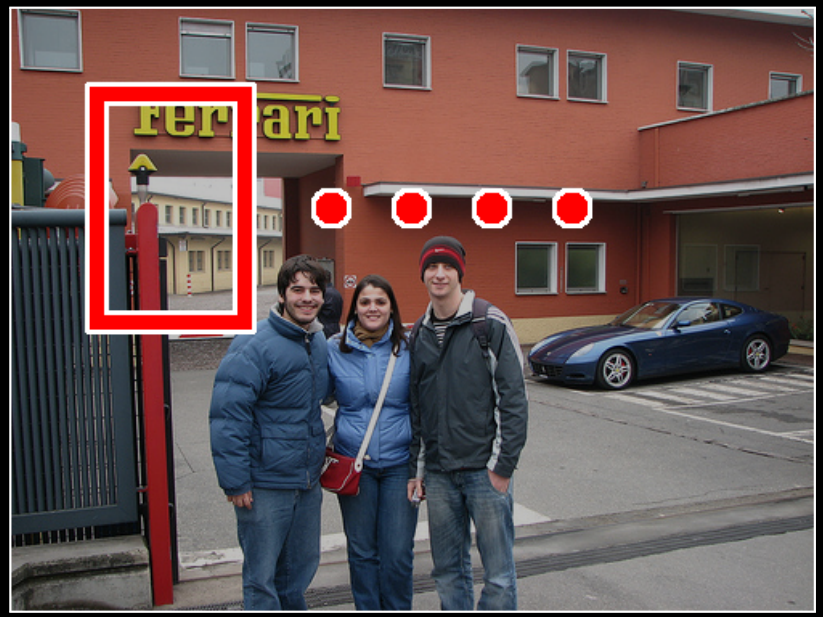
Object Detection and Segmentation from Joint Embedding of Parts and Pixels

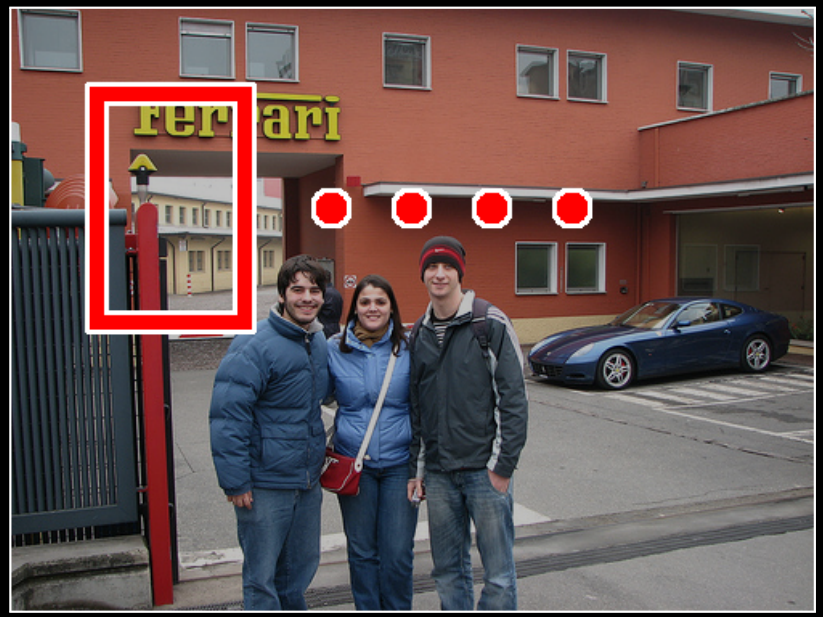
Michael Maire[1], Stella X. Yu[2], Pietro Perona[1]

[1]California Institute of Technology - Pasadena, CA 91125
[2]Boston College - Chestnut Hill, MA 02467

Segmentation



Detection



Segmentation

Detection

Perceptual Grouping Framework

Ingredients

Plug in state-of-the-art components:

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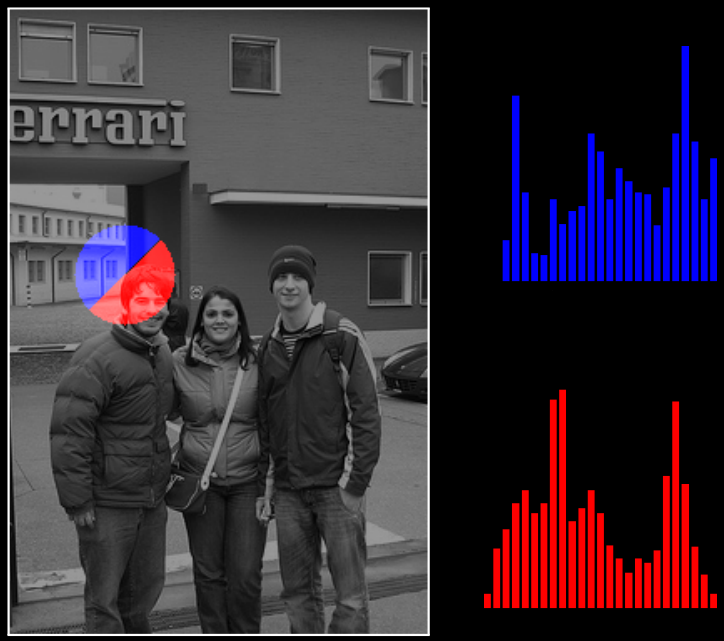

low-level cues:
color, texture, edges

[Arbeláez, Maire, Fowlkes, Malik, PAMI 2011]

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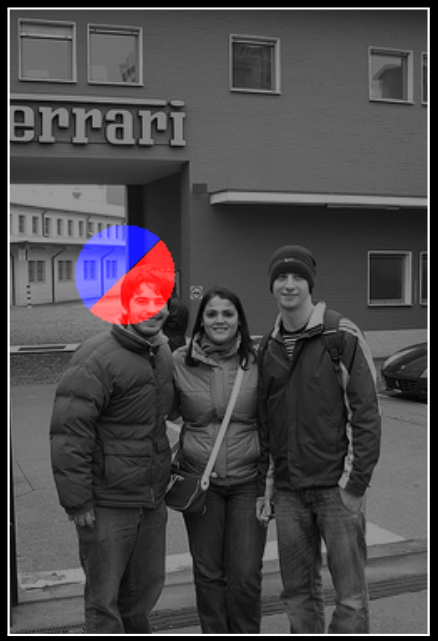

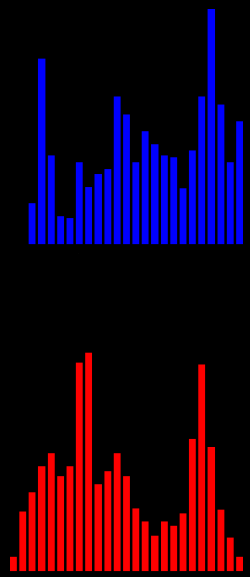

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poselets for person detection

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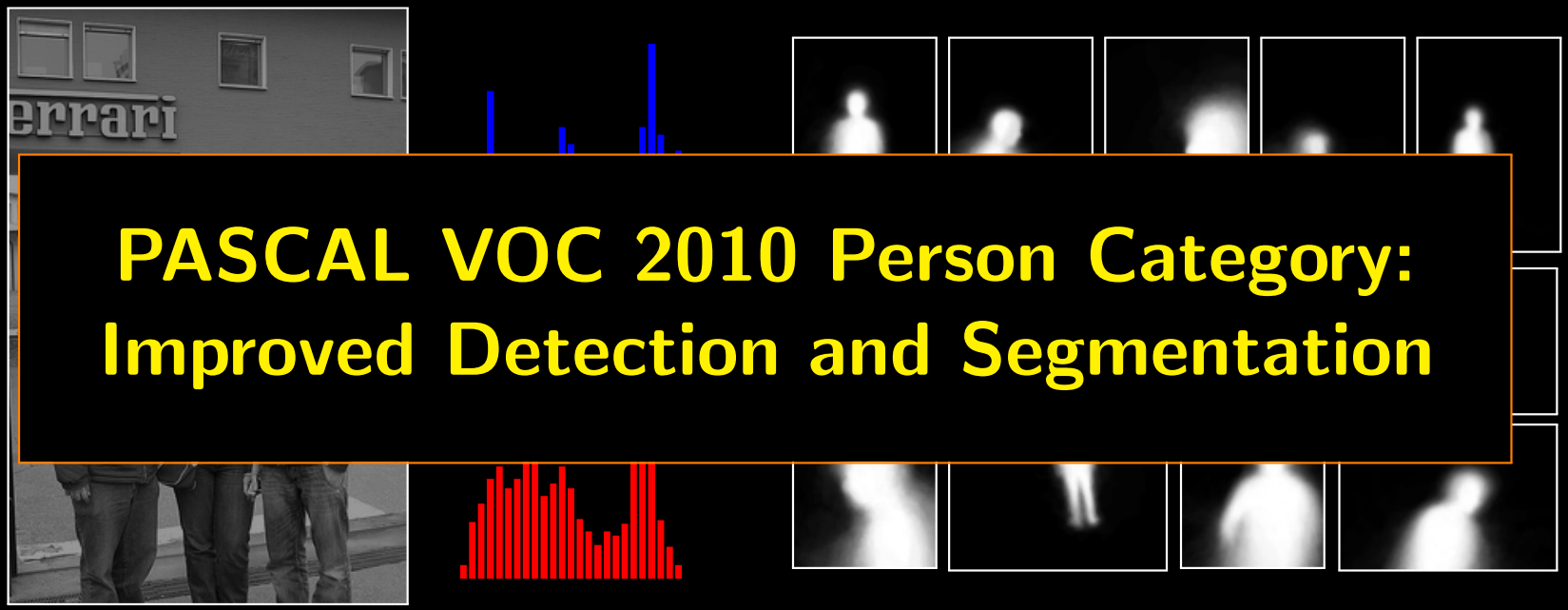

PASCAL VOC 2010 Person Category: Improved Detection and Segmentation

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[Arbeláez, Maire, Fowlkes, Malik, PAMI 2011]

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Grouping Relationships

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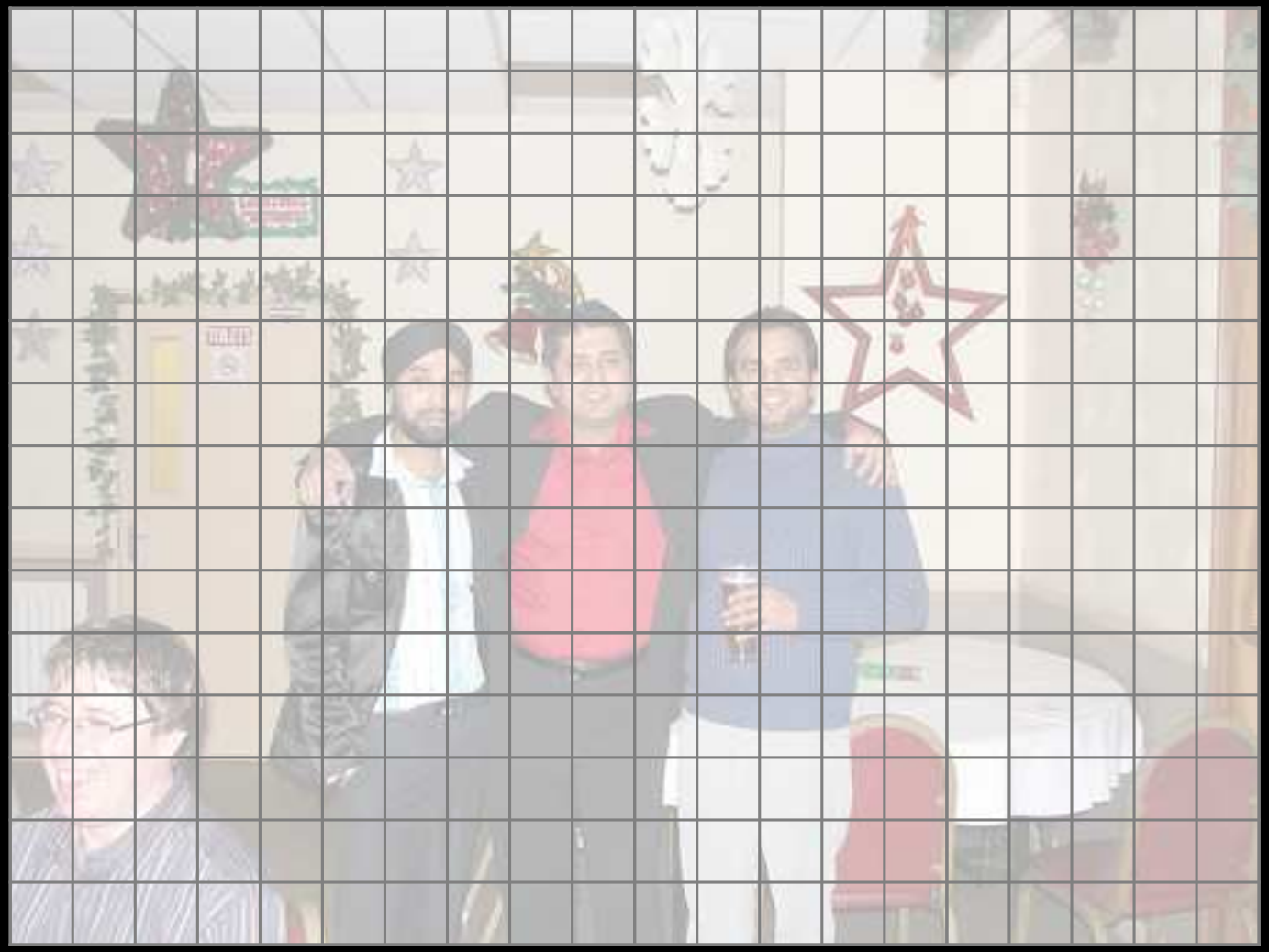
Pixel Affinity: Color, Texture Similarity



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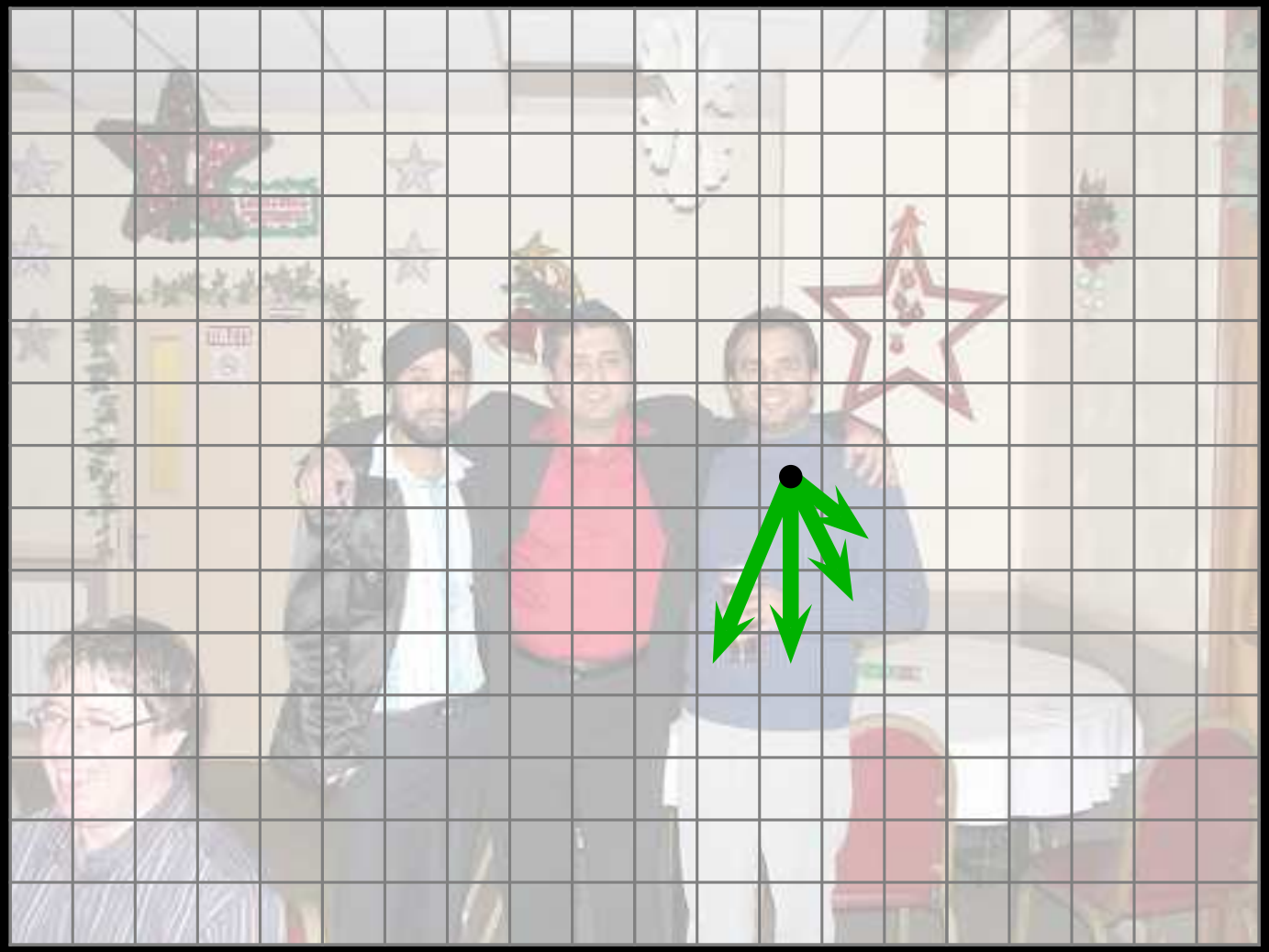

