Information Access for the Blind – Graphics, Modes, Interaction

H. Jürgensen,[1,2] C. Power[1]

[1]Department of Computer Science, The University of Western Ontario,
London, Ontario, Canada, N6A 5B7

[2]Institut für Informatik, Universität Potsdam,
August-Bebel-Straße 89, 14482 Potsdam, Germany

Abstract: We describe experiments with various forms of computer-mediated access to technical and graphical information for visually impaired persons. The study involves multimodal and interactive document presentations. We make recommendations for both document specification and rendering systems.

1. Beyond Text

For visually impaired persons access to non-textual information is severely impeded even when specialized computer hardware and software is available. Complex graphical scenarios, as are quite common with graphical user interfaces for instance, while manageable with the visual sense, are confusing at best for the haptic and acoustic senses.

In this paper we report on research into methods by which complex documents can be made available *automatically* to visually impaired computer users *in real time*.

This work started nearly 20 years ago when one of the authors (HJ) had a blind student (R. Arrabito) in his computer science classes on data structures and algorithms and on automata, formal languages and computability. Such courses rely heavily on mathematics and on drawings. For mathematics, several Braille codes are available (see e.g. [40, 7, 19, 18, 26, 55, 58] and, hence, at the time we considered the problem of obtaining Braille-encoded mathematics as fairly easy. For drawings, on the other hand, no standards existed; since then some guidelines have evolved (see e.g. [54, 12, 24]).

As a general scenario, we envisage a working environment in which persons with different abilities (or disabilities) share documents. The access to the documents is mediated by computing technology and various input-output devices. In such an environment it is essential that each participant have immediate access to the current version of the document and, subject to data integrity constraints, be able to modify a document. This, essentially, rules out the transformation, by a human, of the document to accommodate special needs and the rendering of the transformed document in hard copy. Instead, the rendering process has to be automatic and instantaneous. Moreover, changes made to the document need to be incorporated without delay and to be made available to all users in their preferred rendering modes.

With the background of a science teaching and research environment at the university level, in this paper we use the typesetting language TEX as the guiding paradigm. We assume documents to be specified in TEX as the common language. This choice is adequate as TEX is not only used by researchers and instructors, but has also been adopted by several of the major science publishers as the preferred submission format for research papers and books. Moreover, TEX provides, through its macro facilities, graphics capabilities, albeit limited, as needed for publications in the sciences. Most importantly, TEX is programmable and provides a powerful processing kernel which can be used for much more than just typesetting printed documents.

The choice of TEX is not restrictive in the sense that with other document processing systems (like Word, for instance) similar experiments can be conducted and similar conclusions can be drawn, the difference mainly arising from implementation issues rather than matters of principle.

Our first and rather optimistic attempt, about 1985, was to create a TEX-to-Braille translation program incorporating a translation of mathematics according to the Nemeth code. This attempt is documented in [2, 3, 4] with the conclusion that a comprehensive translation is impossible due to the fact that both in TEX and in the Nemeth code the document specification is based on lay-out issues and not on the semantics of the constituents of the document; moreover, the Nemeth code is static, that is, it does not provide an automatic mechanism for incorporating new symbols with new meanings or for overloading existing symbols with additional meanings as would be required for an open authoring model (see [13]). What became of this project is summarized in Section 6 below.

At about the same time we also started experimenting with the generation of tactile graphics. In the context of this paper, *graphics* means *diagrams*, mainly as used in science: graphs, circuits, trees, flow charts, structure diagrams, histograms, etc. We also investigated other types of diagrams like floor plans, pictograms and maps to some extent. An important step was achieved in Poh's thesis [41] of 1995, which advocates to focus on the meaning of drawings, disregarding their shapes, and to incorporate their active and passive multimodal exploration. Several experimental implementations were completed since then to test these ideas. The system design concepts resulting from these are described in [31]. Details of some of our experiments are described below.

An extensive survey, as of 1996, on tactile graphics is presented in [30]. On this basis a new survey with more than 700 references, addressing issues in mathematics, graphics, user interfaces, web access, haptics etc. for the blind is in preparation [29].

In this paper, we present a summary of work in our research project. We provide only the occasional reference and comparison to related work. For details of this we refer to the surveys mentioned before ([30, 29]).

This paper is structured as follows: After this introductory chapter, in Section 2, we define what we mean by graphics and we outline the vision guiding our research. In Section 3 we describe the laboratory setup. Multimodal interfaces and exploration techniques are discussed in Section 4. Issues of resolution and diagram size are presented in Section 5. A brief account of our work on mathematical documents is given in Section 6. In Sections 7–10, we consider several types of graphical objects and their multimodal rendering. Some conclusions and guidelines are summarized in Section 11.

2. Types of Graphics

In this paper, we consider as graphics images which can be rendered by lines, texture and symbols. This excludes, for example, photographs and paintings. The term *image* means this restricted type of object. Typical examples of images are: maps, floor plans, drawings, technical diagrams, statistical diagrams, mathematical drawings.

For the purposes of this paper, we distinguish images in two ways, as continuous or discrete and as real-time or static. For a more comprehensive classification, see [29].

We distinguish images according to their rendering mode as *continuous* and *discrete*. Typically, images on swell paper or formed plastic material are continuous; uninterrupted lines can be rendered at any angles and with any curvature, the latter subject only to the resolution of the tactile sense. On the other hand, images created by a braille embosser or displayed as raised dots on a tactile display are discrete. Lines are represented by sequences of dots, typically about 2.3 mm apart horizontally and vertically; areas can be represented by dot patterns. For continuous images, many different heights of the features can be used thus using three dimensions, albeit in some limited sense; a discrete image normally uses only two heights, high or low.[3]

We also distinguish between images which are *real-time* and images which are *static*. We consider the rendering of images by computer. A real-time image is always shown in its most up-to-date version and changes to the image are incorporated in its rendered version instantaneously. For text, a Braille output line is a device for real-time rendering; for images, this task can be performed by a dot-matrix display as described below. Static images, on the other hand, can be embossed on paper or rendered on swell paper or formed plastic.

We envisage the usage of images in a document sharing environment – say, a real estate office or a hardware design laboratory. In such an environment, it is essential that images be real-time and that they can be modified by any user involved, with changes immediately available to every other user.

The focus of this paper is on real-time images. The limitations of the present technology force us to consider discrete images – in this case as rendered on a tactile display. For the tactile sense, in addition to the basic information of whether a dot is raised or not, also vibration of dots could be used to some extent.

