Discriminative Image Warping using Attribute Flow

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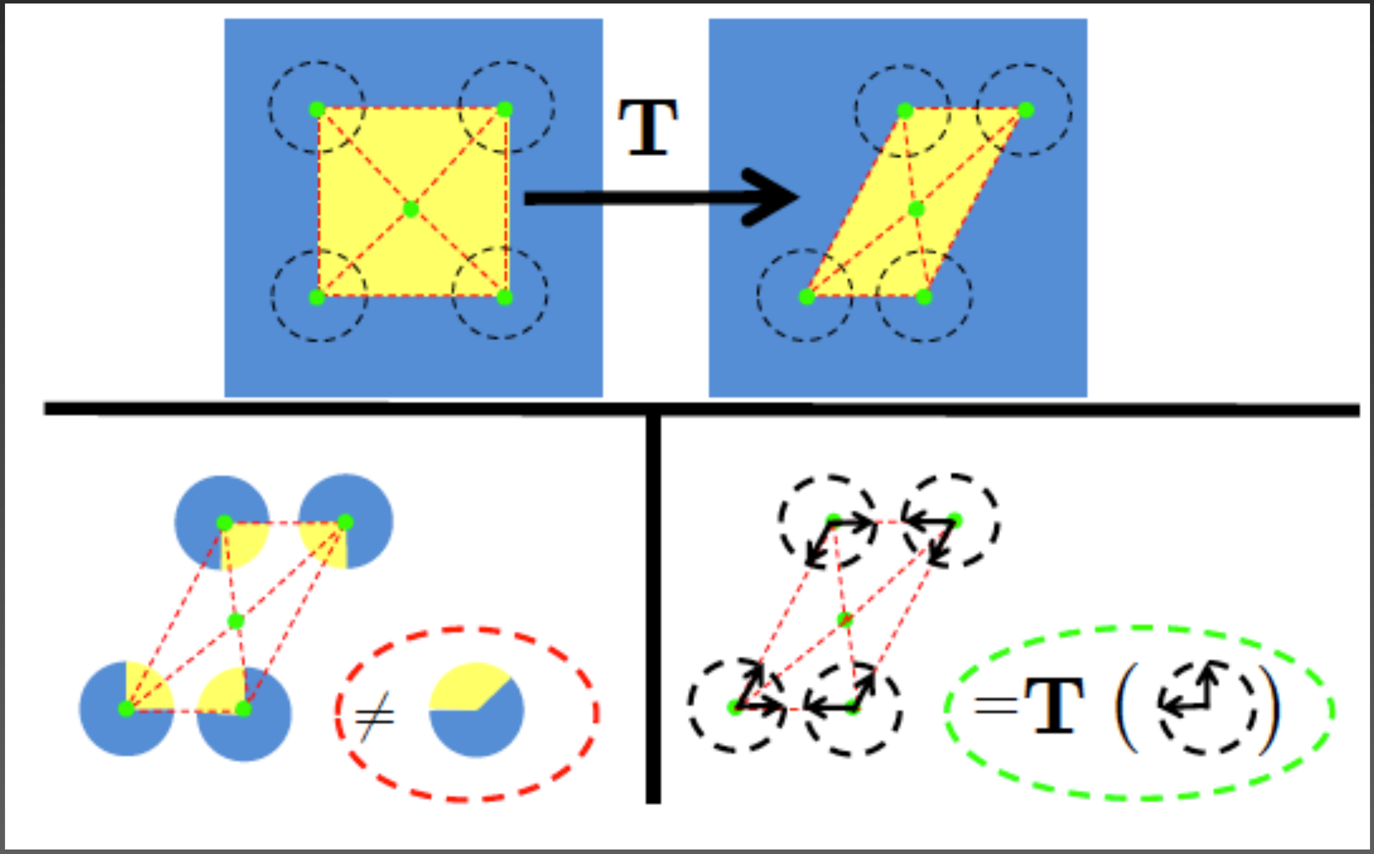
Penn

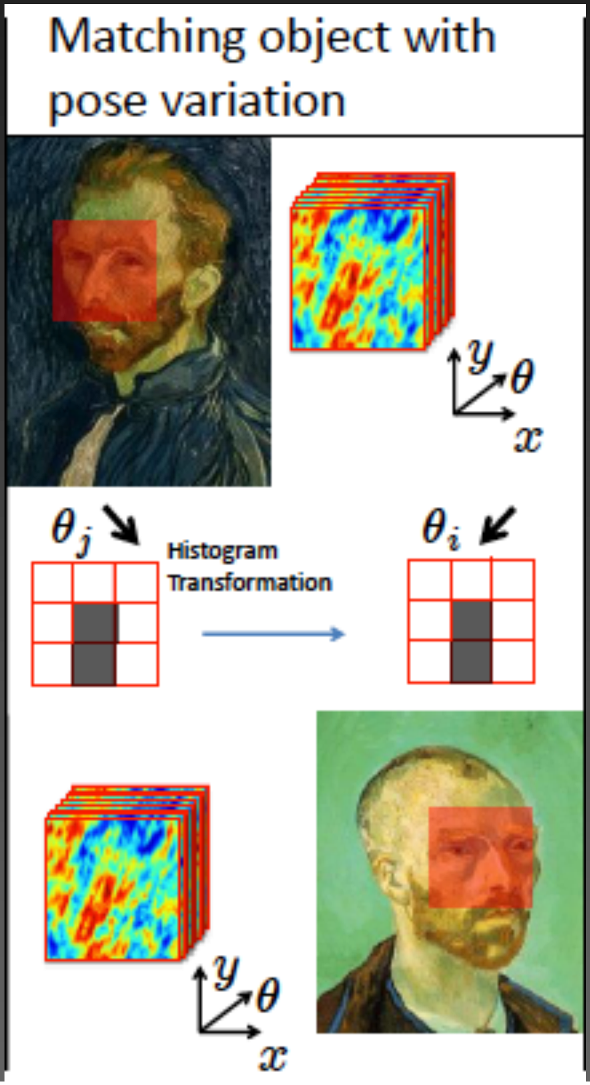
Attribute flow : idea 1

need to frame features right



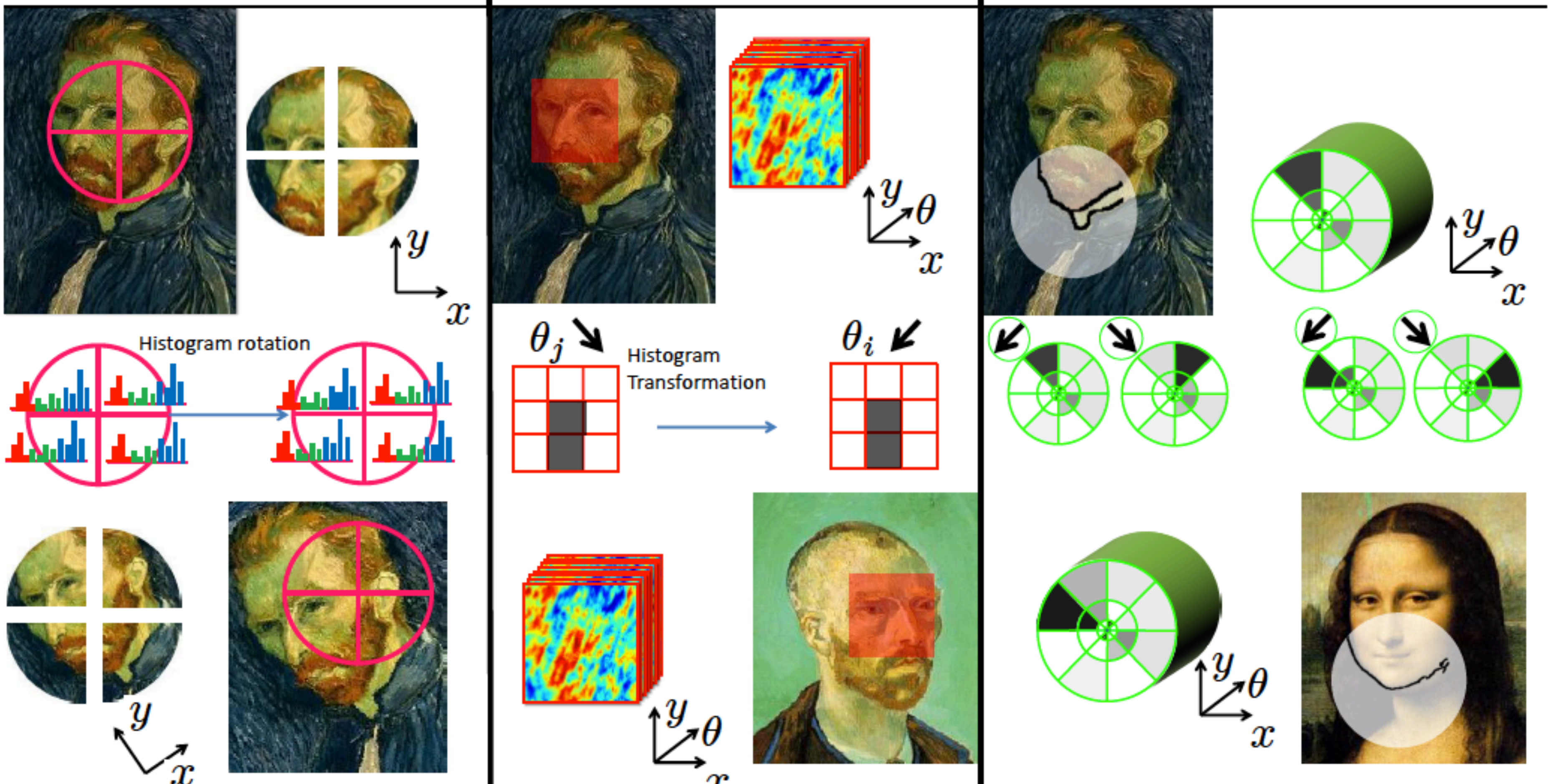
Attribute flow : idea 2

Transformation that explains attribute change



Attribute Flow

Matching same object with deformation	Matching object with pose variation	Matching instances in the same object category



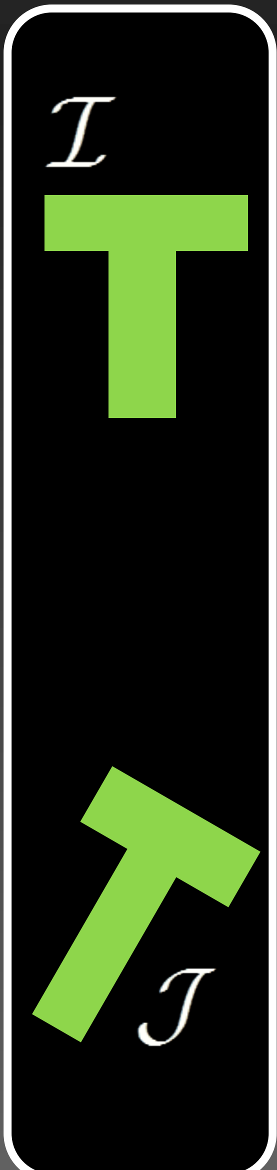
Challenges

Q1: How to compute the spatial transformation efficiently without explicit search?

Q2: How to constrain the computation such that it leads to valid spatial transformation?

Q3: How to deal with clutter environment?

Image Deformation as Attribute Flow



Input Model

T ?

Input Image

Transformation that explains attribute change

$$\min_{\mathbf{T}} \int_{\mathrm{R}^2} ||\mathcal{A}_{\mathcal{I}}(x) - \mathcal{A}_{\mathcal{J}}(\mathbf{T}(x))||_p dx$$

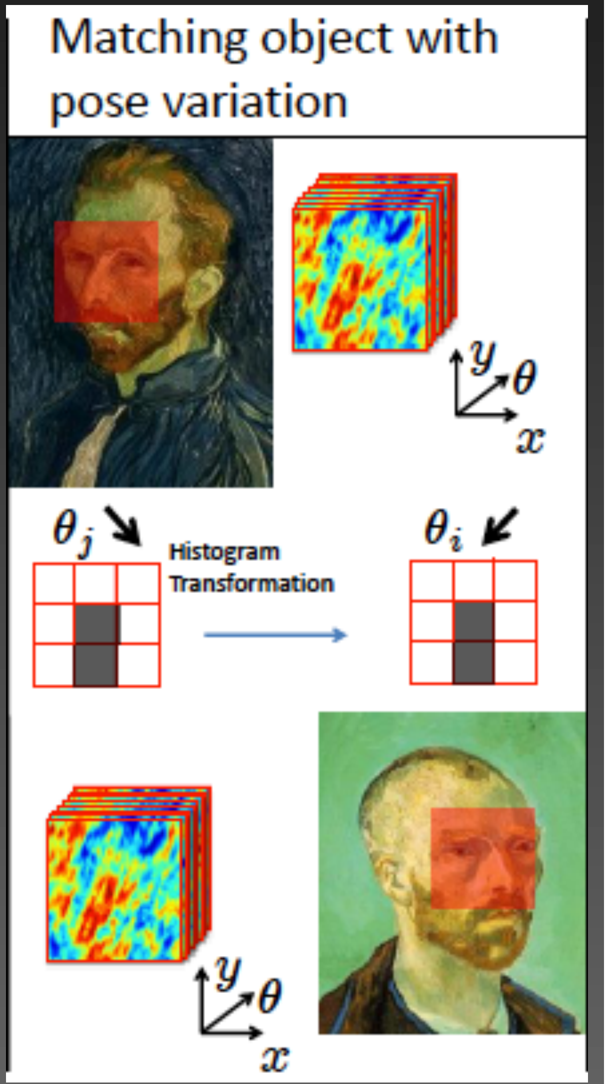
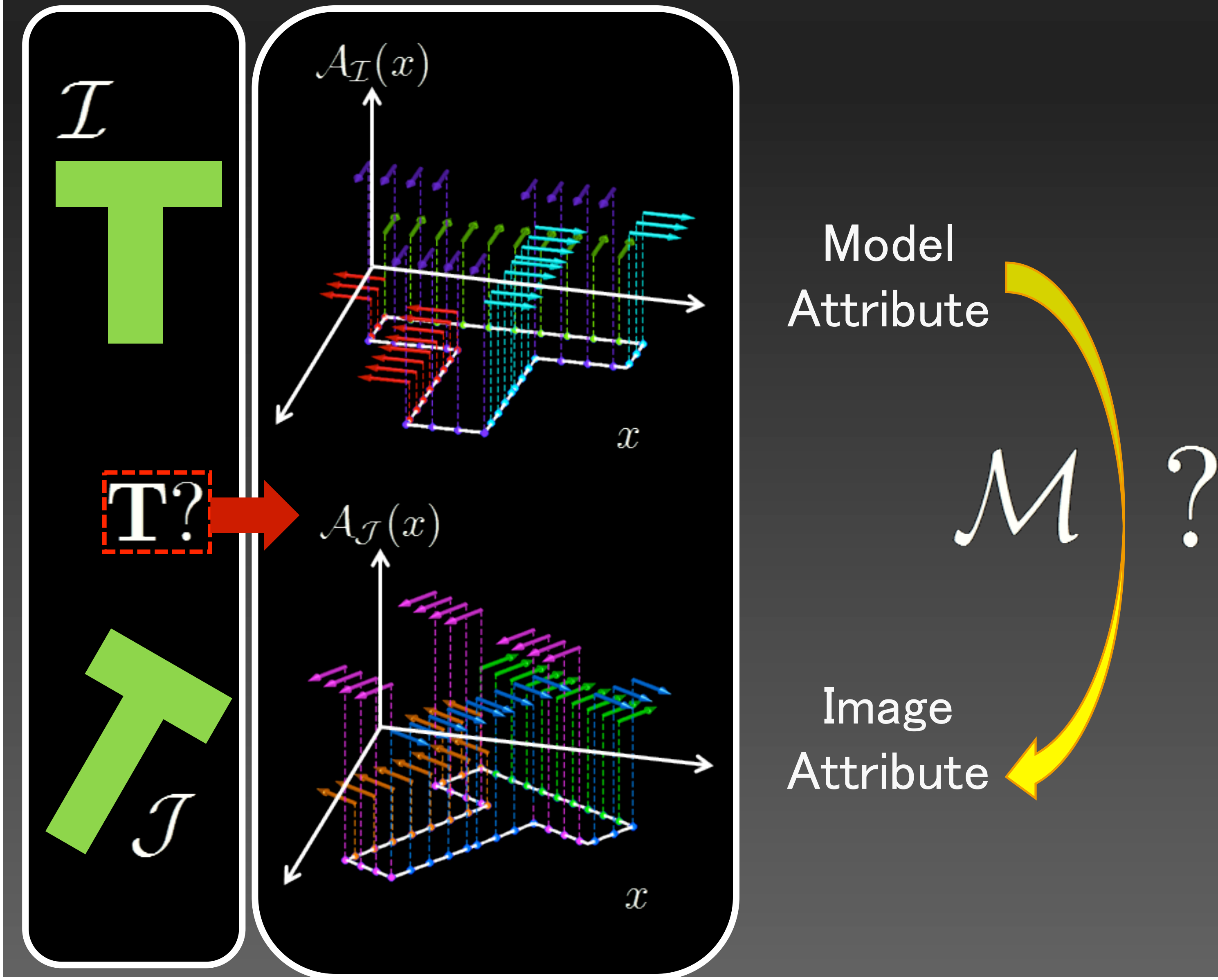


