Computer Vision

Spring 2006 15-385,-685

Instructor: S. Narasimhan

Wean 5403

T-R 3:00pm – 4:20pm

Lecture #18

Polyhedral Objects and Line Drawing

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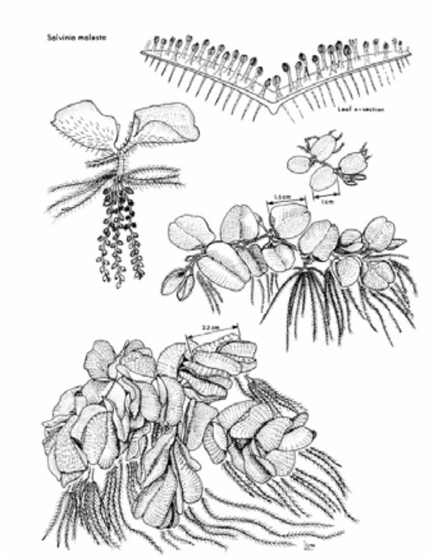
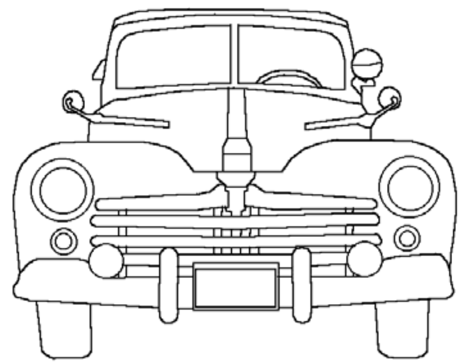
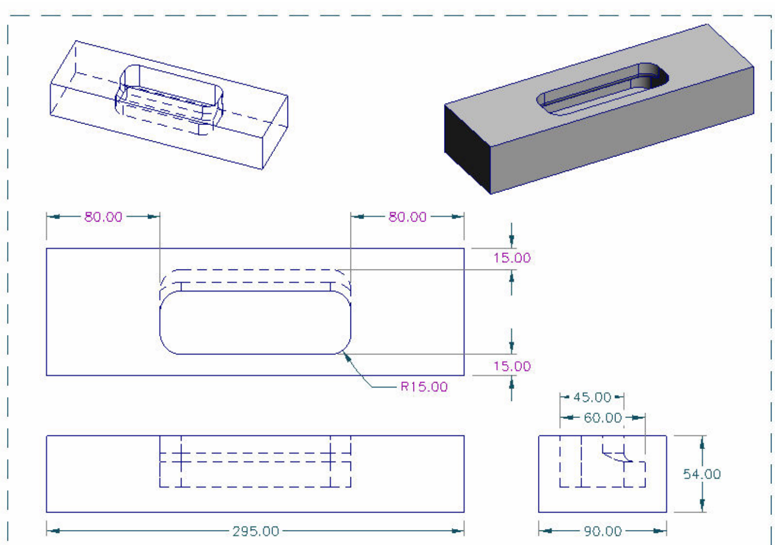
Line Drawings





We often communicate using Line Drawings

Engineering Drawings

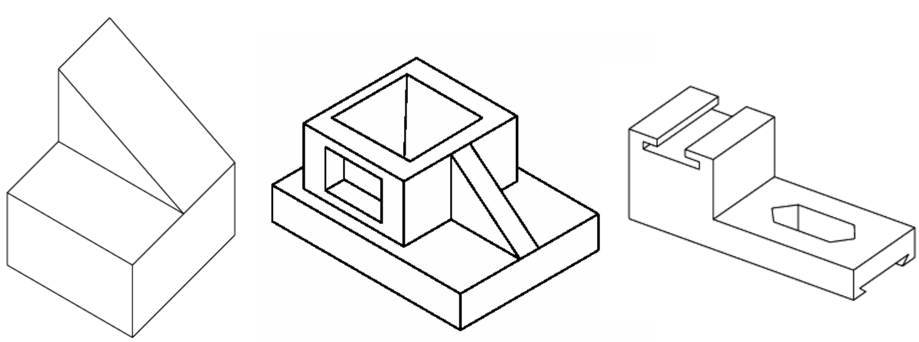


Topics

We can recover 3-D shape information from lines in the image.

