Object Recognition Overview

- Overview of Model-based recognition.
  - Different types of assumptions.
  - What is a model?
- Look at constraint based tree search.
  - Search for geometric consistency
  - Prune based upon local consistency
- Look at invariants.
  - Great promise:
    - Compute invariant features, then lookup objects.

Model-Based Recognition

- Problem Statement:
  - What: Which models in the database match the data.
  - Where: What is the location of each modeled object.
- Are these separate considerations?
  - Eigenspace Image Analysis.
  - LiME - Line Matching.
  - Evidence from Cognitive Science.
- Related problem:
  - What is the form of the object model.
    - Image templates.
    - CAD Model.
    - Others?

Different Variations

Problem 1: What objects are we looking at?
Model search and image region search are needed.

Problem 2: Is this part of the image an instance of X?
Given a model and given and image region.

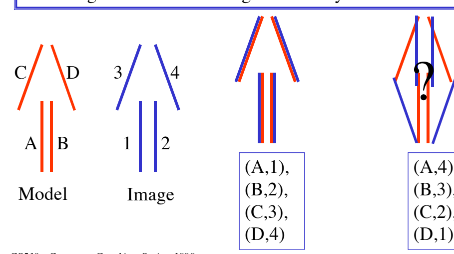
Problem 3: What is this part of the image?
Model search is needed by image region is given.

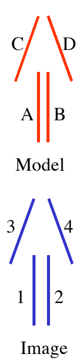
Problem 4: Are there any instances of X in the image?
Given model, image region search is needed.

Related question, is the model expressed in 2D image space or 3D scene space.

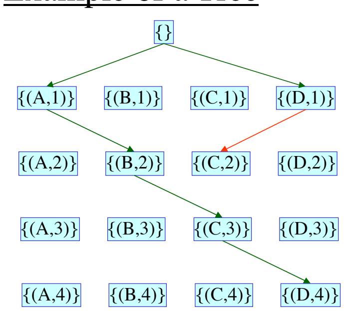
Interpretation Tree Overview

Use tree search to find a mapping of model features to image features which is geometrically consistent.





Example of a Tree



Observations

- Note the size of the tree
  $s = 1 + m + m^2 + \ldots + m^n$, complexity $O(m^n)$
- Pruning based upon geometric constraints is critical!
- Pruning using directed line segments based upon:
  - Relative length, distance and orientation
- Eric Grimson has proven polynomial complexity if:
  - Consider only rotation and translation.
  - Model guaranteed to be present.
  - No partial symmetries.
- Otherwise, complexity is exponential.

More Observations

- Exponential behavior interesting, time is lost ....
  - enumerating powerset of feasible interpretations,
  - not sorting through unrelated features.
- Local consistency does not guarantee global consistency
- Spurious data requires addition of wildcard in model list.
- Easy to match multiple data features to a model feature.
- Cannot match multiple model features to a data feature.
- Branch and bound extensions do better in practice.
- Pose equivalence analysis a more powerful polynomial follow on to this work (Cass 92).

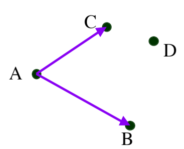
Invariants

- In general, we can say that:

  An invariant is a measurable property of a geometric configuration which does not changed under a class of geometric transformations.
- The text speaks of projective invariants.
  - For example, the Cross Ratio of four colinear points.
- Invariants need not be geometric.
  - There is active work on "color" invariants.
- However, most of the work has focused on geometry.
- We will consider a simpler example.

2D Invariants

Consider 4 arbitrary points: ***A, B, C and D.***



$$\vec{U} = B - A,\ \vec{V} = C - A\ \ \vec{D} = D - A$$

$$\textit{Consider}\ \ P = \begin{vmatrix} \vec{D}\cdot\vec{U} \\ \vec{D}\cdot\vec{V} \end{vmatrix}$$

The point P is the point D measured relative to A, B and C. With respect to what transformations is it invariant?

