Modeling Educational Software for People with Disabilities: Theory and Practice

Nelson Baloian, Wolfram Luther
Institut für Informatik und Interaktive Systeme
Gerhard-Mercator-Universität Duisburg
Lotharstraße 65, D 47048 Duisburg
Germany
{baloian,luther}@informatik.uni-duisburg.de

Jaime Sánchez
Department of Computer Science
University of Chile
Blanco Encalada 2120, Santiago
CHILE
jsanchez@dcc.uchile.cl

ABSTRACT
Interactive multimedia learning systems are not suitable for people with disabilities. They tend to propose interfaces which are not accessible for learners with vision or auditory disabilities. Modeling techniques are necessary to map real world experiences to virtual worlds by using 3D auditory representations of objects for blind people and visual representations for deaf people. In this paper we describe common aspects and differences in the process of modeling the real world for applications involving tests and evaluations of cognitive tasks with people with reduced visual or auditory cues. To validate our concepts, we examine two existing systems using them as examples: AudioDoom and Whisper. AudioDoom allows blind children to explore and interact with virtual worlds created with spatial sound. Whisper implements a workplace to help people with impaired auditory abilities to recognize speech errors. The new common model considers not only the representation of the real world as proposed by the system but also the modeling of the learner's knowledge about the virtual world. This can be used by the tutoring system to enable the learner to receive relevant feedback. Finally, we analyze the most important characteristics in developing systems by comparing and evaluating them and proposing some recommendations and guidelines.

Keywords
Modeling methodologies, Tutoring systems, Sensory disabilities, User adapted interfaces

INTRODUCTION

A large number of educational systems for supporting people with disabilities have already been developed. While most systems targeting the hearing-impaired are oriented toward training people by developing the necessary skills to overcome their disabilities, a large proportion of the systems for blind people aim to increase considerably their access to current computing resources which are based on graphic user interfaces, such as games and web navigation systems.

Apparently, the task of developing computer systems for visually impaired and hearing-impaired people may be considered to be of very different nature because the restrictions in both cases are contrary. In the first case, the problem is to construct interfaces which do not rely on graphics.

Assets 2002, July 8-10, 2002 Edinburgh, Scotland
Copyright 2002 ACM ISBN 1-58113-464-9-02/07 ...$5.00

In the second, on the other hand, graphics are the main - if not the only - way for the system to communicate with the user. However, we found a great number of similarities in the procedure of designing and constructing computer systems for people with different kinds of disabilities. This is especially true in the case of developing cognitive systems the aim of which is the modeling and implementation of various aspects of the real world by a computer system.

This paper proposes an integrated model for developing learning systems for people with different kinds of disabilities, which consists of a series of steps and recommendations to be followed; it considers the common aspects and outlines the differences. Special attention is paid to the feedback issue, which seems to be a critical point in existing systems. To be able to give proper feedback the system needs to include an intelligent tutor module concerned with the interaction of the student with the implemented model of the real world. Problems in constructing learning systems for people with disabilities arise when the model is to be presented to the user who is supposed to interact with it. In systems for people without disabilities this model is transmitted to the learner by using graphics (with or without animation), sounds and text, taking advantage of the whole spectrum of the computer's multimedia capabilities. For people with disabilities this spectrum is limited according to the type of disability they have. This fact forces system designers to project all the information the model has to give to or receive from the student on the available channel the auditory channel for the visually-impaired and the visual channel for the hearing-impaired. Additionally, non-traditional interaction modes, for example haptic devices can be used. The same considerations are valid for the construction of the learner's model. The common model highlights the importance of an automatic and accurate measurement of the differences between the system's model and the one the student has developed in his mind.

To validate the proposed development model, we will test it on two existing systems, one designed for blind and the other for hearing-impaired people: AudioDoom and Whisper, respectively. AudioDoom allows blind children to explore and interact with virtual worlds created with spatial sound. It was inspired by traditional Doom games, where the player has to move inside a maze discovering the environment and solving problems posed by objects and entities that inhabit the virtual world. In doing so, it emphasizes sound navigation throughout virtual spaces in order to develop cognitive tasks to enhance spatial orientation skills in blind children [7, 8, 15, 16, 19, 20].

AudioDoom has been tested with more than forty Chilean children aged 7-12 in a blind school setting. Primary results are described in Lumbreras and Sánchez [9]. Long term data from a full field study were also communicated in Sánchez [17, 18].