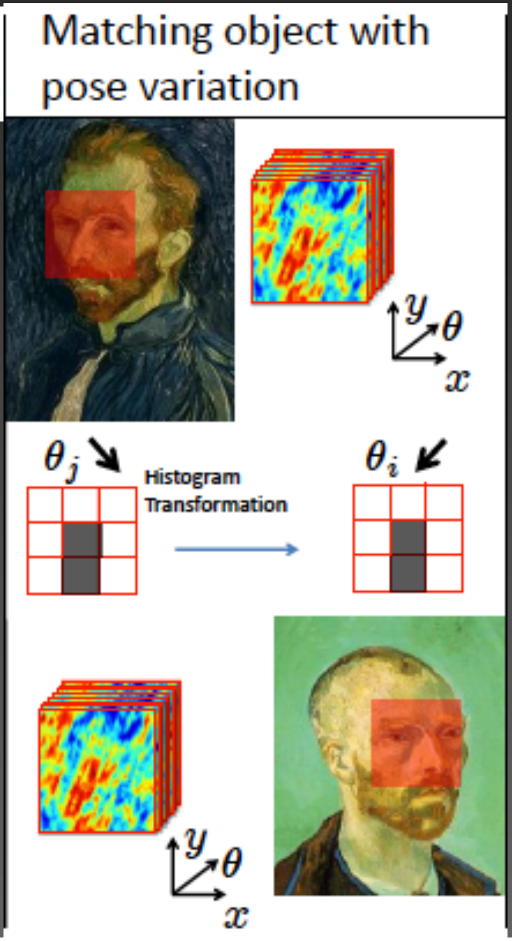
Image Deformation as Attribute Flow



$$\min_{\mathcal{M}} \int_{\mathbf{R}^{n+2}} |\delta(y - \mathcal{M}(\mathcal{A}_{\mathcal{I}}^{+})) - \delta(y - \mathcal{A}_{\mathcal{J}}^{+})|_1 dy$$

Assuming the first elements of $\mathcal{A}(\mathcal{I}(x))$ are the spatial location x

$$\mathcal{M}(\mathcal{A}(\mathcal{I}(x))) = (\mathbf{T}(x), m(a_2), ..., m(a_n)).$$



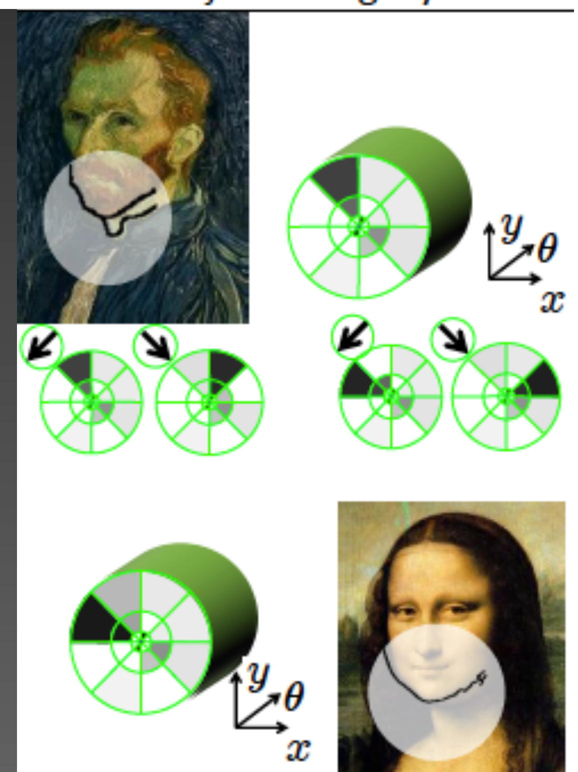
Attribute: edge orientation, or oriented filter

$$\min_{\mathcal{M}} \int_{\mathbf{R}^{n+2}} |\delta(y - \mathcal{M}(\mathcal{A}^{+}_{\mathcal{I}})) - \delta(y - \mathcal{A}^{+}_{\mathcal{J}})|_1 dy$$

Assuming the first elements of $\mathcal{A}(\mathcal{I}(x))$ are the spatial location x

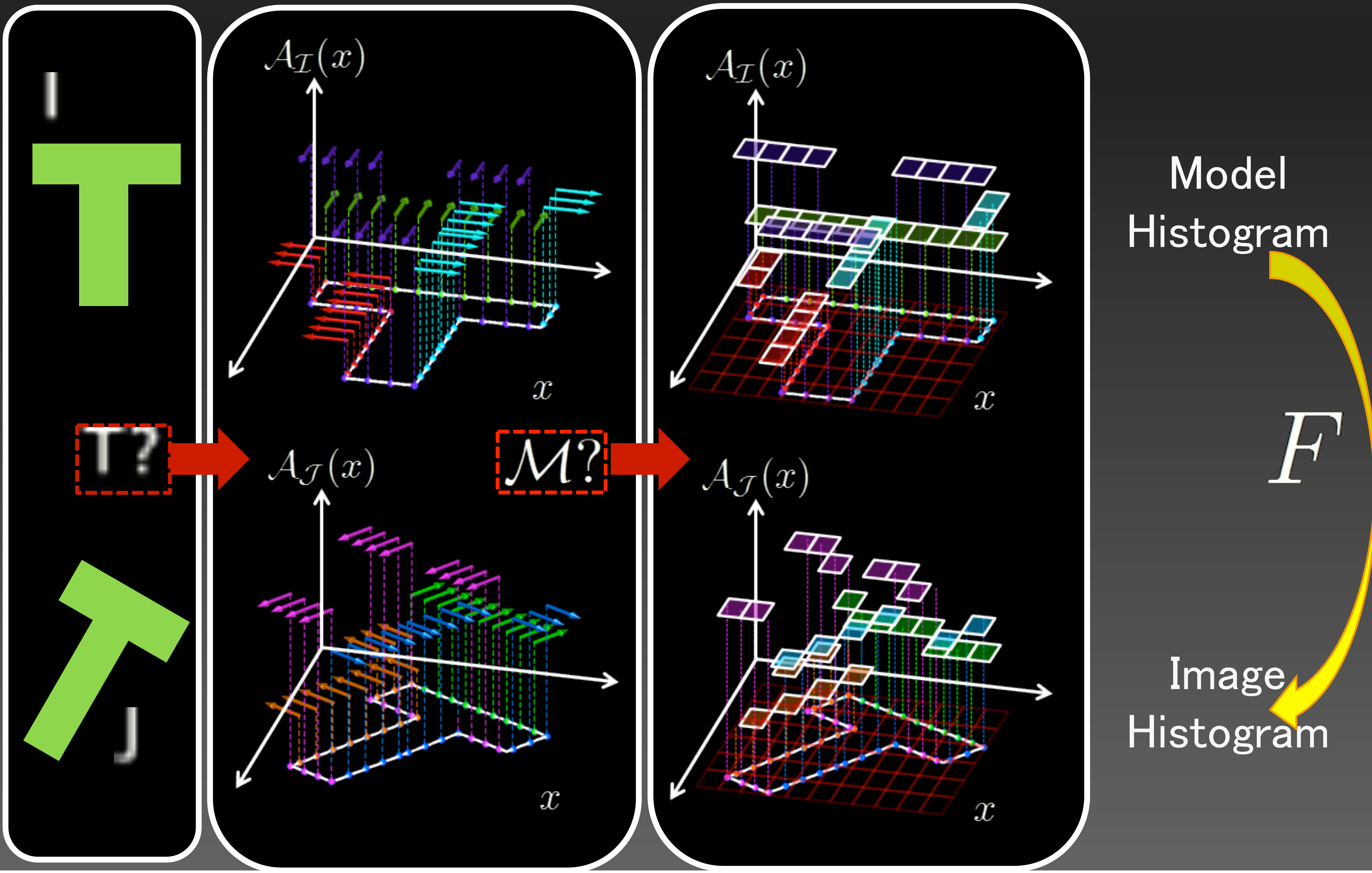
$$\mathcal{M}(\mathcal{A}(\mathcal{I}(x))) = (\mathbf{T}(x), m(a_2), ..., m(a_n)).$$

Matching instances in the same object category



Attribute: edge orientation, or oriented filter

Image Deformation as Attribute Flow



Solve Attribute Flow via Histogram Matching

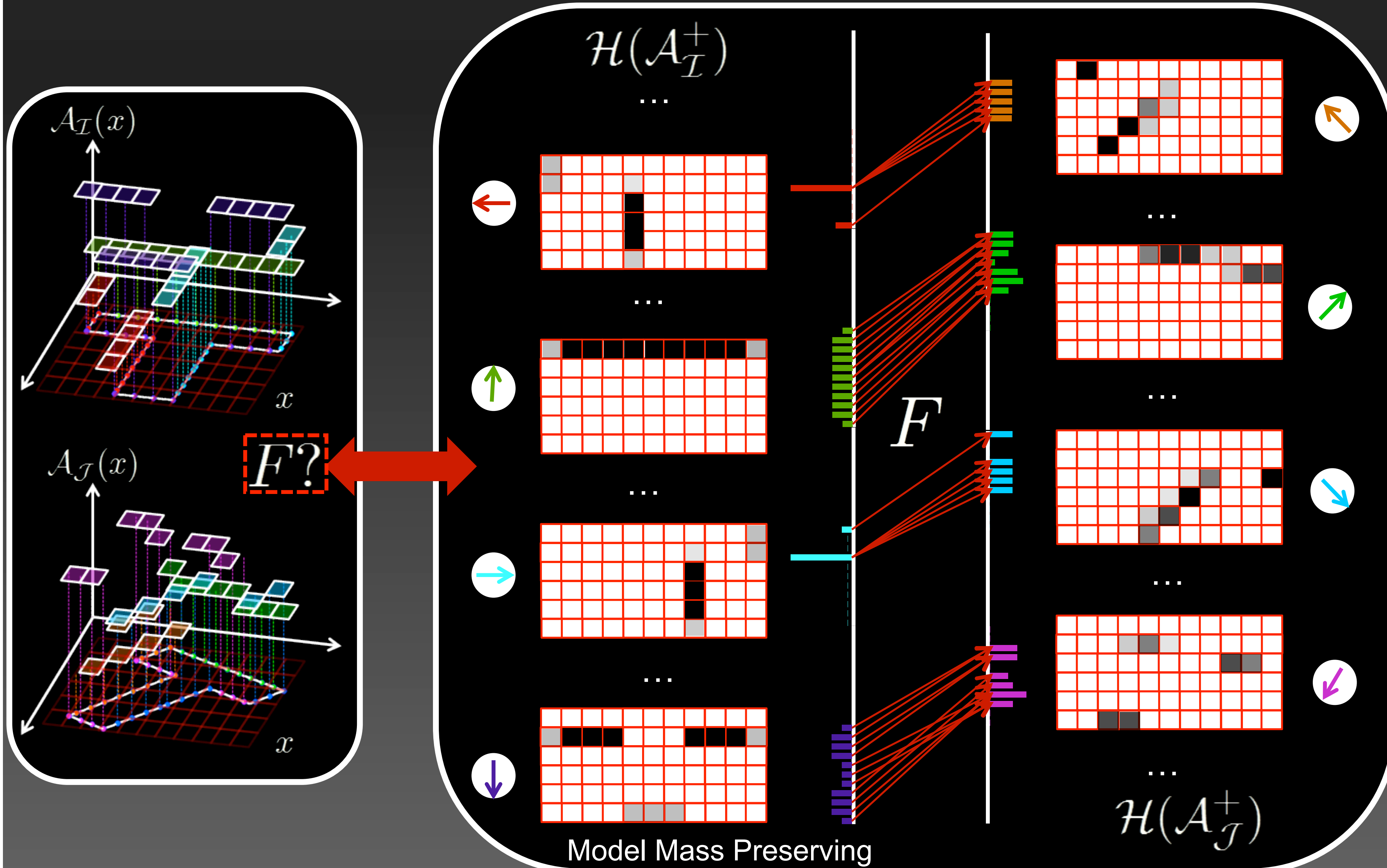
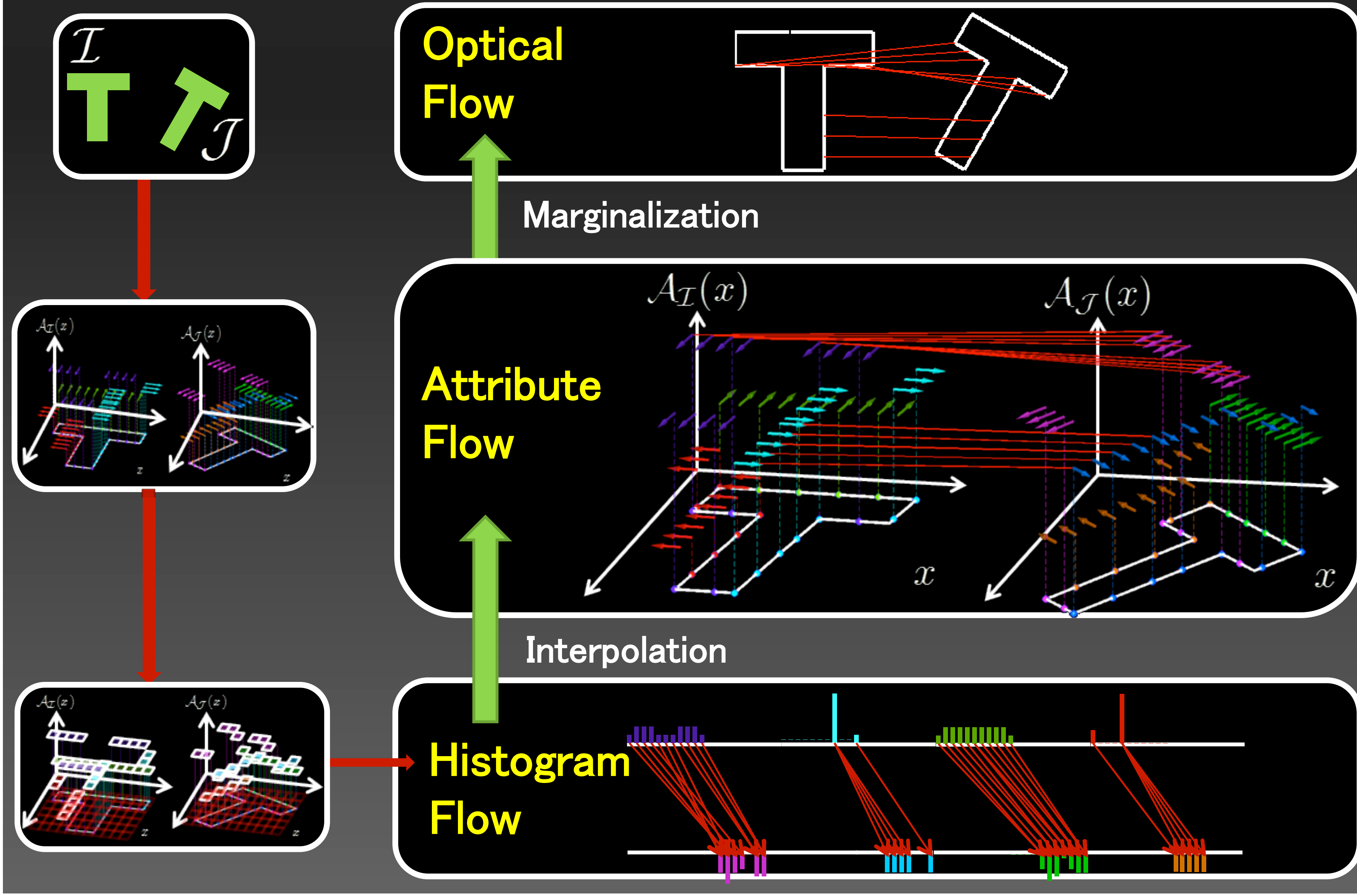
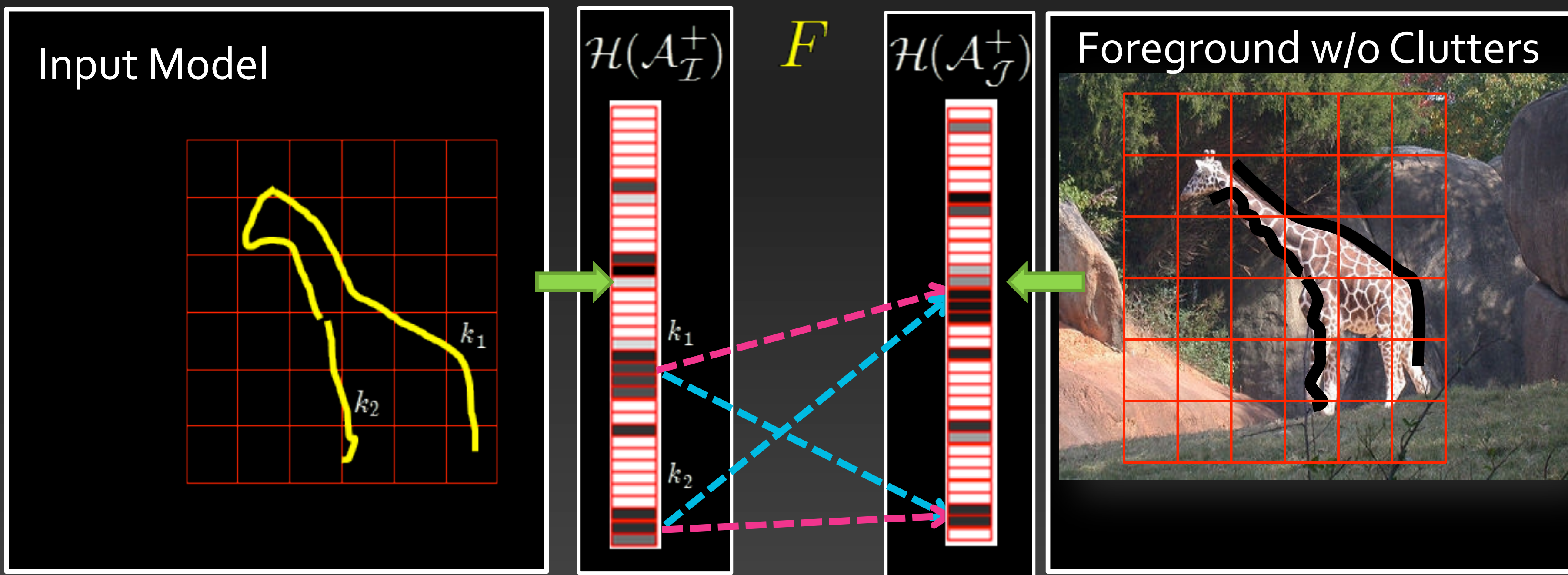


