Scale-invariant Region-based Hierarchical Image Matching

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PROBLEM STATEMENT

Problem Statement

Given a set of images

containing objects from an unknown category

where the images are captured

at varying distances from the objects

discover and segment all objects of the category

Illustrative Example

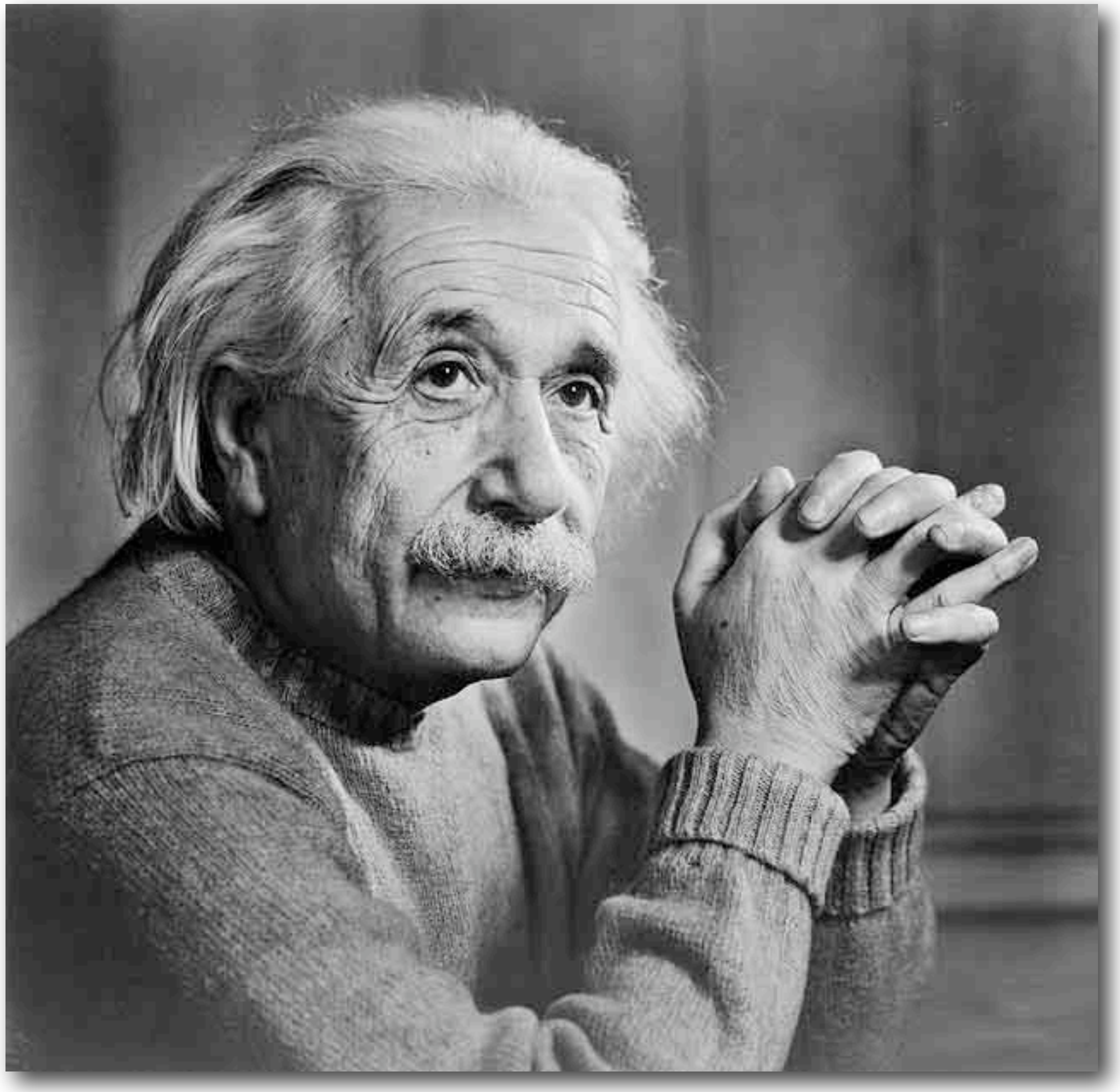
input

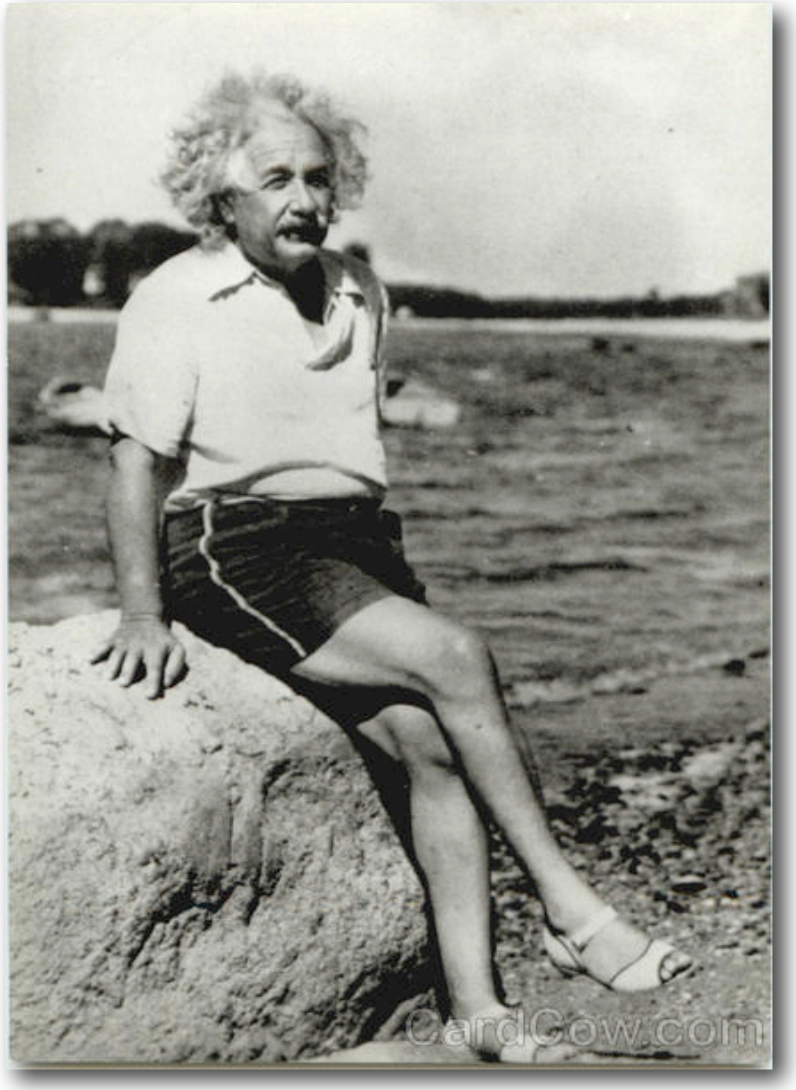
output

Faces should be identified and segmented as the frequently occurring category in the input images

Note that this is not a face-detection talk

Challenges: Scale Variations





- **Geometric and photometric properties of objects change**
- **Details visible in the high zoom-in, disappear at coarse scales**

MOTIVATION

Motivation: Image = Segmentation Tree

original image

contrast > 10

contrast > 20

multiscale segmentation

N. Ahuja 96, Tobb & Ahuja 97, Arora&Ahuja 06

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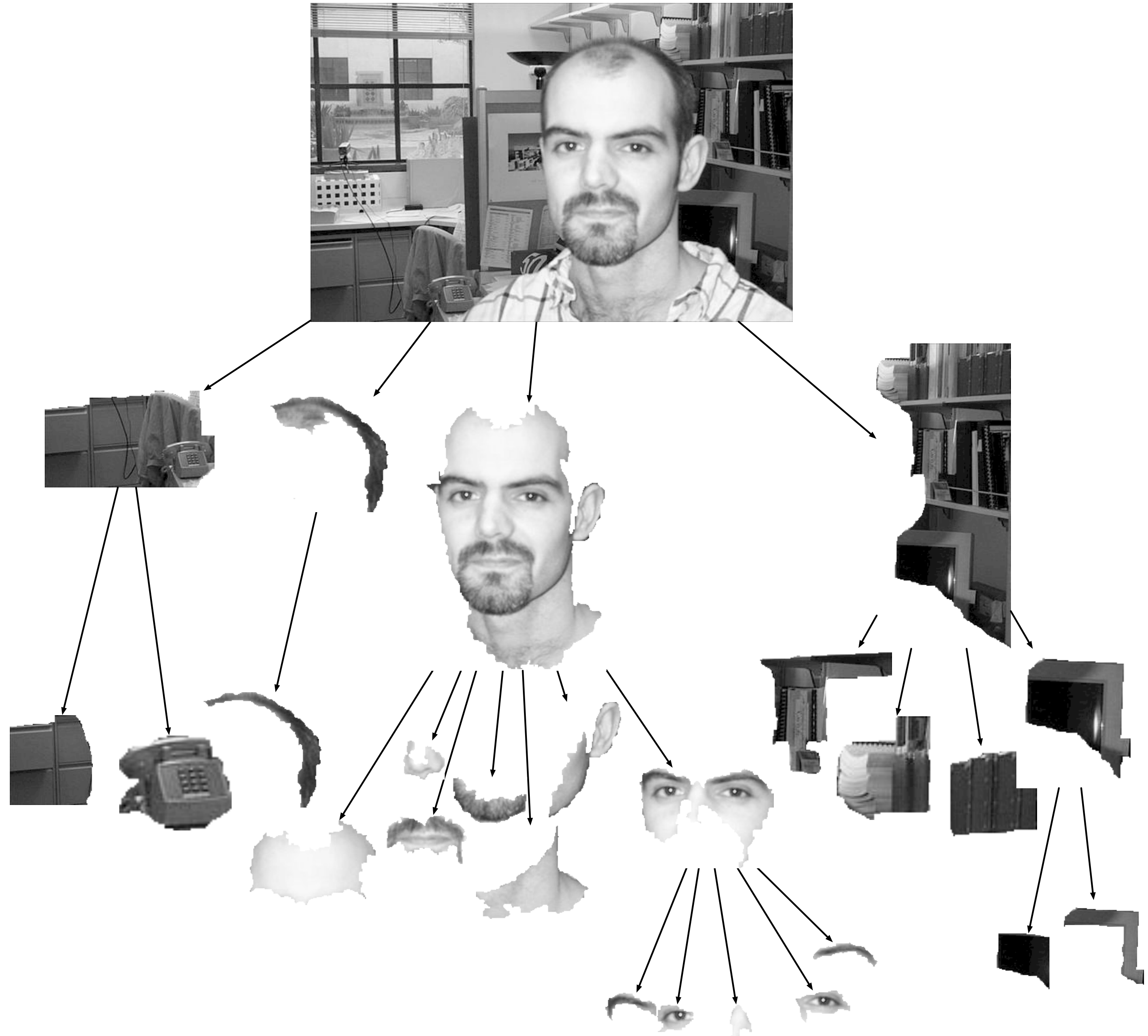
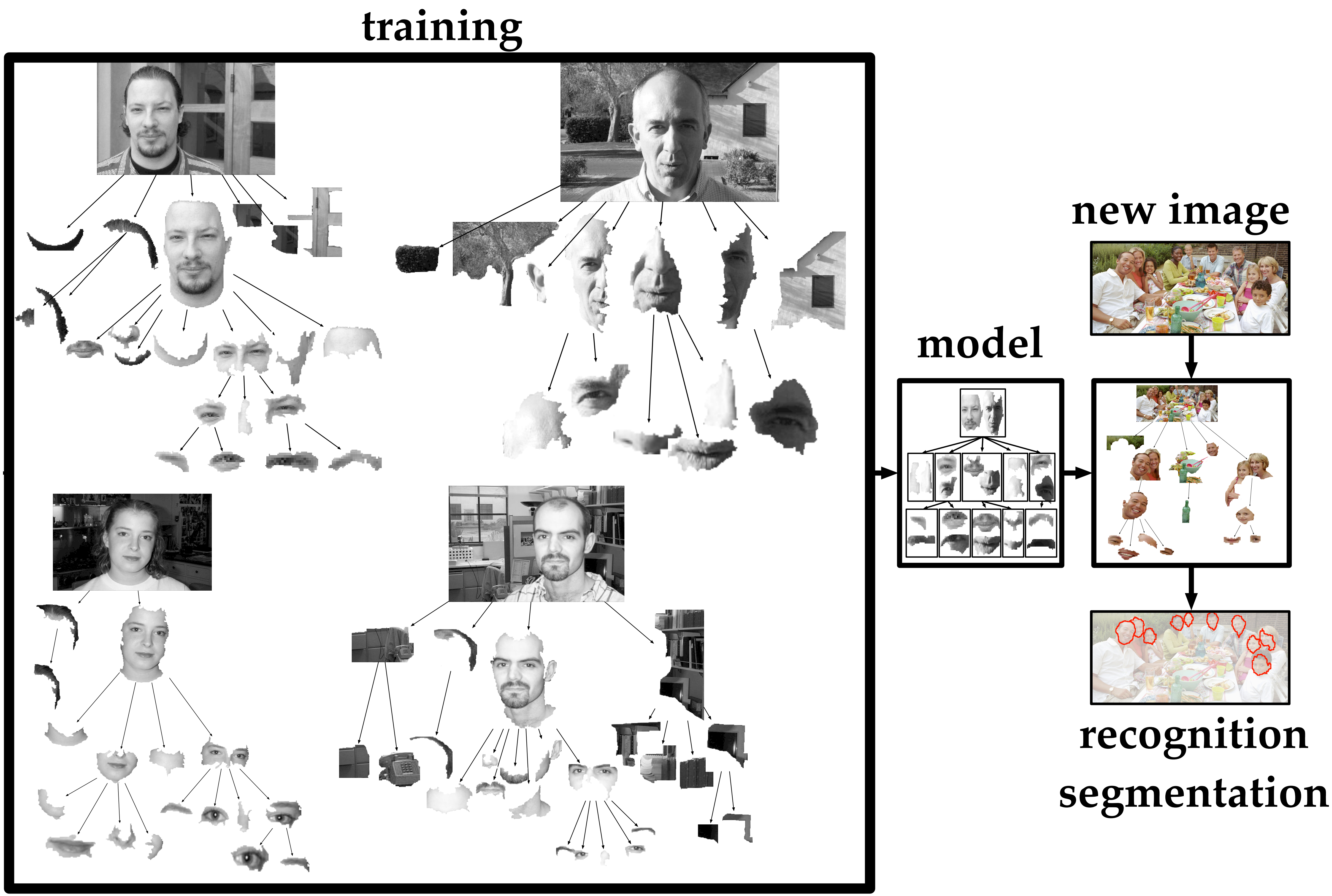
multiscale segmentation