Whisper implements a workplace for hearing-impaired to recognize speech errors. Thus, words, sentences, and small stories are taken from everyday life; learners explore a typical situation by repeating words or short sentences. Typical speech errors are displayed in a way appropriate to the learner. Whisper was presented at the REHA 99 exhibition at Düsseldorf, Germany and was evaluated during a six month period at special schools for the hearing-impaired, with the aid of all leading German rehabilitation centers. The usability of the English version was tested in collaboration with the National Association for Deaf People in Dublin/Ireland [23, 34, 25].

EDUCATIONAL SYSTEMS FOR PEOPLE WITH DISABILITIES

Several virtual reality systems and virtual environments combined with appropriate human-machine interfaces were used to enhance the sensual capabilities of people with sensory disabilities: Presentation of graphic information by text-to-speech, and 3D auditory navigation environments to construct spatial mental representations or to assist users in acquiring and developing cognitive skills [21].

A sonic concentration game described in [13] consists of matching pairs of different levels of basic and derived geometric shapes. To represent geometric shapes it is necessary to build a two-dimensional sound space. The concept allows the shape to be rendered by the perception of moving sound in a special plane. Each dimension corresponds to a musical instrument and raster points correspond to pairs of frequencies on a scale. Moving horizontally from left to right is equivalent to a frequency variation of the first instrument, and moving vertically to a frequency variation of the second one.

VirtualAurea by Sánchez [18] was developed after sound-based virtual environments proved to trigger the development of cognitive spatial structures in blind children. VirtualAurea is a set of spatial sound editors that can be used by parents and teachers to design an ample variety of spatial maps such as the inner structure of the school and rooms, corridors and other structures of a house. Users can also integrate different sounds associated to objects and entities in a story. VirtualAurea is being used to develop complex cognitive spatial and temporal structures in blind children.

Mehida [1] is an intelligent multimedia system for deaf or hearing-impaired children designed to assist them in acquiring and developing communication skills. Mehida covers the following types of communication: Finger spelling (representing the letters of the alphabet using the fingers), gestures or sign languages, lip reading (understanding spoken language through observing lip motion), and voice recognition.

The IBM SpeechViewer III [http://www-3.ibm.com/able/snsspv3.html] is a powerful speech and language tool that transforms spoken words and sounds into imaginative graphics. The system is intended for people who have speech, language or hearing disabilities and includes functions for the administration of the learners' data. There are different types of exercises: The awareness exercises are simple games concentrating on basic speech parameters and can be used by very young children. The skill building exercises ask the learner to work towards achieving a goal set by the expert and provide feedback on pitch, voicing, and vowel articulation. The patterning exercises offer a graphic representation of the learner's and expert's voices for comparison concerning pitch and loudness.

ISAEUS [6] is a speech training system for deaf and hearing-impaired people on a multilingual basis which has been developed in the context of an EU-project begun in 1997 by Jean-Paul Haton (Nancy, France) and other groups in Spain and Germany.

The Visual Talker [http://www.ed.gov/offices/OERI/SBIR/FY99/phase1/ph199t02.html] provides a real-time speech-to-text visual translator system for classroom environments. The aim of this research is the development of a real-time speech-to-text system to be used by teachers, their students with hearing loss and/or speech impairments, and all other students in classroom settings to provide a 'full participation' communication system.

Summarizing, we can identify two ways to improve systems for people with sensory disabilities: by complementing graphic interfaces with other communication facilities and by supporting direct interactions with internal models or representations of virtual models. For blind people, systems tend to transform graphic output information in a haptic or audible format. Speech processing is used to generate text or graphics from acoustic input in order to permit hearing impaired users to navigate through and communicate with the model. In the next section we will show how the modeling process should reflect the user's impairments.

UNIFIED MODEL

Unified modeling pipeline for developing educational software

We propose a unified model for creating educational software for people with disabilities. The modeling process starts with the definition of cognitive skills the learner has to acquire; then it considers the creation of a virtual environment composed by a navigable world and built by using an adequate modeling language, dynamic scene objects, and acting characters. Scenic objects are characterized by graphic and acoustic attributes; character's actions are based on deterministic and non-deterministic plans as in an interactive hyperstory [9]. The learner explores the virtual world by interacting with appropriate interfaces and immediately obtains feedback. The learner's actions, such as sound reproductions or utterances, are collected, evaluated, and classified, based on a student's modeling and diagnostic subsystems.

The modeling pipeline is divided into seven sections.

