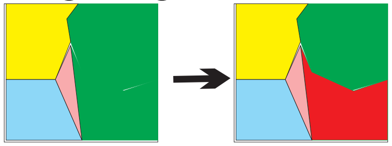
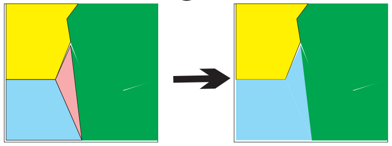
Region Segmentation

- Connected components analysis often results in many small disjointed regions.
- A connection (or break) at a single pixel and split (or merge) entire regions.
- There are three basic approaches to segmentation:
  - Region Merging - recursively merge regions that are similar in some way.



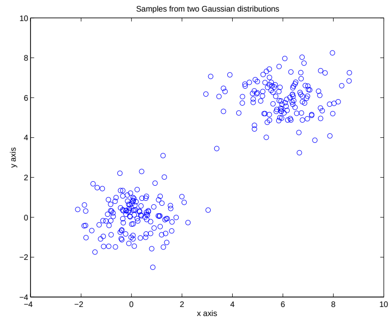
  - Region Splitting - recursively divide regions that are too heterogeneous.



  - Split and merge - iteratively merge and split regions to form the "best" segmentation.

Hierarchical Clustering

- Clustering refers to techniques for separating data samples into sets with distinct characteristics.



- Clustering methods are analogous to segmentation methods.
  - Agglomerative clustering - "bottom up" procedure for recursively merging clusters ⇒ analogous to region merging
  - Divisive clustering - "top down" procedure for recursively splitting clusters ⇒ analogous to region splitting

Image Regions and Partitions

- Let $R_m \subset S$ denote a region of the image where $m \in \mathcal{M}$.
- We say that $\{R_m\}|_{m\in\mathcal{M}}$ **partitions** the image if

$$\begin{aligned} \text{For all } \ m \neq k, \quad R_n \cap R_k &= \emptyset \\ \bigcup_{m\in\mathcal{M}} R_m &= S \end{aligned}$$

- Each region R_n has attributes or **features** that characterize it.

Region Features

Typical region features include

- Color - mean color in RGB; color histogram in RGB;
  * Mean RGB value
  * 1-D color histograms in R, G, and B
  * 3-D color histogram in (R,G,B)
- Texture
  * Spatial autocorrelation
  * Joint probability distribution for neighboring pixels (e.g. the spatial co-occurrence matrix.)
  * Wavelet transform coefficients
- Shape
  * Number of pixels
  * Width and height attributes
  * Boundary smoothness attributes
  * Adjacent region labels

Recursive Feature Computation

- Any two regions may be merged into a region $R_{new} = R_k \cup R_l$.
- Let $f_n = f(R_n) \in \mathbb{R}^k$ be a k dimensional feature vector extracted from the region R_n.
- Ideally, the features of merged regions may be computed without reference to the original pixels in the region.

$$\begin{aligned} f(R_k \cup R_l) &= f(R_k) \oplus f(R_l) \\ f_{new} &= f_k \oplus f_l \end{aligned}$$

here $\oplus$ denotes some operation on the values of the two feature vectors.

Example of Recursive Feature Computation

Example: Let $f(R_k) = (N_k, \mu_k, c_k)$ where

$$\begin{aligned} N_k &= |R_k| \\ \mu_k &= \frac{1}{N_k} \sum_{s \in R_k} x_s \\ c_k &= \frac{1}{N_k} \sum_{s \in R_k} s \end{aligned}$$

We may compute the region features for $R_{new} = R_k \cup R_l$ using the recursions

$$\begin{aligned} N_{new} &= N_k + N_l \\ \mu_{new} &= \frac{N_k \mu_k + N_l \mu_l}{N_{new}} \\ c_{new} &= \frac{N_k c_k + N_l c_l}{N_{new}} \end{aligned}$$

Recursive Merging

- Define a distance function between regions. In general, this function has the form
$$d_{k,l} = D(R_k, R_l) > 0$$
- Ideally, $D(R_k, R_l)$ is **only** a function of the feature vectors f_k and f_l.
$$d_{k,l} = D(f_k, f_l) > 0$$
- If features may be computed recursively, then this may include a dependency on $f_{new} = f_k \oplus f_l$

Example of Merging Criteria

- Distance between color means

$$d_{k,l} = \frac{N_k}{N_{new}}|\mu_k - \mu_{new}|^2 + \frac{N_l}{N_{new}}|\mu_l - \mu_{new}|^2$$

- Distance between region centers

$$d_{k,l} = \frac{N_k}{N_{new}}|c_k - c_{new}|^2 + \frac{N_l}{N_{new}}|c_l - c_{new}|^2$$

