Extracting Texels in 2.1D Textures

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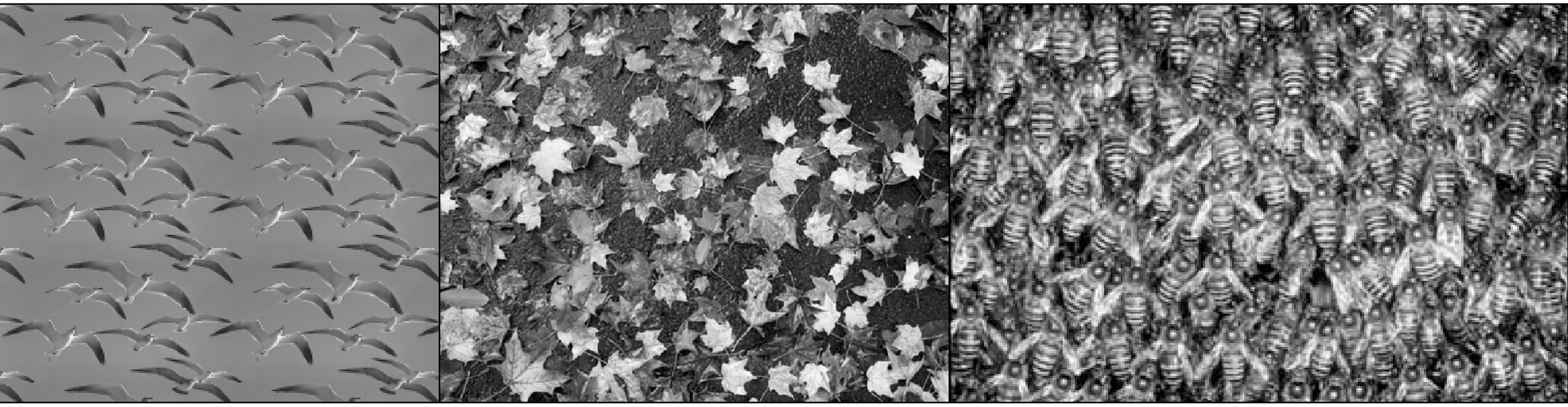
What is image texture?

...Repeated occurrence of image texture elements (or texels)...

[Beck ‘82]

Texture is Often Random

- **Image texels = Images of spatially recurring physical texture elements**
- **Texels are not identical, only statistically similar**
- **Texel placement is not regular**



Motivation

Texel is a natural primitive of texture models

Our goal here = Estimation of texel model

Prior Work

- **Texture research has a long history...**

  as old as computer vision...

  and continuing...

- **Most work in terms of texture features, for**
  - **Modeling**
  - **Classification**
  - **Segmentation**
  - **Shape from texture...**

Prior Work

- **Hardly any work on texel modeling and segmentation**
- **Closest work = Locating point(s) within each texel**

Our Goal:

Modeling and Extraction of Texels in Natural 2.1D Textures

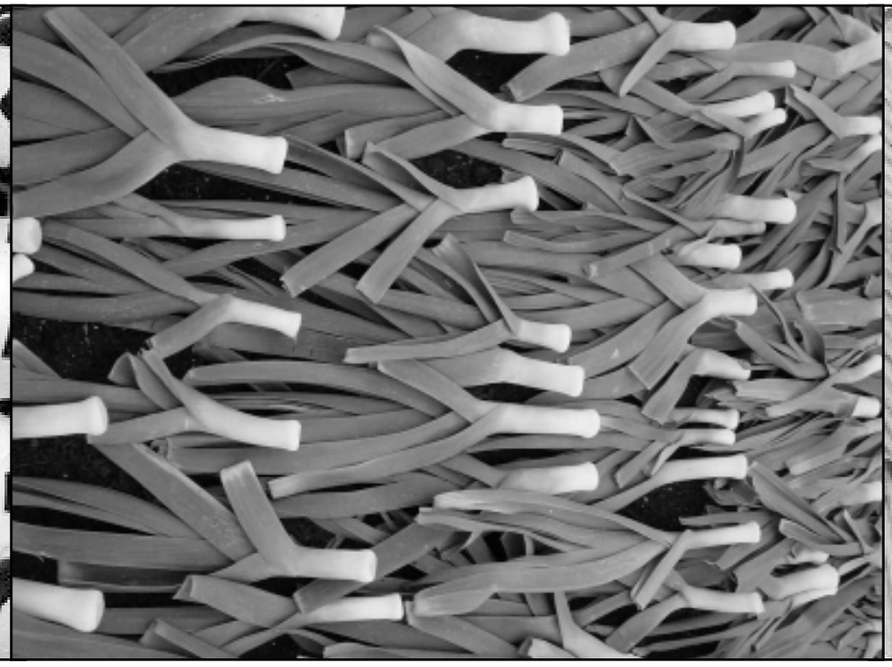
What is 2.1D Texture?

Physical texels are characterized by

- **Texel thickness << Texel distance**
- **Overlap ⇒ Inter-texel occlusion**

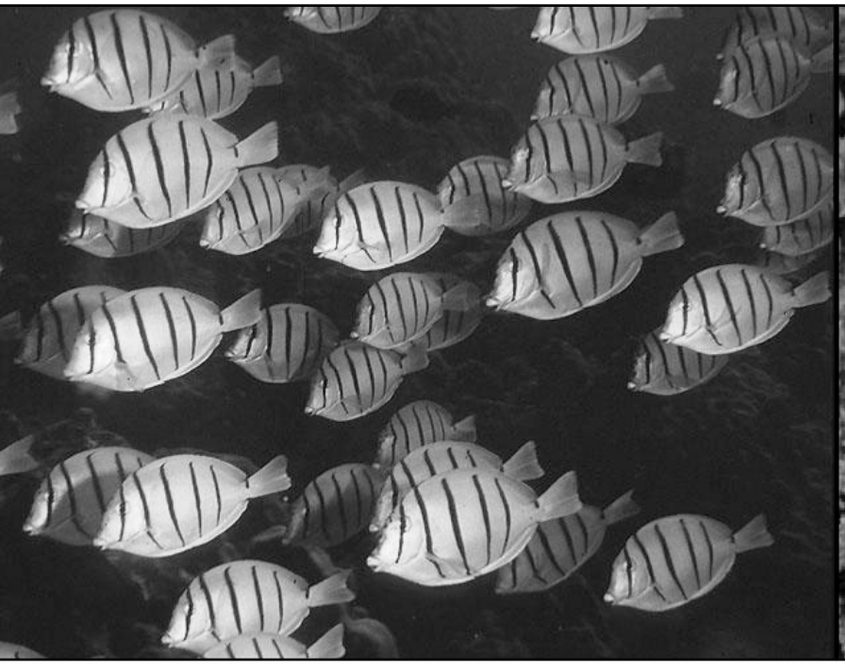
Implications

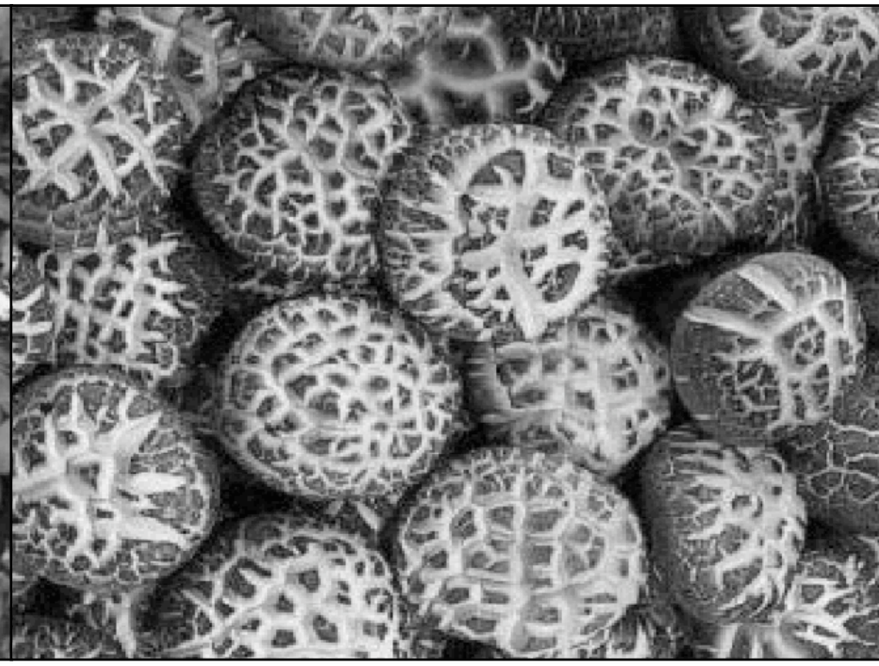
- **Only a part of a texel may be visible**
- **Visible texel parts = Samples of different, unknown texel parts**