While we emphasize the issues arising with real-time discrete images we also review related problems concerning static or continuous images; we also briefly discuss the rendering of mathematics, because we believe, that even for that purpose tactile images can be a useful means to present information.

3. Experimental Setup

For our experiments we use the following specialized equipment, aside from the necessary computers and software.

(1) A Metec dot-matrix display (see Figure 3.1): This device, of which only a few units exist, has 60 rows with 120 raisable dots each. The distance between dots is that of Braille dots, that is, approximately 2.3 mm both horizontally and vertically. Our unit has two finger-position sensors. There is a way of selecting position-sampling modes to compensate for the inevitable fuzziness of the position information. To communicate with the computer, the user

[3] The *tiger* embosser is an exception: It provides dots at different raised heights and also different spacings of dots.

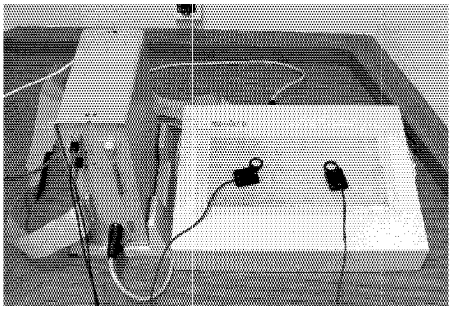

Figure 3.1. The METEC tactile display DMD 120060. The picture shows two finger-position sensors on the display area; on the left, one sees the control unit. The display is made by METEC GmbH, Stuttgart, Germany.

will either have to move the hands to a keyboard or will use voice input.

The company offered also a smaller and a larger version of this device with 30 or 120 rows, respectively. To our knowledge, only the 60-row version was ever produced.

In our laboratory, the unit serves as an experimental device, mainly to test issues related to finger-position feed-back, exploration strategies and to experiment with resolution, scrolling and zooming.

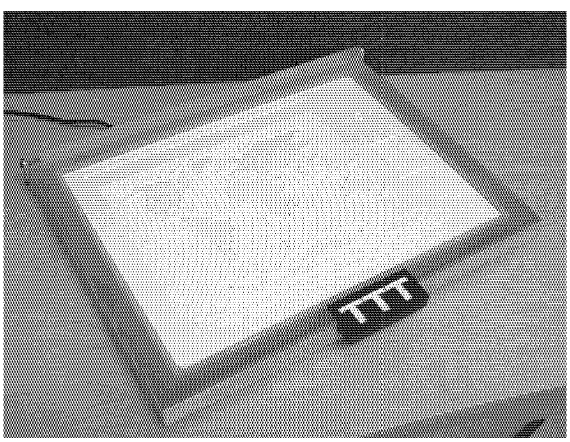

Figure 3.2. The Talking Tactile Tablet by Touch Graphics, Inc. [34].

(2) A Talking Tactile Tablet (see Figure 3.2): This tablet senses the positions of fingers, which information can be used for multi-media assistance in exploring a tactile image or for guidance of such an exploration. For this purpose, a tactile image is placed on the tablet. Software prepared with image-specific information is then used during the tactile exploration. It is one of the goals of our project to identify methods by which such information can be generated and linked to the image automatically.

(3) A touch-screen computer (Toshiba M200 Tablet PC): This computer serves for simulation and demonstration. A proposed tactile interface can be simulated and tested by a sighted person before an implementation for the tactile devices is attempted.

(4) Voice and sound input and output: Voice and sound output are used to complement the tactile information, possibly also to guide the exploration of the tactile image. Voice input is used in the preparation of information data and as an interaction medium for blind users, so that they do not have to move their hands off the tactile image.

Other equipment, like a Braille embosser, as well as software for Braille are available to us at the centre for students with disabilities of the University of Western Ontario.

4. Multimodal Interfaces for Blind Persons, Exploration Techniques

For a survey of computer-mediated access to information for blind persons see [30, 29]. In this paper we focus on technical or scientific documents and on real-time access methods. We envisage a working environment of persons with different abilities. In such a setting the computer will act as an intermediate to enable communication.

Every user will have a preferred individual working environment. From this point of view, visually impaired users are just a special case. User-centered interface design *should* accommodate any type of users.

Given the present technology, we assume that the blind user will have a tactile display (preferably real-time), finger-position input, voice or sound output and voice input – in addition to standard input-output devices.

To facilitate communication, the rôles of the various modes need to be determined. For sighted users the present quasi-standards for interfaces, forced on users by industry, are hardly acceptable and far too inflexible. Given the opportunity to design interaction modes for blind users, one should not make the same mistakes by proclaiming standards too early. The community of blind users is diverse. Interfaces will need to be tailored to the users. Thus, while guidelines are useful, standards might actually hurt progress.

Our experiments include a combination of tactile and acoustic information, provided interactively. We use the METEC dot-matrix display for real-time graphics and the Talking Tactile Tablet for exploration techniques.

Early experiments with the METEC dot-matrix display concerned access to the *videotext* system [56], multimodal graphics [65] and, using the finger-position sensors, gesture input [63, 62, 64]. We have used this device to experiment with circuit diagrams, automaton diagrams, mathematical graphs and statistical diagrams. The finger-position sensors are used as feed-back to guide the diagram exploration [53].

We also use a Talking Tactile Tablet to investigate exploration techniques. We have experimented with the software of several similar tablets finding that it can be easily 'tricked' into nonsensical output, stammering, useless repetitions etc. To make the software misbehave does not actually require a trick, but just a slightly unsteady hand. The mouse paradigm is not applicable to the exploration of an area using ten fingers. The older METEC display simplifies this issue by providing two identifiable sensors to be carried on two different fingers.

As discussed in [41], the rendering of a tactile image can be *active* or *passive*. In an active system, the user is guided towards features. For instance, while exploring a tree diagram, the user might be told:

> *This node has label A. Please move slightly to the right and down. You will find a branch with two nodes labelled B and C* . . .

Such an interaction mode could be most useful when the user has little experience with the type of diagram. On the other hand, a passive system would only react to the user's hand movements. It might either provide information spontaneously, as determined by the movement of the hands,[4] or supply information on demand.[5]

The active and passive modes are extremes. A user may wish to use a mixture of these techniques and even change the mixture. Our findings re-enforce the point that the choice of the interaction mode must be left to the user.

This sounds like a triviality; it is, however, far from practice in the prevailing current systems for sighted users. Their accessibility packages certainly do not add flexibility.

