TDraw: A Computer-based Tactile Drawing Tool for Blind People

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ABSTRACT

Considerations about blind people's relation to pictures of real world objects lead to the conclusion that blind and sighted people have very similar mental models of the 3D world. Because perception works completely differently, the mapping of the 3D world to a 2D picture differs significantly. A tool has been developed to allow blind people to draw pictures and at the same time study their drawing process. A first evaluation shows interesting results. These will eventually lead to a design of a rendering tool for (tactile) pictures for blind people.

Keywords

Tactile drawings, tactile rendering, mental model, tactile drawing tool, TDraw.

INTRODUCTION

Ordinary pictures are visual representations of referents from the real world or of an artist's or designer's imagination. Therefore they are of no use for people without vision. This is what common sense might tell us. And this is where "common sense" is wrong.

The most important characteristic of a picture is not its channel of perception (visual or non-visual), but the method of arranging information in space. This is, in most cases, the 2D space: the plane, of paper or canvas. The spatial arrangement and depiction of objects carries information about the real world arrangement of the depicted objects or about other relationships between these objects (such as hierarchical position in an organisation chart). It can be perceived visually or tactually or even sometimes acoustically.

This theoretical consideration, as well as practical experiences with blind people's interaction with graphically represented information, leads to the conclusion that blind people can read pictures. As will be shown below, their understanding of pictures depends on a number of conditions and possibly takes more time, but nonetheless they must be given a chance to receive the same information as sighted persons especially when they ar working in a common environment with sighted colleagues.

At this point, we should keep in mind that most pictures exist in a context. Pictures are part of a textbook or of an on-line information source such as a WWW page. In this paper I will concentrate on those pictures which are used in business tasks. Art also is a very important area for the use of pictures, but I shall concentrate on the use of pictures in professional tasks and leave the field of art to others.

Since the visual channel is excluded for the perception of pictures, blind people use tactile and/or acoustical perception to read a picture. This requires media to convey the picture to the tactile sensation. In the context of computer graphics, no interactive device for displaying tactile graphics and receiving positional input from the hand is yet known. Although this will probably change in the future [5], today one has to work with either small erasable tactile devices such as a Braille display or with non-erasable media such as swell-paper. The latter is preferred here because it allows smooth lines to be produced with no dot matrix approximation as in a Braille display. In addition, swell-paper can be put on a digitizer tablet and thus explored interactively [9, 10]. I will not address the problem of appropriate devices in much more detail here, since the main attention is directed to the drawing and exploration of the pictures themselves. Expressed differently: the question is not "with which devices can we convey tactile images", but rather "what do pictures for the blind look like?".

In other words: how should we render a picture of a real world scene so that it can be easily understood by a blind person? The first, rather straight-forward decision is to concentrate on the tangible properties of these objects, not the visible. Shadows, for example, are an important feature in photorealistic renderings for sighted people, but they are of no use in a tactile picture. The same is true for colours. On the other hand, the edge of an object can be touched in the real world and it can be rendered as a line in a drawing. Of course, a flat object such as a tabletop could be rendered as a filled polygon, but even in this case the blind person would orient on the edge of the polygon not caring whether it is filled or not [5].

The next question is how to render the table at all. For sighted persons this is already solved: using a perspective view with the known distortions, the table would look like a distorted trapezoid with up to four (partly) visible lengthy boxes representing the *legs* (see Fig. 1). The tactile version of a picture of a table would look quite different [5, 8], as will be shown towards the end of this paper.

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However, before we get there, we should study the way blind people draw objects. In this context we must survey the relation of perception, drawing and acting by blind and sighted people. Then we will look at a system developed for this purpose.

HOW DO BLIND PEOPLE DRAW?

Among psychologists there is a discussion whether or not (blind) people have a "mental model" of their environment, which is the spatial 3D real world.

The representatives of the "mental model approach" believe that perception is based on a process of fitting sensory-received information (stimulus) from the environment to an existing internal idea, the mental image. This mental image is a kind of "datastructure" which has a set of possible actions attached to it. Both, the mental image and the set of actions together constitute the mental model. If the stimulus does not fit, the model must be adapted, if it fits processing can be carried out easily with the mental model. Thus the mental model is the result of perception. The concept of 3D space is a part of the mental model.

The representatives of the "ecological approach" deny that something like a mental model exists at all. Their view is based on the idea of "direct perception" [4, 5]. Stimuli from the real world are processed directly without fitting it into a mental model. The spatial concept exists in mind but is not bound to an abstract representation such as a mental model.

