

Interpreting Technical Drawings

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The paper presents a new approach to the input of computer graphic data in which the digitized images are interpreted using the knowledge attached to graphic elements. The standardization supplies a well defined and limited knowledge of problem domain which allows for an easy model implementation. In the prototyping process the knowledge is implemented by rules and semantic network. The object recognition strategy finally uses goal-driven processes which cooperates with data-driven one.

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1. INTRODUCTION

Discovering the meaning connected with technical drawings, although standardized, is a human task, and presently their digitized input in a computer system do not include any interpretation. The actual state of the art provides for the automatic reading of graphical data, and ad-hoc descriptions are introduced if necessary during the output. Sometimes the necessary non-graphic data are searched for in proper data-bases: this is the case in which an integration of data from different sources must occur. The paper proposes a method for acquiring and interpreting a graphic input based on the following considerations.

In all technical drawing standards we can discover a well defined knowledge which is attached to some graphic elements and to their spatial organization. This is the knowledge normally used by the human in order to understand the meaning of the drawing. This knowledge may be formalized, stored in a computer system and used as a model in a 'knowledge-based' recognition process. The adoption of Artificial Intelligence techniques allows us to automatically introduce jointly graphical data and descriptions. Moreover this fact suggests some modifications in the current standardizations: for instance we can increase the semantic contents by using more grey-levels or colours. We will take a glance firstly to input techniques and secondly to the interpretation problems.

A fast and available technique to automatically introduce graphical data in a computer system is the scanning. A scanner input often provides a binary thresholding in order to separate the objects from the background. That is the grey-level global histogram of an image is built and examined. If this is bimodal the value between the two peaks of the histogram is assumed as a threshold which divides the grey-levels in two partitions. A good quality commercial scanner can give available results in the case of non-degraded black and white technical drawings. In this case the system returns data with an apt to CAD/CAM environment format. This format may be used to analyse the standard graphic elements and their spatial organization, in order to match them with the previous defined models.

The binary thresholding¹ may be extended² to multimodal case. The segmentation so obtained is characterized by a number of grey level more than 2: the

image is composed by various regions, each with a grey-level selected from a given list. This type of image needs a more complex input device, for instance a system including a TV-camera and an image-processor. The problems arising now are twofold: first a good illumination of the image is necessary in order to avoid a perturbed grey-level distribution; secondly it is necessary to process the multi-grey image by more sophisticated routines. The advantage offered from this approach depends on the possibility of connecting knowledge also to the greys (or colours) rather than to only graphic elements. If the standards include a grey (or colour) scale the models will be enriched and the recognition process may be accelerated.³

Our understanding method can use both the scanner output and the TV-camera output. The current technology normally supplies good quality scanners but the systems with TV-camera which are able to automatically process the grey-level images seems less reliable. Then it is necessary to briefly describe the problems arising in the grey-level image segmentation.

The segmentation⁴ is a fundamental problem of Computer Vision which allows to supply primitives, named segments, to interpretation process. It attempts to extract meaning parts from image, which means objects and/or their parts. The segmentation process may be viewed as a classification process of pixels, in which the classes can be either grey-levels or regions or contour, edges, etc.: Our approach to the segmentation uses a multithresholding technique. The pixels are gathered on a basis of spatial and global characteristics: the grey-level distribution of the whole image gives an histogram each peak of which corresponds to a region. Then a region is identified by all pixels between two grey-levels, within which is a peak. A series of these grey-levels constitutes the thresholds and are detected in the valleys. Because the effect of local properties can mask the peaks of the histogram, some methods are adopted in order to accentuate the valleys, using gradient based operators.^{5, 2}

The objects so obtained may constitute the basis for the recognition process performed in a goal driven manner, as described later. We think that a human normally interprets a figure by matching with mental models. The analogous machine interpretation is very hard. Nevertheless a possible machine task seems the understanding of conventional drawing. The aim may be reached by including the spatially organized knowledge in a structural model and by implementing a recognition

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process which matches this model with the transformed visual data.

