Line Drawing Interpretation as Polyhedral Objects to Man-Machine Interaction in CAD Systems *

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ABSTRACT

Man-machine interaction, and especially 3D object creation, is one of the weak spots of CAD systems. We present here a system to overcome such weakness by interpreting hand-line drawings as 3D objects. Our system has a multilevel structure. Two levels have already been developed: the *Feature extraction level*, which produces a line description of the image and the *Feature interpretation level*, which provides a labelled description of the object whose projection is likely to match the line-drawing. The system will culminate in a third level, still in progress, that will provide the three-dimensional reconstruction of the object. Since the drawing is hand drawn, a set of tolerances has been defined in both levels to allow a more flexible adjustment of the entities.

1. Introduction

CAD systems for solid modelling have a set of techniques aimed at three- dimensional scene creation, storage, visualization and analysis. In such systems, user-system interaction is essential to make good use of the resources offered by the CAD system (menus, command language, icons, etc.)

In general, the user must have learnt creation techniques to be able to use a CAD system. Further, the implementation of the techniques may well differ from a system to another.

In the recent years, several authors have put forward the improvement of user-system interaction, and more concretely, the three-dimensional solid creation process where interaction plays a substantial role. Some of these works are framed in the

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creation of two-dimensional scenes.[13,5] As for three-dimensional scenes, 3D object creation systems from three views have also been proposed.[1,3] It is Sugihara[14] who formalizes line drawing description and who proposes a system to reconstruct objects from a single view onto the trihedric domain.

With the purpose of ameliorating man-machine interaction in CAD systems, the project here described proposes a system for three-dimensional object creation in a CAD model from a hand-line drawing corresponding to the projection of the object from a single view. The drawing's image capture is performed by optical means, that is, through a camera, a scanner, etc. The system is structured in three levels:

Feature Extraction: extracts a line description of the image obtained by scanner using image processing techniques.

Feature Interpretation: an interpretation of the line drawing as 3D object is performed to characterize possible objects.

Three-dimensional Reconstruction: obtains the position and orientation of the object whose projection corresponds to the line drawing.

The first and the second of these are described in this communication and make up the interpretation system.

2. System Description

Next we will enunciate the rules any user should keep in mind concerning the hand-line drawing as well as the constraints of the system. However, before enunciating the system assumptions, let us define the concepts used in the description of the system.

2.1. Definitions

As many other computer vision systems, ours works in different domains. In principle, we consider three domains on each of which a set of entities is defined and related to the other two. These are, ordered from higher to lower level, the following: *Scene Domain*, *Line Drawing Domain* and *Image Domain*.

2.1.1. Scene Domain

Objects based on planar surfaces are the ones considered in the three-dimensional space. For this reason, an object is represented by a set of *vertices* (V), *edges* (A) and *faces* (F).

2.1.2. Line Drawing Domain

In this domain our attention is focused on drawings with dashed lines that describe hidden lines in the scene domain. Following Sugihara's definition,[14] a line drawing is defined by a quadruple $D = (J, E, u, v)$ where J is a finite set of junctions, E of lines, u is application such that $u(s)$ represents the position of the s $(s \in J)$ and v is an application of E on AS, $AS = \{solid, dashed\}$ such that $v(l)$ represents the appearance of the line $(l = (s,t)\ s,t \in J)$. The appearance represents the visibility of the corresponding edge.

Two types of junctions may appear in line drawings with dashed lines:

Pseudovertices: junctions corresponding to a vertex of the object.

Accidental Crossings: junctions corresponding to edge crossings at different depths in the scene domain. These junctions exhibit collinearity in the lines meeting at them. According to the appearance of their lines, accidental crossings are classified into: *false crossing* and *change of visibility crossing*.

This classification justifies the creation of two subsets of J, J_1 and J_2, respectively formed by pseudovertices and accidental crossings.

Due to the meaning of accidental crossings in the scene domain, the existence of two collinear lines meeting at this junction implies that both belong to the same edge of the object. This leads to the definition of the entity *pseudoedge* that corresponds to an edge of the object. Namely, the set E^*, constructed from E and formed by the line-drawing pseudoedges, is defined.

On the basis of the entities previously named, we build ordered and closed sequences representing polygonal shapes of the drawing. Depending on the entities forming them, they can be either *regions*, if formed by elements form E and J, or *pseudofaces*, if by elements of E^* and J_1.