Image Deformation as Attribute Flow

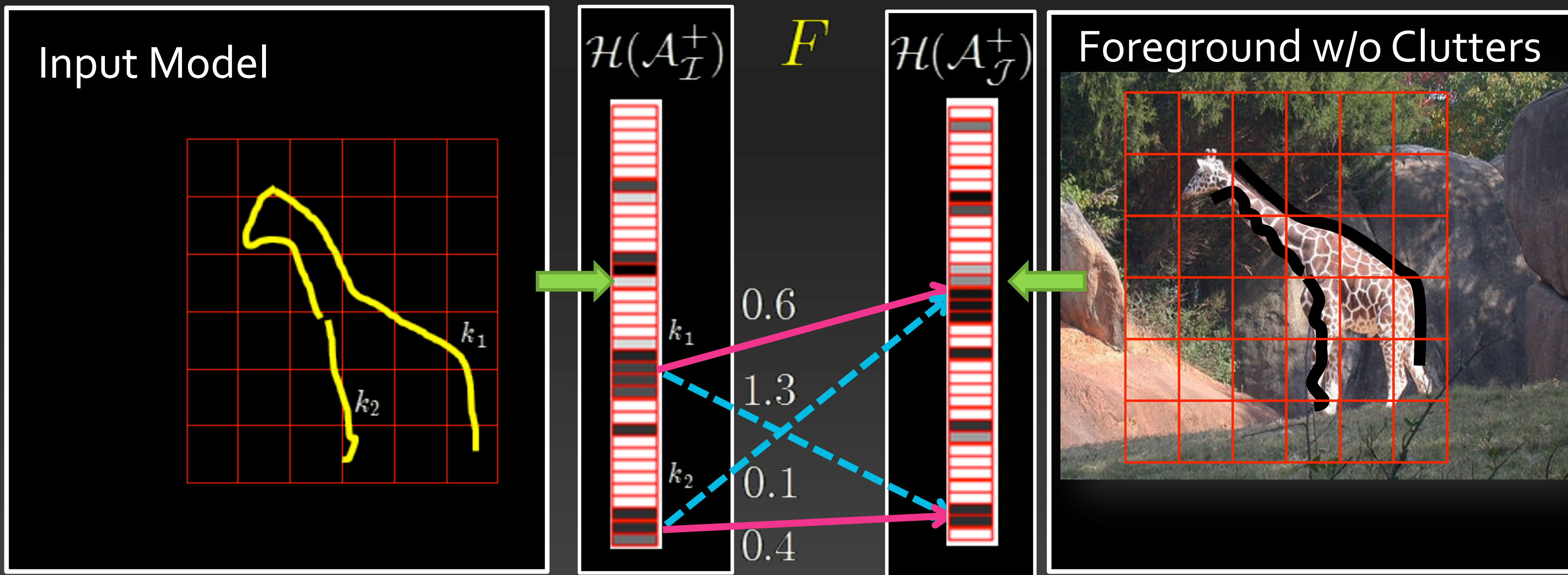


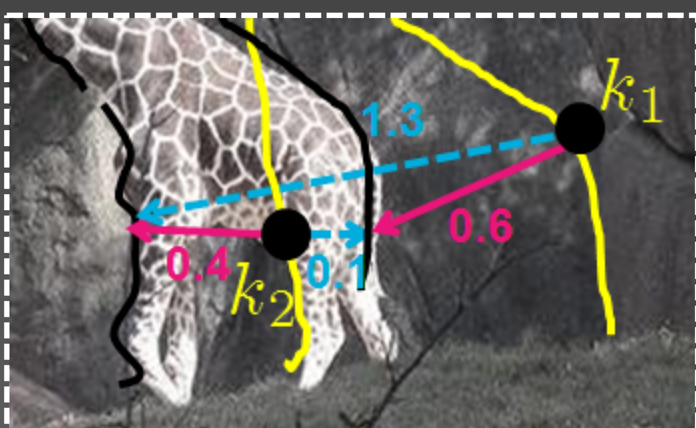
Histogram Flow



How to differentiate two flows?

Histogram Flow Ground Distance Cost

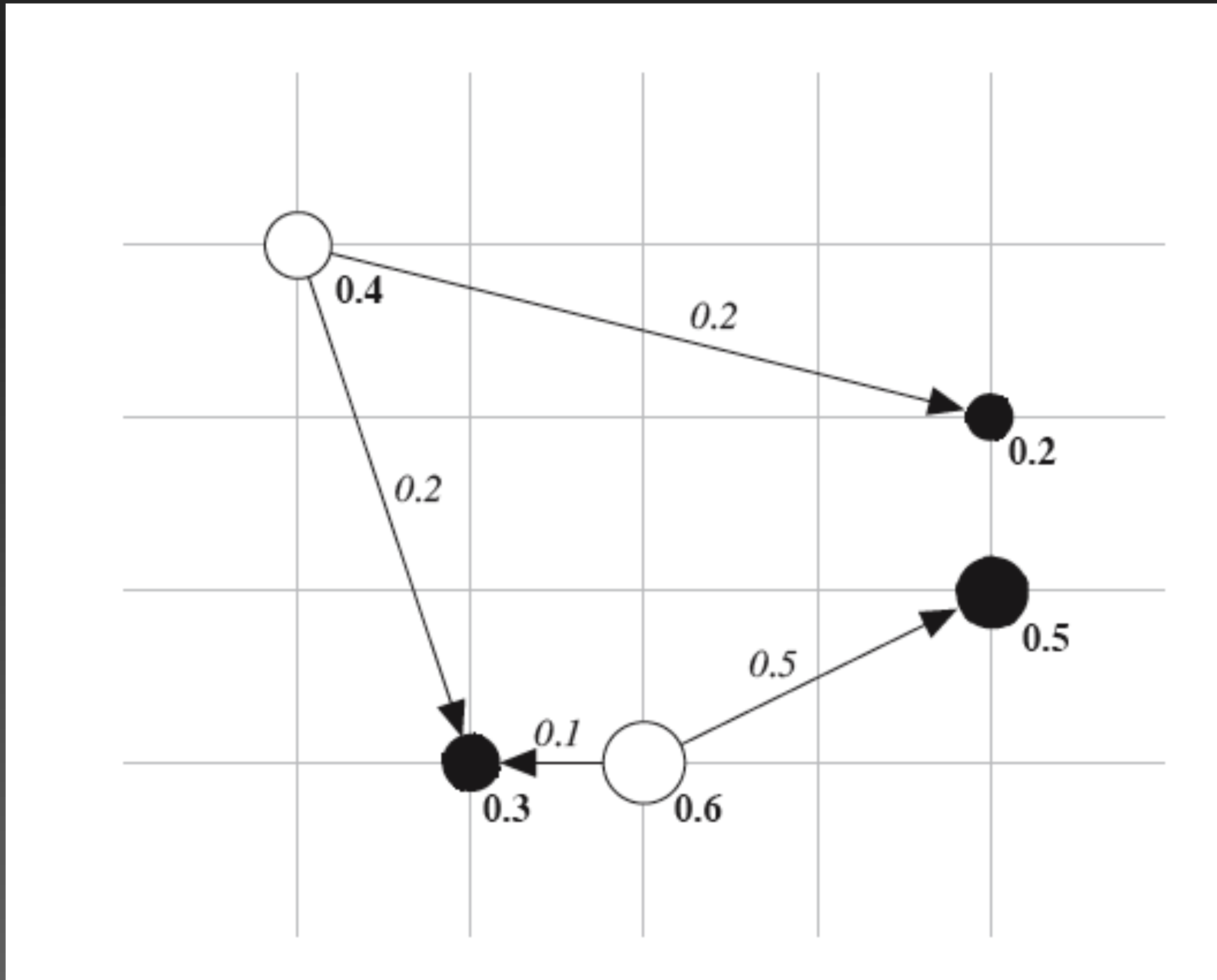




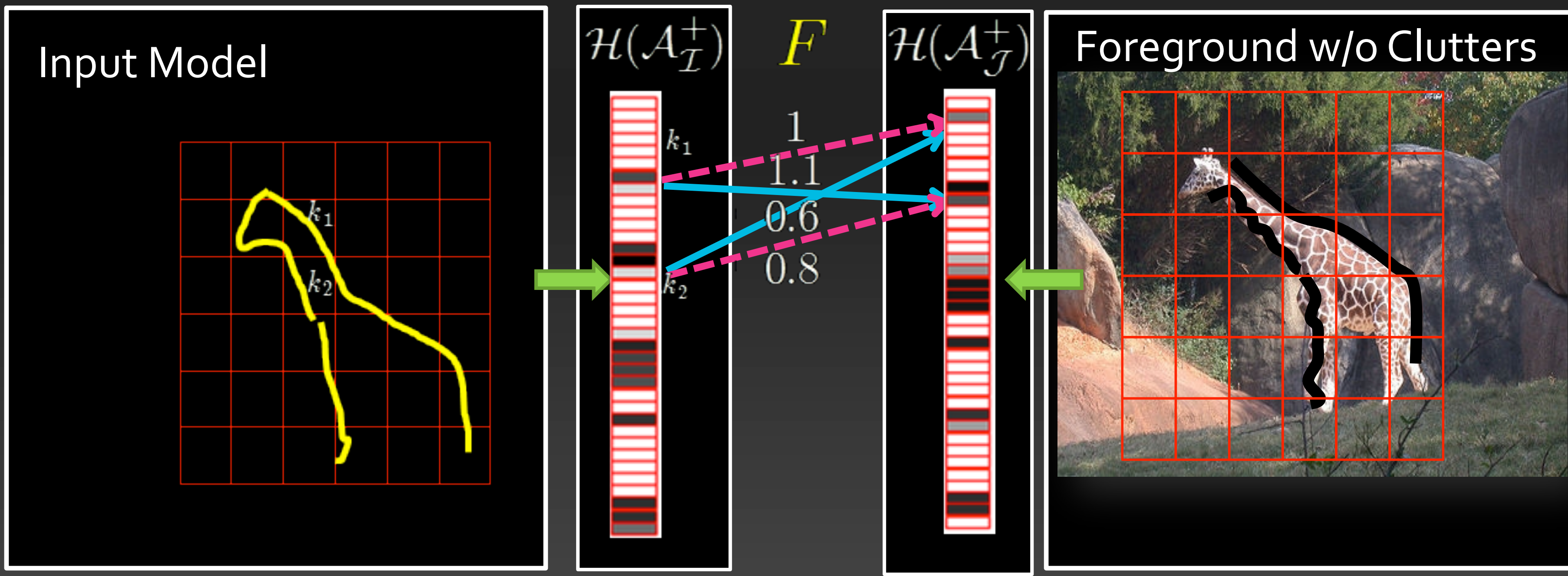
Earth Mover's Distance:

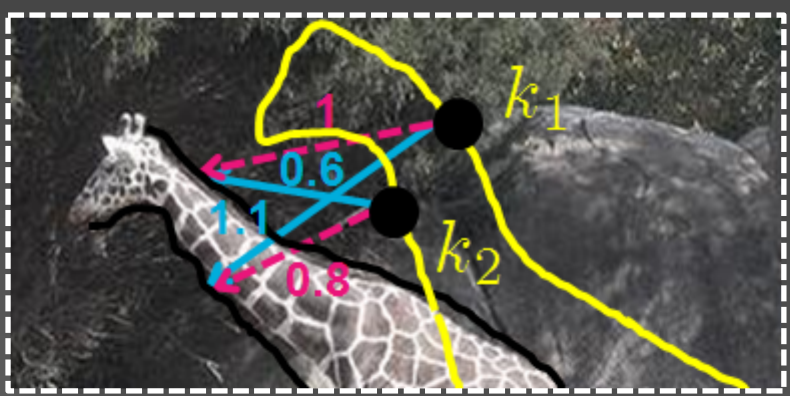
$$\mathrm{GD}(F) = \sum_{k,l} F_{k,l} d_{k,l}$$

Linear programming for solving EMD



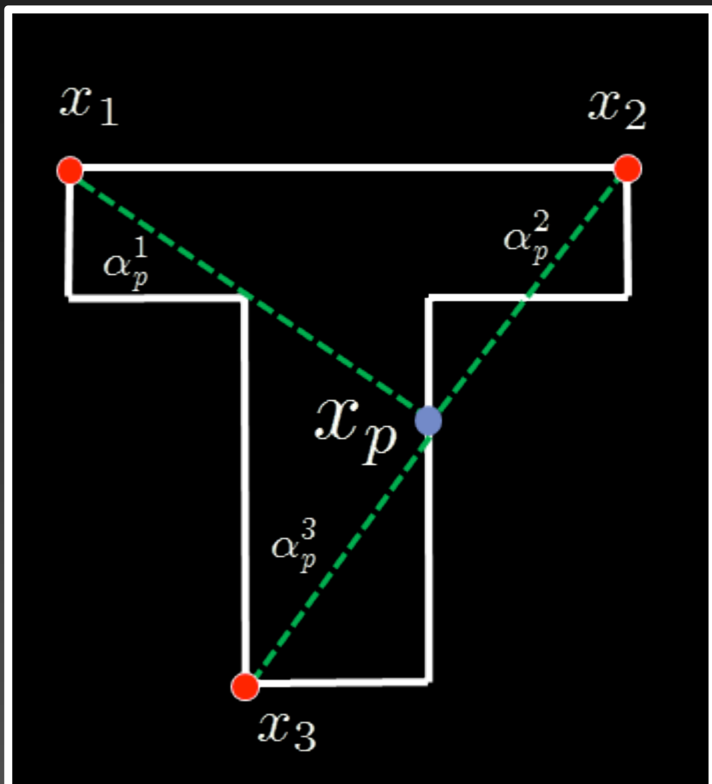
But, Ground Distance fails in rotation!