segmentation tree

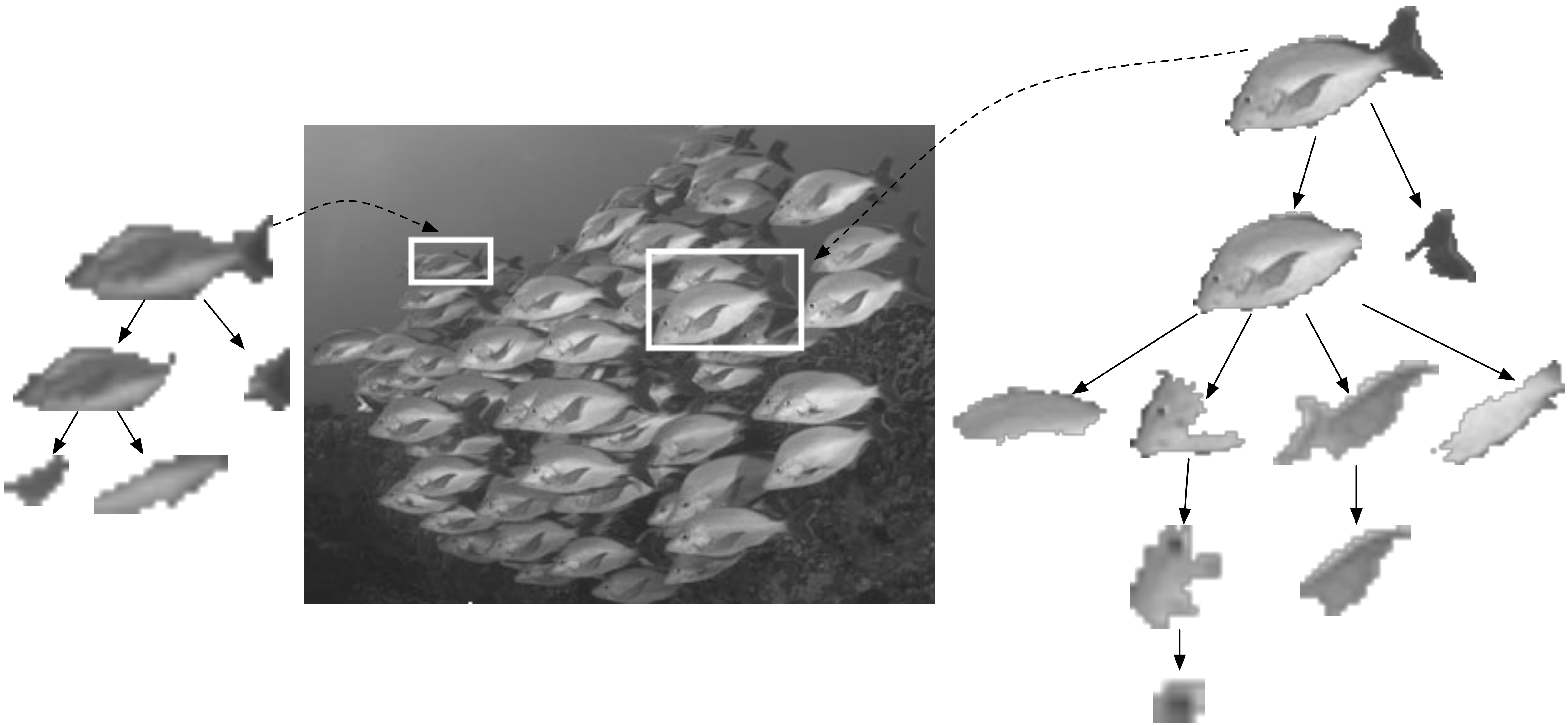
N. Ahuja 96, Tobb & Ahuja 97, Arora&Ahuja 06

Motivation: Learning Objects = Tree Matching



Objects = Similar subtrees

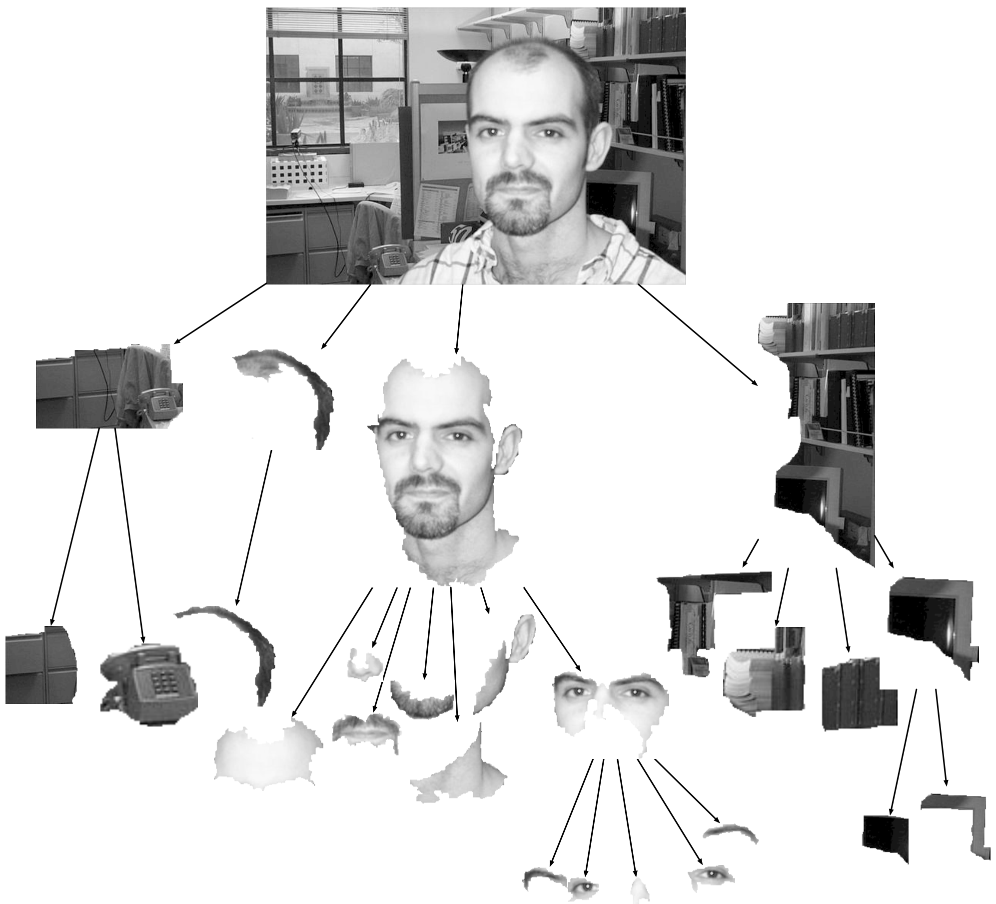
Effect of Scale Changes



Width and depth of object subtrees varies

PRIOR WORK

Region Properties Associated with Each Node



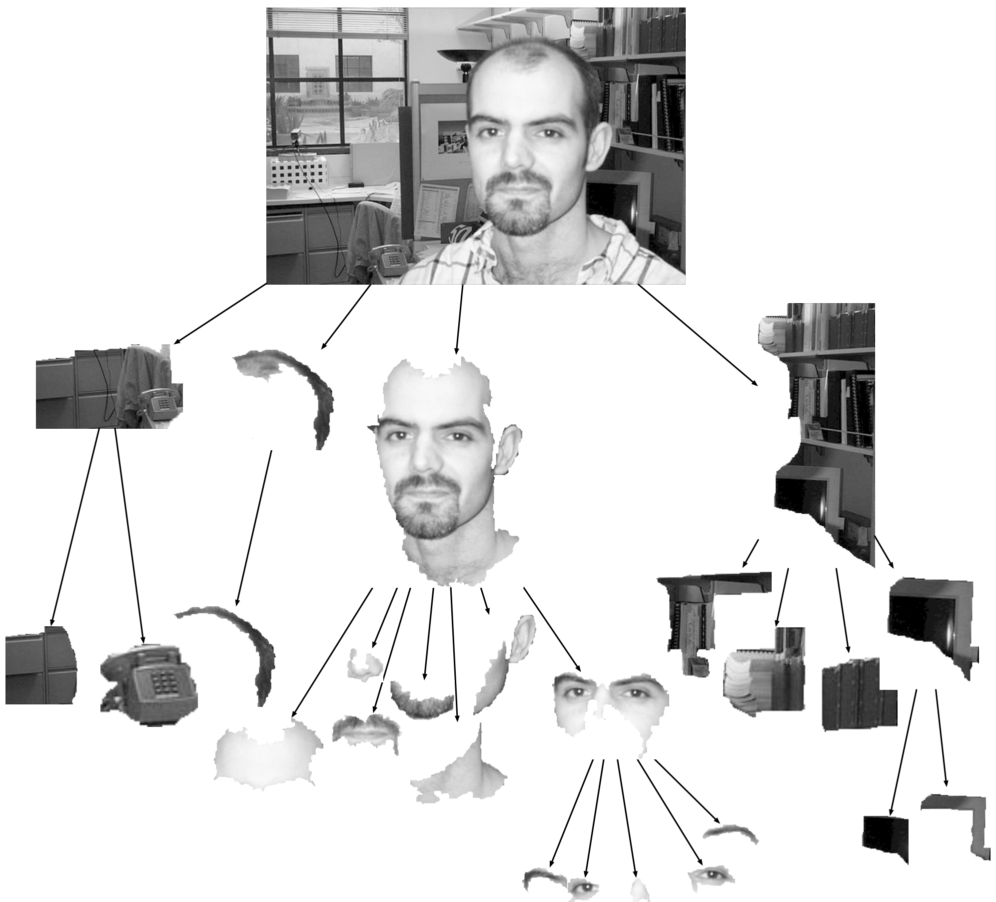
ψ vector of region properties:

- Contrast with surround
- Area
- Displacement of centroids
- Orientation of principal axes
- Perimeter

⋮

Todorovic & Ahuja 06, Ahuja & Todorovic 07

Region Properties Associated with Each Node



ψ vector of region properties:

- Contrast with surround
- Area
- Displacement of centroids
- Orientation of principal axes
- Perimeter

⋮

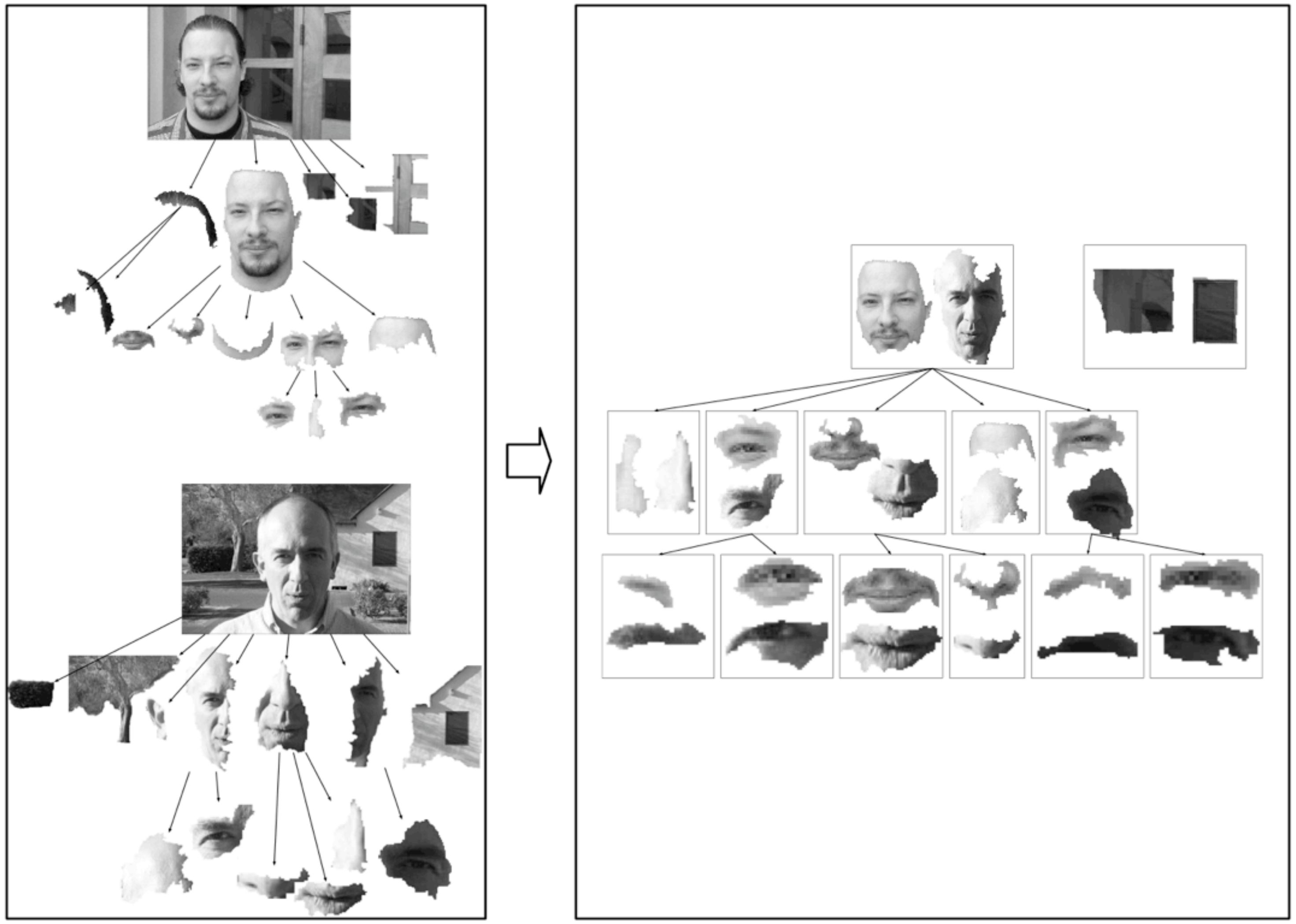
Area defined relative to parent's area

$\Downarrow$

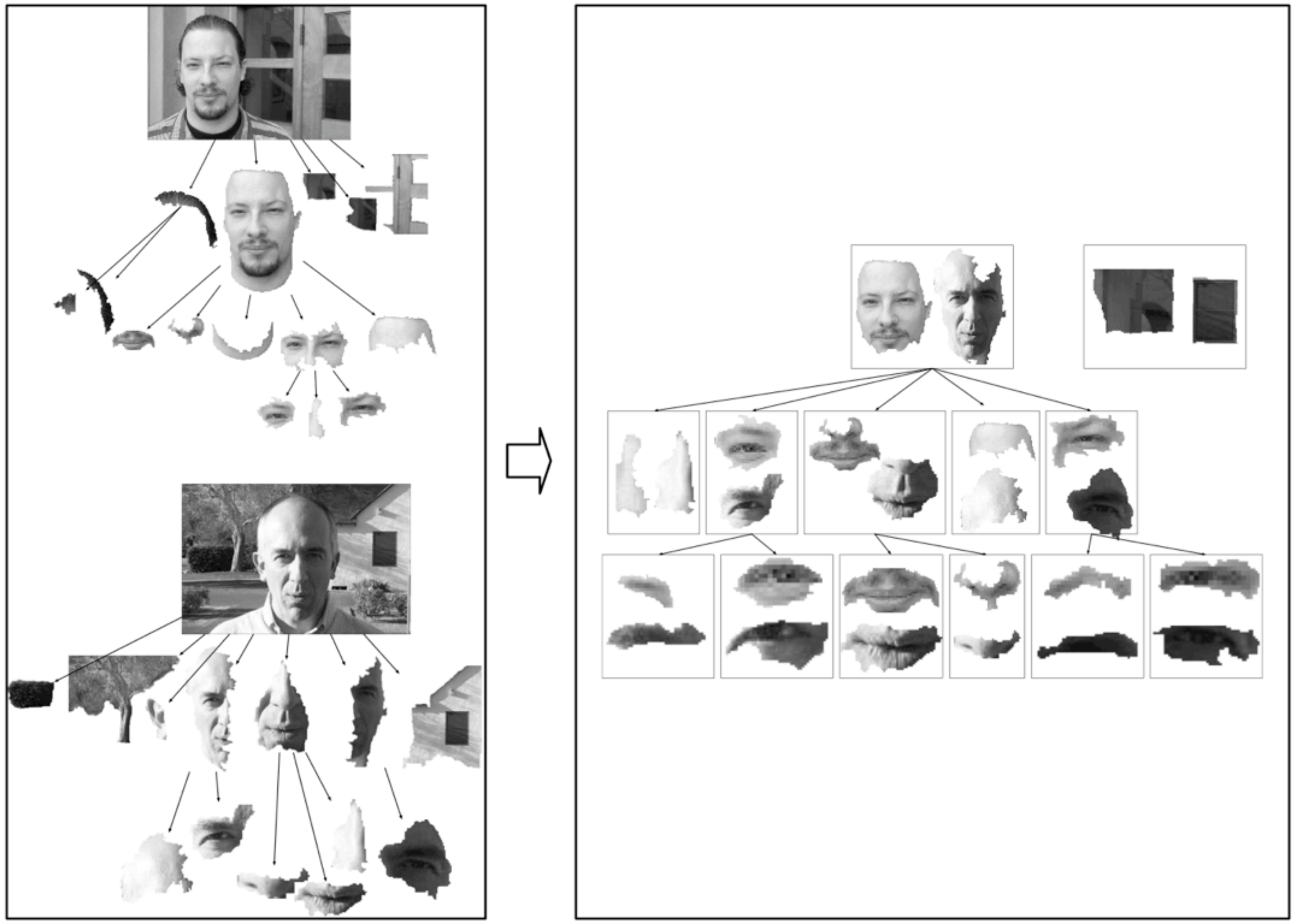
Invariance to small scale variations

Todorovic & Ahuja 06, Ahuja & Todorovic 07

Tree Matching = Subtree Isomorphism

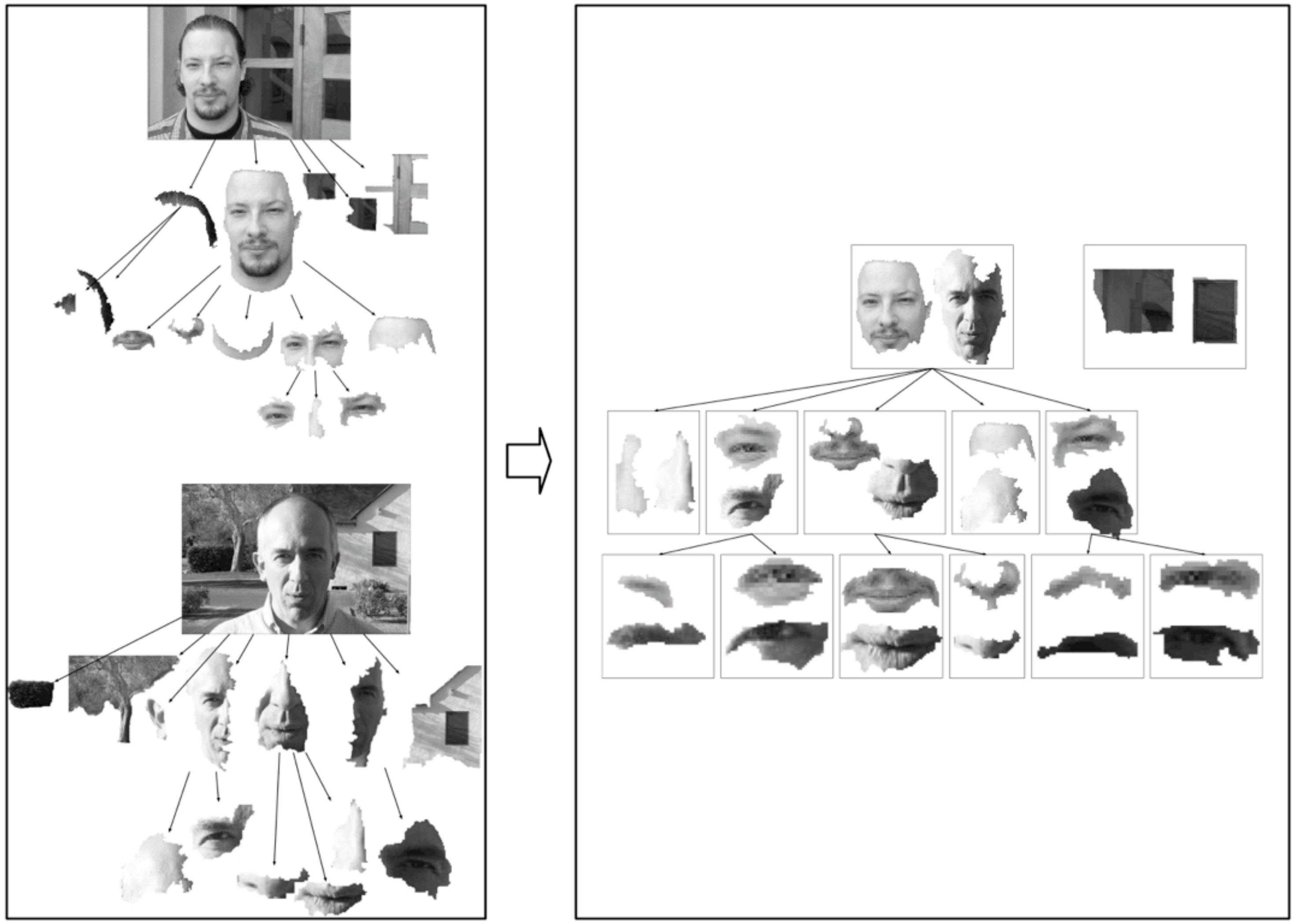


Tree Matching = Subtree Isomorphism



Match two regions

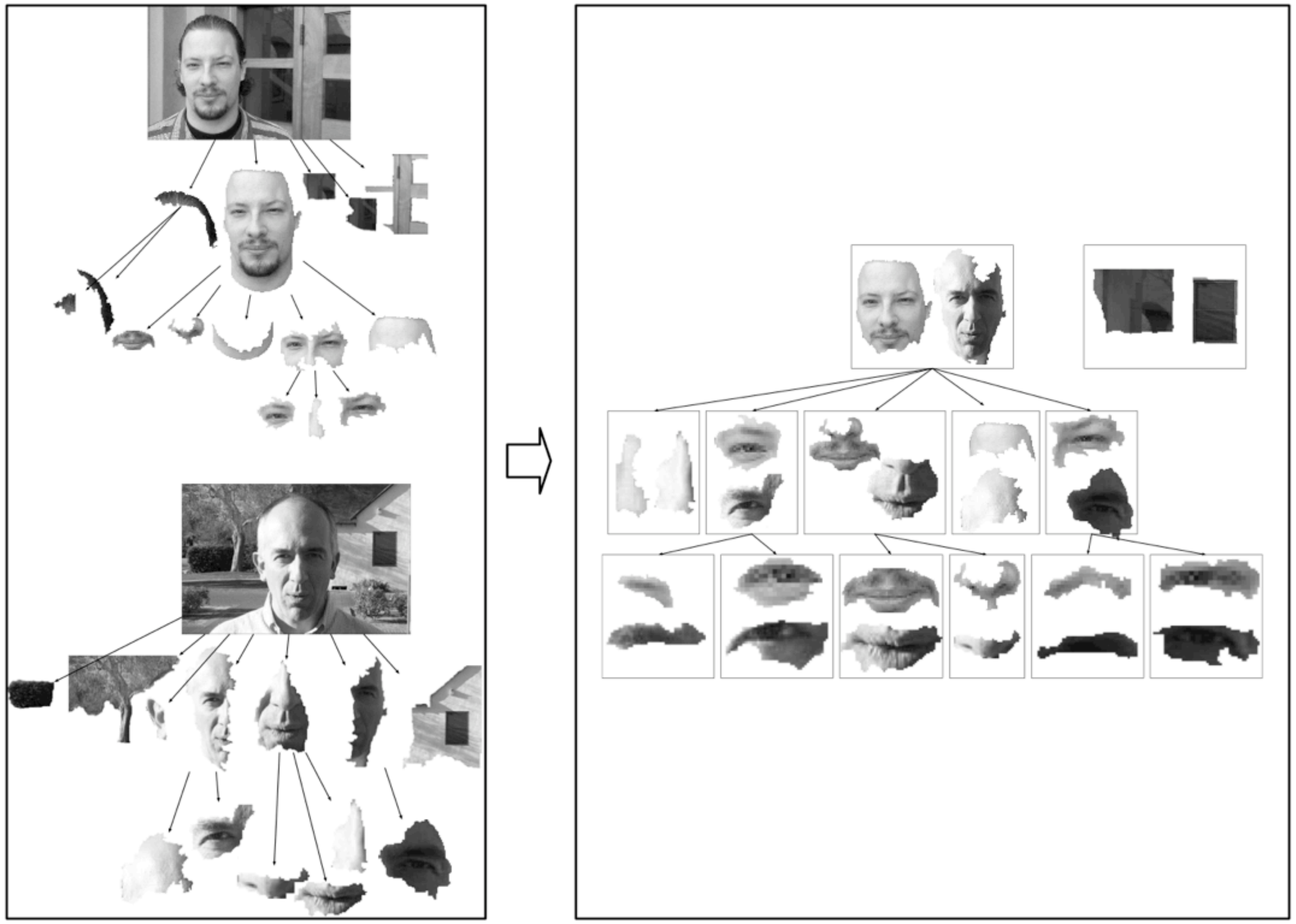
