# INFORMATION NEEDED TO LABEL A SCENE

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## ABSTRACT

I analyze the information content of scene labels and provide a measure for the complexity of line drawings. The Huffman-Clowes label set is found to contain surprisingly little additional information as compared to more basic label sets. The complexity of a line drawing is measured in terms of the amount of local labeling required to determine global labeling. A bound is obtained on the number of lines which must be labeled before a full labeling of a line drawing is uniquely determined. I present an algorithm which combines local sensory probing with knowledge of labeling constraints to proceed directly to a labeling analysis of a given scene.

## I INTRODUCTION

Huffman [4] and Clowes [2] developed (independently) a basic labeling scheme for blocks world picture graphs. Given a basic labeling set: + (convex), - (concave), → (occluding, region on arrowhead side), and a standard set of simplifying restrictions on scene content and viewpoint, the physically realizable junction labelings are just those shown in the last column of Fig. 1.

Waltz [5] explored the richer label sets obtained by including additional information in the labels (and loosening the scene restrictions). In this paper I explore weaker, cruder label sets. I identify three stages of scene labels, of which the standard set is the third and richest. I then explore the increase in information content embodied in each successive stage. Rather surprisingly I find that there is very little real information gain as we move from stage to stage. A first stage scene labeling may well determine a unique second stage labeling. If it does not, it will come quite close to doing so, and I am able to identify precisely the additional information that is necessary and sufficient to complete the second stage labeling. Similar results are obtained for the transition from Stage II to Stage III. These results supply some theoretical insight into the nature and strength of the basic line labels and physical constraints.

I go on in Section III to analyze the amount of information required to obtain a Stage I labeling. The information is measured in terms of the number of line labels which must be determined in order for labeling constraints to unambiguously imply a unique labeling of the entire line drawing. In practice the required line labels can be obtained by local sensory probing of the physical scene.

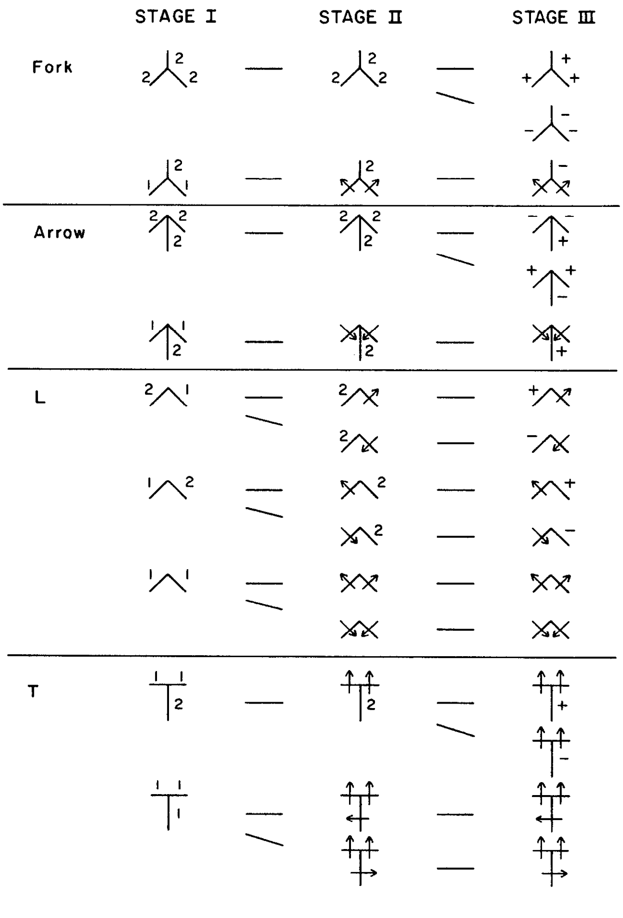


Fig. 1. Junction labelings at each stage.

I obtain a bound on the number of labels required to imply a full labeling of an arbitrary line drawing. Finally I discuss an algorithm that effectively combines sensory probing for labels with knowledge of labeling constraints. The algorithm proceeds directly to a full labeling, reflecting a presented physical scene, while requiring neither a complete sensory scan for every line label nor a consideration of all possible physical realizations of the line drawing.

