Reflection Symmetry Detection in 2D Images

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Computer Vision Researcher, Qopius

Nantes Machine Learning Meetup
10 Dec 2018

Agenda

- About Me
- Introduction
- Problem Definition
- Related Work
- Framework
  - Feature Extraction
  - Symmetrical Weights
  - Feature Representation

About Me: Education

- BSc of Computers & Informatics (Major: Computer Science) - Suez Canal University, Egypt [2002 - 2007]

- Erasmus Mundus MSc Program in Computer Vision & Robotics - Burgundy/Girona/Heriot-Watt Universities, Europe [2012 - 2014]

- PhD in Computer Vision - Jean Monnet / Lyon Universities, France [2014 - 2019]

About Me: Research

- Research Assistant - Computer Science Department, Suez Canal University, Egypt [2008 - 2012] : Web Services

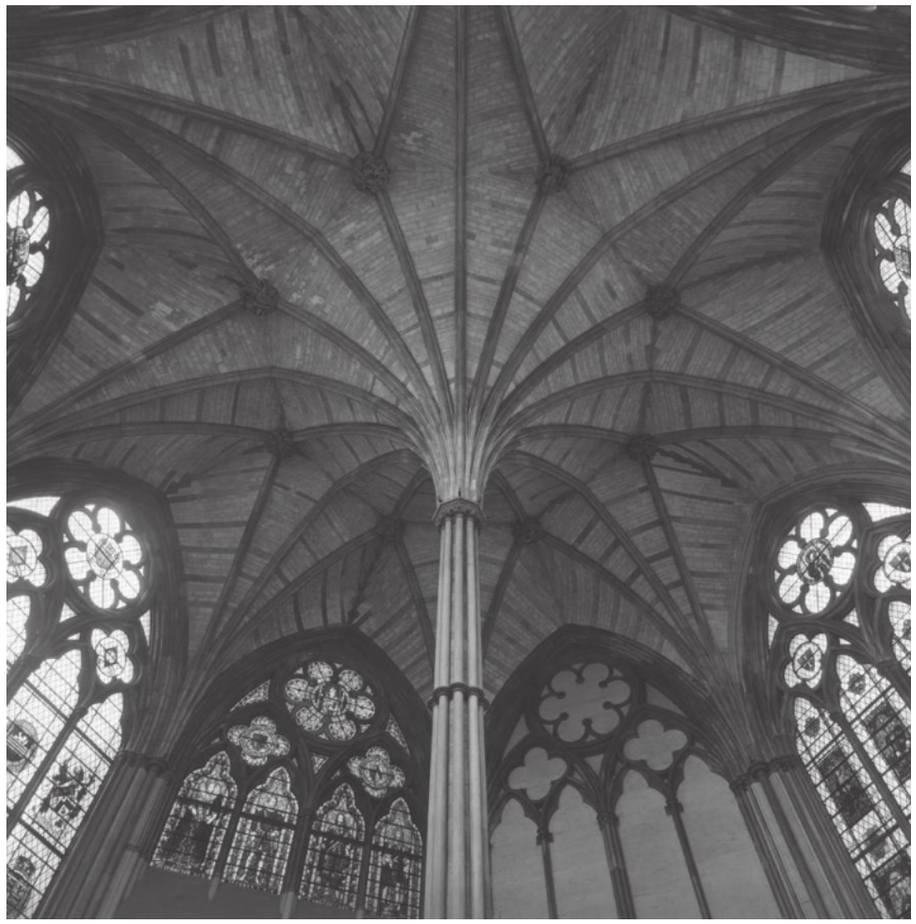
- Research Intern - Le2i Lab UMR CNRS 6306, France [2013] : Thermal Imaging

- Research Intern - VisionLab, Heriot-Watt University, UK [2014]: Underwater Image Classification using Deep Learning

- Doctoral Researcher - Hubert Curien Lab UMR CNRS 5516, France [2014-2018]: Image Processing and Analysis

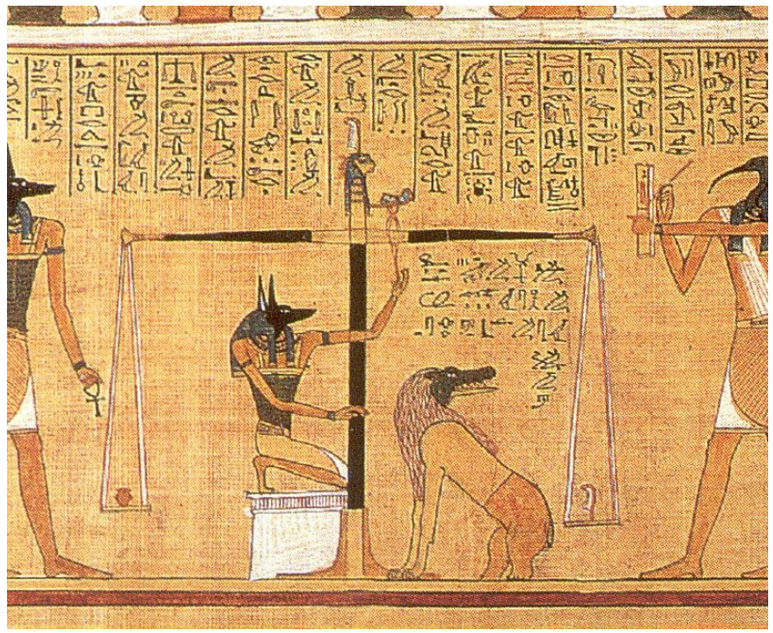
About Me: Winner of recent symmetry competitions

Introduction:
What is Symmetry?



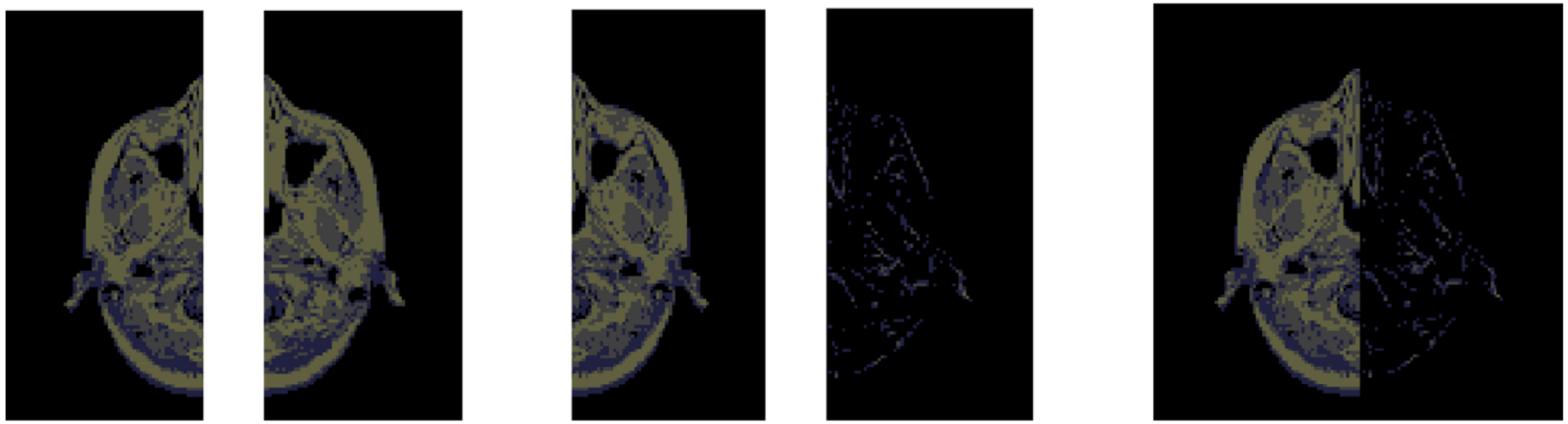
Freeman, Michael. The Photographer's Mind: Creative Thinking for Better Digital Photos. Hachette UK, 2018.

Introduction:
Symmetry in History



Introduction:
Symmetry in Computer Vision

Medical Image Compression

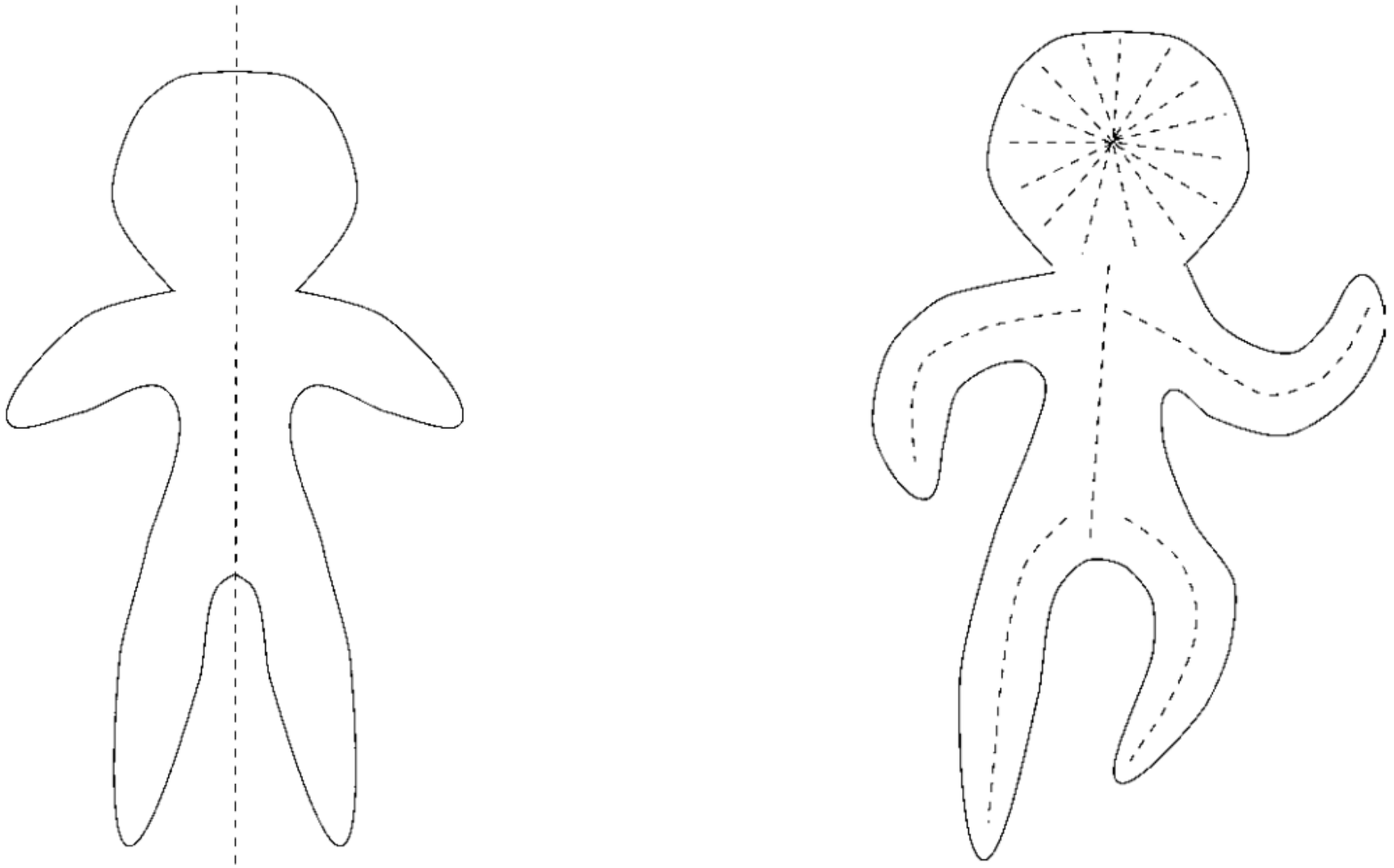


a) Actual Left Part b) Actual Right Part c) Flip of Left Part d) Right – Flip of left e) Symmetry Processed Image

Depth Estimation

V. Bairagi, “Symmetry-based biomedical image compression,” Journal of digital imaging, pp. 1-9, 2015.
L. Yang, J. Liu, and X. Tang, “Depth from water reflection,” Image Processing, IEEE Transactions on, vol. 24, no. 4, pp. 1235-1243, 2015.

Introduction:
Global vs Local Symmetries



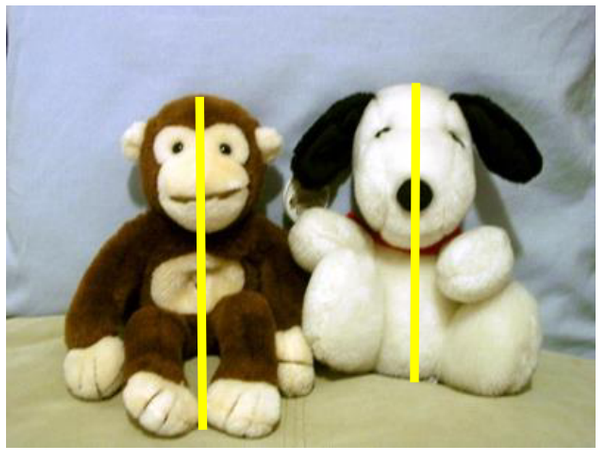
Liu, Yanxi, et al. "Computational symmetry in computer vision and computer graphics." *Foundations and Trends® in Computer Graphics and Vision* 5.1–2 (2010): 1-195.

Introduction:
Types of Symmetry

Reflection / Bilateral / Mirror

Single

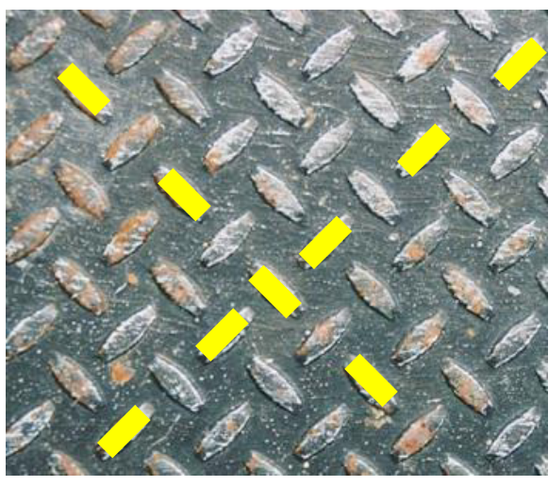
Multiple



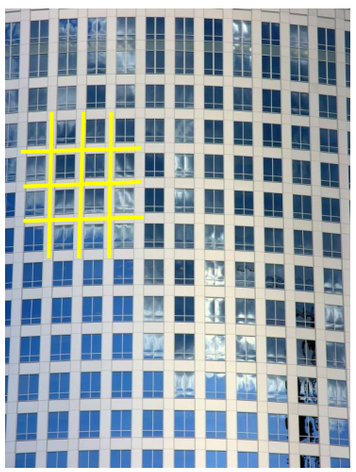
Rotation

Translation

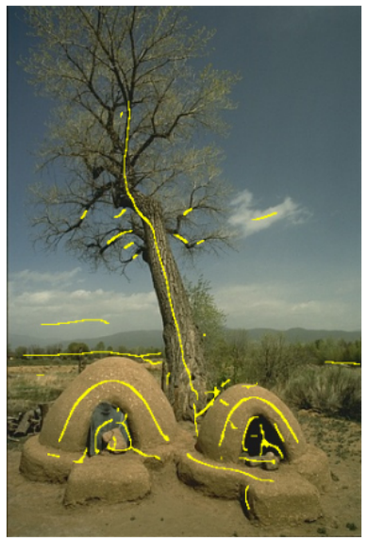
Frieze



Wallpaper

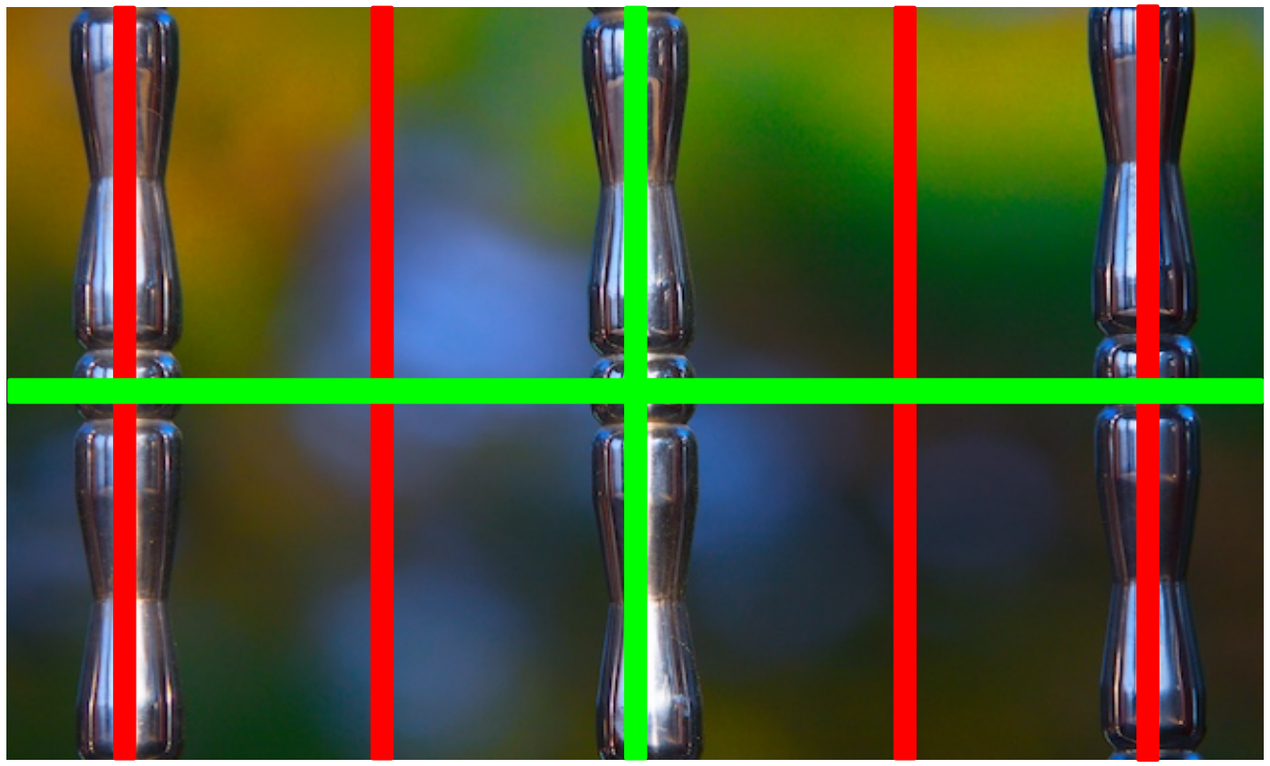


Medial



Liu, Jingchen, et al. "Symmetry detection from realworld images competition 2013: Summary and results." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops*. 2013.
Tsogkas, Stavros, and Iasonas Kokkinos. "Learning-based symmetry detection in natural images." European Conference on Computer Vision. Springer, Berlin, Heidelberg, 2012.

Problem Definition



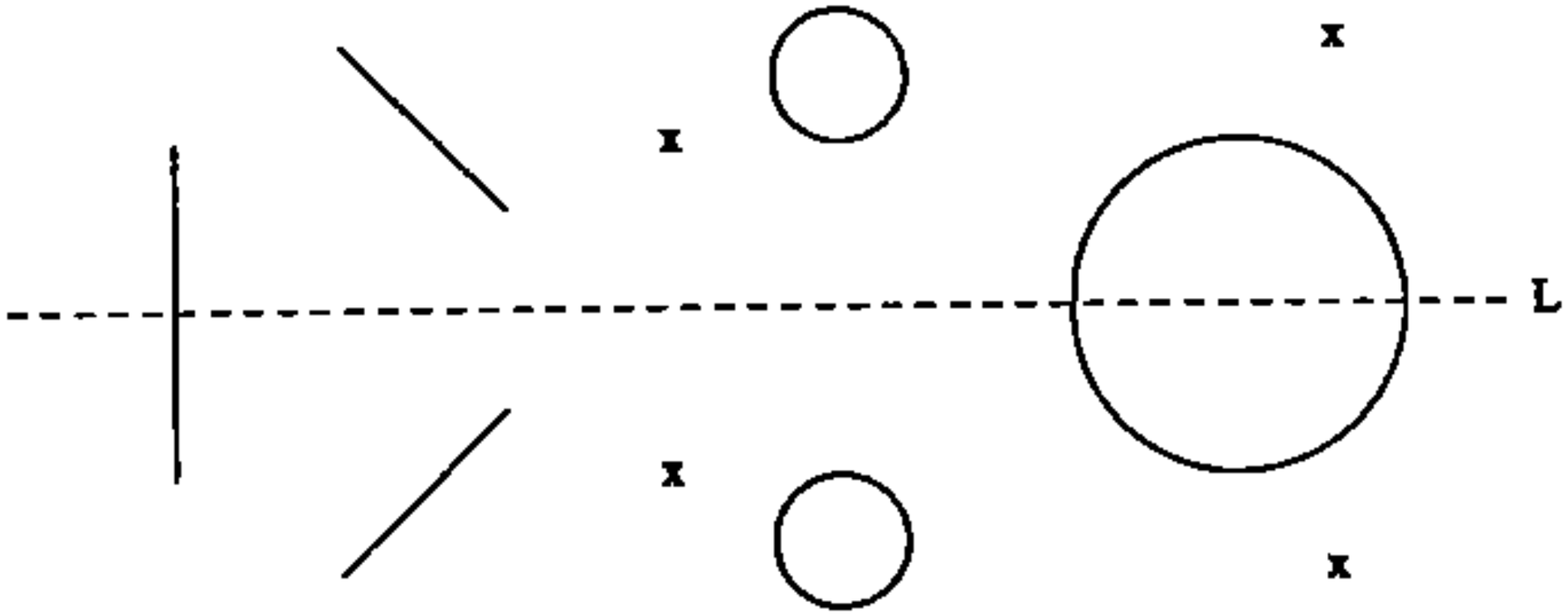
Murray, Naila, Luca Marchesotti, and Florent Perronnin. "AVA: A large-scale database for aesthetic visual analysis." *Computer Vision and Pattern Recognition (CVPR), 2012 IEEE Conference on*. IEEE, 2012.