Tree Matching = Subtree Isomorphism



Match two regions

- **If their immediate properties are similar**

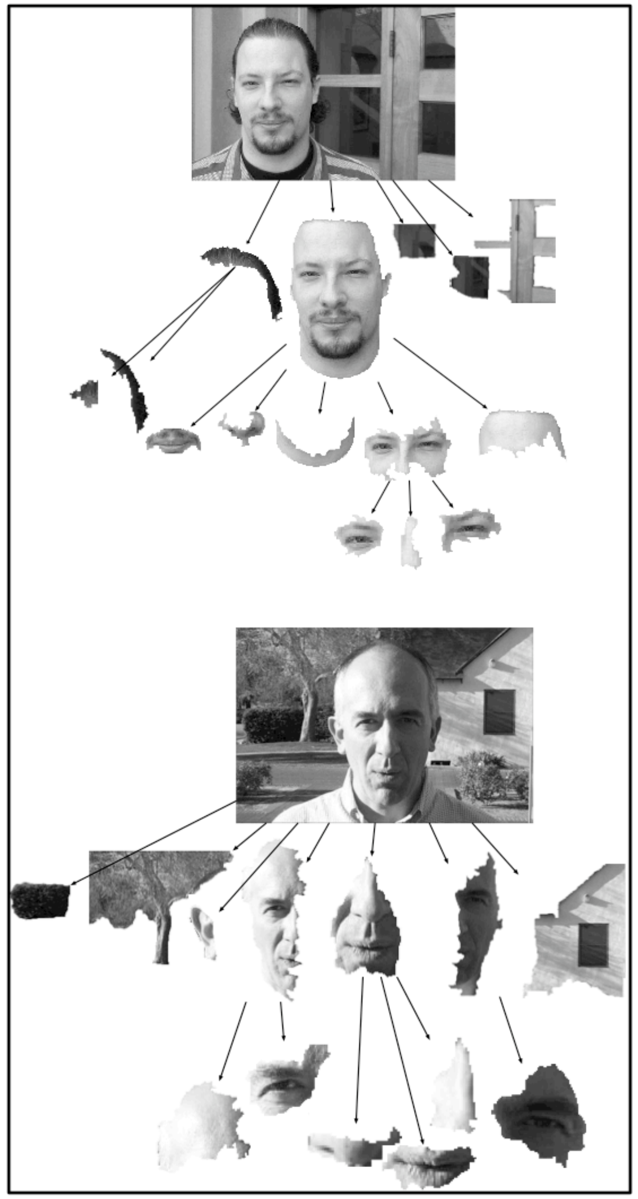
Tree Matching = Subtree Isomorphism



Match two regions

- **If their immediate properties are similar**
- **AND the same holds for their subregions**

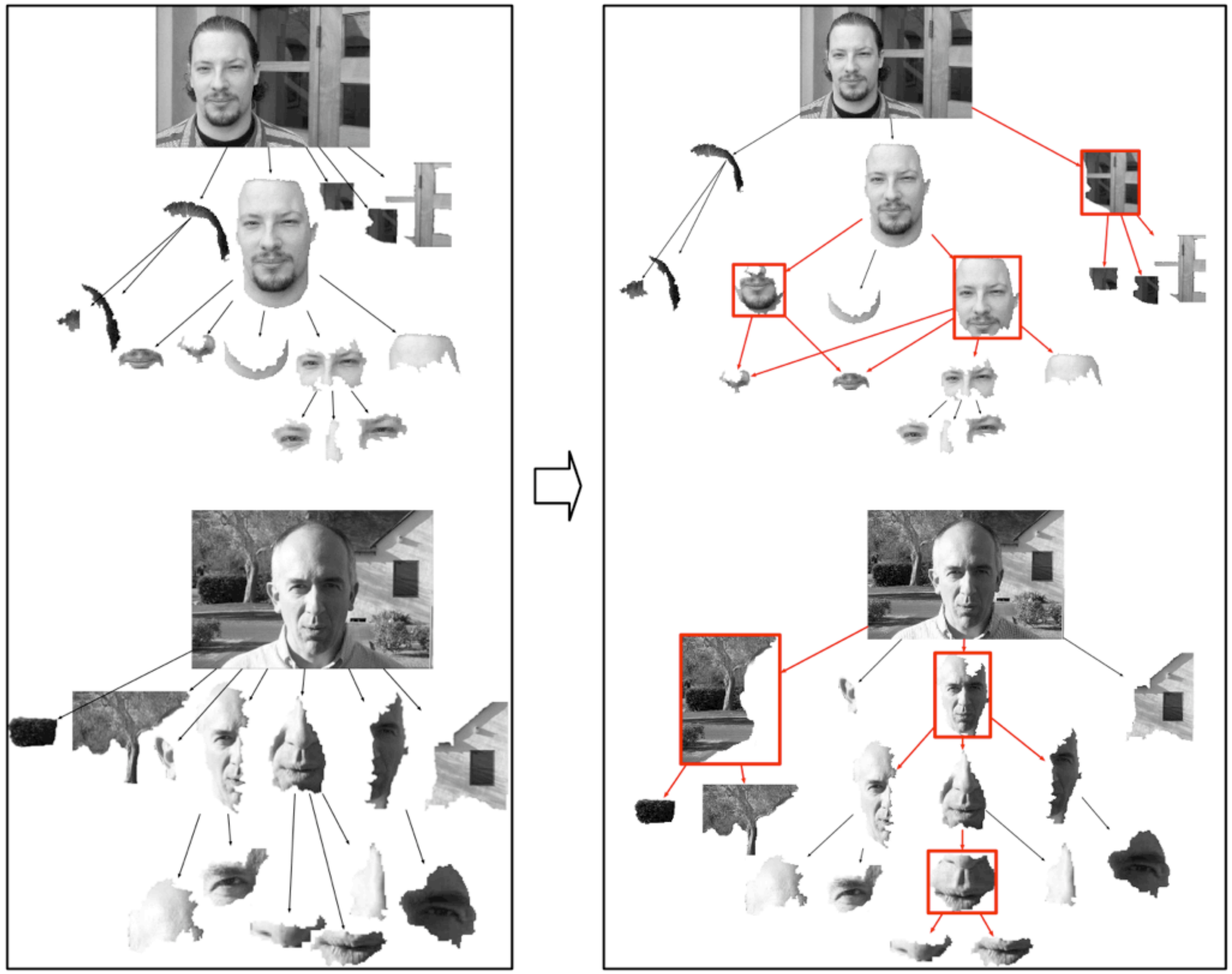
Addressing Instability of Image Segmentation



Many-to-many matching = Augmenting trees with mergers

Todorovic & Ahuja 06, Ahuja & Todorovic 07

Addressing Instability of Image Segmentation



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Todorovic & Ahuja 06, Ahuja & Todorovic 07

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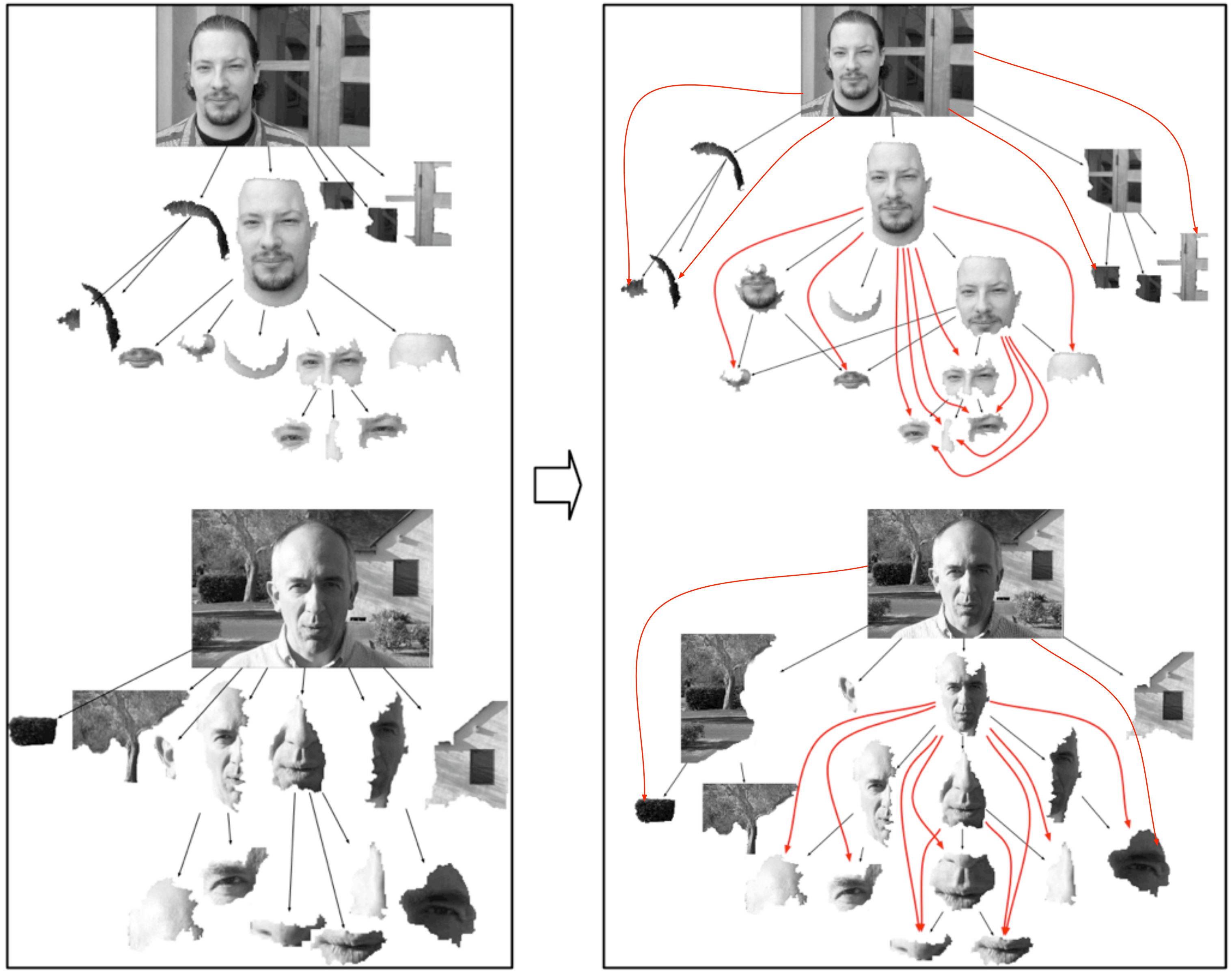