Multi-modality and exploration should not be an afterthought – they should be essential constituents of document design. As a professional typesetter designs books for beauty and readability, as an author writes novels to thrill the readers – documents need to be specified with their presentation to a varied usership in mind. We propose some simple guidelines: information contents of a document is important; appearance can vary; documents may be used in unforeseen ways. This suggests a layered document specification method in which information is clearly separated from rendering (see e.g. [14, 13] for mathematical documents). The system design as proposed in [41] can serve as a first approximation.

5. Resolution and Size Limitations

One of the most serious problems arises from the low resolution of the tactile sense. The precise limit is not that important. The resolution is too low to put any realistically complicated image as tactile graphics into a reasonable area. For circuit diagrams, flow charts, transition graphs, automaton diagrams, spread sheets etc. only toy examples can be represented completely. For continuous media this problem is severe, for discrete media this problem seems unsurmountable.

The literature concerned with discrete tactile graphics tends to side-step this problem. Some attempts in our project (see e.g. [1, 17, 23, 37, 38, 41, 42]) suggested various modes of scrolling. Scrolling is, however, rather confusing. Similarly, using different levels of detail and some kind of zooming, has turned out to be far less helpful than expected. Our present line of thought is to use tactile graphics for providing global information only and to use acoustic cues for the details, possibly combined with an active or passive exploration system.

For tables, an ingenious solution was proposed by Raman [49]: To use stereo sound and different speaker identities to read the table by rows. Obviously, this method is limited to a single way of working with a table. The typical usage of a table is quite different from this organized approach. Thus, even for such simple objects as tables [5], there is a need for thorough investigation.

Difficult test cases, which we want to try next, include large circuit diagrams and spread sheets.

6. Mathematics: TEX to Nemeth and Other Codes

The conclusion of [3] was that a *complete* TEX-to-Braille translation including all macro features was impossible. On the other hand, Raman's work [47, 49] demonstrated that a limited translation would be feasible. Raman's system translated LATEX files into voice output, assuming *standard* LATEX without user-defined macros as input. With Braille output substituted for the voice output, this would provide a feasible LATEX-to-Braille translation path. This approach, however, ignores the inherent extensibility of TEX or LATEX and the context-dependence of the semantics of mathematical notation.

In subsequent studies, we attempted various parts of a complete TEX-to-Braille translation including mathemat-

[4] As mentioned, such systems have a serious synchronization problem. The ones we have seen could be made to behave erratically with a few rather innocent movements of the hands.

[5] At this point, no system seems to exist which provides this feature with ease. If a new tactile display were designed, it should incorporate this type of feed-back, equivalent to a mouse click, in addition to finger-position information. Moreover, it should provide a means for distinguishing fingers.

ics.[6] The approach taken is as follows: The macro package of plain TeX is rewritten so as to eliminate nearly all usage of concrete measurements; all remaining dimensions are expressed in terms of small values of TeX's basic unit, the `sp`[7] [21, 25]. The Braille rendering program (dvi driver) will then equate 1 `sp` to the distance between Braille dots. Thus, two pixels spaced 1 `sp` apart will be rendered as two Braille dots.[8] A special Braille font created with Metafont contains Braille characters and the relevant dimension information; thus, for TeX, a 6-dot Braille character occupies a rectangle of 3×2 `sp` [21]. Special macros redefine TeX's manipulation of mathematics.

We expect to have a functioning TeX-to-Braille translation system by the end of 2005. The translation process works as follows: TeX is started on the input document with the *Braille macros* instead of the *plain macros.* The resulting `dvi` file is translated by the Braille driver to create output for screen preview or a Braille device. An extension to LaTeX or any other TeX variant would only require that the corresponding macros be modified.

The advantage of this approach, compared to Raman's, is that TeX itself is used for processing the document. Therefore, user-defined constructs do not constitute an obstacle in principle. The fundamental limitations identified in [3] are not lifted, of course. A greater obstacle than these, however, are bad mark-up habits of authors and bad style descriptions of publishers.

Non-tactile presentation of mathematics has been under consideration for quite some time. This ranges from voice-only rendering as in Raman's system [47, 49] to multimodal presentation (see e.g. [57]) and even to general sound (see e.g. [52, 44]). For a survey on mathematics rendering systems see [32].

A new proposal for rendering mathematics using both, a tactile display and voice output, and for guided exploration of mathematical formulæ is presented in [43]. The output is distributed to the modes roughly as follows: structural information of a formula is rendered on the tactile display as a tree-like diagram using a representation technique similar to the one explained further below. The details of the formula – e.g. the actual symbols – are provided by voice output. The voice output is "synchronized" with the movement of the reading fingers.

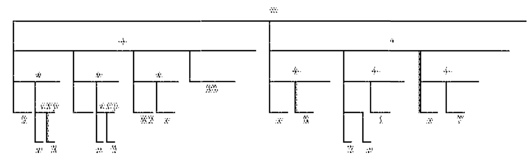

Figure 6.1. The formula $(x+5)(2x+1)(x+7)$ displayed according to [43]. Only the lines would show on the tactile display; the symbols belong to the spoken output.

This proposal is consistent with our general strategy for assigning rôles to media. The tactile image provides global structural information; the details are supplied by other means. A general methodology for implementing this type of mathematics system is described in [14, 13]. In Figure 6.1 a formula is displayed in a form which imitates the tactile display.

7. Graphs, Automata, Circuits, Trees

Diagrams for automata, circuits, data structures – mathematical graphs – are one of the main test examples. We have tried various representation methods [1, 17, 23, 36, 37, 38, 41, 42]. The outcome of this work can be summarized in two statements:

- The visual shape of the tactile diagram is not important at all; it is much more important that it be easy to explore.
- Active or passive guidance needs to be provided for the exploration of such diagrams.

It should be emphasized, that our system is intended to generate the rendering information *automatically* from the document specification and that, to maintain document integrity, we do not rely on specifics for tactile documents.

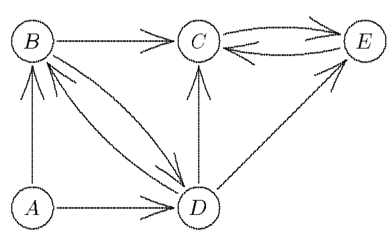

Figure 7.1. A directed graph [20].