- Line Drawings
- Line Labeling
- Possible Labels and Coherence
- Constraint Propagation
- Gradient Space Constraint

Line Drawings of Polyhedral Objects

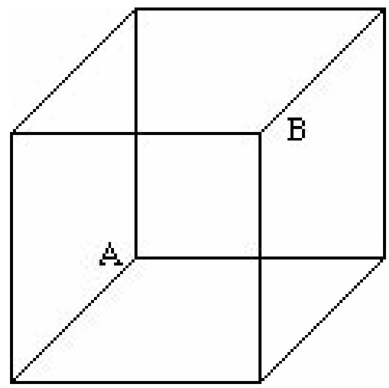


We can recover 3-D shape information from lines in the image.

We will assume that lines are “clean” and “well-connected”.

Limitations of Line Drawings

Necker's Cube Reversal

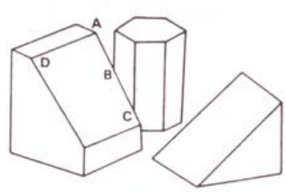


Sometimes multiple interpretations are possible!

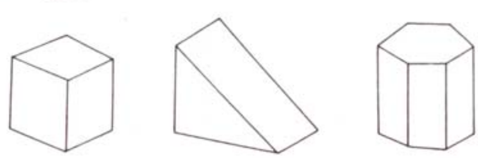
First Attempt – Primitives

[Roberts, 1965]

• Scene:



• Primitives



Note: Convex polygons in scene project onto convex polygons in the image.

Step1: Use features (edges, faces, vertices) to identify Primitives in the image.

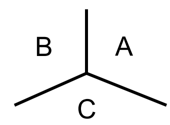
Step2: Find transformation of Primitives.

Step3: UNGLUE Primitives and introduce new lines. Return to Step1.

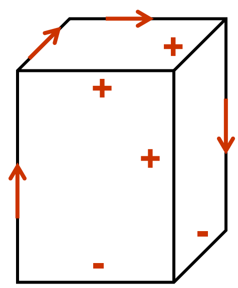
Line Labeling

- Assume Trihedral Corners:

  Meeting of 3 Faces



- Example:

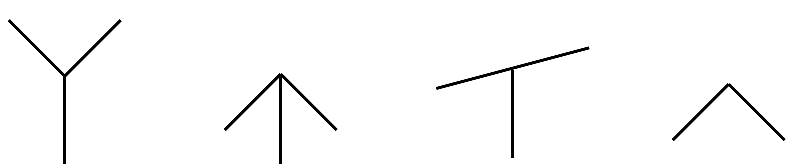


- Line Labels:

  + : Convex
  — : Concave
  > < : Occlusion

[Huffman and Clowes, 1971]