Matching all descendants under a node

$\Downarrow$ $\quad\Rightarrow$ **tree flattening**

Matching transitive closures of trees

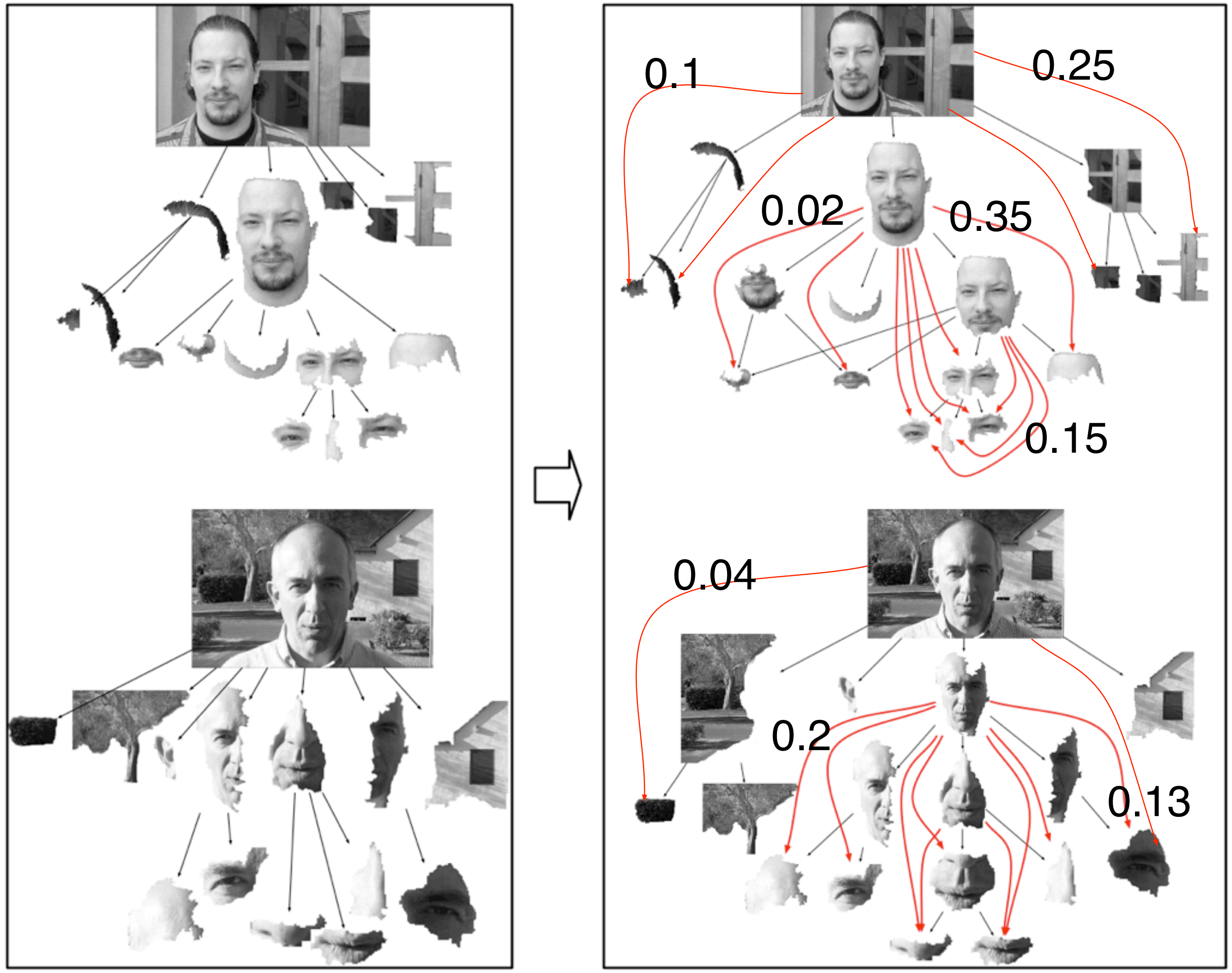
Torsello & Hancock 03, Pelillo et al. 99, Glantz et al. 04

OUR APPROACH

Our Approach

- **Represent images as segmentation trees**
- **Down-weight fine details closer to leaf nodes --**
  Find weighted transitive closure of the trees
- **Match by separating the scales of the objects and scene --**
  Normalization of region properties