For graph-like structures, as in Figure 7.1, Poh [41] proposed to use a tactile representation as shown in Figure 7.2. Nodes are represented by squares of raised dots; directed edges are straight lines originating at a node and ending above or below a node. With two-handed exploration, one hand can record the position on the margin

[6] For mathematics, the target is the Nemeth code [40]. Once this has been achieved, it would be easy to replace the Nemeth module by a module for a different mathematics code.

[7] In normal usage of TeX, 1 `sp` is 1/65536 `pt`, where 1 `in` (inch) is approximately 2.54 `cm` or 72.27 `pt`. Thus, dots of size 1 `sp` are practically invisible.

[8] Using a screen driver, we can also simulate the Braille display.

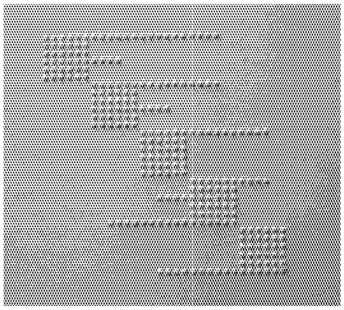

Figure 7.2. The squares, read diagonally from left to right, represent the nodes A through E of the graph. The horizontal lines represent the edges. It is assumed that the tactile diagram is explored with two hands. Spoken information is supplied as the hands move [20].

of the display (a line not shown in the figure) while the other hand follows the lines and the acoustic guidance.

To apply this type of representation to other kinds of diagrams, one may have to change the rendering of the nodes.

While the problem seems to have been solved in principle, one major practical issue remains. We need a path from the usual representation of such diagrams to the representation required by this work. An attempt on these lines was made in [37, 38] where a translation of VHDL specifications of hardware diagrams into multimodal rendering was implemented. A slightly more general approach was taken in [42]. The need is easily formulated:

- We need a specification language for graphs (in the sense of graph theory) such that both the translation from specific languages (like VHDL) and the translation into multimodal renderings are easy.

Guidance for how to design such a language can be found in [37, 38, 42, 30].

8. Statistical Diagrams

Statistical diagrams can take many shapes. A summary of display techniques is available in [59] including aesthetical and psychological evaluations of these. For tactile displays nearly all such techniques are useless. The focus has to be on conveying the essential information.

With this restriction, the diagram will present quantitative information only, both in terms of absolute numbers and in terms of relative numbers. A division of the rôles for the rendering media seems nearly obvious: absolute numbers and explanations are given to the voice output; comparative information is presented as a tactile diagram. Moreover, on a tactile dot-matrix display or an embossed page, only rectangular shapes are easily understood. This rules out pie charts, for instance. One is left, essentially, only with histograms – and even those can be too complicated.

The framework for statistical diagrams should therefore be as follows: the input document is a statistical diagram providing all relevant data; for a sighted person this document may include generic rendering information. For the blind reader the rendering information is completely ignored. The actual statistical data are used to create the multi-modal output *automatically.*

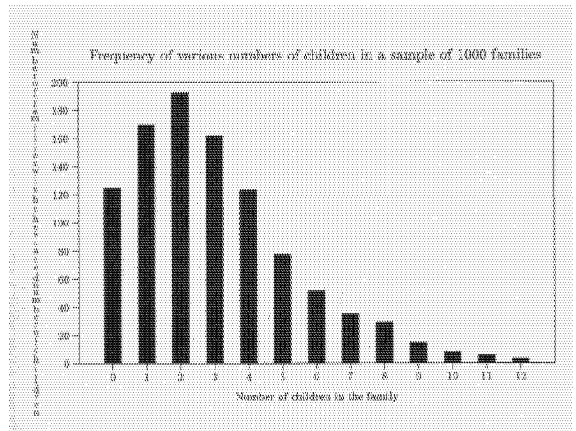

Figure 8.1. Histogram as printed for a sighted person [39].

```
\input visicht
%\input audicht
%\input tactcht
\setparameter {} to {} endtext
\charttitle Frequency of various numbers
of children in a sample of 1000
families endtext
\abstitle Number of children in the family
endtext
\ordtitle Number of families with the
stated number of children unit {} endtext
\data labels 0,1,2,3,4,5,6,7,8,9,10,11,12
values 125,170,193,162,124,
78,52,35,29,15,8,6,3
enddata
%\saychart
```

Figure 8.2. Input for histogram from [39].

A prototype of such a system was designed and implemented in [39].[9] An example of a histogram is shown in Figure 8.1. The input file is displayed in Figure 8.2. When processed by TEX with the `visicht` macros for visual output, a file is generated which will print as shown in Figure 8.1. In the input file several lines have been

[9] In [9] a predecessor of this system is documented.

commented out which would afford the switch between the macros for various output modes. With the `audicht` macros activated, the system of [39] would generate approximately the following voice output *automatically* from the input file:

> *This is a summary of the chart entitled: Frequency of various numbers of children in a sample of 1000 families. The horizontal axis represents: Number of families with the stated number of children. The vertical axis represents: Number of children in the family. The table of values is* . . .

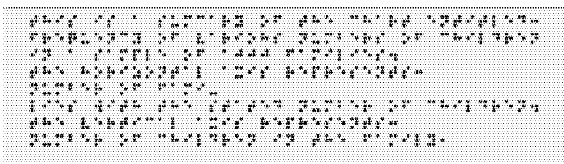

Figure 8.3. First page of tactile output for the histogram of Figure 8.1 from [39].

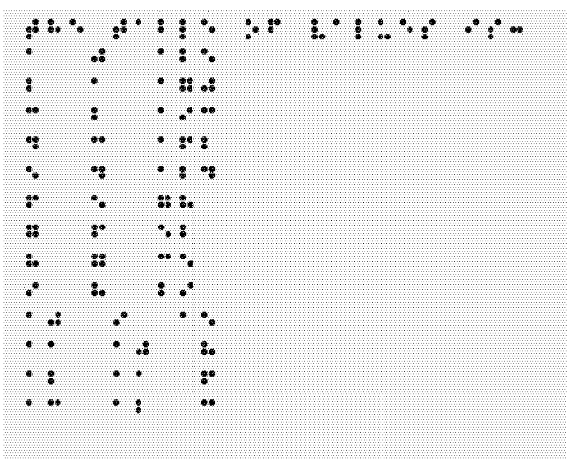

Figure 8.4. Second page of tactile output for the histogram of Figure 8.1 from [39].

As tactile output, using the `tactcht` macros, three pages are generated as shown in Figure 8.3, Figure 8.4 and Figure 8.5. In the tactile representation, to reduce potential confusion, the bars of the histogram are not separated; this simplifies the comparison of the heights of the columns. A vertical line in the middle of each column identifies the column and guides the fingers to the axis and corresponding labels.