In general the image understanding is a complex process⁶ and the related problems are not completely investigated in all their aspects. The process has multiform faces and involves various levels, one other related, which we can summarize in the following four types: early-processing, low-level recognition, object-recognition, scene-understanding. The first level is greatly simplified if the input is carry out by scanner, and some problems may arise with the TV-camera. However in both cases a good lit and not degraded input drawing can guarantee an acceptable segmentation. In this condition the second level is in general not necessary. Then fundamental problems are defining the model and the matching strategy. The model of an object is compared with its instances and when a match occurs the object is recognized. The set of graphic objects so recognized, supplies the matter for a scenario description. The object-recognition problem is approached by an expectation-driven strategy, in which goal-driven processes may cooperate with data-driven one.

The paper is organized as follows. A first paragraph describes the problems arising when we attempt to interpret a technical drawing. Then they are delineated the problems related to the image segmentation. A third section concerns the system architecture. The next section concerns the knowledge representation adopted which holds the knowledge connected with the used graphic elements and with their spatial organization. Another section is devoted to a particular application, namely the recognition of technical drawings related to the building design. The last section contains the conclusion and the forecast on future developments of the project.

2. SEGMENTATION OF GREY-LEVEL DRAWINGS

As we have seen a first aim of this work is defining a methodology for the graphical object detection concerning both black-white and grey-level images. As the problem of black and white drawing detection is in general solved in commercial scanner, that one of grey-level drawing detection may be faced by defining a series of standard grey-level patterns. A drawing built with these patterns may be segmented by an ad hoc multithresholding technique.

Let us consider some proper characteristics of the graphic symbol understanding:

- (a) well defined line edges,
- (b) high lines-background contrast,
- (c) black-and-white images,
- (d) textures,
- (e) lines with different thickness,
- (f) discontinuity of tracks.

Firstly the (a), (b), (c), properties make easier the early-processing, in particular the thresholding and the edge detection. Secondly the (e) property suggests to define an optimum lower bound of thickness for automatic line-detection. Finally (d) and (f) suggest two choices: (1) the introduction of multiple grey-level, and/or colours, in order to represent both lines and fields; (2) the avoidance of 'complex' textures as well as of discontinuous tracks. Then in order to have an easy

automatic detection of the image it seems reasonable to introduce the following criteria:

- (i) defining a set of enough distanced grey-levels, making easy the threshold discrimination;
- (ii) defining a set of graphic objects;
- (iii) structuring the complex drawing in sub-drawing and adopting a number of graphical objects less than the number of grey-levels;
- (iv) assigning a given grey-level to each graphical object of sub-drawing.

The detection module of the system is organized in four levels. Firstly we have an image preprocessing, in order to uniform the homogeneous areas. This process maps the initial grey-level distribution in a more adequate one; then it smooths locally the image by a mask: the size of mask is locked to a mean gradient by an inverse proportionality. Secondly the pixels of image are clustered by a multithresholding technique. The image is processed in order to detect a series of thresholds. These thresholds are used in order to detect grey-level clusters, which constitute the basic image partition: the method assumes that different peaks represent different regions; the assumption is valid if massive texture are absent, and, in general, if the global properties are not masked by the local one. The method, normally applied to bimodal histogram,⁷ required the introduction of relevant local information, in order to process the multimodal case. Thirdly the image is coded using the quadrees. That is the image is partitioned in four quadrants; each quadrant if not uniform enough, is again partitioned in four quadrants, and so on; the recursive process stops when we reach homogeneous quadrants. The result is a maximal block representation and the related tree data-structure, named quadtree; in this structure the root represents the entire image and each node a quadrant; a non-terminal node is related to a non-homogeneous quadrant as a terminal one to an homogeneous one. Fourthly we have the labelling process which detects connected sets of pixels with the same label, named regions. The algorithm is developed in three phases: (1) visit of quadtree and assignment of labels to all nodes; (2) grouping of all assigned labels in class of equivalence; merging of all labels concerning the same grey-level; (3) visiting the quadtree in order to assign the same label to blocks belonging to the identical class of equivalence.