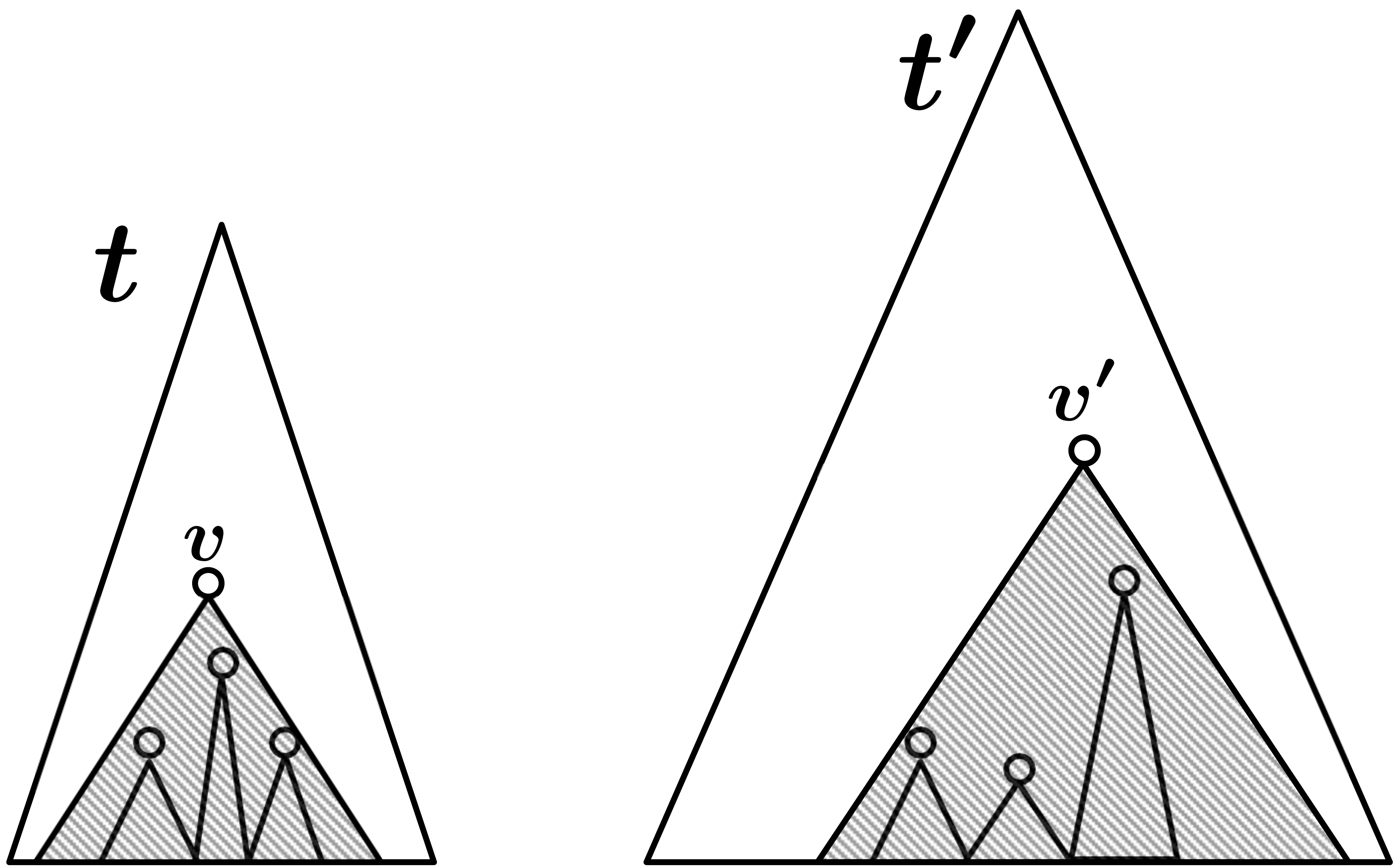
Weighted Transitive Closures



Weights ρ associated with all edges in the tree

$$\rho(v,u) = \frac{\text{area}(u)}{\text{area}(v)}$$

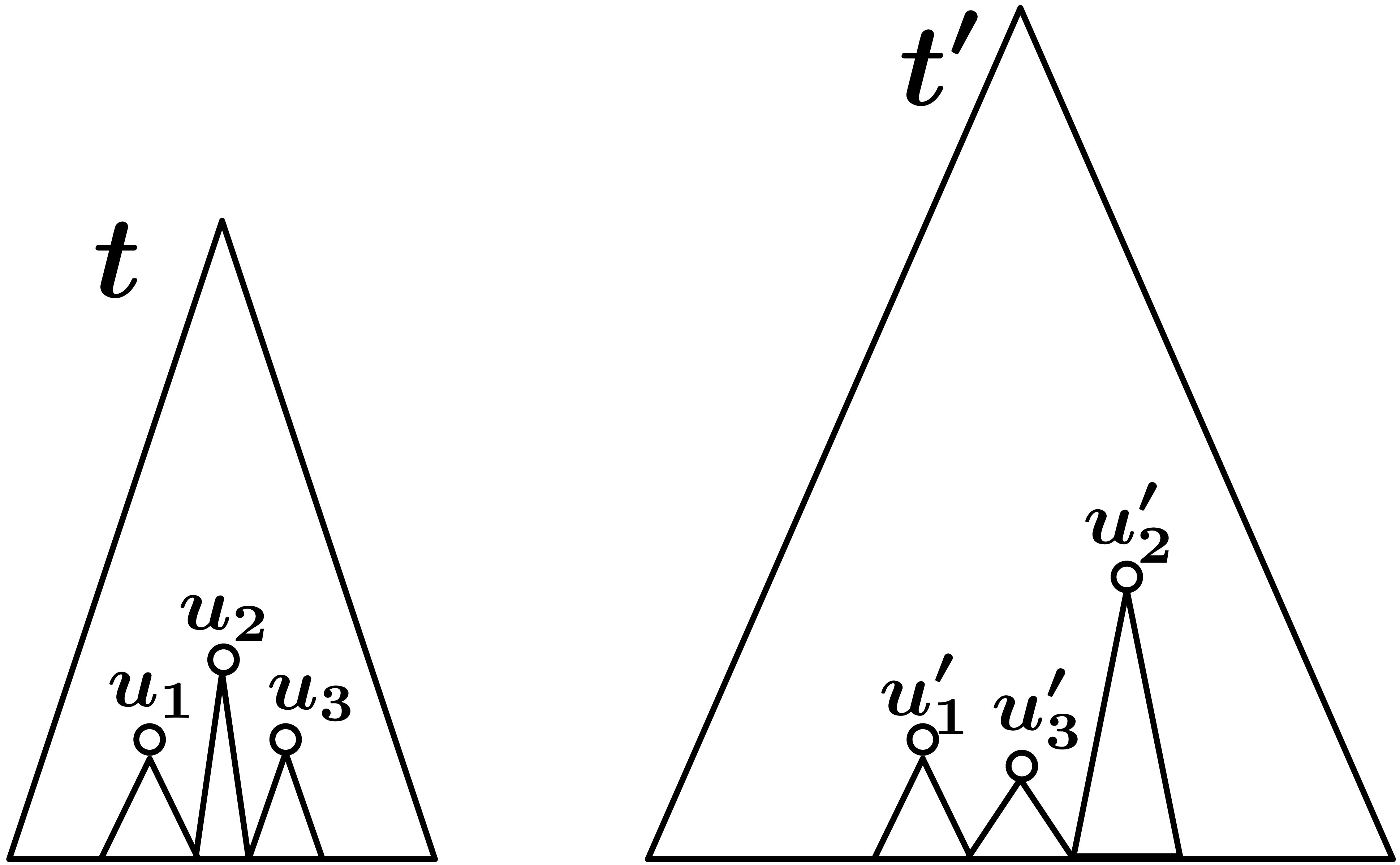
Bottom-Up Matching



$$COST_{vv'} = C_{vv'} + \min_{f_{vv'}} \sum_{(u,u') \in f_{vv'}} COST_{uu'}$$

mapping function

Bottom-Up Matching



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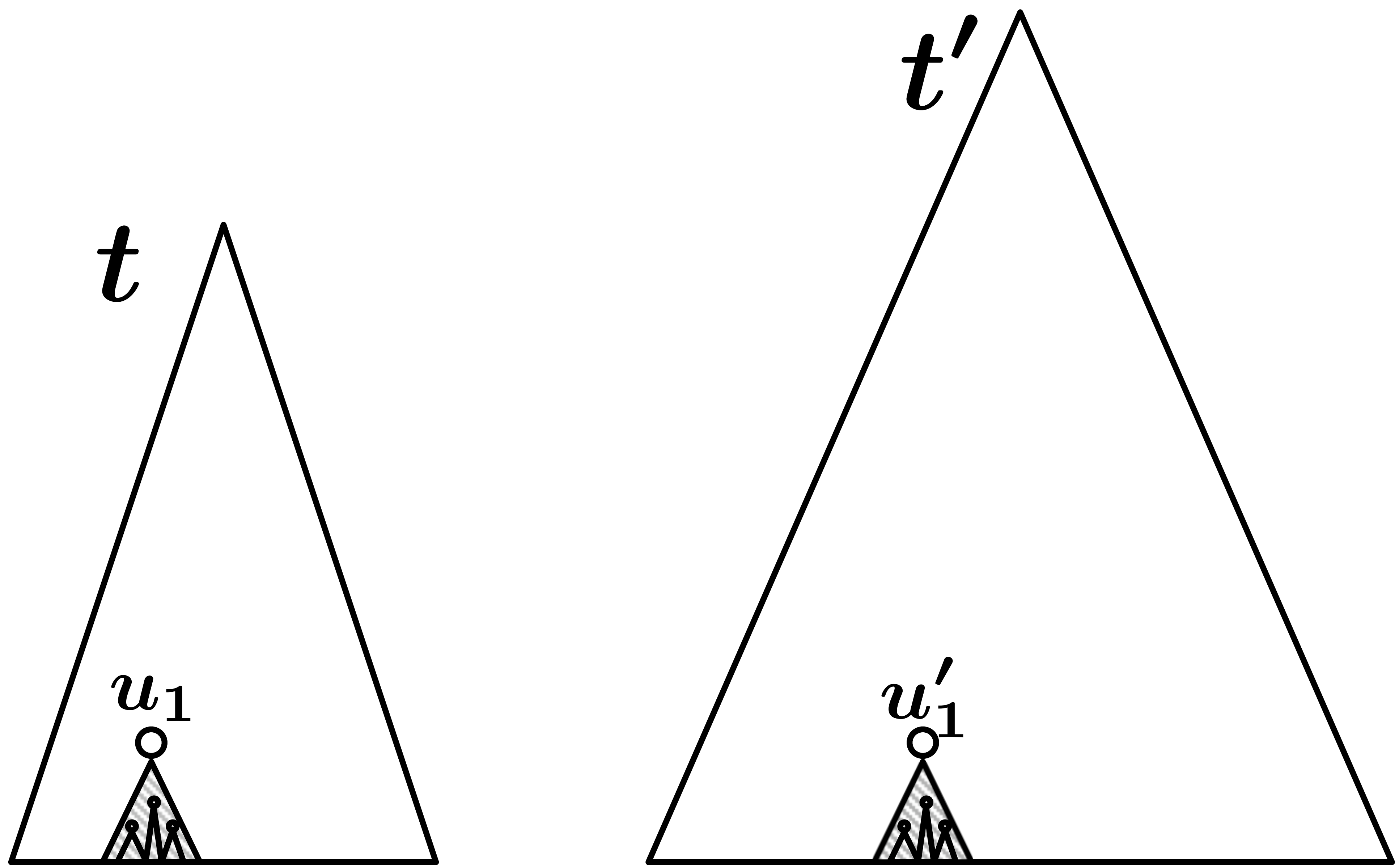

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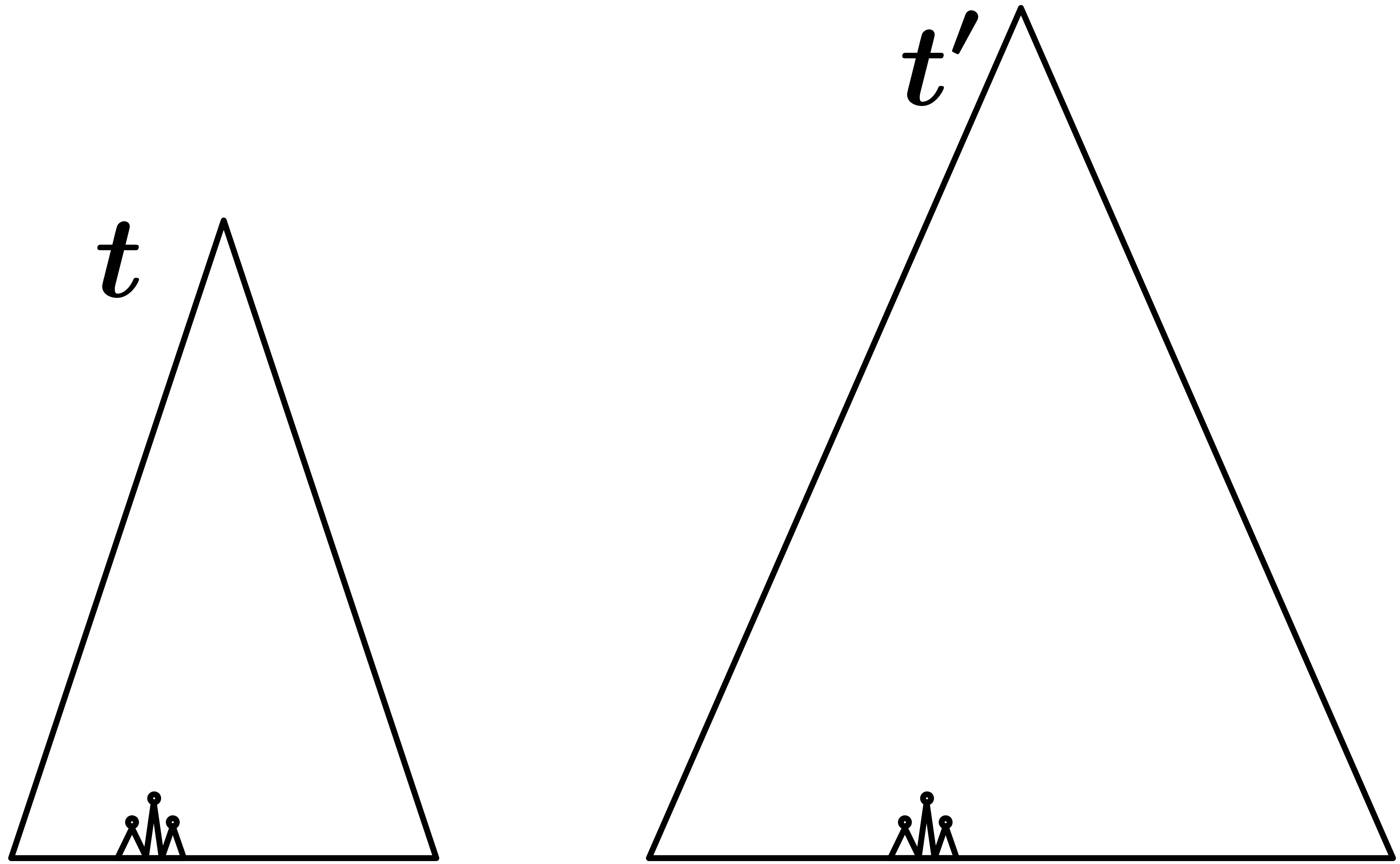

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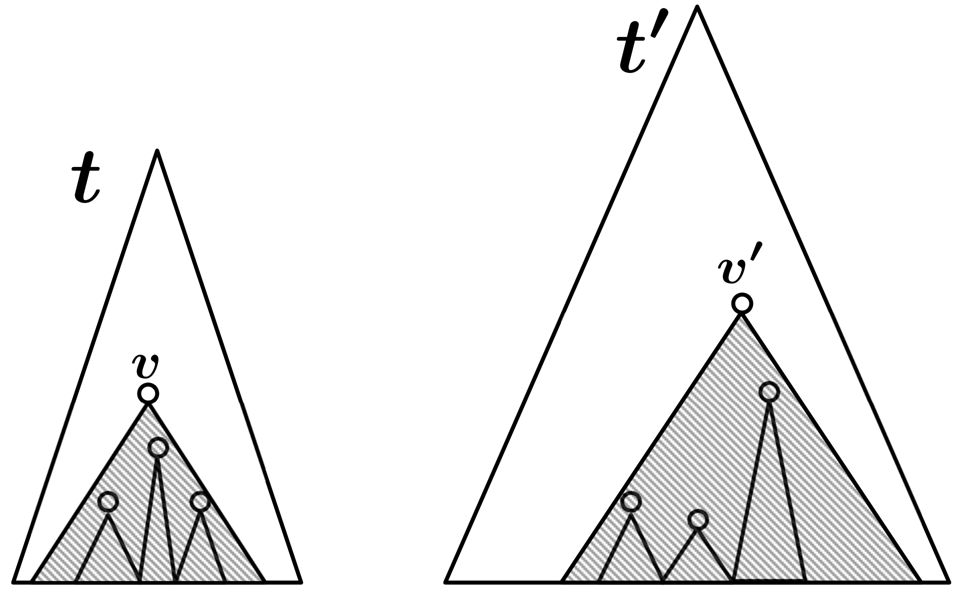
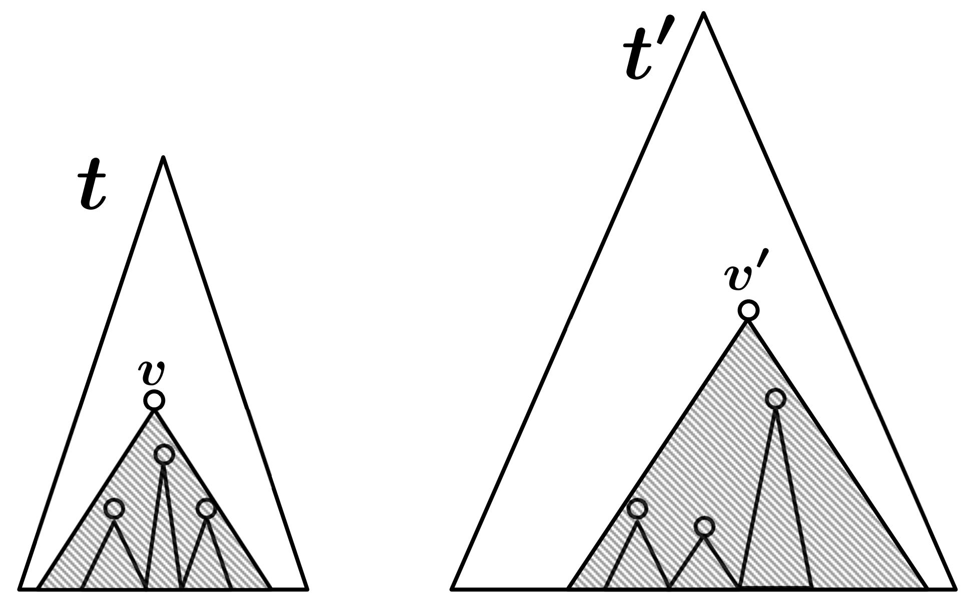
Separation of Scene Scale from Object Scale