Following the idea that something like a mental model exists, a computer scientist can look at this relation as a function which accepts sensory information and produces a corresponding mental model:

$$f_{perception}: \text{Real World} \xrightarrow{Sensation} \text{Mental Model}$$

For a sighted person, the sensation is based largely on vision. For a blind person it is based mainly on acoustic and tactile sensations. Of particular importance in this context is the mental model. Is it different for blind and for sighted people?

To answer this question, we could have a look at the reverse function of perception, lets call it action:

$$f_{action}: \text{Mental Model} \xrightarrow{Motion} \text{Real World}$$

In a familiar environment, a blind person can act much like a sighted person. In other words: if the mental model of the environment is complete and covers all the relevant objects and their position in space, sighted and blind people can perform comparable tasks. This and other (e.g. [8]) argumentation leads to the conclusion that blind people do have a spatial mental model of the world.

This model has all the relevant properties of the real world itself (this is the definition of term "model"). Otherwise the model would not work and therefore would be wrong. Since the referent of both the mental model of the blind and the mental model of the sighted person is the same (the real world), we can conclude that they have about the same model as sighted people have (except for some obvious features such as colour).

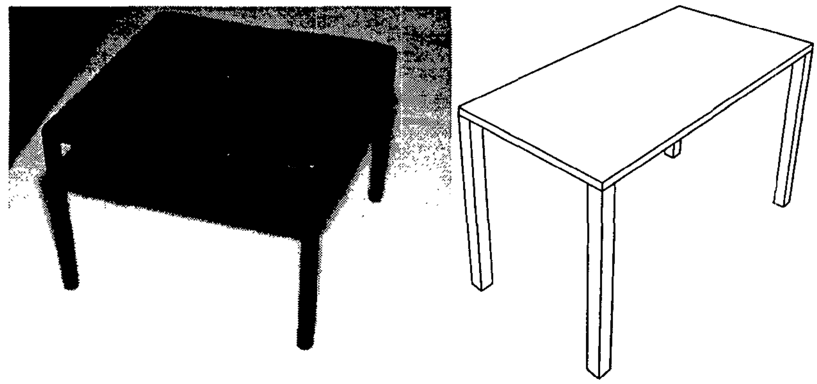

Fig. 1 A photograph and a rendered image of a table.

In addition, we can verify this conclusion by the following observation: Asked about the spatial relation of objects in space (position, orientation, size) blind people give about the same answers as sighted people do.

After these considerations about the mental model, let us look at the way sighted and blind people take a picture from the real world.

For sighted people, that is an easy task. We have a machine to do that for us: the camera (Fig. 1). Even if we "take" the picture "by hand", that is, if we draw a picture on paper or canvas, the result looks more or less like a photograph (depending on our talent and intention). This is the logical result of the way we perceive the picture: by vision.

For blind people, the question is much harder to answer. If a blind person wants to take a picture of the real world scene, a camera is of little use (except to show the photographs to a sighted person who can tell him what is on them). Blind people use their tactile sense to perceive a picture of the environment. This means that blind people touch surfaces of objects and follow edges and other tangible elements with their hands. This is a process which takes time and requires movements of the hand, the arm or even the whole body. For this reason, a tactile picture which a blind person takes from a given scene might be adapted to the tactile perception of the original scene.

Again looking at this process from the position of a computer scientist, we can formulate:

Taking a picture is a process of mapping a sensation of a 3D scene to a 2D medium. For drawing, this is true even if the 3D scene is not actually available. A sighted person draws not what is on his retina but what is in his mind, the mental model (Expressionists did the same in art). So how does a blind person draw? Since the mental model of the real world is to a large extent the same as for the sighted person, the channel of sensation obviously plays an important role when answering this question.

Fig. 2 makes this relation clear: Both, the real world and the mental model are spatial. The (mental) model has all the relevant properties of its referent in the real world. There are two directions of effect between them: Perception is effective to the mental model, action changes the real world. Since blind and sighted people both can act in the same real world, their mental models must be very similar. The problem is: How can we map the real world (or the respective mental model) to a 2D drawing?