Fig. 1 represents a technical drawing in which to each graphical element is assigned a different grey-level. A

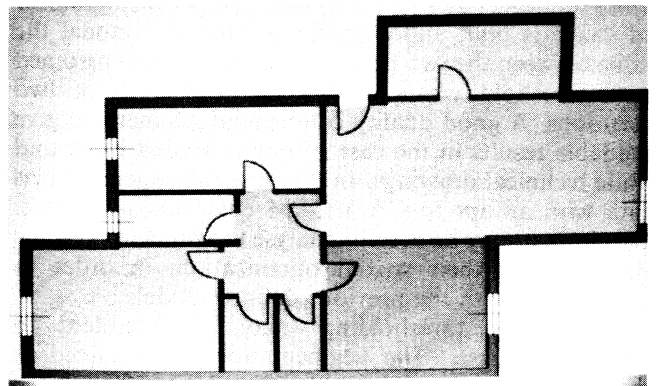


Figure. 1 Grey-level coding of graphical objects in technical drawing.

reasonable choice seems to use 256 grey-levels partitioned in 25 ranges. These ranges can constitute a series of standard grey-patterns for both manual and automatic execution of graphics. Fig. 2 shows the detection of desired graphical objects by processing the image with multithresholding technique.

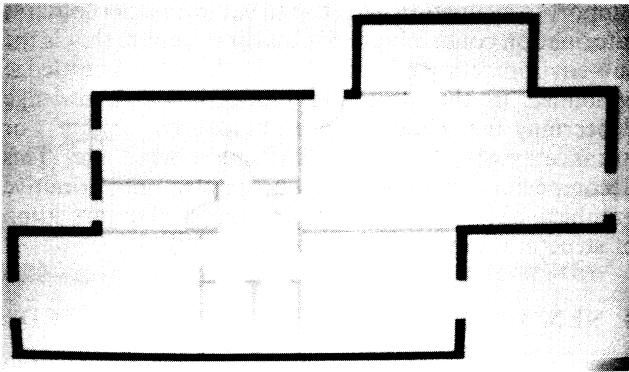


Figure 2. Automatic detection of graphical elements from a technical drawing.

3. THE KNOWLEDGE BASED APPROACH

Understanding a casual design is typical human task: in fact the human interprets the figure by matching it with mental model derived from its great amount of knowledge, stored during all one's life. This is a very hard problem for the machine. Nevertheless a possible task for the machine may be the understanding of conventional drawing. This can match the data with models representing a delimited and well known knowledge, which may be easily stored in a computer memory. A technical drawing, in fact is built using standards, concerning elementary graphic elements. The graphic elements can be structured in more complex graphic elements, which derive their meaning from a more wide environment. With these we can construct more complex graphic elements, and so on. This spatially organized knowledge can be represented in a structural model.

As we have seen the image understanding process involves various levels. An early-processing level, which includes the feature extraction and a processing based on physical and optical properties. In this phase takes place the image segmentation in meaning parts or in tokens; a low-level recognition, in which are detected intrinsic properties of the image and the objects are recognized by means of cognitive organization rules⁸; an object-recognition level, which attempts to recognize objects by matching between a model and an instance of this model; a scene-understanding level that finally produces a description of the scenario in which the preceding objects are located.

The particular nature of the problem domain let us to approach the automatic scenario description in a simplified manner. The first level is greatly simplified if the input is performed by scanner, and a good segmentation can be guaranteed by a not degraded input. The second level seems not necessary. The system implementation requires the definition of the following parts: the model, the matching strategy and the scenario description. The model will contain the knowledge related

to the graphic elements, both elementary and complex; its definition will be aided by the standard nature of the drawing elements, whose knowledge is contained in a well-defined domain. The matching strategy will be necessary in order to recognize the graphic objects in the scenario: the model of each object is compared with its instances and the object is recognized when a match occurs. Finally the scenario description will describe the meaning of the objects so recognized and organized in a complex scene.

A reasonable solution to object-recognition strategy problem seems the expectation-driven approach, cooperating with a data-driven one. In general a recognition strategy may be conceived as a set of plans, in which each plan is constituted of two parts: (1) a bottom-up, or data-driven, part which moves from visual data, and using inference rules allows to recognize an object; (2) a top-down, or expectation-driven, part which moves from the model and using planning rules attempts to verify an hypothesis generated by the system.