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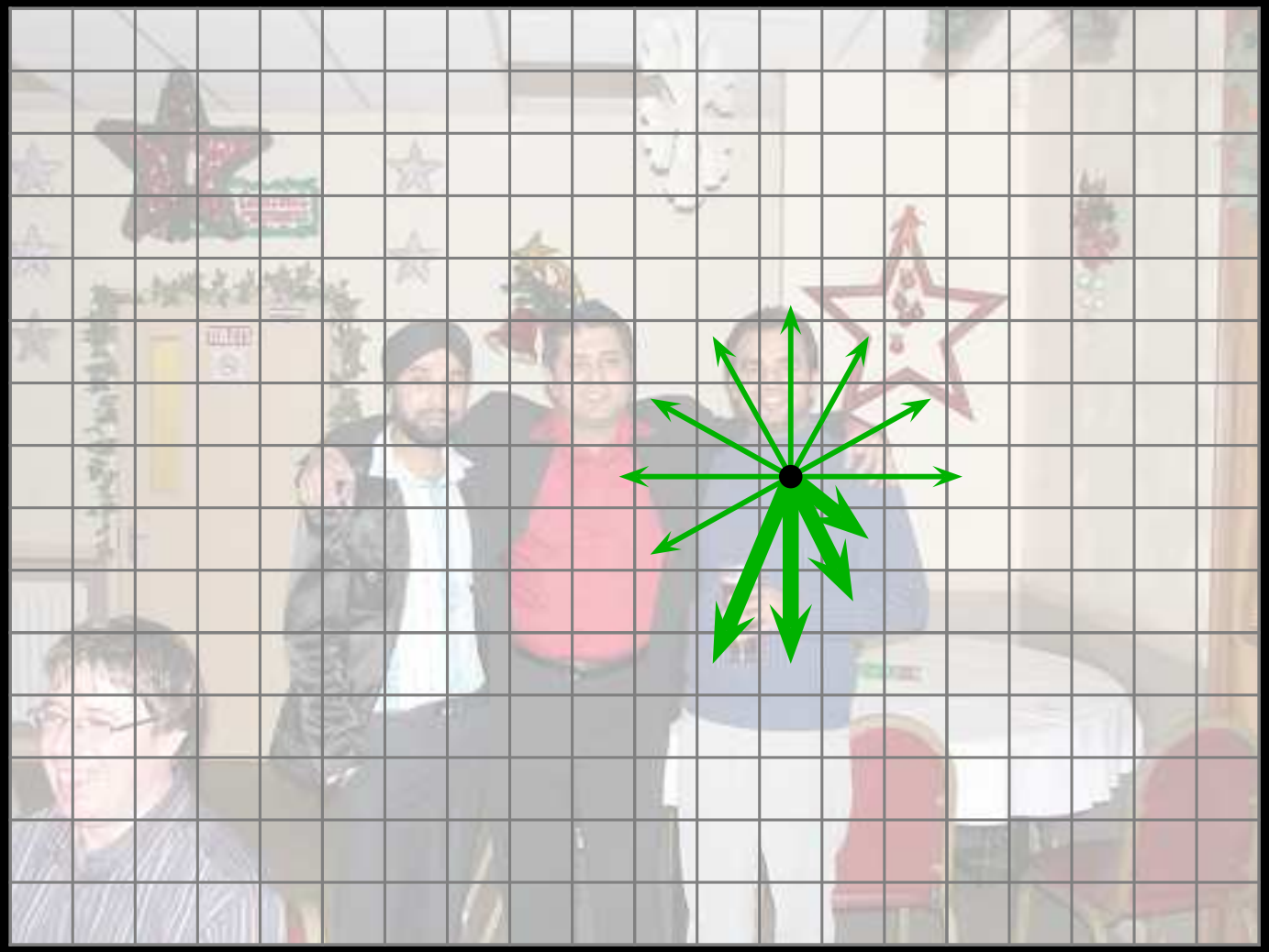
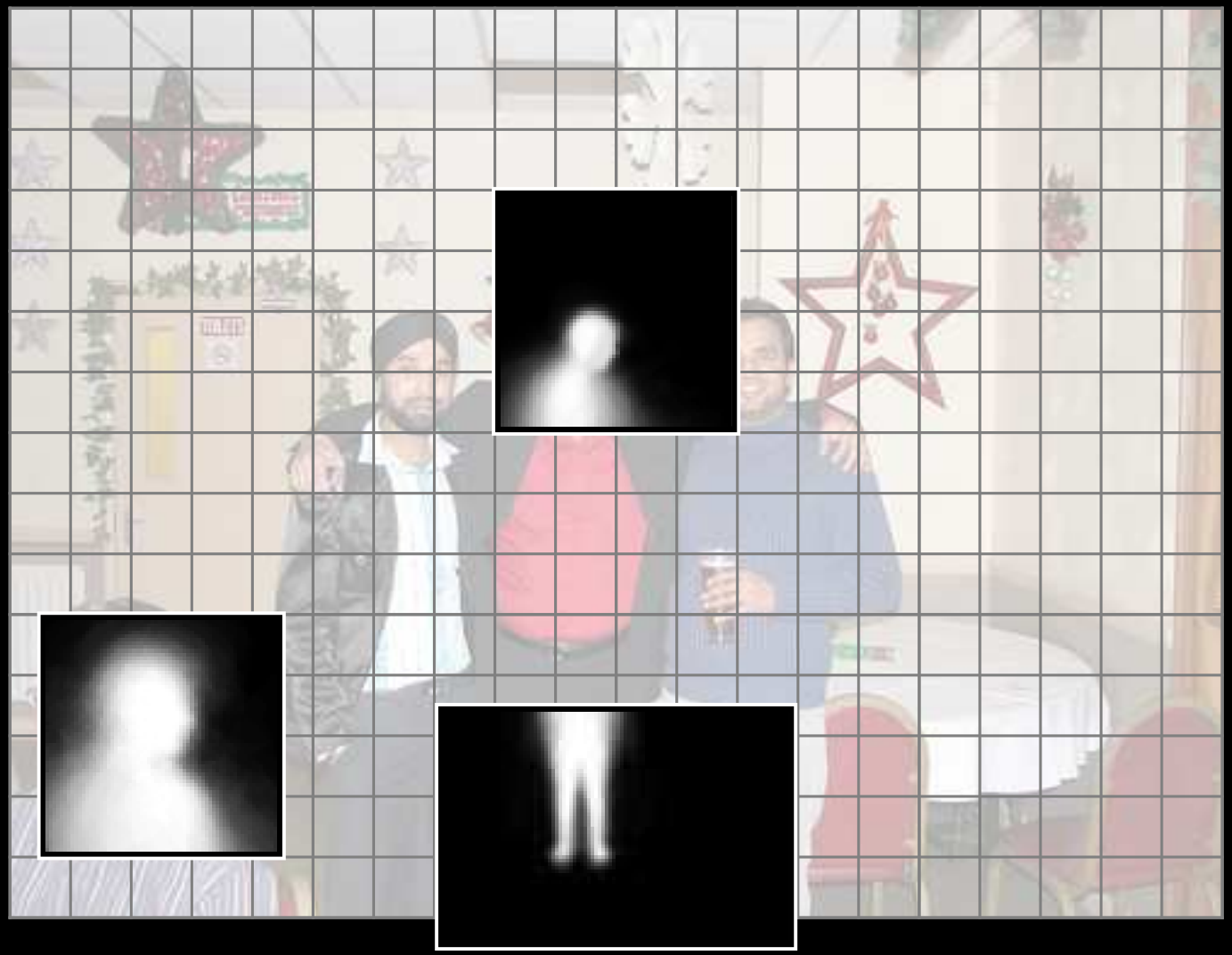


Part Affinity: Geometric Compatibility



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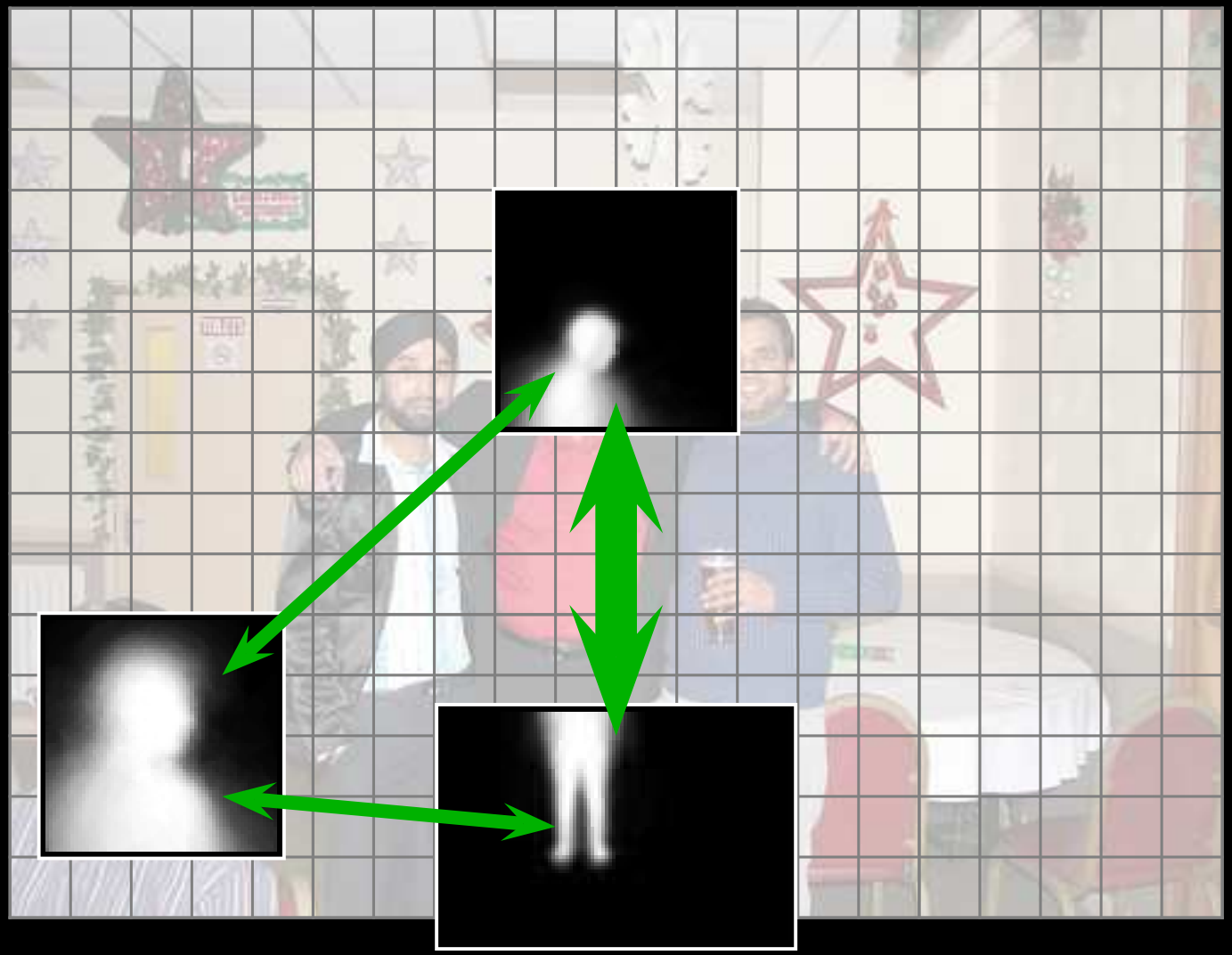
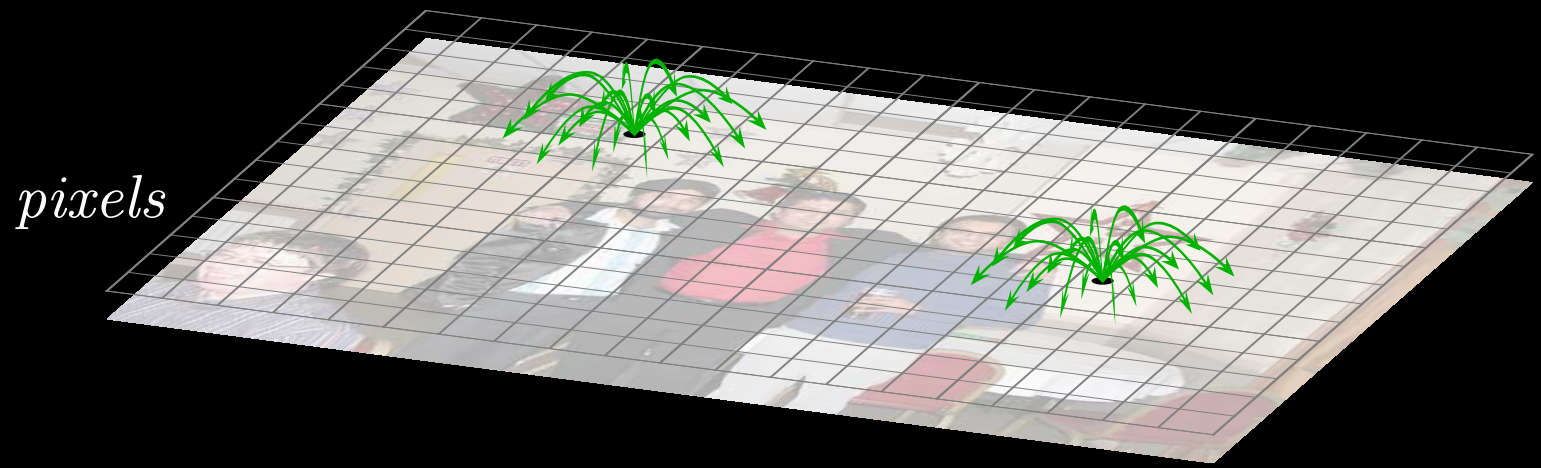
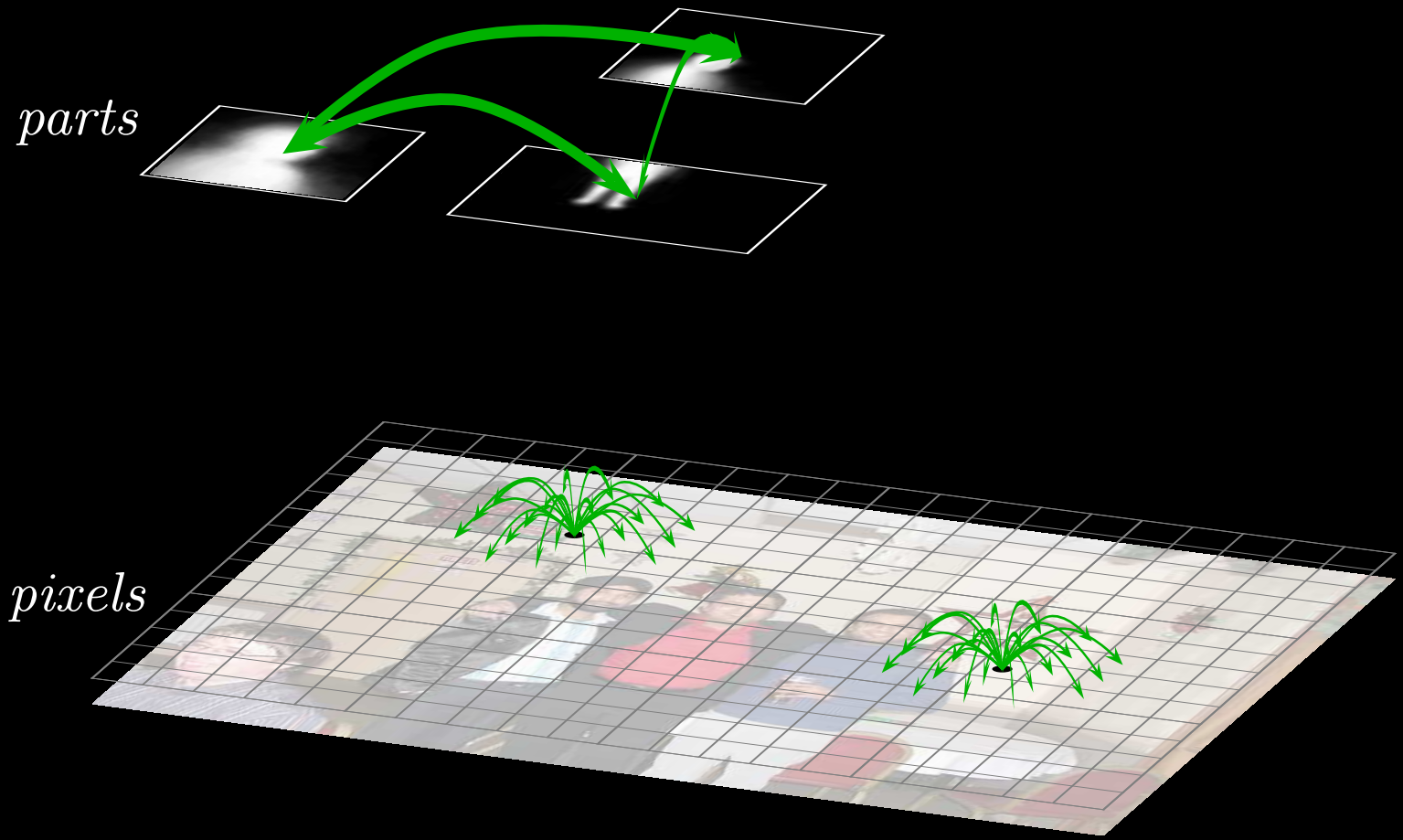