Example:

$$\delta_{\text{area}} = \text{area}(v)/\text{area}(v') \;\rightarrow\; \widetilde{\text{area}}(v') = \delta_{\text{area}} * \text{area}(v')$$

Separation of Scene Scale from Object Scale



Example:

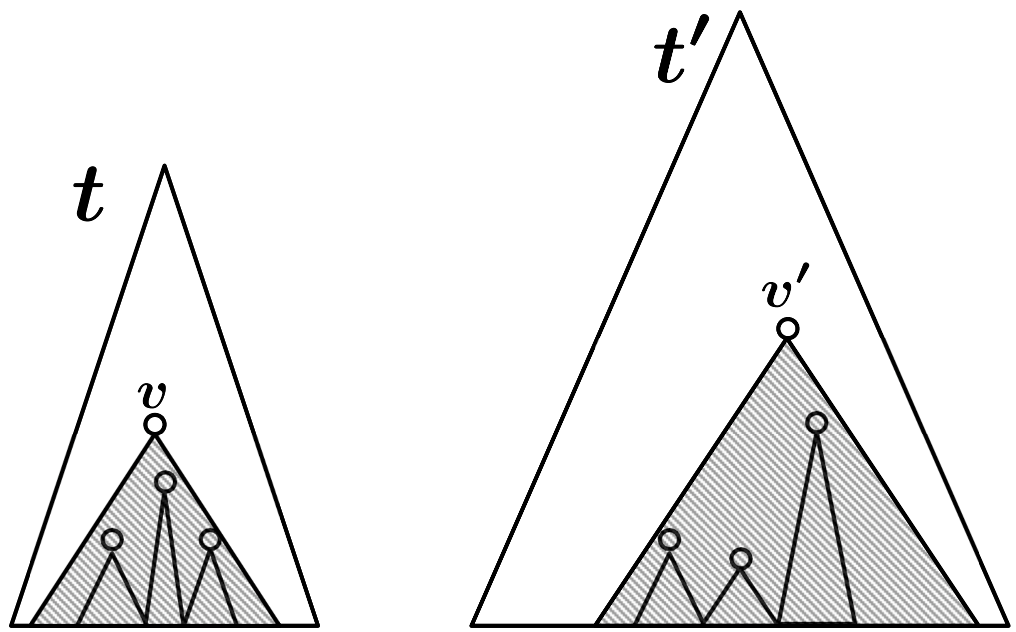
$$\delta_{\mathrm{area}} = \mathrm{area}(v)/\mathrm{area}(v') \;\rightarrow\; \widetilde{\mathrm{area}}(v') = \delta_{\mathrm{area}} * \mathrm{area}(v')$$

$\boldsymbol{\psi}(v),\ \boldsymbol{\psi}(v')$ = **vectors of region properties**

$$\delta_i = \psi_i(v) \oslash \psi_i(v') \;\rightarrow\; \widetilde{\psi}_i(v') = \delta_i \otimes \psi_i(v')$$

$\Rightarrow\quad \boldsymbol{\Delta} = \{\delta_1, \ldots, \delta_d\}$ **normalization factors**

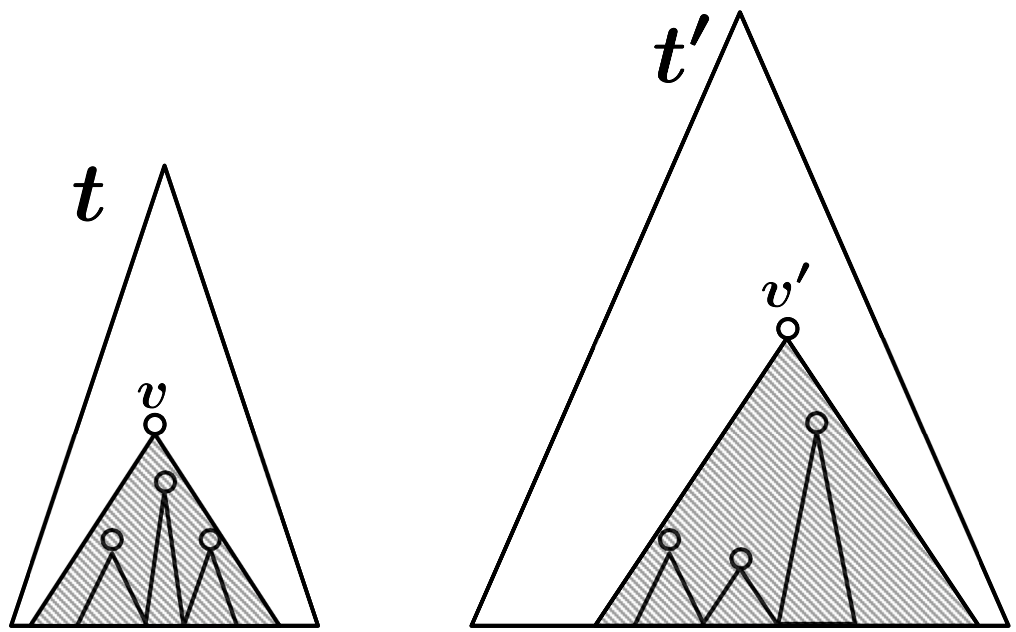
Normalization



Use $\boldsymbol{\Delta}$ to normalize all descendants u' of v'

$$\widetilde{\boldsymbol{\psi}}_i(u') = \delta_i \otimes \boldsymbol{\psi}_i(u') \quad i = 1, \ldots, d$$

Normalization



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$$\widetilde{\psi}_i(u') = \delta_i \otimes \psi_i(u') \quad i = 1, \ldots, d$$

$$\Downarrow$$

Properties of all nodes are normalized to those of root v

$$\Downarrow$$

Separation of the scale of the object from the scale of the scene

Tree Matching: Formulation

Given two weighted trees: $t = (V, E, \psi, \rho)$ **and** $t' = (V', E', \widetilde{\psi'}, \rho')$

For each pair of nodes: $(v, v') \in V \times V'$

Find bijection between the descendants of v **and** v'

$$f = \{(u, u')\} \subset V \times V'$$

which minimizes the cost of matching:

$$C_{vv'} = \min_{f} \left[\sum_{(u,u') \in f} A_{vv'} + \sum_{(w,w',u,u') \in f \times f} B_{vv'uu'} \right]$$

where A **and** B **are defined in terms of region properties and edge weights**

Tree Matching: Formulation

Relaxation of the discrete problem

$$\boldsymbol{C_{vv'} = \min_{X} \left[A^T X + \frac{1}{2} X^T B X \right]}$$

s.t.

$$\boldsymbol{x_{uu'} \in [0,1], \quad \sum_{u} x_{uu'} = 1 \quad \sum_{u'} x_{uu'} = 1}$$

Results: Discovery and Segmentation

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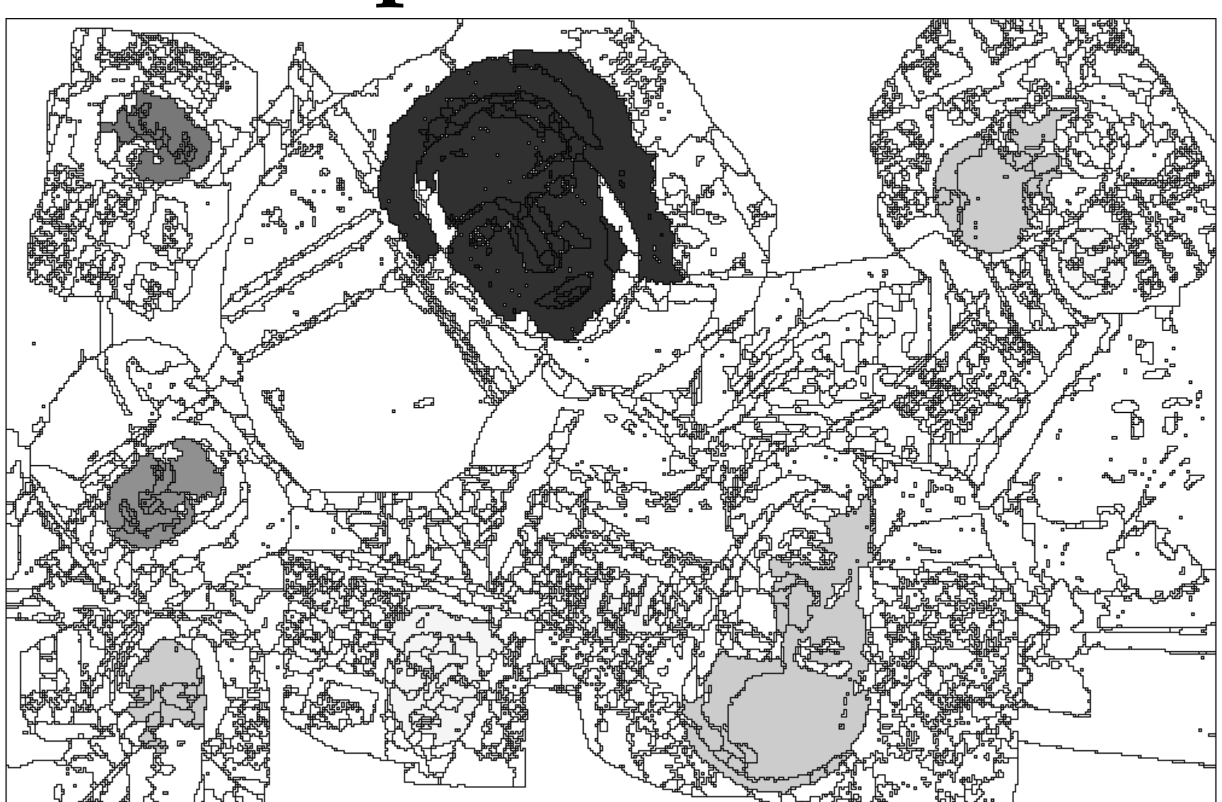
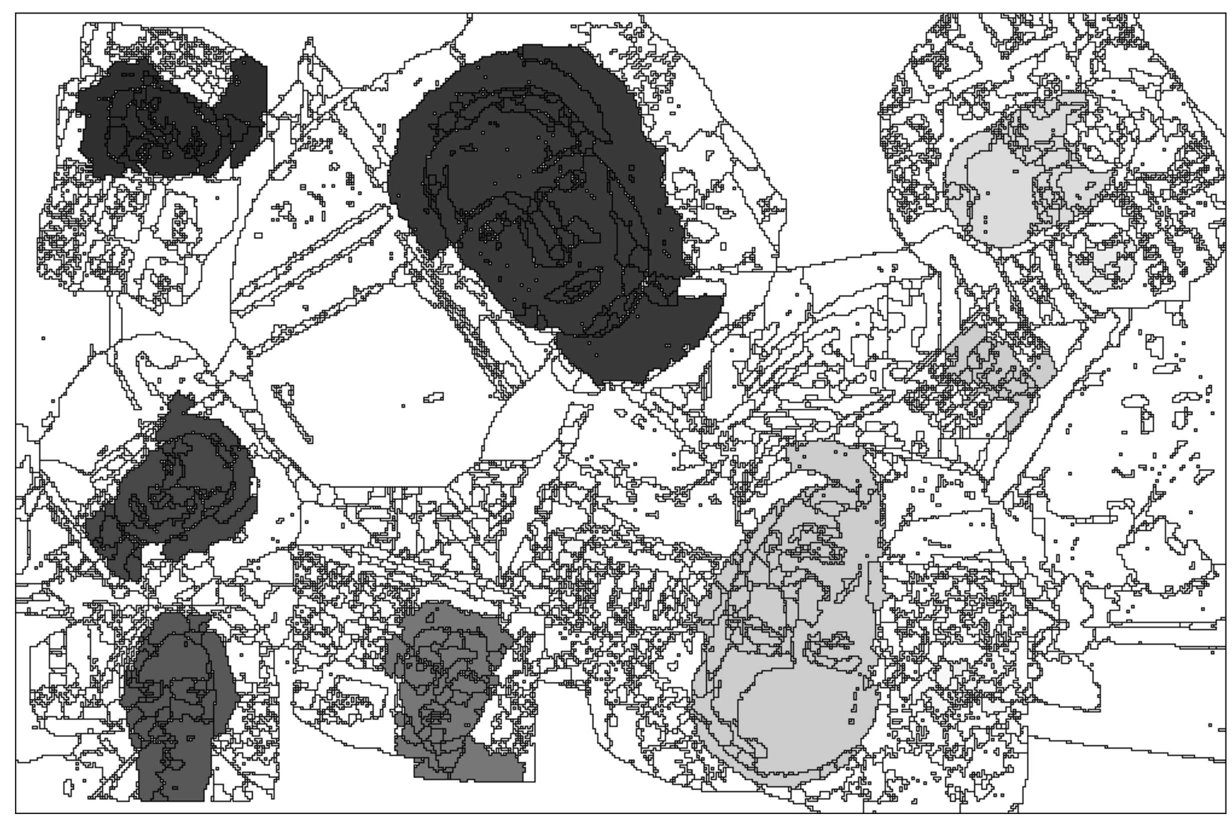
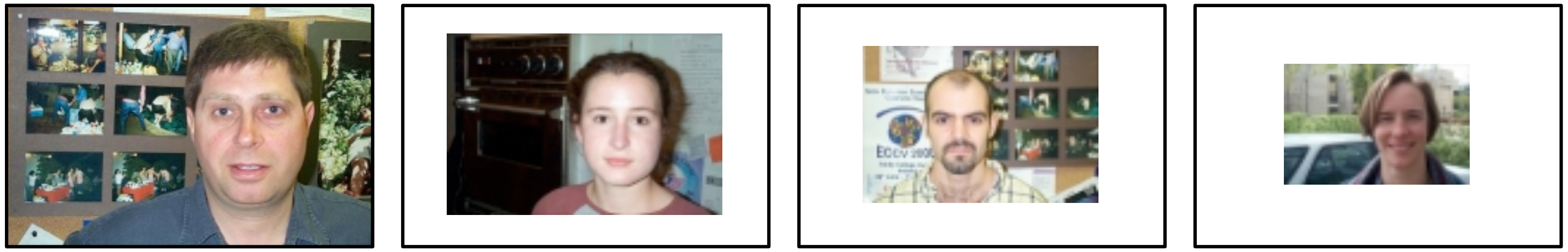
prior work