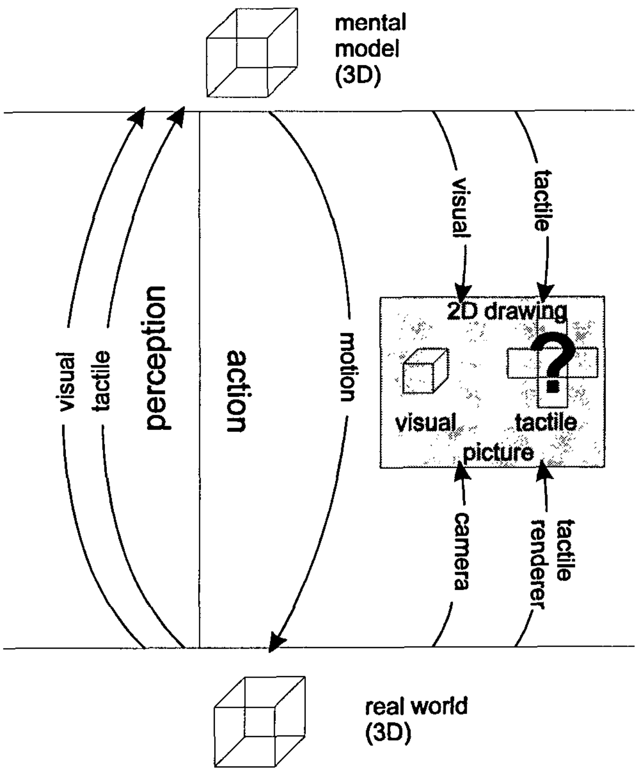

Fig. 2 Visual and tactile perception result in (nearly) the same mental model. However, methods for 2D depiction are different.

An adult quite talented sighted person draws an image which looks like a cameras image. The tactile renderer (the ultimate goal here) should draw an image which feels like a blind persons tactile drawing. Therefore, the first question to answer is the one in this sections heading: How do blind people draw? Here is an attempt for an answer:

Blind people draw as they experience real world objects: surfaces and edges, shapes defined by their surrounding borders. The interesting question is the transformation of the 3D model to the 2D picture. Except for the experiments (see below), little other research has been undertaken so far to investigate blind people's drawings [3, 5, 11].

Perhaps the most surprising result in these investigations is the role of spatial relation. After drawing an object from one side for some time, some blind people draw the same object (or single features of it) from a different "viewpoint" [3, p 449]. Sometimes this results in drawings which look "crude" to sighted persons. However, it makes two things clear. It is not only important to answer the question, "What do blind people's drawings *look like*?" but even more important is the question, "how do blind people *draw*?". We must have a look at the *process* of drawing and we must listen to blind people while they are drawing and telling us what they draw.

Once we know how blind people draw, we can think about producing tactile pictures, which meet the requirements of blind people.

Put as a computer scientist: as drawing a visual picture tells us something about the way we should render our visual computer graphics (e.g. photorealistic, as everybody does, or sketch-like, as some newer work suggests [1, 12]), the process of drawing a tactile picture (by a blind person) tells us something about the requirements for a tactile renderer.

Surprisingly, using the ecological approach, Psychologists like Kennedy come to nearly the same results about blind people's capabilities in producing and understanding pictures. The approach outlined above seems to be applicable to the problem no matter from which point of view one looks at it. The process of drawing by blind persons must first be examined.

In the following section, I will describe a drawing tool for the blind which helped us to better understand the mapping of a 3D scene to a 2D-tactile drawing and to design a tactile renderer.

A COMPUTER SUPPORTED TACTILE DRAWING SYSTEM

In the past, a few attempts were made to develop a drawing program for blind people [2, 13]. They used the approach of giving blind people a set of commands comparable to those of conventional drawing programs for the sighted. The user could create and manipulate circles, lines and rectangles on a symbolic basis with no feedback and only a very limited possibility to draw freehand lines. While the main reason for this is probably the absence of an interactive device for tactile graphic input and output, the approach as such is based on 2D scenes or abstract drawings.

A drawing tool for blind people, intended to serve them in drawing even 3D scenes, must meet some requirements:

- *immediate feedback*: the user must be able to touch/explore the line(s) which he is currently drawing to navigate in the existing drawing.
- *no perceivable raster*: the drawing should consist of lines as smooth as the user drew them. A pin-matrix to display the drawing must either be avoided or be extremely fine-grained.
- *personal comments*: each line or object in the drawing should have either a name or another personal comment attached to it.
- *erasability*: all lines or objects should be removable if the user wants to correct his drawing.
- *usability*: the system should be easy to use, even without moving the hands away from the picture currently being drawn.

I have designed and implemented a drawing system which meets most of the above constraints. In addition, the system can serve as a tool for sighted developers to learn about the process of drawing by blind people.

