A 3D Interpretation System Based on Consistent Labeling of a Set of Propositions. Application to the Interpretation of Straight Line Correspondences†

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Abstract: We propose a 3D interpretation system where knowledge is represented by a set of propositions, and where interpretation and truth maintenance are based on a consistent labeling of this set of propositions. The basic concepts are illustrated on the problem of 3D interpretation of image straight line correspondences.

1. Introduction

A number of 'truth maintenance' systems have been proposed [1]-[3] that keep track of the dependencies between propositions (statements resulting from observations) by associating to each proposition a *justification* which is the set of propositions that have allowed its derivation, or an *origin* which is the minimal set of assumptions that must hold for the proposition to be valid. Because of this structure, the interpretation of the resulting data base is often quite complex. Special care must also be taken to avoid contradictions. To facilitate the process of inference, some systems use *context*, which is a subset of *beliefs* under which the analysis is currently made. In this case, the problem is to determine how and when a context switching should be made.

KNOBIS is not a justification-based or an assumption-based system. It does not use complex dependency pointers between propositions. Rather, recording of dependencies is directly incorporated in a dedicated database. Futhermore, KNOBIS clearly separates the process of inference from the one of interpretation, and it generalizes the notion of uncertainty by considering both *data uncertainty* and *rule uncertainty.*

2. General structure of KNOBIS

KNOBIS contains three knowledge bases: a *rule base*, a *data base*, and a *constraint base* (Fig. 1). These are supervised by two distinct schemes, one to manage inferencing, the other to interpret the current data base.

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In the present system, propositions are represented by labeled nodes (Fig. 2). Each label of a node contains conjunctions of primitive propositions. A node is not a representation of individual propositions but, rather, the set of all nodes constitute a non-disjoint segmentation of the data base in which each element contains jointly derived propositions. The assignment of a particular label to a node validates the associated propositions. *Null* labels are allowed to indicate that no valid proposition is associated with a node.

Rules can be *certain* or *uncertain*. Uncertain rules have a consequent which may not be a logical consequence of its antecedent. In addition, rules can have several distinct consequents, allowing various alternate decisions. The parsing of these rules can be done using standard resolution methods that are applied on the data base formed by the union of all propositions present in the different labels. The only restriction is that, in the satisfaction of an antecedent, each node can contribute to only one label. Therefore, the application of one rule results in the creation of a node i having L_i labels $\Psi^i_1,...,\Psi^i_{L_i}$. These propositions come from the different labels of existing nodes in the data base. Consider now the set Γ_i which is the union of all propositions included in the different labels used in the derivation of node i:

$$\Gamma_i = \Psi^{i_1}_{\ell_1} \cup ... \cup \Psi^{i_K}_{\ell_K}$$

which means that propositions included in the label ℓ_k of node i_k has contributed to the derivation of node i. This set, called the *support set*, includes all the propositions that satisfied the condition expressed by the antecedent of the rule and, eventually, other propositions that are also included in the selected labels (recall that a given label may include several propositions). This support set is only used during constraint recording; once done it does not have to be memorized anymore.

Constraints make explicit the possible interrelationship between each proposition (label). Two types of constraints are considered. The *dependency constraint* expresses the fact that the validity of a given proposition depends upon the validity of the propositions used in its derivation. The *compatibility constraint* is used to determine if two labels are compatible or not. Two labels are incompatible if they include contradictory propositions.

An *interpretation* can be obtained at any moment by resolving the corresponding constraint satisfaction problem. This can be realized by assigning a unique label to each node of the data base. The labeling thus found must be consistant according to the constraints recorded in the constraint base. Possible interpretations will therefore be all the consistent assignments thus found. The theory associated with an interpretation is the union of all propositions included in the selected labels.

More details on the structure and semantics of KNOBIS can be found in [4][5].

3. Interpretation of image line correspondences

Various mathematical formulations of the problem of interpreting image straight line correspondences have been proposed [6] that are often unstable and sensitive to image measurement errors [7]. This is in part due to the fact that these formulations are mainly concerned with general cases, treating special cases with marginal interest. However, special cases abound in man-made environments; their occurrence, if ascertained, simplifies drastically the task of 3D interpretation.

We proceed to show how KNOBIS can effectivly interpret image straight line correspondences in such a context [8]. By hypothesizing plausible special configurations in the scene, it will be possible to suggest a number of interpretations. Ideally, we end up with a single interpretation. The role of KNOBIS is to control the process of inference and to propose possible interpretations under the various sources of uncertainty (data, rules). A proposition designates, here, either a relation existing between a number of lines or a particular numerical assignment for a given attribute of a line. We use orientation as the attribute. In this case, the negation of a proposition would be the assignment of a different orientation (within some tolerance) to a given line. Rules that will be used for our particular example are:

Hypothesizing parallel lines rule: if two lines are nearly parallel in at least one image, then these lines are hypothesized to be parallel in the scene.
Hypothesizing orthogonal lines rule: if three lines meet at one point in both images, then these three lines are hypothesized to be orthogonal.
Orthogonal lines rule: if three lines are orthogonal, then their orientation can be computed by the corresponding computational unit [7].
Parallel lines rule: if two lines are parallel, then their orientation can be computed by the corresponding computational unit [7].
Propagation rule: if the orientation of two non-parallel lines is known over two views, then the orientation of all the other lines can be found by propagation [7].