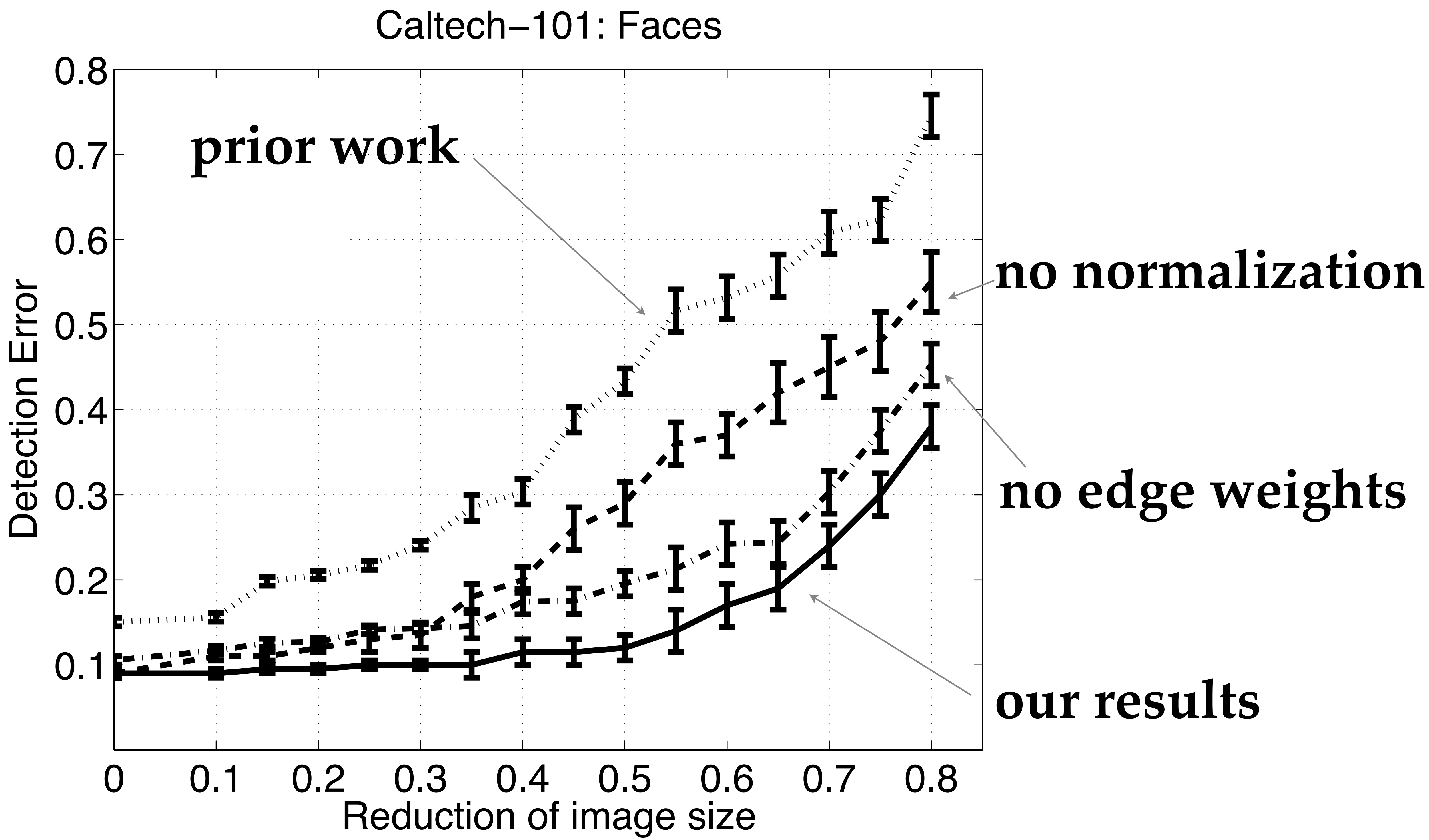


our results

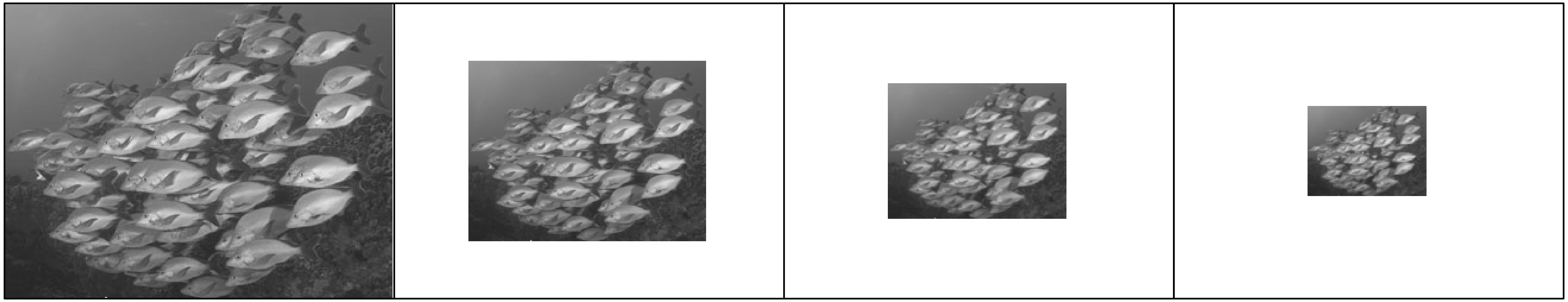


Results: Discovery and Segmentation

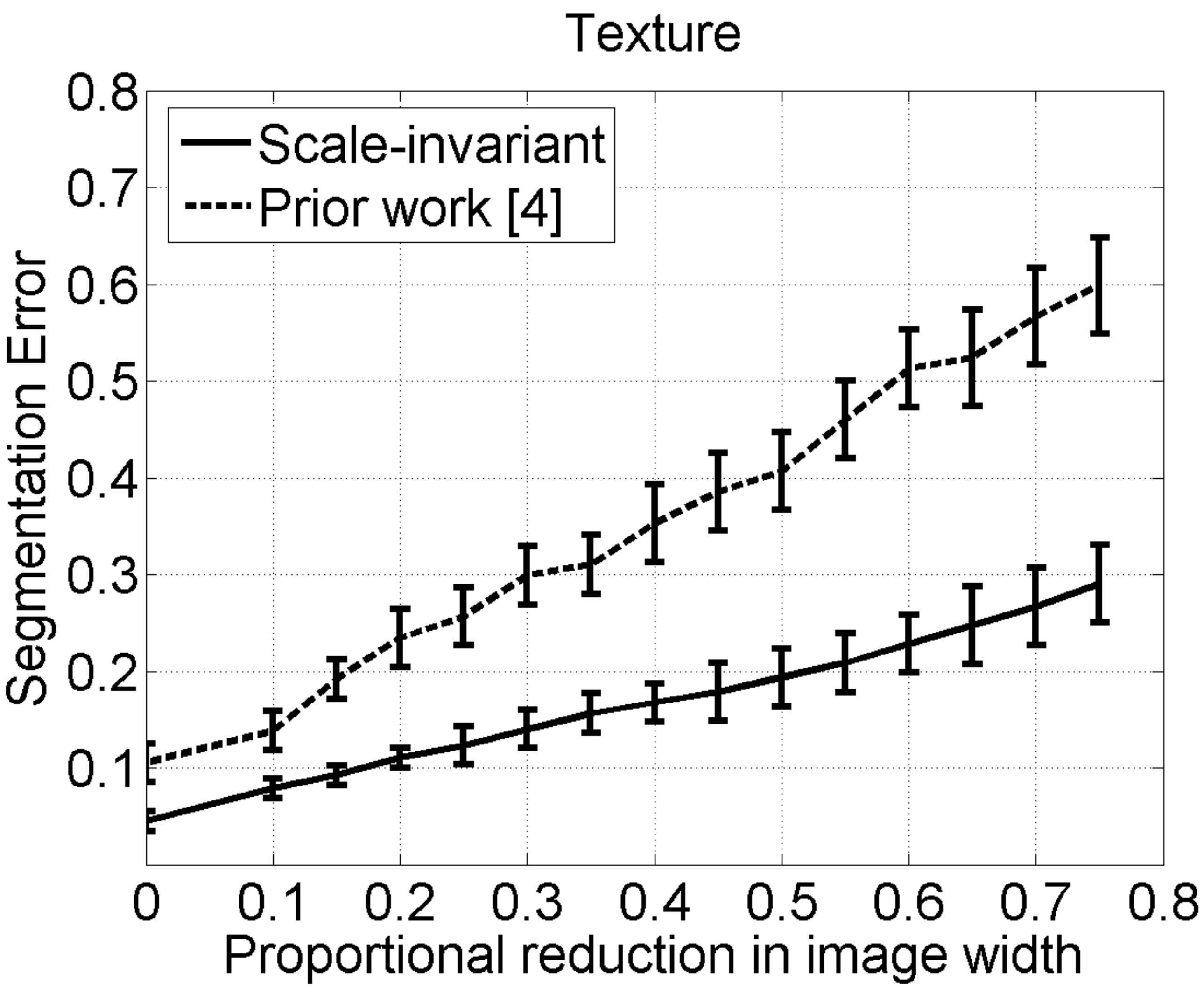




Results: Discovery and Segmentation



matching the down-sampled textures



Summary

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- **Scale-invariant object matching achieved by:**

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- **Down-weighting the effect of missing fine details at coarser scales**

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- **Scale-invariant object matching achieved by:**
- **Down-weighting the effect of missing fine details at coarser scales**
- **Separating the scale of the object from the scale of the scene**