Related Work

- Intensity-based Methods
- Feature-based Methods
- Segmentation-based Methods
- Learning-based Methods

Related Work: Intensity-based Methods I

First Algorithm: Atallah [1985]

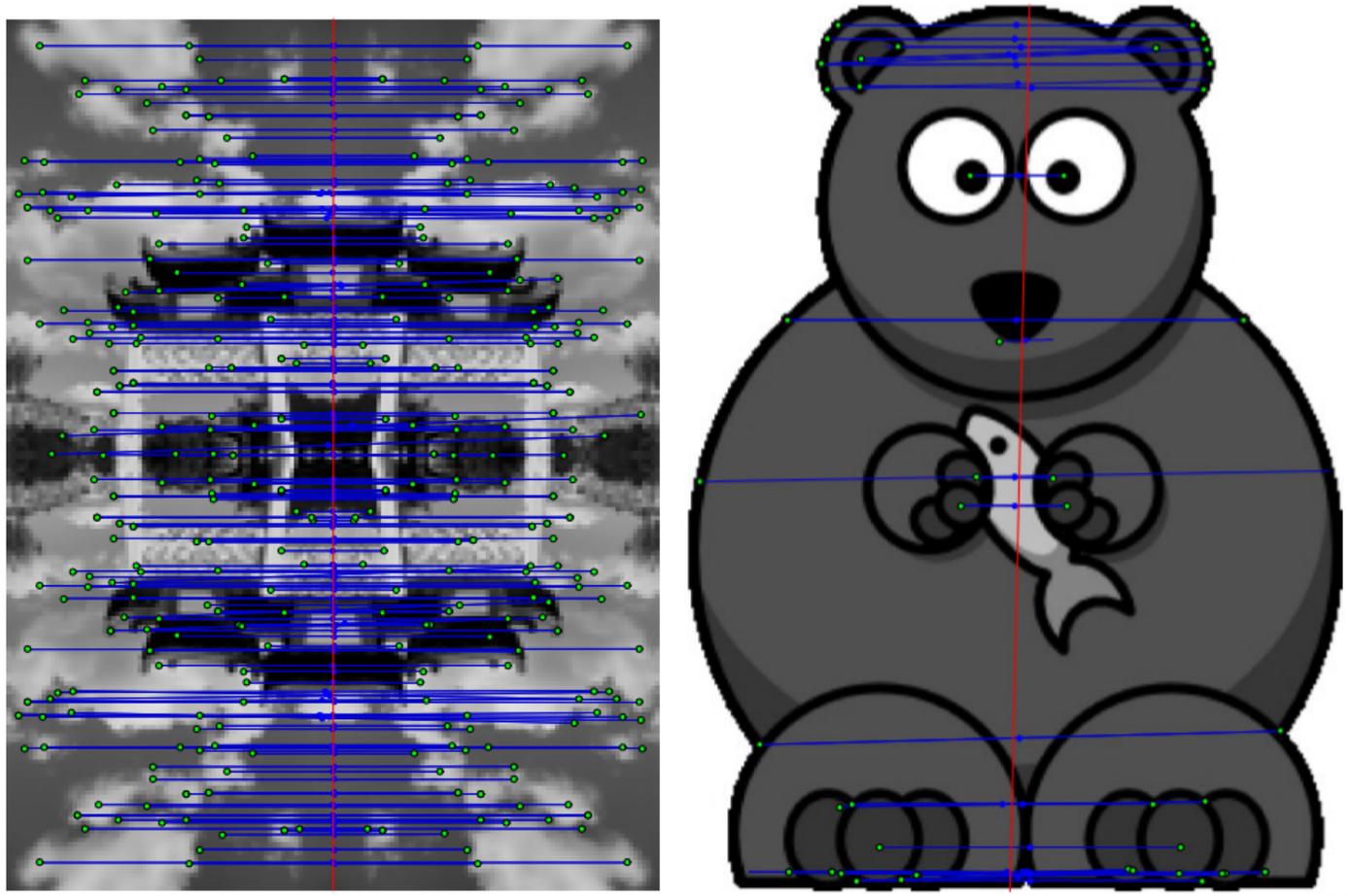


Similarity between geometrical characterization of predefined primary objects

Atallah, Mikhail J. "On symmetry detection." *IEEE Transactions on Computers* 7 (1985): 663-666.

Related Work: Intensity-based Methods II

Recent Algorithm: Nagar and Raman [2017]

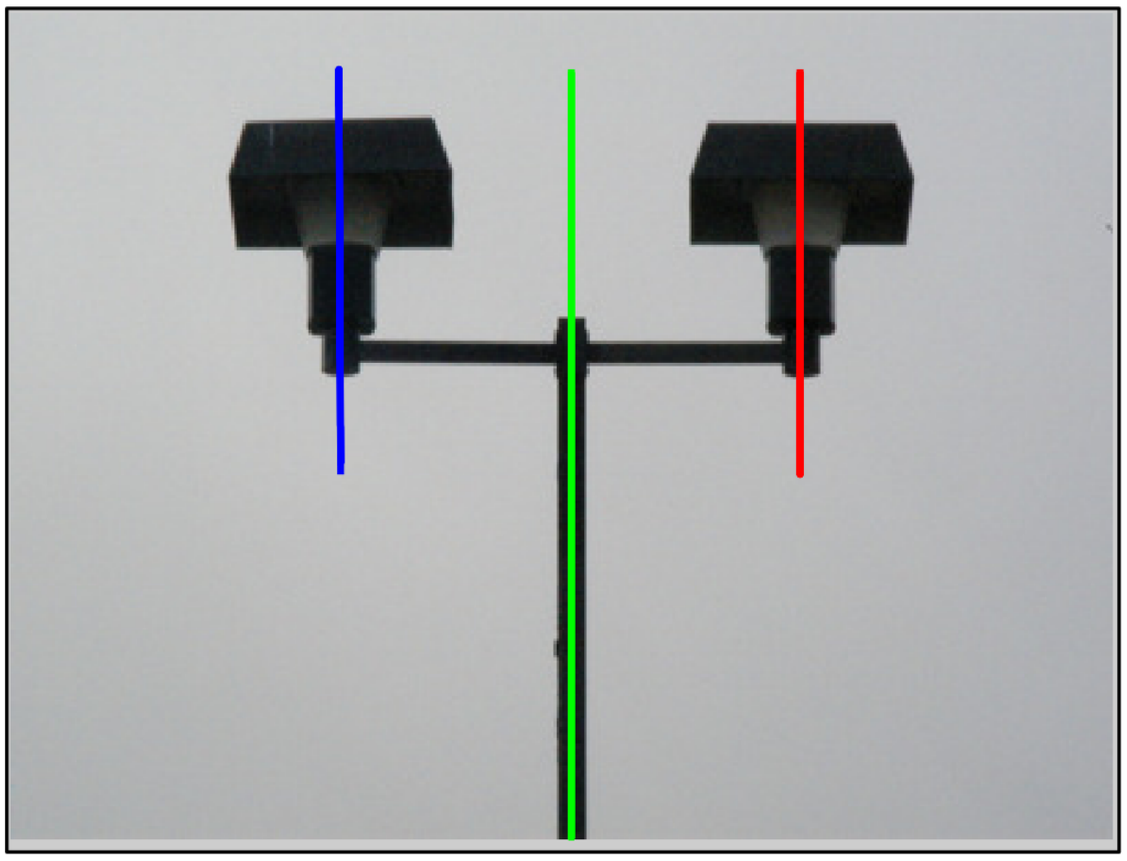


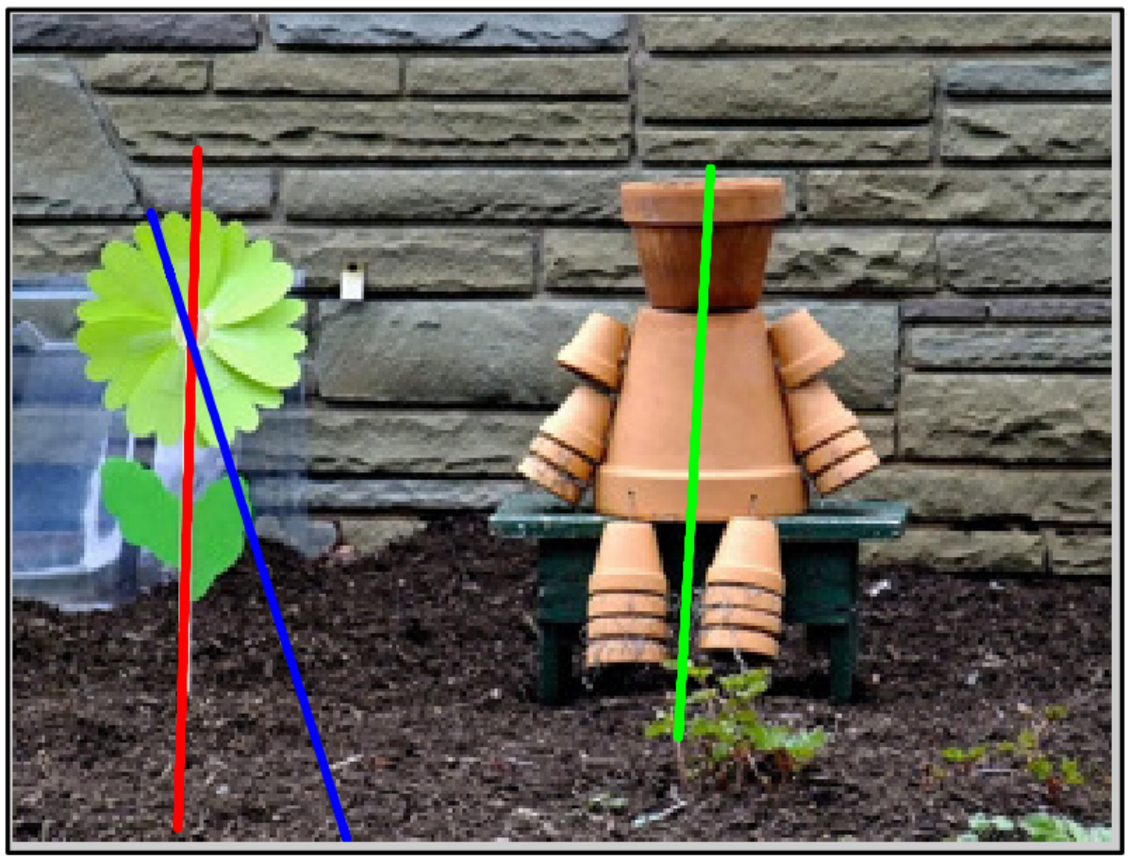
Riemannian manifold optimization algorithm

Nagar, Rajendra, and Shanmuganathan Raman. "Approximate reflection symmetry in a point set: theory and algorithm with an application." *arXiv preprint arXiv:1706.08801*(2017).

Related Work: Intensity-based Methods III

Recent Algorithm: Gnutti et al. [2017]



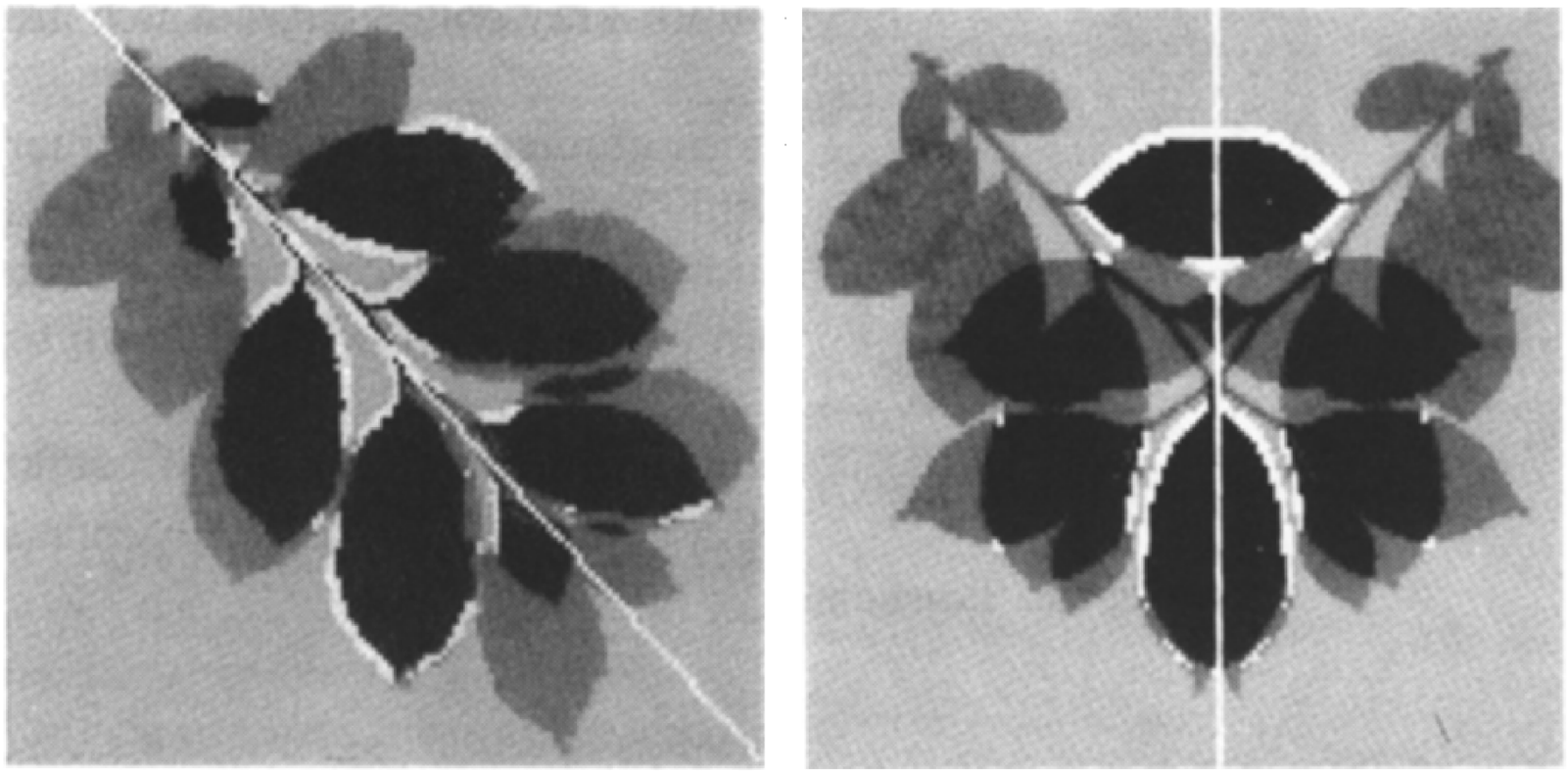


Symmetry measure of orientation-based patches

Gnutti, Alessandro, Fabrizio Guerrini, and Riccardo Leonardi. "On Reflection Symmetry In Natural Images." Proceedings of the 15th International Workshop on Content-Based Multimedia Indexing. ACM, 2017.

Related Work: Feature-based Methods I

Early Algorithm: Masuda et al. [1993]

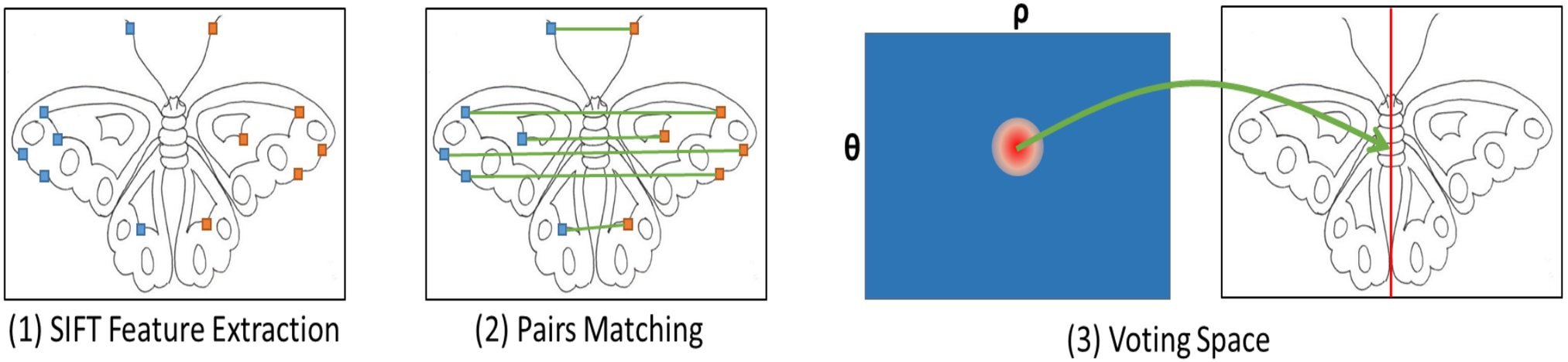


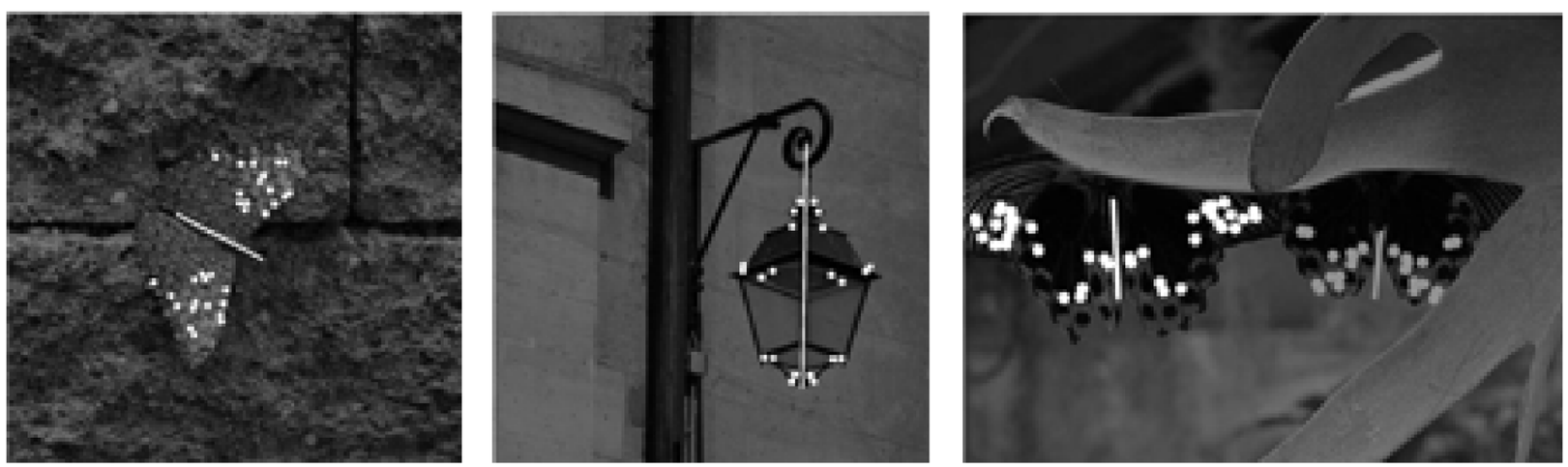
Feature extraction based on gradient information (Gaussian filters)

Masuda, Takeshi, Kazuhiko Yamamoto, and Hiromitsu Yamada. "Detection of partial symmetry using correlation with rotated-reflected images." *Pattern Recognition* 26.8 (1993): 1245-1253.

Related Work: Feature-based Methods II

First Baseline Algorithm: Loy and Eklundh [2006]





Loy, Gareth, and Jan-Olof Eklundh. "Detecting symmetry and symmetric constellations of features." *European Conference on Computer Vision*. Springer, Berlin, Heidelberg, 2006.

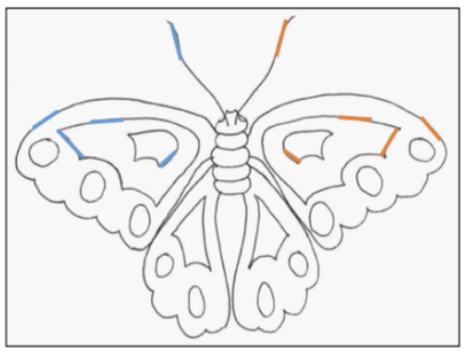
Related Work: Feature-based Methods III

First Baseline Algorithm: Loy and Eklundh [2006]

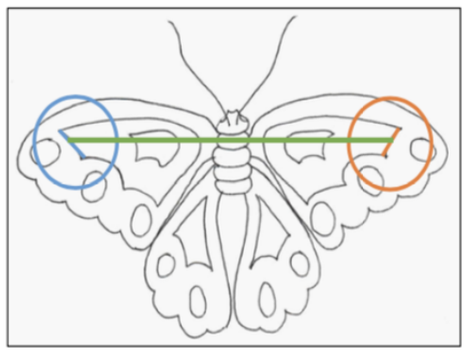
Loy, Gareth, and Jan-Olof Eklundh. "Detecting symmetry and symmetric constellations of features." *European Conference on Computer Vision*. Springer, Berlin, Heidelberg, 2006.