The main findings of this work can be summarized as follows:

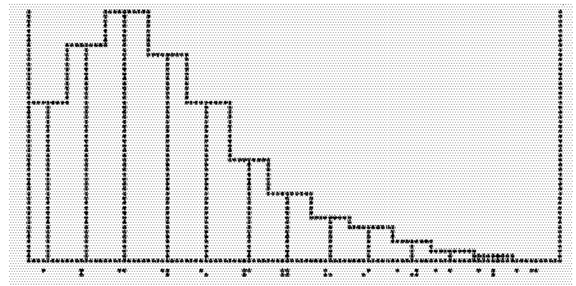

Figure 8.5. Third page of tactile output for the histogram of Figure 8.1 from [39].

- The tactile graphics must be simplified to the extreme; a resemblance to the visual presentation may be less important than a clear and simple expression of meaning.
- The comparison information is represented in the tactile diagram; the explanations and actual numbers are handled by voice output.
- Continuous guidance must be provided for the fingers. Much detail is just confusing.
- A method (language) for specifying statistical information is required which clearly identifies the statistical data and separates the rendering issues from the actual information.

In [39] a language fragment – as shown inFigure 8.2 – using TEX and, in addition, the TEX macros was designed by which these goals were achieved for the purpose of experiments, that is, as a proof of principle.

9. Pictograms, Metaphors

To break language barriers, pictograms (or icons) appeal to a common cultural background. They are, essentially, metaphors conveying a meaning by analogy. That there is a common cultural background, is important for the pictograms to be understood. The symbol used to represent a file folder in the Windows systems has no meaning on its own in Europe. Such file folders are simply not used there. For a blind person, depending on the experience before becoming blind, pictographs may have little meaning or none at all. Hence, why would one even bother to attempt representing computer icons as graphics? A blind person may have to talk about these things with a sighted person – but why else? Hence, there is no compelling reason why pictograms or icons need to be made available as graphical objects with any resemblance to the visual objects. The obvious solution is to look for communications modes which best convey the intended information to the specific individual, regardless of what is used for sighted persons.

10. Maps, Plans

Maps, floor plans and similar kinds of drawings do not usually change frequently. Thus, one can relax the requirement of real-time graphics and thus employ more permanent tactile media like swell paper or formed plastic. This also implies that continuous lines can be used, increasing the variety of recognizable and distinguishable shapes. Many systems exist – mostly still at some stage of prototyping – which combine such tactile diagrams with various input-output modes, like voice or sound output and guided exploration. We briefly review two examples showing that our proposals for discrete real-time tactile graphics apply also to the seemingly less complicated case of maps and floor plans. We keep this discussion brief, as it does not concern the main issues of this paper.

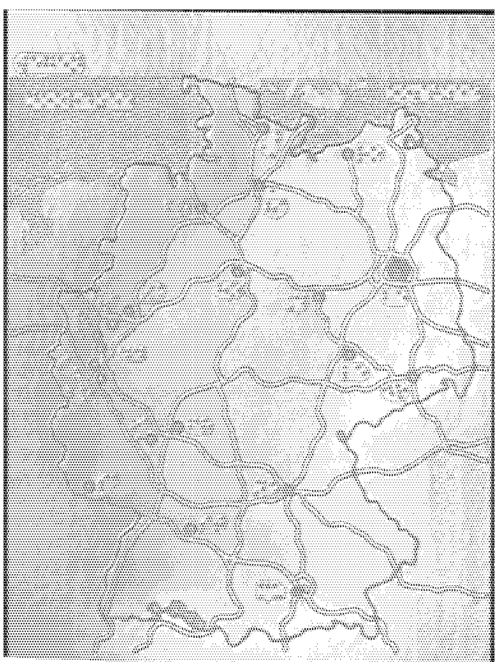

Figure 10.1. Map of Germany: formed plastic material (source unknown).

Figure 10.1 shows a tactile map of Germany.[10] It combines Braille and several features of tactile graphics: (1) texture is used for the North Sea and the Baltic Sea; (2) neighbour countries are rendered at a lower level; (3) major cities are indicated by big round hills with Berlin being represented by a special one; for no apparent reason the hills for Munich and Hamburg are also different;[11] (4) city names are indicated by two-symbol labels in Braille; (5) major roads, *Autobahnen,* are represented by raised lines about 2 mm wide; (6) Lake Constance, *Bodensee,* is rendered as a kind of staircase.

This map is confusing and misleading – not just for the blind reader – for several reasons: (a) small Dutch and Danish islands are shown while German islands are not shown at all or, as in the case of the islands of *Fehmarn* and *Rügen,* shown as being part of the main land; (b) there is no apparent reason for the selection of cities and roads shown; in particular, sometimes useless detail is shown like the small triangle between Munich and Stuttgart or the partial double ring around Berlin, where one of them in reality passes right through the city; (c) close to cities the roads seem to be interrupted; this is most notable in the case of Magdeburg and in the Cologne area; (d) the Braille labels are neither horizontal not vertical, but printed at various angles depending on the space available; (e) the areas containing the Braille labels is raised slightly, but cut off where characters do not use all dots; (f) the abbreviations in the labels are non-standard; for instance, BE is used for Berlin, ES for Essen, MB for Magdeburg, NE for Nuremberg *(Nürnberg)*, MU for Munich *(München);* these abbreviations are not even systematic;[12] (g) if the purpose of the map is to show the network of major roads in Germany, far too much detail is provided both regarding the country's borders and shorelines and the bends and intersections of roads; (h) there does not seem to be an indicator for map orientation.

A significantly simplified map would serve the same purpose. If the map were presented in a multi-media environment acoustic information could be provided (replacing, in particular the Braille labels), possibly coupled with feed-back through finger-position sensors.

In Figure 10.2, a map of Canada is shown.[13] It also combines Braille and several features of tactile graphics: (1) wavy lines are used as texture to indicate water areas (lakes and oceans); (2) Canadian lands are surrounded by heavy raised solid lines (problematic with islands); (3) Other countries – USA and Greenland – are indicated by heavy raised dashed lines; (4) Canadian provinces are separated by less heavy raised solid lines; (5) country names are provided in Braille; (6) provinces and the state of Alaska are labelled by their standard abbreviations

[10] Unfortunately, we do not know the source of this map, which was obtained from an exhibitor at the Second International Conference on Tactile Diagrams, Maps and Pictures held in Hatfield, UK, 2002.