Vertex Types

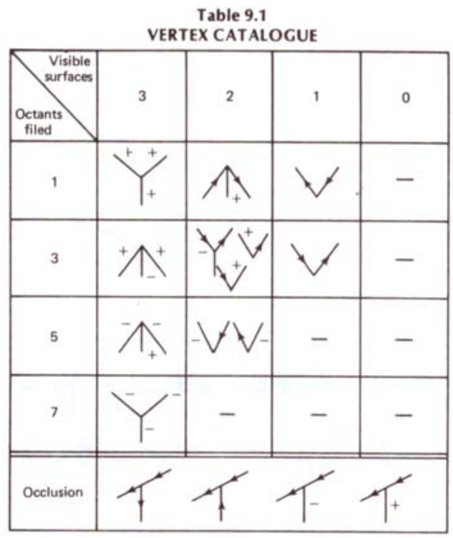


Fork | Arrow | T | L

- Possible Labelings: (Exhaustive)
  - Each edge can have one of 4 Labels

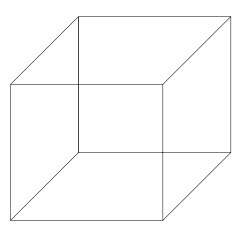
4^3 4^3 4^3 4^2

Vertex Dictionary



In a Trihedral World, all image vertices must belong to the Dictionary

Constraints on Labeling

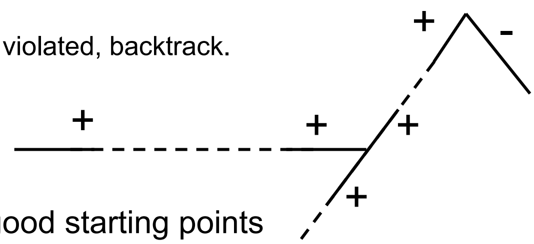


N edges

- Number of possible labels without any constraints : 4^N labelings
- Two Important Constraints:
    - Vertex Type must belong to Dictionary
    - A line must have the SAME label at both ends (COHERENCE RULE)

Labeling by Constraint Propagation

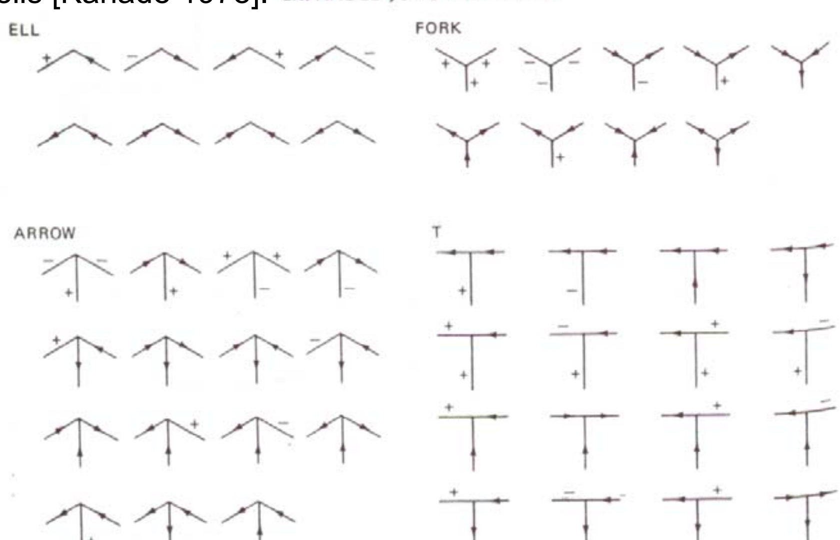
- Waltz Filtering [Waltz 75]
- Extended Dictionary (includes shadows, 4 line vertices)
- Constraint Propagation:
  - Pick a vertex and assign a label.
  - Propagate coherence rule to pick labels of connected vertices.
  - If Coherence rule is violated, backtrack.



NOTE: Boundaries are good starting points

Origami World

- Generalizes line labeling from solid polyhedra to non-closed shells [Kanade 1978]. EXPANDED JUNCTION TABLE



Origami World

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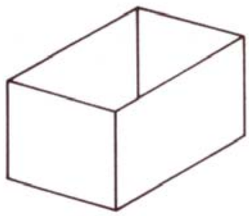


(a)

Fig. 9.39 (a) Box. (b) Labeled edges according to origami world label set.

