UNCERTAINTY REDUCTION PARADIGM USING STRUCTURAL KNOWLEDGE IN LINE-DRAWING UNDERSTANDING

Yasuo Ariki, Masashi Morimoto and Toshiyuki Sakai

Department of Information Science, Faculty of Engineering, Kyoto University, Kyoto, 606, JAPAN

ABSTRACT

In this paper, we investigate the problem of interpretation uncertainty caused by the conventional deterministic approaches to drawing image understanding from the three view points of homograph, heuristic knowledge and data ambiguity. To reduce these three factors of uncertainties, we propose new paradigm with *context-sensitive and hierarchical interpretation* for homograph, *multiple-interpretation* for heuristic knowledge, and finally a *certainty factor* for data ambiguity. The validity of this paradigm is investigated by establishing a structure analysis system for drawing images with five hierarchical levels The interpretation proceeds from the lower level to the higher level in bottom-up manner using heuristic knowledge described as rules in a production system The heuristic knowledge is effectively used to compute or modify the certainty factor of multiple-interpretation in context-sensitive manner.

I. INTRODUCTION

The understanding of typewritten or handwritten schematic line-drawings increases the importance of automatic input to CAD databases in the industry (Groen and Munster 1986). Conventional understanding approaches start from the segmentation of the line-drawing image into *image constituents* such as black connected-regions. Then, by splitting and merging the image constituents in a deterministic way, they are interpreted as *drawing constituents* such as symbols, interconnections and characters which compose line-drawings (Jarvis 1977).

The problem of these approaches is the misunderstanding caused by the deterministic interpretation ignoring its uncertainty. The uncertainty of interpretation arises mainly from the three factors: *homograph, heuristic knowledge* and *data ambiguity* (Roth and Reddy 1980).

Homograph:

Physical image constituents are generally smaller than conceptual drawing constituents in their size. Image constituents, therefore, have no direct correspondence to drawing constituents one to one. To make the direct correspondence, drawing constituents must be hierarchically broken into lower or smaller ones and finally into constituents with same size as the image constituents. Along with this hierarchy, image constituents are inversely integrated according to their interpretation. Homograph is caused by the local interpretation of image constituents based on the restricted knowledge at low levels. This kind of nomographic uncertainty may be reduced by a global interpretation which refers to its surroundings *{context-sensitive)* and by *hierarchical interpretation.* Hierarchical interpretation can increase the certainty factor by integrating image constituents and enlarging the range of reference for higher hierarchical levels

Heuristic Knowledge:

Heuristic knowledge is not permanently valid but becomes valid or invalid according to the world state. Due to the uncertainty of this heuristic knowledge, interpretation becomes ambiguous and sometimes contradictory. To reduce this conflict and to use heuristic knowledge effectively, *multiple-interpretation* with a certainty factor representing the validity of each interpretation is required Better than a procedural approach, the *knowledge representational* approach supports multiple-interpretation

Data Ambiguity

The image constituents are extracted by signal processing from a line-drawing image. Data ambiguity results from the uniform application of the signal processing irrespective of image quality. As the image quality decreases, the data ambiguity relatively increases, due to the fade-out and the false-appearance of image constituents. It can not be completely avoided even by data adaptation techniques. To represent this data ambiguity, the *certainty factor* is effective for image constituents extracted by the corresponding signal processing (Ohta, Kanade and Sakai 1978).

A new paradigm to reduce uncertainty caused by the above-mentioned factors in schematic line-drawing interpretation can be established by incorporating 1) *context-sensitive interpretation* and *hierarchical interpretation* for homograph, 2) *multiple-interpretation* and representational approach for heuristic knowledge, 3) *certainty factor* for data ambiguity.

II. HEURISTIC KNOWLEDGE ON LINE-DRAWINGS

A. Knowledge Type

Two different types of knowledge may be uBed in the interpretation of line-drawings. One is *task independent* and *common-sense* knowledge for solid line, broken line and character. It is generally used to integrate lower-level image constituents into higher-level constituents in bottom-up manner, irrespective of the kind of line-drawings. The other is *task dependent* knowledge (e.g. symbols). It is used particularly for certain line-drawings to reduce the uncertainty of interpretation in top-down manner.

Task independent and common-sense knowledge

An example for a broken line is as follows:

(K-l) The element of a broken line is slender.
(K-2) The interval between elements is not so long.
(K-3) The elements are placed repeatedly along its direction.
(K-4) A group of such elements composes a broken line.

Task dependent knowledge

Examples are the knowledge about logical circuit symbols (AND,OR,NOD, flow chart symbols or chemical plant symbols.

This paper, at present, concentrates its topics on the effective application of task independent and common-sense knowledge in bottom-up manner to reduce ambiguity under the strategy of context-sensitive, hierarchical interpretation with multiple-interpretation.