The system is based on swell-paper and a special pen (thermo pen with digitizer pen) to draw on it. The swell-paper is fixed on a digitizer tablet which gives us the state (pressed/released) and position of the pen at all times. Input can be made via a (currently simulated, see below) speech-recognition simulating keyboard input. The whole system is controlled by a program which I have called TDraw (for Tactile Draw).

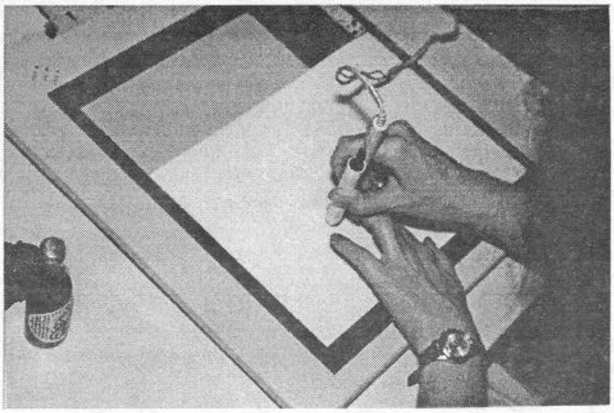

Fig. 3 The tactile drawing-pad of the workstation

Since tactile perception is based mainly on planes and edges, I restricted myself to providing only two geometric primitives in the program: lines/line sequences and free-form planes (polygons). Each line or polygon can have a name or another comment as an attribute. This attribute is given verbally while the object is being drawn. If several lines drawn separately belong to the same object (i.e. have the same name), the name must be entered only once.

The blind user can now draw on the swell-paper on the digitizer tablet (see Fig. 3). Each object with its name is immediately tangible as he draws it and at the same time recorded by the computer and provided with a name as the **user speaks it. The** user does not need to move his hands away from the drawing. The default geometric primitive is the line. If a line ends very close to its beginning and a command is spoken ("home key" on the keyboard), the line will be converted to a polygon.

In a second mode, the drawing can be explored on the digitizer tablet and the comments for each object (e.g. its name) can be retrieved verbally (using a text-to-speech system). When the user presses the digitizer pen (without the "thermo pen") on a line or near to it, the line's name will be spoken. When he presses it inside a polygon, the polygon's name is spoken. In this way the purely tactile exploration is significantly enhanced, even if blind people other than the drawer himself explore the drawing. Since the drawing is recorded by the system, it can be reproduced on every printer capable of printing graphics, tactually or visually.

To produce a tactile copy of the graphic, a tactile plotter can be used (a regular plotter with the thermo pen). Alternatively, a blackprint version can be photocopied onto swell-paper. The result is a raised-line drawing on the swell-paper.

All the constraints mentioned above are met, except for the erasability. This is not an easy task with swell-paper, although it can be done mechanically. I considered this feature to be less important because the main purpose for the system was the observation of blind people drawing 3D scenes.

The implementation was carried out with C++ in the MS-Windows environment. I use the "Thermostift" by Erika and a Genius digitising tablet. For speech recognition, the use of DragonDictate is planned; currently I am running a test in the "Wizard of Oz" style. Since speech recognition is supposed to simulate keyboard input, it seems legitimate to replace it with a person who types the spoken words. Speech output is realised with Talking Blaster. The program can write files either as vector-graphic files or in a format compatible with the "AudioTouch" system [9].

OBSERVATIONS WITH THE TACTILE DRAWING SYSTEM

Practical experiments have already been carried out. The test subjects were selected to cover a range of characteristics (male and female, young and not so young, ...). The most important aspect for the compilation was the inclusion of both people blind from birth and the late blind. Table 1 gives some details about the blind people in the experiment.

The blind subjects had different backgrounds in the use of tactile graphics and in drawing pictures. Firstly, I explained the drawing system and let them practice its use a little. Then they were asked to touch and investigate certain 3D objects (plastic models of a chair, a table, a bottle and other objects). Later they were asked

Table I Personal data overview of the 5 blind subjects

Subject	S1	S2	S3	S4	S5
age	25	25	45	56	61
sex	female	male	male	male	male
profession	psychology student	masseur	public service	English lecturer	technician
visual perception	none	none	outlines	none	one eye: <4%
blind since (age)	1	1	15	14	57
knows tactile graphics	maps, from school	maps, from school	maps, charts	maps, art, school	maps
produced tactile graphics	charts (dot-printer, crinkle foil)	None	None	math sketches (wax-paper)	maps (swell-paper)