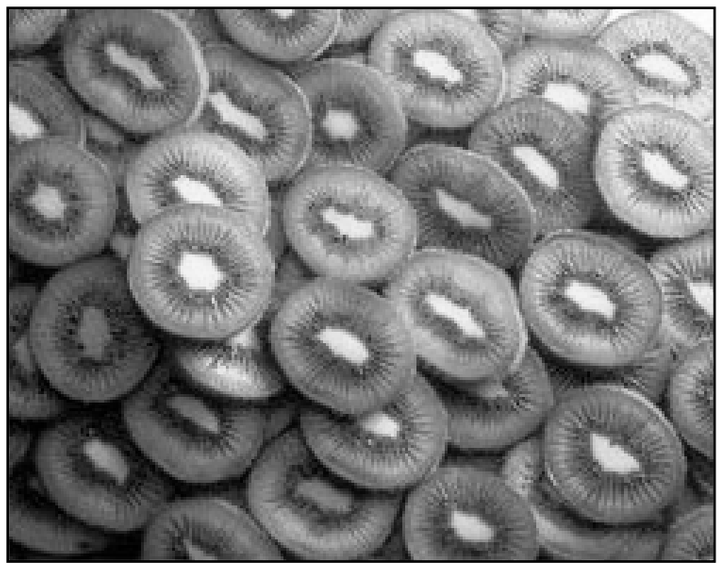

Added Challenges of Natural 2.1D Textures

- **Texels are not homogeneous regions -- they contain subregions**
- **Texels may have different sizes, orientations**
- **Multiple textures may be interleaved**
- **No identifiable background**





Problem Statement



GIVEN

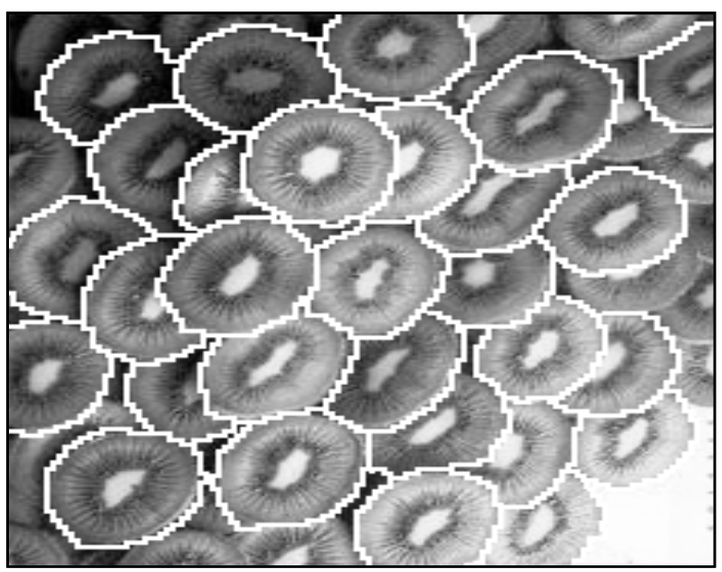
an image of frontally viewed 2.1D texture,

IDENTIFY

the texels, and

LEARN

the texel model



In a new image of the same texture

DETECT

and

SEGMENT

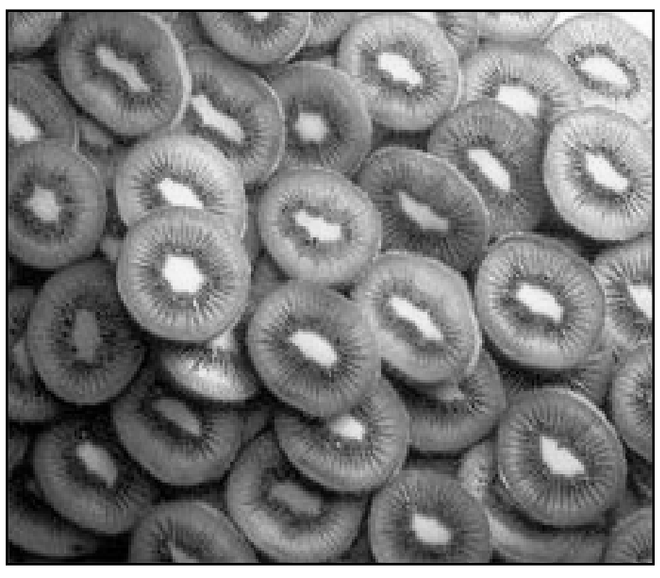
all texels by using the learned model.

From Texel Parts to Texel Model

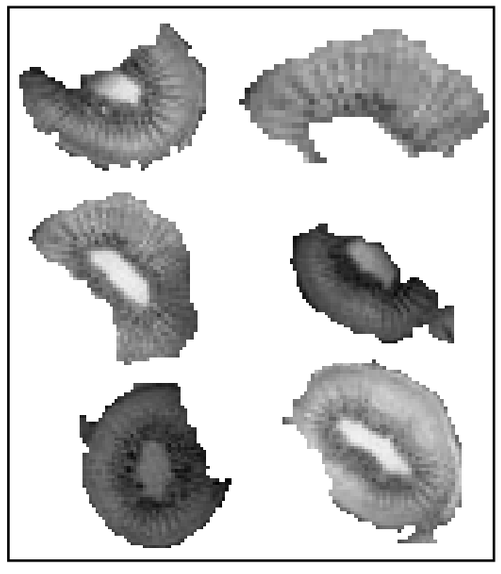
To build a texel model:

- **Identify subimages representing (partial) texels**
- **Register the subimages ⇒ Many overlaying texel samples**
- **Find their union ⇒ Texel model structure**
- **Estimate PDF of subimage properties ⇒ Texel model PDF**