The system generates an hypothesis that involves a series of goals which the system itself attempts to satisfy using processed visual data. Driving the recognition by searching what we expect to discover facilitates the ambiguity clarification in object detection, as well as the default propagation may handle the data and knowledge incompleteness. In other words the computation process attempts to estimate the truth of an hypothesis, chosen by default. This must be regarded as an hypothesis to be accepted until proof to the contrary. An evaluation procedure, activated to search for objects, has its result in the hypothesis refusal rather than in an element confirmation. The object is recognized by default if there is not evidence to the contrary. An expert will be activated which tries to confirm a candidate. They are provided both geometric and relation experts. The first one are procedures which allows to detect geometrical, morphological and dimensional characteristics; in particular these experts are specialized in detection of qualitative geometric element. The relational experts are procedures which verify the spatial relation between two parts of an object: connection, position, inclusion relations, etc.

The model adopted is a semantic network,⁹ which facilitates the knowledge organization: the nodes represent the graphic concepts as the links structural, spatial and specialization relations. Particular attention is devoted to the geometric-structural knowledge. The scenario structure is characterised by the various environments and sub-environments, as well as by the objects which can have different occurrence-frequency. The spatial relations allow to define the mutual position of objects, such 'right-of', 'orthogonal-to', 'over', 'parallel', etc. Each part of a drawing is a concept in a semantic network and each structural and geometrical relation is an oriented arrow. A concept can have proper characteristics which are described by attributes. An attribute can be both quantitative and qualitative; for instance: length 10, quadrangular, short, etc. The relations can be partitioned in: structural, as part-of, has, etc.; specialization; spatial, as left-of, orthogonal, etc. By looking through the network it is possible to generate instances of concepts. The network is firstly visited top-down from the concept, and then bottom-up to the concept. There is a practical advantage in using the

semantic network: it not exists a semantics of the network, but this is connected to the procedures which operate on the network: then we can make inference on the same network with different procedures.

The strategy generates, from a goal, a set of sub-goals, each of which concerns the expectation of a sub-part; it analyzes top-down the semantic network until the primitive concepts, i.e. the graphic elements. If the elements involved in the hypothesis are not refused they are composed in order to instantiate the higher subgoals, and so on until the main goal, providing backtracking when necessary.¹⁰

3.1. The system definition

The recognition of objects in a technical drawing requires the introduction of semantic in the image representation. In order to define a model of the graphical image a main requirement is the knowledge related to the world of the computer vision system. Actually the involved problem-domain is the knowledge related to a residence and to its parts. Firstly this domain must be analyzed in order to define a structural model. Then the knowledge representing the structural model will be coded in a semantic network. Finally the knowledge enclosed in the semantic network will be used in order to recognize a part or a set of parts of technical drawing, according to a given strategy.

The problem domain is limited and its definition is related to both the operating context and the utilization of our vision system. As for context this concerns the inspection of technical drawings, which represent residence partitions, as well as the recognition of their parts for professional purposes. The objective is to automatize the object recognition work, improving the drawing analysis and the file information handling. As for utilization the analysis defines the type of environments in which is placed the computer vision system: that is the various types of buildings. The first analyzed environment is the drawing of a dwelling-house and of its part, inspected by a professional. Then are analyzed the sub-environment and the objects with proper characteristics of shape and grey-level intensity.

For instance in a dwelling-house drawing we individuate as sub-environment: floors, flats, rooms; as graphical objects: outer walls, partition walls, doors, windows, staircases, etc.

Each of these objects may be present in a sub-environment: for instance a flat must have the partition walls, and a room may have a staircase. This optionality is described by a parameter f with values $0-n$: if $f = 1$ to n the object is necessary, if $f = 0$ to n the object presence in the sub-environment is optional.

After the sub-environment analysis each object must be analyzed in all its components: for instance the graphical object 'window' is constituted by a rectangle, with a given grey-level, with a longitudinal axis, adjacent to outer space and inserted in an outer wall or in a partition wall.

Finally the model definition is necessary in order to drive the recognition. In this phase the knowledge on the world is acquired and formalized. This prototype definition is connected to the knowledge kind: for instance functional or structural knowledge. This partition is necessary only for operating purposes; the world

model must contain all the knowledge necessary to its description.

The functional model describes objects that have different function and identical or different geometry and structure. The function is described by its decomposition in a set of connected primitive function. For instance functional primitive may be: environment destination, support to evaluation, etc. The structural model contains information concerning the scenario structure, that is the sub-environment and the objects. Another knowledge contained in the structural model is the knowledge concerning the spatial relations among the objects. For instance: right_of, left_of, on, under, near, etc. This decomposition procedure may be iterated until primitive graphical object. The result is a hierarchical organization of structural models.