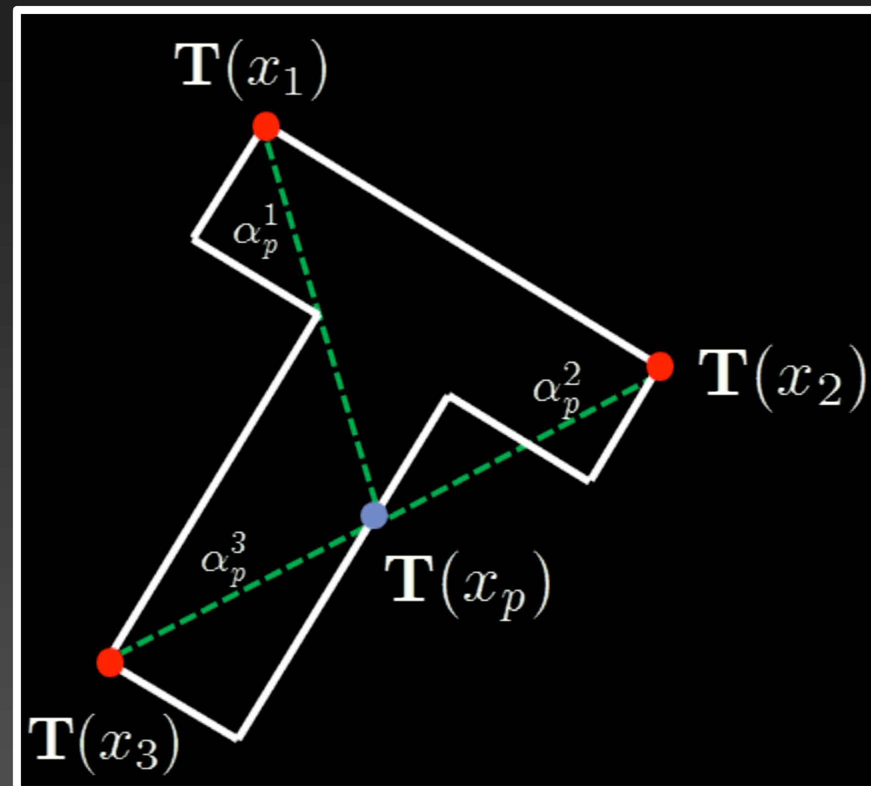




Minimizing ground distance fails when the object rotates.

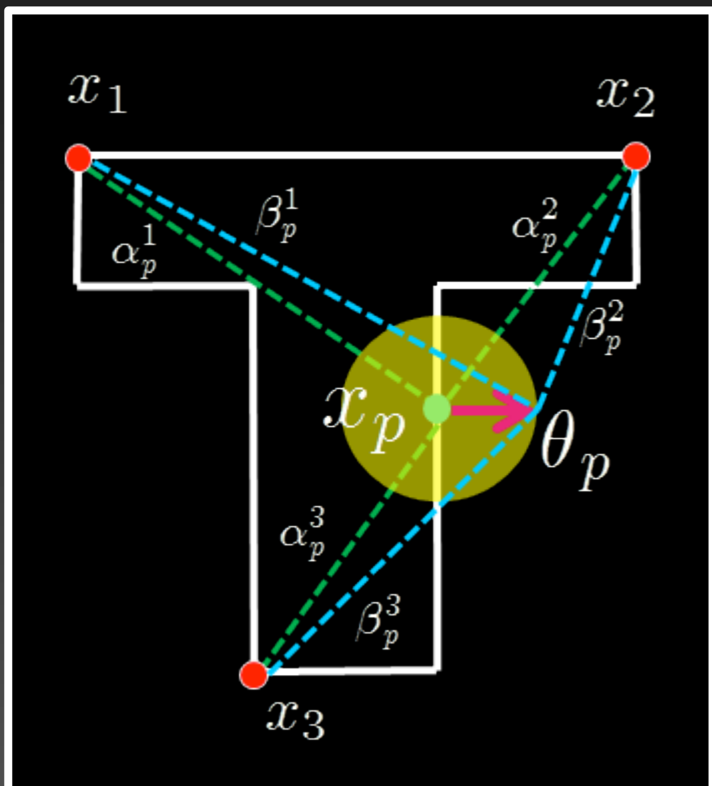
Affine Constraint on Spatial Transformation

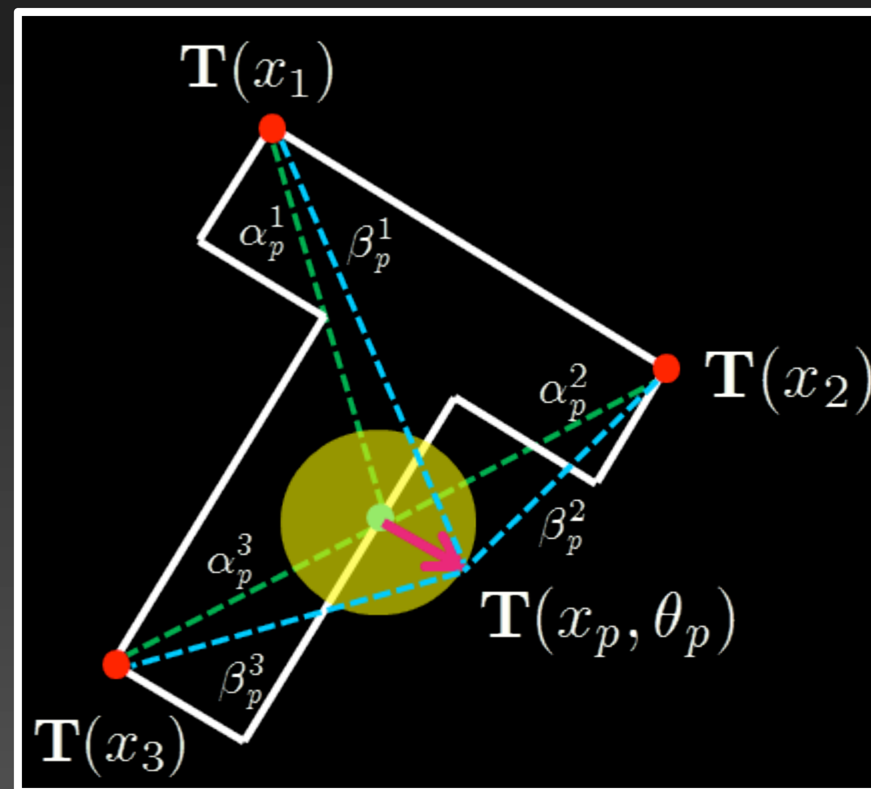




Affine Constraint 1: $$\mathbf{T}(x_p) = \sum_{i=1}^{3} \alpha_i^p \mathbf{T}(x_i)$$

Affine Constraint on Spatial Transformation

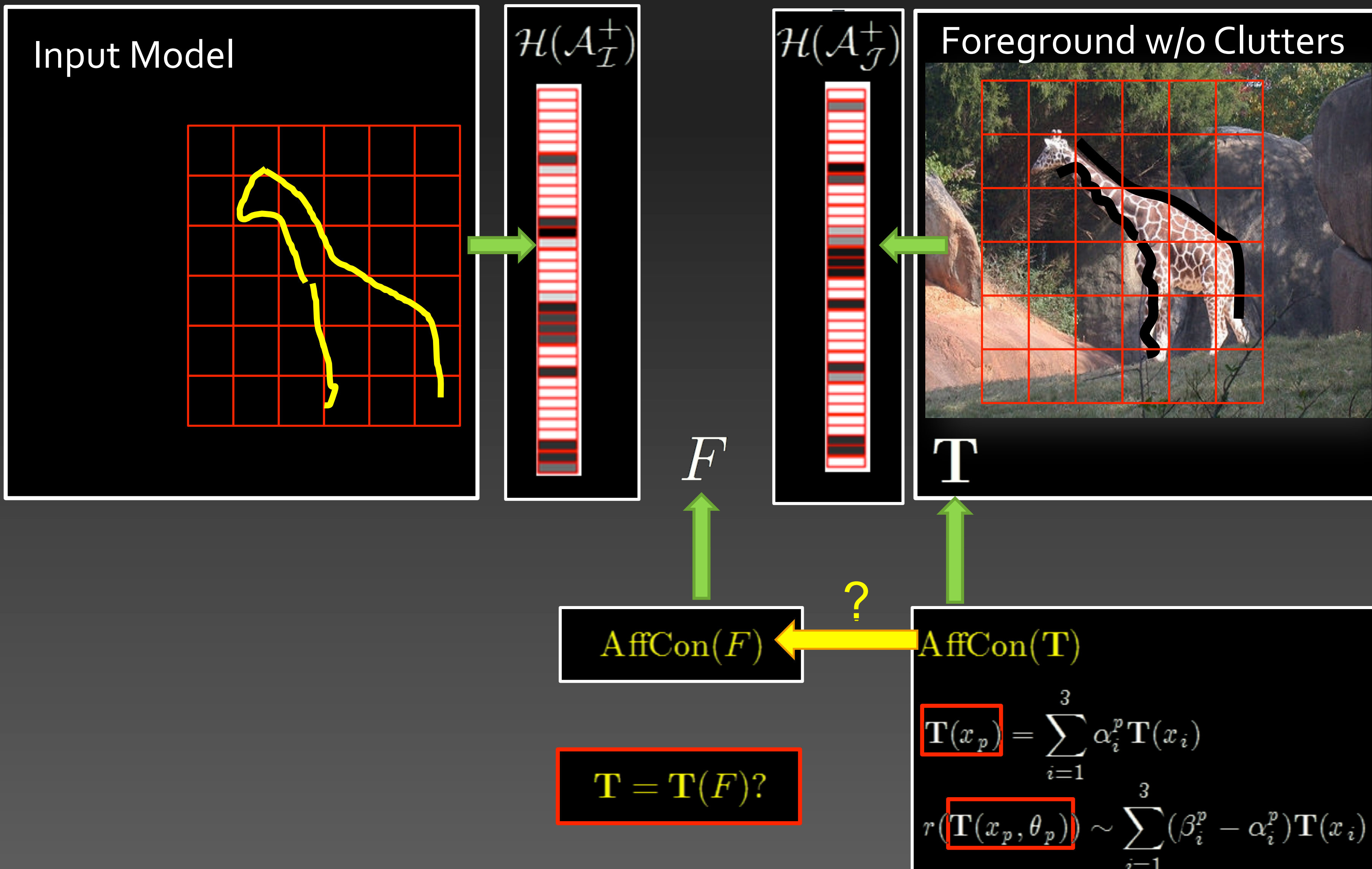




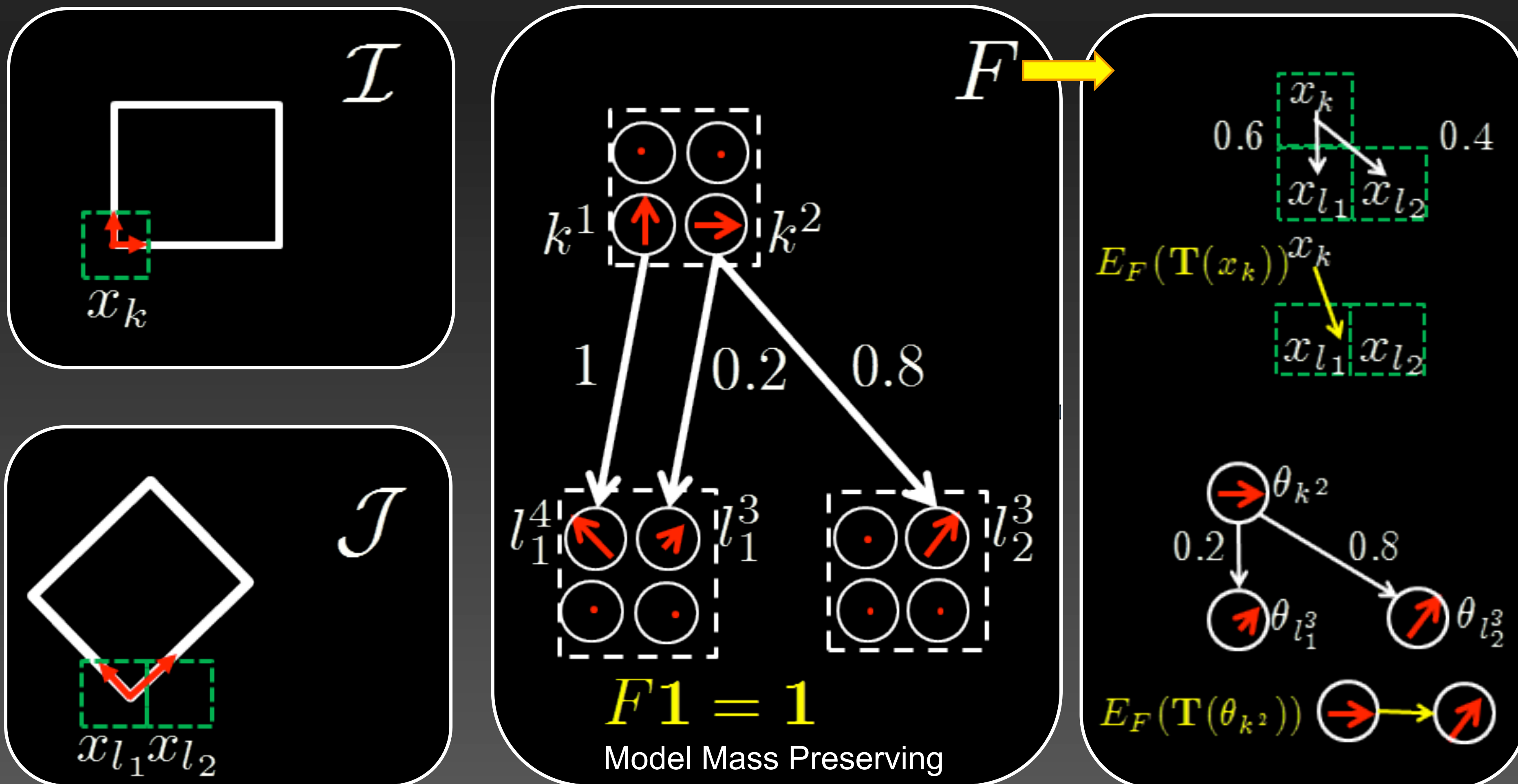
Affine Constraint 2: $$r(\mathbf{T}(x_p, \theta_p)) \sim \sum_{i=1}^{3} (\beta_i^p - \alpha_i^p)\mathbf{T}(x_i)$$