B. Knowledge Representation

Common-sense knowledge is represented as heuristic description of the shape and the relation of constituents in line-drawings. (K-l) and (K-2) are the description of the shape. (K-3) and (K-4) are the relational description. In the interpretation process, the knowledge is converted into rules such as,

(R-l) If the image constituent is slender, it may be the element of a broken line with some *certainty factor.*

(R-2) If there are the other slender constituents around it at not so long distance, its *certainty factor* as an element is increased.

(R-3) If there are the other elements of the broken line around it, its *certainty factor* is more increased.

In the conversion of common-sense knowledge into rules, uncertainty occurs because the reverse expression is not always true. The example is that a hyphen "-" in a character string has the same local attribute as an element of a broken line. This kind of uncertainty is expressed effectively by multiple-interpretation with the certainty factors of the hyphen or the element of a broken line. Context-sensitive and hierarchical interpretation will increase one of their certainty factors.

C. Knowledge Utilisation

Common-sense knowledge about the shape *of* image constituents like rule (R-l) is utilised to compute their certainty factor. On the other hand, relational knowledge like rules (R-2), (R-3) modifies the already computed certainty factor. The modification proceeds in two ways. One increases the certainty factor according to the positive evidence around the constituent. The other decreases it according to the negative evidence. For example, if there are slender elements around the constituent, the certainty factor as element of a broken line is increased by the application of rule (R-2). Inversely, if there are non-slender elements, the certainty factor as element of a broken line is decresed. In this way, context-sensitive interpretation increases or decreases the certainty factor according to its context

In rule (R-2), a slender element at a low level of interpretation is searched for. On the other hand, an element of a broken line is searched at a high level of interpretation in rule (R-3). Hierarchical interpretation enables the modification of the certainty factor by the evidence at multi-level environment.

III STRATEGY OF STRUCTURE ANALYSIS USING KNOWLEDGE

A. Hierarchy of Constituents and Knowledge

Figure 1 shows the hierarchical structure of the constituents with five levels.

1. Image constituent level

The drawing image is segmented into image constituents on the basis of the segmentation algorithm (Kaneko and Wakana 1982). The algorithm scans the image both in horizontal and vertical direction and gives each black pixel the number of succeedingly connected black pixels in respective direction as the value u*p.* According to the value ip, the drawing image is segmented into three types.

(1) type 1 : $1 \leq \psi \leq 60$ in vertical, $21 \leq \psi \leq 60$ in horisontal.

(2) type 2 : $1 \leq \psi \leq 60$ in horisontal, $21 \leq \psi \leq 50$ in vertical.

(3) type 3 : $1 \leq \psi \leq 30$ in both direction.

2. Geometrical element level

Segmented image constituents type 1, 2 are interpreted as linear element and type 3 as massive element. Certainty factor is computed for linear element using the common-sense knowledge such that "the line width is uniformly thin" and for massive element "the site is small or it does not contact to a linear element." (Representation of the knowledge is shown in APPENDIX A. and B.) If the certainty factor is not high, the constituent is re-interpreted as both linear and massive element.

3. Drawing-primitive level

The linear and the massive elements are respectively classified and interpreted as drawing primitives by the heuristic knowledge about their shape and relation.

Interpretation of massive elements

A massive element is interpreted as solid-line element, broken-line element, arrow, character and noise on the basis of the common-sense knowledge shown in APPENDIX C. The certainty factor of four drawing primitives without noise is computed as an example in APPENDIX D.

Interpretation of linear elements

A linear element is interpreted as solid-line element, short line, line in characters and noise. The certainty factor is computed for solid line and line in characters. The short line is merged and noise is removed at the next structural element level.

Modification of the certainty factor

The certainty factor is modified using knowledge about the relationship between drawing-primitives as shown in APPENDIX E.

4. Structural element level

Drawing-primitives are gathered and integrated into structural elements like line, connecting point and character string.

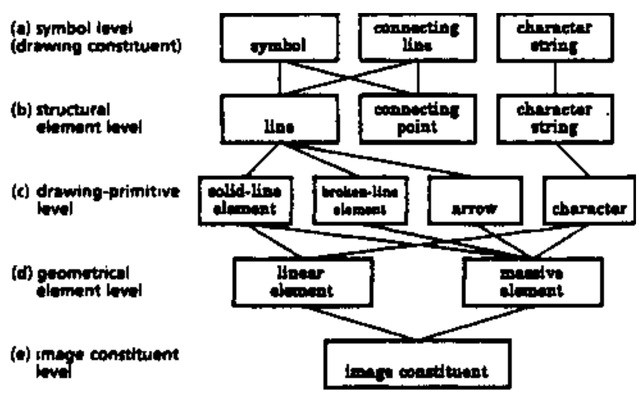


Figure 1 Hierarchy of constituents

5. Symbol level (drawing constituent)

Lines which compose symbols are interpreted as symbol lines, and the remaining lines are interpreted as connecting lines As task dependent knowledge for symbol is not available at present, symbol recognition is not carried out. At this level, symbol extraction is only done using the following semi-task dependent knowledge. (1) A symbol is almost closed by lines. (2) Lines with arrow do not compose symbols. (3) A symbol includes characters in itself.