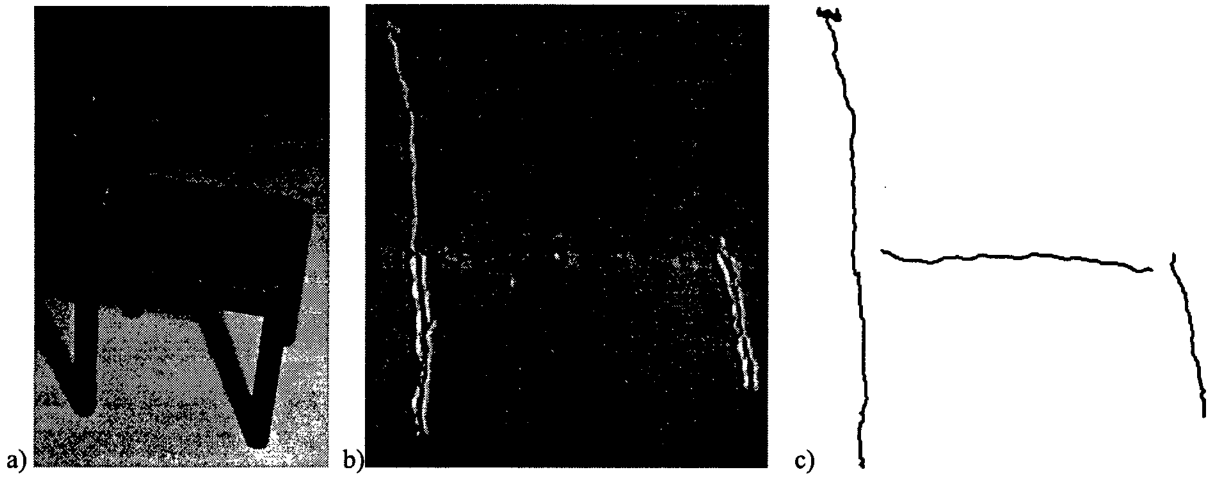

Fig. 4 A tactile drawing produced with TDraw; b) on swell-paper, c) as recorded by TDraw

to draw single objects in such a way as to keep as much 3D information about the objects in the drawing as possible. Finally, a complete scene with several objects arranged in 3D space had to be drawn.

The observations confirm most of those of Edman [3] and Kennedy [5] and add some new findings about the usefulness of comments in drawings.

Observations and examples

In general, all subjects performed with considerable effort and were highly motivated. They all liked the idea of being able to produce drawings, take them away as hardcopies and explore them with the computer. S1 and S4 proposed using the system in school to provide graphical communication between blind (and sighted) teachers and students.

Since swell paper is used as the tactile medium, a gifted drawer (like S1, who discovered her talent during the experiments) can produce various styles of lines (thick or thin, single or double, dotted or straight, see Fig. 4). Thus tactile drawings are indeed more than just 2D, they can use several layers in the third dimension.

- Single objects are drawn in their most significant shape. For example, a chair is drawn from the side (see Fig. 4).

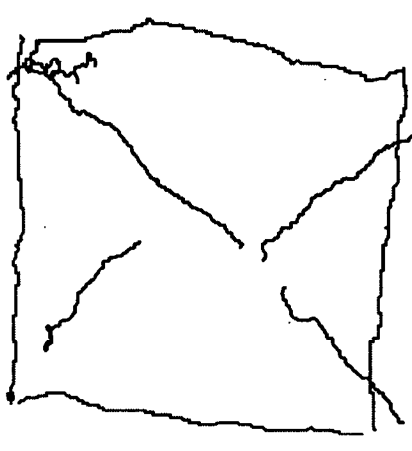

Fig. 5 A table drawn separately

- Scenes with several objects are drawn corresponding to the *scene's* most significant shape. While in Fig. 5 the table alone was drawn "from above", Fig. 6 shows the same table as part of a scene. Here it is drawn "from the side".

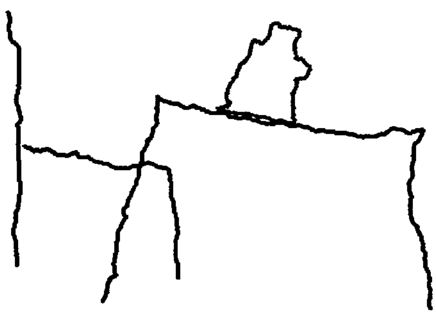

Fig. 6 A scene with a chair, a table and a bottle

- All subjects found it most difficult to draw a complex scene (a toy truck and a bottle on a table) while preserving the spatial relations. One subject resigned after drawing the table and the truck. The bottle "from above" would simply be one or two circles which would not be recognisable as a bottle later on. Others drew the table from above and the bottle from the side (see Fig. 7).