$r(\theta) = [\cos(\theta), \sin(\theta)]^{\mathrm{T}}$

Affine Constraint on Histogram Flow



Spatial Transformation from Histogram Flow



F can be viewed as a probability encoding of T

Geometrical constraint 1

$$\mathbf{T}(x_z) = \sum_{i=1}^{3} \alpha_i^z \mathbf{T}(x_i)$$

$$\mathrm{AffCon}_{\mathbf{x}}(F,k) : ||E_F(\mathbf{T}(p_k)) - \sum_{i=1} \alpha_i^k E_F(\mathbf{T}(p_{k_i}))||_1$$

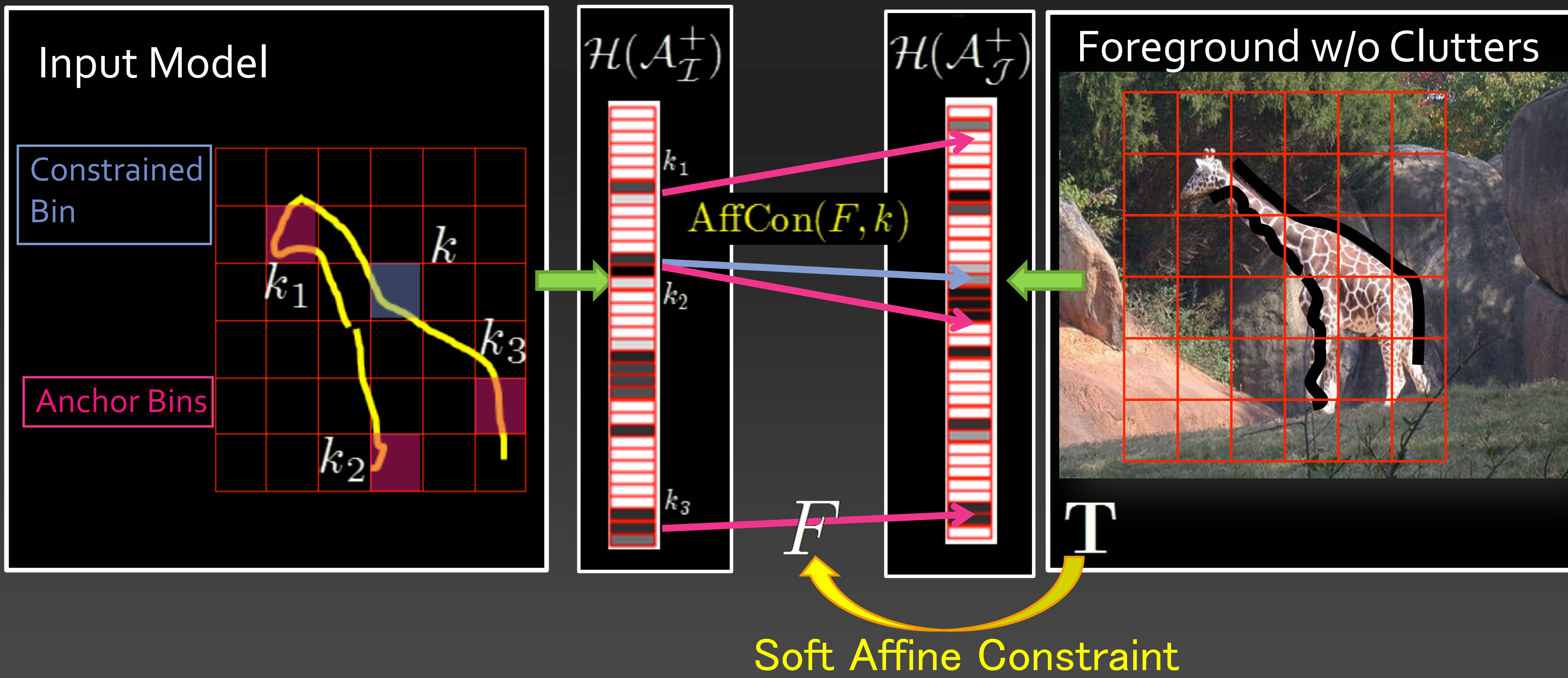
Geometrical constraint 2

$$\mathbf{T}([\cos(\theta_z)\,\sin(\theta_z)]^{\mathsf{T}}) \sim \sum_{i=1}^{3}(\beta_i^z - \alpha_i^z)\mathbf{T}(x_i),$$

$$\downarrow$$

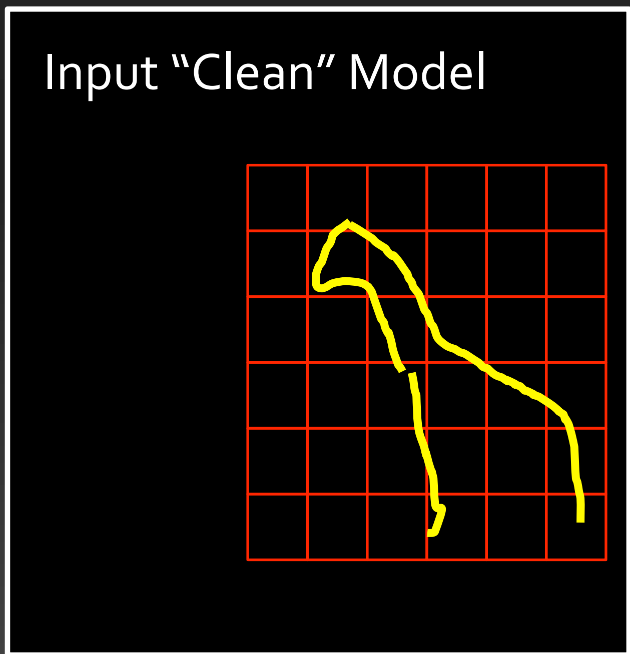
$$E_F(\mathbf{T}([\cos(\theta_k)\,\sin(\theta_k)]^{\mathsf{T}})) \sim \sum_{i=1}^{3}(\beta_i^k - \alpha_i^k)E_F(\mathbf{T}(p_{k_i})).$$

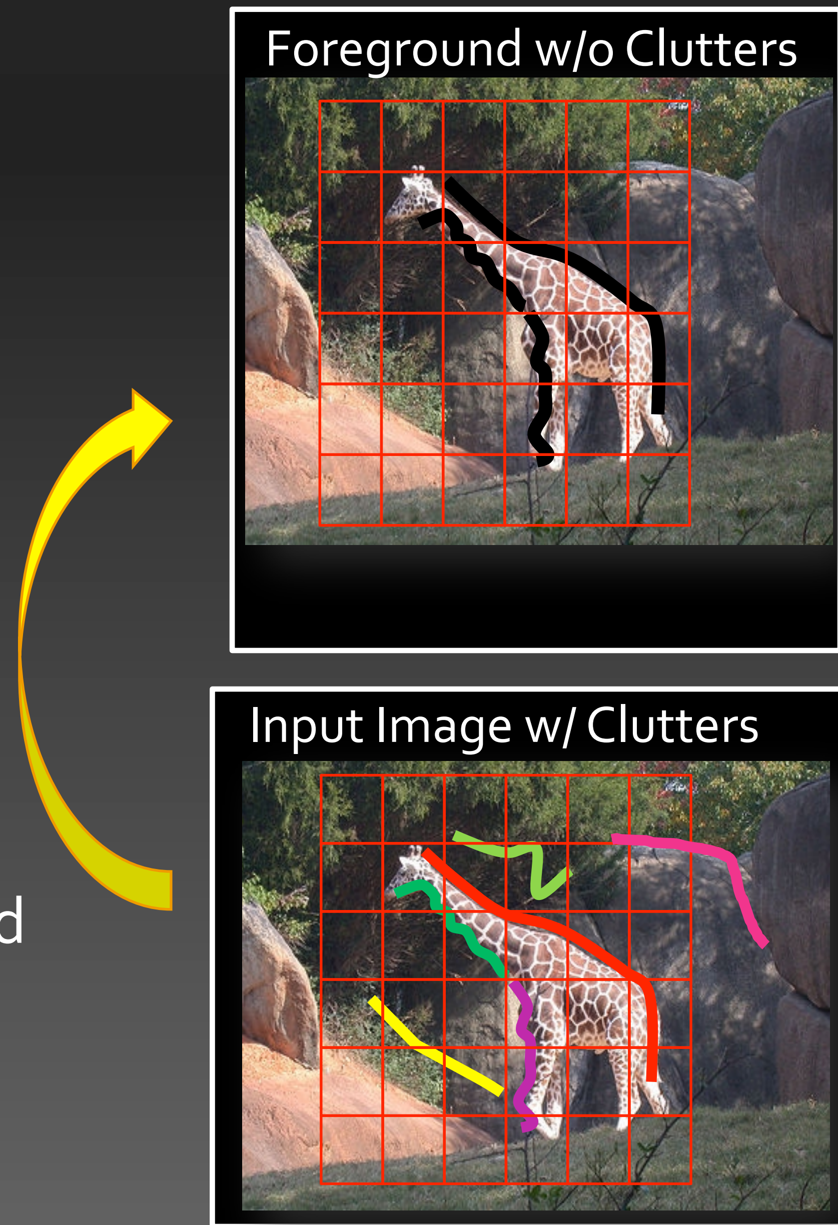
Constrained Attribute Histogram Flow



$$
\mathrm{AffCon}(F,k) = \begin{array}{ll} \mathrm{AffCon}_{\mathbf{x}}(F,k): & |E_F(\mathbf{T}(x_k)) - \sum_{i=1}^{3} \alpha_i^k E_F(\mathbf{T}(x_{k_i}))|_1 \\ + & \\ \mathrm{AffCon}_{\theta}(F,k): & \min_s |s \cdot r(E_F(\mathbf{T}(\theta_k))) - \sum_{i=1}^{3} (\beta_i^k - \alpha_i^k) E_F(\mathbf{T}(x_{k_i}))|_1 \end{array}
$$

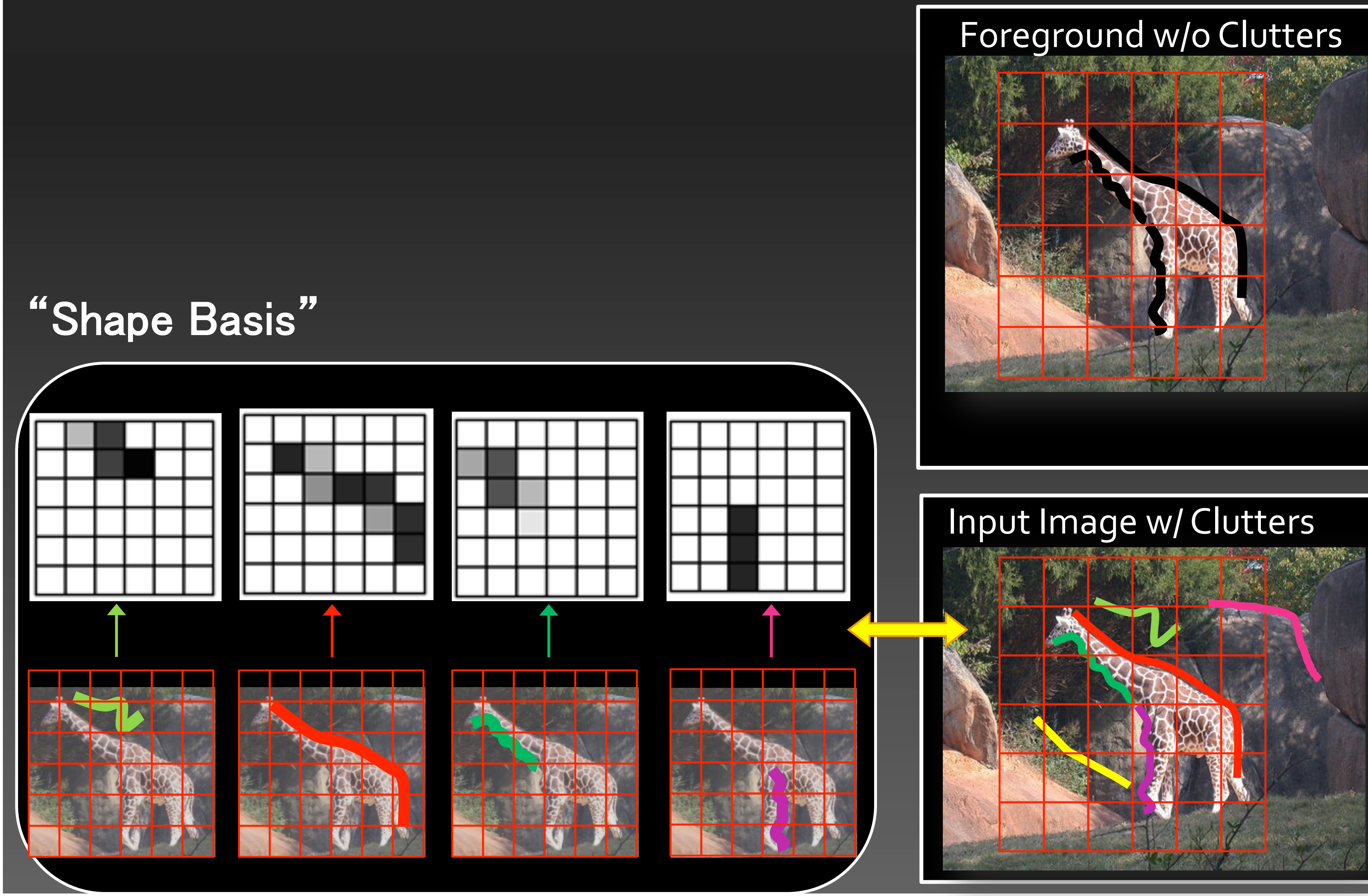
Match with Selected Region



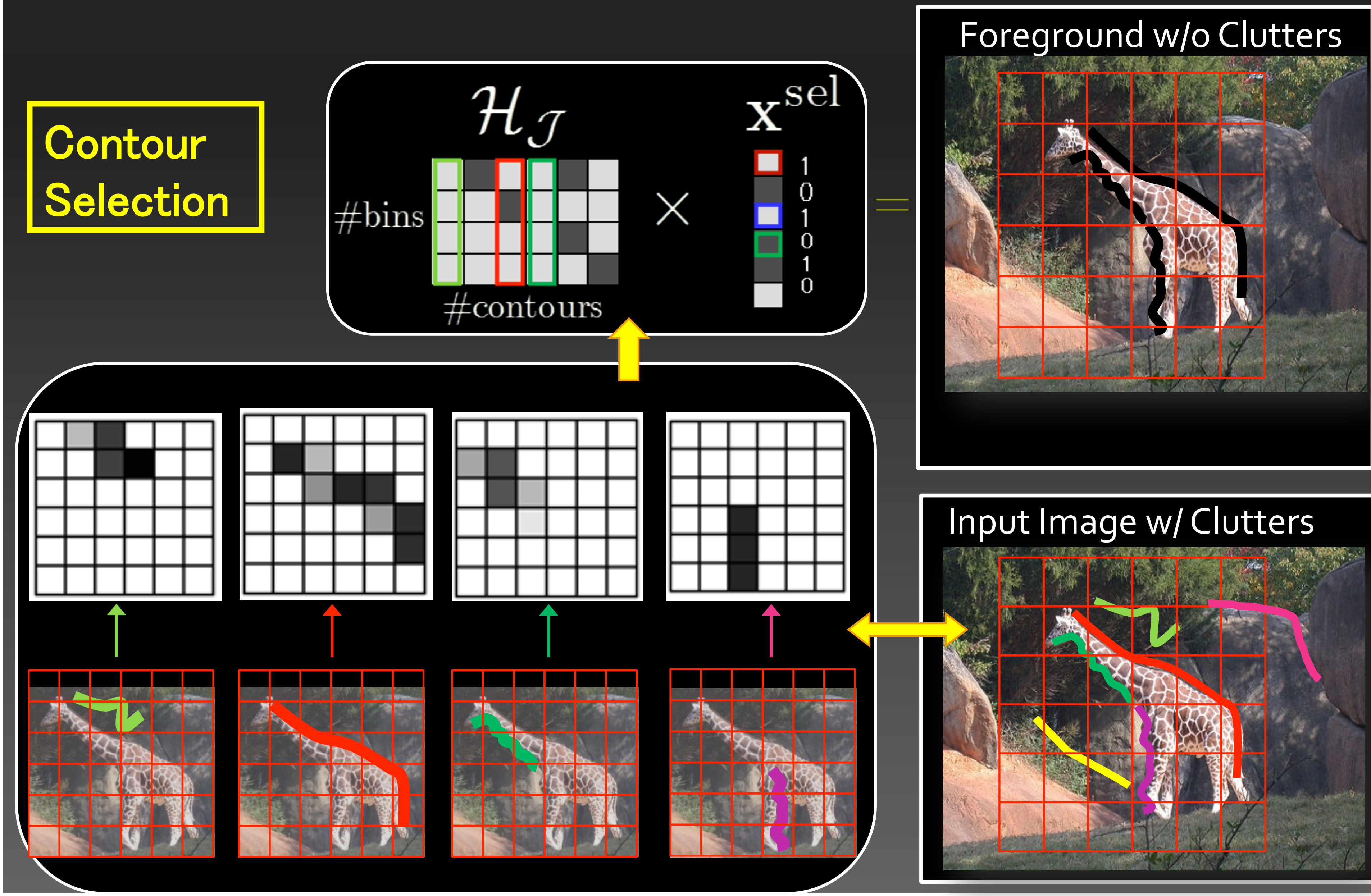


Q: How to efficiently select foreground region to avoid "cherry-picking"?

