MVA'94 IAPR Workshop on Machine Vision Applications Dec. 13-15, 1994, Kawasaki

ROBUST LINE DRAWING UNDERSTANDING INCORPORATING EFFICIENT CLOSED SYMBOLS EXTRACTION

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Abstract

This paper presents an efficient extraction method of closed loops as primitive symbols of line drawings, and an robust line drawing understanding system incorporating this extraction method. A graph search technique is used for the symbols extraction method to provide efficient model prediction and verification facilities, and quantitative consideration on the computational cost is shown. The line drawing understanding system can efficiently extract models from fairly complicated line drawings preserving the computational cost fairly small.

1 Introduction

This paper presents an efficient extraction method of closed loops as primitive symbols of line drawings, and an robust line drawing understanding system incorporating this symbols extraction method.

Generally, an image/drawing understanding process is composed of model prediction and model verification, which are performed complementarily and alternatively. The model prediction phase requires exhaustive and reckless search of feasible primitive symbols as triggers of models, and the model verification phase requires extraction of a certain kind of symbols. These operations need much expensive computational cost, as the target images get much complicated and models become composite ones.

It basically originates in ambiguity of images. There are some researches to reduce combinations of symbols from given images/drawings using cognitive psychological knowledges. For example, [1] gives reasonable number of combinations of symbols rather than combinatorial explosion from given line drawings; however, former researches did not provide actual computational procedure to obtain symbols.

In contrast to this, we give a formal algorithm of symbol extraction from line drawings which also can incorporate "feasibility" of symbols, i.e., cognitive psychological knowledges given in former researches. An image understanding method incorporating an efficient symbols extraction method is described, using line drawing understanding as an example and giving quantitative considerations on the computational cost. Firstly, an extraction method of closed loops as primitive symbols using graph search technique is proposed with consideration on its computation order. Then being provided efficient model prediction and verification by the symbols extraction method, a line drawing understanding system is presented. This system can extract objects from fairly complicated line drawings along with given models preserving the computational cost fairly small. This system reveals an effectiveness of this symbols extraction method, and importance of the view point on the computational cost of image understanding.

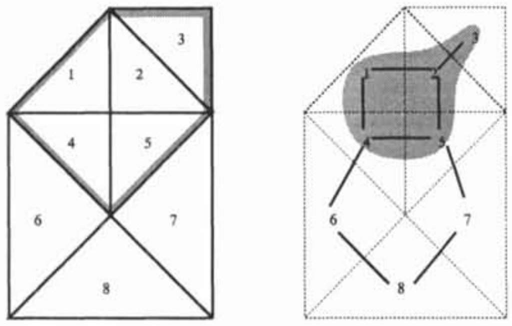
2 Closed Symbols Extraction

A closed symbols extraction method is realized using an efficient graph search technique. This method can exhaustively and efficiently extract candidate symbols, and can be controlled easily to generate feasible symbols earlier based on a certain criterion of feasibility, e.g., psychological criteria. To explain our method, we give an informal definition of a *fundamental cycle graph*, and a *search tree* based on this graph structure. Then a search strategy of tree to extract candidate symbols incorporating feasibility criteria of symbols is described.

2.1 Fundamental cycle graph

Firstly, a graph structure is composed from given line drawings. Every crossings and corners correspond to nodes of the graph, detaching lines at the nodes, and detached lines correspond to edges of the graph. This graph is obviously a planar graph. Then all fundamental cycles are extracted from this graph. Intuitively speaking, a fundamental cycle is a simple cycle which does not include other simple cycles in it, where a simple cycle is a cycle which does not arrive any node more than twice.

Given fundamental cycles made from line drawings, a fundamental cycle graph will be composed. In this graph, each fundamental cycle corresponds to a node, and an edge shows adjacency relation of two neighboring fundamental cycles. Every subsets of fundamental cycles which compose a sub-graph of the fundamental



(a) a line drawing. (b) a fundamental cycle graph.