B Interpretation Process

The hierarchical interpretation proceeds from the image constituent level to the symbol level in bottom-up manner, using heuristic knowledge about shape of and relation between the constituents.

Multiple-interpretation is done at three places in Figure 1. 1) The image constituents are interpreted both as linear elements and massive elements. 2) The massive elements are interpreted as solid-line elements, broken-line elements, arrows and characters. 3) The linear elements are interpreted as solid-line elements and characters.

The multiple-interpretation is converged by the hierarchical and context-sensitive interpretation as shown in Figure 2. In this figure, the hyphen in **"P-2"** is interpreted as solid-line element, broken-line element and character Character **"2"**, however, has a high certainty factor as character so that the certainty factor of "-" is increased as character This hierarchical and context-sensitive interpretation has two effects;

1 The certainty factor of constituents with distinct features is increased rapidly. This means that the interpretation of distinct constituent converges faster at a low level.

2. Inversely, the interpretation of ambiguous constituent is postponed until the processing proceeds to a higher level. It is, however, accelerated by the already converged interpretation of distinct constituents

IV EXPERIMENTS

A. Application of Structure Analysis

An application system has been developed to investigate the validity of structure analysis described in section III. The system can transform the input drawing image into an output drawing image with beautiful sense according to the user specification such as language translation from Japanese to English, or a figure size change leaving the character size unchanged (Ariki and Sakai 1985).

Transformation results are shown in Figure 3 and Figure 4 Figure 3(a) is an input image with low quality due to gaps in solid lines, contact of a character with a line, false appearance of lines and white noise. The structure analysis described in section III succeeded and the transformed image of Figure 3(b) was generated. Symbol lines and connecting lines are shown by solid lines and broken lines respectively In Figure 4, handwritten drawings with a broken line are digitized at low resolution. Structure analysis separated the characters touching lines and recognized the broken line. In Figure 3 and Figure 4, automatic character recognition and language translation are not implemented at present. They are left to user specification.

B. Evaluation of Knowledge Quality

We briefly investigated the rate of correct interpretation at the drawing-primitive level for 32 line-drawing images with the quality of Figure 3. They are summarized as follows.

1. The rate of correct character interpretation is **98.5%**. This is because the common-sense knowledge such that "if characters exist around itself, it may be character." has a high validity for interpretation.

2 Broken-line element is correctly interpreted at rate of 100% It is concluded that the common-sense knowledge such that "if broken-line element exists around itself, it may be broken-line element." has a strong validity.

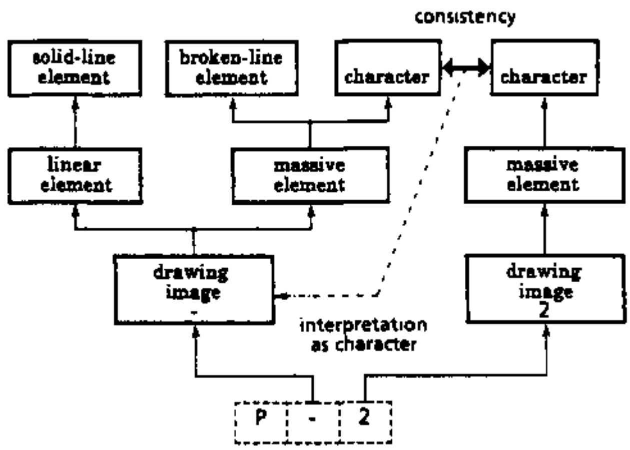
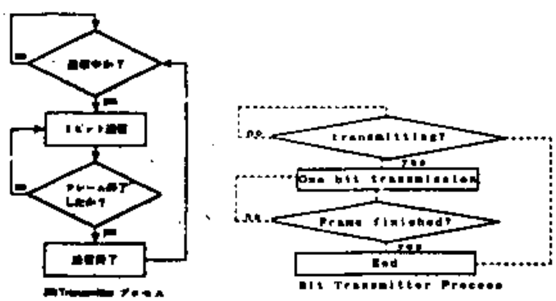
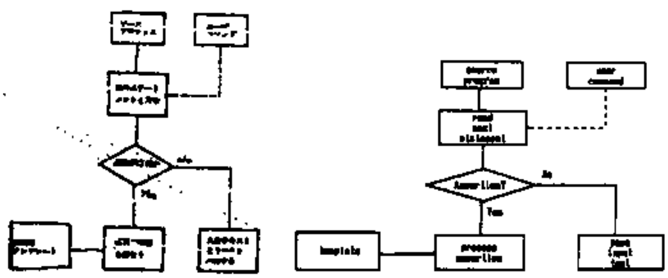