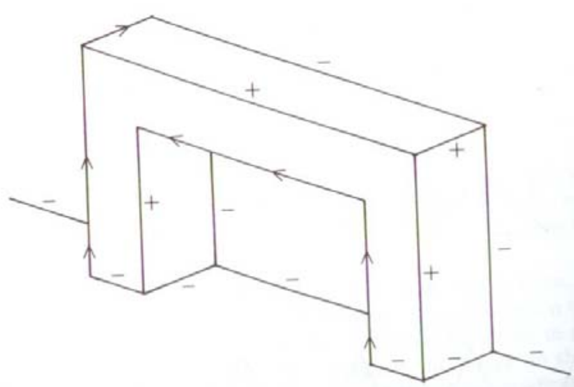
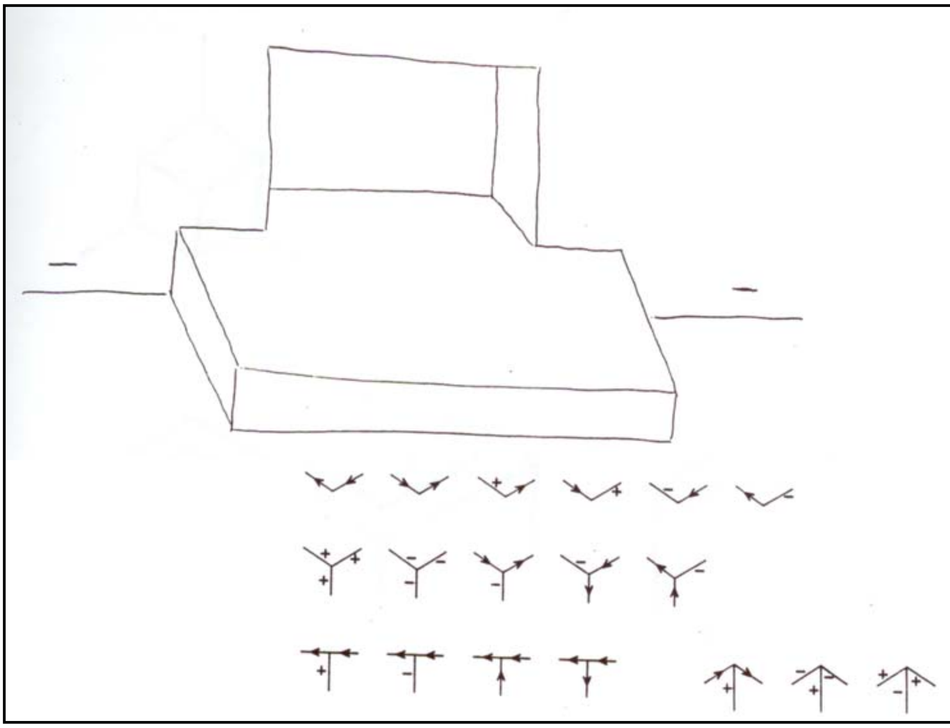
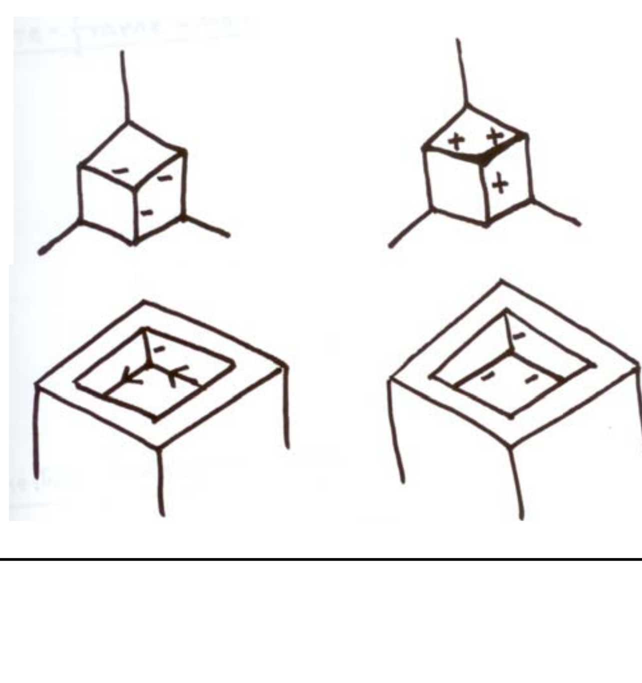


Figure 15-2. Each line in a line drawing can be assigned a label in such a wa
that the combination of labels at each vertex can be found in the dictionary. I
no consistent labeling exists, then the scene is "impossible," that is, no collectio
of polyhedra with trihedral vertices could have given rise to it. There may, o
the other hand, be several different valid labelings.