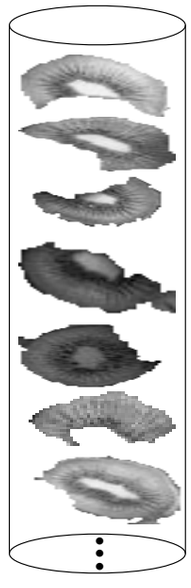
} **jointly**



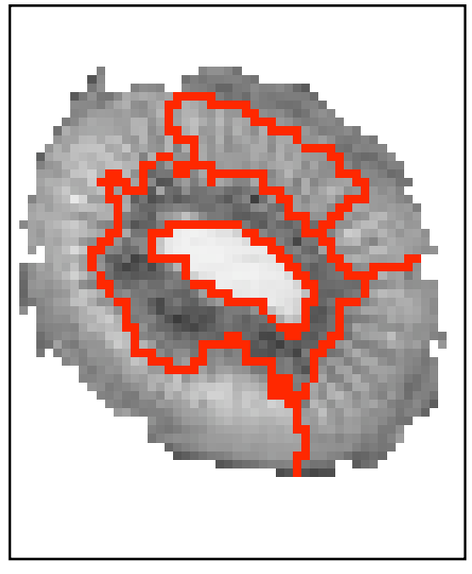
2.1D texture



identified subimages



registration



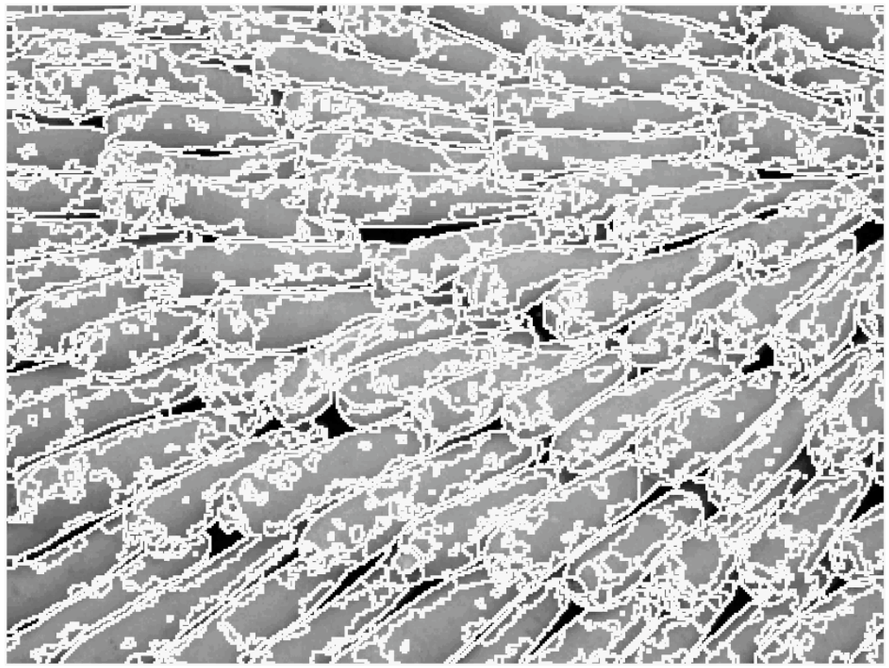
union + PDF

Our Approach: Step 1

Texture image ⇒ Segmentation tree

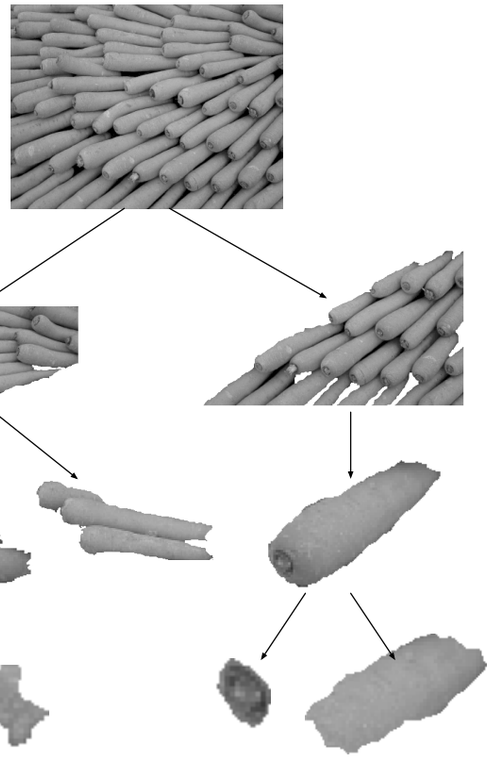
[Ahuja PAMI '97]

Multiscale segmentation
for all contrasts



Homogeneous regions at many contrasts, shapes, sizes

Segmentation tree
captures region embedding



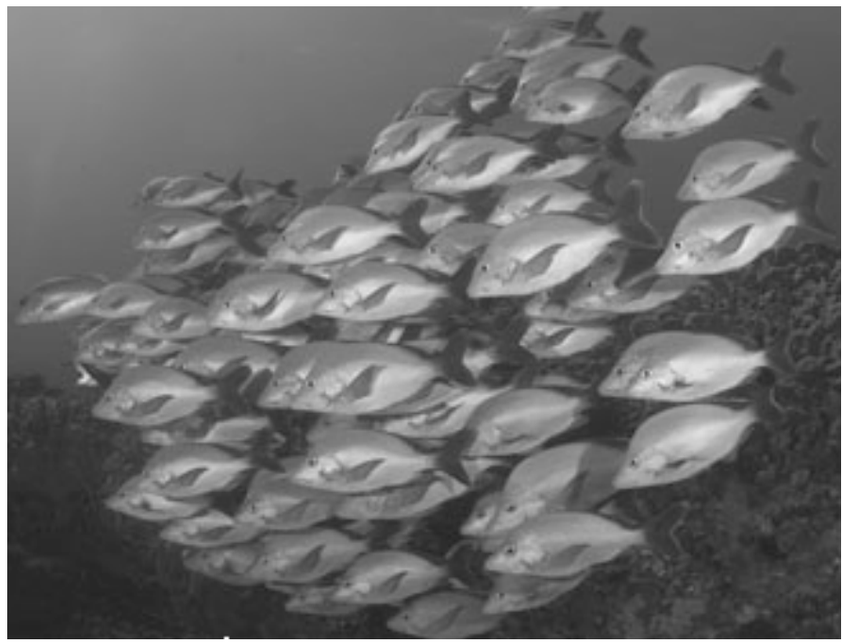
Regions are recursively embedded

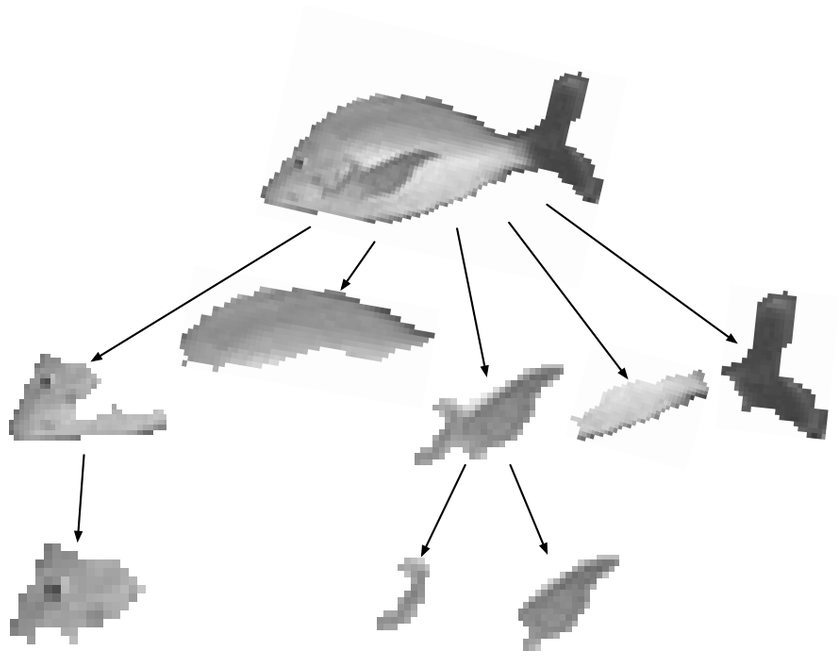
Geometric and photometric region properties recorded at each node

Step 1

Texels = Largest, recurring subtrees with statistically similar properties

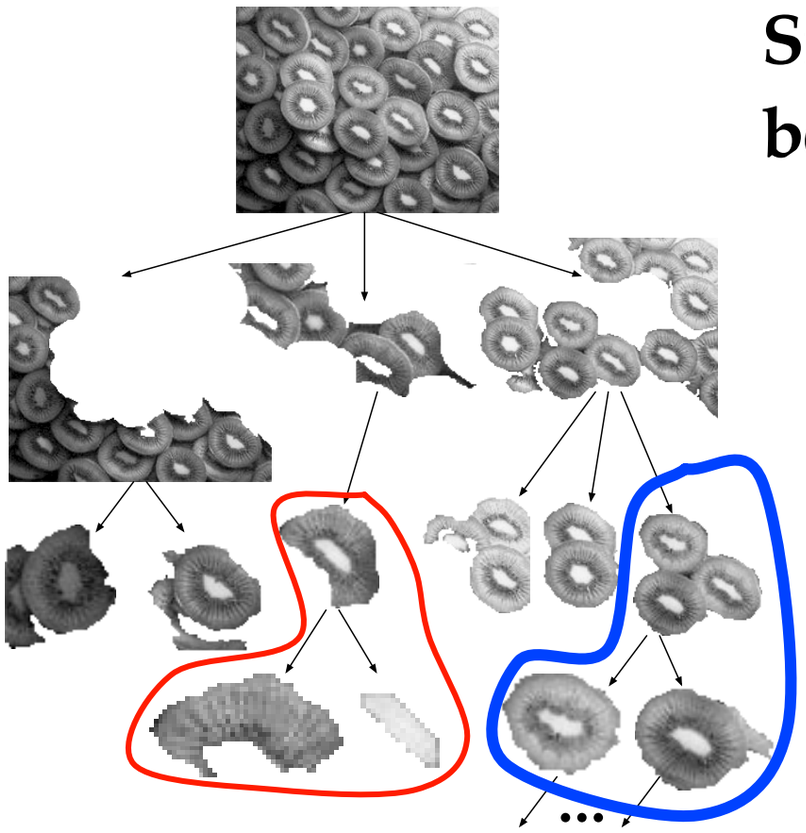
- **Geometric (area, shape)**
- **Photometric (contrast)**
- **Topological (subregion layout and containment)**