[11] This could be a manufacturing defect.

[12] One would have expected to see the abbreviations used for vehicle licenses, that is, B for Berlin, E for Essen, MD for Magdeburg, N for Nuremberg, M for Munich.

[13] Designed by Mapping Services Branch, Natural Resources Canada; printed by Tactile Vision, Inc.

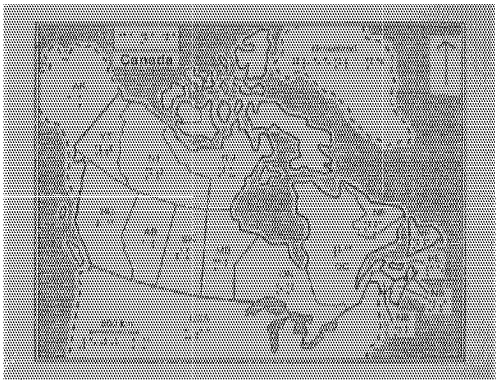

Figure 10.2. Map of Canada.

in Braille; (7) guiding lines connect labels with their features, when the latter are too small as is the case for PE, NS and NB; (8) an arrow indicates the orientation of the map; (9) the scale is indicated by a raised line with end markers and an explanatory label in Braille; (10) all Braille labels have the same orientation; (11) the map has a definite two-line frame.

This map is far less confusing than the one shown in Figure 10.1. Some further simplification could probably make it even easier to use without any loss of essential information: (a) the contours of borders and shore-lines could be straightened even further; this applies, for instance, to the border between the Yukon and the North-West Territories, the shapes of the Great Lakes, the shapes of islands; (b) there should be a better separation between the mainland and island parts of Nova Scotia; (c) the provincial borders on two of the northern islands are a bit confusing; (d) some smaller northern islands could have been omitted; (e) the US border leading into Lake Ontario can be confused with a river; (f) the cut-off in the west of Alaska and the north of Greenland is a bit confusing; (g) occasionally the wavy lines interfere with the dashed boundaries of Greenland and Alaska.

However, despite these issues, the Canada map, by focussing on essentials, conveys the intended information clearly enough.

Tactile maps, tactile floor plans and so on serve many different purposes including those of reading, reference and planning material and of orientation guides. In the former cases, as their usage would be stationary, they could be combined with a multi-media information system, like the tactile tablet described above. In the latter case, they might be carried around and must, therefore, provide the relevant information through mobile (light) equipment and possibly connections to relay stations.

Challenge: In principle it should be possible to create portable maps with intelligent interaction built-in. Ignoring the weight of the power supply, the additional weight for the electronics could probably be kept at less than 100 g.

There are some lessons to be learnt which are equally relevant for any kind of tactile graphics, with or without multi-modal assistance:

- One needs to focus on the relevant information; everything else, interesting as it may be, needs to be simplified to the extreme.
- Orientation and coherence need to be provided.
- Labels must be consistent, appear at predictable spots, and be uniformly oriented.
- Object separation may have to be exaggerated.

In summary, even when shape carries information, it is important to simplify shapes to make perception and forming a mental image easier. The limitations of resolution and overall size are less severe for continuous tactile graphics than for discrete tactile graphics. However, more detail put into the same area does not necessarily provide more information.

11. Conclusions, Guidelines

It is an elementary requirement of a human-machine interface that it be easily tailored to the specific needs of the individual user. This applies to any kind of user, not just users with disabilities. Conceptual background and experience, in addition to perception capabilities determine to a large extent, which way of rendering a document is most adequate. To illustrate this point: the pictogram used to indicate a file folder in the Windows interface is quite meaningful to a North American user; to a German user it is puzzling, because folders look quite differently there.

A blind person who has seen and been working with mathematics and circuit diagrams before turning blind may prefer to find known shapes rather than encodings, whereas someone lacking this experience may actually find it easier to work with abstract encodings and simplified abstract shapes. Thus, it does not seem adequate to force a specific type of rendering on the users if there is a choice of methods to convey the same information. If the relevant information is *readily* available in the document specification, the necessary translation and rendering can be provided easily. This leads to the first general guideline:

- Objects in a document must be specified by their meaning. The rendered appearance of the objects and the document is afforded by an interpretation (a filter) of the specification according to the user's needs.

In essence, this statement extends the principle of semantic markup-up to objects like formulæ, drawings, general graphics and even multi-media objects in a document.

The OpenMath or MathML concepts can serve to illustrate this guideline albeit in a rather limited sense.

The variation of rendering extends to the choice of modalities and, possibly, their interaction. A low-vision person may prefer to be presented with only a sketch of a drawing with voice-output providing the details; a deaf-blind person may have to rely completely on the tactile representation. Different strategies and capabilities for memorizing and organizing perceptions can influence the choice of presentation. This leads to a second requirement:

- The document specification must not prejudice the choice of rendering mode, but enable an automatic translation into various modalities and even combinations thereof.

Again, this is possible if enough content information is present in the document specification. We have shown above how this can be achieved for mathematics or simple diagrams.

As the experience and background of users differ, a graphical representation which makes sense for one person may be meaningless for the next one:

- By the rendering of objects, it is their meaning which must be conveyed, not necessarily their shape.

Thus, rendering a pictogram as such for a blind person may not be particularly useful. Similarly, horizontal lines put into a tactile histogram – as discussed in [10] may be more confusing than helpful if the same information can be conveyed by voice output.

Blind persons explore tactile graphics in various ways (see e.g. [8, 60]):

- Exploration strategies, both active and passive, need to be investigated systematically. A study should also identify the means by which a blind person determines a *global* mental image when exploring tactile graphics.
- For real-time interactive tactile displays, an input mode must be provided which does not require the user to move the position of the hands.
- For dot-matrix displays or embossed paper, a systematic study of which shapes can be recognized and which separation between objects is needed, given the low resolution, should be conducted.

A document designed for a specific set of rendering processes may become unusable when technology changes. For example, nobody thought of using the mathematics in a printed book as input to a computer algebra program twenty years ago. Being able to do so has turned out to be quite useful. For mathematics encoded as such (as in TEX) and not just as symbols to be printed it is quite easy to write the required translation program. This leads to our final guideline (see also [14, 13]):

- The document specification must be open to applications not envisaged at the time when the document is prepared.