The description of these polygonal entities on the drawing entails the definition of the sets R and P composed of sequences of regions and pseudofaces of a line drawing. The concept *pseudoface* is directly linked to the surfaces of the 3D object corresponding to the drawing. Hence, any pseudoface includes one or several regions of the drawing. According to this criterion, a given pseudoface can be *Ambiguous*, if it includes only a region, or *non-ambiguous*, if it includes more than one.

Any region of a line drawing belongs at least to a pseudoface and given pseudoface we can know how many regions belong to it. Depending on the number of regions and on the appearance of the pseudoedges forming the pseudoface, a pseudoface can be:

Visible. If the appearance of every pseudoedge forming it is solid. Consequently we can obtain the regions associated to this type of pseudoface.

Half-hidden. If it has pseudoedges with dashed appearance and it includes regions non-belonging to visible pseudofaces.

Hidden. If it has pseudoedges with dashed appearance but, at the same time, all the regions forming them belong to visible or half-hidden pseudofaces.

An opacity attribute is associated to every pseudoface. This yields that are classified as *Opaque*, if they correspond to solid surfaces of the object, or as *transparent*, if the attribute does not define any surface of the object.

2.1.3. *Image Domain*

In this domain the image obtained by the scanner is defined through a bidimensional matrix of pixels, whose (x, y) position stores its corresponding grey level. In this domain the entities are:

Segment. Set of connected points with the same slope among them. It can correspond either to a line of the drawing or to a part of a dashed line.

Characteristic Point. Extrema of segments of the drawing. We distinguish three types of characteristic points: *terminal points* (an only neighbour), *multiple points* (more than two neighbours) and *corner points* (points with a sudden change of direction of the contour).

2.2. *System Assumptions*

System assumptions are classified into[8]: *three-dimensional object domain*, *viewpoint* and *drawing rules*.

The three-dimensional object domain is based on flat surfaces, named as *up-to-three surfaces* by Kanade,[6] and extended by us to hidden lines. On the other hand, a *general position* is assumed. As drawing rules, there exist two line appearances to represent edges: *solid* for the visible lines and *dashed* for the hidden lines.

3. Feature Extraction

The purpose in this level is to obtain a description of the image sensed by a scanner in terms of a line drawing $D(J, E, u, v)$. This is composed by the following modules:

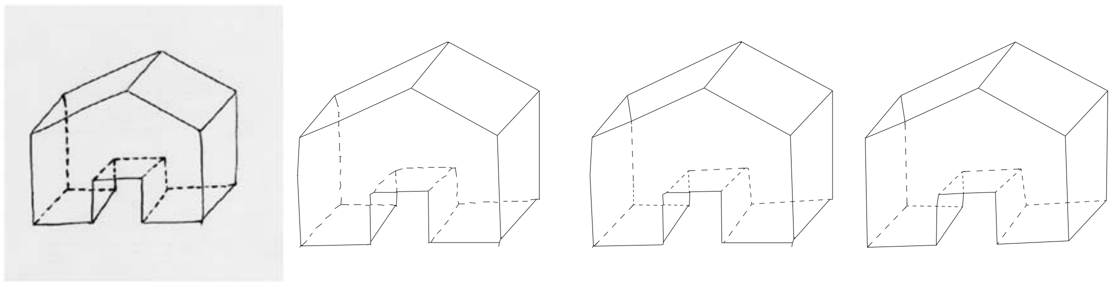
Acquisition and initial processing. The image acquisition is performed by a scanner using 127 dpi (0.2 millimetres per pixel) resolution and 256 grey levels. Next, we successively apply a binarization (using Otsu method[10]), a filtering (to remove isolated points) and a thinning to obtain a new image (TI). This latter will be the basis for characteristic point detection, once we pass it to 4-connectivity.

Characteristic Point Detection and Approximation by Straight Line Segments. In terminal-point detection we use two different techniques: terminal and multiple points are found by means of convolution and binarization techniques. In corner-point detection contours between the previously detected terminal and multiple points are encoded with a Freeman code, on which the Weighted-K-Curvature[12] method to detect corner points is applied.

Dashed Line Detection. Once characteristic points are detected, we come to a new representation of the image in terms of a graph $E(P, S, \mu)$ with the set of characteristic points (P) as nodes, the set of segments (S) as archs and an application $\mu : P \rightarrow Z^2$, where $\mu(p)$ represents the position (x, y) of the characteristic point p on the image ($p \in P$). Dashed-line extraction is performed from this description. Since these drawings are hand made, there is no point in applying a strict collinearity condition to the segments belonging to a dashed line. So, certain margins of tolerance have been defined for their slope and position.

Characteristic Point Merging. We merge those characteristic points considered to be close according to the tolerances defined by the user. Moreover, we calculate the possible accidental crossings (see next section) that might not be included in the drawing.