Figure 1: An example line drawing and a fundamental cycle graph.

cycle graph obviously correspond to closed symbols, and vice versa. Thus closed symbol extraction is realized as sub-graph search from the fundamental cycle graph. Figure 1 shows an example line drawing and a fundamental cycle graph obtained from this drawing. The shaded area in fig. 1(a) corresponds to the shaded subtree in fig. 1(b).

The optimal computational cost to obtain fundamental cycles is known to be $O(n(e-n+1))$ where n is the number of nodes and e is the number of edges[2]. The number of fundamental cycles is at most $e-n+1$, thus obviously the cost to generate fundamental cycle graph is not more than $O((e-n+1)^2)$. (it will optimally be $O((e-n+1)\log(e-n+1))$.) It is sufficiently small in comparison with the total cost.

2.2 Search tree

The most efficient sub-graph enumeration algorithm has been proposed as one of the outcome of the graph theoretic research [3], however, such algorithm generates sub-graphs in arbitrary order, i.e., never paying attention to feasibility of symbols. We use a search tree of a fundamental cycle graph for symbols extraction, which can incorporate feasibility criterion as a search strategy. We give several definitions to define a search tree of a fundamental cycle graph.

Definition Let $G = [V, E]$ be a fundamental cycle graph where V is set of nodes corresponding to fundamental cycles and $E = \{(v_i, v_j) | v_i, v_j \in V\}$ is set of edges corresponding to adjacency relations of nodes. Two nodes $v_k, v_l \in V$ are *adjacent* under G if $(v_k, v_l) \in E$ or $(v_l, v_k) \in E$.

Definition Let Z be set of integers and V be set of fundamental cycles. A function *select*:$Z \times 2^V \longrightarrow V$ is defined as follows:

$$\mathrm{select}(i, C) \in C (1 \leq i \leq |C|). \tag{1}$$

$$\mathrm{select}(i, C) = \mathrm{select}(j, C) \rightleftharpoons i = j$$
$$(1 \leq i, j \leq |C|). \tag{2}$$

$$\bigcup_{1 \leq i \leq |C|} \{\mathrm{select}(i, C)\} = C \tag{3}$$

$$\mathrm{select}(i, C) = \mathrm{undefined}$$
$$(i < 1, |C| < i). \tag{4}$$

Definition Let $G = [V, E]$ be a fundamental cycle graph. A *search tree* of subsets is defined recursively as follows:

1. Let *root node* n_r be $< \phi, V >$.
2. Let V_{adj} of a node $n =< L, C >$ be $\{v | \exists v_L (v_L \in L, v \in C$, v and v_L are adjacent under G$)\}$. A node $n =< L, C >$ has $|V_{adj}|$ children. The *i-th child node* n_i is defined as:

$$n_i = < L \cup \{\mathrm{select}(i, V_{adj})\}, C \setminus \bigcup_{1 \leq j \leq i} \{\mathrm{select}(j, V_{adj})\} > . \tag{5}$$

3. A node $n_l =< L_l, C_l >$ which satisfies $\forall v_L, v_C (v_L \in L_l, v_C \in C_l \rightarrow v_L$ and v_C are not adjacent under G$)$ is a *leaf node*.

Every subsets of fundamental cycles composing subgraphs of the fundamental cycle graph are found at the first element of each node of the search tree, occurring at most once. Thus closed loops extraction is realized as retrieving nodes of the search tree exhaustively without duplicates.

The size of a search tree is exponential to the size of a drawing, because the number of closed loops which can be extracted from a drawing is exponential. In actual implementation, a search tree is generated only partially on demand of a search procedure described in the next section.

2.3 Search strategy

Given this search tree, symbols extraction is realized as search of this tree. The number of extracted loops from a search tree is basically exponential to the size of the given line drawing, (i.e., the number of lines,) so it is required to obtain desired symbols as early as possible using appropriate search strategy. We discuss about search strategy of this tree to perform desirable symbols generation for understanding system.