pixels


parts
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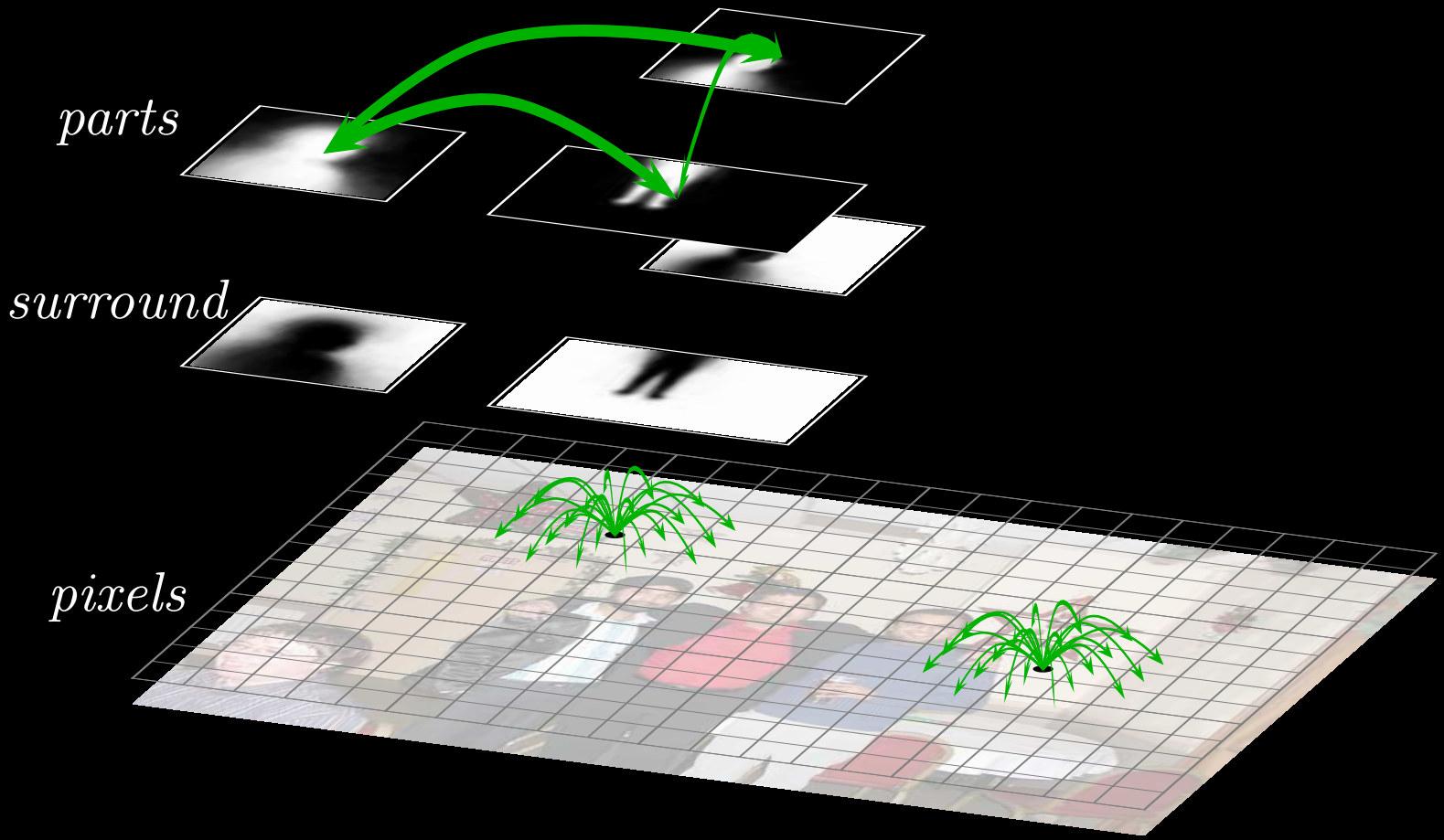
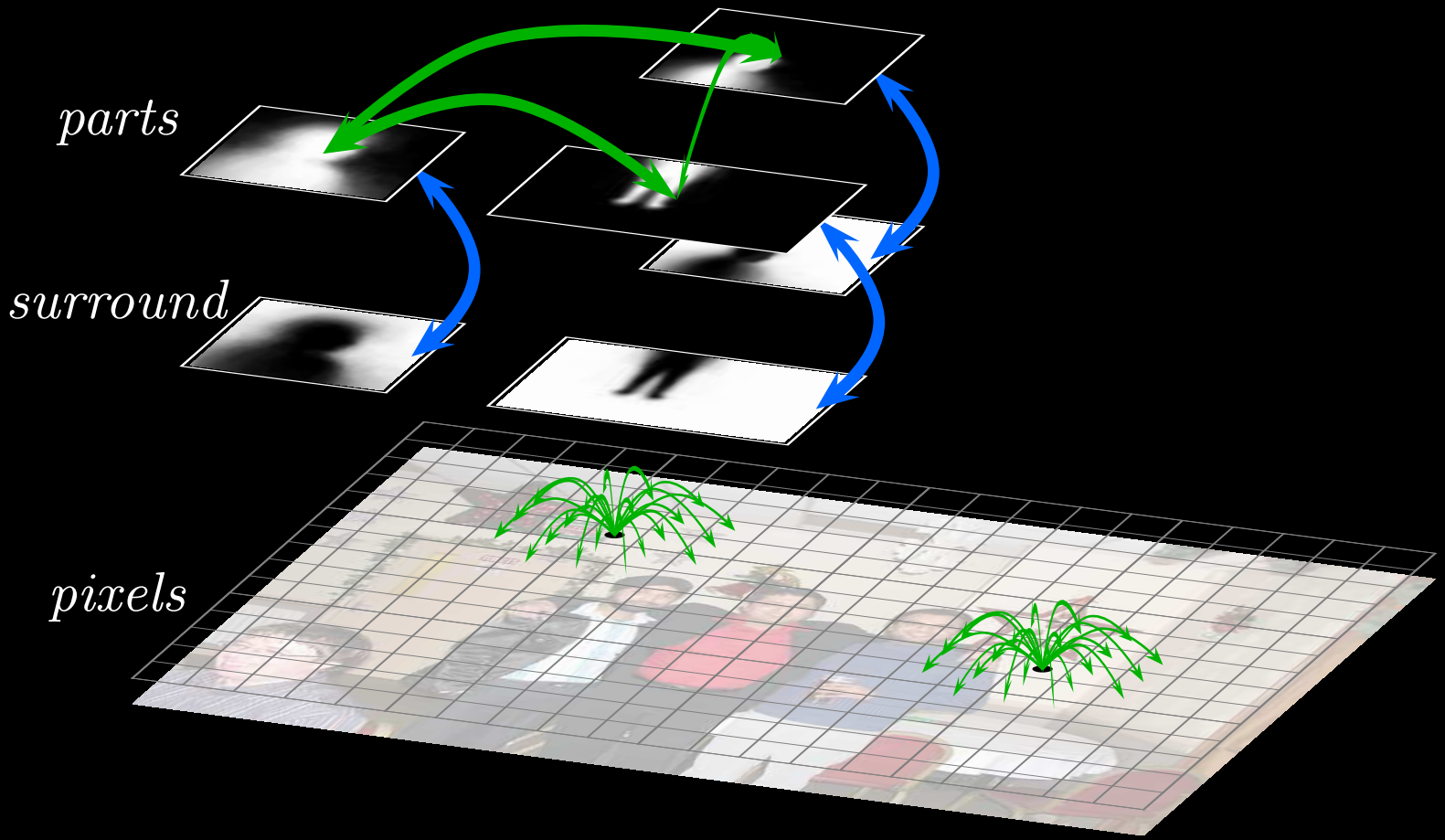

parts
surround
pixels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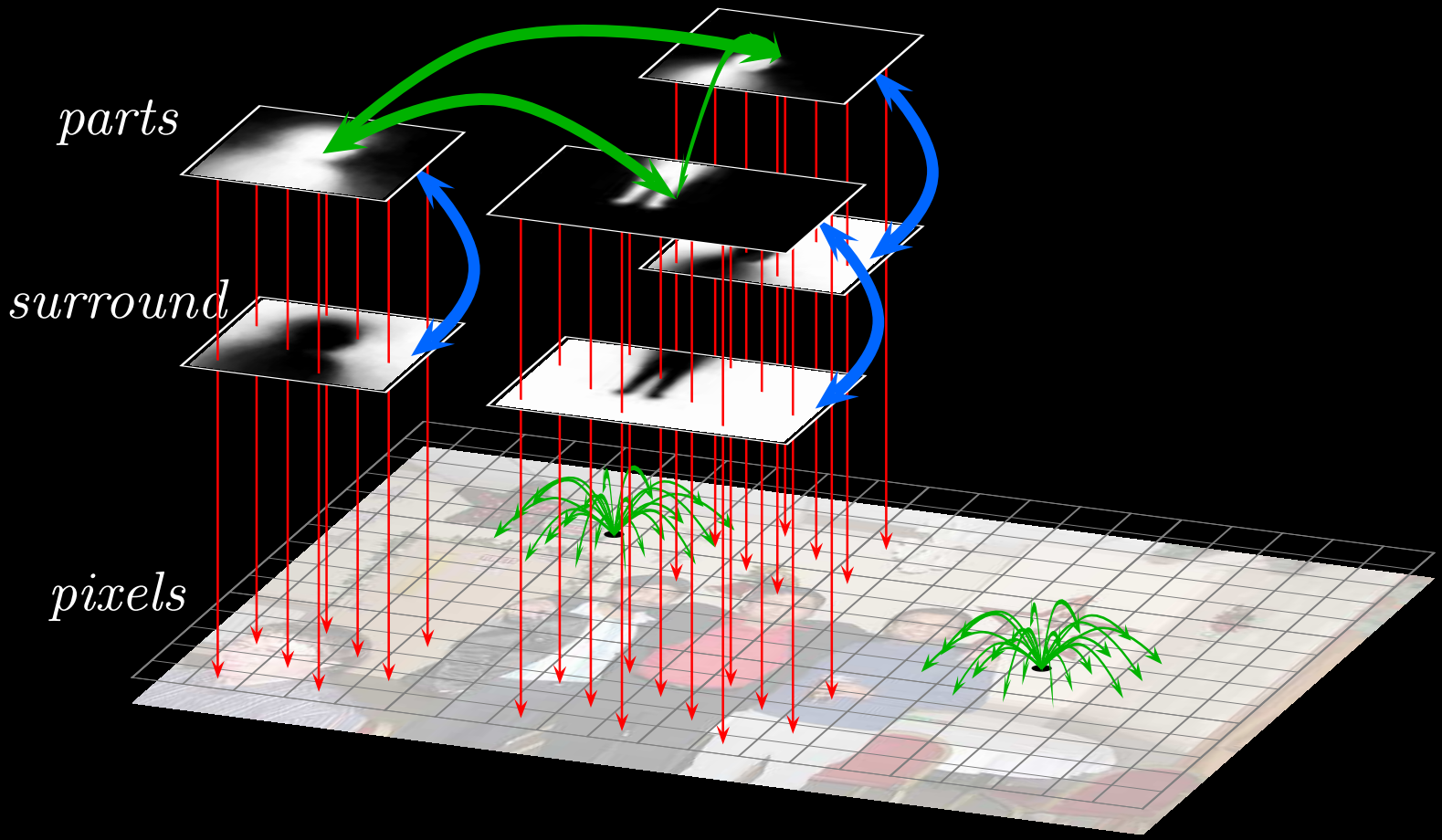
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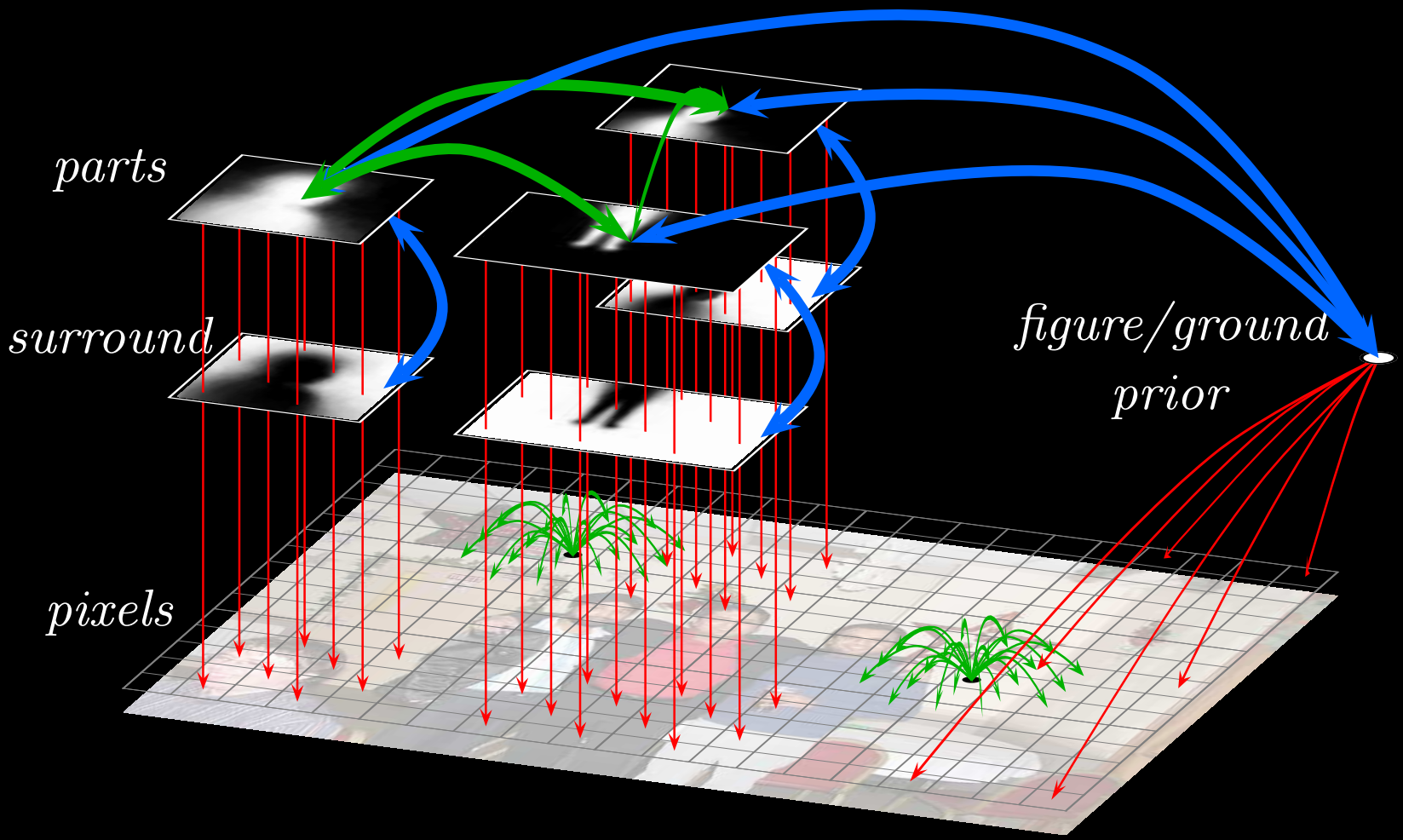
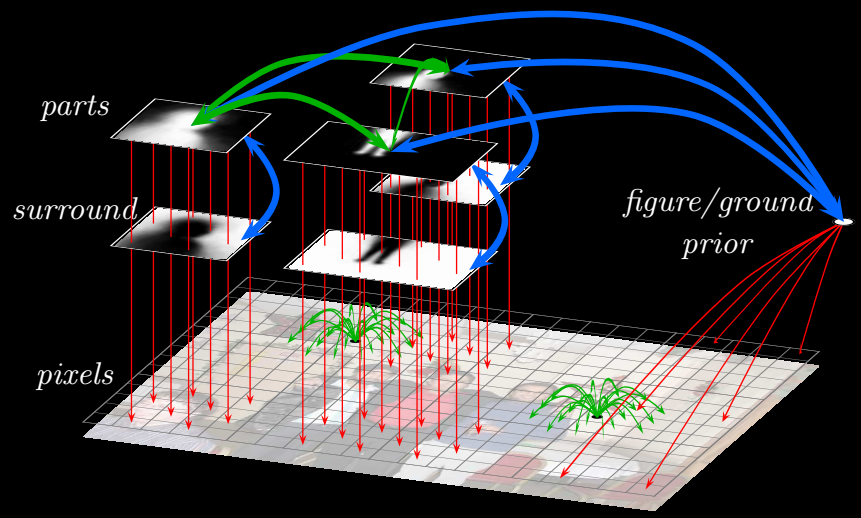