Step 2

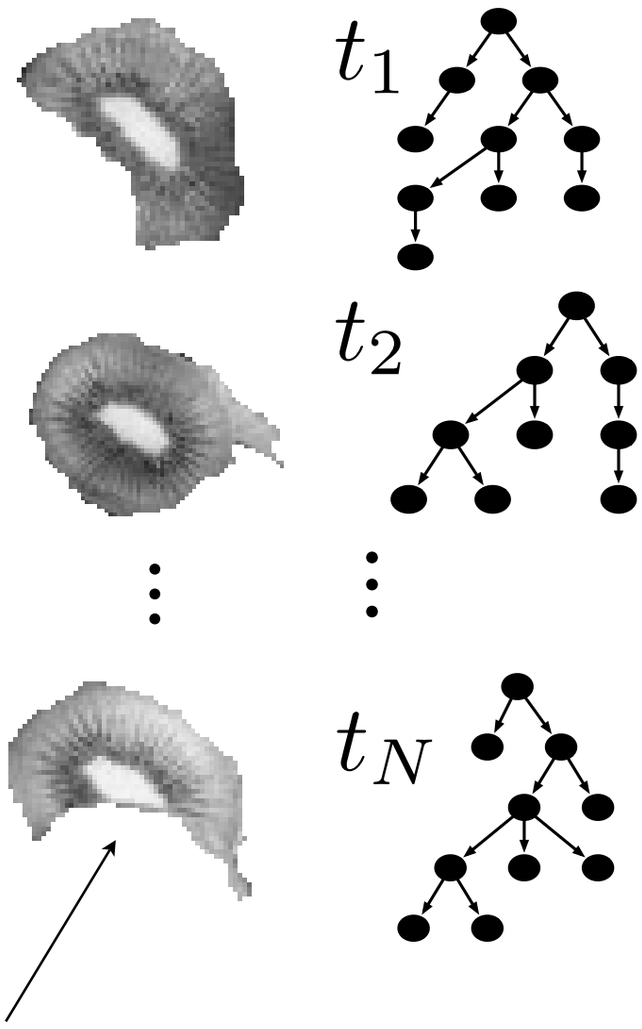
Find all matching subtrees within the segmentation tree



Similarity measures $\mathcal{S}_{ij}$ between subtrees i and j

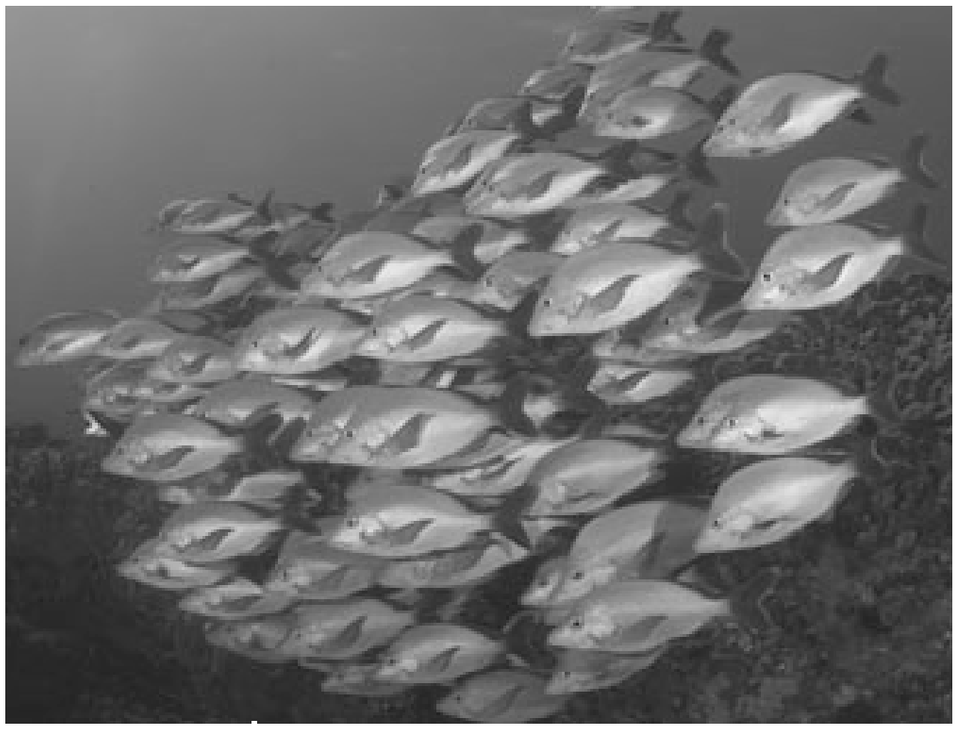
$$\begin{bmatrix} \times & \mathcal{S}_{12} & \mathcal{S}_{13} & \dots & \mathcal{S}_{1M} \\ \times & \times & \mathcal{S}_{23} & \dots & \mathcal{S}_{2M} \\ & & \vdots & & \end{bmatrix}$$

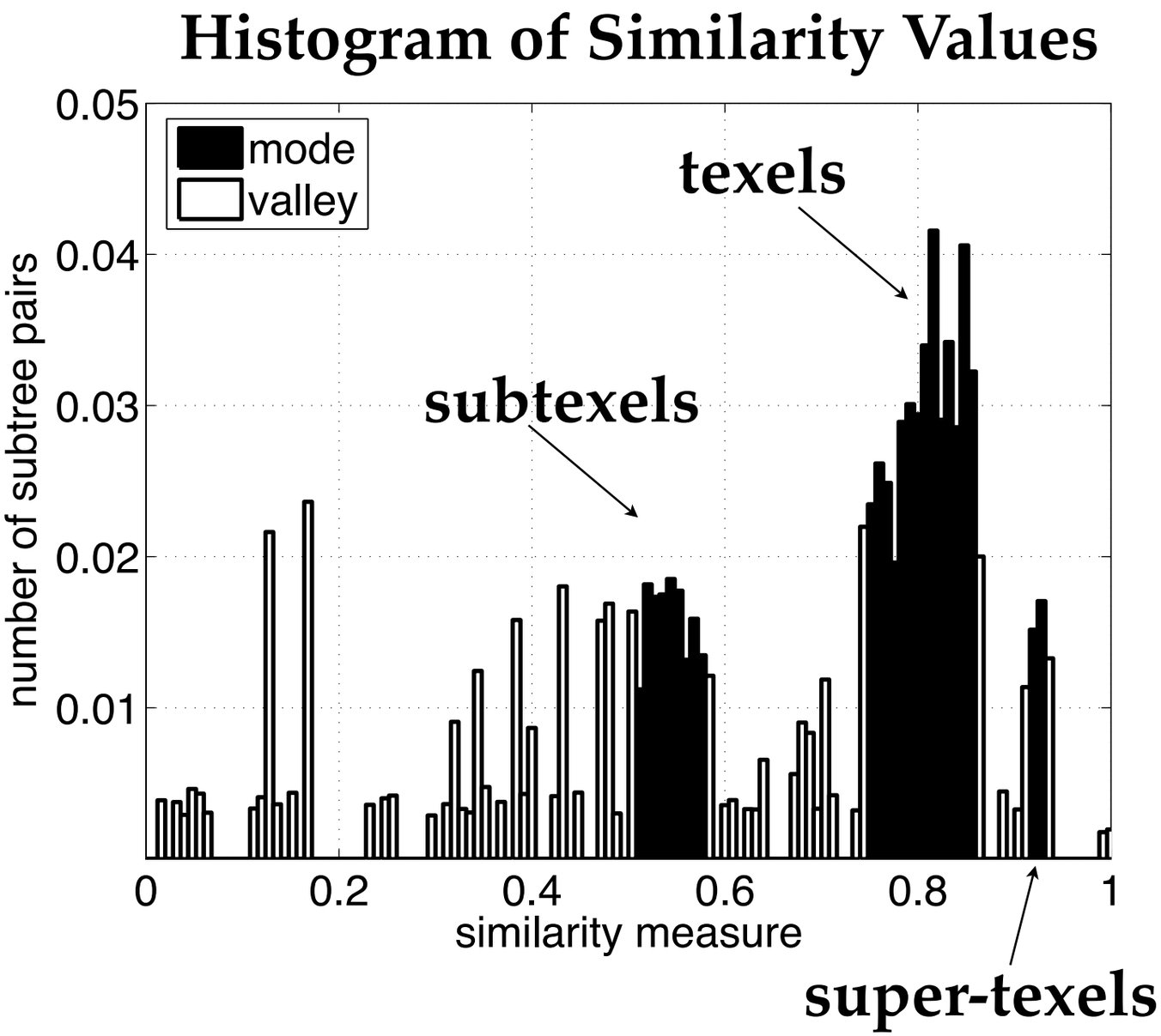
[Todorovic&Ahuja IJCV '07]



