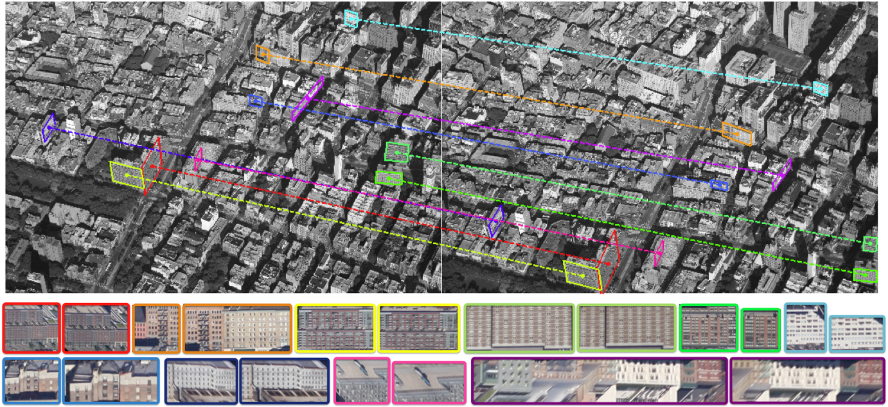
- Comparison against [Park, et al., ACCV10]
- Area based evaluation







- Matching facades with similar orientation
- Resolve relative depth ambiguity
- Frontal-view image patch matching with no rotation/scaling



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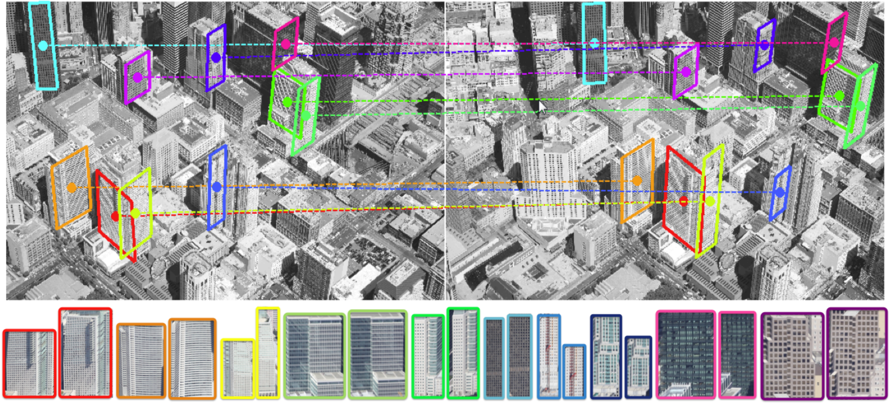

- We have proposed and validated a novel and robust local regularity measure using Gini score on urban scenes
- Our algorithm detects and localizes facades in city-scale aerial images
- The output of our algorithm leads to feasible facade matching and alignment across views

Efficient integral histogram [F. Porikli, CVPR05] for dense feature computation

- pre-compute $C_\theta(i,j)$ for all θ
- $h_\theta(i,j) = C_\theta(i,j+k) - C_\theta(i,j)$