Figure 2 Context-sensitive and hierarchical interpretation



(a) Input image (b) Transformed image

Figure 3 Example of transformation



(a) Input image (b) Transformed image

Figure 4 Example of transformation

3. Arrow is interpreted correctly at rate of 56%. The knowledge about the shape of an arrow does not seem to have strong validity.

4. Solid-line element is interpreted correctly in most cases, but sometimes it is confused with an arrow.

V. CONCLUSION

In this paper, we proposed an uncertainty reduction paradigm based on context-sensitive and hierarchical interpretation for homograph, multiple-interpretation for heuristic knowledge, and finally certainty factor for data ambiguity.

In the paradigm, the interpretation proceeds from the image constituent level to the symbol level in bottom-up manner using common-sense knowledge given as the heuristic description. The common-sense knowledge is used to compute or modify the certainty factor of multiple-interpretation in context-sensitive manner. The hierarchy of constituents and also the hierarchy of knowledge effectively serve to reduce the uncertainty of interpretation at lower level. Remaining problems are summarised as follows:

1. Integration of top-down approach to this paradigm by using task dependent knowledge at the symbol level.
2. Detail evaluation of knowledge quality and automatic increase of knowledge quality by inductive reasoning.

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APPENDIX

A. The line width is uniformly thin." This is described as

$$fuzzy := \begin{cases} 1.0 & (max - mean \leq NOTCH) \\ mean/(max - NOTCH) & (max - mean \geq NOTCH) \end{cases} \quad \text{(exl)}$$

where max and mean indicate max width and mean width of linear element respectively, and NOTCH is a constant to present notch value. If the difference between max width and mean width is smaller than NOTCH, line width is considered to be uniformly thin so that the certainty factor becomes 1.0. Otherwise, the certainty factor decreases as the difference increases.

B. The size is small or it does not contact to a linear element." This is described at

$$fuzzy := \begin{cases} 0.2 & (1 \leq max \leq 5) \\ 1.0 & (5 \leq max \leq 20) \\ 1.0 - (max - 20) \times 0.2 & (20 \leq max \leq 50) \end{cases} \quad \text{(CX 2)}$$

where max is the maximum value within the minimum boundary rectangle of the massive element. If the max is too small, it is considered as noise so that the certainty factor becomes low 0.2. If the max is too large, it is considered to contact to a linear element so that the certainty factor becomes low as the max increases.

C. The certainty factor in the following knowledge indicates that of a massive element.

1. Solid-line element:- The shape is slender. / Linear elements exist around it. / The certainty factor is low as a massive element.

2. Broken-line element:- The shape is slender. / Massive elements exist along its direction. / The certainty factor is high.

3. Arrow:- The shape is like an arrow / A linear element exists towards the arrow. / The certainty factor is low.

4. Character:- Massive elements exist around it. / The certainty factor is high. / The vertical to horizontal ratio is near 1.

5. Noise.- The size is small. / The certainty factor is low

D. An example of computing the certainty factor for characters is as follows:

$$\begin{array}{ll} \textbf{IF} & (isolate \text{ and } figure-fuzzy < THC) \\ \textbf{THEN} & fuzzy' = maximum(0.3 - ratio/10, 0.0) \\ \textbf{ELSE} & fuzzy' = maximum(1.0 - ratio/20, 0.2) \end{array} \quad \text{(ex 3)}$$

where "isolate" is the logical function to investigate the isolation of the massive element, "ratio" is vertical to horizontal or horizontal to vertical ratio which is greater than 1. "figure-fuzzy" is a certainty factor of the massive element and maximum is a function to select the largest one.

This indicates that if the massive element is isolated and the certainty factor is lower than the threshold THC, it may not be a character so that the certainty factor becomes lower as the ratio becomes greater than 1. Otherwise, the certainty factor of a character increases as the ratio tends to 1.

E.

1. Solid-line element:- The certainty factor is low as arrow. / The certainty factor is high as solid-line element.

2. Broken-line element:- Other broken-line elements exist along its direction. / Their certainty factor is high.

3. Arrow:- Solid line elements exist around it. / The certainty factor is low as solid-line element.

4. Character:- Characters exist around it. / The certainty factor is high as characters. / The certainty factor of near characters is high.