## II LABELING STAGES

The standard label set is a refinement of a cruder categorization of lines as representing a physical edge of either one or two visible faces. I consider three labeling stages. In Stage I the only labels are the numbers 1 and 2, indicating the number of associated faces. In Stage II, the number 1 is replaced by occlusion labels (→) indicating which side the single face is on. They will be termed Stage II labels. A Stage II labeling will be one that utilizes → and 2 labels. In Stage III the number 2 is replaced by + and - as the distinction is made between convex and concave edges. The labels + and - will be termed Stage III labels. A Stage III labeling is one that utilizes +, - and → labels.

At Stage I there are only 9 distinct junction labels. At Stage II the L labelings are differentiated, at Stage III the fork and arrow labels are differentiated. Fig. 1 shows the physically realizable labelings at each stage. T labelings are added at each stage, but notice that fork and arrow labelings do not increase in moving from Stage I to Stage II, and the number of L labelings does not increase in moving from Stage II to Stage III. Thus we really do not know any more about forks and arrows at Stage II than we do at Stage I, nor more about L's at Stage III than at Stage II. Once we have labelled a fork 2,1,1 for example, we really know already that it can be labelled 2,←,→.

My interest in Stage I labeling was aroused by the work of Chakravarty [1] who utilized information about the number of regions associated with lines and junctions, in connection with a more elaborate labeling scheme.

### A. The Picture Graph

A blocks world line drawing is, of course, a graph. For the purposes of our analysis we will modify picture graphs by "separating" T junctions, removing T junctions by pulling the shafts away from the crossbars. After labeling a scene separated in this fashion the T junction labelings are easily recovered by rejoining the T junctions to form the original scene. The separation reflects the fact the information does not pass through a T junction, and will permit us to identify independent segments of the scene as connected components of the (separated) picture graph. The segments are independent in the sense that each can be labeled independently, a label in one segment can have no bearing on possible labelings for the other segment.

The connected components of a graph are the maximal connected subgraphs, where a graph is connected if there is a chain of edges between any two vertices.

### B. Stage I to Stage II

Theorem 1. Given a picture graph with a Stage I labeling (separated at T junctions). Further separate the graph by separating L junctions that have a 2 label on one line, i.e. pulling the two sides of each such L apart to remove the junction. The Stage I labeling uniquely determines a Stage II labeling on all connected components of the resulting graph except those consisting solely of 1-labeled lines, none of which is a crossbar of a T. A unique labeling for the exceptions may be determined by specifying the Stage II label of a single line in each such component.

For proofs of the theorems in this paper see [3].

### C. Stage II to Stage III

Theorem 2. Given a picture graph with a Stage II labeling (separated at T junctions). The Stage II labeling uniquely determines a Stage III labeling on all connected components except those consisting solely of 2-labeled lines. A unique labeling for the exceptions may be determined by specifying the Stage III label of a single line in each component.

## III OBTAINING A STAGE I LABELING

Given labels for a sufficient number of lines the physical constraints on the labeling process will imply a unique labeling for the remainder of the scene. A bound on this "sufficient number" will provide a bound on the complexity and potential ambiguity of the picture graph, and on the effort required to label it.

The limitations on physically realizable labelings summarized in Fig. 1 easily give rise to a set of "implication rules" for completing a junction labeling given the labelings of one or two of its lines. These rules are listed in Fig. 2. Note first that labels for shafts of arrows and crossbars of T's can be derived immediately (2's and 1's respectively), without any previous labels. Labels for two of the lines of a fork or arrow imply the third. (Thus, in effect, a single line label, other than for the shaft, determines an arrow labeling.)