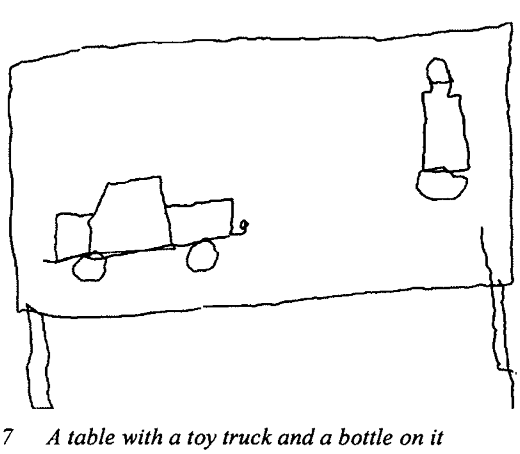

Fig. 7 A table with a toy truck and a bottle on it

- Sometimes objects located behind each other have been drawn completely, including the (optical) occluded parts. Overlapping lines have been accepted (see below).
- Overlapping lines have been drawn in such a way that the rear line was clearly distinguishable from the line in front: (see Fig. 8), The rear line was thinner and flatter, the front line thicker and more embossed. This effect was achieved by drawing faster with the thermo pen for thinner lines. In addition, the rear lines were drawn first, and the front lines were added afterwards. This method is known as “painters algorithm” in computer graphics.

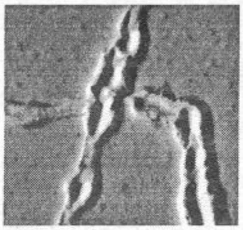

Fig. 8 Two overlapping lines, drawn using the "painters algorithm"

- The same scale was used for all objects in the scene. No optical (perspective) reduction was used.
- Perspective distortion was not used. Rectangular planes were always drawn rectangular.
- Depth information was conveyed via line thickness and/or contour lines. A ball was drawn as a sequence of concentric circles, the inner circles thicker than the outer ones.
- 3D spatial symmetric properties were (partly) transformed into 2D symmetry (see the table in Fig. 5).
- Some objects were folded out. The resulting drawings show details which cannot be seen all at once (see Fig. 9).

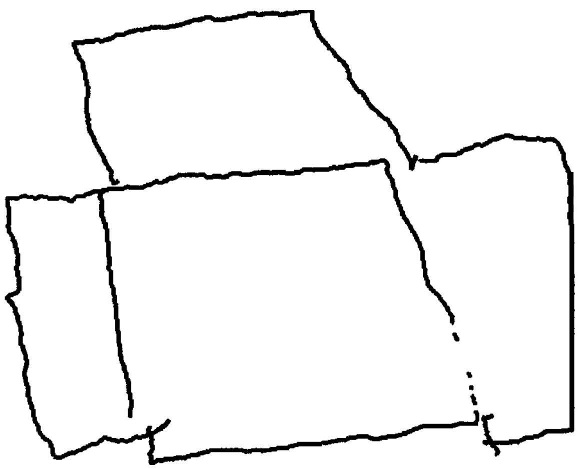

Fig. 9 A cube, partially folded out

- Open and closed parts have been drawn differently: the loading platform of the truck in Fig. 10 a) and c) is clearly distinguishable from the driver’s cab (in the section as well as in the top view).