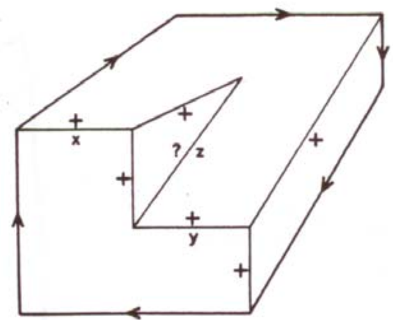
Ambiguity in Labeling

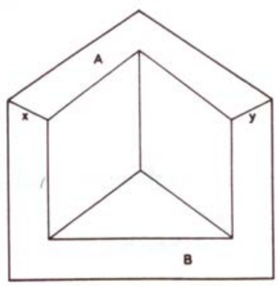
- Sometimes Multiple Labelings are possible!



Impossible Objects

- Impossible under the Polyhedral Assumption
- Impossible Object WITH NO consistent labeling

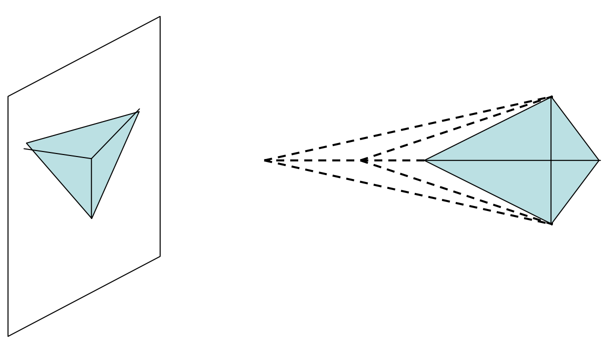




- Impossible Object WITH consistent labeling
- Locally Fine, Globally Wrong!

Ambiguity in 3-D Shape

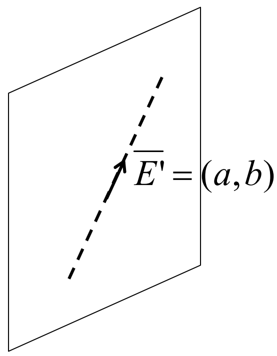
- Even after consistent labeling, 3-D shape is ambiguous.

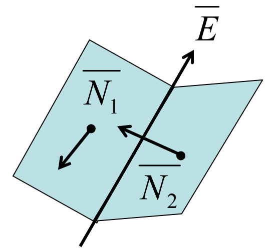


- Infinite number of shapes produce the same image!
- Solution: Use brightness information to find exact shape.

Gradient Space Constraint

[Mackworth 1975]





$$\overline{E} = (ak, bk, k)$$
$$\overline{N}_1 = (p_1, q_1, 1)$$
$$\overline{N}_2 = (p_2, q_2, 1)$$

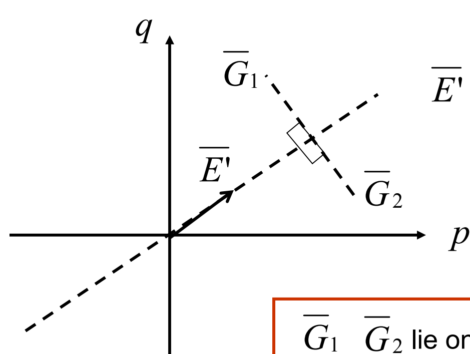
We Know: $\overline{N}_1 \perp \overline{E} \quad \& \quad \overline{N}_2 \perp \overline{E}$

Or: $\overline{N}_1 . \overline{E} = 0 \quad \& \quad \overline{N}_2 . \overline{E} = 0$

Hence, $ap_1 + bq_1 = ap_2 + bq_2 \Rightarrow (a,b).(p_1 - p_2, q_1 - q_2) = 0$

Gradient Space Constraint

Let: $\overline{E'} = (a,b) \quad \overline{G}_1 = (p_1, q_1) \quad \overline{G}_2 = (p_2, q_2)$