Match with Selected Region



Match with Selected Region



Application: Simultaneous Detection and Alignment

Input

Shape Model

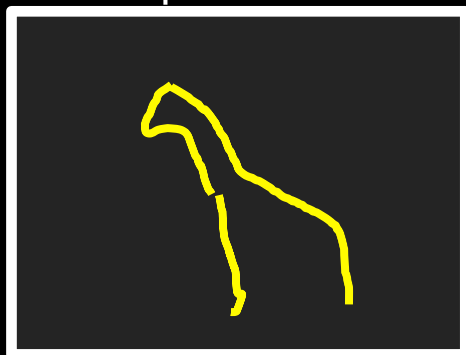
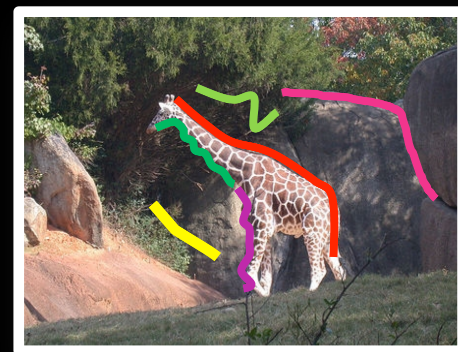
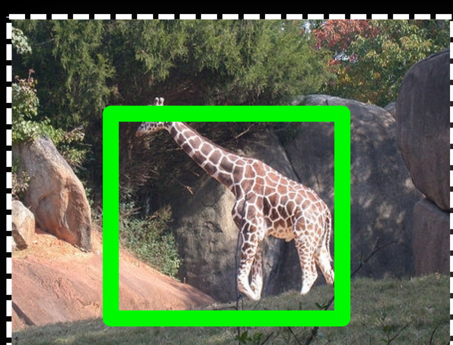


Image with contours, or segments



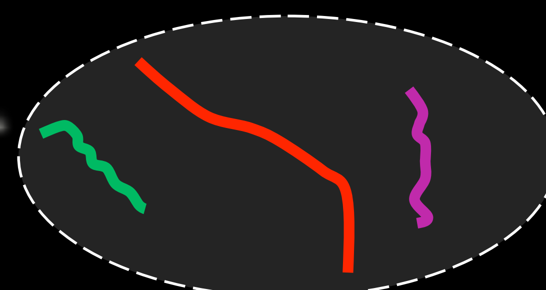
Output

Detection

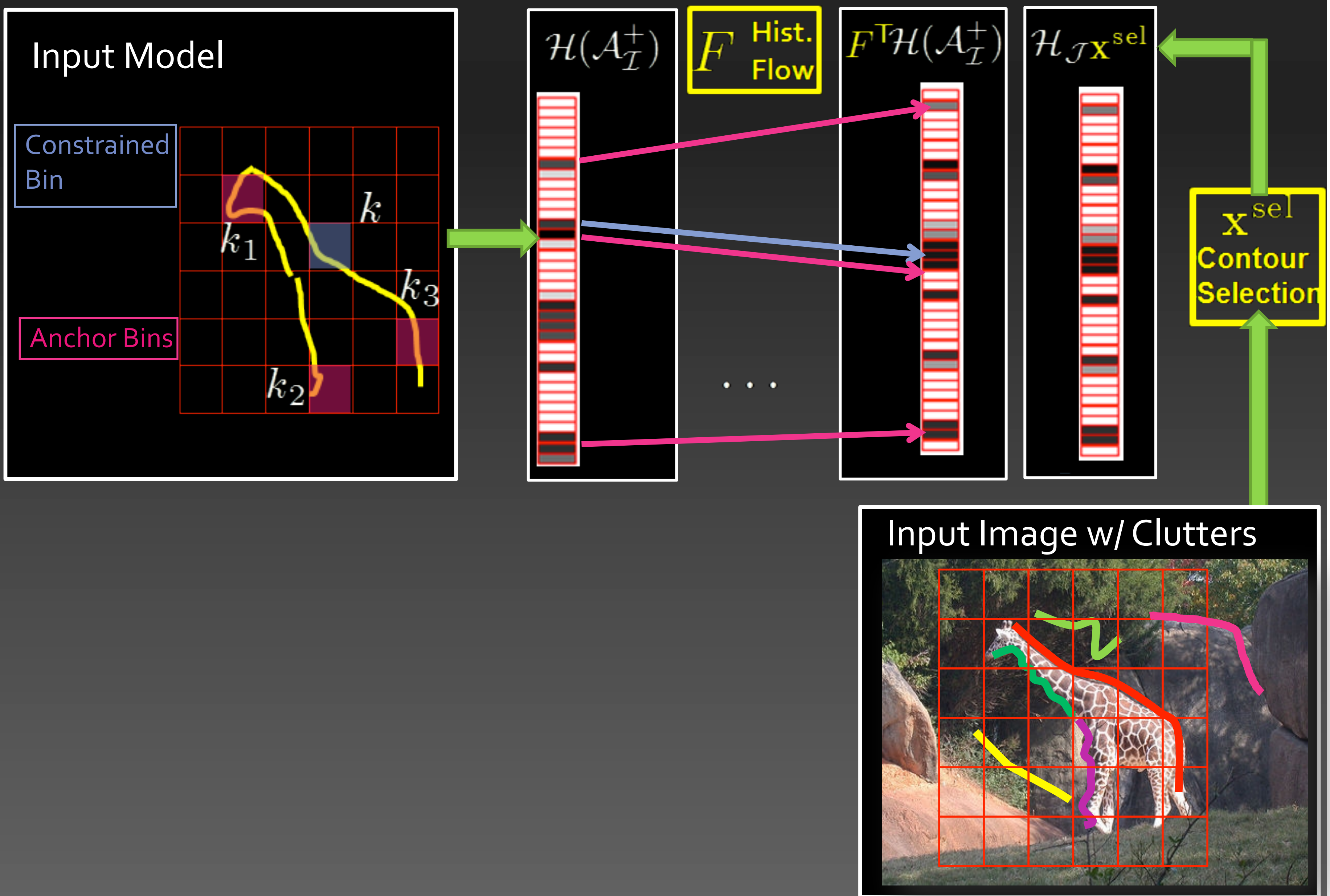


Shape Alignment

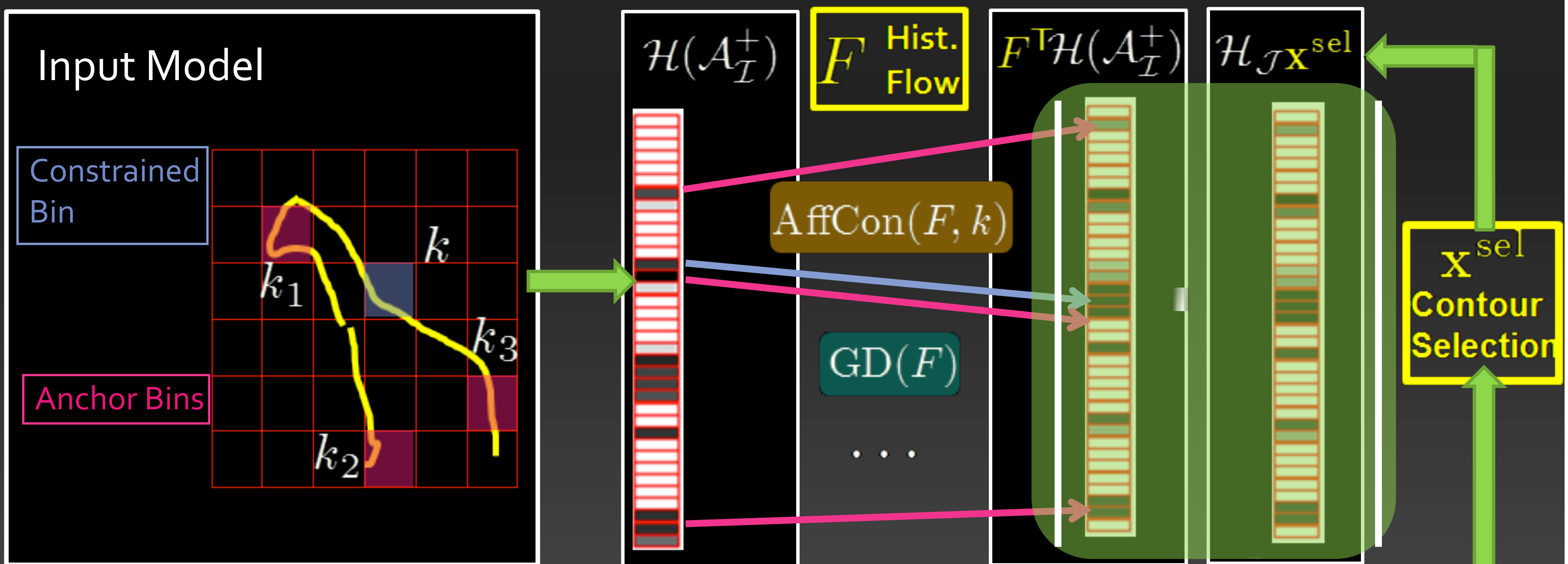
Foreground Segmentation

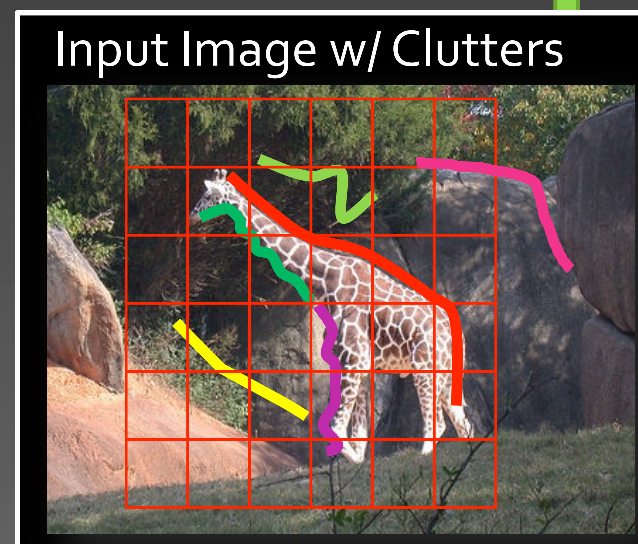


Algorithm Overview



Algorithm Overview





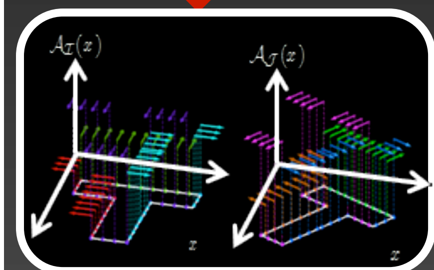
Constrained Histogram Flow

$$\min_{F,\mathbf{x}^{\mathrm{sel}}} \mathrm{GD}(F) + \lambda \sum_{k=1}^{m} \mathrm{AffCon}(F,k) + \gamma \left| F^{\mathsf{T}}\mathcal{H}(\mathcal{A}_{\mathcal{I}}^{+}) - \mathcal{H}_{\mathcal{J}}\mathbf{x}^{\mathrm{sel}} \right|_1$$

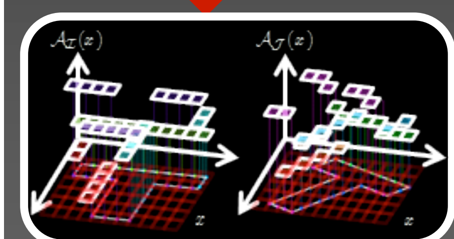
$$\text{s.t.} \quad F\mathbf{1} = \mathbf{1}, \quad F \geq 0, \quad \mathbf{x}^{\mathrm{sel}} \in [0,1]^{|\mathcal{C}|}$$

Image Deformation as Attribute Flow

$\mathbf{T}$?



$\mathcal{M}$?



F

Normalized Histogram Flow

Attribute Optical Flow

$$\min_{\mathbf{T}} \int_{\mathbf{R}^2} ||A_{\mathcal{I}}(x) - A_{\mathcal{J}}(\mathbf{T}(x))||_p dx$$

Attribute Flow

$$\min_{\mathcal{M}} \int_{\mathbf{R}^{n+2}} |\delta(y - \mathcal{M}(\mathcal{A}_{\mathcal{I}}^{+})) - \delta(y - \mathcal{A}_{\mathcal{J}}^{+})|_1 dy$$

Attribute Histogram Flow (LP)

$$\begin{aligned} \min_{F} \quad & |F^{\mathsf{T}}\mathcal{H}(\mathcal{A}_{\mathcal{I}}^{+}) - \mathcal{H}(\mathcal{A}_{\mathcal{J}}^{+})|_1 \\ \text{s.t.} \quad & F\mathbf{1} = \mathbf{1} \quad F \geq 0 \end{aligned}$$

Model Mass Preserving

Challenges

Q1: How to compute the spatial transformation efficiently without explicit search?

A : Attribute Histogram Flow.