Symbols extraction is performed as parallel search of a search tree starting from root node, and descending from each node to its children nodes. Every time it arrives a node, it generates a closed loop corresponding to this node as a candidate symbol. Basic search strategy is simple parallel search, i.e., breadth first search. A descent from a node to one of its children is made along a edge of a search tree, which expresses grouping of a symbol and a fundamental cycle, respectively corresponding to L and $\mathrm{select}(i, V_{adj})$ in equation (5).

To be used properly in understanding system, it is desired to generate feasible symbols earlier. Thus desired search strategy should give high priority to generating feasible symbols. On our experimental embodiment, a tentative feasibility criterion is defined on edges of a search tree, i.e., on grouping of symbols. Each symbol is represented with a finite set of lines which compose a closed loop. Two symbols which can be grouped are adjacent, thus they share a common set of lines. This

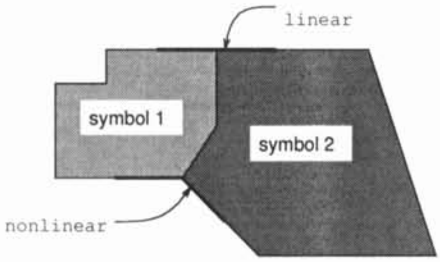


Figure 2: A tentative feasibility criterion.

common set is expected to compose a series of lines with only two terminals, if we prohibit holes in symbols. (and on our experimental system, holes are actually avoided.) Each of two terminals has two connecting lines which are not included in the common set of lines, and each line respectively belongs to each symbol. A tentative feasibility criterion is defined as linearity of this lines as shown in fig. 2.

Using this tentative criterion, we give tentative search strategy of a search tree. Firstly search of a tree is made along only edges corresponding to grouping which has two set of lines being connected straight. (we call such grouping "all straight" grouping.) Soon it will stop on account of exhausting "all straight" groupings. Then it randomly select one of stuck grouping which has one straight connection and one not straight, descend the corresponding edge, and continue search using only "all straight" groupings. If there is no stuck grouping which has at least one straight connection, it randomly select a stuck grouping among groupings without straight connection. These steps are repeated continuously.

Shown feasibility criterion and search strategy give a candidate symbols extraction method. Although we should deeply consider on this feasibility criterion and search strategy to make it much proper and efficient symbols extraction method suited for an understanding system, this tentative method shown here adequately works well as shown in the later section.

This search strategy evidently takes the exponential cost compared with the size of the drawing to extract "all" closed loops. Feasibility criterion is used to reduce the total number of symbols to be generated, but the total number deeply depends on a configuration of a given drawing, moreover, on feasibility criterion used in the extraction method. Therefore it is impossible to generally describe about the computational cost of this phase. However, it is worthy to give the computational cost of an interval of candidate symbols generation. Obtaining the next candidate symbol is equivalent to generating an edge of a search tree. It takes $|L| \times |C|$ to generate an edge from a node $n = < L, C >$ in our "not optimal" implementation, thus the cost may be $O(N_{fc}^2)$ where N_{fc} is the number of fundamental cycles. Then a feasibility check is needed for each edge, and it takes at most $O(N_l)$ computational cost where N_l is the number of lines. Therefore the total cost may not exceed $O(N_{fc}^2 \times N_l)$, which is polynomial of the size of drawings.

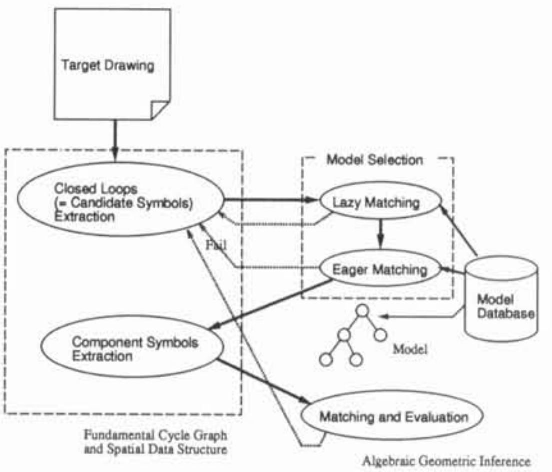


Figure 3: A typical construction of a line drawing understanding system.