Largest, recurring, similar subtrees across the segmentation tree
= Identified (partial) texels

Step 2: Identifying Texels

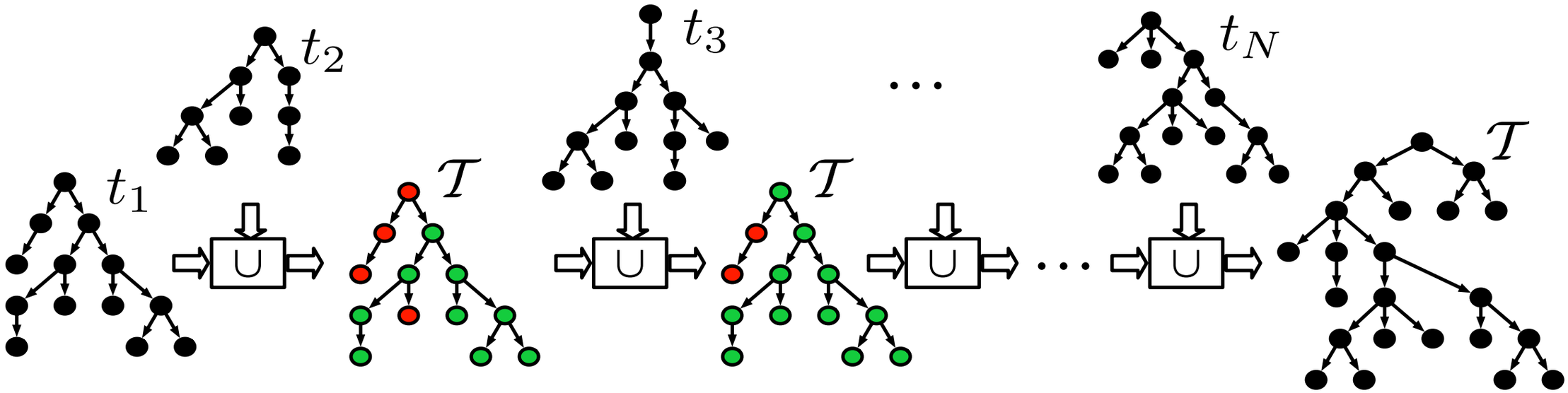




$$\text{texel\_mode} \triangleq \arg\max_{\text{mode}} \sum_{s \in \text{mode}} \mathcal{S} \cdot \mathcal{H}(\mathcal{S})$$