In summary, rather than suggesting *specific* recommendations for how to render tactile graphics and how to use multi-modal interfaces we advocate an open system design in which the document is specified without any regard to rendering and where the rendering itself is achieved using appropriate filters. In particular, the document specification method must allow for the introduction of new object types, a method by which to attach meaning to objects and a framework for the construction of rendering filters (see [31]).

Finally, in designing interfaces for persons with special needs we should not attempt to imitate ‘normal’ interfaces. There is no reason to assume that information rendered by graphics for a sighted person should also be rendered as graphics for a blind person. While how to provide tactile graphics continues to be an extremely difficult issue, one should not forget to ask when tactile graphics makes sense. To put this pragmatically: Not the presentation but the use of information is the issue.

Acknowledgements: This research was supported by the Natural Sciences and Engineering Research Council of Canada, Grant OGP0000243.

References

[1] T. Alves: Talking trees. Undergraduate thesis, The University of Western Ontario, 1994.

[2] R. Arrabito: Using TEX to produce Braille mathematical notation. Undergraduate thesis, The University of Western Ontario, 1987.

[3] R. Arrabito, H. Jürgensen: Computerized Braille typesetting: Another view of mark-up standards. *Electronic Publishing* **1** (1988), 117–131.

[4] R. Arrabito: Computerized Braille typesetting: Some recommendations on mark-up and Braille standards. Master’s thesis, The University of Western Ontario, 1990.

[5] R. J. Beach: *Setting Tables and Illustrations with Style.* PhD thesis, University of Waterloo, 1985.

[6] *Instruction Manual for Braille Transcribing.* American Printing House for the Blind, Louisville, Kentucky, 3rd ed., 1984.

[7] K. Britz, H. Epheser, G. v. d. Mey, F. M. Scheid: *Neufassung und Vervollständigung des Systems der internationalen Mathematikschrift für Blinde. Marburger Systematiken der Blindenschrift.* Verlag der

deutschen Blindenstudienanstalt, Marburg/Lahn, 1955. English translation: *The International Code for Brailling Mathematics.* Verlag der deutschen Blindenstudienanstalt, Marburg/Lahn, 1960.

[8] L. Brown, S. Brewster, R. Ramloll, B. Riedel, W. Yu: Browsing Modes for Exploring Sonified Line Graphs. In *Proceedings of British HCI 2002*, 2. 6–9, London, UK.

[9] N. Cairns: Statistical graphs for the visually impaired. Undergraduate thesis, The University of Western Ontario, 1995.

[10] *Report of Tactile Graphics Sub-Committee Part 3.* Canadian Braille Authority, English Braille Standards Committee, July 10, 2003.

[11] J. Carter, D. Fourney: Using a universal access reference model to identify further guidance that belongs in ISO 16071. *UAIS* **3** (2004), 17–29.

[12] *Computer Braille Code Supplement. Flowchart Design for Applicable Braille Codes.* American Printing House for the Blind, Louisville, Kentucky, 1992. Compiled under the Authority of the Braille Authority of North America.

[13] J. W. M. de Carvalho: *Mathematics as a Game of Types.* PhD thesis, The University of Western Ontario, 2005.

[14] J. W. M. de Carvalho, H. Jürgensen: Dynamic multi-purpose mathematics notation. Technical Report 512, Department of Computer Science, The University of Western Ontario, 1998, 14 pp.

[15] C. Dirckx: A mathematical text to Braille translator. Project dissertation, Churchill College, University of Bradford, 1992.

[16] M. B. Dorf, E. R. Scharry: *Instruction Manual for Braille Transcribing.* Division for the Blind and Physically Handicapped, Library of Congress, Washington, D. C., 1979.

[17] K. Dunne: Multimedia representation of binary tree diagrams. Undergraduate thesis, The University of Western Ontario, 1995.

[18] O.-M. Elgorriaga-Piippo, B. Hotz: *Mathematikschrift für Blinde – ein Handbuch.* Schweizerische Bibliothek für Blinde und Sehbehinderte (SBS), Zürich, 2000.

[19] H. Epheser, D. Prograniczna, K. Britz, B. Betz-Weitzel: *Internationale Mathematikschrift für Blinde – Neufassung und Vervollständigung. Marburger Systematiken der Blindenschrift* **6**. Verlag der deutschen Blindenstudienanstalt, Marburg/Lahn, 1992. Brigitte Betz-Weitzel (red.).

[20] M. Eramian, H. Jürgensen, H. Li, C. Power: Talking tactile diagrams. In C. Stephanidis (editor): *Proceedings of HCI International 2003, Volume 4: Universal Access in HCI, Inclusive Design in the Information Society*. 1377–1381, Lawrence Erlbaum Associates, Mahwah, New Jersey, 2003.

[21] M. Eramian: Displaying DVI files in Braille; a viewer for the visually impaired. Technical Report 500, Department of Computer Science, The University of Western Ontario, 2000, 44 pp. Undergraduate Thesis.

[22] *ETSI EG 202 048, v1.1.1 (2002-08); ETSI Guide: Human Factors; Guidelines on the Multimodality of Icons, Symbols and Pictograms.* Sophia Antipolis, 2002.

[23] I. Gyacskov: Displaying trees on the DMD. Undergraduate thesis, The University of Western Ontario, 1995.

[24] V. F. Hahn, H. Herwig: *Überlegungen zur Herstellung von tastbaren Bildern (Typhlographien) für den Mathematikunterricht mit Blinden.* Deutsche Blindenstudienanstalt, Marburg/Lahn, 2002.

[25] C. Haustein: Anpassung des Plain-TEX-Formats für taktile Displays. Studienarbeit, Universität Potsdam, Germany, 2002, 39 pp.

[26] S. R. Hussey: *Mathematical Notation. The Halifax Code.* Sir Frederick Fraser School, Halifax, 1981. Revised by D. Harmer, L. Legge, D. Hagen.

[27] G. Jansson: Basic issues concerning visually impaired people's use of haptic displays. In P. Sharkey, A. Cesarani, L. Pugnatti, A. Rizzo (editors): *Proceedings, Third International Conference on Disability, Virtual Reality and Associated Technologies, 23–25 September, 2000, Alghero, Sardinia, Italy*. 33–38.

[28] H. Jürgensen, H. Li, C. Power: Towards talking tactile diagrams. In *Proceedings of the Second International Conference on Tactile Diagrams, Maps and Pictures, Hatfield, UK.* 2002. Available at `http://www.nctd.org.uk/Conference/Conf2002/Programme.asp`; retrieved August 31, 2002.