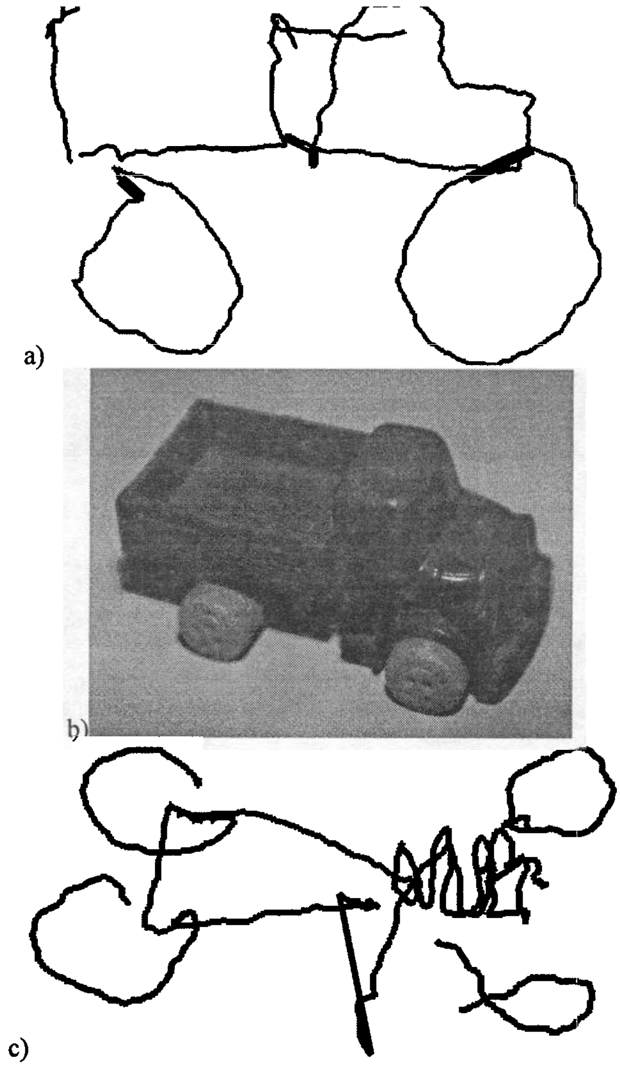

*Fig. 10 section, photo and top view **of** a toy truck*

The results obtained show that blind people are capable of drawing 3D objects, with varying capability and expertise. Those who had some experience with drawing in their education were more satisfied with their work than the others. Most said that more practice would enhance the quality of their drawings (in their own standards).

The late blind sometimes tried to draw as they learned it with sight. The results occasionally looked surprisingly similar to “regular” drawings, but the drawers failed in recognising their own drawings after some minutes!

The restriction to lines and polygons proved not to be a serious limitation. The blind subjects often used lines to draw thin longish objects such as a table leg.

Sometimes they changed the viewpoint while drawing a spatial object. The front and the top sides of a cube are both visible at the same time with no perspective distortion. Both planes are tied together as rectangles.

Classification of the drawing methods

Studying these observations in more detail, three types of drawings can be identified:

- Foldouts: The surface of an object is drawn piece by piece while preserving the pieces' shapes and topology as far as possible. These "pieces" of the surface are called "faces" in computer graphics. Faces are polygonal regions attached to each other at the edges and together determine the objects 3D appearance.

  Sometimes only some parts are folded out to make them more easily detectable: Fig. 10 c) shows a truck from above with the wheels folded out as circles.

- Flattened rubber: Imagine an object being made completely from rubber. If you exert directed pressure onto such an object, it will change its configuration until it is completely flat.

  The table in Fig. 5 is an example for such a drawing. The same table was also drawn with the legs spread out. In both cases the symmetry remains preserved.

- Sections: Fig. 10 a) and the bottle in Fig. 7 are drawn as sections. The most significant section plane was chosen to make the identification clear. In addition, both drawings contain objects not present in the real section (the wheels in Fig. 10 a) and the top and bottom of the bottom in Fig. 7.

Which of these methods was used depended on the object/context and also to a large degree on the subject. Therefore we cannot state that there is a "best" method to draw a specific object. This depends on the personal preferences!

The topographic properties of blind people's drawings are closely connected to the geometric properties of the original objects. The reason for this may be the topological persistence during the mapping of the 3D model to the 2D drawing. In other words: the topology determines which parts are drawn next to which other parts. In a second phase, the context and the drawer's preferences determine the way of mapping the geometric properties of the single parts to the 2D plane using one of the methods listed above. Since the geometric properties of objects or scenes are spatially complete, i.e. all parts of an object are represented, a complete (tactile) drawing contains all parts of the object. And all these parts are drawn completely. This fact distinguishes tactile from visual drawings: visual drawings show the visible parts of an object only.

These considerations fit very well to the observation that blind people's drawings often look a little like children's drawings. All objects are drawn realistically but with no distortion. In particular, the topology of the object remains intact (connected parts remain connected). This might be another indication for the 3D concept which blind people have of their environment.

In addition, the findings of Ed Burton [l] show that topology and completeness play an important role in the process of drawing by people who are not influenced by the photorealistic style of conventional drawings and images. Only during education do people learn to draw what they see as they see it (if they see it).

Having thought about the human process of mapping the real world (or its mental model) to a 2D drawing, we shall now have a first look at the actual challenge of producing appropriate tactile drawings for blind people.