Resolving special configurations such as parallel lines and orthogonal lines, and spreading computation from one configuration to another are simple operations [8].

Figure 3a and 3b show two views of a wedge. With these images as input, the following relations are hypothesized:

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(parallel  0  5)   (parallel  1  4)       (parallel  3  5)
(parallel  2  4)   (orthogonal  0  1  3)  (orthogonal  1  2  5)
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To each of these hypotheses corresponds a node; the hypothesis itself is one label of this node and a null label is another. This null label will be assigned if the hypothesis is rejected. For each activated hypothesis a corresponding computational unit can be applied [8]. The creation of a node causes the updating of the constraint base.

Once inferencing is completed, the resulting constraint satisfaction problem is solved. A total of eleven consistent labelings are thus found for our example. In the absence of any other information, each of these interpretations is acceptable. However, if another view is available (Fig. 3c), the application of the same process on the second and third views can disambiguate the problem. The acceptable interpretation becomes the only one that assigns the same attributes (orientations) to lines of the second view, i.e.

```
Interpretation #0

(parallel  1  4)   (parallel  3  5)   (orthogonal  0  1  3)

              image 1                     image 2                     image 3

0:    ( 0.500,  0.000, -0.866)   ( 0.117, -0.321, -0.940)   ( 0.754, -0.133, -0.643)
1:    (-0.150,  0.985, -0.087)   ( 0.019,  0.947, -0.321)   ( 0.004,  0.980, -0.198)
2:    (-0.215, -0.743,  0.634)   (-0.091, -0.504,  0.859)   (-0.498, -0.652,  0.571)
3:    ( 0.853,  0.174,  0.492)   ( 0.993,  0.019,  0.117)   ( 0.656,  0.147,  0.740)
4:    (-0.150,  0.985, -0.087)   ( 0.019,  0.947, -0.321)   ( 0.004,  0.980, -0.198)
5:    (-0.853, -0.174, -0.492)   (-0.993, -0.019, -0.117)   (-0.656, -0.147, -0.740)
```

These are, indeed, the actual orientations.

Summary: We have presented KNOBIS, an 'intelligent system' that has the capability of reasoning under uncertainty. In this system, propositions are represented by labeled nodes. The label of a node is the set of the propositions that can be derived from the satisfaction of the antecedent of a given rule. Rules, which can be certain or uncertain, have a special format which allows the use of several consequents associated with a given antecedent. Each step of inference creates a new node in the data base and each time a node is created the constraint base is updated. Constraints are used to record compatibilities and dependencies between these nodes. The problem of finding an interpretation is then reduced to the one of finding a consistent labeling of the resulting network. KNOBIS has been applied to the line interpretation problem.

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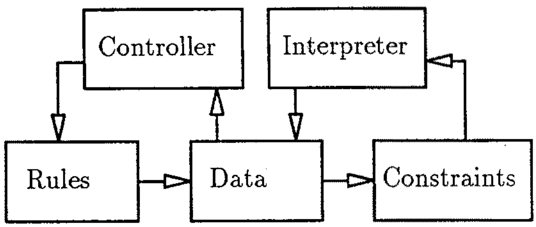

Fig. 1 Structure of KNOBIS.

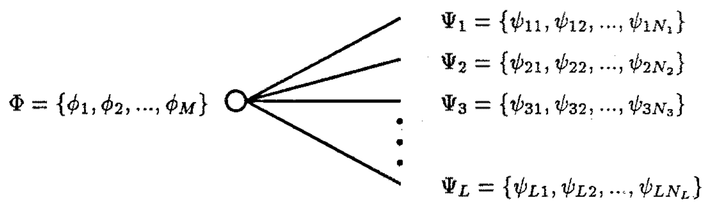

Fig. 2 A node and its associated propositions.

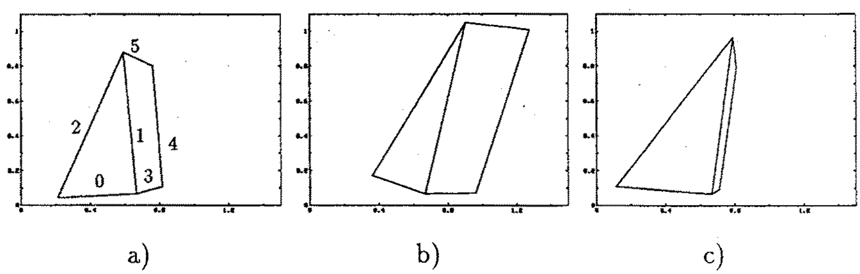

Fig. 3 Images of a wedge.