Related Work: Feature-based Methods IV

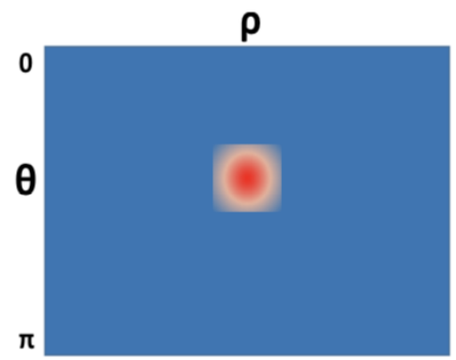
Second Baseline Algorithm: Cicconet et al. [2014]

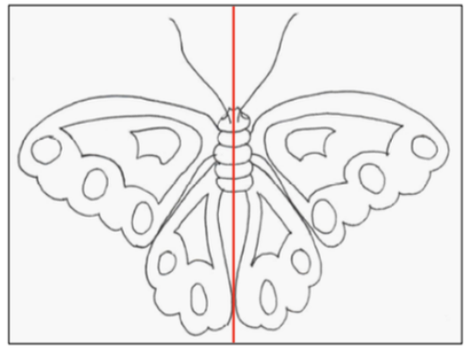


(1) Multiscale Edge Segment Extraction

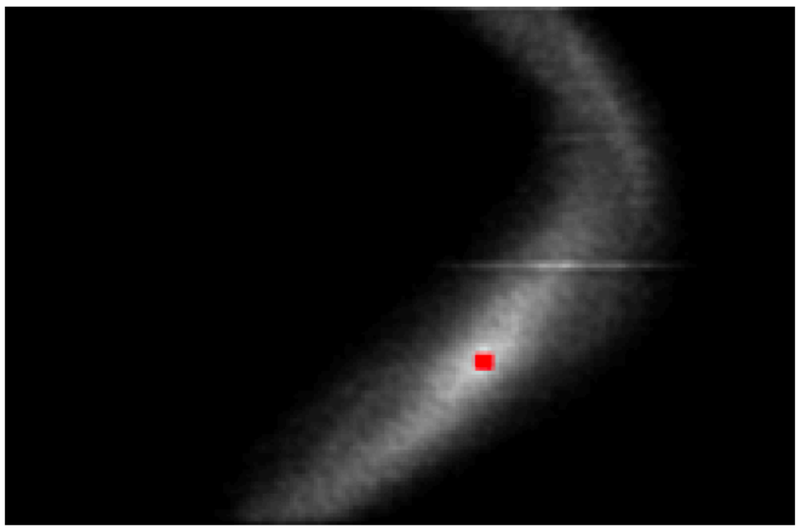


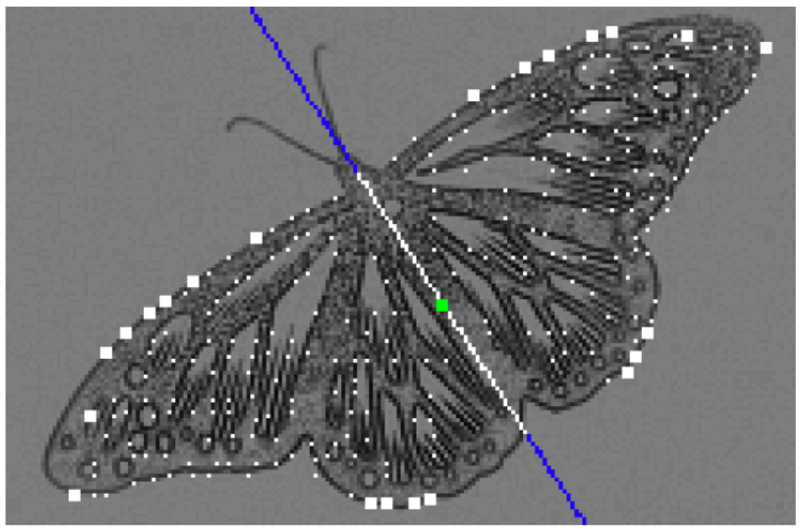
(2) Triangulation based on Local Symmetry Weights





(3) Voting Space for Peak Detection with Handling Orientation Discontinuity.

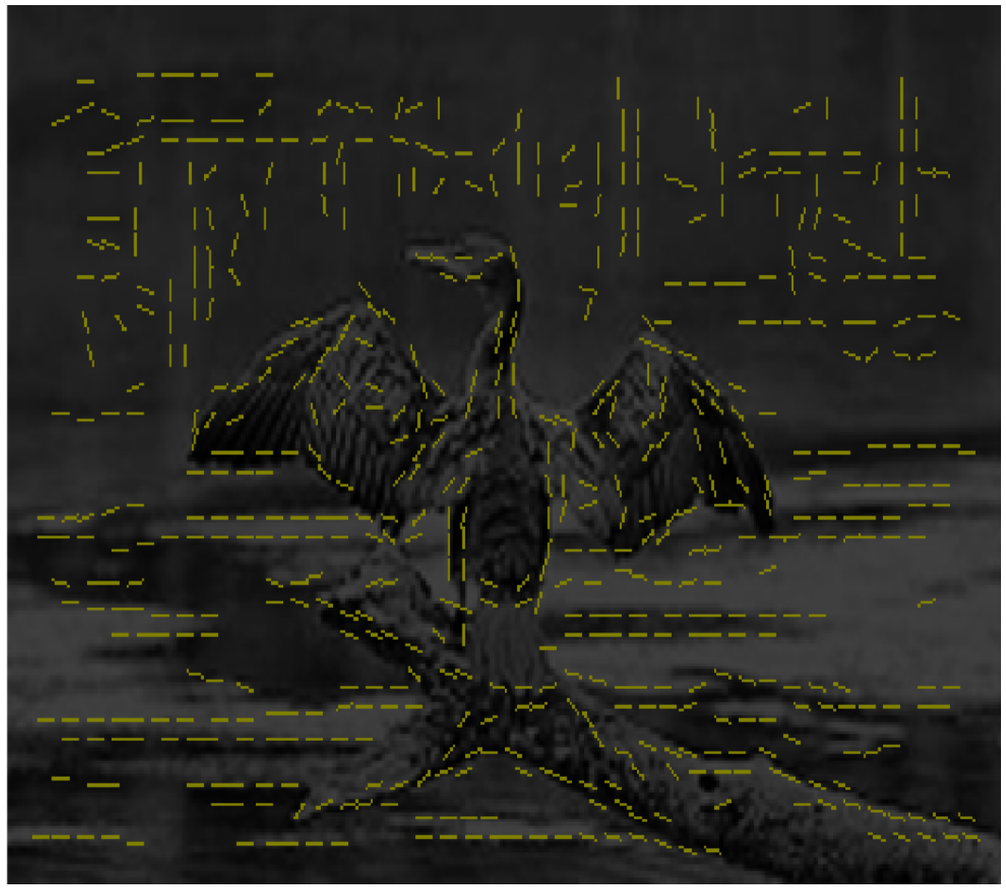


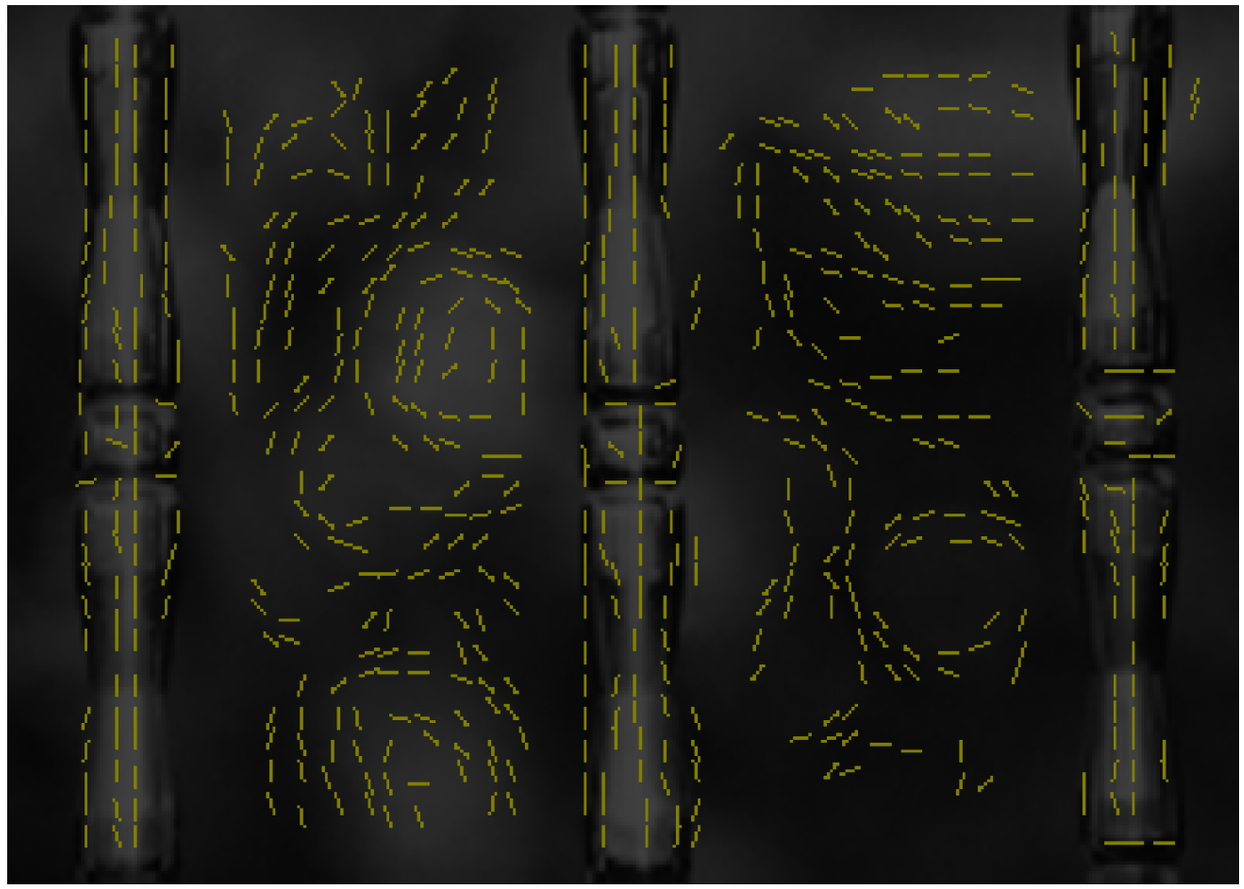


Cicconet, Marcelo, et al. "Mirror symmetry histograms for capturing geometric properties in images." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. 2014.

Related Work: Feature-based Methods V

Second Baseline Algorithm: Cicconet et al. [2014]

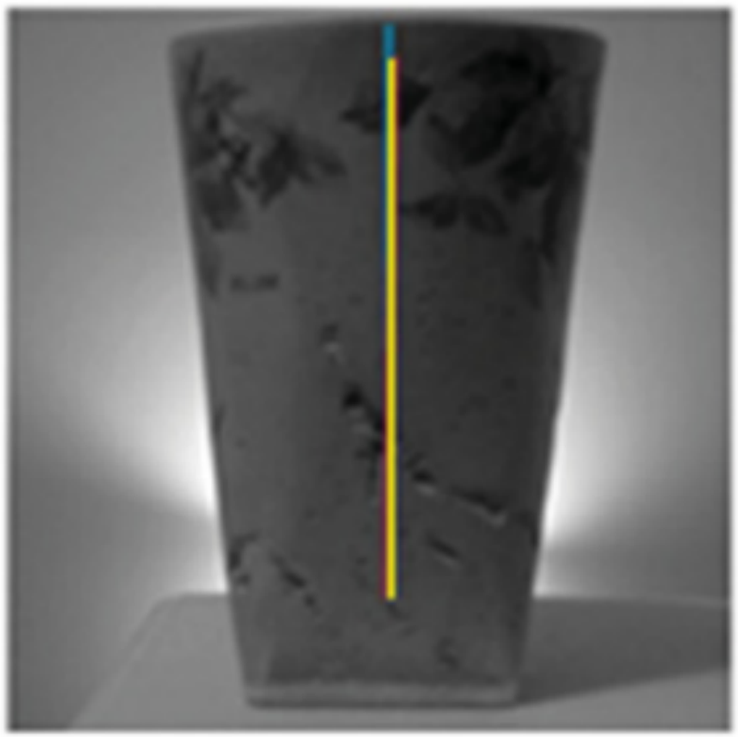




Cicconet, Marcelo, et al. "Mirror symmetry histograms for capturing geometric properties in images." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. 2014.

Related Work: Feature-based Methods VI

Recent Algorithm: Atadjanov and Lee [2016]

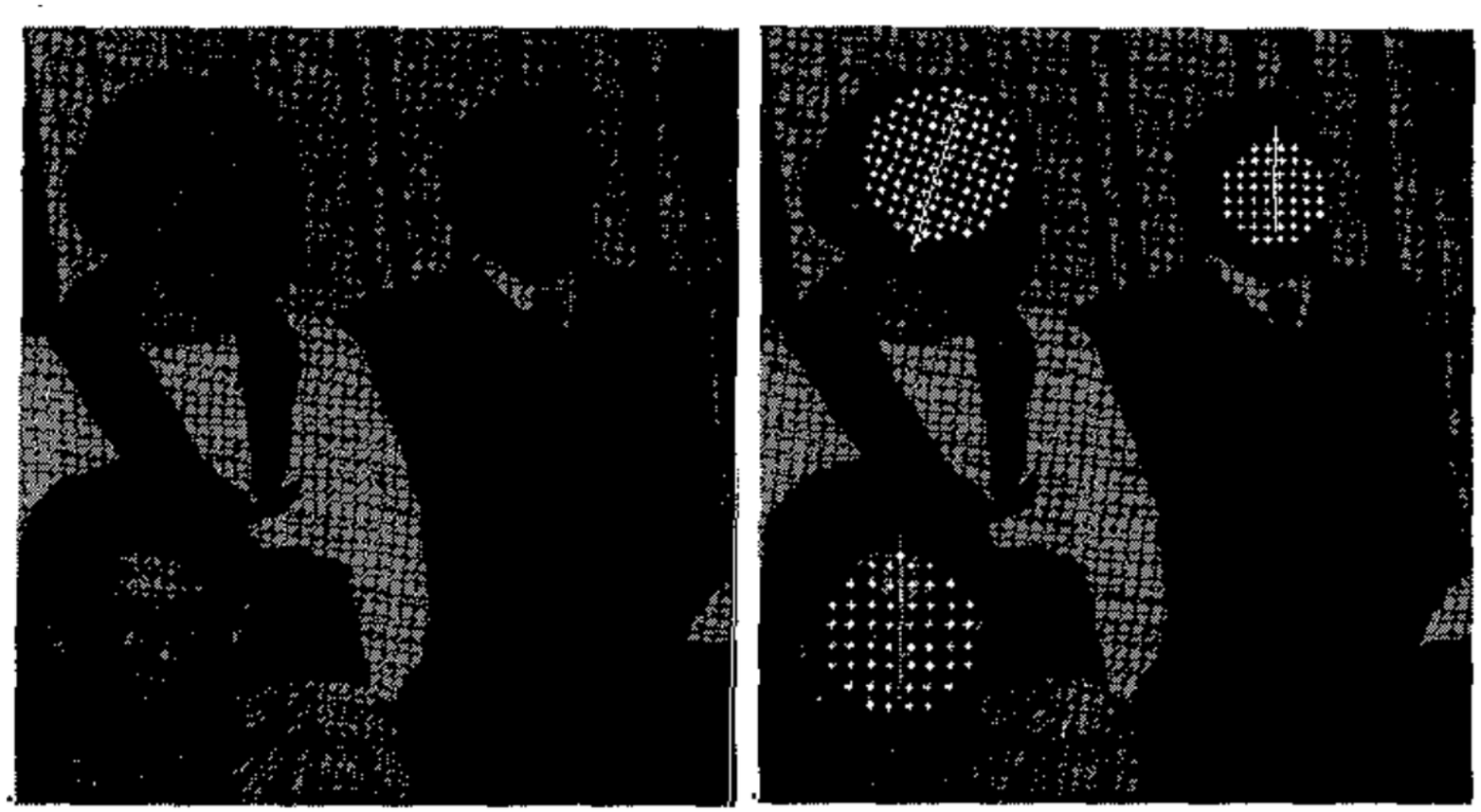


N-dimensional scale-invariant curvature-based histograms

Atadjanov, Ibragim R., and Seungkyu Lee. "Reflection symmetry detection via appearance of structure descriptor." *European Conference on Computer Vision*. Springer, Cham, 2016.

Related Work: Segmentation-based Methods I

Early Algorithm: Zabrodsky et al. [1995]

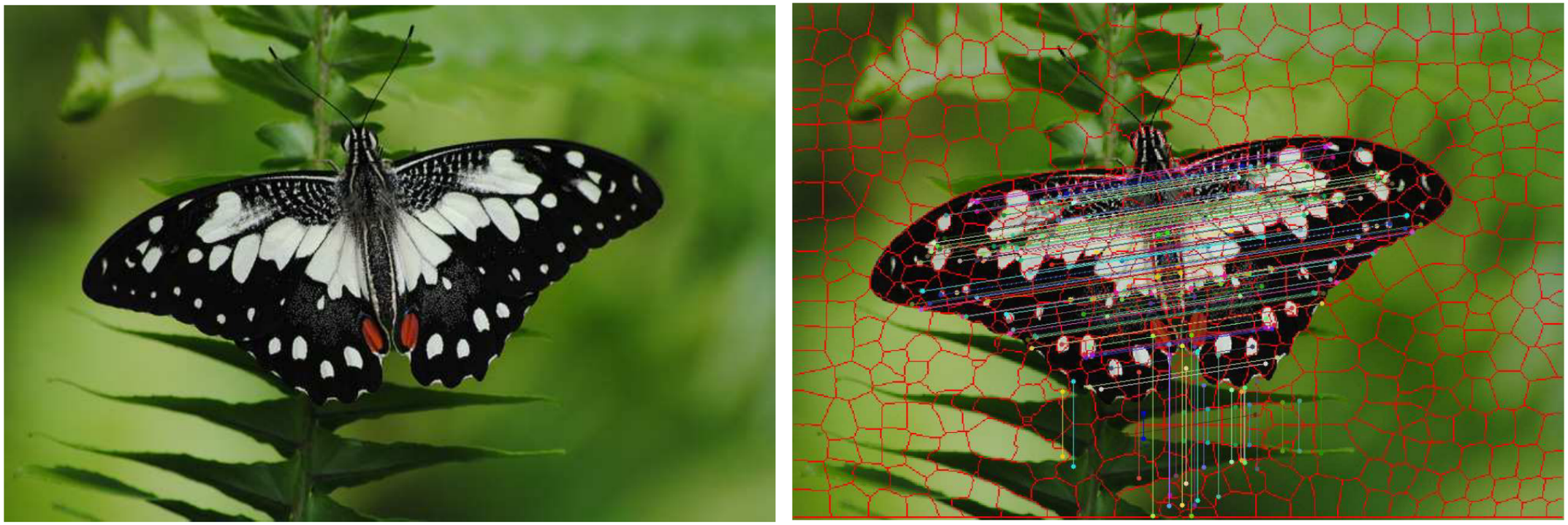


Symmetrical measure to find a similar objects

Zabrodsky, Hagit, Shmuel Peleg, and David Avnir. "Symmetry as a continuous feature." IEEE Transactions on Pattern Analysis and Machine Intelligence 17.12 (1995): 1154-1166.

Related Work: Segmentation-based Methods II

Recent Algorithm: Nagar and Raman [2017]

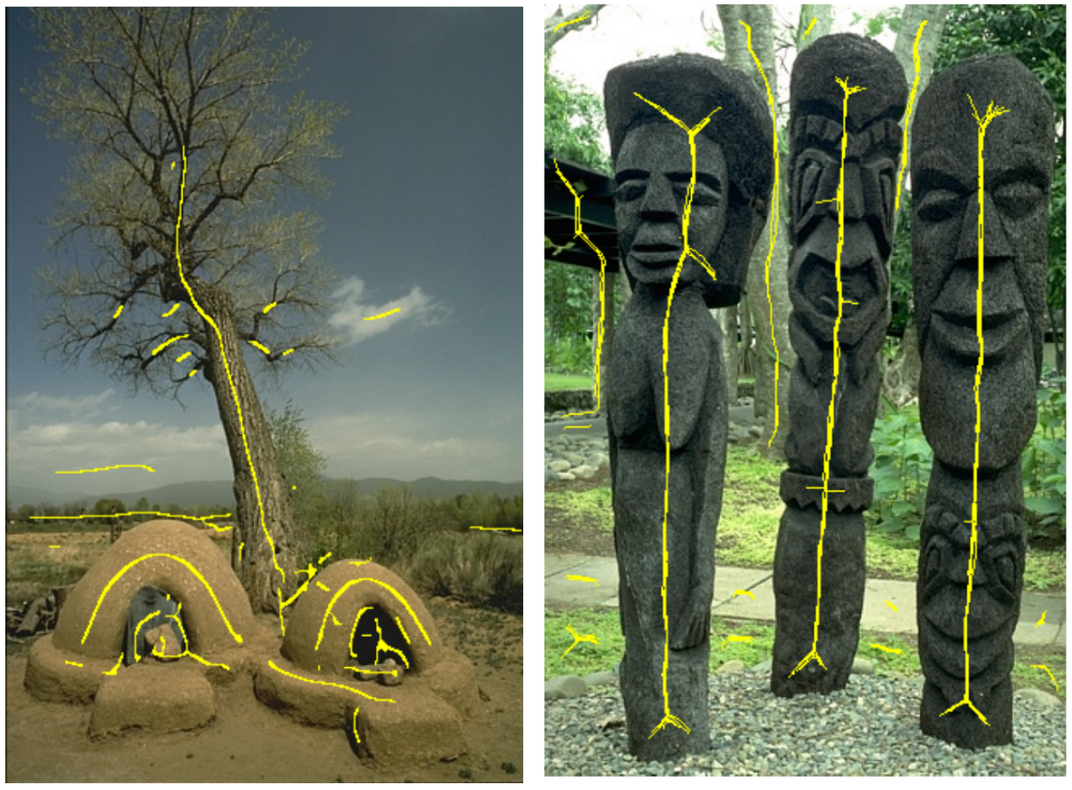


Symmetrical selection based on super-pixel segmentation (i.e. SLIC)

Nagar, Rajendra, and Shanmuganathan Raman. "Symmslic: Symmetry aware superpixel segmentation." *Proceedings, ICCV Workshop on Detecting Symmetry in the Wild*. 2017.