4. SEMANTIC NETWORK IMPLEMENTED

A semantic network has a set of concepts and relation between concepts, that are represented respectively with nodes and arrows. Among the various types of semantic network, we adopt here the epistemic one, in which the nodes represent conceptual classes and the arrows structural or taxonomic relations. The Fig. 3 shows a semantic network representing the technical drawing of a part of a flat.

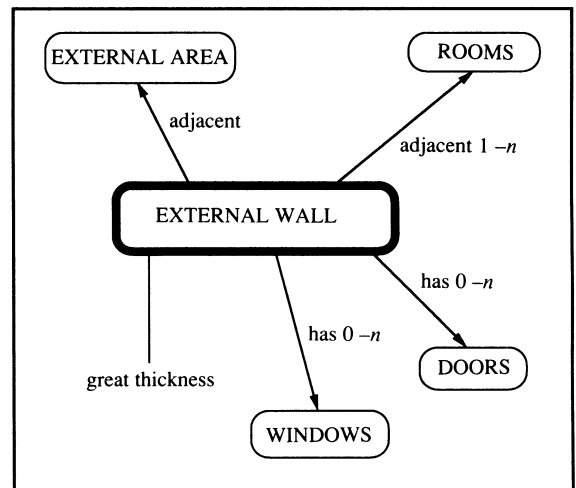


Figure 3. Semantic network representing the technical drawing of a part of a flat (outer wall).

The semantic network is the structural (or/and functional) model of the drawings. It is the reference in the graphical object detection; for instance in order to look for the existence of an outer wall, it will be necessary to verify if this graphical object:

- is adjacent to EXTERNAL SPACE,
- is adjacent to some ROOMS,
- has optionally WINDOWS,
- has optionally AIR SPACE,
- has optionally PIPES,
- has MEDIUM or HIGH THICKNESS,
- etc.

As for strategies they will be related to the various subenvironments of the more general buildings; an ad hoc strategy may be defined for each sub-environment according to the various needs of professionals, as estimates, computations for fiscal or cadastral ends,

listing of graphical objects in a drawing, determination of dwelling qualitative parameters, and so on.

During the matching phase each drawing, in a subenvironment scope, generates a goal; the goal in its turn generates a set of subgoals, each concerning the expectation of a part. From the stand-point of the experts each part may be considered as a region with various characteristics. In the semantic network a drawing part is a node and the spatial and structural relations are labelled arrows.

Nodes are:

drawing, outer wall, partition wall, external area, internal area, window, door, air space, pipe, etc.;

As for relations they are partitioned in

structural relations: has, part-of, etc.;

specialization;

spatial relations: left, right, near, adjacent, orthogonal, etc.

A network concept may have proper characteristics, which are described by the attributes. Here morphological and dimensional properties are adopted, described both quantitatively and qualitatively. For instance: lengthened, rectangoloid, n -grey, square, short, long, etc., are qualitative attributes, as length = 10, thickness = 0.2 are some quantitative one.

The following descriptions are examples as they result from the semantic network adopted.

Outer-wall:

lengthened area, adjacent to external area, adjacent to some rooms, which may have windows, air space, pipes, medium or high thickens, etc.

Window:

rectangular, left-adjacent and right-adjacent to outer wall, adjacent to external area, adjacent to a room, which has three equidistant segments parallel to the outer wall and an orthogonal segment etc.

5. THE IMPLEMENTATION

The system implementation uses the Prolog language because its facilities in the clauses writing and its ability to support the logic reasoning. The computer vision system recognizes the drawing representing flats in a dwelling house. Both the semantic network and recognition strategy are coded in Prolog. As for the experts they are implemented partially in C language and their routines are embedded in the Prolog code.

The semantic network contains concepts representing the basic graphic elements used in the standard drawing plans of building design. These are: outer-wall, partition-wall, window, door, room, staircase, balcony, girders, rafters, roof, fire-place, chimney, pipe, some furnishings, fitting and pertinent spaces, etc. As example Fig. 4 shows the semantic network of the 'window' graphic element. As for concept formalization it is represented by a functor with two arguments, as in the following formula:

concept (OBJECT, LIST),

in which the first argument represents an object and the second a list of relations related to the object. The relation formalization is the following:

relation (OBJECT, LIST).