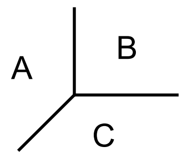
$$\overline{E'}.(\overline{G}_1 - \overline{G}_2) = 0$$

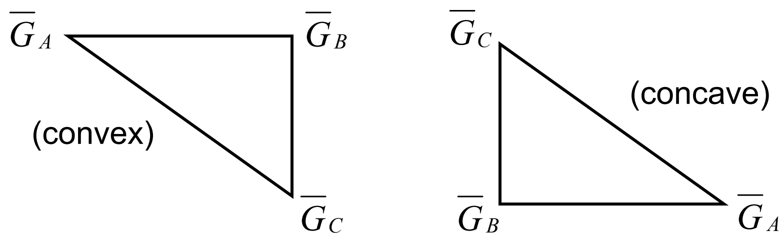
$\overline{G}_1 \quad \overline{G}_2$ lie on a line that is perpendicular to the image edge.

We do not know the distance between $\overline{G}_1 \quad \overline{G}_2$, we only know their relative positions.

Possible Interpretations of Constraint

Example:





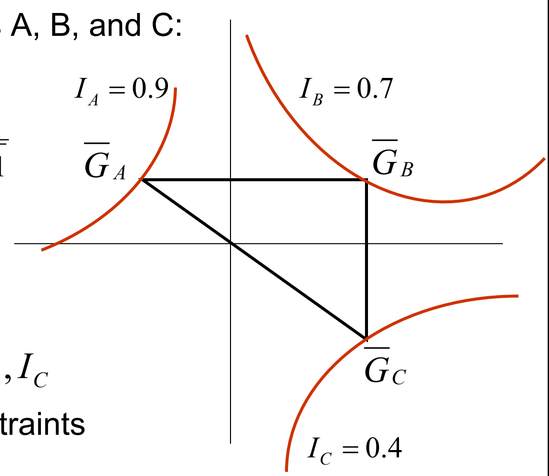
- Scale and positions of the triangles in gradient space are UNKNOWN.
- Brightness values of faces A, B, and C may be used if reflectance map is KNOWN.

Using the Reflectance Map

Assume: Lambertian reflectance and source direction (p_s, q_s)

Image intensities on faces A, B, and C:

$$I_A = \rho \frac{p_a p_s + q_a q_s + 1}{\sqrt{p_a^2 + q_a^2 + 1}\sqrt{p_s^2 + q_s^2 + 1}}$$



- Use equations for I_A, I_B, I_C and gradient space constraints to solve for $\overline{G}_A$ $\overline{G}_B$ $\overline{G}_C$

Early Robot Demo

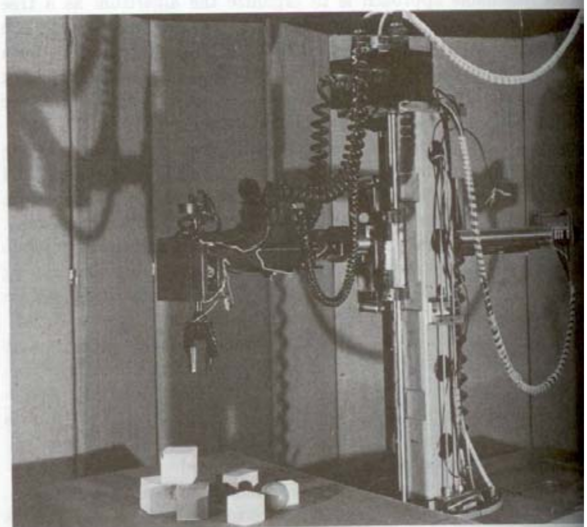


Figure 15-3. The mechanical manipulator used in the “copy-demo,” or first projects in which visual information was used to plan the motion industrial robot. (Photo by Steve Slesinger.)

Next Class

- Principal Components Analysis
- Reading → Notes, Online reading material

Finding Physically Possible Labelings

- Divide 3-D space into 8 octants.

- Enumerate:
    - All ways to fill up 8 octants.
    - All ways to view from unfilled octant.