1. We define cognitive skills in a real world situation, for example self-motivating activities, drill and practice applications, problem solving or leisure time occupations.

2. Objects are constructed of geometric primitives or a combination of these. They are characterized by graphic and acoustic attributes and grouped into components with input and output slots. Control elements of the virtual world are represented by the graphic and acoustic elements, known as icons and earcons.

3. We develop an internal computer representation and define a geometric environment and a 2D/3D visual and acoustic model. Modern object-oriented and message based modeling languages are powerful tools for building virtual worlds using a scene graph as data structure. We insist on the necessity of special editors for teachers and learners to create synthetic models independently.

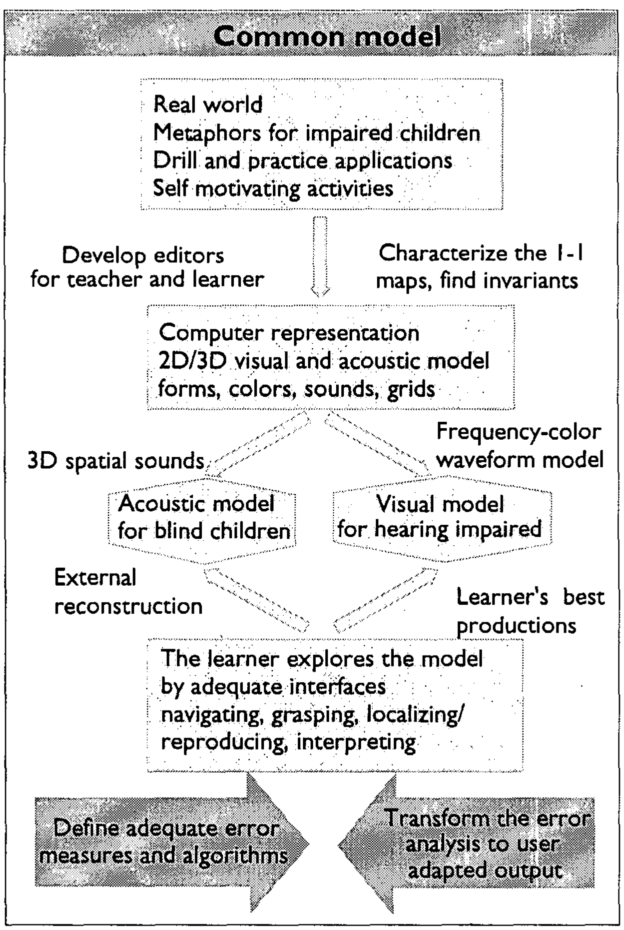

Figure 1: Model synthesis

4. According to the problem characteristics and the target users, problem-specific correspondences between graphic and acoustic attributes or properties are used to reduce the model to its visual or acoustic projection. The resulting model can also generate a special editor for impaired learners. Characteristic model parameters and their domains and ranges are formally defined.

5. The acoustic representation of the model uses spatial sound; the visual model uses graphic representations of the objects. Interaction and navigation are based on visual or acoustic control elements depending on the case.

6. The learner explores the model by interacting with suitable interfaces. This can be done through navigating without changing viewpoint or the use of an internal representation of the user giving him the illusion of being a part of the virtual scene. A blind person explores neighboring models by grasping them, tracking objects or listening to typical sounds. A hearing-impaired person looks at model primitives like letters, finger or lip representations of phones. Then the learner explores the object space by navigating and reproducing the structures. It is imperative to make sure that conditions during the reconstruction process are always the same. Therefore, the interfaces involved are calibrated accordingly.

7. Depending on the particular parameters of the model, error measures between the internal model and the model reproduced by the learner are defined. Appropriate image processing or speech recognition algorithms are necessary to quantify the error. Learner's actions are collected, evaluated and classified. The outcome is transformed to a user-adapted aural or visual output.

The modeling work flow

AudioDoom and Whisper are being used as exemplary applications for blind and hearing-impaired users, respectively. Thus, we will validate our common model by describing the modeling work flow in both educational systems in a more detailed and formalized way.