Then the concept window can be represented by the following relation:

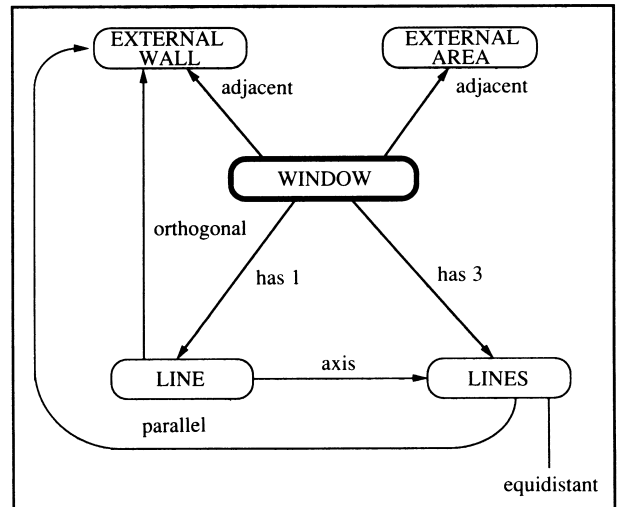


Figure 4. The semantic network of window.

WINDOW = [
concept (window, [has (line1), has (line2), has (line3),
has (line4)]),
relation (line1, [equidistant (line2), equidistant (line3),
parallel (line2), parallel (line3)]),
relation (line2, [equidistant (line1), equidistant (line3),
parallel (line1), parallel (line3)]),
relation (line3, [equidistant (line1), equidistant (line2),
parallel (line1), parallel (line2)]),
relation (line4, [axis (line1), axis (line2), axis (line3)])
].

The occurrence frequency of a concept, necessary to outline the optionality or the obligatoriness of the related concepts, is represented by a quantifier with two values: the minimum and the maximum number of occurrences. '0' occurrences indicates optionality. The specialization relation is useful in the representation of complex concepts, as in the semantic network of the room, shown in Fig. 5. The formalization of this concept is the following:

ROOM = [
concept (room [has (wall,4,4), has (door_wall,1,4)]),

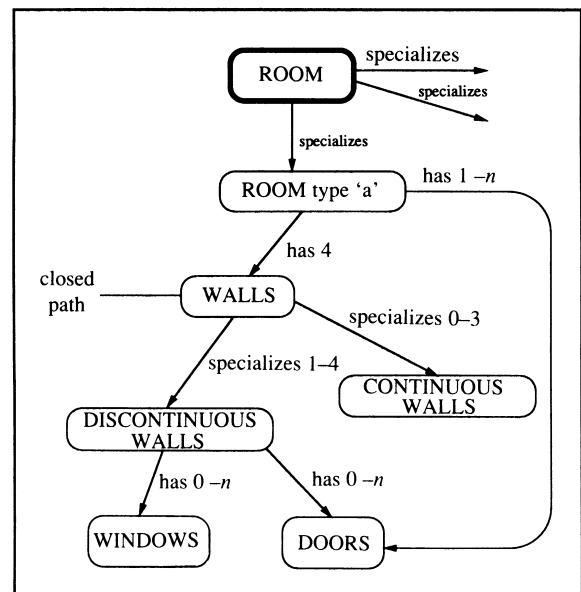


Figure 5. Semantic network of room.

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element (wall, [specializes (continuous_wall,0,3),
specializes (discontinuous_wall,1,4)]),
element (continuous_wall, [text ('primitive')]),
element (discontinuous_wall, [has (window,0,4),
has (door,0,4)]),
relation (wall, [attr (loop)])
].

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In Fig. 5 we suppose a different subnetwork for different type of room. Here we can distinguish two hierarchies: that one of 'has' and, at each level of this, that one of 'specialization'. We can see still the proper quantifier attached to each directed arrow.