Step 3

Register matched subtrees to obtain their union



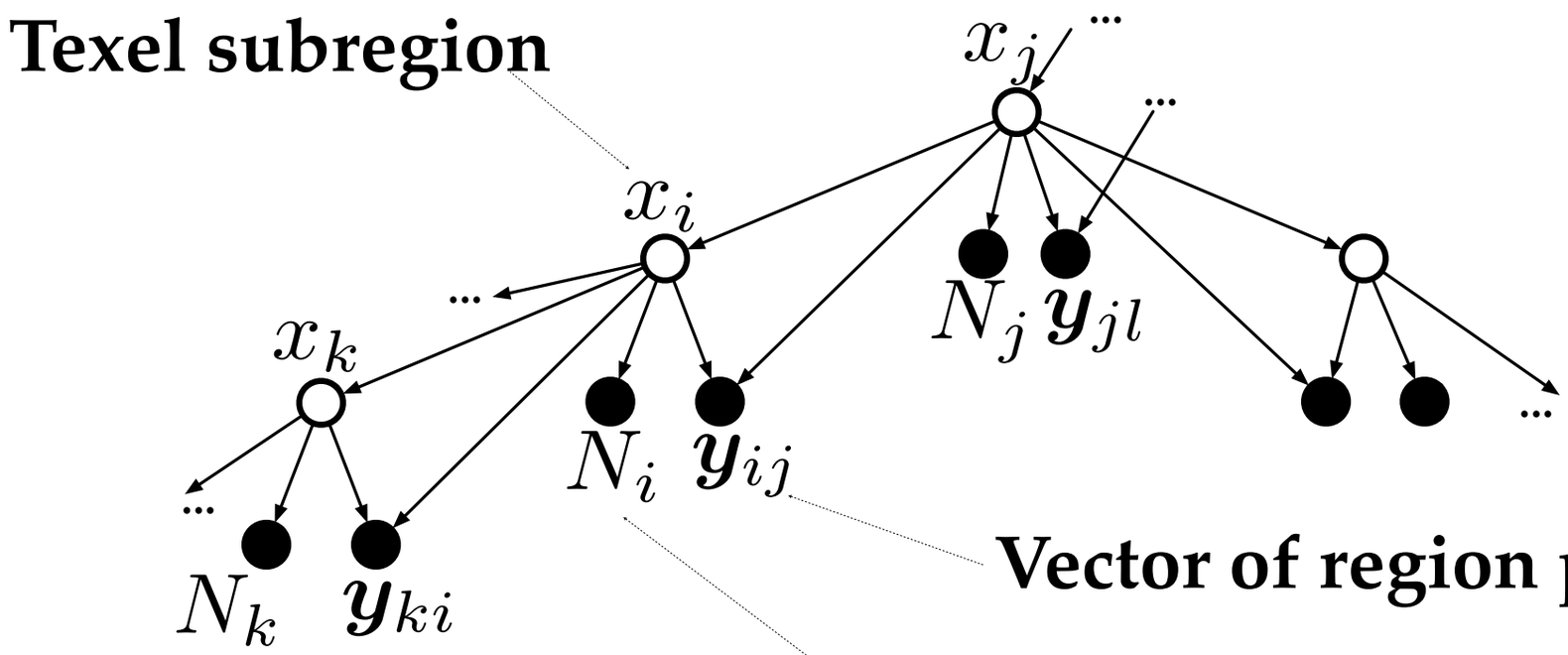
intersection **unmatched nodes**

Union $\mathcal{T}$ = The structure of texel model

Step 4

Estimate the PDF of properties associated with each node in the union

Node in the union = Many overlaying texel regions



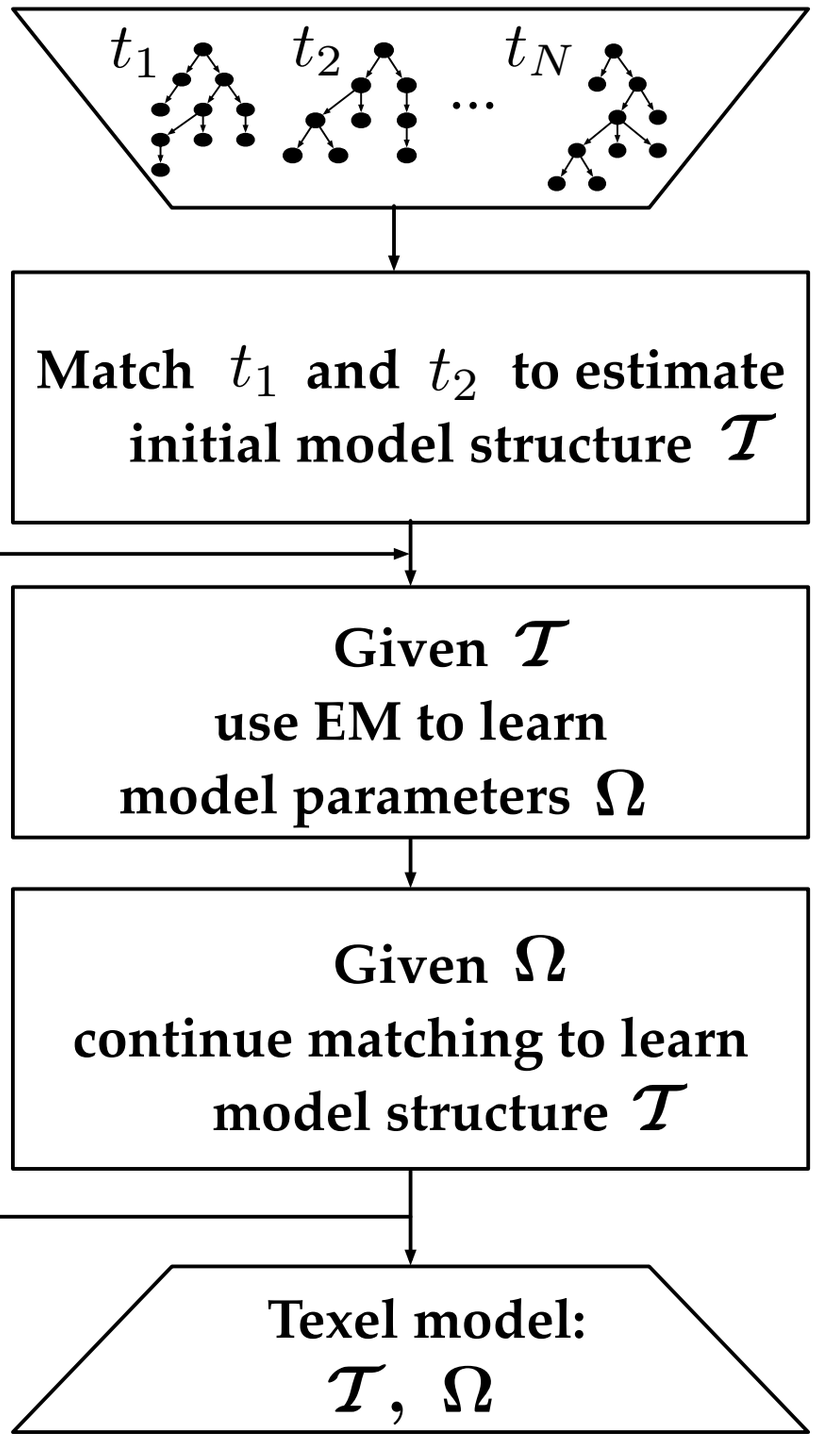
$$P(X, Y, N|\mathcal{T}, \Omega) = \prod_{j \in \mathcal{T}} P(N_j|x_j) \prod_{i=1}^{N_j} P(x_i|x_j) P(y_{ij}|x_i x_j)$$