parts
surround
pixels
figure/ground
prior

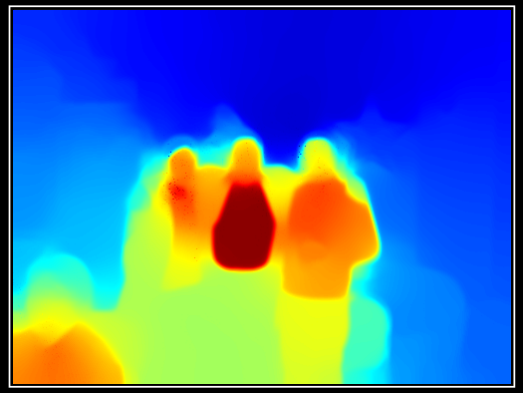


⇓

Angular Embedding

⇓ ⇓ ⇓

objects



figure/ground

segmentation

Angular Embedding

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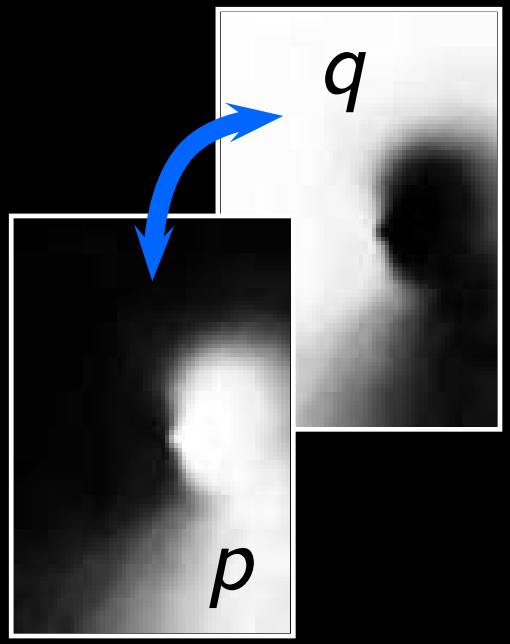

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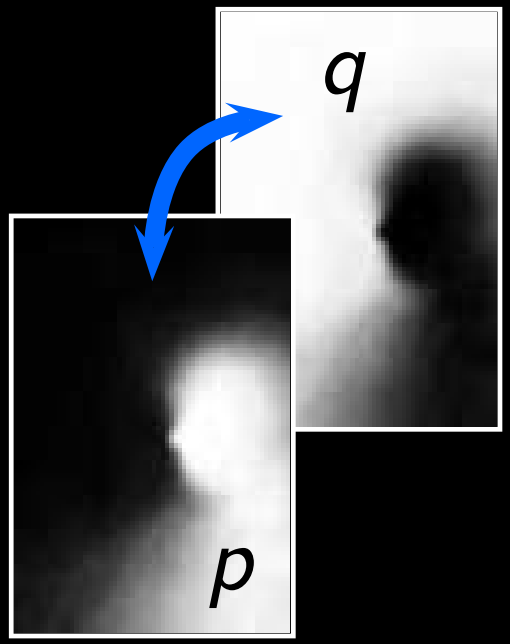
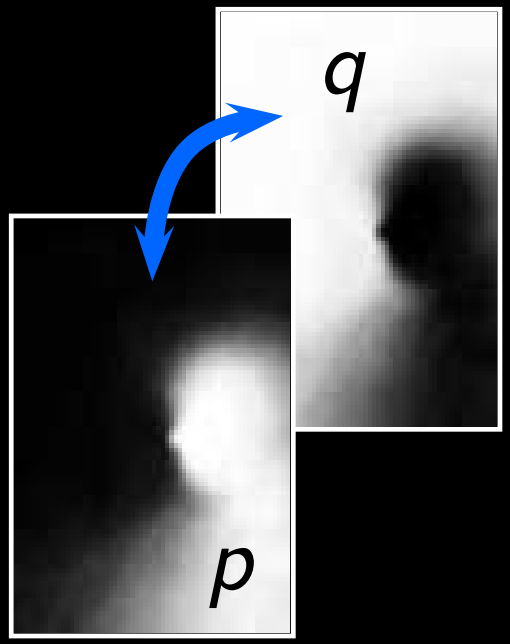


Given:

- Relative ordering $\Theta(\cdot, \cdot)$
- Confidence on relationships $C(\cdot, \cdot)$

Angular Embedding



Given:

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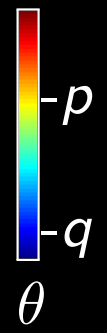
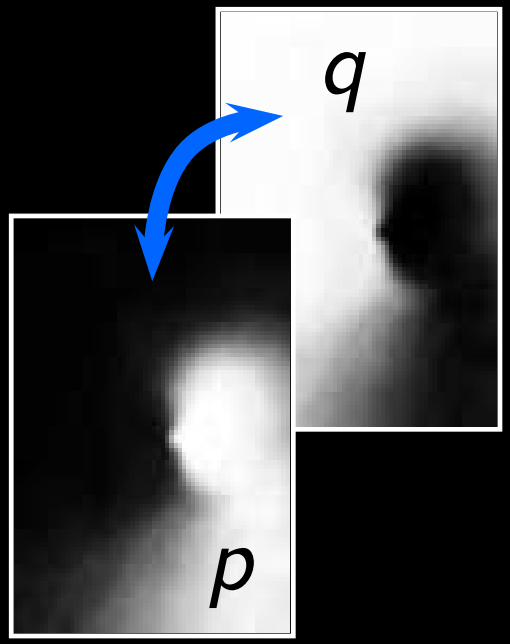
Compute:

- Global ordering $\theta(\cdot)$
- Embed into unit circle:

$$p \longrightarrow z(p) = e^{i\theta(p)}$$



Angular Embedding



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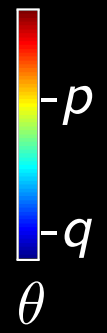
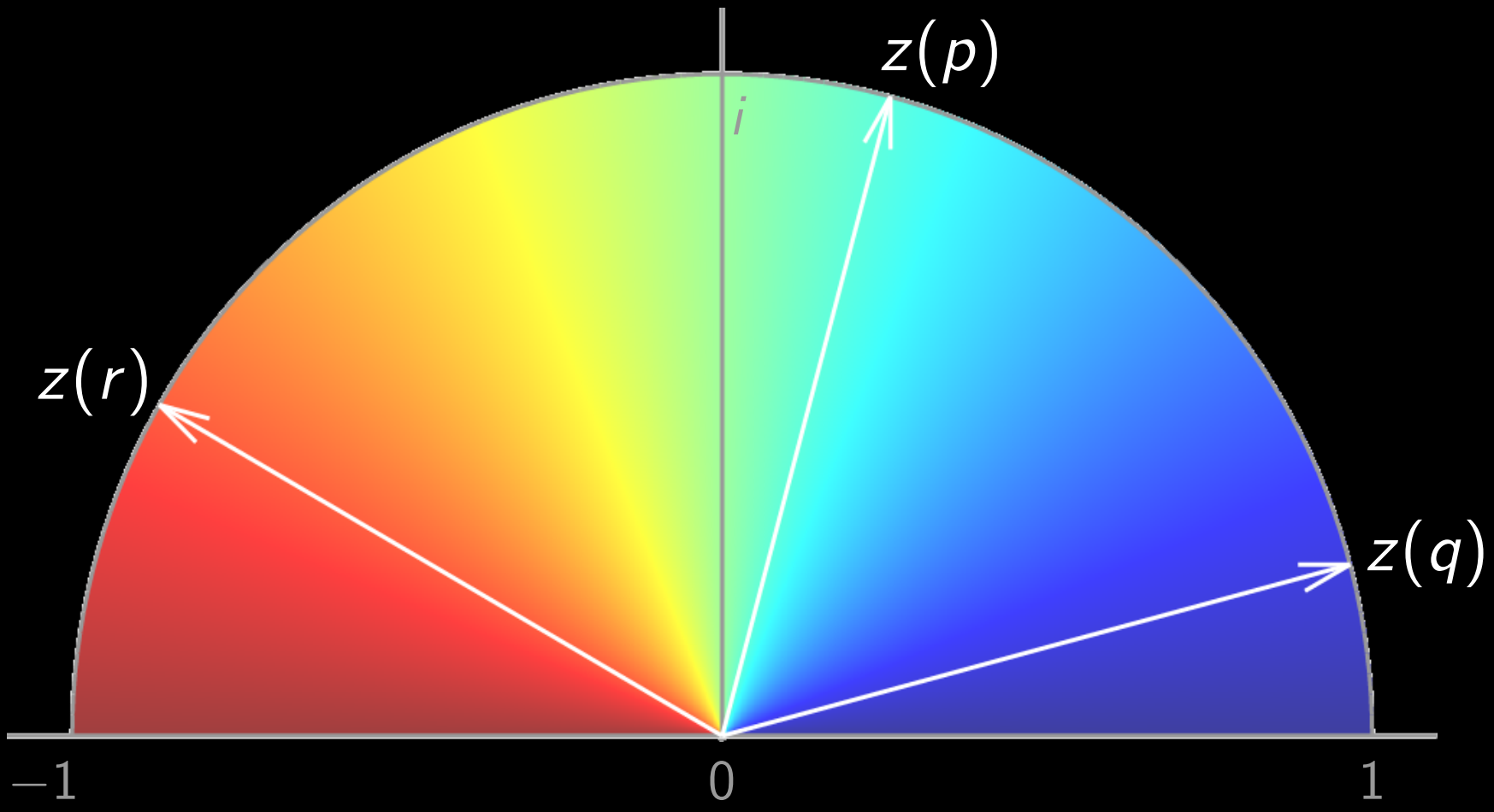
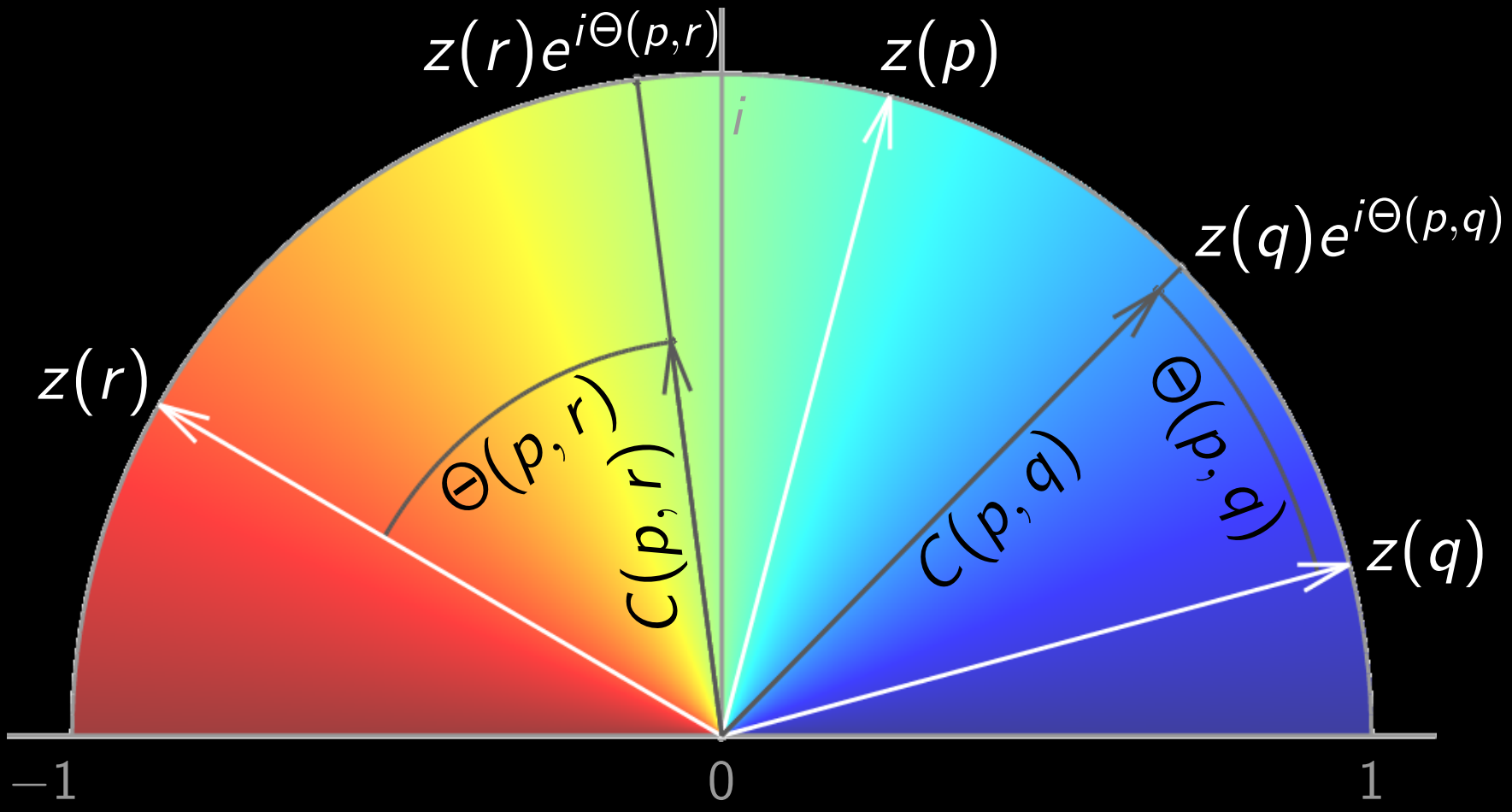