Figure 1 shows the results of these modules in the example *house*.



(a) (b) (c) (d)

Figure 1: Feature extraction in the example *house*: (a) Acquisition and initial processing. (b) Characteristic point detection and approximation by line segments. (c) Dashed line detection. (d) Feature merging.

4. Feature Interpretation

In this module tasks are concentrated on the qualitative analysis of the line drawing obtained in the previous stage. This analysis is based on line labelling techniques by means of a junction dictionary. The module is structured in the following processes: **line labelling**, **region and pseudoface extraction** and **pseudoface validation**.

4.1. Line Labelling

This process consists in assigning two attributes to every line of the line drawing: *label* and *appearance*. The first one describes the incidence of the surfaces on the line. The values defined by Huffman and Clowes[4,2] are adopted. These are *convex* (+), *concave* (-) and *occluded* ($\rightarrow$). This latter has two different meanings depending on its extrema: *input* junction inwards and *output* outwards. The appearance is defined in the line drawing and can accept two values: *solid* (V) and *dashed* (I).

There are two important considerations to be made in the labelling process: **junction dictionary definition** and **line drawing interpretation**.

4.1.1. *Junction Dictionary Definition*

The generation of the junction dictionary is based on the formalization defined by Kanade.[7] Through the incidence of 3 orthogonal planes, 12 *elementary surfaces* are defined. These in their turn describe the central intersection point and 6 lines that define the junction (Fig.2(a).

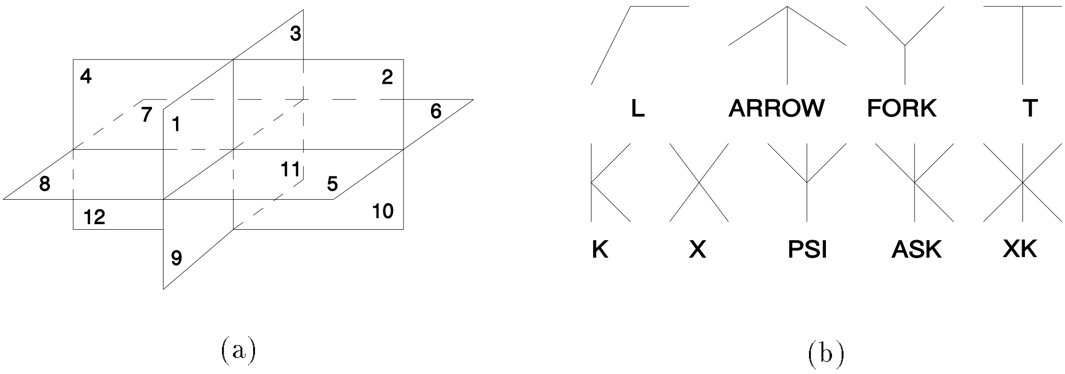


Figure 2: (a) Surfaces considered in the dictionary generation process in Origami World. (b) Shapes of junctions in Origami World.

An element of the junction dictionary is described in terms of the junction's shape and the label and appearance values of surface lines. There are the 4096 combinations of elementary surfaces. The number and position of non-void lines in the junction define the *junction shape*. Origami World defines 9 different shapes shown in Fig.2b.

Since it is actually a labelling pattern, the dictionary is compacted by defining equivalence relationships among the elements of the dictionary in order to keep the canonic shape for each relationship. Three equivalence relationships are defined on the junctions[9]: *rotation*, *symmetry*, *appearance*. As a result of applying these equivalence relationships and of obtaining only a representative for each class, the total amount of elements obtained in the dictionary from the 4096 initial is 715. Table 1 shows its distribution according to shapes.

	l	arrow	fork	t	k	psi	x	ask	xk
Origami[6]	8	15	9	16	19	7	22	41	16
Origami with hidden lines	4	23	9	18	70	89	22	285	195

Table 1: Number of elements in Origami junction dictionaries with and without hidden lines

4.1.2. *Line Drawing Interpretation*

This subsystem is devoted to generate any possible line labelling configuration compatible with the dictionary previously described. From the line-drawing description, it carries out the following processes:

Junction Characterization. The shape and distribution of the lines forming each line-drawing junction are identified by detecting accidental crossings.

Drawing Exterior Lines Identification. Exterior lines are conveniently labelled as occluded because the the support hypothesis[11] is not assumed. Whereas interior lines can accept any labelling value. Figure 3 shows this process in the examples *rampb* and *fulla*.

rampb *fulla*

Figure 3: Exterior-line identification in the drawings *rampb* and *fulla*, labelled as *occluded*.