Related Work:
Learning-based Methods I

Early Algorithm: Tsogkas and Kokkinos [2012]

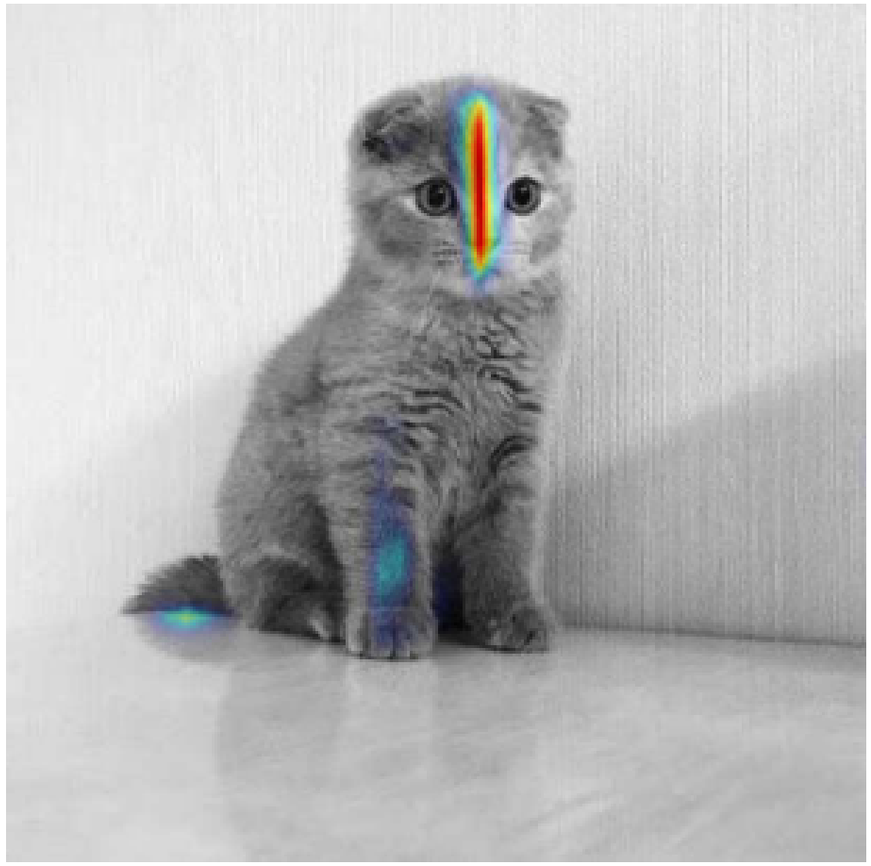


spectral clustering features based on Multiple Instance Learning (MIL)

Tsogkas, Stavros, and Iasonas Kokkinos. "Learning-based symmetry detection in natural images." European Conference on Computer Vision. Springer, Berlin, Heidelberg, 2012.

Related Work: Learning-based Methods II

Recent Algorithm: Funk and Liu [2017]



Deep CNN for finding local and global symmetries

Funk, Christopher, and Yanxi Liu. "Beyond Planar Symmetry: Modeling Human Perception of Reflection and Rotation Symmetries in the Wild." *Computer Vision (ICCV), 2017 IEEE International Conference on*.

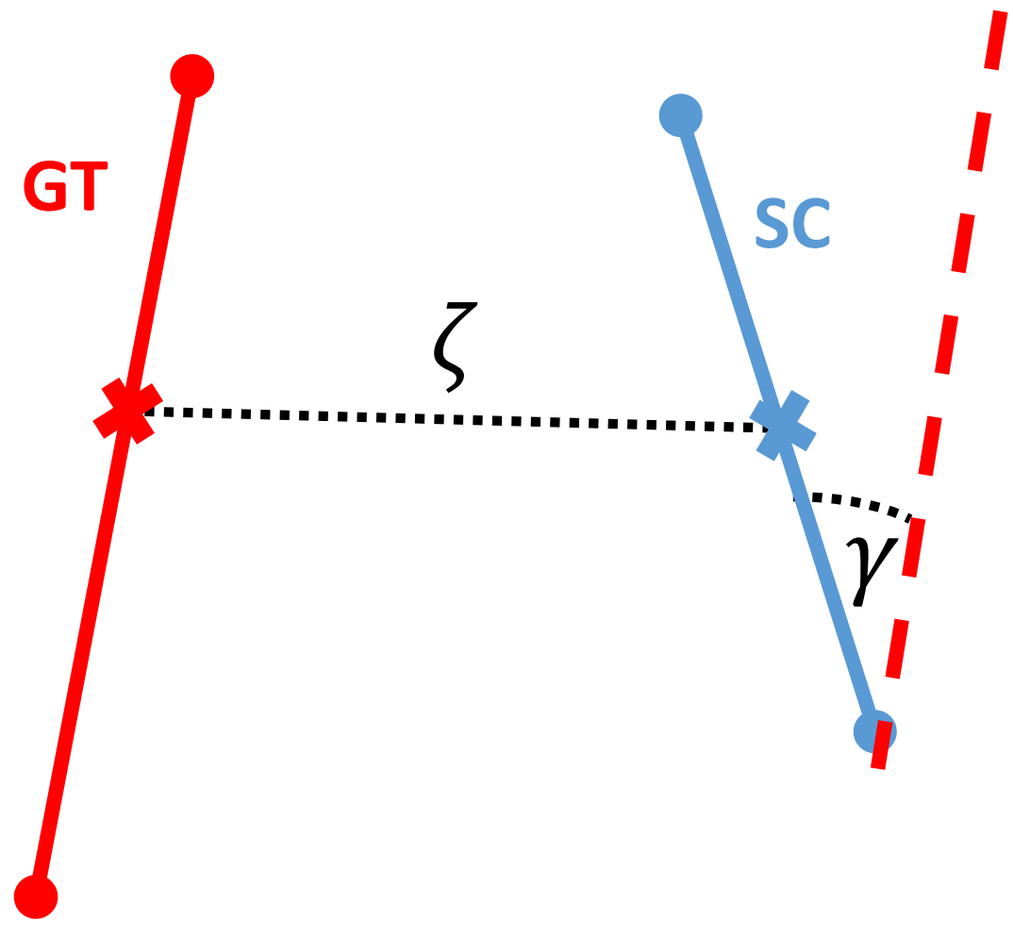
Related Work: Evaluation Metrics I

- True Positive

$$abs(\begin{vmatrix} v_x^{SC} & v_x^{GT} \\ v_y^{SC} & v_y^{GT} \end{vmatrix})$$

$$\gamma = E(atan(\frac{\begin{vmatrix} v_x^{SC} & v_x^{GT} \\ v_y^{SC} & v_y^{GT} \end{vmatrix}}{< v^{SC}, v^{GT} >})); \ \gamma < \gamma_T \,,$$

$$\zeta = \sqrt{(t_x^{SC} - t_x^{GT})^2 + (t_y^{SC} - t_y^{GT})^2}; \ \zeta < \zeta_T \,,$$



- Precision, Recall, Maximum F1 Score

Related Work: Evaluation Metrics II

Competition	γ_T	ζ_T
CVPR2011	10°	$20\% \times len(GT)$
CVPR2013	10°	$20\% \times min\{len(MT), len(GT)\}$
ICCV2017 - Training	3°	$2.5\% \times min\{W, H\}$
ICCV2017 - Testing	10°	$20\% \times min\{len(MT), len(GT)\}$

Related Work: Datasets I

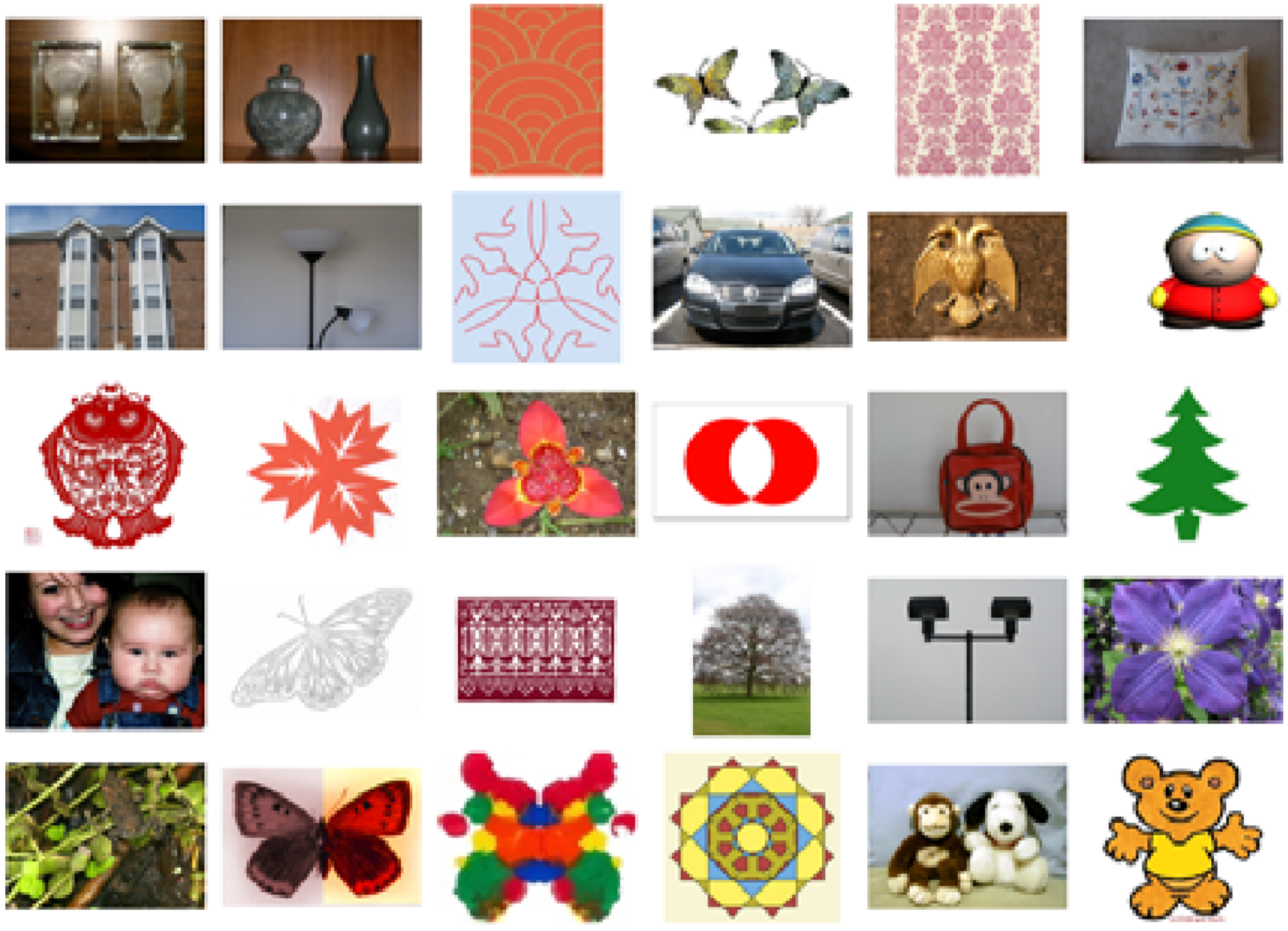
- PSU: Liu's vision group proposed a symmetry groundtruth from Flickr images in ECCV2010, CVPR2011 and CVPR2013

- NY: Cicconet et al. presented a new symmetry database in 2016

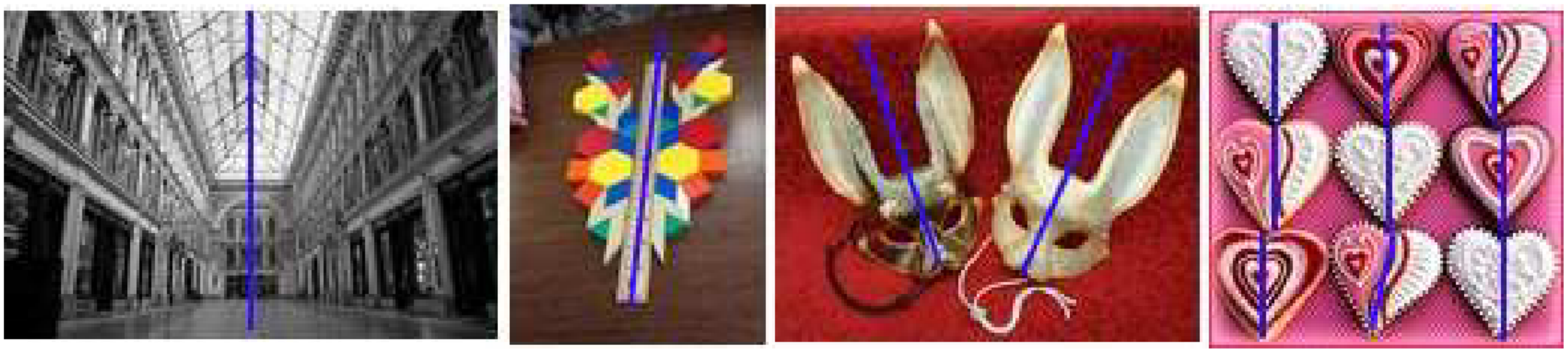
- ICCV2017: Seungkyu Lee delivered a challenge database associated with reflection groundtruth

Dataset	Single	Multiple
PSU	157	142 (479)
NY	176	63 (188)
ICCV2017	100	100 (384)

Related Work: Datasets II - PSU

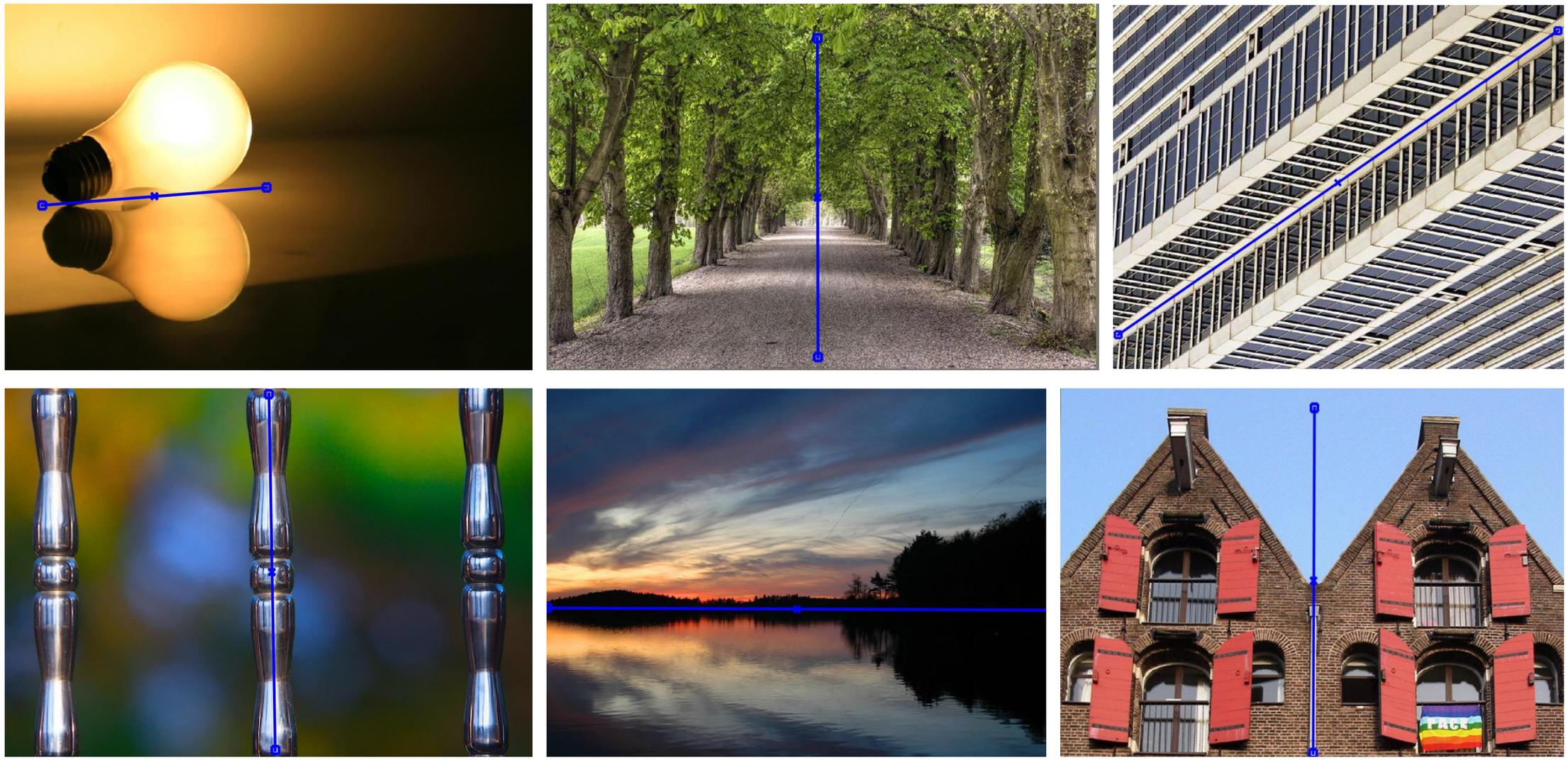


Related Work:
Datasets III - NY & ICCV



Related Work:
Datasets IV - AvaSym

253 images from AVA dataset (http://www.dpchallenge.com/) with global-axis symmetry groundtruth.

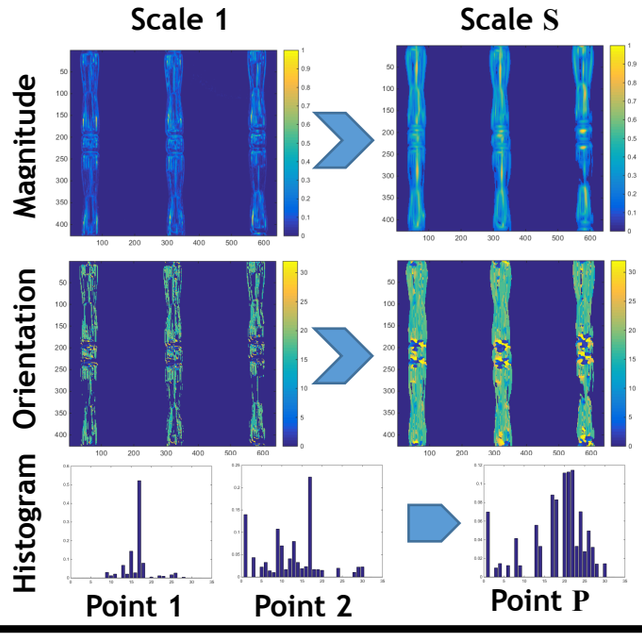


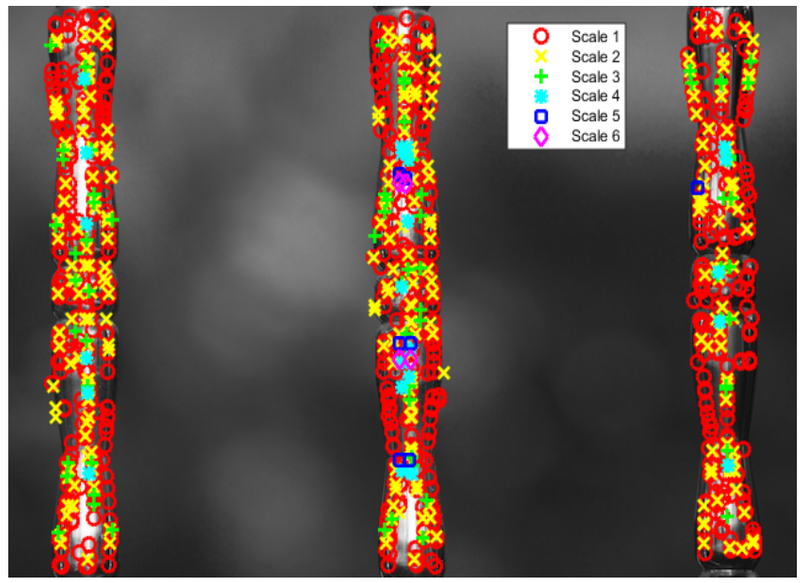
Murray, Naila, Luca Marchesotti, and Florent Perronnin. "AVA: A large-scale database for aesthetic visual analysis." *Computer Vision and Pattern Recognition (CVPR), 2012 IEEE Conference on*. IEEE, 2012.