FURTHER CONSIDERATIONS

Although drawings by children tell us something about the child's mental model of the objects drawn, they differ from drawings for children, e.g. in children's books.

A similar relation can be assumed between drawings *by* blind people and drawings ***for*** them. Children as well as adults (blind or sighted) are often not really satisfied with their own drawings. Many people are simply not gifted enough to draw in a way they would like. Nevertheless, even people who are not such talented draftsmen can and do use professionally produced drawings.

We can conclude from our observations of children's drawings and blind people's drawings that tactile drawings for blind people should not just look like they are made by hand but should use some of the foundations derived from those. Drawings for children are often "beautified" and slightly more mature versions of drawings by children. It is important to realise that these drawings are based on the child's mental model of the scene and not on the real world as a model.

Surprisingly, drawings in children's books often use an optically wrong perspective. Objects are drawn from the point of view which is the most typical view of them. A table with a pot on it is drawn from above (rectangular tabletop), and the pot is drawn from the side (See Fig. 11). This is done because these are the views of the objects which fit best to the mental model of the child.

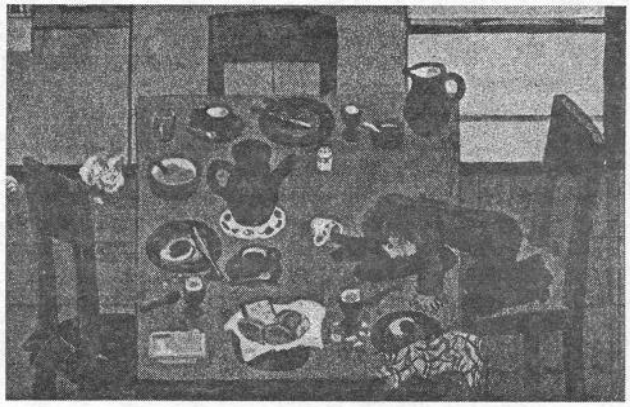

Fig. 11 A drawing for (sighted) children. The tabletop is drawn from above, the chairs and the pot are drawn from the side. (Compare to Fig. 7)

Similarly, we have to design a rendering system for tactile drawings. The objects must be easily recognisable by touch, regardless of their optically correct position in space. Nevertheless, the topological 3D concept of connected objects and parts must be maintained.

This leads to some other problems with which we have to deal when producing tactile drawings. Objects may be arranged in space in such a way that they occlude each other partially or totally. This occlusion may be only an optical one (a chair behind a table) or may also be tactually sensible (e.g. a disk partially sticking in the disk-drive).

Finally, one should keep in mind that the tactile sense does not have the same high resolution as the visual.

CONCLUSIONS AND FUTURE WORK

Blind people have a spatial concept (a mental model) of the real world which is nearly the same as that of sighted people. Therefore, blind people can produce and read pictures. These (tactile) pictures reflect their mode of experiencing the real world: by touch. Tactile pictures look different from visual pictures. To clarify properties which would be hard to detect purely by touch, verbal comments assigned to lines and objects are useful. These comments can also provide background information not actually available in the picture at all (for example "this is *Peter's* house").

To study the process of drawing by blind people and to allow information presentation during the tactile exploration, an interactive device is needed. My approach offers some opportunities for interaction during the drawing as well as in the later exploration. Unfortunately, the hardware devices currently available (and used by me) lack the capability for interactively changing the drawing itself. A truly interactive display (including erasure) would not only allow more detailed research but would above all open up new opportunities for visually impaired people to gather and manipulate graphically presented information.

As the ongoing observations show, *education* is an important basis for producing and understanding tactile graphics for blind people. Also these observations indicate common aspects of drawings by different individuals as well as some different methods of depicting the third dimension. More detailed research has to be carried out as to how depth information can best be conveyed with tactile 2D graphics. Currently promising experiments are being carried out by Jansson with texture gradients. I raise the question whether the fixing of standards for the education of young blind people could be useful.

The use of *sound* (speech as well as non-speech sound) will be considered in more detail (see also [6]). The acoustic channel has a large band width and will possibly enhance blind people's understanding of graphic information. The application of sound as well as advanced force-feedback devices for a guided (directed) *exploration* of a tactile image will be investigated in the near future.

Although the problem of static pictures is not yet completely solved, the next challenge is already clear: *animation* and *virtual reality* are becoming increasingly common as modes of communication and information presentation. To maintain blind people's access to pictorial information will remain a demanding but also satisfying task.

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