2D Rigid Invariants

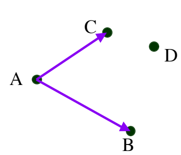
- Consider Rotation and Translation.

$$\vec{U}' = RB + T - RA - T = RB - RA = R(B - A),$$
$$\vec{V}' = RC + T - RA - T = RC - RA = R(C - A),$$
$$\vec{D}' = RD + T - RA - T = RD - RA = R(D - A)$$
$$P' = \begin{vmatrix} \vec{D}'\cdot\vec{U}' \\ \vec{D}'\cdot\vec{V}' \end{vmatrix} = \begin{vmatrix} R(D-A)\cdot R(B-A) \\ R(D-A)\cdot R(C-A) \end{vmatrix} = \begin{vmatrix} (D-A)\cdot(B-A) \\ (D-A)\cdot(C-A) \end{vmatrix} = \begin{vmatrix} \vec{D}\cdot\vec{U} \\ \vec{D}\cdot\vec{V} \end{vmatrix} = P$$

- What about rotation, translation and scale?

2D Similarity Transforms

Consider the same 4 arbitrary points: ***A, B, C and D.***



$$\vec{U} = \frac{B - A}{|B - A|},\ \vec{V} = \frac{C - A}{|B - A|}\ \ \vec{D} = \frac{D - A}{|B - A|}$$

$$\textit{Consider}\ \ P = \begin{vmatrix} \vec{D}\cdot\vec{U} \\ \vec{D}\cdot\vec{V} \end{vmatrix}$$

$$\textit{Note}\qquad P = \begin{vmatrix} \dfrac{(D-A)\cdot(B-A)}{(B-A)\cdot(B-A)} \\ \dfrac{(D-A)\cdot(C-A)}{(B-A)\cdot(B-A)} \end{vmatrix}$$

- The point P is still point D measured relative to A, B and C.
- Now the U basis vector is of unit length.

$$\textit{Because}\ \ |B - A|^2 = (B - A)\cdot(B - A)$$

2D Similarity Invariants

$$\vec{U}' = \frac{sRB + T - sRA - T}{\sqrt{(sRB + T - sRA - T)^2}} = \frac{sRB - sRA}{s\sqrt{(B-A)^2}} = \frac{R(B-A)}{\sqrt{(B-A)^2}},$$
$$\vec{V}' = \frac{sRC + T - sRA - T}{\sqrt{(sRB + T - sRA - T)^2}} = \frac{sRC - sRA}{s\sqrt{(B-A)^2}} = \frac{R(C-A)}{\sqrt{(B-A)^2}},$$
$$\vec{D}' = \frac{sRD + T - sRA - T}{\sqrt{(sRB + T - sRA - T)^2}} = \frac{sRD - sRA}{s\sqrt{(B-A)^2}} = \frac{R(D-A)}{\sqrt{(B-A)^2}}$$
$$P' = \begin{vmatrix} \vec{D}'\cdot\vec{U}' \\ \vec{D}'\cdot\vec{V}' \end{vmatrix} = \begin{vmatrix} \dfrac{R(D-A)\cdot R(B-A)}{(B-A)\cdot(B-A)} \\ \dfrac{R(D-A)\cdot R(C-A)}{(B-A)\cdot(B-A)} \end{vmatrix} = \begin{vmatrix} \dfrac{(D-A)\cdot(B-A)}{(B-A)\cdot(B-A)} \\ \dfrac{(D-A)\cdot(C-A)}{(B-A)\cdot(B-A)} \end{vmatrix} = \begin{vmatrix} \vec{D}\cdot\vec{U} \\ \vec{D}\cdot\vec{V} \end{vmatrix} = P$$

Invariants More Generally

- There are a number of special 3D projective invariants
  - Cross ratio
  - Five coplanar lines
- There are no universal 3D projective invariants. In other words, invariants which hold over ALL configurations of K distinct points (Burns)
- The attraction of invariants should be obvious.
  - Compute invariants measures in image
  - Lookup corresponding objects
  - You are done (neglecting noise, spurious features, etc.)