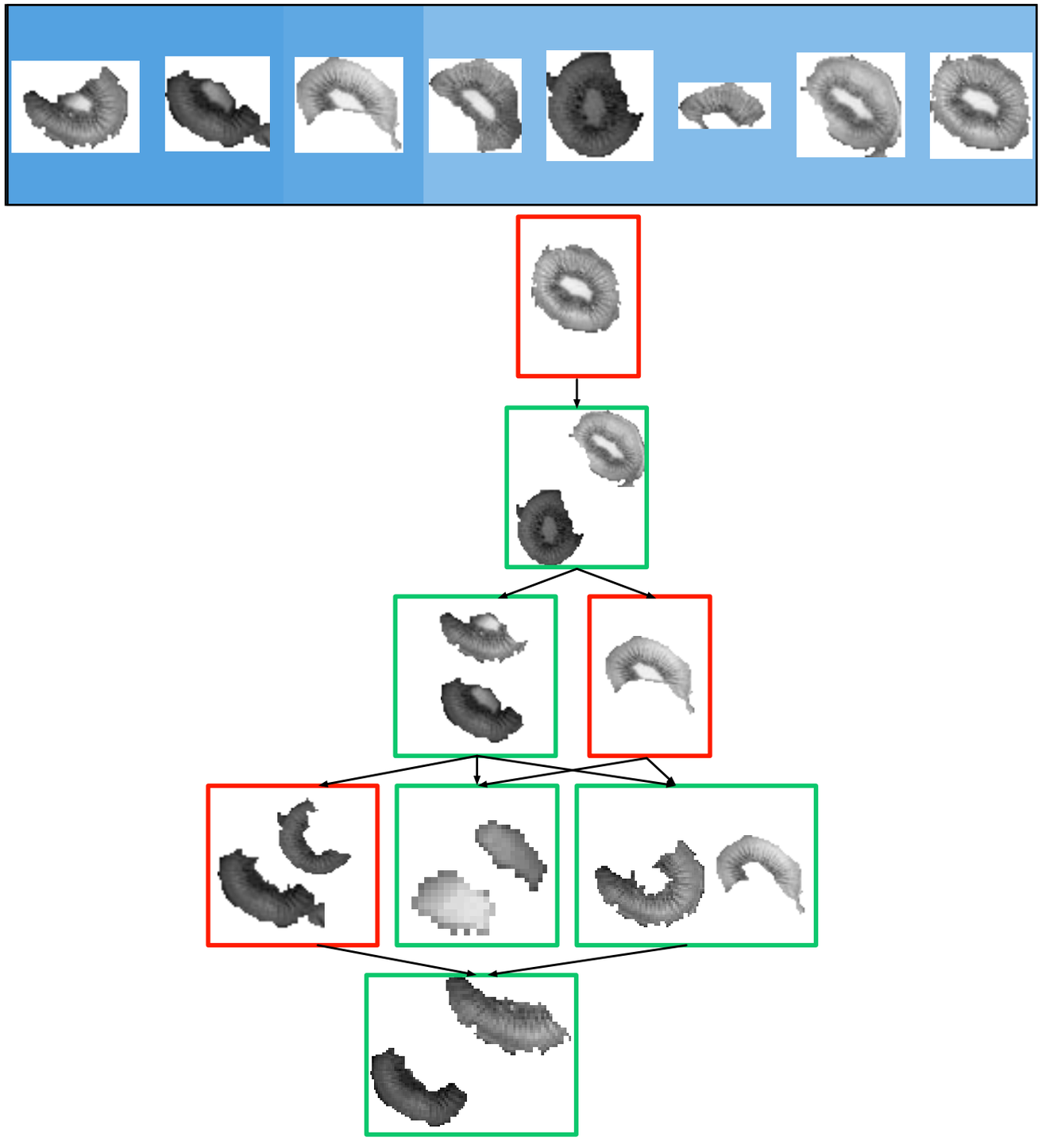
exponential **Gaussian**

Model parameters Ω = Exponential and Gaussian parameters

Step 4

Simultaneous learning of $\mathcal{T}$ and Ω





Evaluation: A New Dataset of 2.1D Textures

80 images of

planar physical textures

under near-frontal viewing

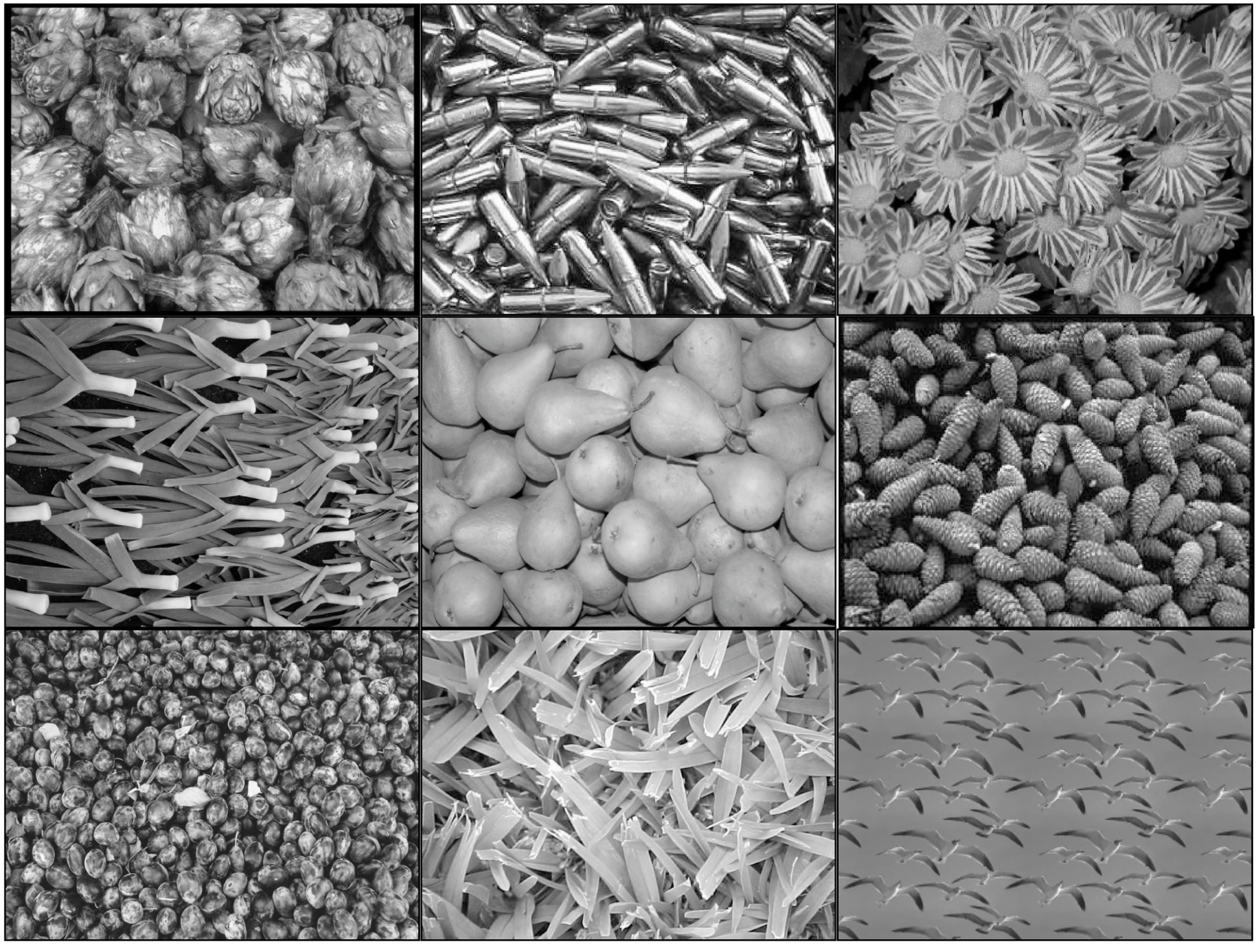
sample

Characterized by a large range of

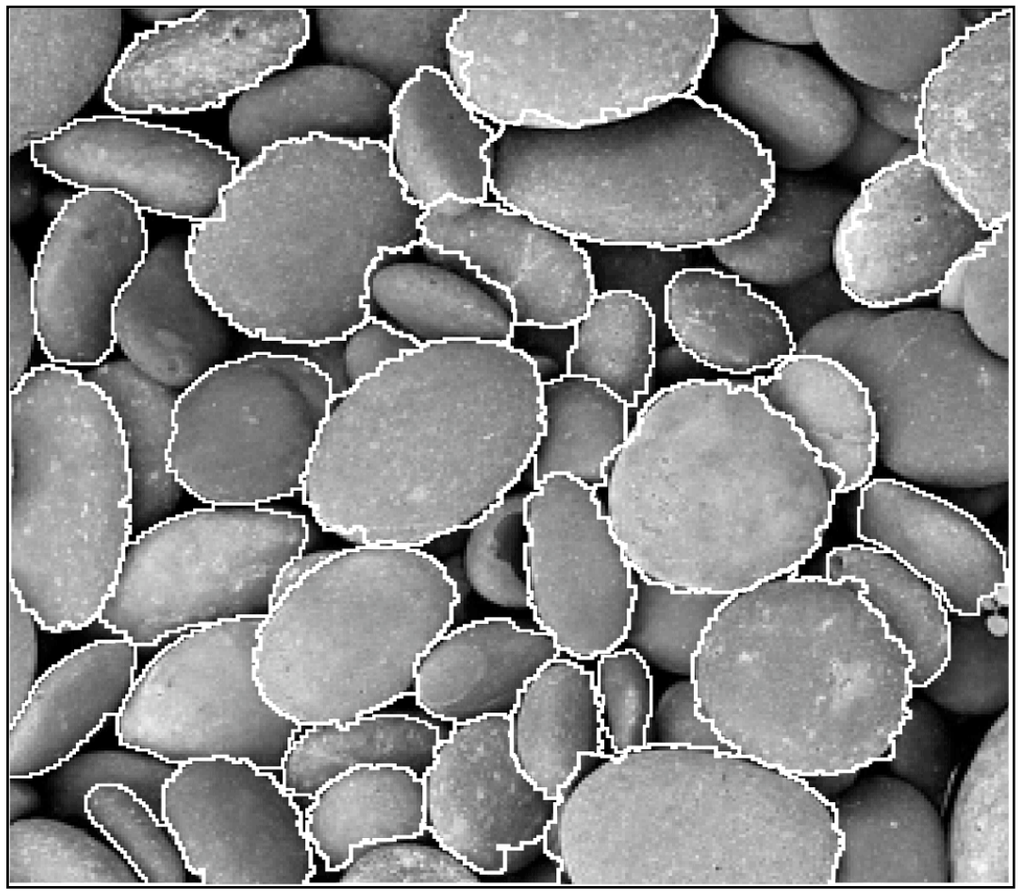
- **Size**
- **Orientation**
- **Subregion structure**
- **Shading, contrast and blur**
- **Shape complexity**
- **Topological complexity**