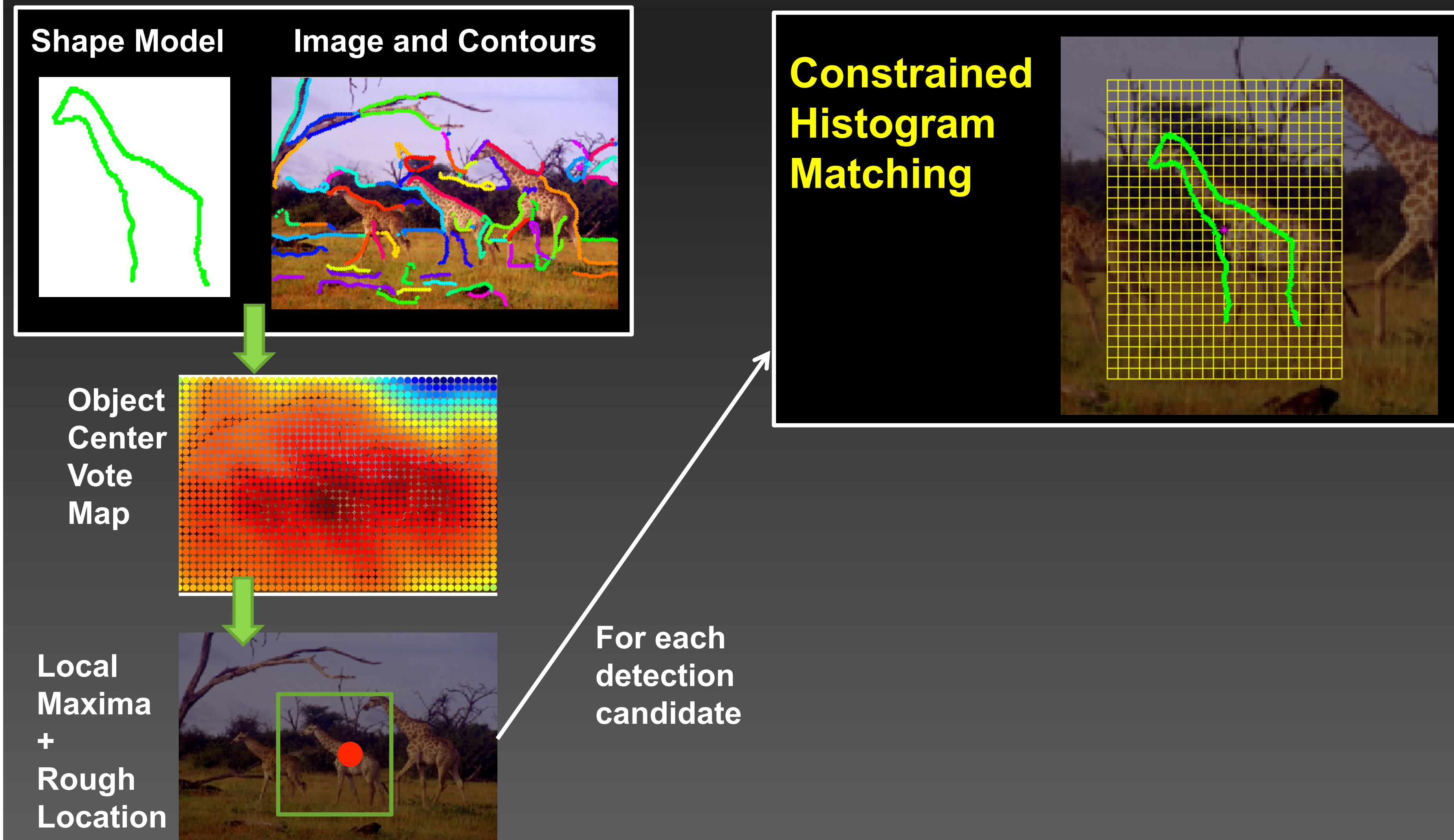
Q2: How to constrain the computation such that it leads to valid spatial transformation?

A : Soft Affine Constraint on expectation.

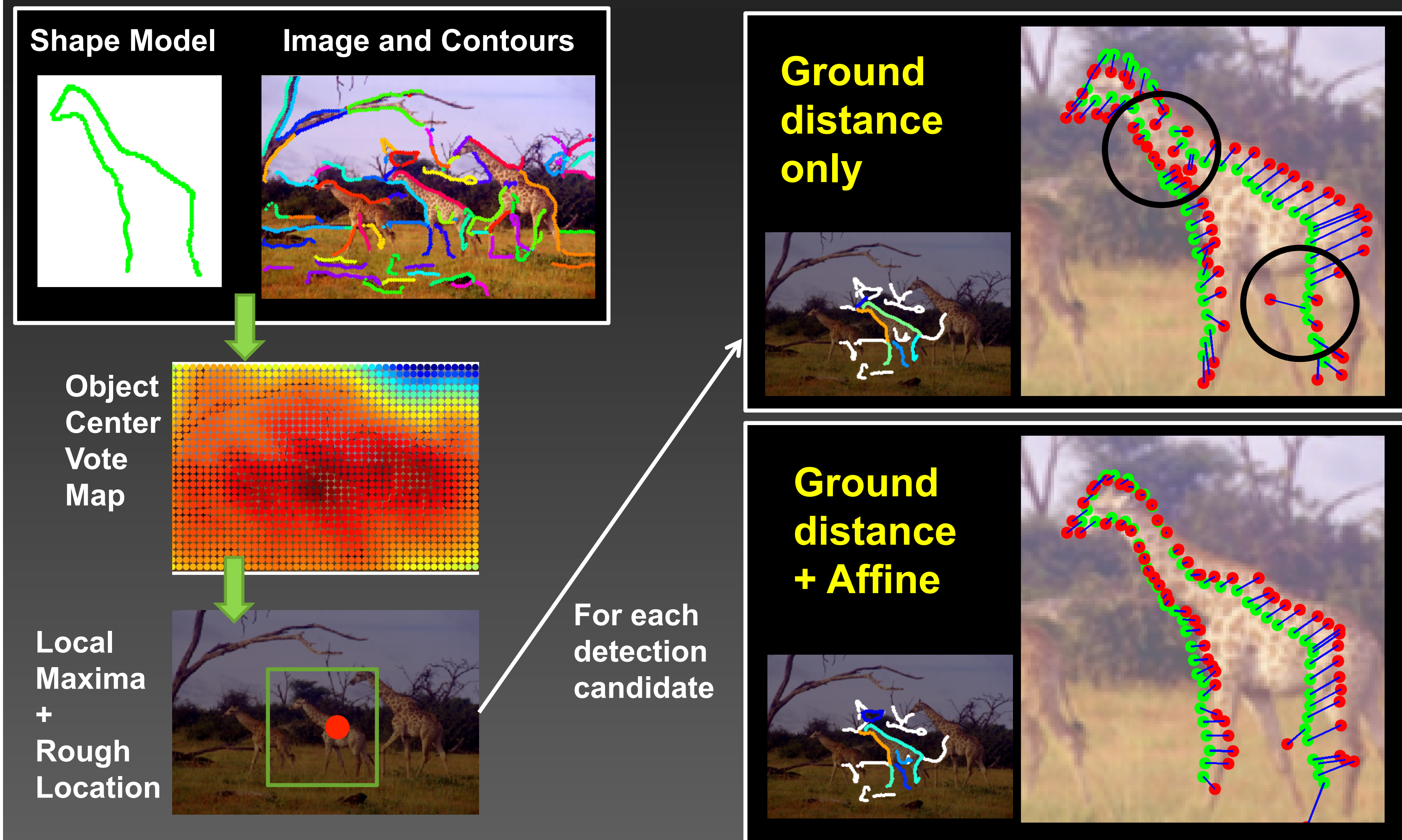
Q3: How to deal with clutter environment?

A : Contour Selection.