Framework:
Main Steps I

Input Image

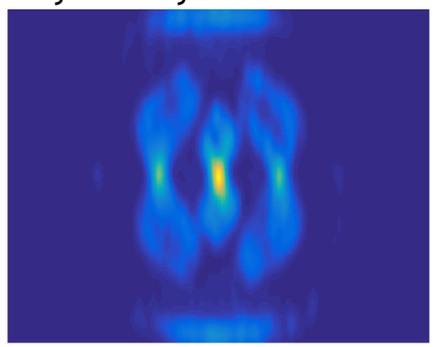
a) Feature Extraction



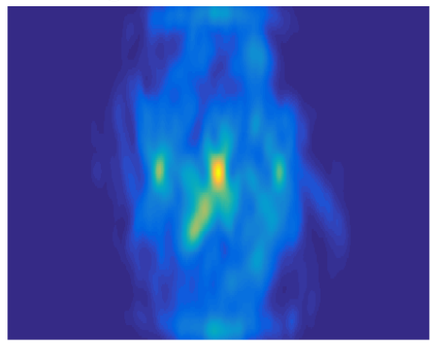


b) Feature Triangulation

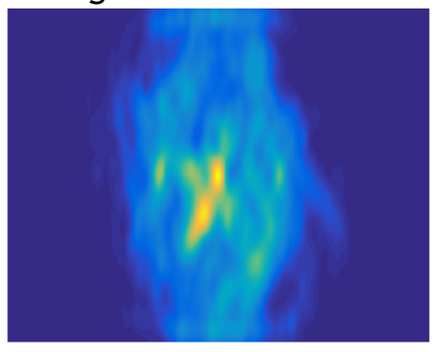
Symmetry Coefficient



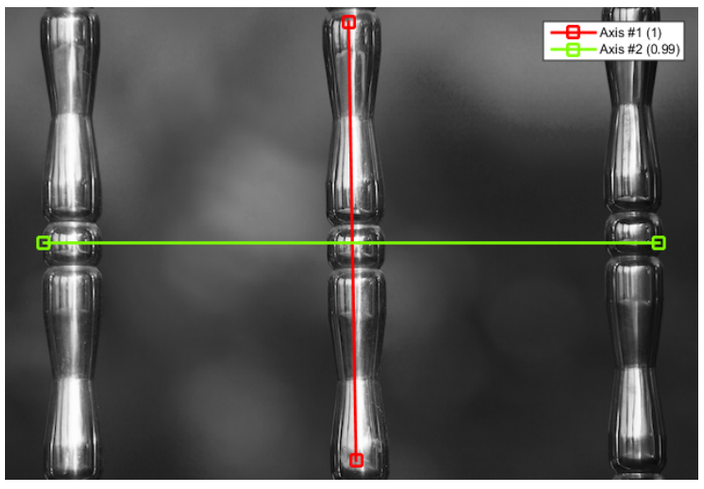
Neighborhood Color

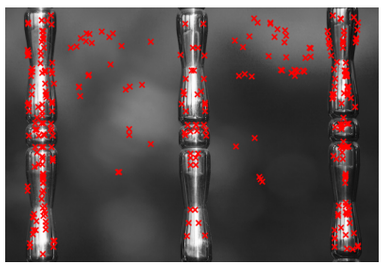


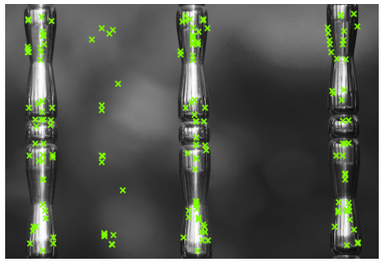
Neighborhood Texture



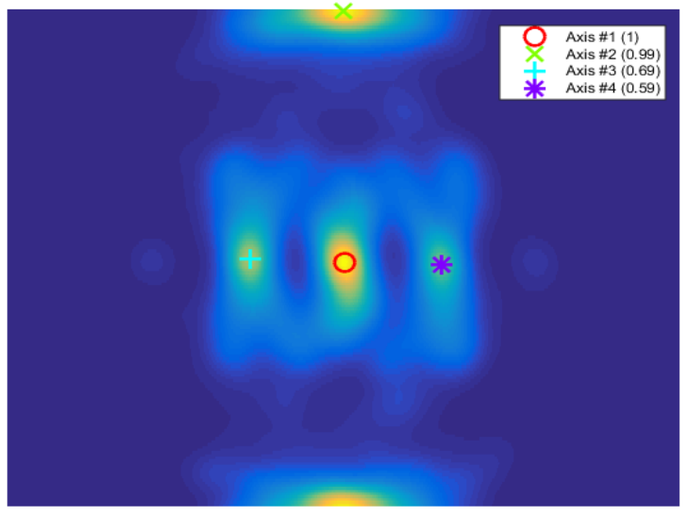
d) Symmetry Selection







c) Feature Representation



Framework: Main Steps II

- Feature Extraction

$$p^i \leftarrow I * G$$

$$p^i = [p^i_x, p^i_y]^T,\ i = 1 \ldots P$$

- Feature Triangulation

$$q_n = (p^i, p^j, O^I),\ i \neq j,\ n = 1 \ldots \frac{P(P-1)}{2}$$

$$q_n \rightarrow (\rho_n, \theta_n, \omega_n)$$

- Feature Representation

$$H(\rho, \theta, \omega) \leftarrow (\rho_n, \theta_n, \omega_n)$$

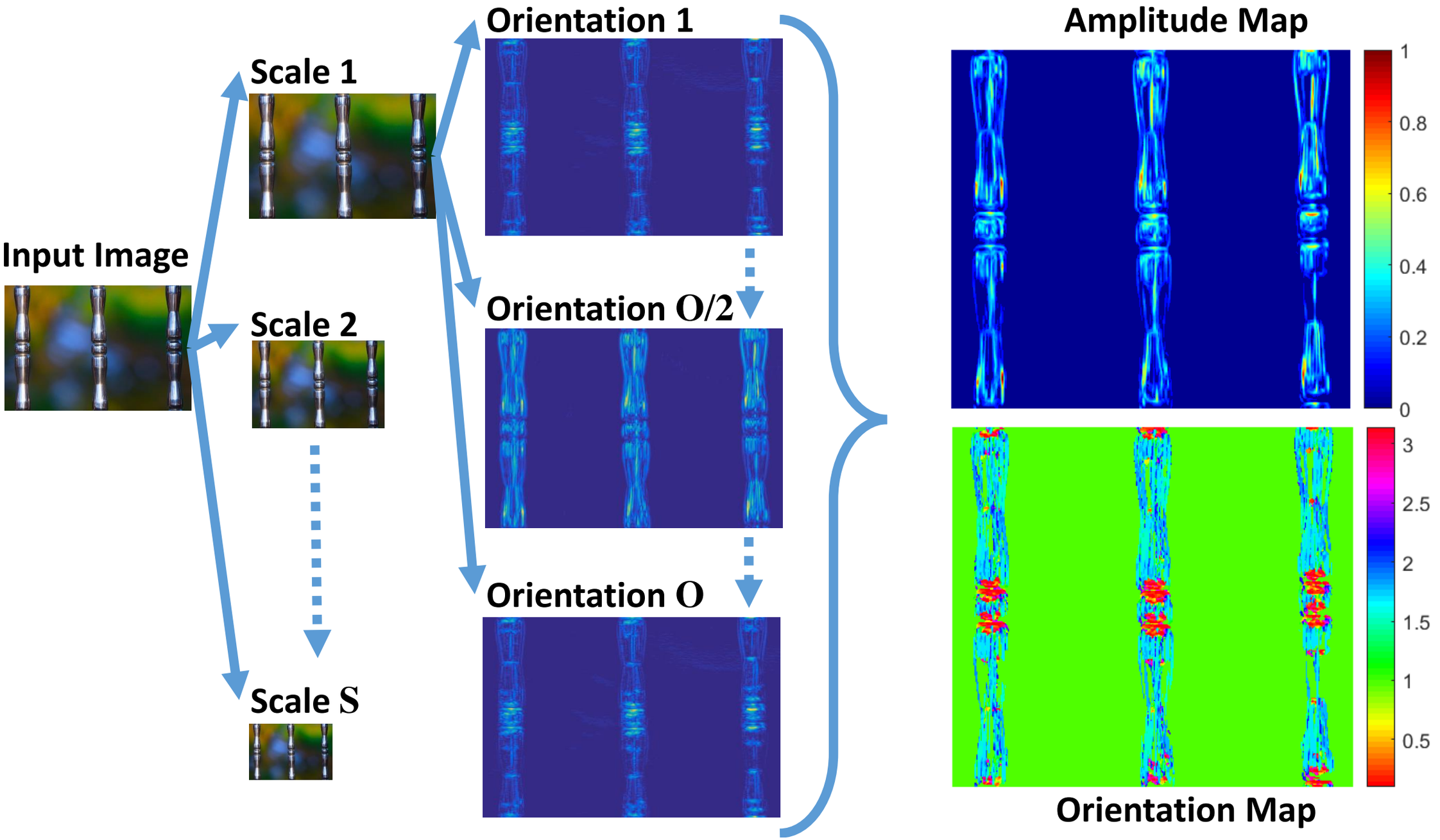
- SymmetrySelection: Non-maximal suppression scheme

$$SC^m \leftarrow H(\rho, \theta, \omega)$$

$$SC^m = [a^{SC^m}, b^{SC^m}]^T,\ m = 1 \ldots M$$

Framework:

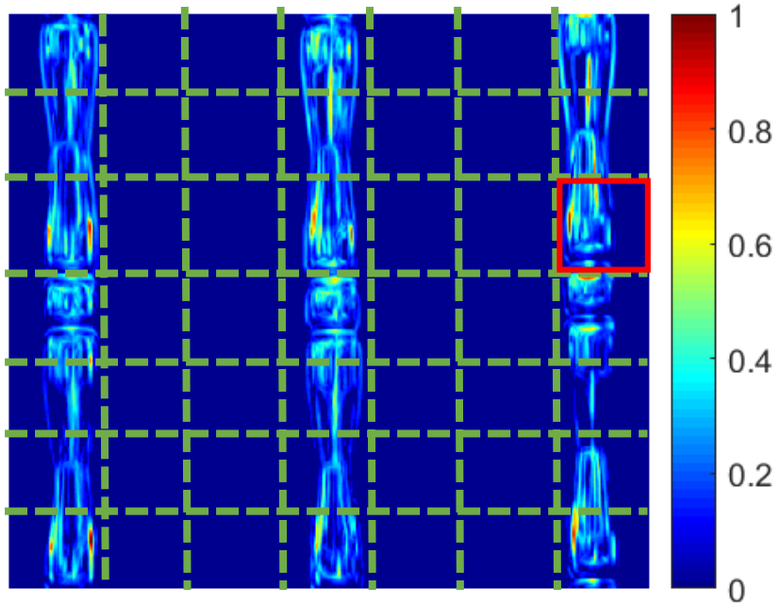
Feature Extraction I



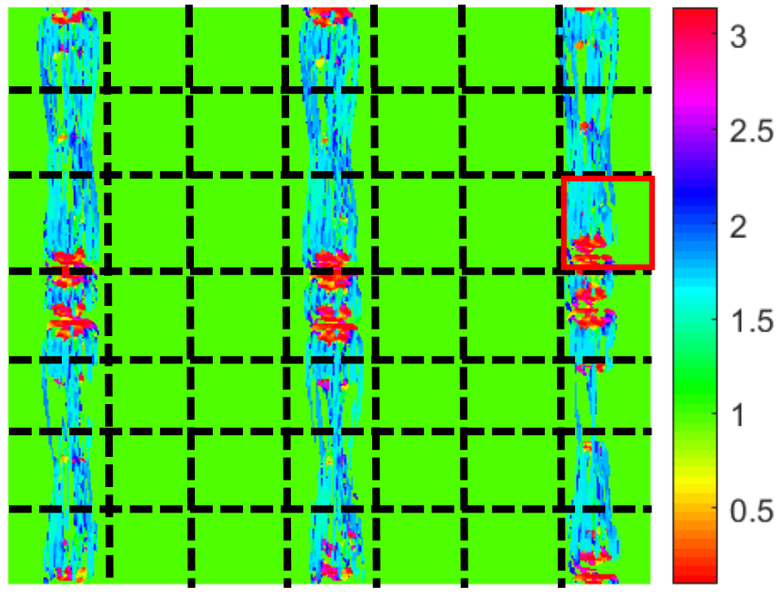
Framework:

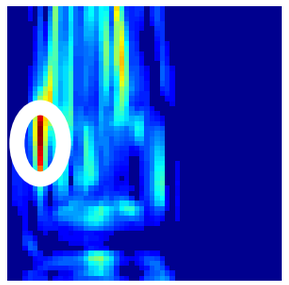
Feature Extraction II

Amplitude Map

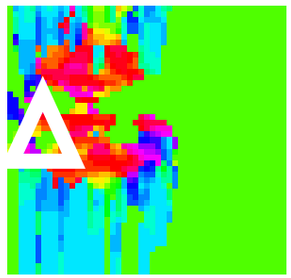


Orientation Map

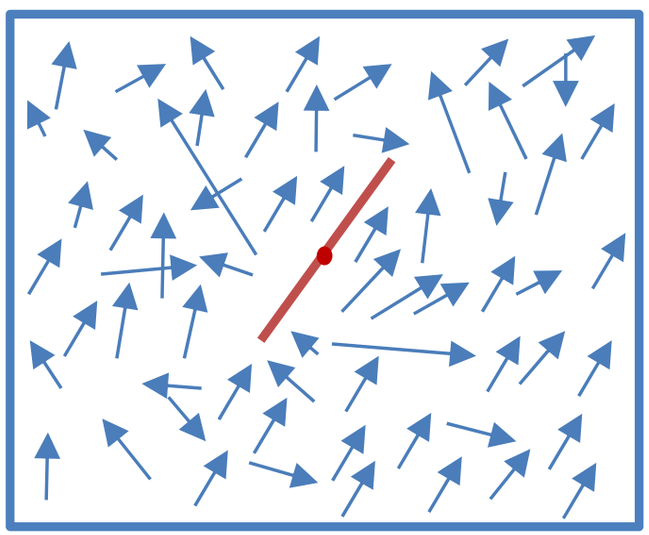


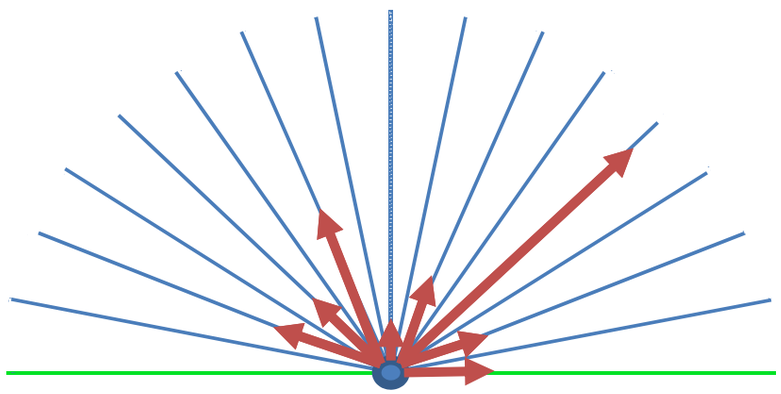


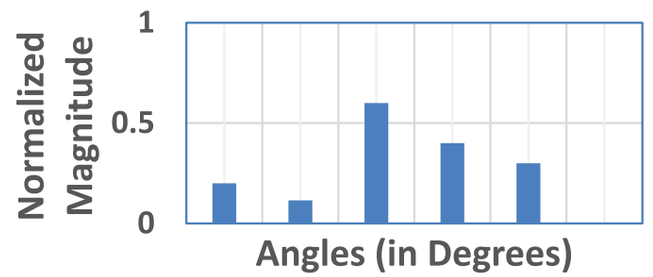
Max Amplitude

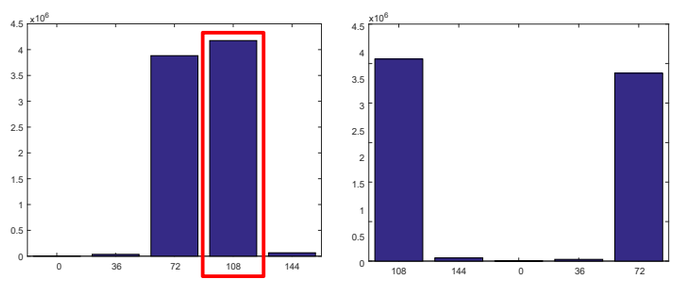


Corresponding Orientation





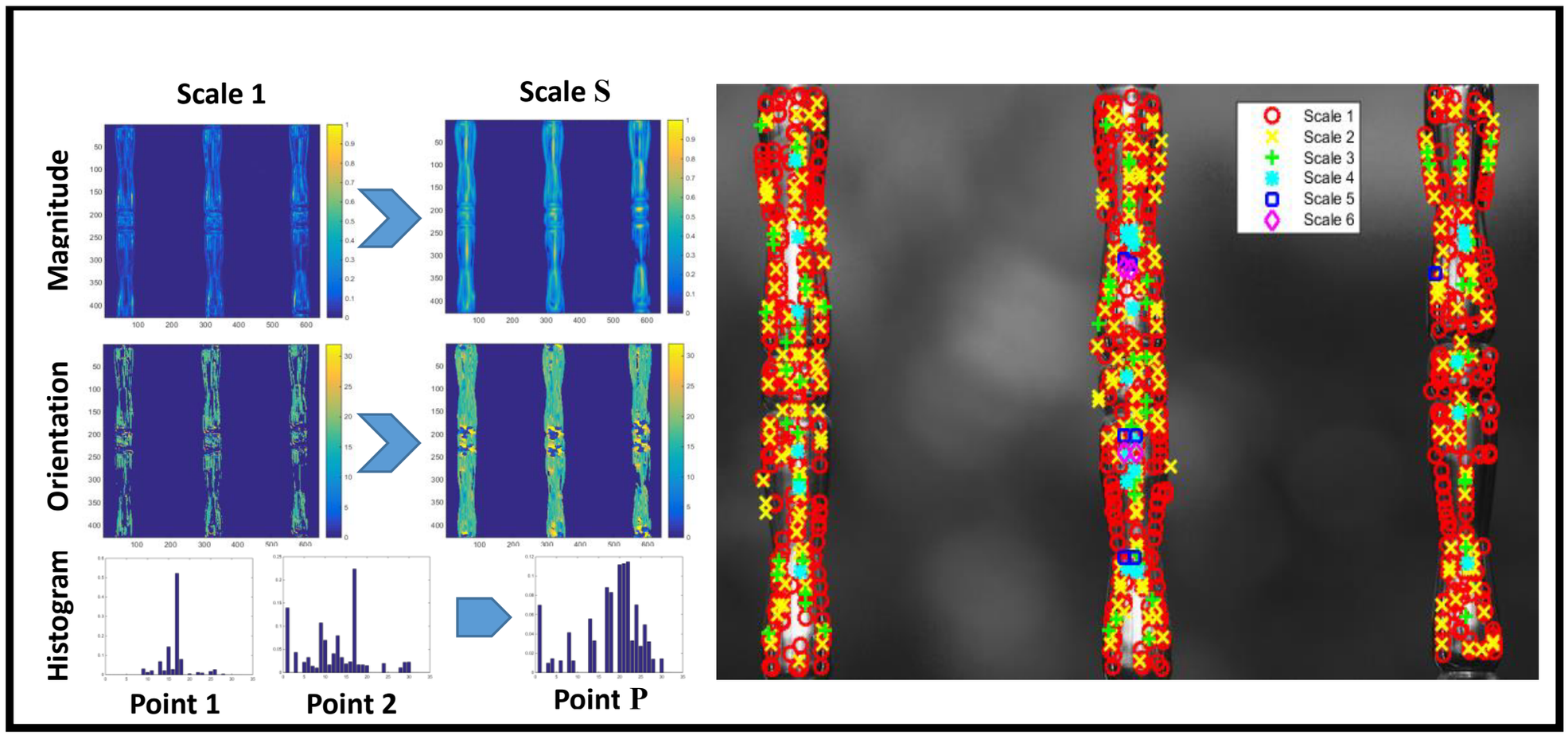




Framework:

Feature Extraction III

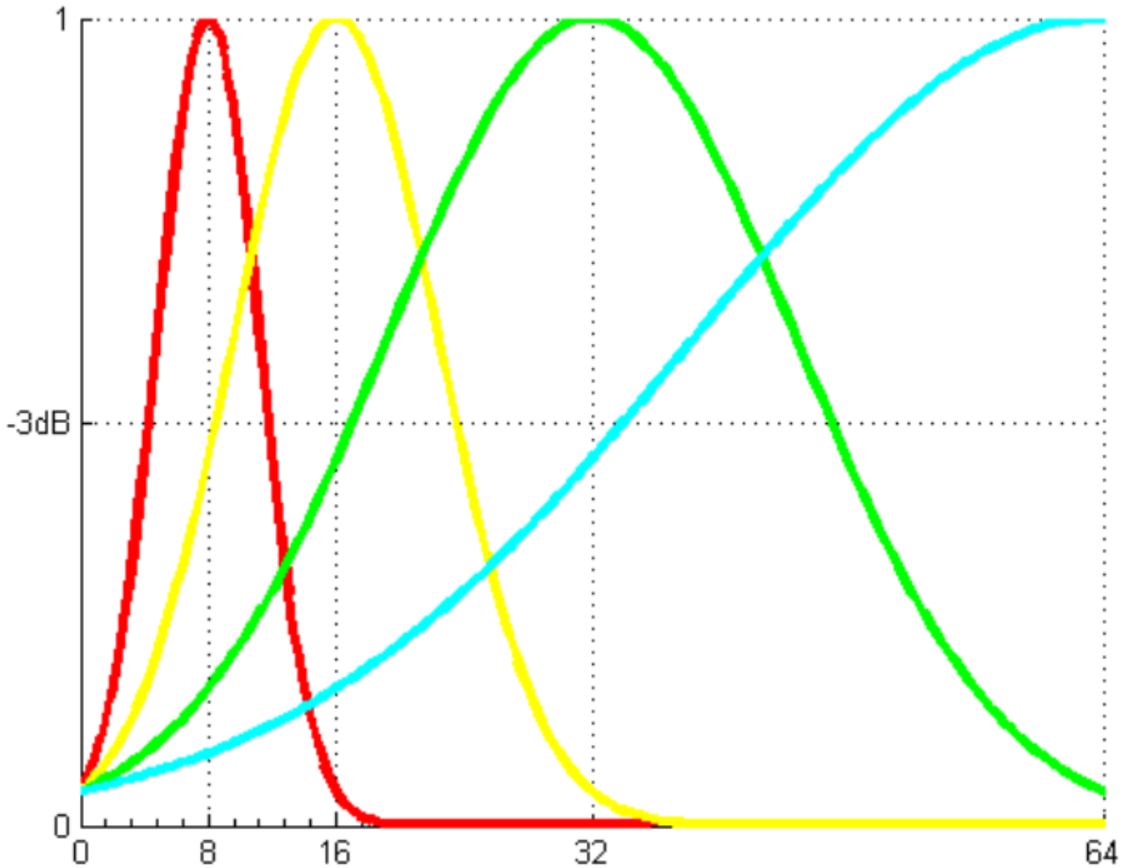
Input Image

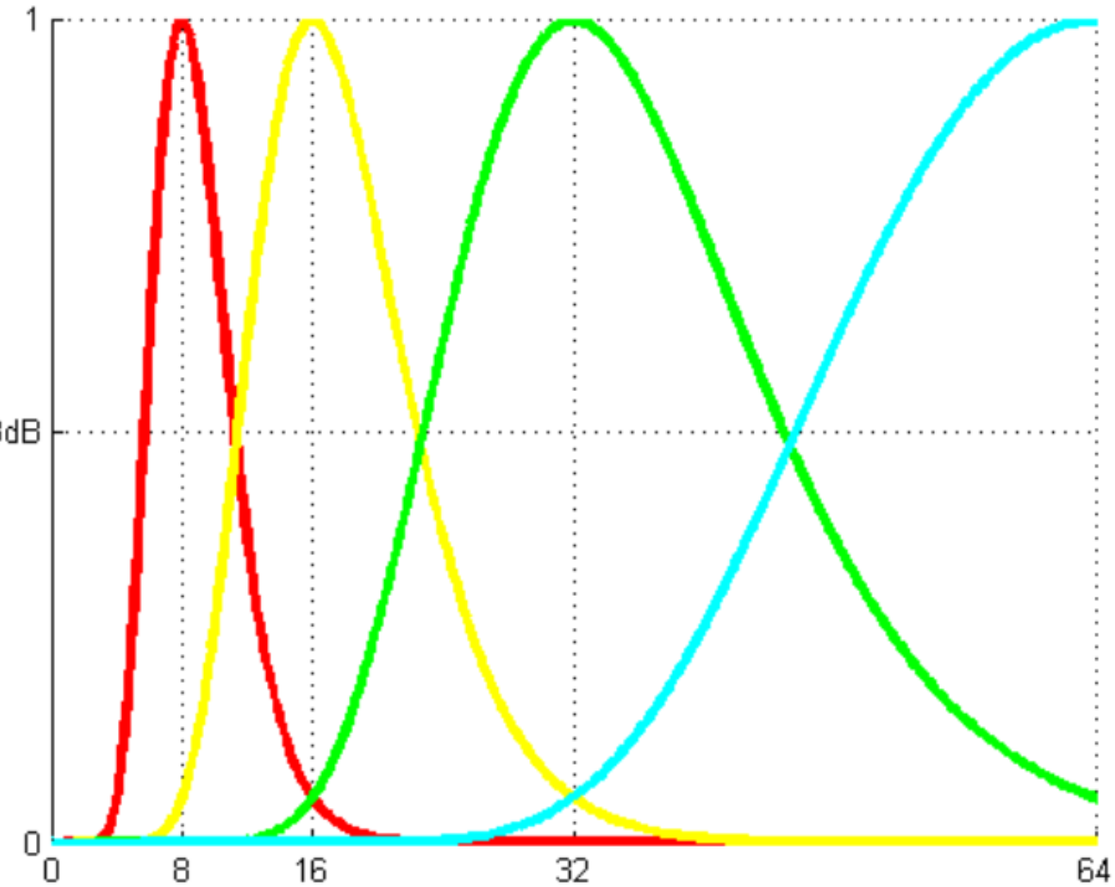


Framework:

Feature Extraction IV (Gabor vs Log-Gabor)

Frequency response at 4 angular frequency bands

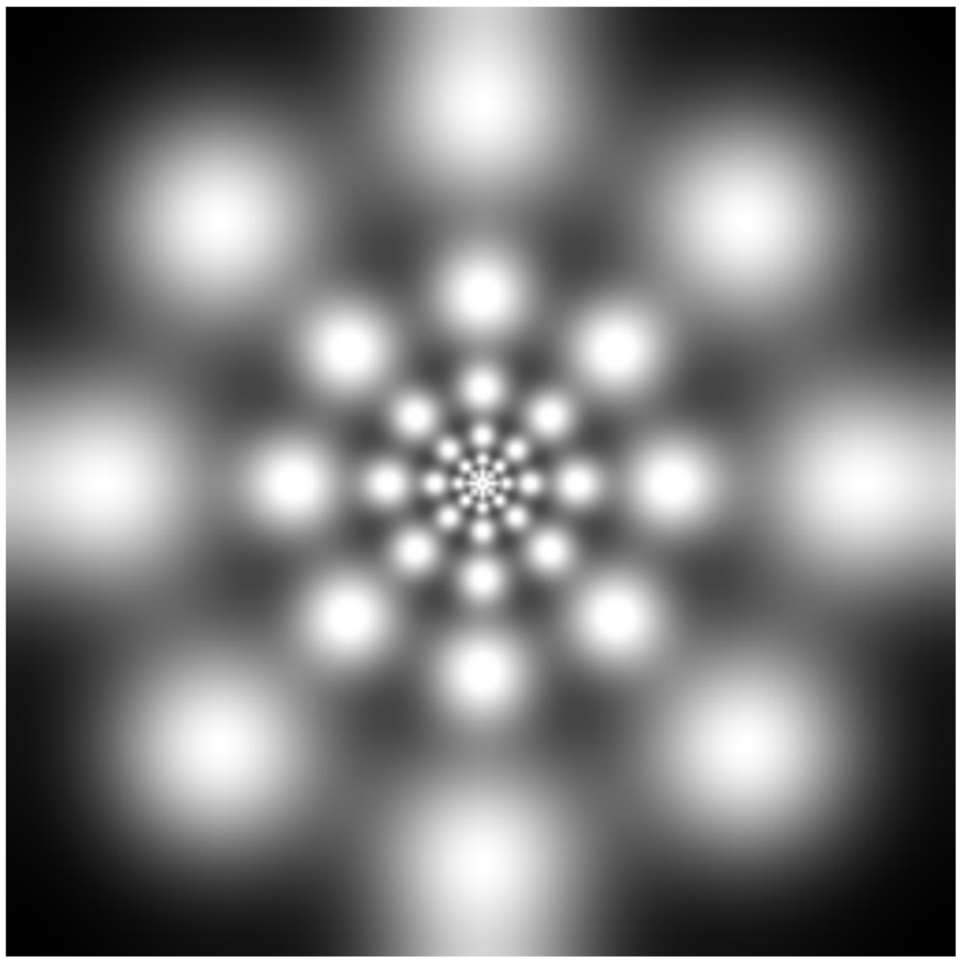


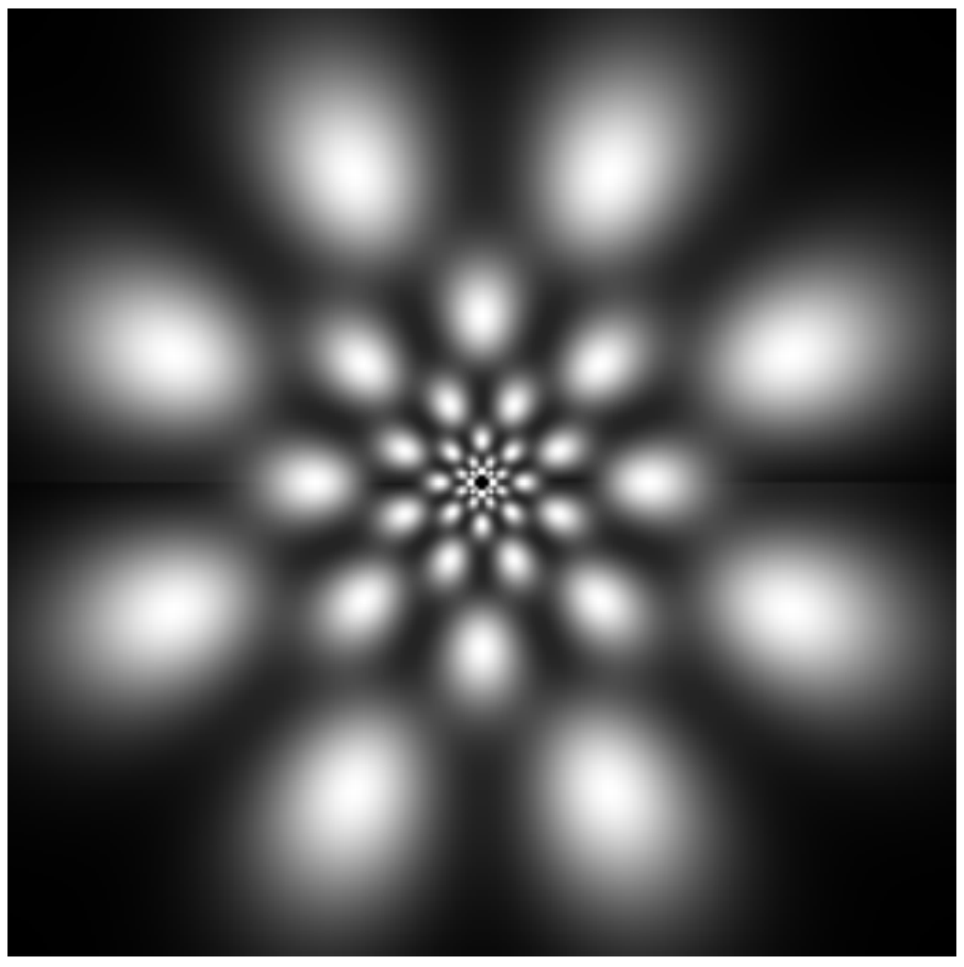


Nava, Rodrigo, Boris Escalante-Ramírez, and Gabriel Cristóbal. "A comparison study of Gabor and log-Gabor wavelets for texture segmentation." *Image and Signal Processing and Analysis (ISPA), 2011 7th International Symposium on*. IEEE, 2011.

Framework:
Feature Extraction V (Gabor vs Log-Gabor)

Multiscale complex filter banks with 8 orientations and 6 scales



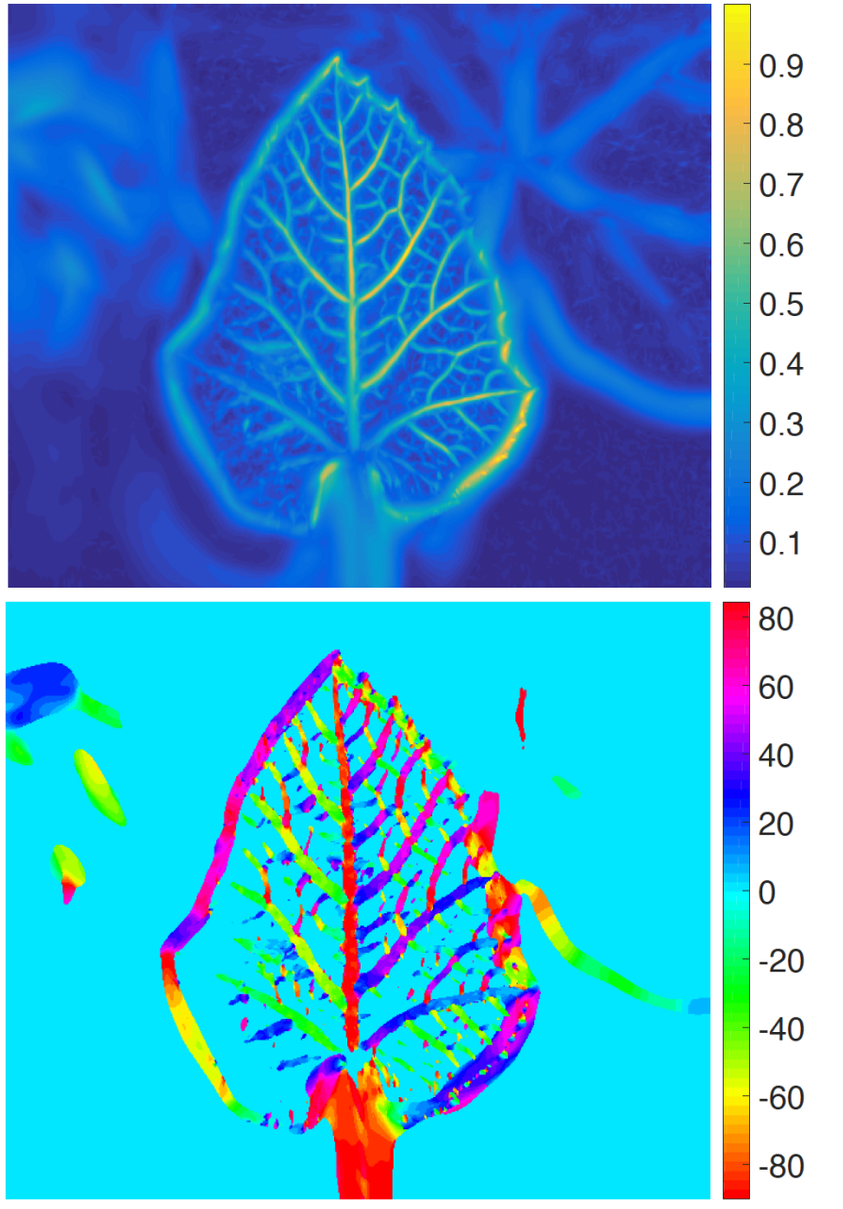


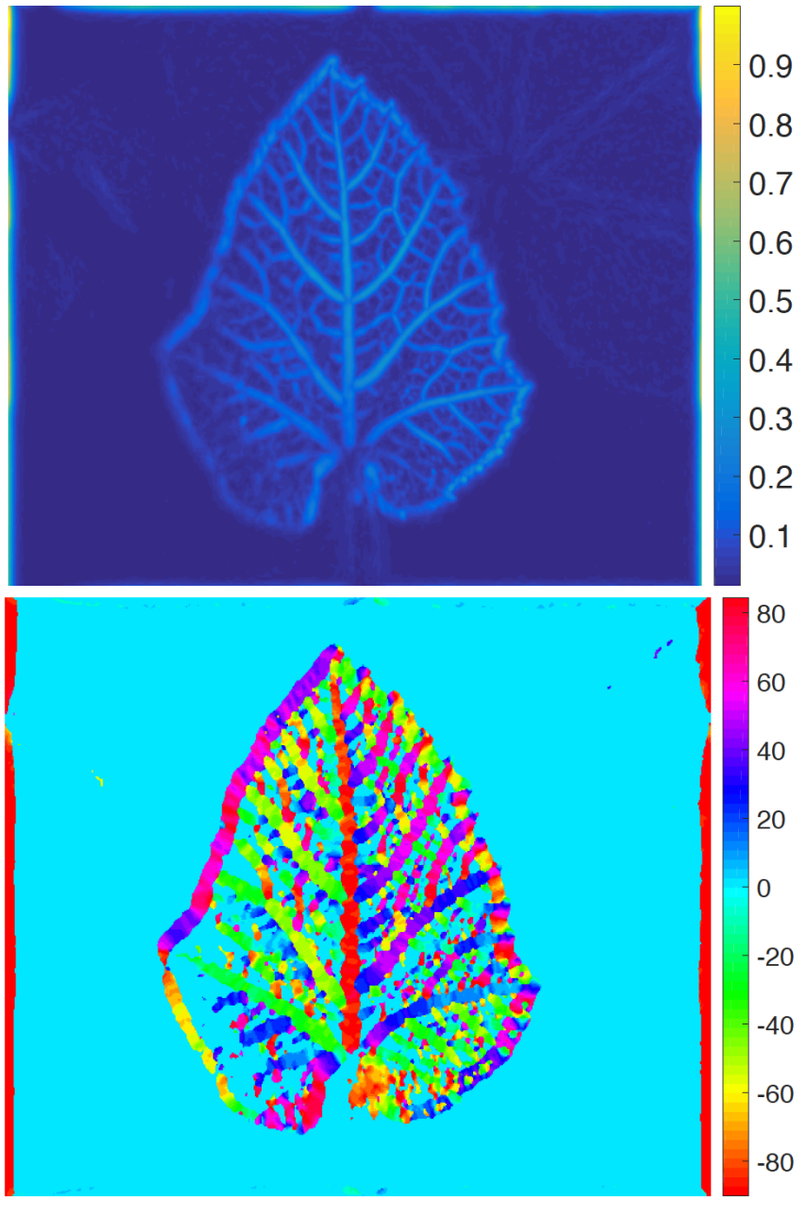
Nava, Rodrigo, Boris Escalante-Ramírez, and Gabriel Cristóbal. "A comparison study of Gabor and log-Gabor wavelets for texture segmentation." *Image and Signal Processing and Analysis (ISPA), 2011 7th International Symposium on*. IEEE, 2011.

Framework:

Feature Extraction VI (Gabor vs Log-Gabor)

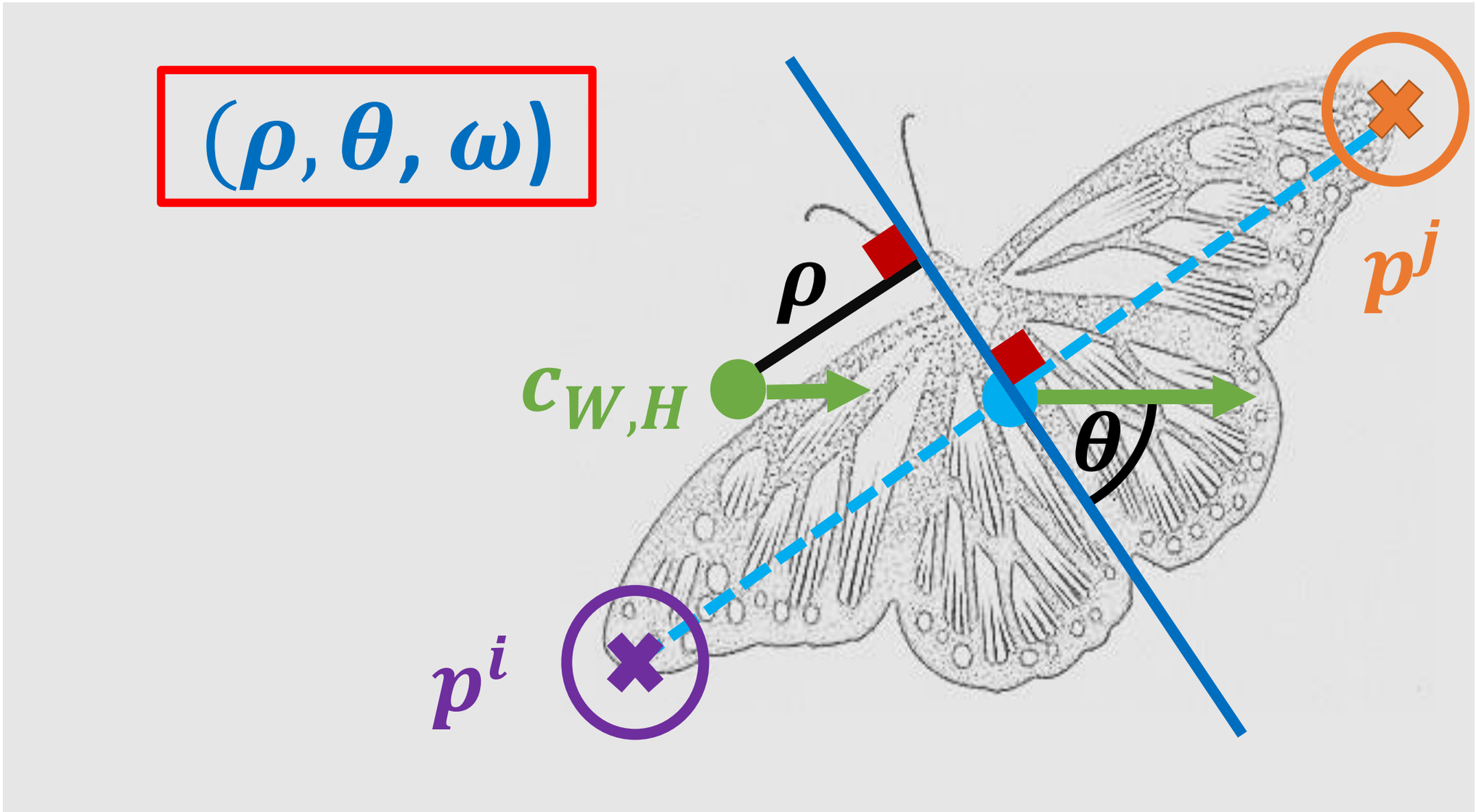
Comparison of amplitude and its corresponding orientation responses





Framework:

Feature Triangulation I



Framework:
Feature Triangulation II

$$\omega_{i,j} = \omega(p^i, p^j) = S_E(i,j)\ S_T(i,j)\ S_C(i,j)$$

$$S_E(i,j) = J_i\ J_j\ |\ \tau^i R(T_{ij}^{\perp})\tau^j\ |$$

Mirror Symmetry Coefficient - Cicconet et al. [2014]

$$S_T(i,j) = \sum_{n=1}^{N} min(h^i(n), \tilde{h}^j(n))$$

Similarity Textural Measure - Elawady et al. [2016]

$$S_C(i,j) = \sum_{c=1}^{C} min(g^i(c), g^j(c))$$

Similarity Color Measure - Elawady et al. [2017]

Results:

Feature Extraction and Triangulation I

Algorithms	Detection & Extraction			Weights		
	SIFT	Gabor	Log-Gabor	Edge	Textural	Color
Loy [100]	✓			✓		
Cic[28]		✓		✓		
GbT		✓		✓	✓	
LgT			✓	✓	✓	
LgTC			✓	✓	✓	✓

Results:

Feature Extraction and Triangulation II

Metrics: TP of CVPR2013 - Single Case (first 4 rows) and Multiple (next 3 rows)