Interpretation Tree Generation. The interpretation process is generated. The algorithm is based on the one proposed by Waltz[16] through the run along an interpretation tree by prior depth using relaxation techniques. As important feature, one must stress that the matching operation performed at each tree level does not define but restrict the set of possible values for each line of the drawing.

Consequently, a great number of interpretations is obtained mainly because of the extent of the dictionary and the great number of label values allowed in interior lines of the line drawing. This leads to generate interpretations clearly incoherent. In order to reduce this number of interpretations, we have defined several *labelling hypotheses*.

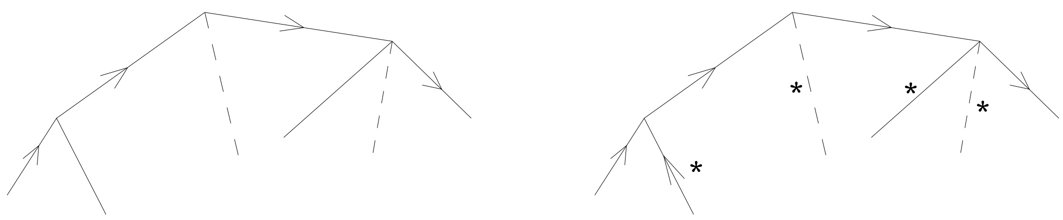
4.1.3. Labelling Hypotheses

Labelling hypotheses result from the formulation of criteria to reduce the number of possible label values in the interior line of the line drawing taking into account global features.

When formulating hypotheses, label values are grouped in two types: *connected* (*), that includes convex (+) and concave (-) labels; *occluded*, that corresponds to both senses: Input (I) and Output (O). After formulating each hypothesis, we apply relaxation techniques so that label values incompatible with the restrictions applied and the junction dictionary are removed. The following hypotheses have been formulated:

Hypothesis X: Labelling restrictions are applied to the two types of accidental crossings depending on the appearance of their lines and their meaning in the three-dimensional scene. The application of this hypothesis supposes 50% possible configurations reduction in false crossings and 75% in change of visibility crossings. Moreover, if we apply relaxation techniques after hypothesis consideration, the reduction can be even more dramatic.

Hypothesis 1: This hypothesis removes labels incompatible with the structure of the line drawing pseudofaces and considers opaque those pseudofaces corresponding to hidden surfaces of the object. It consists in the localization of groups of interior lines with certain appearance properties. An example of this hypothesis is shown in Fig.4. Its application has resulted in 72% reduction of possible configurations for each group of lines in the line drawing.



(a) (b)

Figure 4: Example of application of hypothesis 1. (a) Drawing with exterior lines labelling. (b) Application of hypothesis 1 to interior lines.

Table 2 shows the decrease in the number of interpretations on some examples of line drawings.

	Without Hip.	Hip. X	Hip.X + Hip.1
casa	15360	2904	6
fulla	6	6	4
rampb	2252	40	4

Table 2: Number of interpretations with or without labelling hypothesis

4.2. Region and Pseudoface Extraction

Here we will obtain a description of the line-drawing regions and pseudofaces compatible with the values previously obtained.

Both extraction algorithms are based on the run along the drawing's lines and junctions in search of closed sequences (the first junction must equal the last one). To control such run, we assign a weight corresponding to the maximum number of elements (regions or pseudofaces) meeting on the line.

4.2.1. Region Extraction

The definition of the regions of a line drawing affects the validation of pseudofaces – which justifies their extraction. A given region is classified as *exterior*, if it corresponds to the background of the scene, and as *interior*, if it is located inside the folding formed by the exterior lines of the drawing.

The extraction algorithm obtains the interior regions of the line drawing. Due to the definition of region, any interior line belongs to two interior regions whereas any exterior belongs only to one. Accordingly, a weight w_i is assigned to a line l_i corresponding to the number of interior regions meeting at l_i.

4.2.2. Pseudoface Extraction

The line drawing itself and the line labelling values obtained in the interpretation process affect pseudoface extraction.