Subject to:

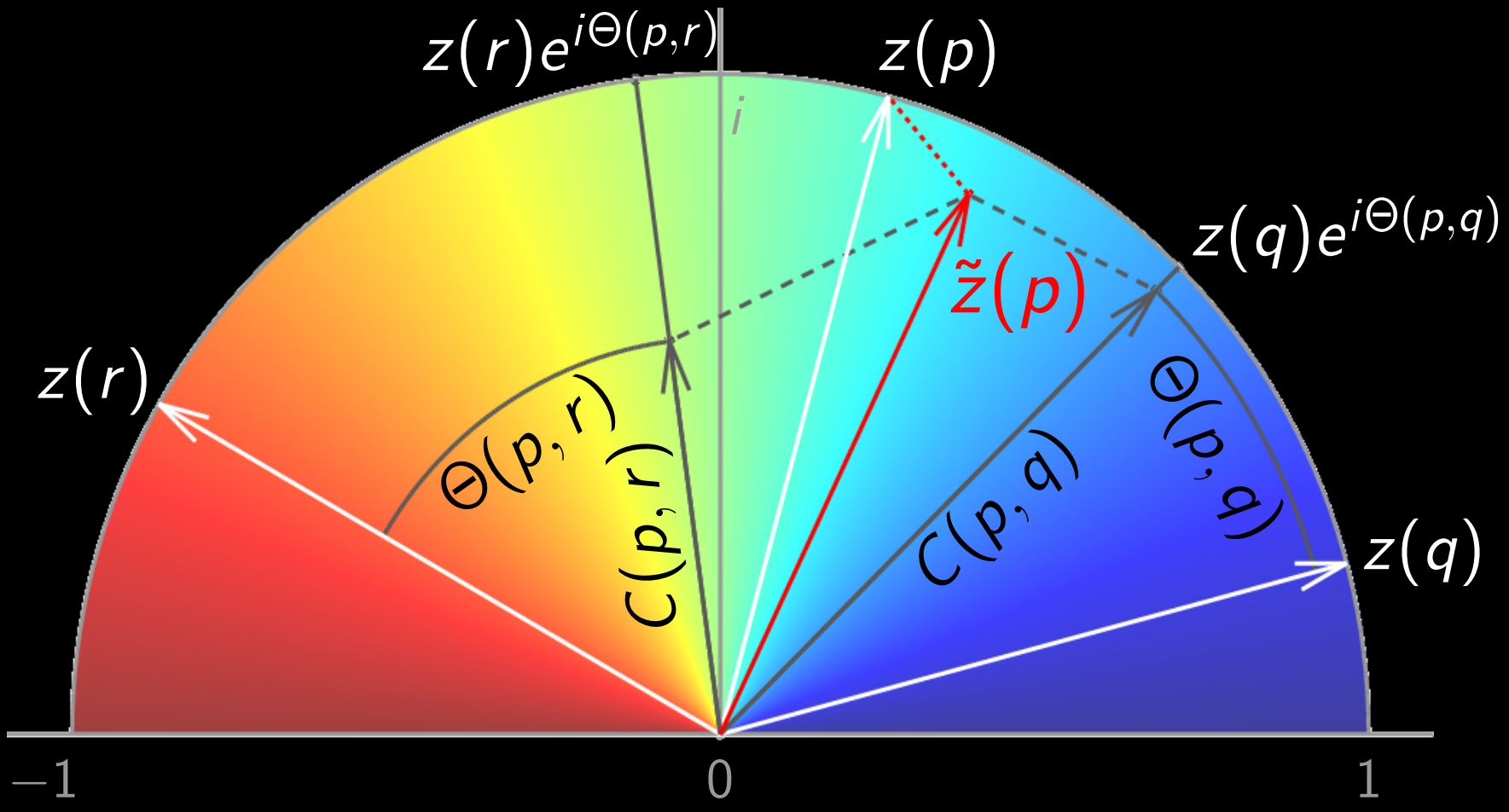
- Linear constraints on embedding solution in columns of U



[Yu, PAMI 2011]

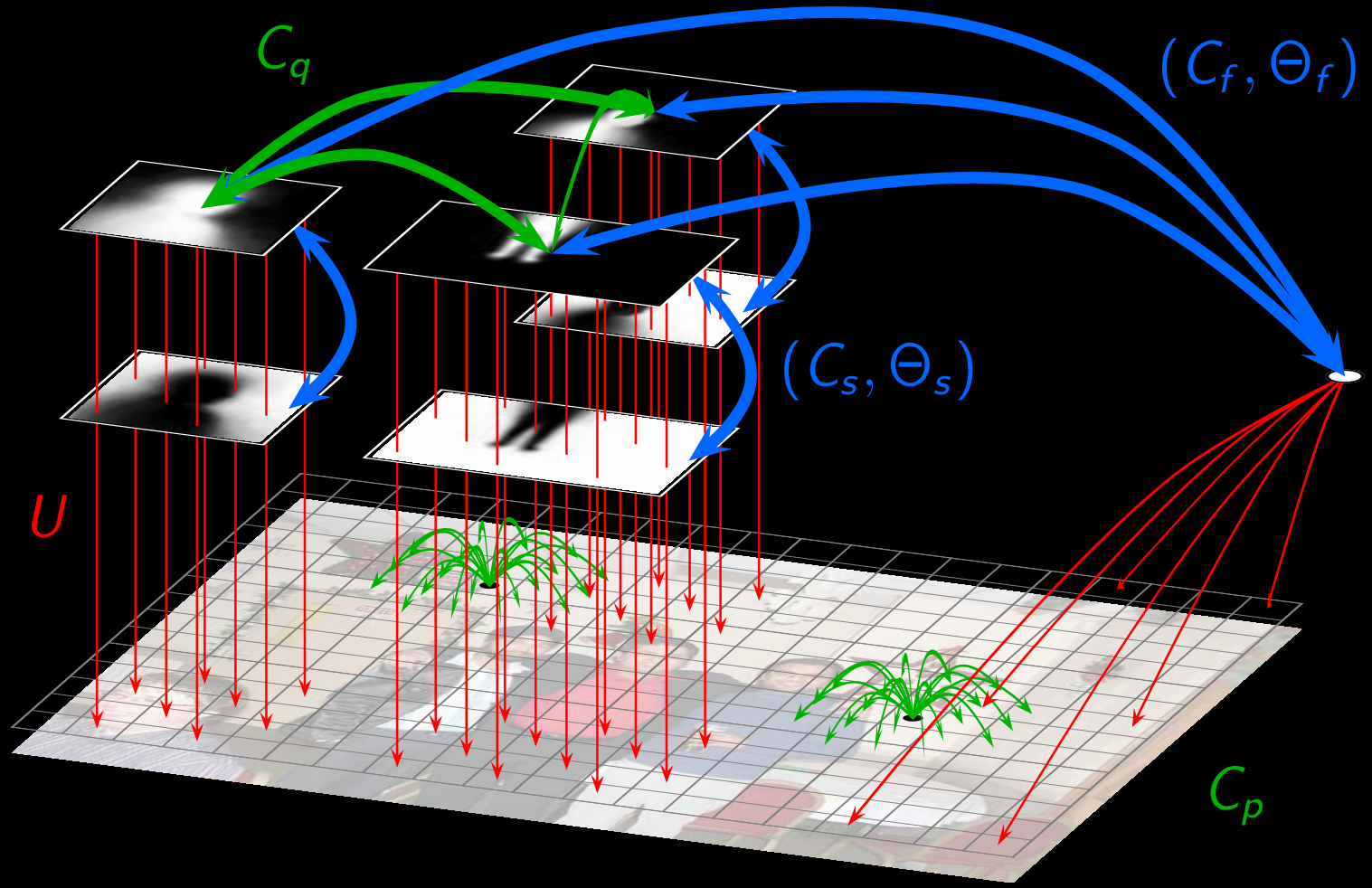

$z(r)e^{i\Theta(p,r)}$
$z(p)$
i
$z(q)e^{i\Theta(p,q)}$
$z(r)$
$\Theta(p,r)$
$C(p,r)$
$C(p,q)$
$\Theta(p,q)$
$z(q)$
-1
0
1

[Yu, PAMI 2011]



minimize: $\varepsilon = \sum_p \frac{\sum_q C(p,q)}{\sum_{p,q} C(p,q)} \cdot |z(p) - \tilde{z}(p)|^2$

[Yu, PAMI 2011]


C_q
(C_f, Θ_f)
(C_s, Θ_s)
U
C_p

$$
C = \begin{array}{c}
\begin{array}{cccc} \overbrace{}^{pixels} & \overbrace{}^{parts} & \overbrace{}^{surround} & \overbrace{}^{prior} \end{array} \\
\begin{bmatrix}
C_p & 0 & 0 & 0 \\
0 & \alpha \cdot C_q & \beta \cdot C_s & \gamma \cdot C_f \\
0 & \beta \cdot C_s^T & 0 & 0 \\
0 & \gamma \cdot C_f^T & 0 & 0
\end{bmatrix}
\end{array}
$$

$$
\Theta = \Sigma^{-1} \begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & \Theta_s & \Theta_f \\
0 & -\Theta_s^T & 0 & 0 \\
0 & -\Theta_f^T & 0 & 0
\end{bmatrix}
$$

Angular Embedding

Relax to generalized eigenproblem $QPQz = \lambda z$:

$$P = D^{-1}W$$
$$Q = I - D^{-1}U(U^T D^{-1}U)^{-1}U^T$$

with D and W defined as:

$$D = Diag(C1_n)$$
$$W = C \bullet e^{i\Theta}$$

Eigenvectors $\{z_0, z_1, ..., z_{m-1}\}$ embed pixels and parts into $\mathbb{C}^m$

Angular Embedding

$\angle z_0$ encodes global ordering

$z_1, z_2, \ldots, z_{m-1}$ encode grouping

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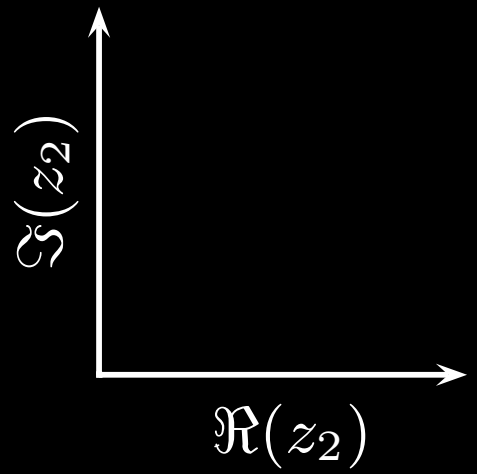
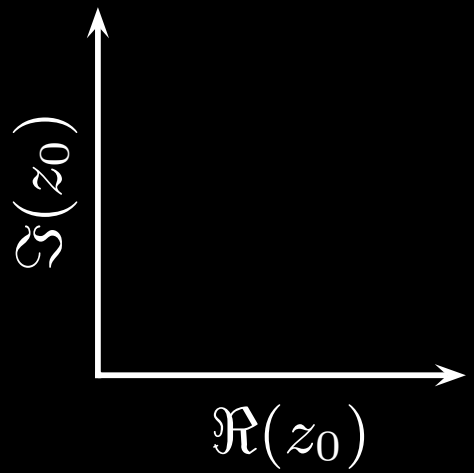
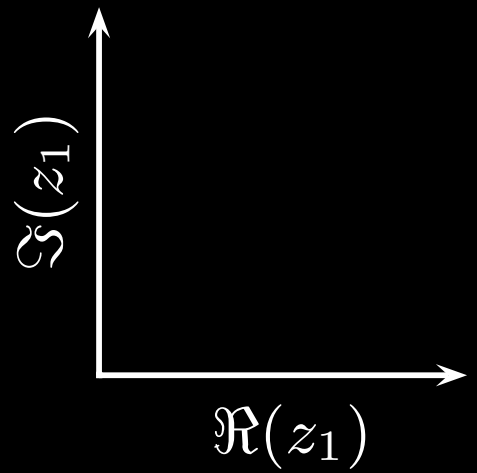
if $\Theta = 0 \quad \Rightarrow \quad$ Normalized Cuts
(grouping without ordering)

Decoding Eigenvectors: Object Detection







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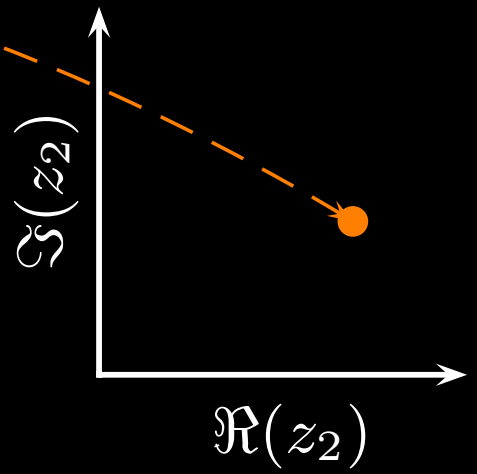