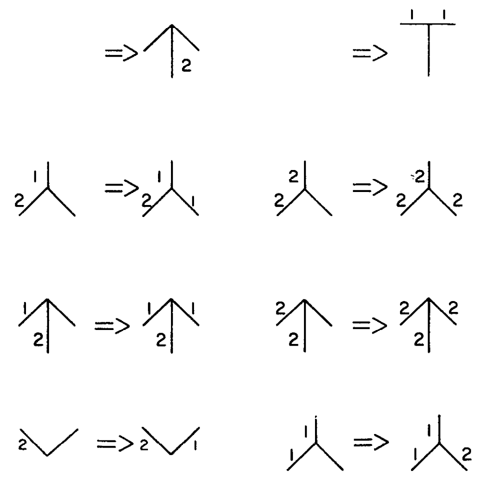

Fig. 2. Implication rules.

I will say that the labeling of a subset of picture graph lines *implies* the labeling of the entire graph, if repeated application of the implication rules of Fig. 2, starting with the given subset, leads to a complete, unique labeling of the graph. The *labeling* of a subset of lines is *sufficient* if the labeling implies the labeling of the graph. A *subset of lines* is *sufficient* if any consistent labeling of the subset is sufficient. The minimal number of lines in a sufficient subset will be called the *sufficient number of the picture graph*. The sufficient number must, of course, be determined relative to a specified label set. We will be dealing with sufficiency for Stage I labeling in this paper.

In Section A I obtain an upper bound on the sufficient number of a picture graph. In [3] I discuss means of obtaining sufficient sets of lines (and thus, bounds on sufficient numbers) for individual graphs; I modify one of these methods to provide a test for the sufficiency of a set of lines or line labels, and a labeling algorithm. This algorithm is discussed in Section B.

## A. *A Bound on the Sufficient Number of a Picture Graph*

Theorem 3. The sufficient number of a picture graph is no more than the number of forks and arrows plus the number of connected components of the graph separated at T's and L's.

The bound provided by the theorem is tight, in the sense that I can exhibit a picture graph with sufficient number equal to the given bound. A simple triangular figure may consist of all occluding lines, or one of the lines may have a 2 label. Knowing the labeling of two lines is not sufficient to imply the label of the third for all possible labelings. Thus, the sufficient number is three, which equals the number of forks and arrows (0) plus the number of connected components in the graph separated at T's and L's (3). (In general the sufficient number of a picture graph will be considerably less than the bound provided by the theorem).

## B. *A Labeling Algorithm*

Algorithm:

1. Obtain any labels that can be deduced by repeated application of the implication rules of Figure 2. (Note arrow shafts and T crossbars can be labeled immediately.)

2. While unlabeled lines remain:

2.1. Pick an unlabeled line and "probe" the physical scene to determine its label. (This information could be obtained from visual, tactile, or range finding data.)

2.2. Deduce any further labels that can be obtained by repeated applications of the implication rules.

Note that deduction can "propagate": we may deduce a label for a line which in turn permits deduction of the label for an adjoining line, etc. There is room for heuristic tuning in choosing which lines to probe for labels.

Fig. 3 demonstrates this labeling algorithm on a simple scene. The fortuitous choice of a 2-labeled L line to probe for labeling permits us to get away with a single sensory probe. (Actually the choice need not be entirely fortuitous. It is reasonable to suspect that the "bottom lines" will be 2-labeled.)

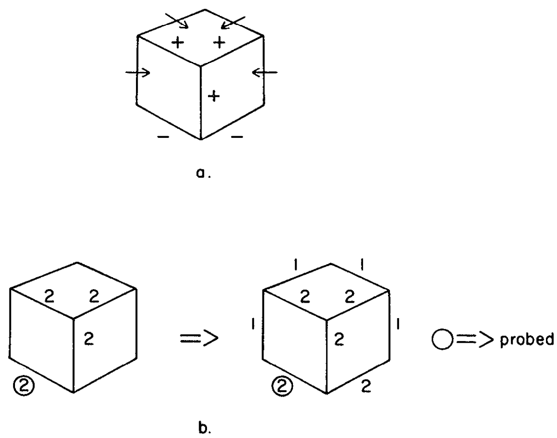


Fig. 3. Labeling algorithm.

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