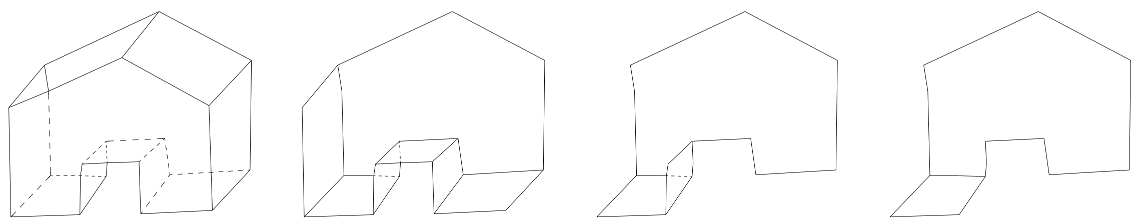


Figure 5: Example of drawings resulting from pseudoface extraction at each level for the example *casa*.

Firstly, we assign a weight W_i (corresponding to the maximum number of pseudofaces meeting at a pseudoedge) to each pseudoedge l_i^* of the line drawing. This assigning is made in accordance with the following two criteria:

- Possible labelling values of l_i^*.
- Number of lines meeting at each of the extrema forming the pseudoface.

Pseudoface extraction is made by levels. At each level two processes occur:

- Pseudoface localization through search of closed sequences of pseudoedges and junctions.

- Updating the appearance of lines considering the absence of the pseudofaces previously extracted.

After several iterations, a description of pseudofaces is obtained. Different relationships of belonging between the pseudofaces and the regions are established. These relationships play an essential role in the validation process. Figure 5 shows an example to this extraction process.

4.3. Pseudoface Validation

Once we have a description of pseudofaces and regions and their mutual relationships, we proceed to verify for the first which of them correspond to opaque or transparent surfaces of the object. These correspondence must agree the system assumptions and especially the "up-to-three surfaces".

The validation process is broken down into two stages to evaluate the following groups of pseudofaces: *ambiguous/non-hidden pseudofaces* and *ambiguous/hidden pseudofaces*.

4.3.1. Non-Ambiguous/Non-Hidden Pseudofaces

This first group includes the set of pseudofaces with lines inside and solid pseudoface-exterior lines. If all the interior lines are dashed, the pseudoface is opaque; if not, the pseudoface is transparent. The opacity assignment in this type of pseudofaces shows no ambiguity. Consequently, if after this assignment any system assumption is not verified, the pseudoface validation is wrong. Therefore, we obtain the set of regions associated to the opaque pseudofaces previously assigned.

4.3.2. Ambiguous/Hidden Pseudofaces

For this type of pseudofaces the opacity assignment may show ambiguity. For this reason the following rule is considered: *Whenever you can, consider pseudofaces opaque.* Hence, two opacity assignment strategies are defined for these pseudofaces: **justification** and **assumption hypothesis**.

Justification This strategy is based on the following constraint: *Every pseudoedge should belong at least to an opaque pseudoface.* Therefore, any pseudoedge belonging to an unique pseudoface justifies the opacity of this latter.

Assumption Hypothesis Once we have applied the previous rule, we apply to the pseudofaces still unknown the hypothesis of considering each of them opaque. The accomplishment of the system assumption under this hypothesis justifies the opacity of the pseudoface analyzed; else, it justifies its transparency.

As a result of the validation process, the opacity attributes of the line drawing pseudofaces are obtained. After a labelled interpretation, called *validated interpretation* is associated to these attributes. Next this validated interpretation is matched with the set of interpretations obtained in the labelling process. Consequently, a set of labelling interpretations compatible with the validation process is obtained and these will pass to the higher level of the system. If the matching is void, then the the labelling interpretations are not compatible with the system assumptions, that is, there is no 3D object corresponding to the line drawing. In table 3 we show the number of interpretations compatible with the validation on several examples of line drawings.

	Interpretations	Compatible Interpretations
casa	6	2
fulla	4	1
sillo	4	2

Table 3: Number of interpretations compatible with the validation of pseudofaces in the examples of line drawings.

5. Conclusions

We have presented a system for hand-line drawing interpretation as three- dimensional objects in the frame of a system for object reconstruction as input technique in CAD systems. We have presented the following work: (a) The definition of entities inside the different work domains of the system. (b) The formalization of a dictionary for line labelling which constitutes an application of Origami World to hidden lines as well as a line-drawing labelling to obtain labelled configurations of the line drawing. (c) Some constraints on labelling values grouped in labelling hypotheses proposed for a greater knowledge of the drawing supposing a considerable reduction of the number of interpretations obtained in the labelling process. (d) Some algorithms for line-drawing regions and pseudofaces extraction according to the labelled values. (e) A set of rules to assign opacity attributes to pseudofaces and be able to evaluate if the object agrees the system assumptions and obtain a set of labelled interpretations compatible with such assignment.

As future work, we are already developing the three-dimensional reconstruction level using the set of compatible interpretations and the top-down relationship among system levels.

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