[29] H. Jürgensen, C. Power. Computing and the Visually Impaired (tentative title). Manuscript in preparation, 2005.

[30] H. Jürgensen. Tactile Graphics (1996). Technical Report 651, Department of Computer Science, The University of Western Ontario, 2005.

[31] H. Jürgensen, C. Power: An application framework for the presentation of tactile documents. In C. Stephanidis (editor): *Universal Access in HCI: Exploring New Interaction Environments. Proc. HCI International 2005, 11th International Conference on Human-Computer Interaction, Volume 7.* Lawrence Erlbaum Associates, Mahwah, New Jersey, 2005, 6 pp.

[32] A. I. Karshmer, C. Bledsoe: Access to mathematics by blind students. In *Computers Helping People with Special Needs : 8th International Conference, ICCHP 2002.* 471–476, Springer-Verlag Heidelberg, Heidelberg, 2002.

[33] S. Landau: Tactile graphics and strategies for non-visual seeing. In *Thresholds 19.* 78–82. MIT School of Architecture, 1999.

[34] S. Landau, K. Gourgey: Development of a talking tactile tablet. *Information Technology and Disabilities* **7**(2) (2001).

[35] S. Landau, M. Russell, K. Gourgey, J. Erin, J. Cowan. Use of the talking tactile tablet in mathematics testing, 2002. Manuscript.

[36] H. Li: The implementation of tactile graphics exploration. Master's thesis, The University of Western Ontario, London, Canada, 2003.

[37] A. Lüdemann: Dynamisch erweiterbarer Übersetzer zur Print- und Sprachausgabe von VHDL-Dokumenten (konzeptioneller Entwurf). Studienarbeit, Universität Potsdam, 2001.

[38] A. Lüdemann: Dynamisch erweiterbarer Übersetzer zur Text- und Sprachausgabe von VHDL-Dokumenten. Diplomarbeit, Universität Potsdam, 2002.

[39] C. Miller: Multimedia statistical diagrams. Undergraduate thesis, The University of Western Ontario, 1996.

[40] *The Nemeth Braille Code for Mathematics and Science Notation, 1972 Revision.* American Printing House for the Blind, Louisville, Kentucky, 1985.

[41] S.-P. Poh: Talking diagrams. Master's thesis, The University of Western Ontario, 1995.

[42] C. Power: The implementation of talking diagrams for the visually impaired. Undergraduate thesis, The University of Western Ontario, 2000, 25 pp.

[43] C. Power, I. McQuillan: Presentation of mathematics through multi-modal techniques. Technical Report 646, Department of Computer Science, The University of Western Ontario, 2004.

[44] T. V. Raman: Congrats: Converting graphics to sound. Master's thesis, Indian Institute of Technology, Bombay, 1989.

[45] T. V. Raman: TEX talk. *TUGboat* **12** (1991), 178.

[46] T. V. Raman: An audio view of LATEX documents. *TUGboat* **13** (1992), 372–379.

[47] T. V. Raman: *Audio System for Technical Readings.* PhD thesis, Cornell University, 1994, xi+128 pp.

[48] T. V. Raman: An audio view of LATEX documents – Part II. *TUGboat* **16** (1995), 311–314.

[49] T. V. Raman: *Auditory User Interfaces: Toward the Speaking Computer.* Kluwer Academic Publishers, Norwell, Massachusetts, 1997.

[50] T. V. Raman: Emacspeak: A speech-enabling interface. *Dr. Dobb's Journal* **22**(9) (September 1997), 18–23.

[51] T. V. Raman, D. Gries: Documents mean more than just paper! In *Proceedings of the Second International Workshop on the Principles of Document Processing.* 1994.

[52] T. V. Raman, M. S. Krishnamoorthy: Congrats – a system for converting graphics to sound. In *IEEE Proc. Johns Hopkins National Search for Computing Applications to Assist Persons with Disabilities.* 170–172, 1992.

[53] J. Redekop: BrailleSens Report '93. Undergraduate thesis, The University of Western Ontario, 1993.

[54] H.-H. Schenk (editor): *Schaltungsschrift. Kurzer Leitfaden für die Übertragung von Schaltbildern und Texten aus der Elektronik und verwandten Sachgebieten in Blindenschrift. Marburger Systematiken der Blindenschrift.* Verlag der deutschen Blindenstudienanstalt, Marburg/Lahn, 1980.

[55] W. Schweikhardt: Die Stuttgarter Mathematikschrift für Blinde, Vorschlag für eine 8-Punkt-Mathematikschrift für Blinde. Technical Report Report 9/1983, Institut für Informatik, Universität Stuttgart, 1983.

[56] W. Schweikhardt: Presenting videotex-pages to the blind. In *Proc. 3rd Annual Workshop on Computers and the Handicapped.* 23–29, IEEE Computer Society Press, Silver Spring, 1984.

[57] R. D. Stevens, A. D. N. Edwards: Access to Mathematics for Visually Disabled Students through Multimodal Interaction. *Human-Computer Interaction (Special issue on Multimodal Interfaces)* **12**(1&2) (1997), 47–92.

[58] Система обозначений для слепых по математике, фисике, астрономии и химии. Всероссийское общество слепых, Moscow, 1975.

[59] E. R. Tufte: *The Visual Display of Quantitative Information.* Graphics Press, Cheshire, Connecticut, 1982; 14th Printing, 1995.

[60] S. Ungar, M. Blades, C. Spencer: Mental rotation of a tactile layout by young visually impaired children. *Perception* **24** (1995), 891–900.

[61] J. N. Wallace, T. A. B. Wesley: The access to scientific and mathematical information for blind people. 1991.

[62] G. Weber: Gestures as a means for the blind to interact with a computer. In H.-J. Bullinger, B. Shackel (editors): *Human-Computer Interaction – INTERACT'87.* 593–595, North-Holland, Amsterdam, 1987.

[63] G. Weber: Reading and pointing – modes of interaction for blind users. In G. X. Ritter (editor): *Information Processing 89.* 535–540, North-Holland, Amsterdam, 1989.

[64] G. Weber: FINGER – a language for gesture recognition. In D. Diaper, G. Cockton, D. Gilmore, B. Shackel (editors): *Human-Computer Interaction, INTERACT'90.* 689–694, North-Holland, Amsterdam, 1990.

[65] G. Weber: Adapting graphical interaction objects for blind users by integrating braille and speech. In *Proc. International Conference on Computers for Handicapped Persons.* 546–555, Oldenbourg, Wien, 1992.