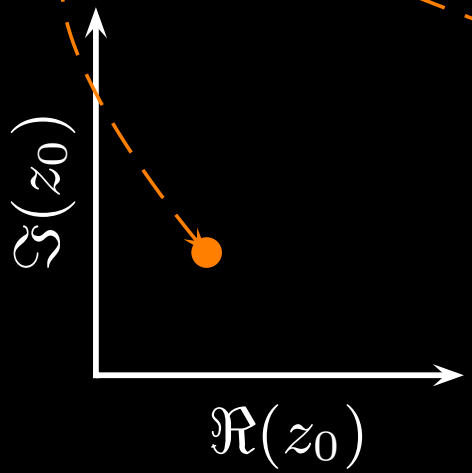

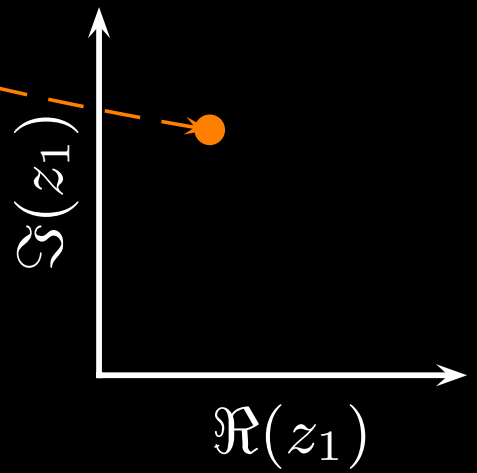

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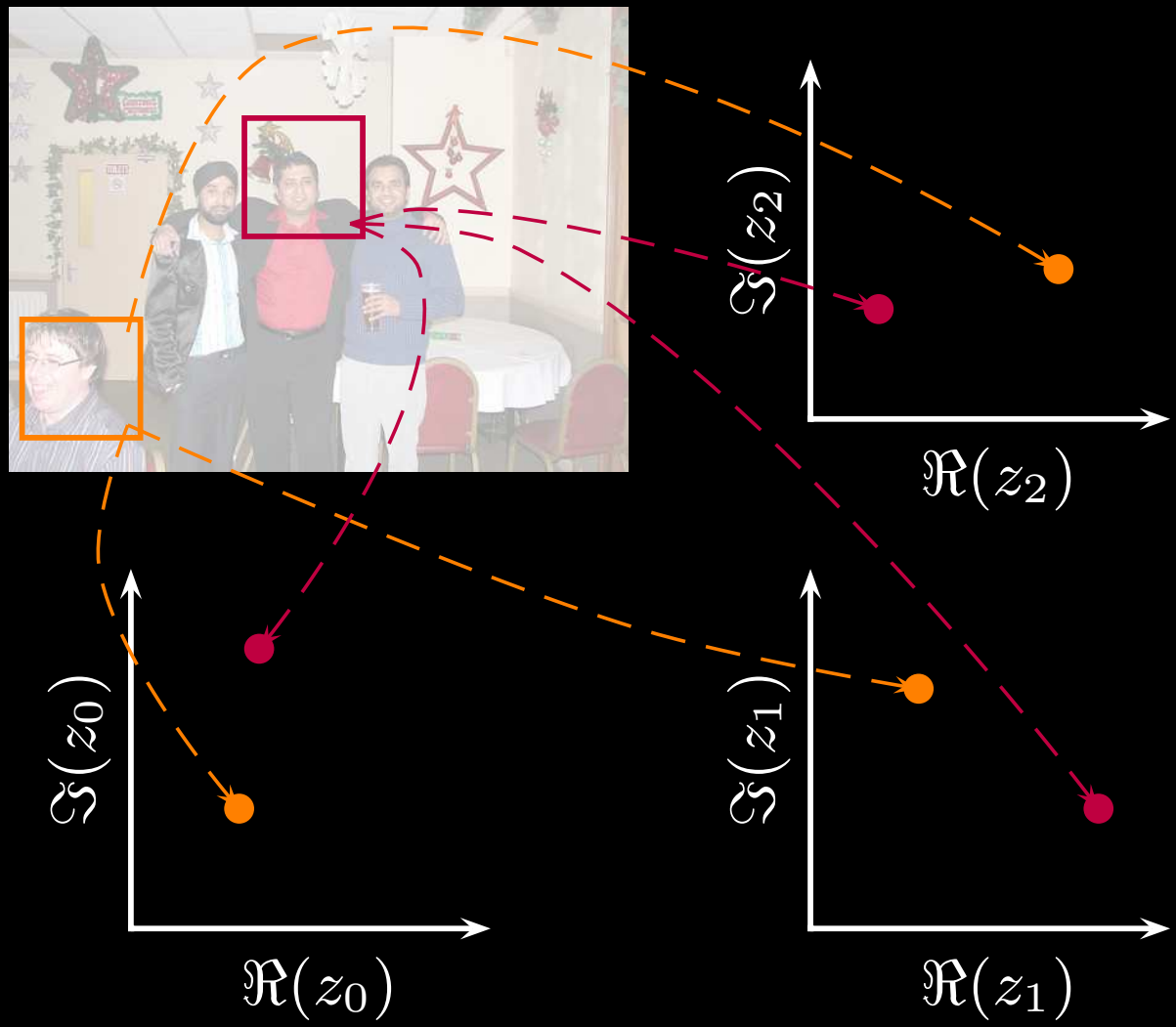

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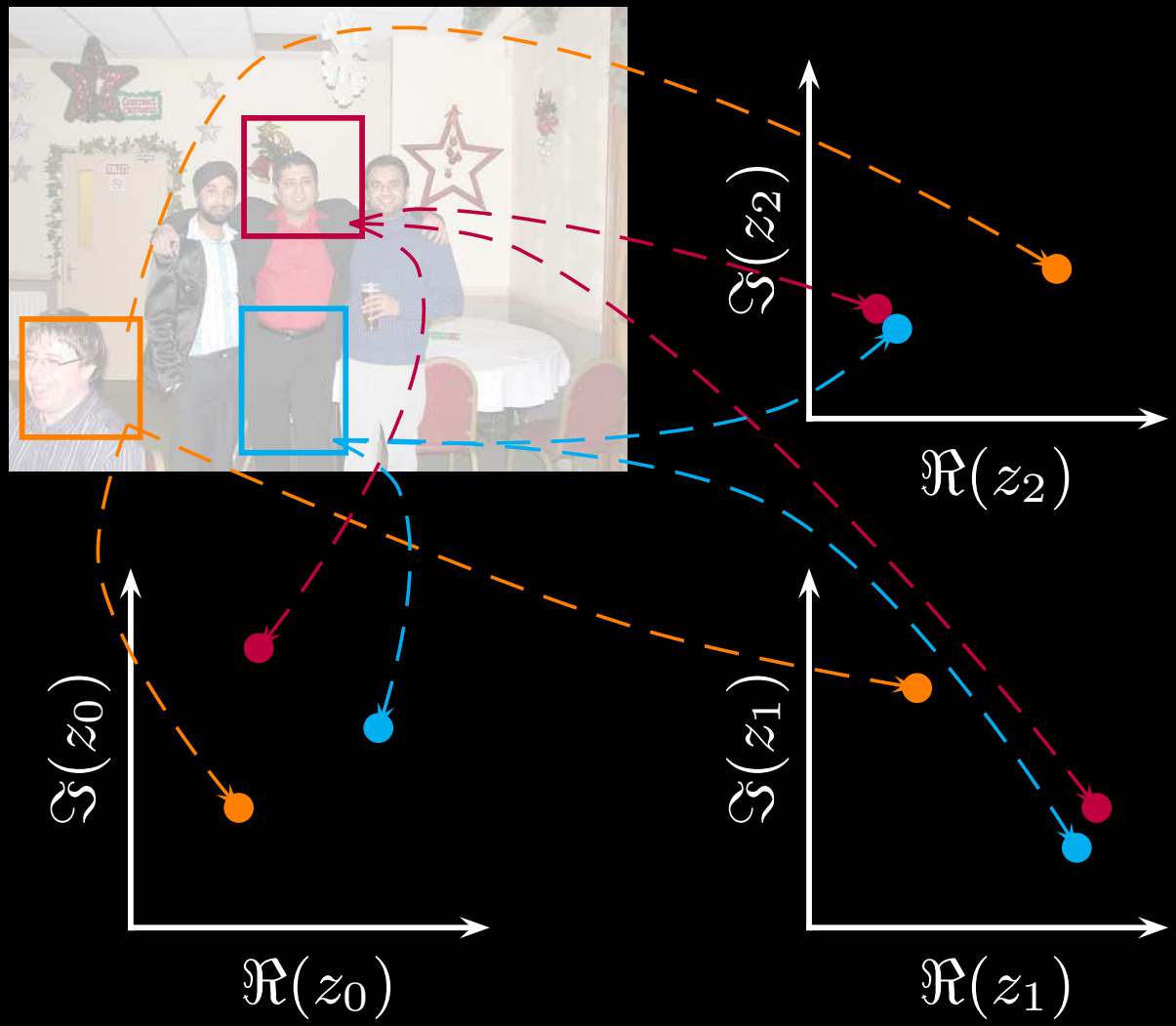

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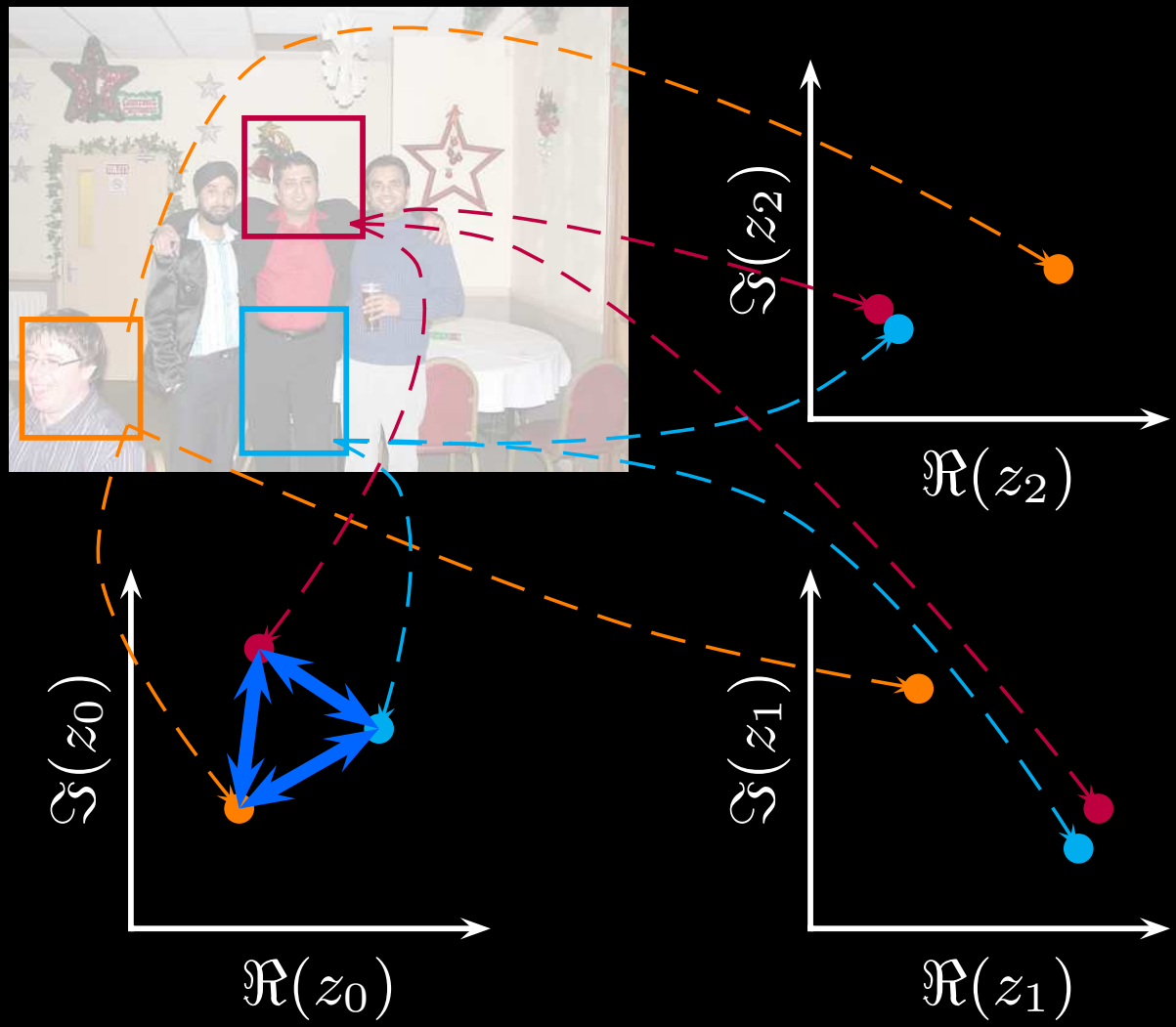

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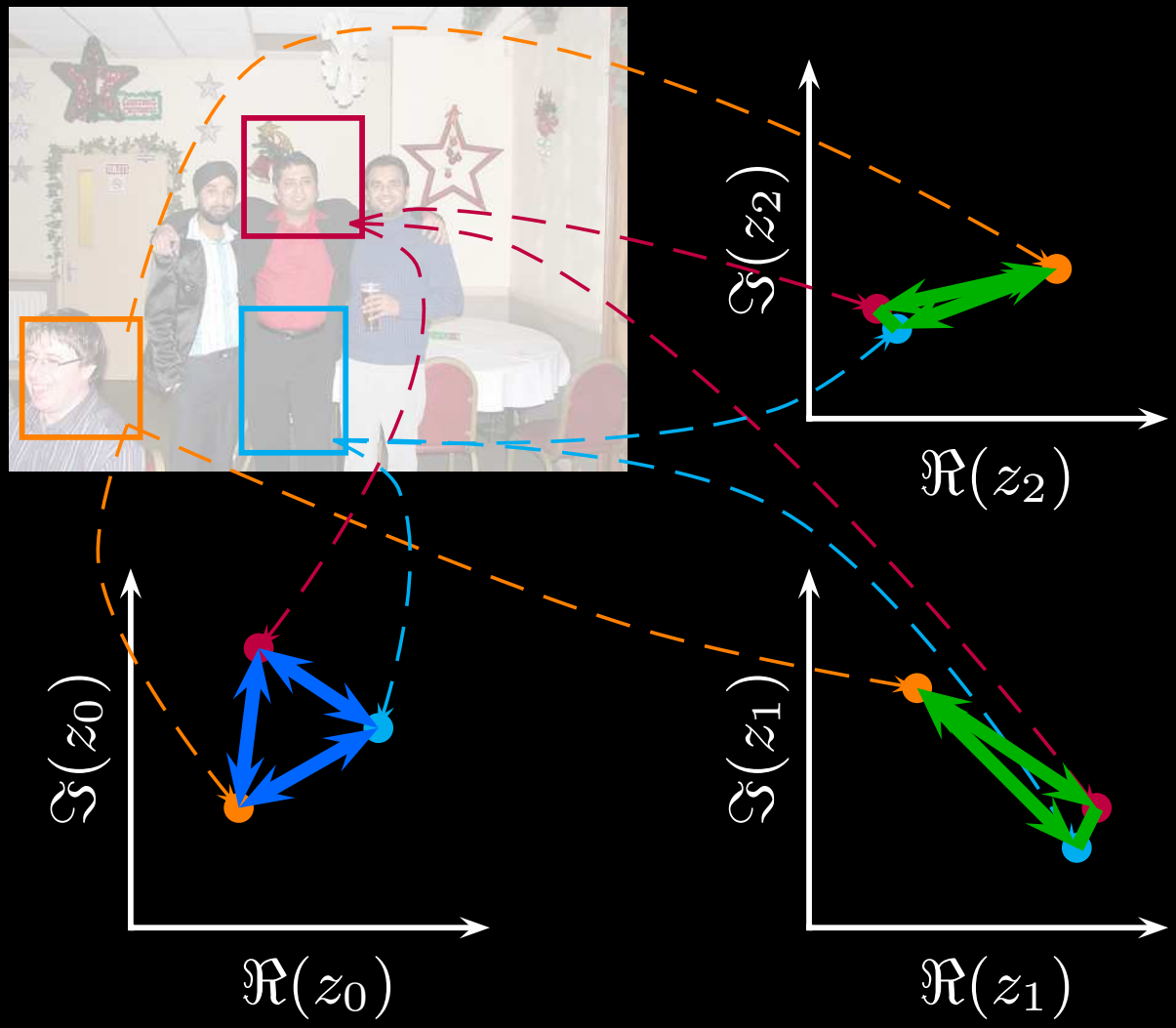