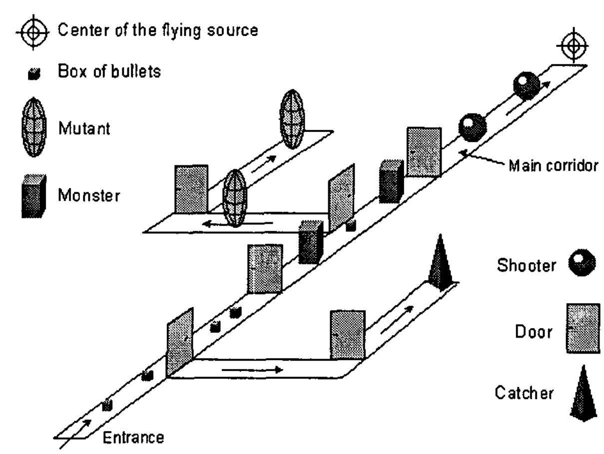

Figure 2a: External model **C**

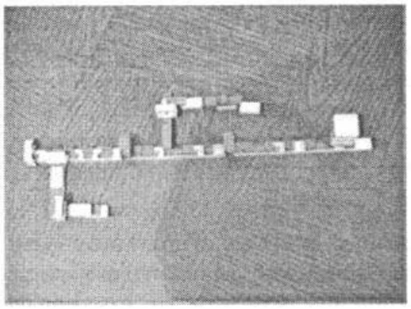

Figure 2b: Reconstructed LEGO-model **D**

In AudioDoom and Whisper the modeling process follows the steps introduced above: First, a virtual model **B** is derived from the real or fictive world scenario **A** by means of abstraction and reduction without taking into consideration the limitations of the potential users. Then, model **B** is projected to an appropriate model **C** which can be explored by people with sensory disabilities using available communication channels. Appropriate editors support the modeling process. Important model parameters must be identified at this stage. By interacting with the system, the learner makes an internal reconstruction of the model **C** called **D**. Additionally, the learner can build an external representation of **D**, which has to be evaluated (cp. Figures 2a and 2b). This can be done by using an appropriate multidimensional error measure $\mathbf{m_I(P,X,Y)}$ depending on the objects and their attributes. **I** represents the parameters, **P** a learner, **X** the computer model, and **Y** the reconstructed model.

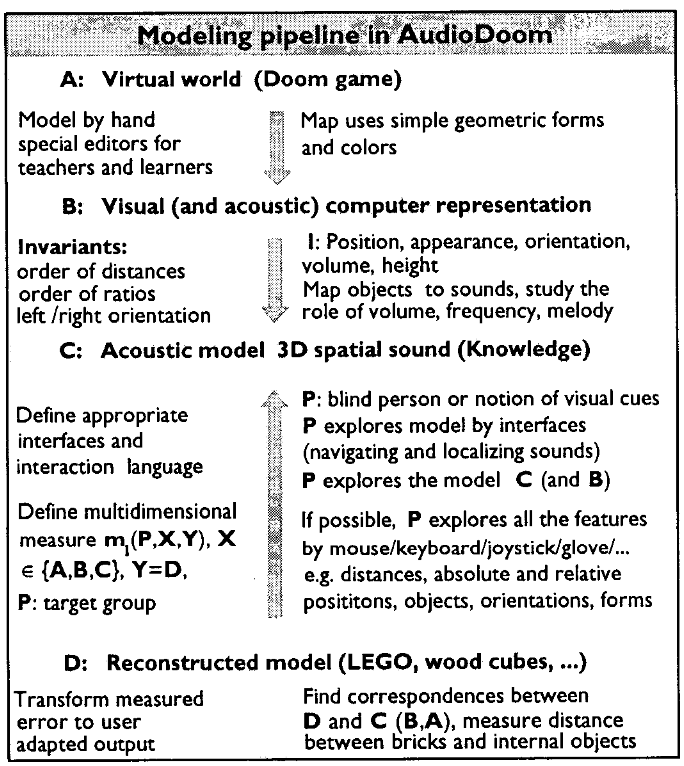

Figure 3: The modeling pipeline in AudioDoom

Finally, the degree of similitude is derived from the error measure and the result is displayed in an learner-adapted output and used for updating the student model.