Samples from the Dataset

http://vision.ai.uiuc.edu/~sintod/datasets.html

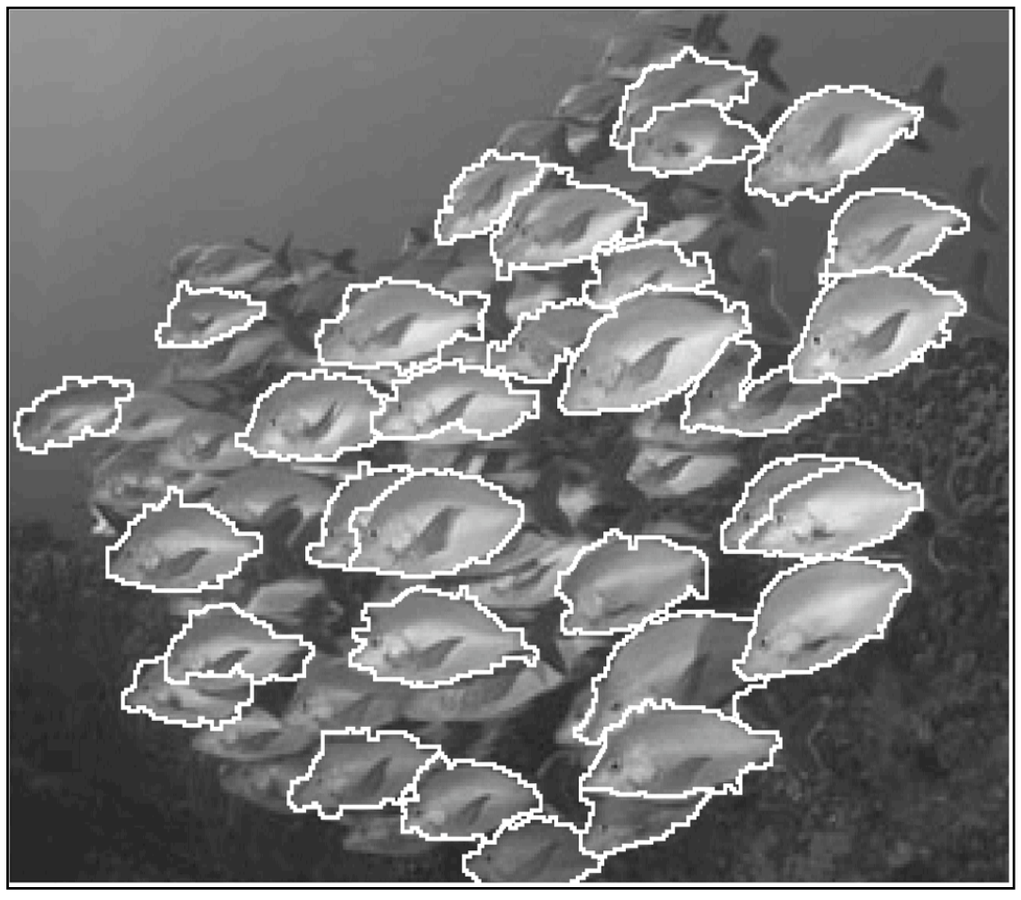


Evaluation



Extracted texel boundaries reasonably approximate Perceptual texel boundaries

Evaluation



Extracted texel boundaries reasonably approximate Perceptual texel boundaries

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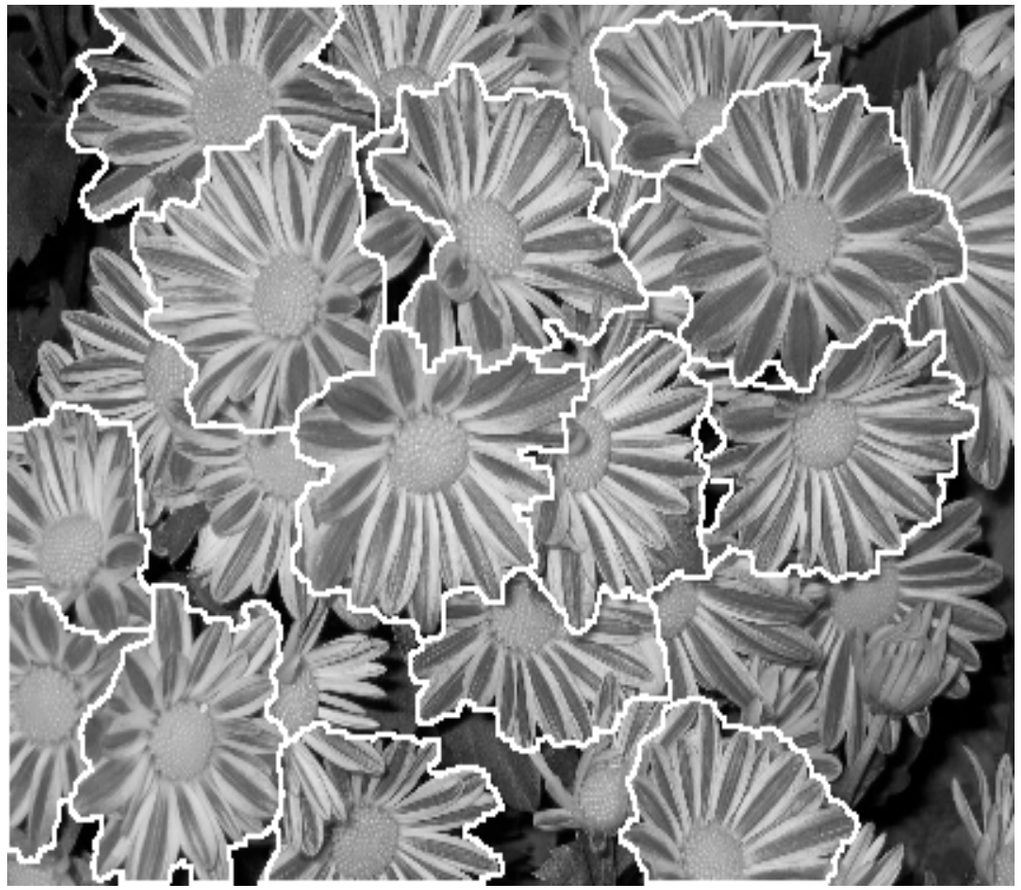

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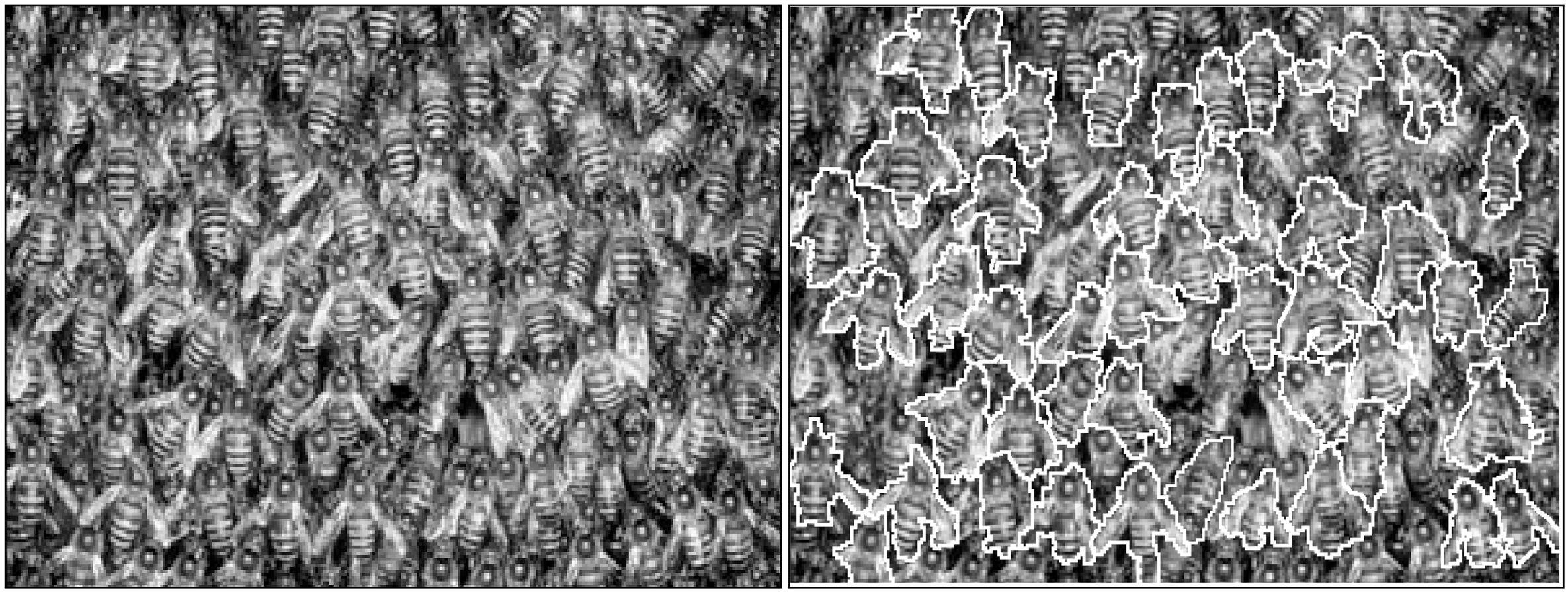

Extracted texel boundaries reasonably approximate Perceptual texel boundaries

Summary

- **Formulation of a new problem:**
  - **Definition of 2.1D texture**
  - **Texel extraction from an image of 2.1D texture**

- **Texel model is a natural primitive for modeling texture**

- **Definition of a generative statistical model of texels**
  - **PDF of intrinsic texel properties: geometric and photometric**
  - **PDF of texel subregion structure: spatial layout and containment**

- **Simultaneous learning of**
  - **model structure**
  - **model parameters**

  from a single texture image with partially occluded texels

- **Simultaneous texel detection and segmentation**