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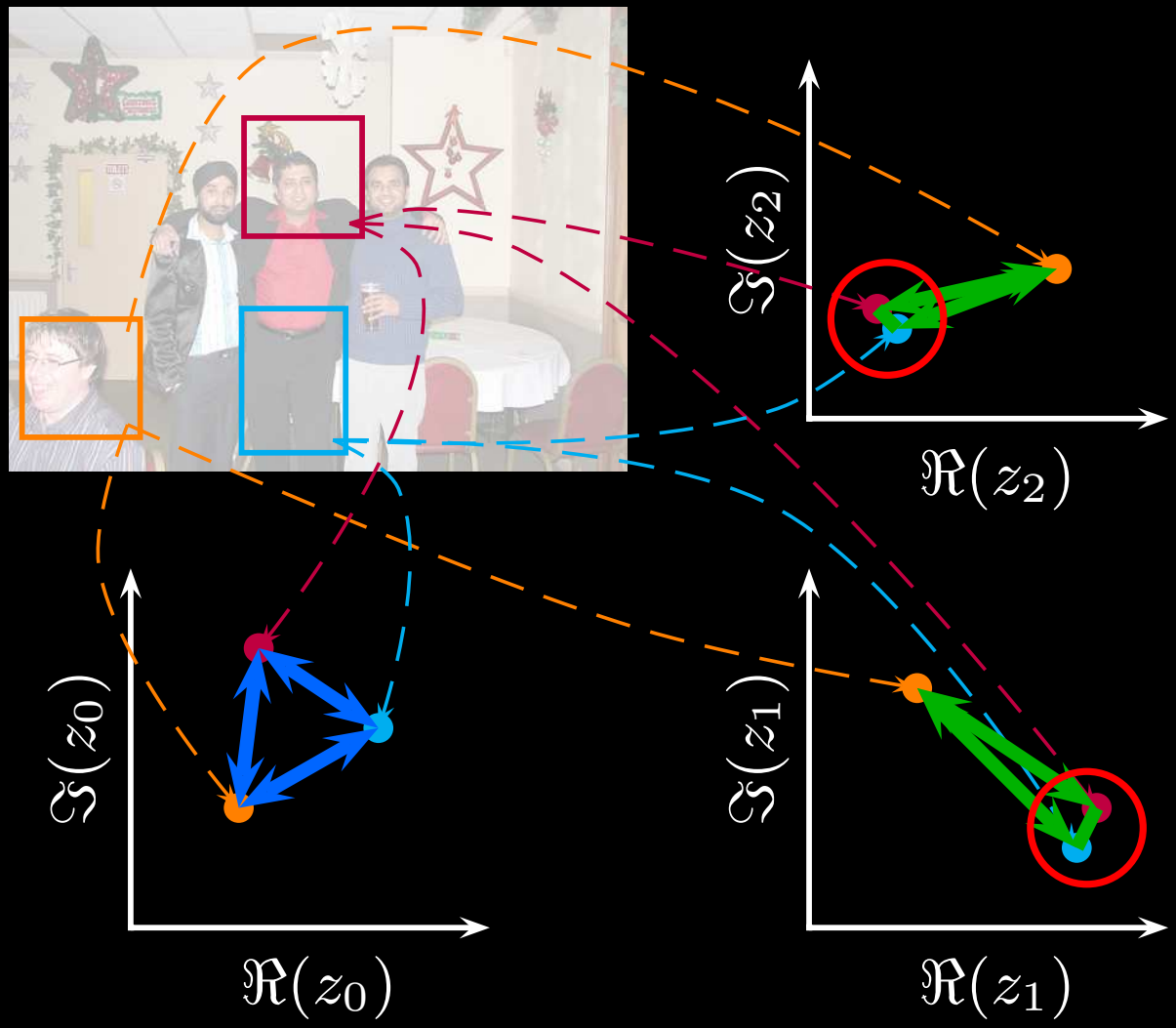

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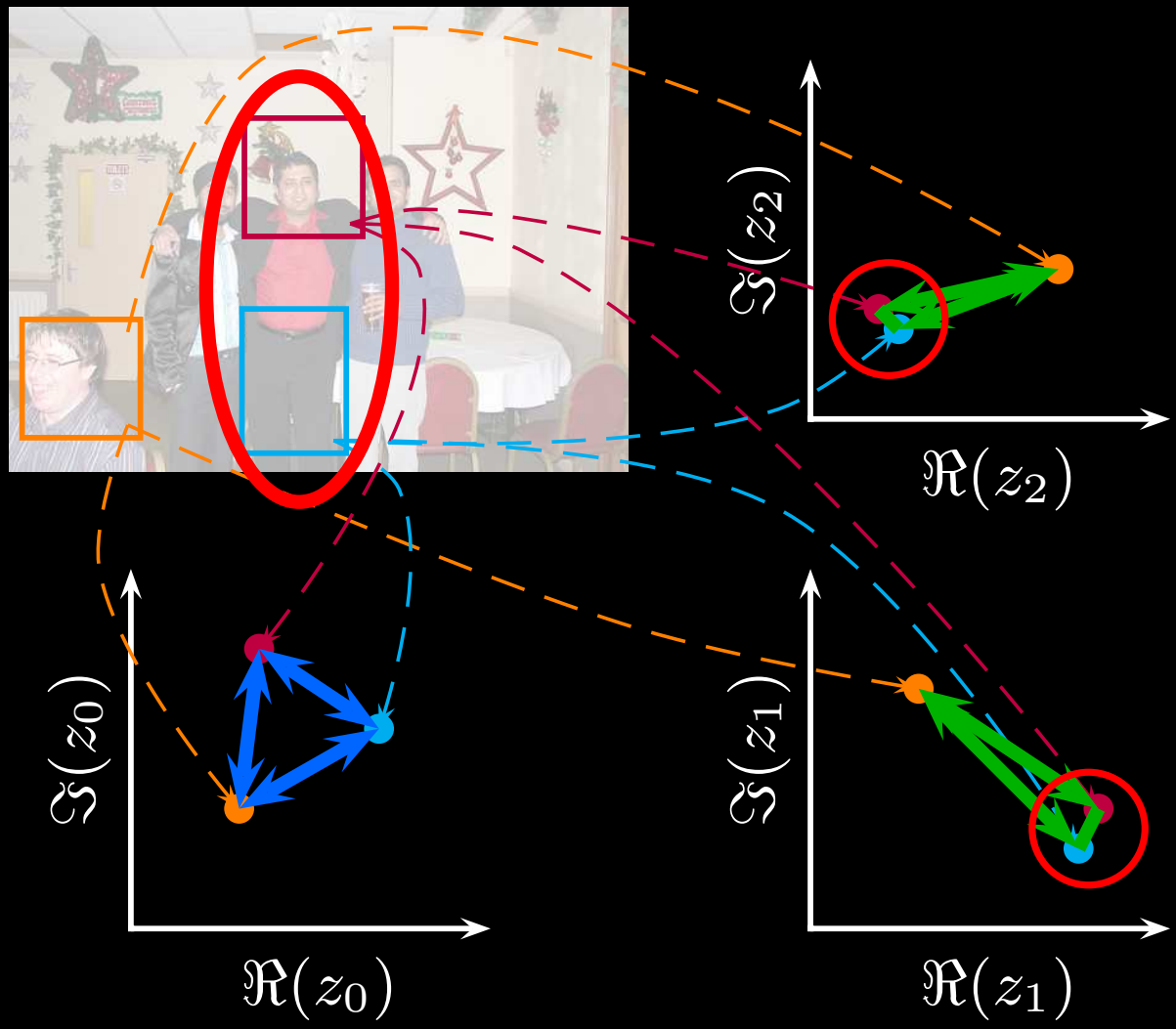
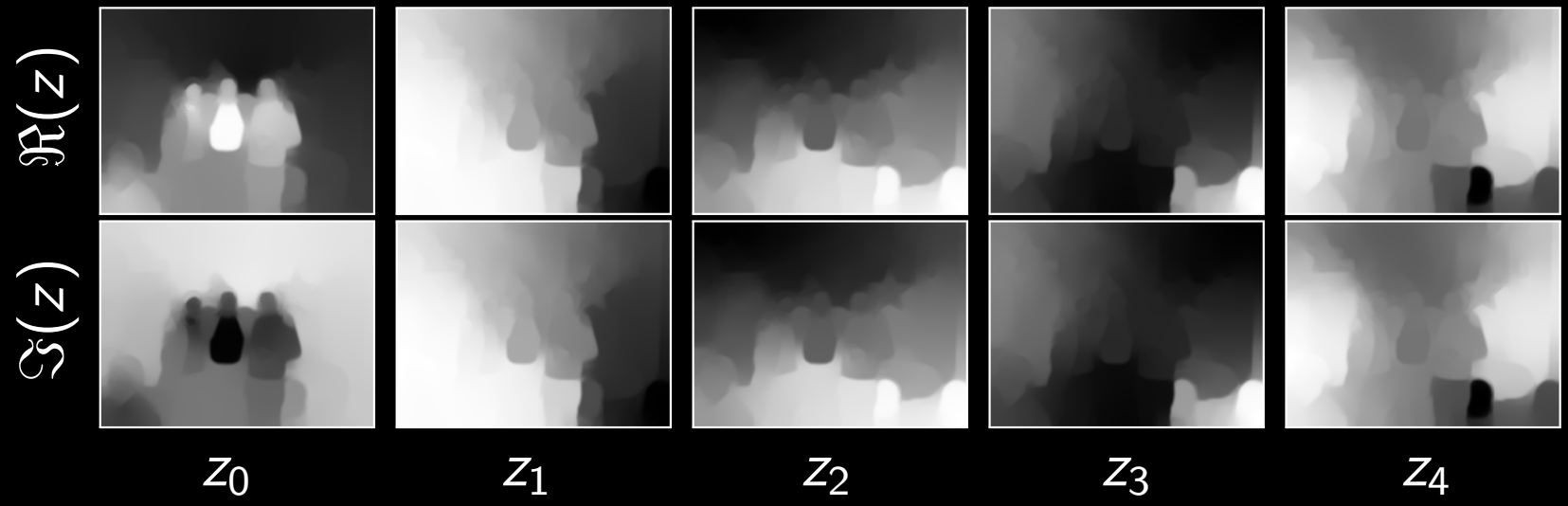


Decoding Eigenvectors: Figure/Ground



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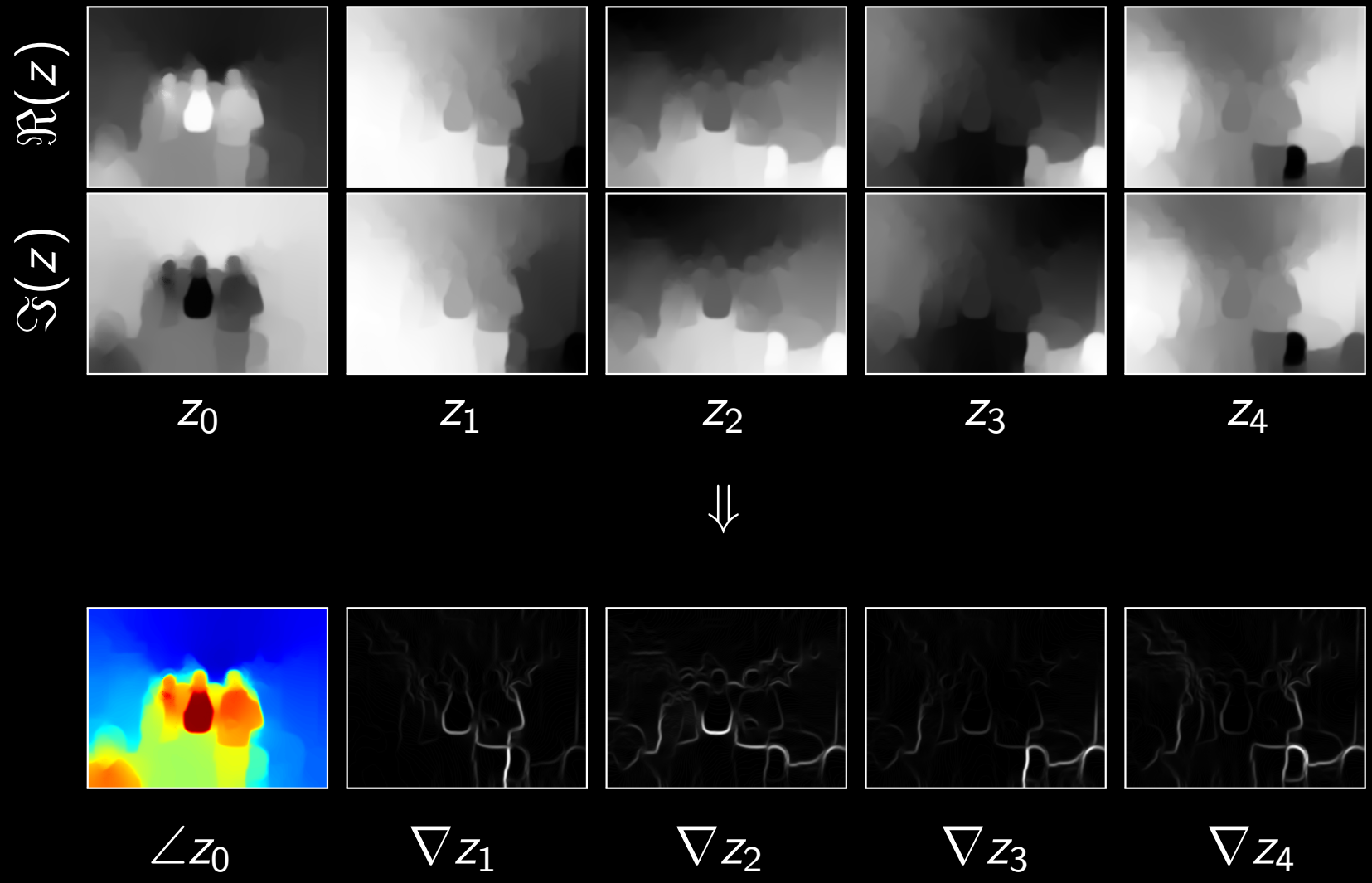
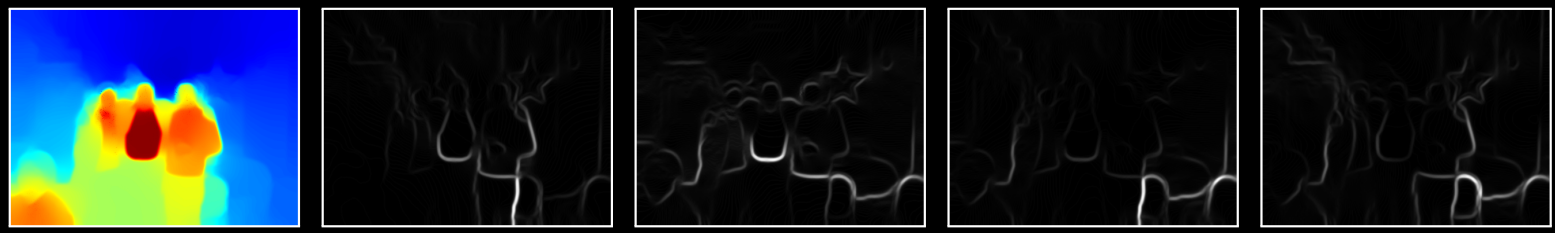


Decoding Eigenvectors: Segmentation



$\angle z_0$ ∇z_1 ∇z_2 ∇z_3 ∇z_4

Figure/Ground

Hierarchical Segmentation

[Arbeláez, Maire, Fowlkes, Malik, PAMI 2011]

Decoding Eigenvectors: Object Segmentation

Assign pixels p_k to objects Q_i via parts q_j:

$$p_k \rightarrow \underset{Q_i}{\operatorname{argmin}} \left\{ \min_{q_j \in Q_i} \{ Dist(p_k, q_j) \} \right\}$$