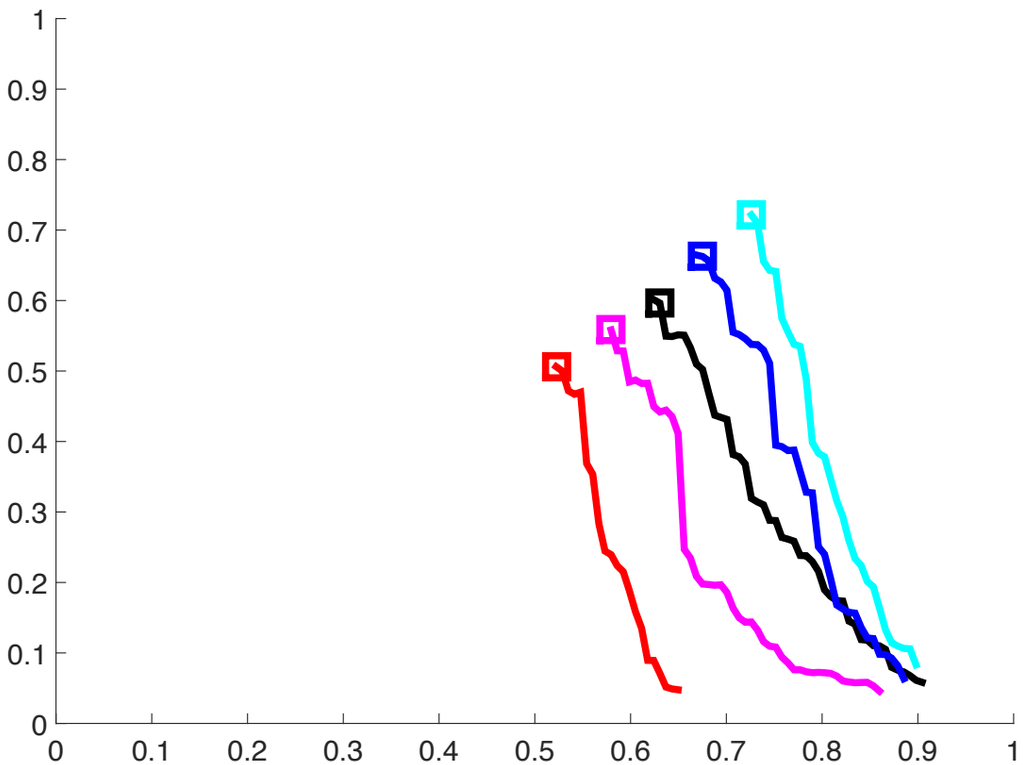
Datasets	*Loy* [100]	*Cic* [28]	*GbT*	*LgT*	*LgTC*
PSU (157)	81	90	**97**	**104**	**113**
AVA (253)	**174**	124	170	**188**	**182**
NY (176)	98	92	**109**	**124**	**135**
ICCV17 (100)	**52**	**53**	**52**	**70**	**70**
PSUm (142)	69	68	**67**	**72**	**75**
NYm (63)	32	**36**	**36**	**38**	**40**
ICCV17m (100)	**54**	39	**52**	**52**	**57**
Total (991)	560	502	**583**	**648**	**672**

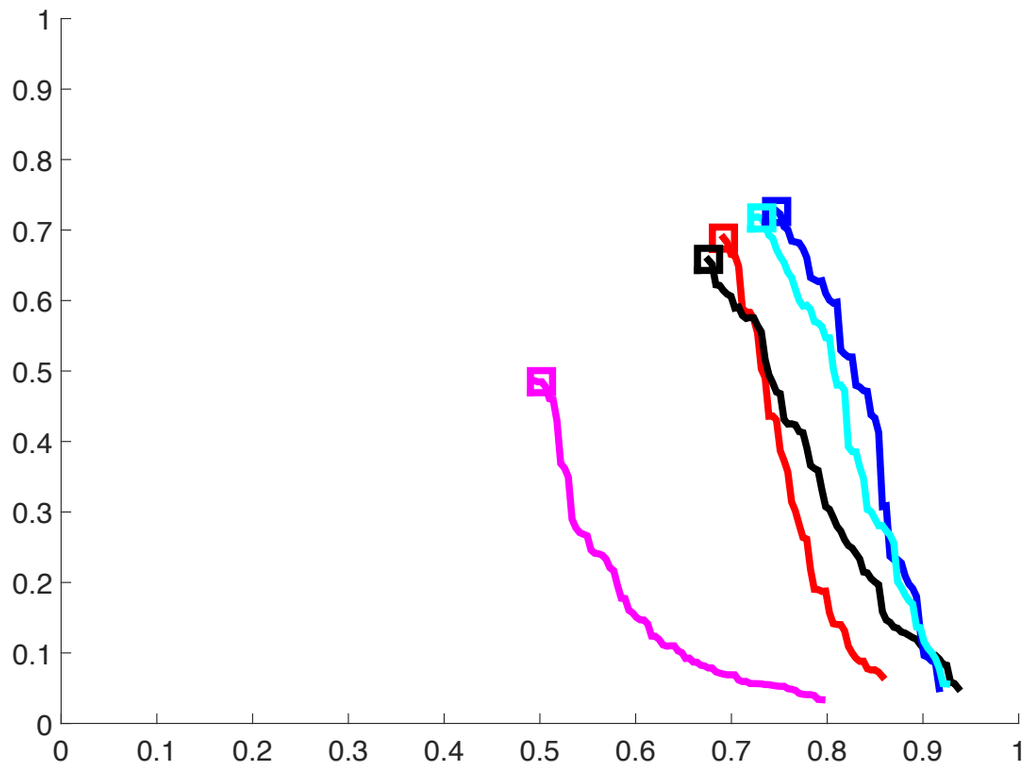
Top 3 results are in Bold with red, blue and green colors respectively

Results:

Feature Extraction and Triangulation III

Metrics: PR curves of CVPR2013 - Left (PSU), Right (AVA)



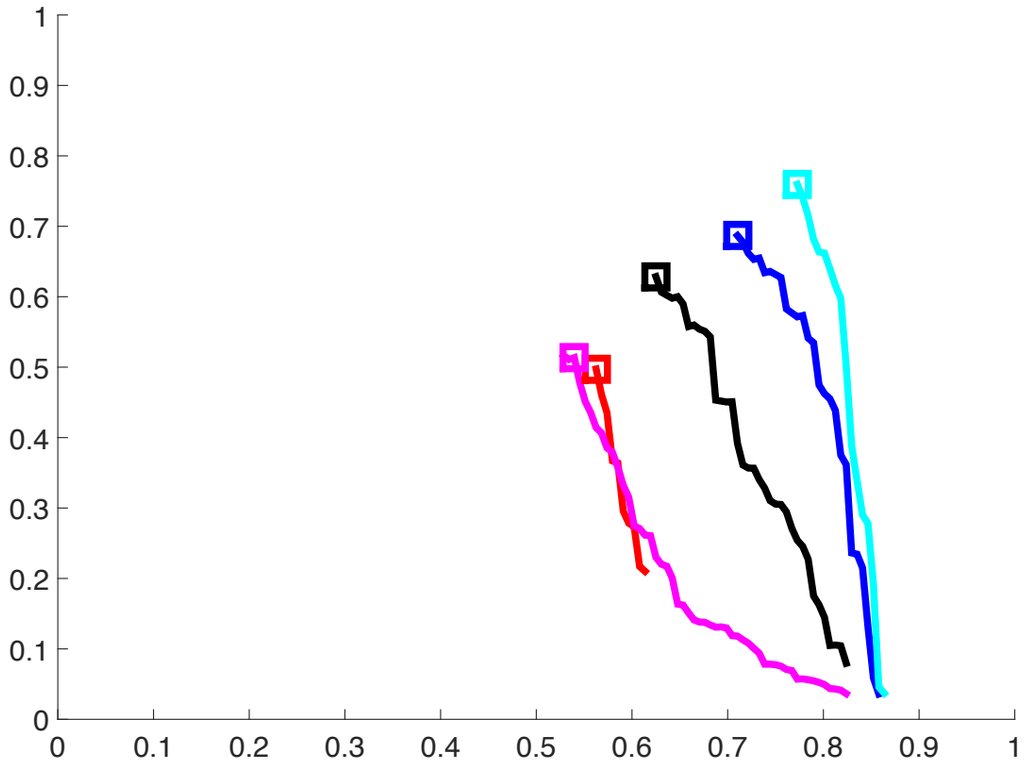


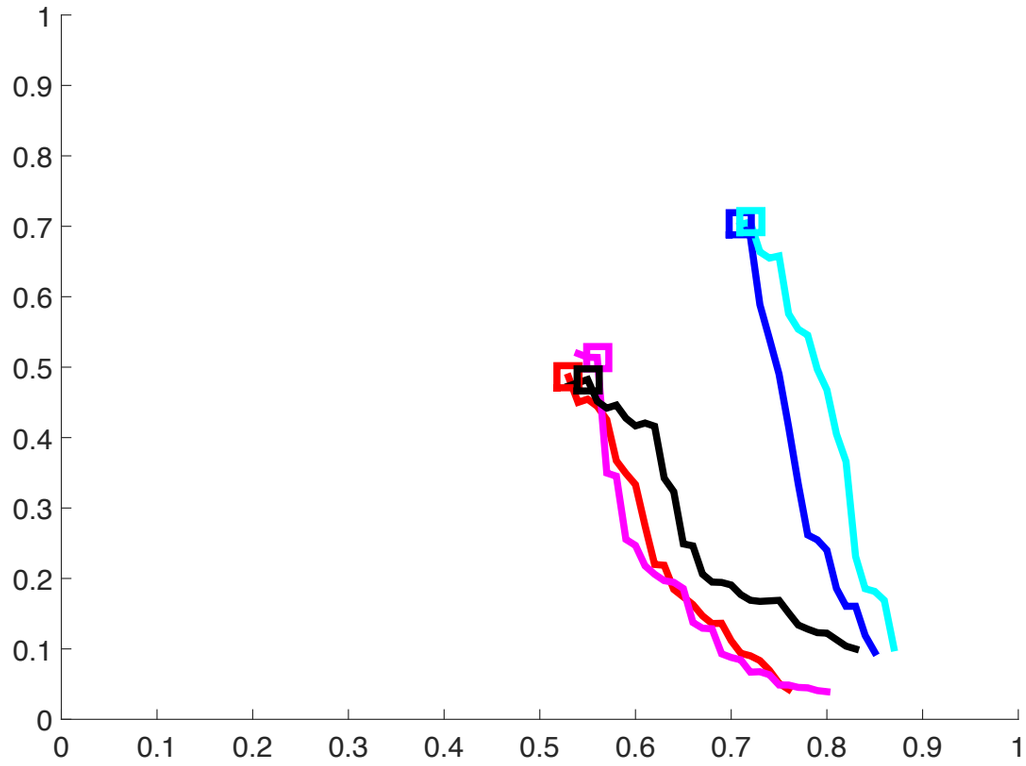
GbT(**black**), LgT (**blue**), and LgTC (**cyan**);
against the prior algorithms: Loy (**red**), and Cic (**magenta**)

Results:

Feature Extraction and Triangulation IV

Metrics: PR curves of CVPR2013 - Left (NY), Right (ICCV2017)

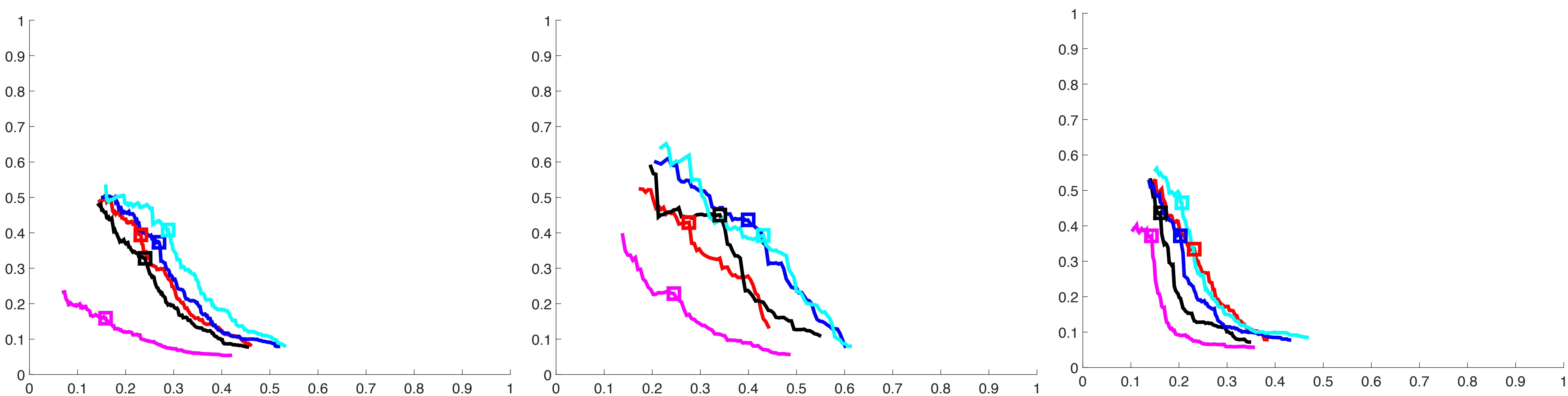




GbT(**black**), LgT (**blue**), and LgTC (**cyan**);
against the prior algorithms: Loy (**red**), and Cic (**magenta**)

Results:
Feature Extraction and Triangulation IV

Metrics: PR curves of CVPR2013 - Left (PSUm), Middle (NYm), Right (ICCV2017m)

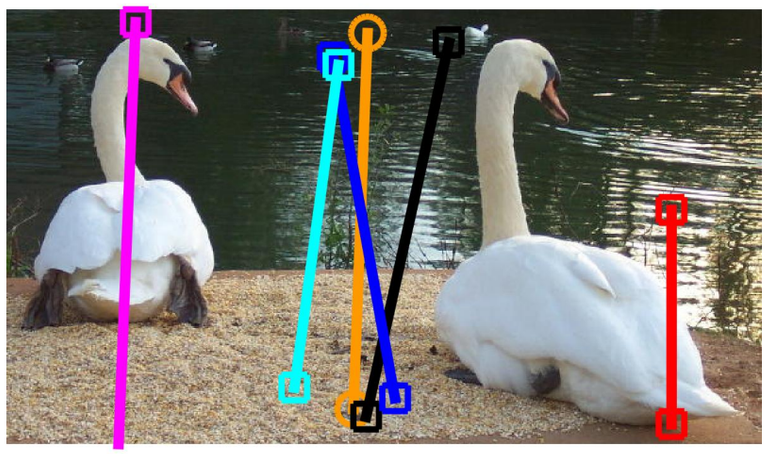
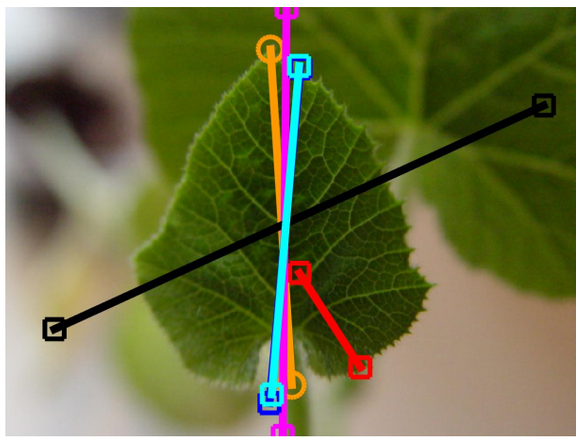
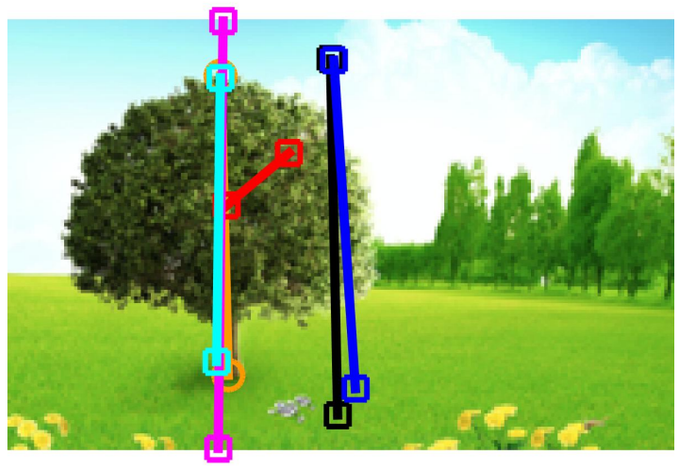
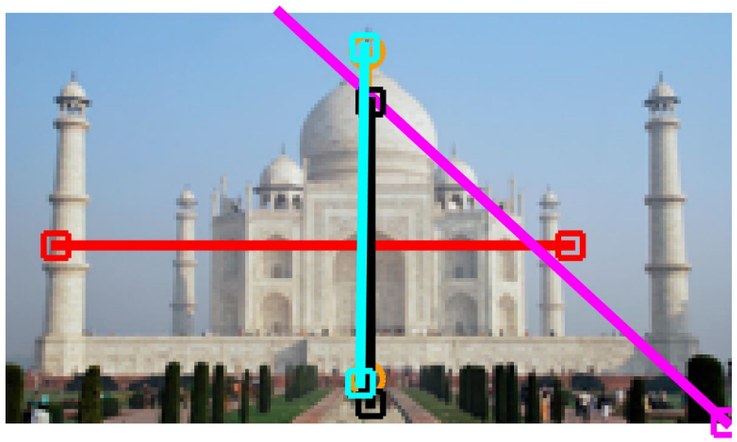
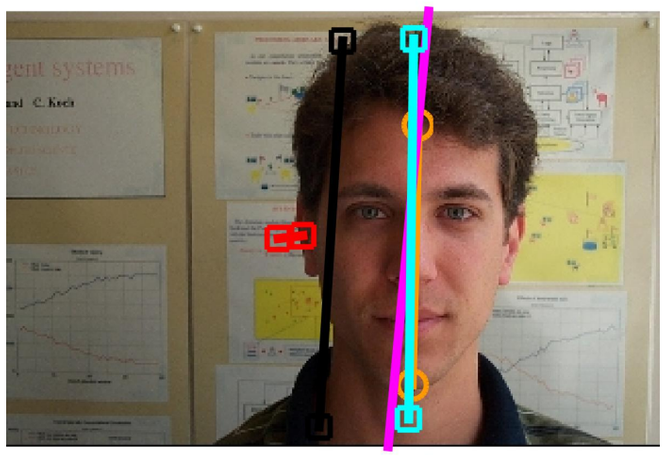
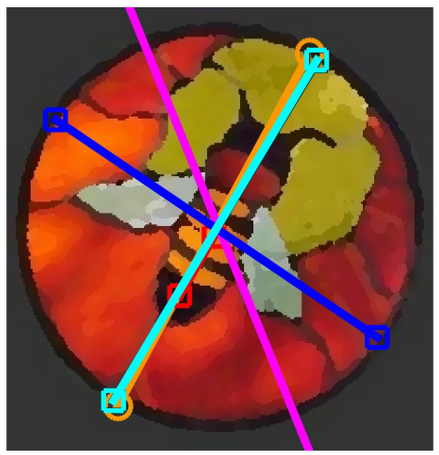


GbT(black), LgT (blue), and LgTC (cyan);
against the prior algorithms: Loy (red), and Cic (magenta)

Results:

Feature Extraction and Triangulation V

Single case symmetry results

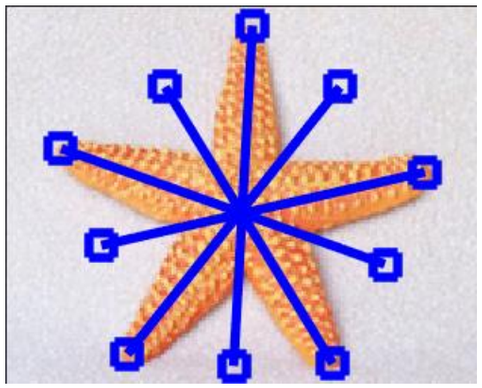
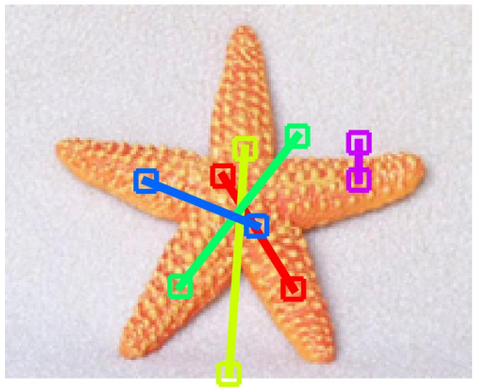
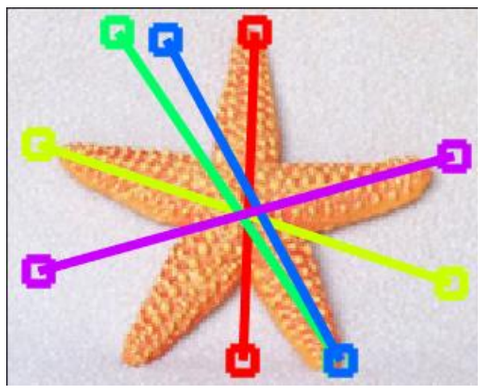
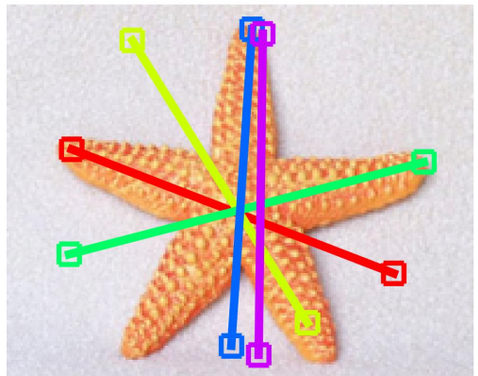
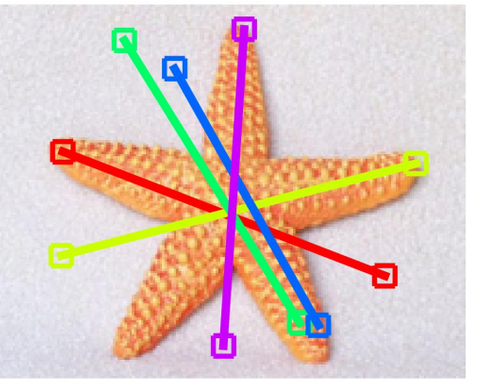