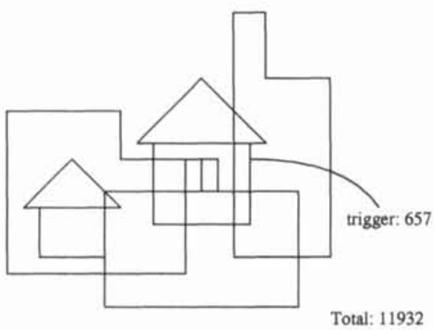
3 Drawing Understanding System

We assume that the drawing understanding is typically realized as the model prediction by eventual primitive symbols extraction, and the model verification, where each model is composed of combination of primitive symbols. (closed loops.) The system cannot assume beforehand in which part in given line drawings the object that represented as the model is, so it is required to exhaustively and recklessly generate candidate primitive symbols which may be triggers of models in the model prediction phase. The graph search method can be used effectively to extract trigger symbols. The proposed system uses models expressed in an algebraic constraints form, which is given as pairs of a trigger symbol and algebraically expressed verification methods of the rest of symbols. This verification is performed efficiently using the proposed graph search method incorporating with spatial data structure.

Figure 3 shows a typical construction of a line drawing understanding system. Given target drawings are processed by a closed loops extraction part to recklessly generate a trigger symbol of models using the symbols extraction method described in previous section. An extracted symbol is matched with model database and select a candidate model. On our experimental embodiment, the system allows only one model to be matched thus this model selection part performs mere model matching.

If the extracted symbol matches to a trigger symbol of the given model, this model is evaluated incorporating component symbols extraction using the symbols extraction method. The model is composed of a trigger symbol, set of component symbols, and spatial relations between trigger and components. Given a trigger symbol, existing area of each component will be reduced to some extent using these spatial relations. Then the system selects lines which are included in this area using spatial data structure, and generates symbols among selected lines with the proposed method. We use BD-tree[4] on our experimental system as an example. This selection drastically reduces computational cost because it is exponential to the number of lines as described before.

If all phase are performed satisfactorily, a given model is found in a given drawing. If it fails at some phase, it immediately continues to generate the next candidate symbol at closed loops extraction phase.



(a) a line drawing including house.

(b) a house model.

Figure 4: An example line drawing.

4 Experiment

We constructed an experimental line drawing understanding system and tested it with example line drawings. Figure 4 shows one of example line drawings. Given a line drawing of fig. 4(a), the system successfully extracted a house of which model shown as fig. 4(b).

The system totally extracted 11932 closed loops from fig. 4(a), however, it got a trigger symbol (a rectangle shown as fig. 4(b)) which caused successful matching of the house model after generating 656 symbols, i.e., got it as the 657th symbol using the feasibility criteria described before. As for extracting the house shown in fig. 4(b), $11932 - 657 = 11275$ symbols will not be generated. Thus the feasibility criteria can be said to be effective thus far.

5 Conclusion

A new method of efficient closed loops extraction is presented. This method is suitable for model prediction and verification for drawing understanding, and a line drawing understanding system incorporating this loops (symbols) extraction method is described. Graph descriptions are used for the proposed symbols extraction method, where enumeration of sub-graphs that correspond to closed loops is used as exhaustive symbols extraction. The graph search method is much suitable for drawing understanding, because it can easily be controlled by a certain criteria, i.e., feasibility based on the psychological consideration. The computational cost of drawing understanding is also considered to offer efficient and practical understanding, where this view point has been insufficiently considered in the former researches. Further research should be directed at getting optimal implementation of the method, considering precisely about feasible criterion of symbols grouping, and constructing practical understanding system with sufficiently large scale model database.

References

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