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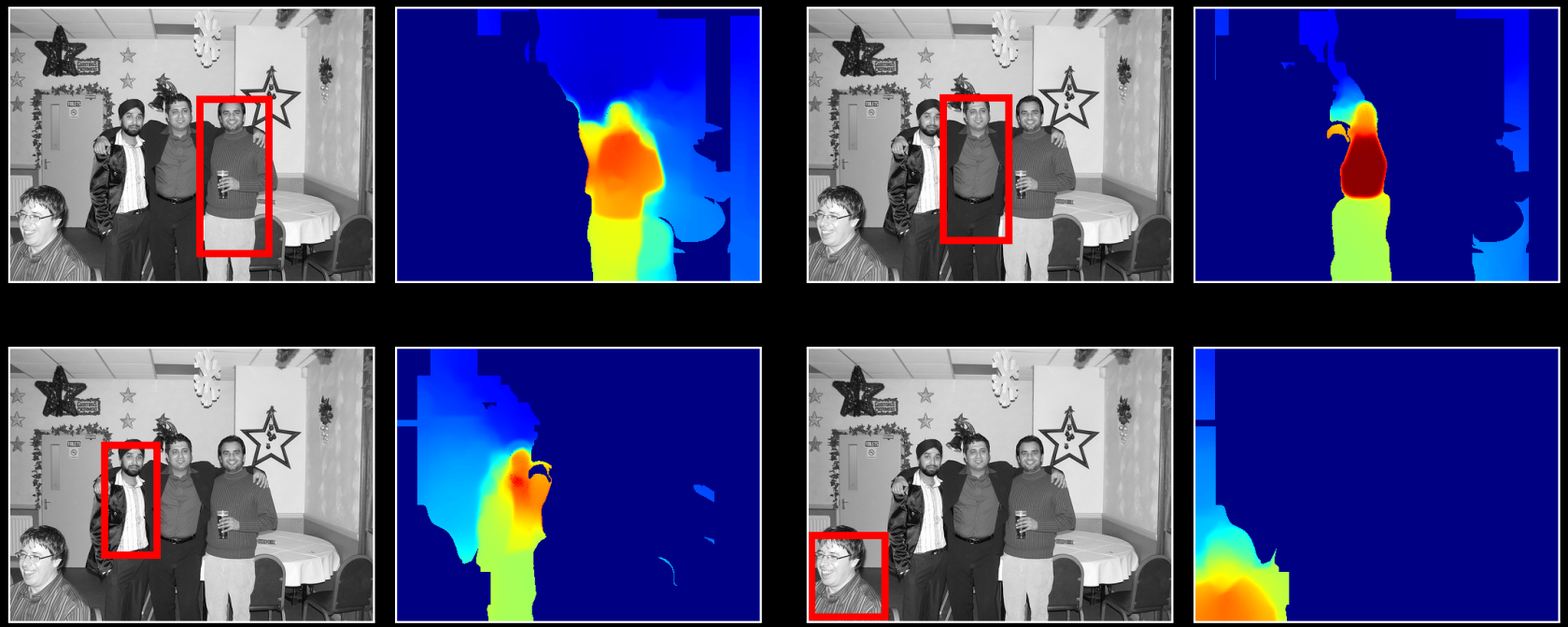
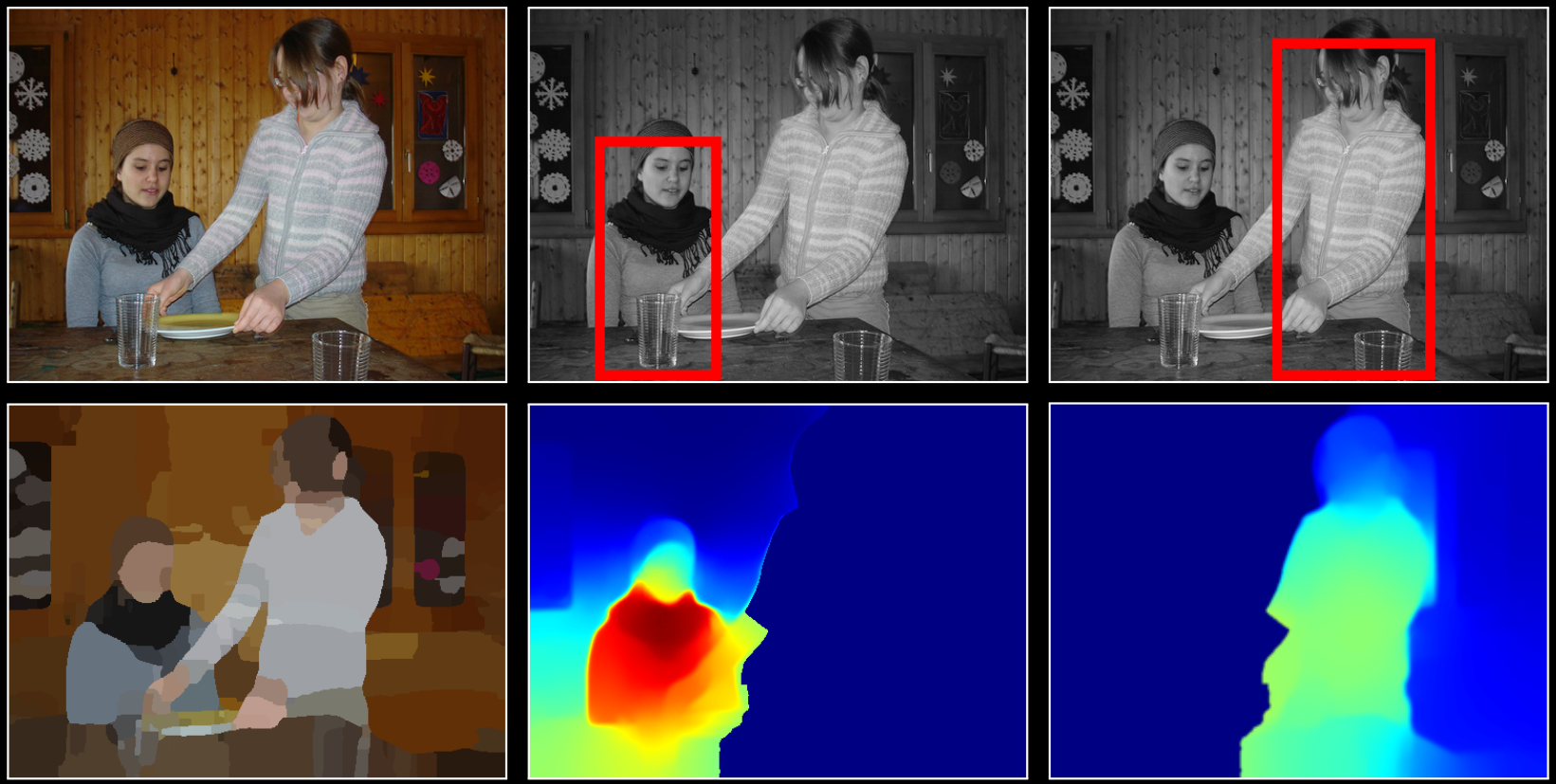
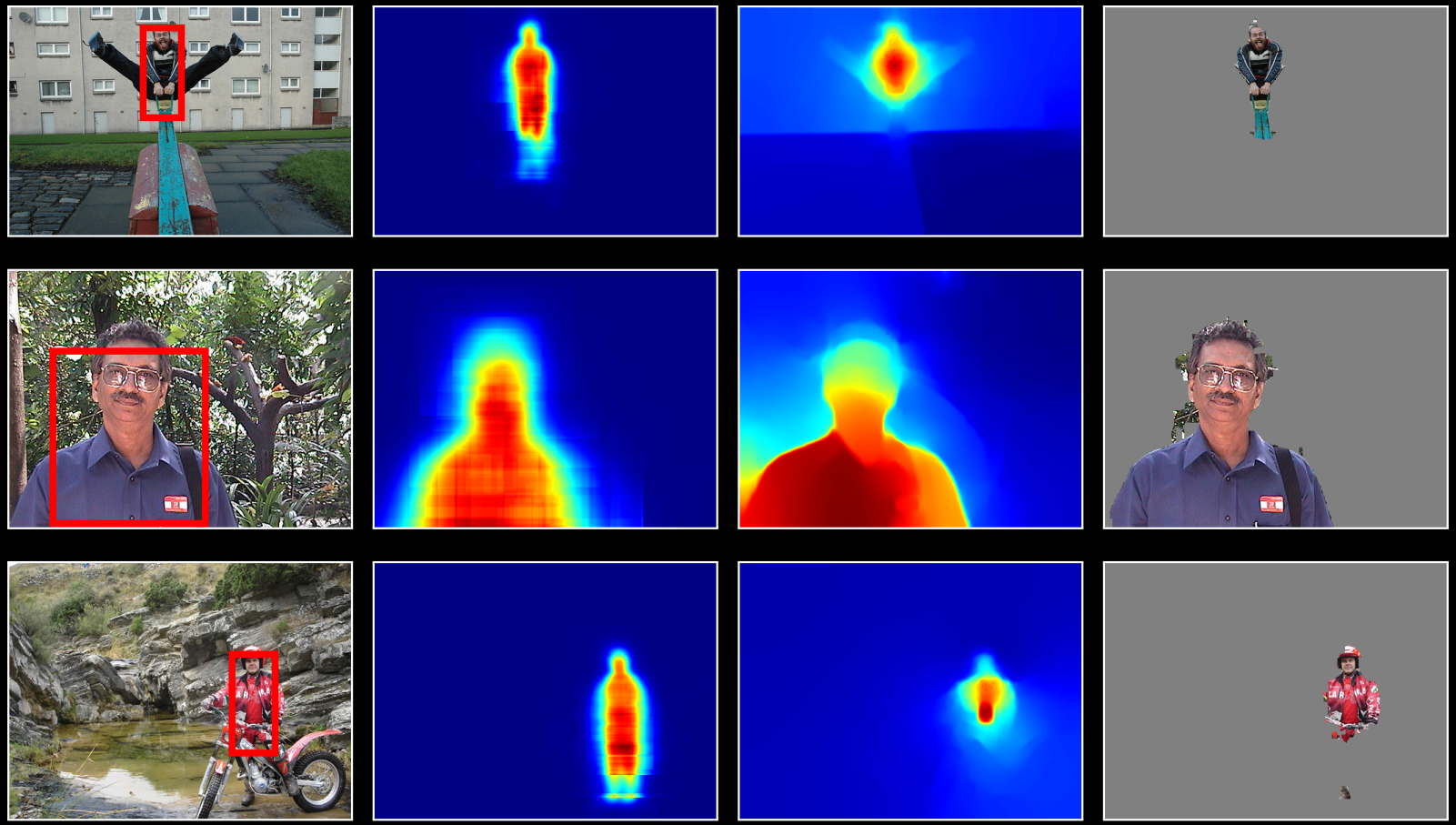


Decoding Eigenvectors



Results: PASCAL 2010 Person Category



Detections Poselet Mask F/G Mask Segmentation

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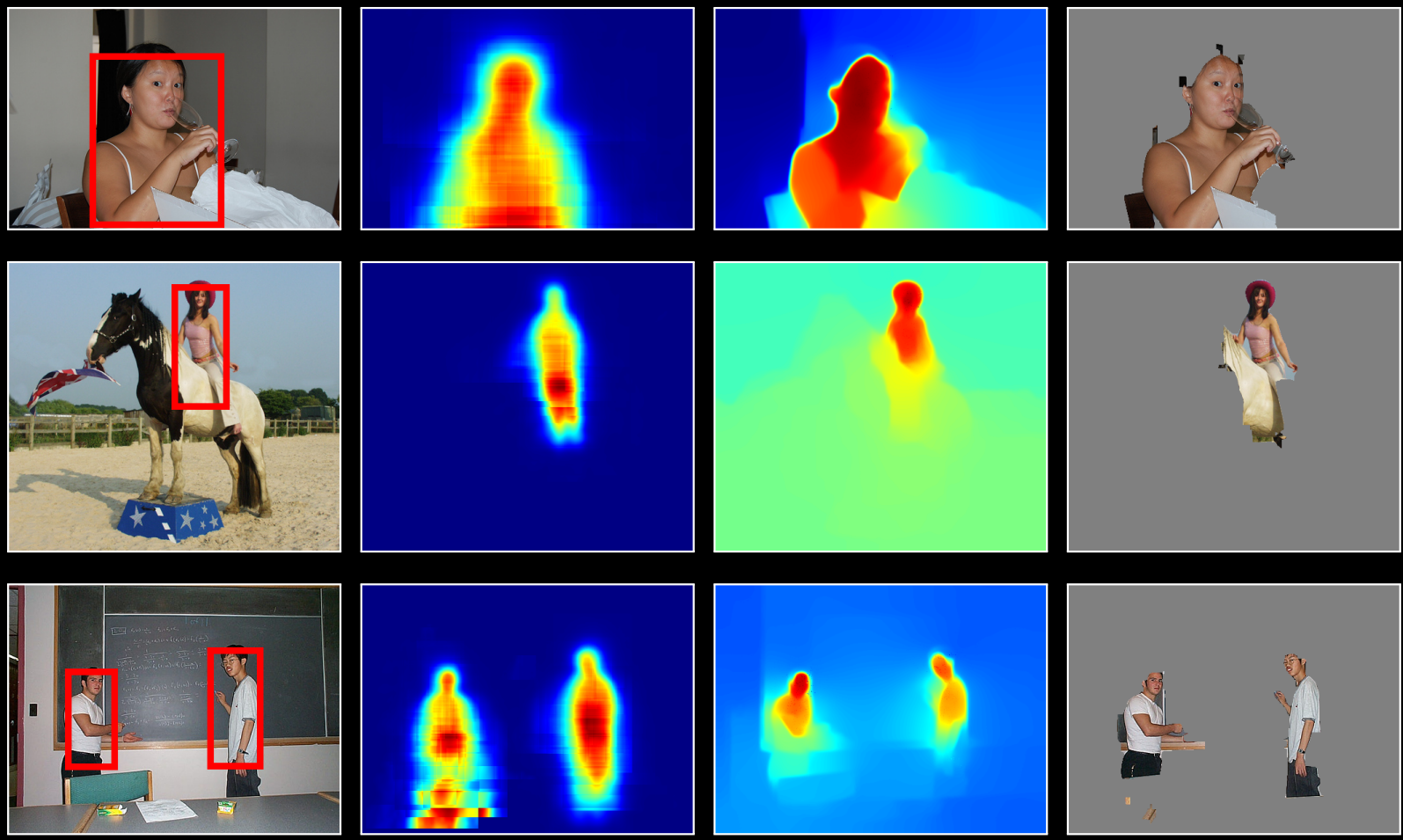

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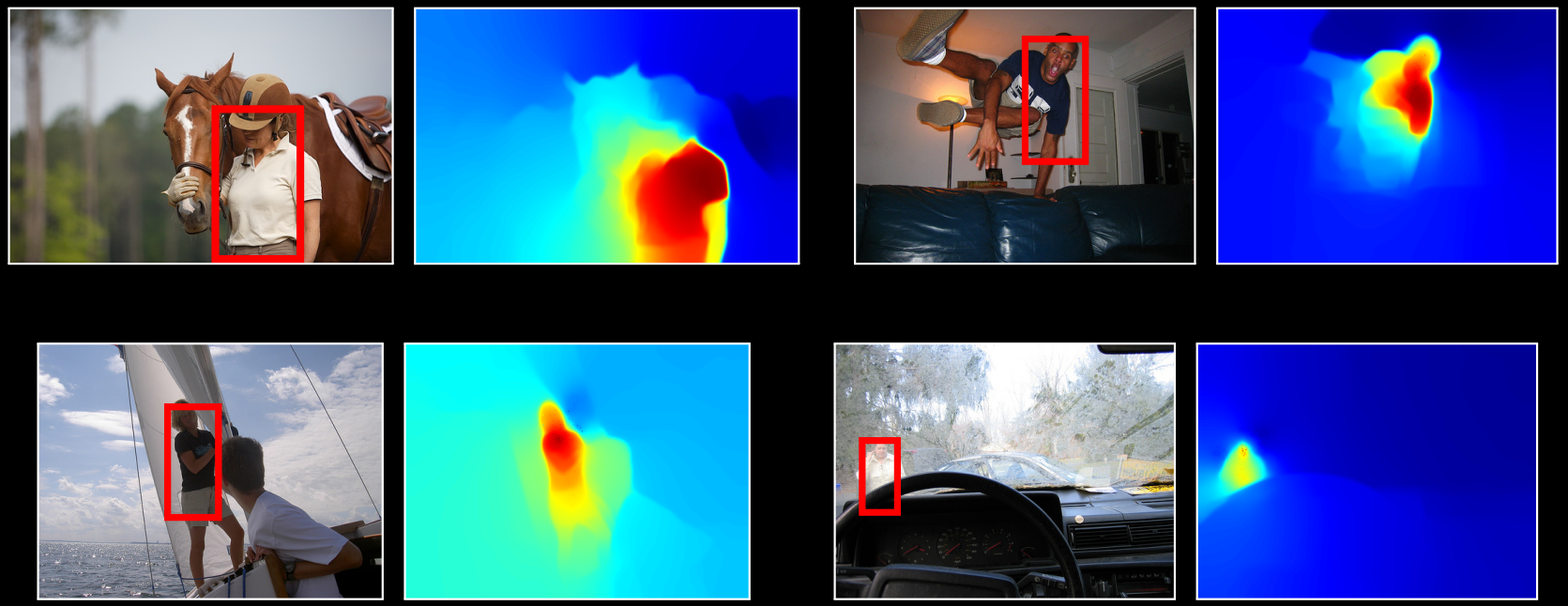

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