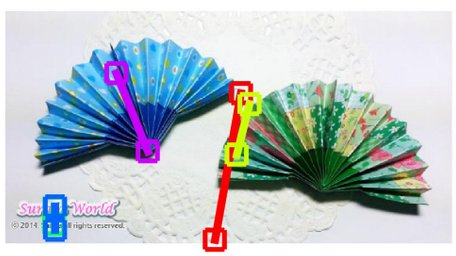
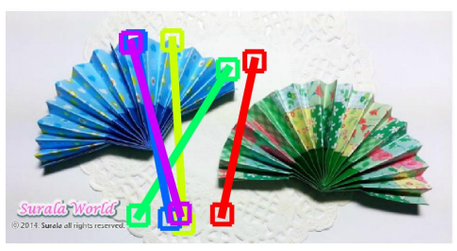
Groundtruth (Orange), GbT(black), LgT (blue), and LgTC (cyan) against the prior algorithms: Loy (red), and Cic (magenta)

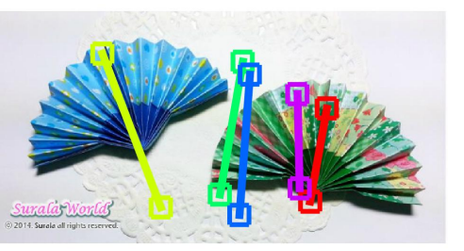
Results:

Feature Extraction and Triangulation VI

Multiple case symmetry results (order left to right: Groundtruth, Loy, GbT, LgT, LgTC)



Top five symmetry results is presented in such order:
red, yellow, green, blue, and magenta

Results:

Feature Extraction and Triangulation VI

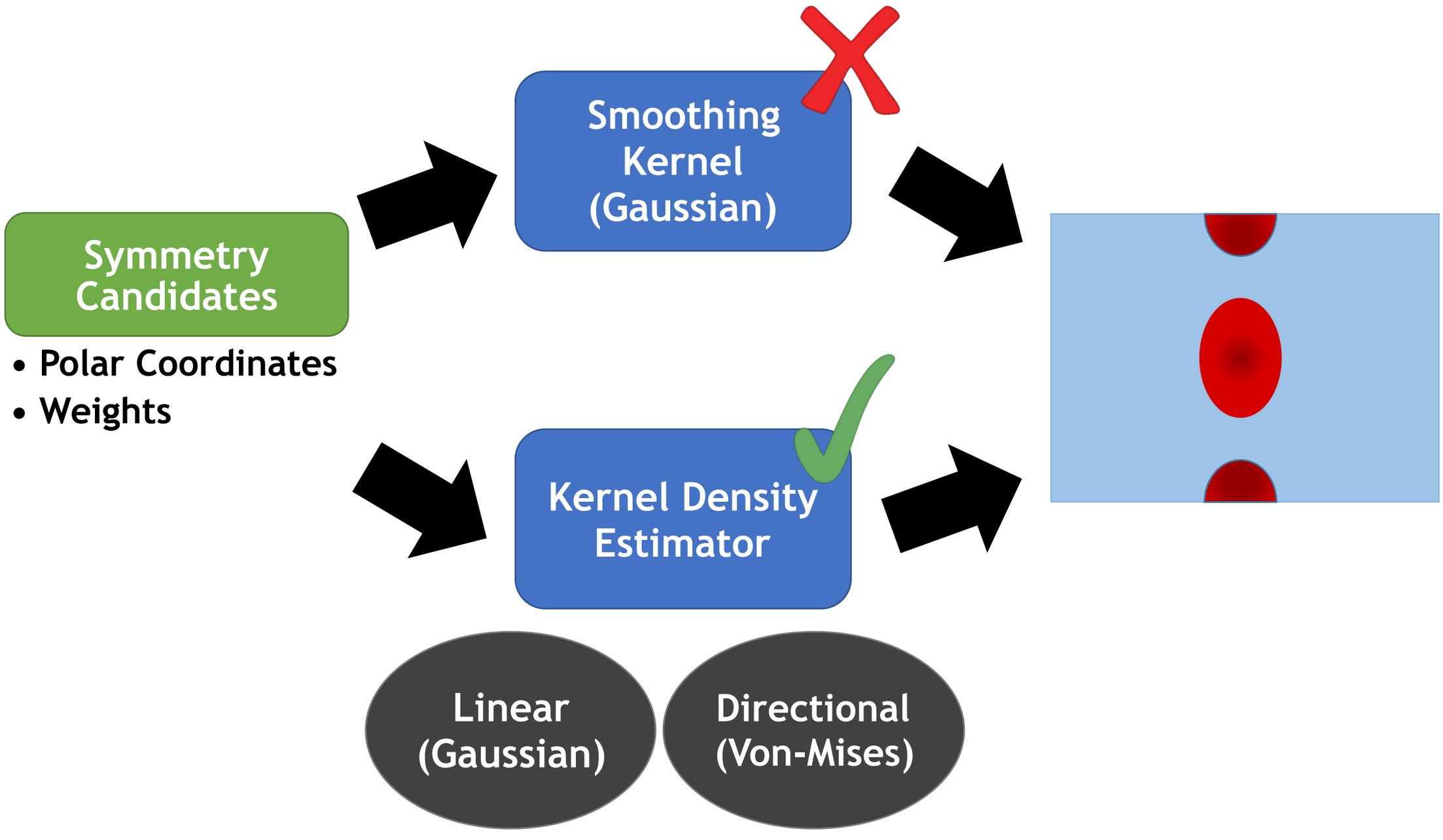
Metrics: Max F1 of CVPR2013 - Single Case (first 4 rows) and Multiple (next 3 rows)

Datasets	*Loy* [100]	*Cic* [28]	*GbT*	*LgT*	*LgTC*
PSU	0.514	0.569	**0.613**	**0.669**	**0.724**
AVA	**0.690**	0.493	0.667	**0.736**	**0.729**
NY	0.528	0.526	**0.627**	**0.698**	**0.766**
ICCV17	0.507	**0.536**	0.514	**0.707**	**0.713**
PSUm	**0.292**	0.159	0.277	**0.313**	**0.338**
NYm	0.337	0.237	**0.388**	**0.417**	**0.411**
ICCV17m	**0.273**	0.207	0.236	**0.263**	**0.285**
Average	0.449	0.390	**0.475**	**0.543**	**0.567**

Top 3 results are in Bold with red, blue and green colors respectively

Framework:

Feature Representation I



Framework:
Feature Representation II

- Linear (Parzen [1962])

$$f_\epsilon(x;\sigma) = \frac{1}{N}\sum_{n=1}^{N} G_\epsilon(\frac{x-\rho_n}{\sigma}), x \in \mathbb{R}$$

- Directional (Hall [1987])

$$f_\vartheta(\mathbf{y};\kappa) = \frac{1}{N}\sum_{n=1}^{N} G_\vartheta(\theta_n^T\mathbf{y};\kappa), \mathbf{y} \in \Omega_2$$

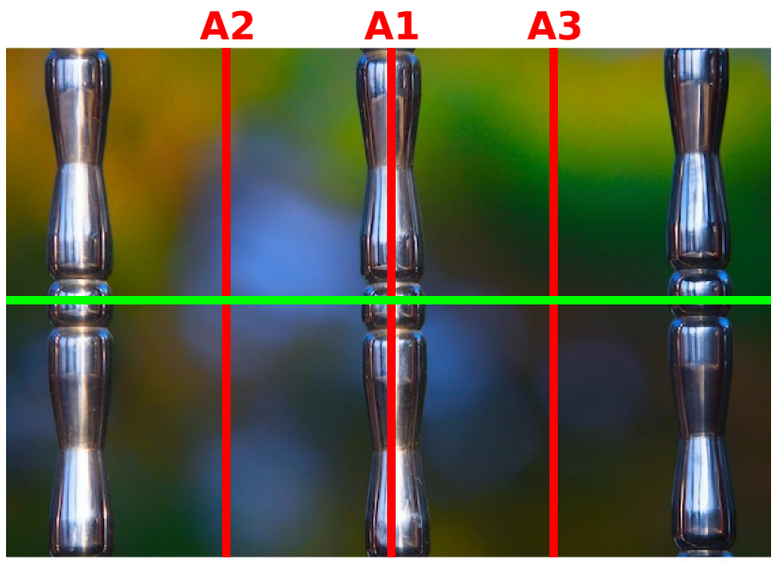
- Weighted Linear-Directional

$$\hat{f}_{\epsilon,\vartheta}(x,\mathbf{y};\sigma,\kappa) = \frac{1}{N}\sum_{n=1}^{N} \omega_n G_\epsilon(\frac{x-\rho_n}{\sigma}) G_\vartheta(\theta_n^T\mathbf{y};\kappa)$$

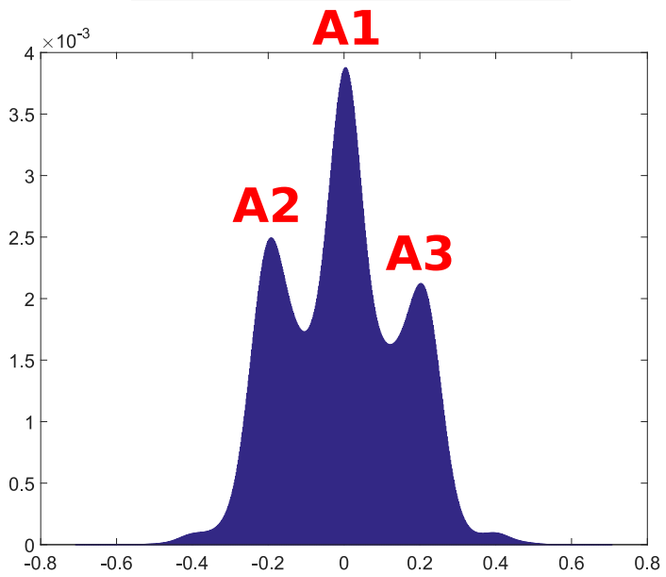
Framework:

Feature Representation III

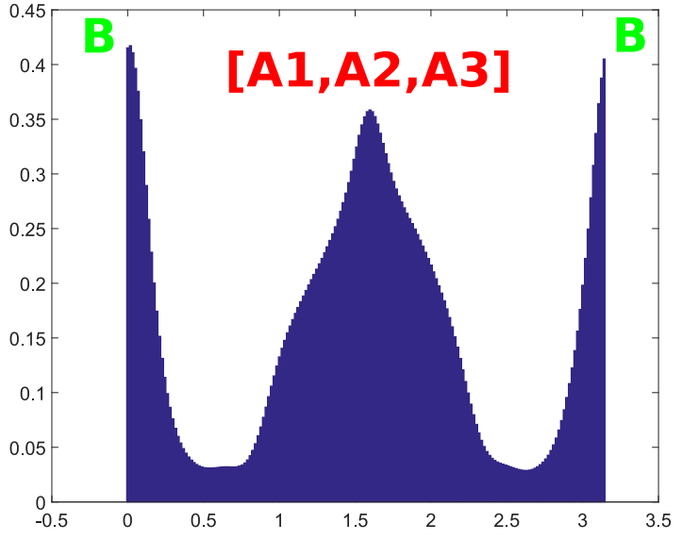
Input



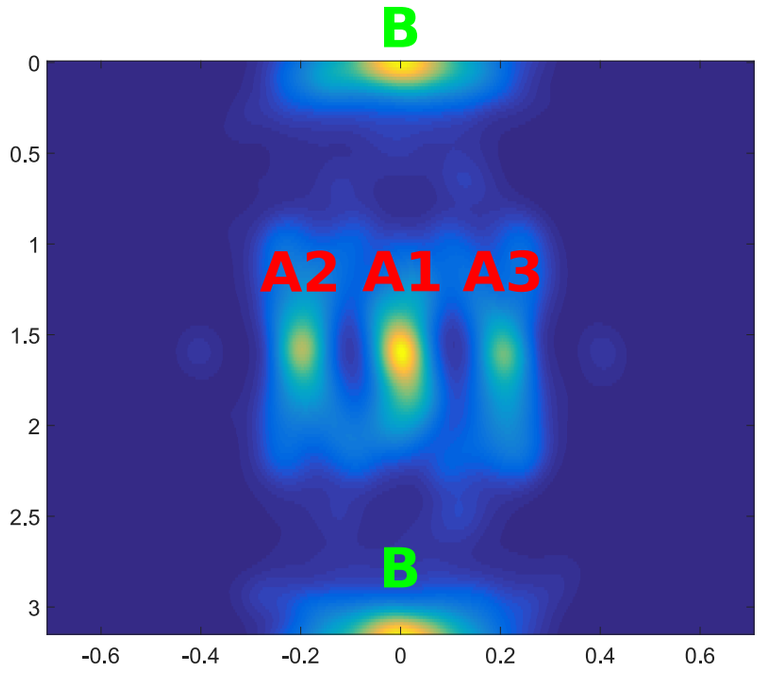
Weighted Linear



Weighted Directional

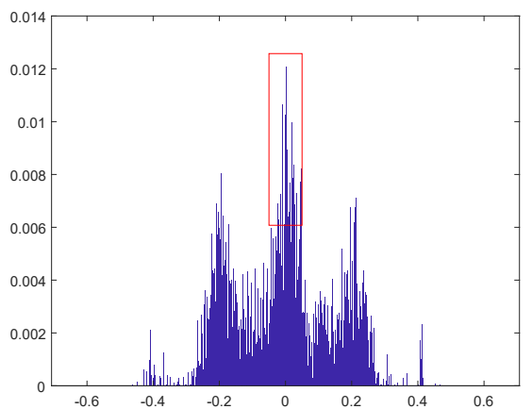


Weighted Linear-Directional

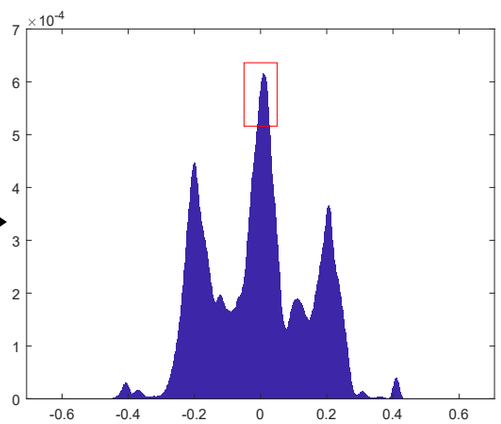


Framework:

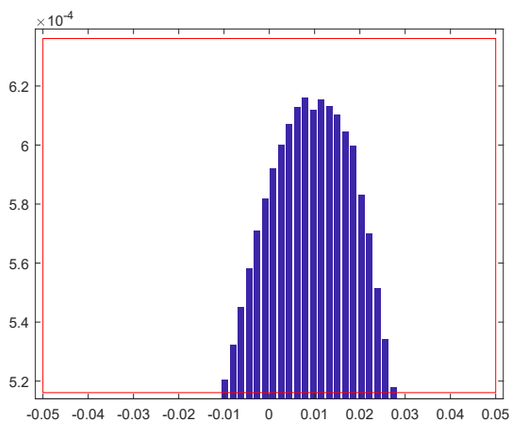
Feature Representation IV (Hough-like vs KDE)

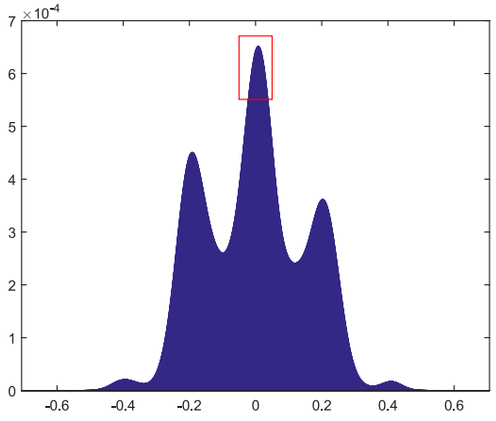


Gaussian

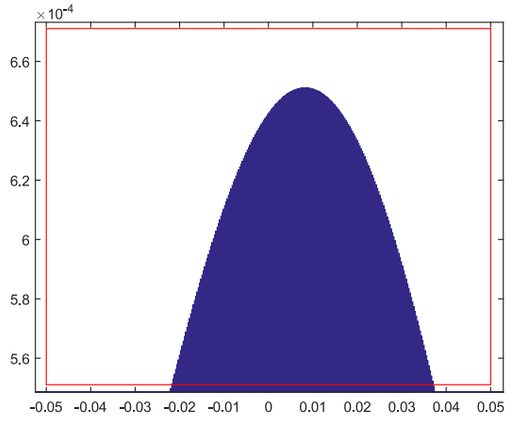


Zoom-in





Zoom-in



Results:

Feature Representation I

Metrics: TP of CVPR2013 - Single Case (first 4 rows) and Multiple (next 3 rows)

Datasets	*Loy* [100]	*Cic* [28]	*GbT*	*LgT*	*LgTC*	*LgTC-KDE*
PSU (157)	81	90	97	**104**	**113**	**118**
AVA (253)	**174**	124	170	**188**	**182**	**188**
NY (176)	98	92	**109**	**124**	**135**	**135**
ICCV17 (100)	52	**53**	52	**70**	**70**	**74**
PSUm (142)	69	68	67	**72**	**75**	**78**
NYm (63)	32	**36**	**36**	**38**	**40**	**38**
ICCV17m (100)	**54**	39	52	52	**57**	**56**
Total (991)	560	502	583	**648**	**672**	**687**

Top 3 results are in Bold with red, blue and green colors respectively

Results:

Feature Representation II

Metrics: Max F1 of CVPR2013 - Single Case (first 4 rows) and Multiple (next 3 rows)

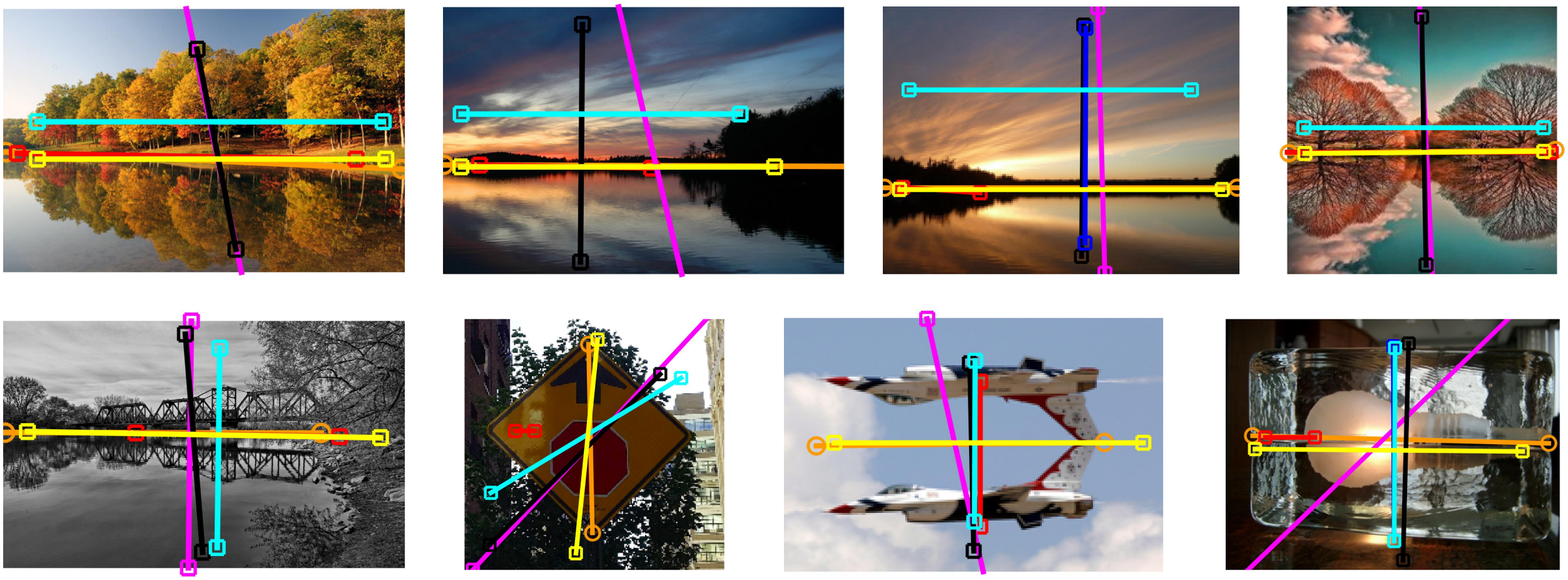
Datasets	*Loy* [100]	*Cic* [28]	*GbT*	*LgT*	*LgTC*	*LgTC-KDE*
PSU	0.514	0.569	0.613	**0.669**	**0.724**	**0.757**
AVA	0.690	0.493	0.667	**0.736**	**0.729**	**0.737**
NY	0.528	0.526	0.627	**0.698**	**0.766**	**0.771**
ICCV17	0.507	0.536	0.514	**0.707**	**0.713**	**0.753**
PSUm	0.292	0.159	0.277	**0.313**	**0.338**	**0.341**
NYm	0.337	0.237	0.388	**0.417**	**0.411**	**0.413**
ICCV17m	**0.273**	0.207	0.236	0.263	**0.285**	**0.287**
Average	0.449	0.390	0.475	**0.543**	**0.567**	**0.580**

Top 3 results are in Bold with red, blue and green colors respectively

Results:

Feature Representation III

Single case symmetry results



Groundtruth (Orange), GbT(black), LgT (blue),
LgTC (cyan), and LgTC-KDE (yellow)
against the prior algorithms: Loy (red), and Cic (magenta)

Summary

- A reliable global symmetry detection is developed among variants of visual cues.

- A novel symmetry detection algorithm to find global axes based on Log-Gabor feature extraction, plus textural and color neighboring information.

- A weighted joint density estimator is proposed to handle both orientation and displacement information.

- A groundtruth of single symmetry axes inside artistic photographs extracted from the large-scale Aesthetic Visual Analysis (AVA) dataset.

Thanks for your attention!

Questions?