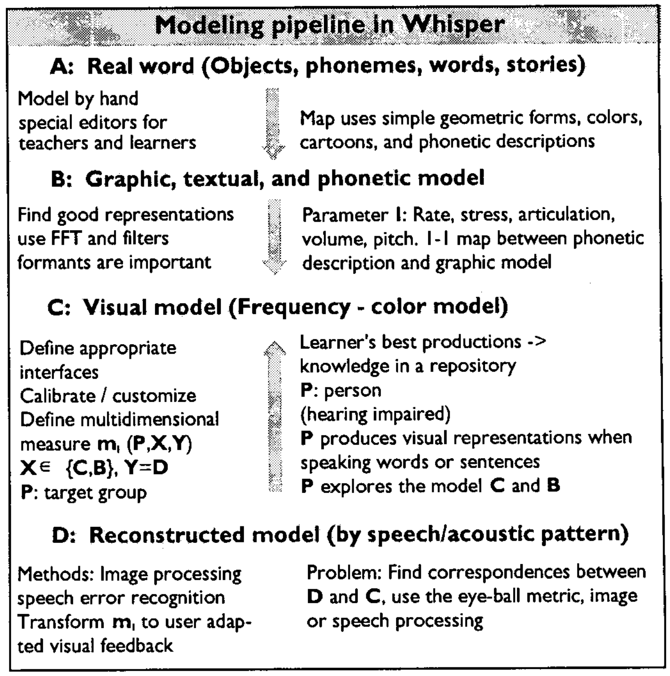

Figure 4: The modeling pipeline in Whisper

The modeling work flow in AudioDoom is represented in Figure 3. The model of the virtual game world (which in our application is a simple labyrinth with one main corridor and two secondary corridors including entities and objects) is projected on another model consisting only of sounds. At this stage, the role of volume, frequency, melody, and rhythm in representing different forms, volumes, and distances is analyzed. Learners interact with this model by 'virtually walking' through this labyrinth with a keyboard, mouse, and ultrasonic joystick. Sound-emitting objects help them to build a mental model of the labyrinth. Finally, they make concrete replications of mental models with LEGO blocks and try to rebuild the internal model as it was perceived and imagined after an exploration of the spatial structure. Different kinds of blocks represent the objects of the internal model **C** in a well-defined way.

The concrete representation is checked by a human tutor or a camera to look for any correspondence with the original model embedded in the computer. The error measurement (represented by the function $\mathbf{m_I(P,X,Y)}$) reflects this difference. The index **I** stands for different properties of objects which are part of **X** and **Y**, **P** denoting the learner, **Y** the reconstructed model **D**, and **X** the internal model **C** of the labyrinth. Bricks can be represented by two coordinate triples of a three dimensional discrete vector space. Then the distance between the same object in models **C** and **D** must be calculated using an appropriate vector norm. Summing up, we obtain a candidate for an error measure $\mathbf{m_{Distance}}$.

The modeling work flow in Whisper is represented in Figure 4. The modeled entities are nouns or objects which are named using phonemes and words. This model is projected on a visual representation using only graphic resources. The learner explores the visual model of a short story and reconstructs the visual wave form representation by speaking words or sentences. Correspondences between the internal model and its representation are detected by the learner or a human tutor using the 'eyeball metric' or by means of image processing.

As we can see, despite some differences in object representation, interfaces, perception modes, and error measures, there are important common tasks which should be undertaken when developing systems for either blind people or people with hearing disabilities. In fact, by comparing the two work flow diagrams, we were able to formulate a model synthesis for developing systems for people with different kind of disabilities.

A critical task in the modeling pipeline is the reduction of the original model to either only graphic or only acoustic output. This topic has already been discussed in our recent paper *Visualization for the mind's eye* [2].

TESTING THE MODEL

Now we want to explain two steps of the modeling pipeline in more detail.

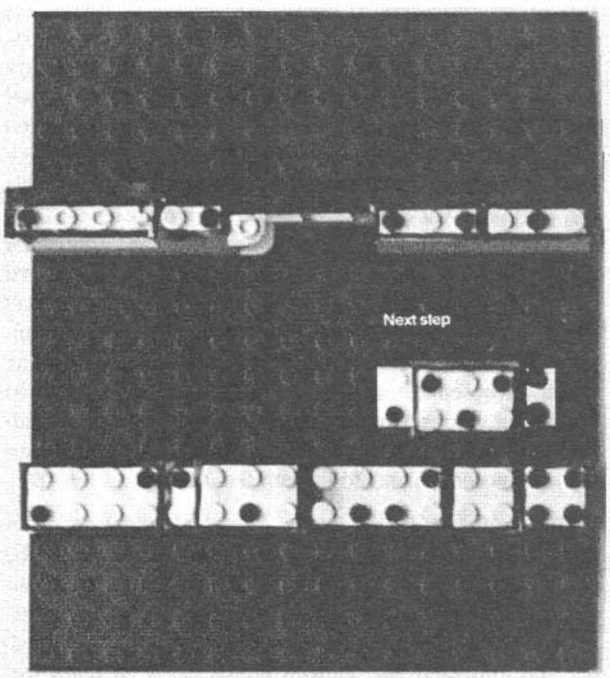

Figure 5: Reconstruction process in AudioDoom

To process an external model and to evaluate error measures, we will assume that a blind user reconstructs AudioDoom's maze structure by using special LEGO blocks. Each block is individually marked by black bars and dots. A blind user takes note of the different kinds of blocks, selects the appropriate ones, and rebuilds the mental image by using the blocks one by one.