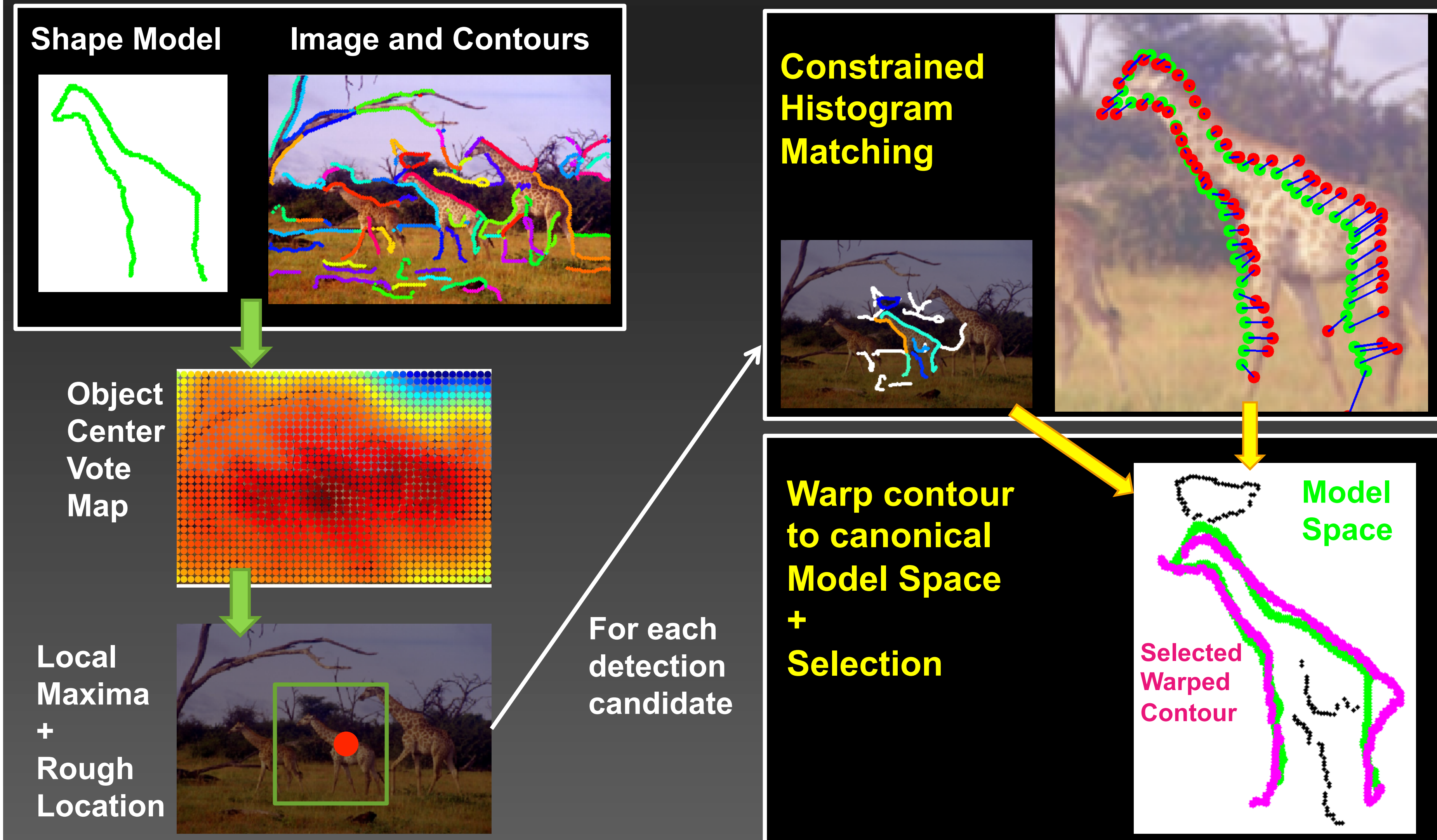
Detection Example



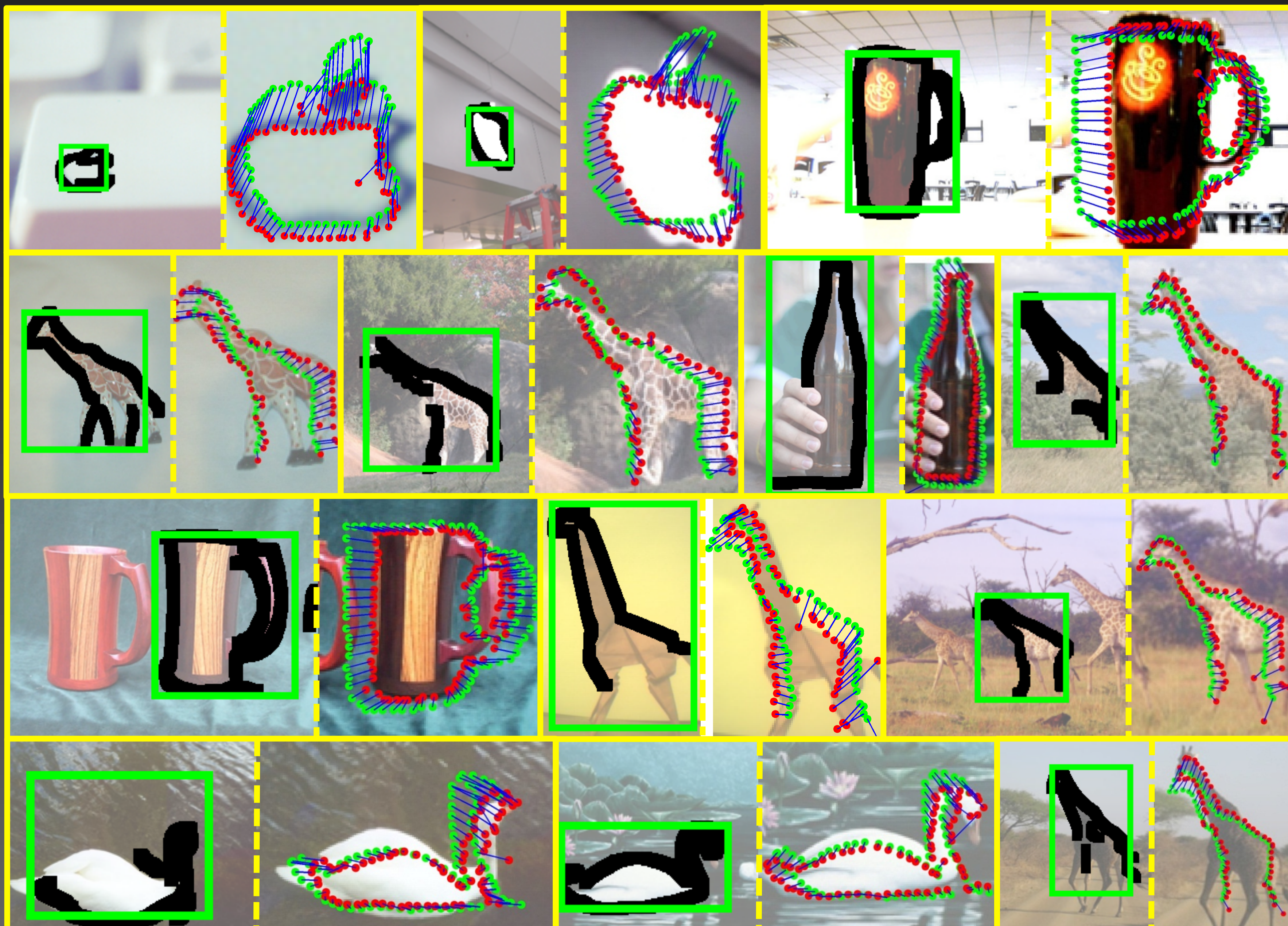
Detection Example



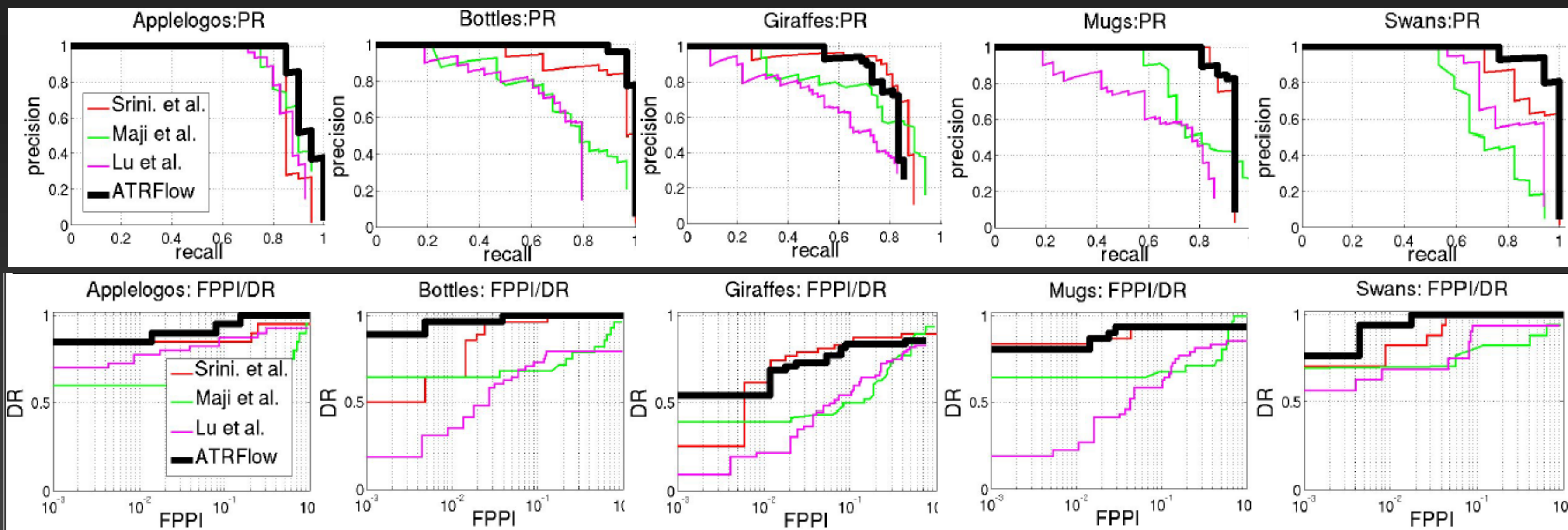
Discrimination in Canonical Space



Results on ETHZ



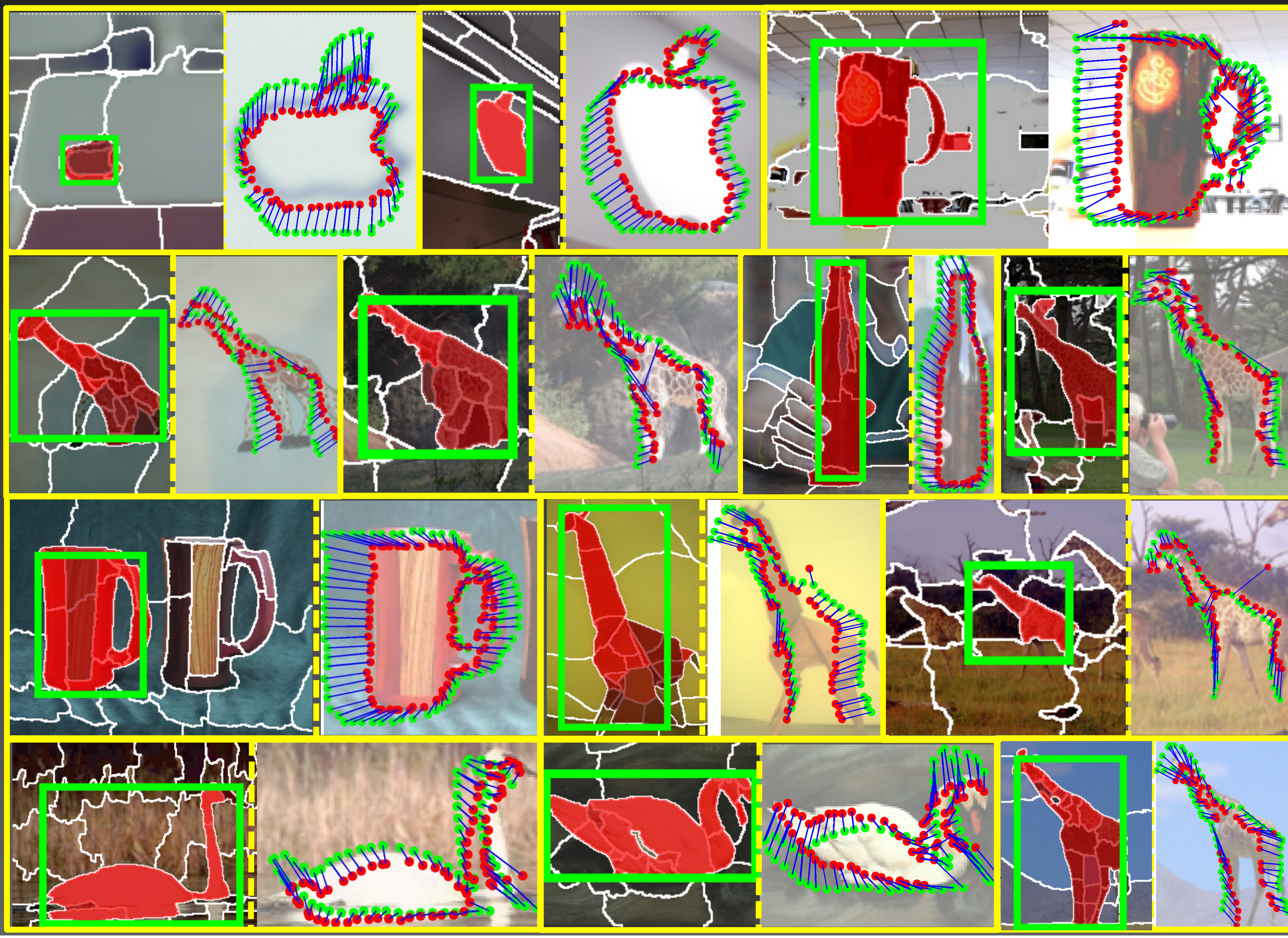
Quantitative Evaluation



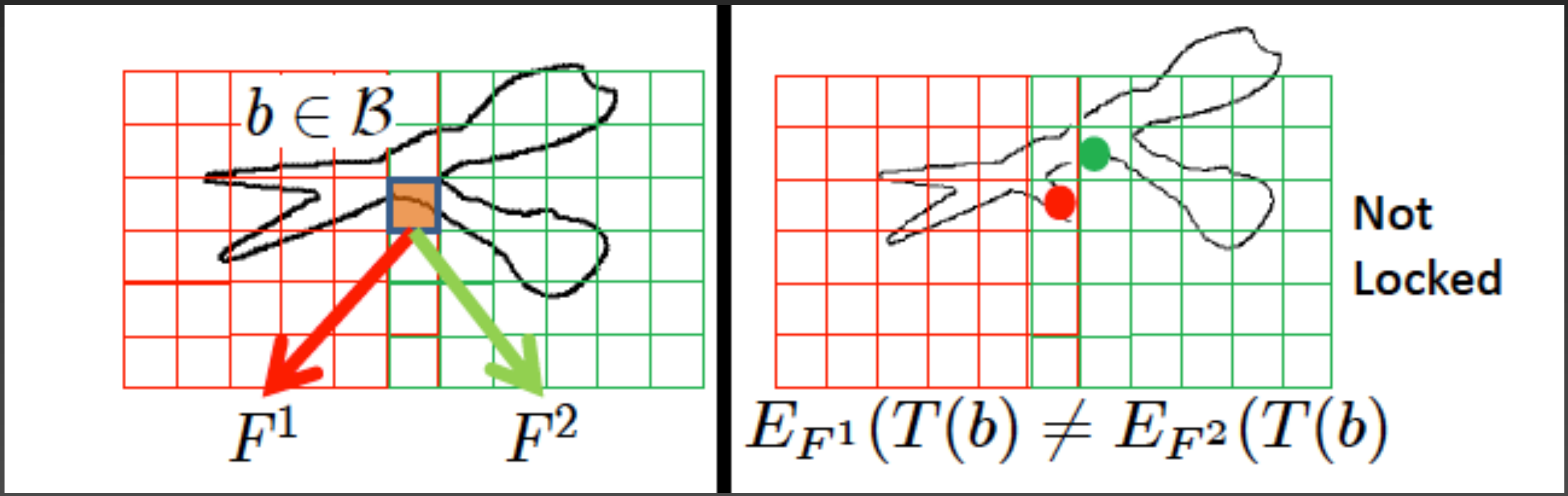
Average Precision

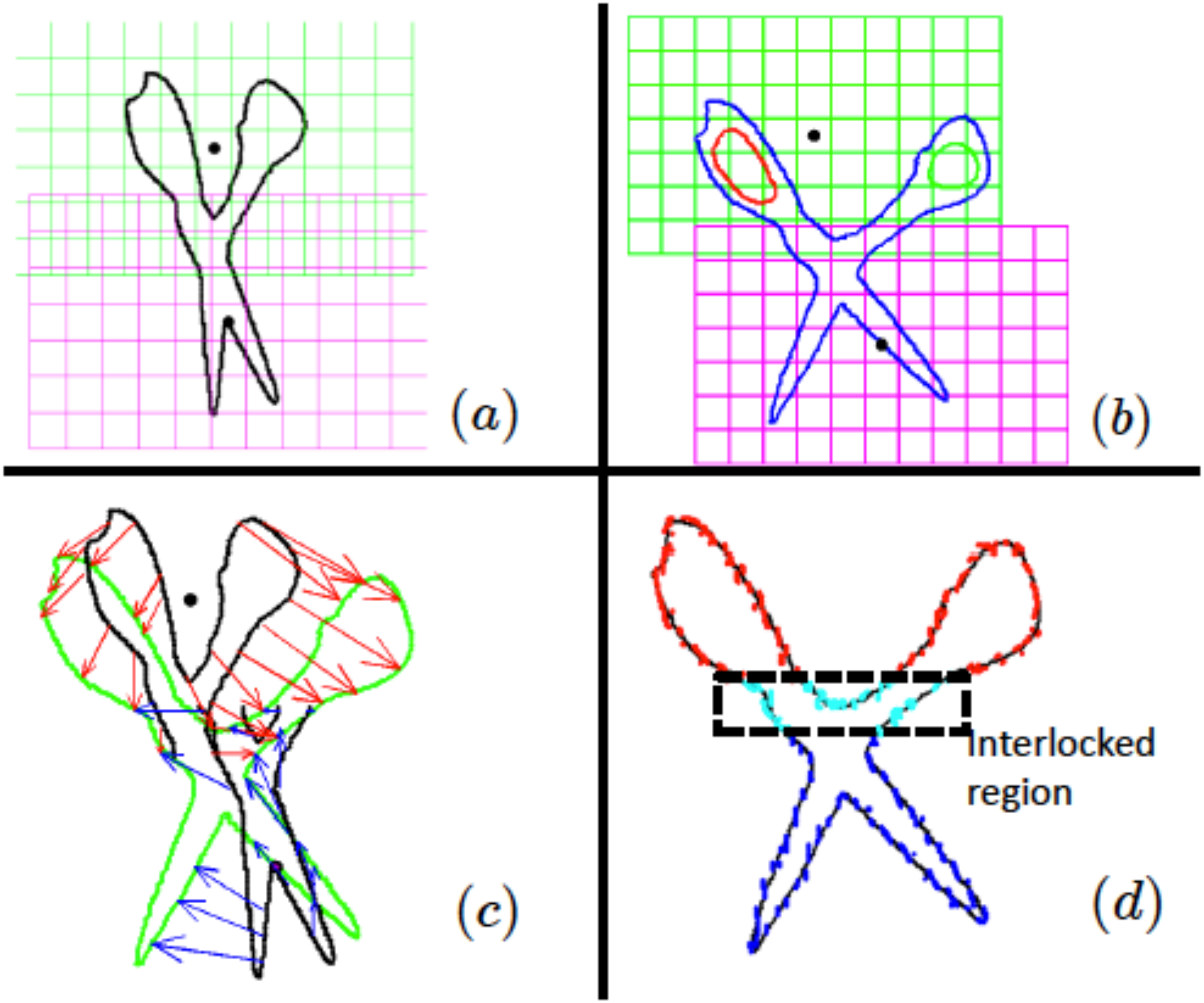
	Applelogos	Bottles	Giraffes	Mugs	Swans	**Mean**
Attribute Flow	0.930	0.977	0.783	0.895	0.972	0.911
Ma et al. [6]	0.881	0.920	0.756	0.868	0.959	0.877
Srini. et al. [10]	0.845	0.916	0.787	0.888	0.922	0.872
Maji et al. [7]	0.869	0.724	0.742	0.806	0.716	0.771
Lu et al. [5]	0.844	0.641	0.617	0.643	0.798	0.709
Toshev et al.§ [12]	0.983	0.936	0.713	0.718	0.973	0.865

Results on ETHZ using Segments

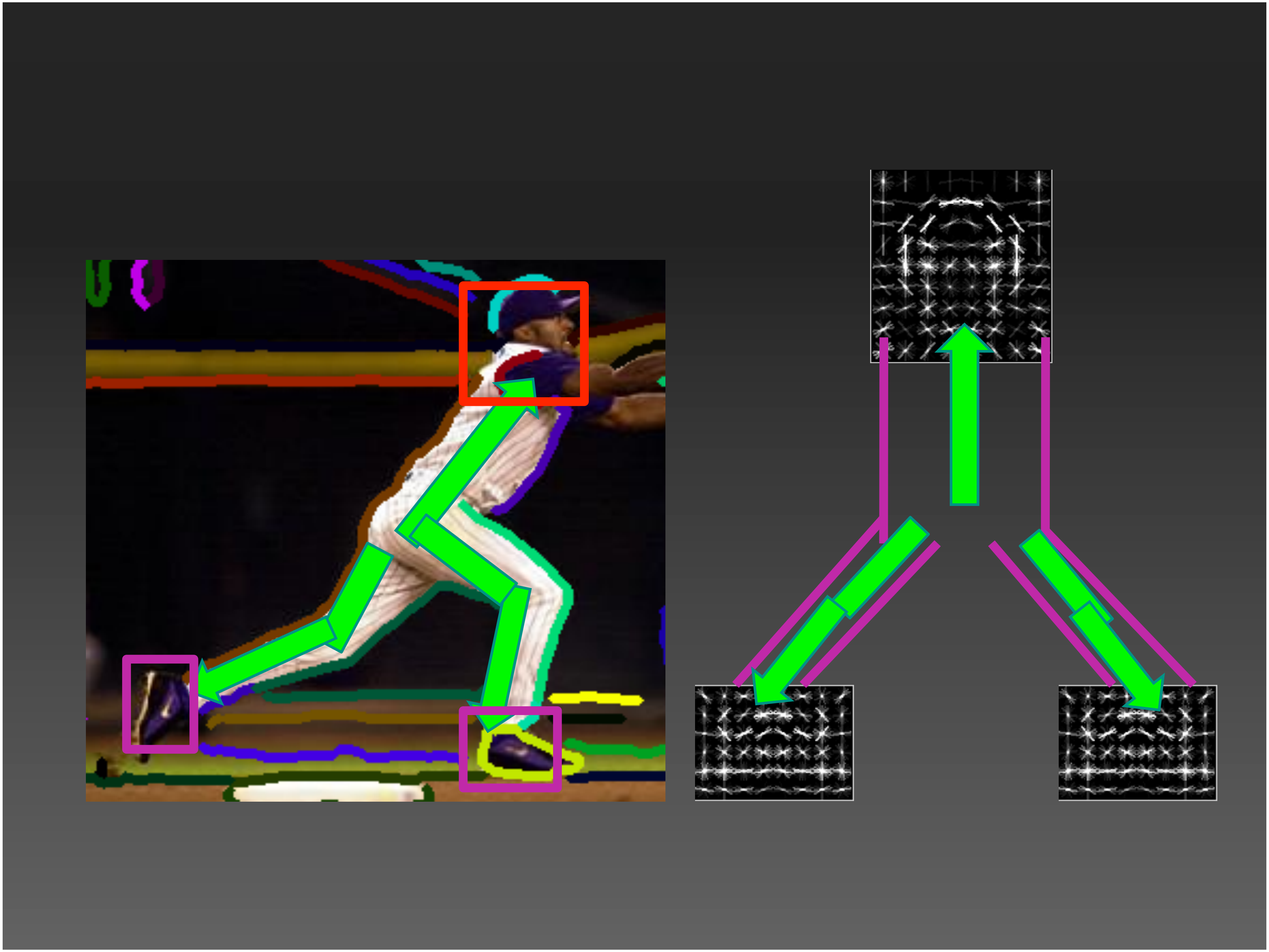


Piecewise affine Attribute Flow:





(a)
(b)
(c)
(d)
Interlocked region



	Head	Hips	Knees	Ankles	Mean
Attribute Flow	**12**	**27**	**24**	**27**	**26.5**
Zhu et al. [15]	N/A	N/A	N/A	N/A	30
Mykhaylo et al. [1]	24	36.5	43	71	47

$$
\begin{tikzcd}
\mathcal{I}(x) \arrow[r, dashed, "T\text{: }\textit{Spatial Flow}"] \arrow[d] & \mathcal{J}(x) \arrow[d] \\
\mathcal{H}(\mathcal{I}) \arrow[r, "F\text{: }\textit{Attribute Flow}"'] & \mathcal{H}(\mathcal{J})
\end{tikzcd}
$$

$$T = T(F)$$