The time spent in the semantic network visit may be relevant because of the great number of graphic elements. This is a classical problem which is faced in two manners. First of all we have provided a number of constraints which greatly reduce the path explosion. Secondly the search time is reduced by defining a minimum set of proper characteristics of each environment represented in the semantic network. Belonging triggers may be defined on statistics basis. For instance a set of furniture and equipment may signal the type of environment: dining chair signals a kitchen dining room in the 19 % of cases, stool in the 15 %, kitchen table in the 14 %, as we can see in the following table, from Noble,¹¹ valid for the kitchen environment:

FURNITURE IN KITCHEN	
Item	Per cent
dining chair	19
stool	15
kitchen table	14
dining table	13
other chairs	9
shelving units	2
armchair	2
dresser	1
plant box	1
cupboard/cabinet	1
other table	1
TV	1

The system implemented is capable of recognizing a dwelling's building objects given its plan. It receives, as input, the complete drawing of a dwelling. After the preliminary processing we can recognize all parts of the drawing component. The system can interact with the user by asking for the part to be individualized (e.g. 'window'); then recognizes the object selected by the user and returns a graphic output which highlights it. Moreover, the system updates an internal data base which will contain all the information gathered during recognition and will be used for final descriptions.

It is easy to see that such a system can be employed to list all the graphic objects in a drawing. The list, of course, can be organized by the users at their will. Attached to this objects then can be provided all the computational entities, such areas, perimeters, etc., which have great interest for designers and/or for fiscal and cadastral ends. Fig. 6 shows a typical work session for object recognition.

Another application of automatic recognition of graphic elements concerns the automatic determination of dwelling's qualitative parameters based on technical documentation and in particular on distributive features.

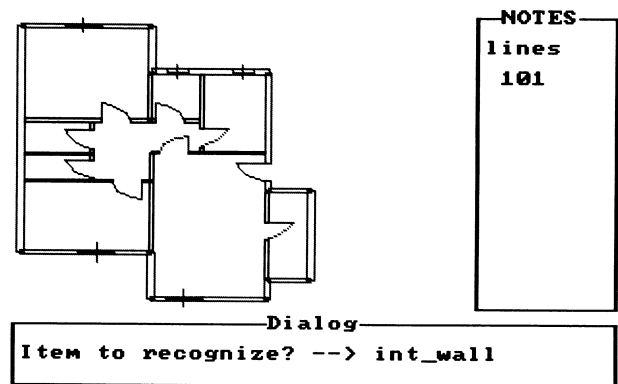


Figure 6. A typical interactive recognition session.

To this end it is firstly necessary to integrate the graphic elements of the semantic network with those of furnishings, fittings and pertinent spaces. Having a knowledge of furnishing and fitting graphic elements is helpful for room recognition, and it significantly cuts computing time. Some writings¹¹ adopt statistical techniques to study the classification of rooms according to typological features (e.g. 'kitchen'). These techniques supply a set of room triggers (even with a degree of confidence) which can lead and simplify room recognition process. Once a room has been recognized, the system can easily recognize some morphological aspects of the same room. More particularly it can:

- (1) recognize possible paths after considering physical and functional spaces occupied by furnishing into;
- (2) spot furnishings interference and determine the degree of functionality of use;
- (3) analyse visibility features, e.g. if the day area can be screened from the entrance.

6. CONCLUSION AND FUTURE IMPLEMENTATION

A system to acquire and to interpret the computer graphic input has been developed in order to automatically integrate data originated from different sources. Several aspects have been outlined:

- (1) the knowledge related to the standards of technical graphic elements is well defined;
- (2) the adoption of Artificial Intelligence techniques allows to merge automatically graphical data and image descriptions;
- (3) the semantic content of the current technical graphical standards may be increased using an adequate set of grey-levels or/and colours;
- (4) an 'until proof to the contrary' strategy allows both: the recognition of uncertain objects and the control of object recognition accuracy.

In substance we have shown the possibility of implementing a system based on the preceding principles which has the ability of both interpreting the completed drawing and controlling the drawing construction. Obviously, such ability is not open to any drawing; this is applicable only to those drawings with standard features which allow to manage the domain in terms of knowledge.

The future will see a better definition of structural models and an extension of the domain of knowledge bases. The method extension to three-dimensional

representation is also foreseen, which will imply the use of stereo vision. The future will regard also the extension of the semantic network to integral problem domain, as well as the recognition of axonometric and perspective drawing with integration of actual standards. The guided interpretation of perspective and axonometric two-dimensional drawing is currently under development. In the near future, the system should be able to recognize volumes, corresponding to given structural models, in a conversational manner.

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