- Distance formed by a weighted combination of the two

$$d_{k,l} = \alpha\left(\frac{N_k}{N_{new}}|\mu_k - \mu_{new}|^2 + \frac{N_l}{N_{new}}|\mu_l - \mu_{new}|^2\right) + \beta\left(\frac{N_k}{N_{new}}|c_k - c_{new}|^2 + \frac{N_l}{N_{new}}|c_l - c_{new}|^2\right)$$

Recursive Merging Algorithm

- Define a distance function between regions

$$d_{k,l} = D(f(R_k), f(R_l), f(R_k \cap R_l)) > 0$$

Ideally, $D(R_k, R_l)$ is a function of the feature vectors $f(R_k)$, $f(R_l)$, and $f(R_{new})$.

Repeat until $|\mathcal{M}| = 1$ {

Determine the minimum distance regions

$$(k^*, l^*) = \arg \min_{k,l \in \mathcal{M}} \{d_{k,l}\}$$

Merge the minimum distance regions

$$R_{k^*} \leftarrow R_{k^*} \cup R_{l^*}$$

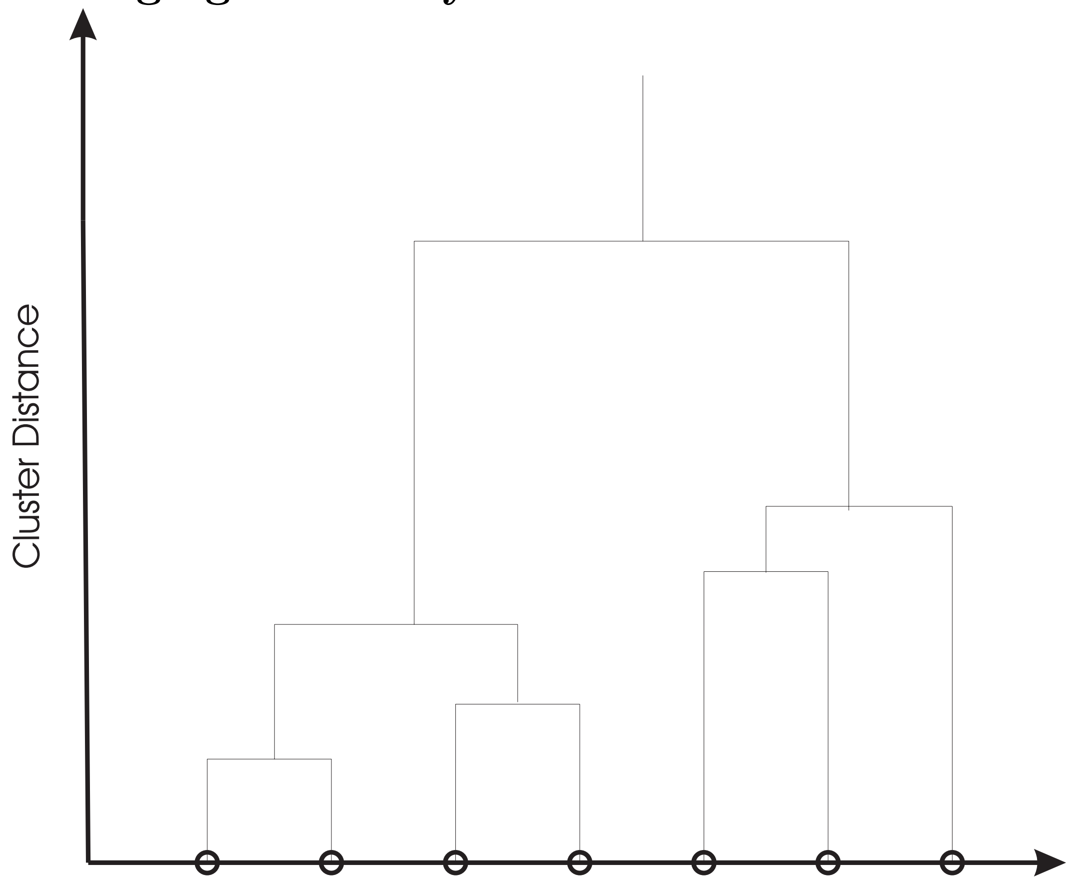
Remove unused region

$$\mathcal{M} \leftarrow \mathcal{M} - \{l^*\}$$

}

- This recursion generates a binary tree.

Merging Hierarchy and Order Identification



- Clustering can be terminated when the distance exceeds a threshold

$$d_{k^*,l^*} > Threshold \Rightarrow \text{Stop clustering}$$

- Different thresholds result in different numbers of clusters.