After each step a picture is taken by a digital camera placed on a fixed position over the scene. We highlight a typical state of a reconstruction process and indicate the next step by adding a new LEGO block on the lower wall. Figure 5 shows the situation before and after the next step. Reducing the colors to black and white makes it possible to apply low level image processing routines to detect the new LEGO block. After a calibration of the two pictures, we can localize the new block through an XOR-operation on both images resulting in two dashes or only one, otherwise in new dots. Starting from these new picture elements we calculate the position and type of the new LEGO block. Finally, the learner's model representation is updated.

Thus it is proved that by certain low level operations on succeeding pictures the external model can be transferred into an internal representation which is used to feed an appropriately defined error measure function $\mathbf{m_I(P,C,D)}$. A degree of fidelity is derived and displayed by text-to-speech. For a more sophisticated approach using LEGO RCX robots see [12].

Now we will look at the frequency-color model representing words in Whisper. From a more technical point of view we sample the recorded speech signal and execute several fast Fourier transforms per second to obtain a frequency representation using an RGB color map with three overlapping triangular characteristics for red, green, and blue which can be freely modified.

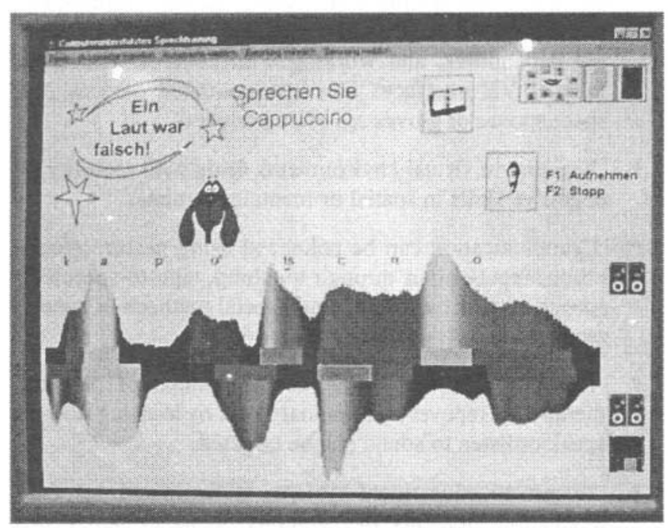

Figure 6: Frequency-color representation in Whisper

The resulting frequency-color representation is smoothed and simplified by an appropriate cluster and threshold algorithm (cp. Figure 6). Whereas the wave amplitude image provides any feedback concerning volume and rate in the xy-plane, omitted syllables are characterized by a lack of colored areas, and intonation and articulation by the parameters hue and saturation as well as the shape of the curves. Details are described in Hobohm [5] and Gräfe [4].

In recent years it has been shown that the combination of neural networks with Hidden Markov Models is a powerful approach to speech recognition [26]. Next, we will include these techniques in our system by using a phoneme-labeled speech database providing a morpheme-to-morpheme transposition of an oral language into the visual channel. In this process all structures of the unique oral language are preserved. However, speaker adaptation of a certain amount of available training data does not have the intention of reducing the error recognition rate. On the contrary, the system is intended to detect errors in examining deformed or omitted phones or erroneous articulation. Here it will be interesting to search for the most probable phone sequences. Furthermore, the phones are to be displayed within a separate window using an adequate segmentation.

MODELING GUIDELINES AND RECOMMENDATIONS

Virtual environments (VE) can be used to simulate aspects of the real world which are not physically available to users for a wide variety of reasons. They become more realistic through multimedia displays which include haptic, visual, and auditory information. According to Colwell et al. [3] and Paciello [10], there are several domains in which VEs can be used to build educational software for people with disabilities.

- In education a virtual laboratory assists students with physical disabilities in learning scenarios. Possible applications concern problem solving, strategic games, exploring spaces or structures, training of speech or hearing capabilities, and working with concrete materials. Special VE interfaces like head-mounted devices, the space mouse or gloves are often included.
- Training in virtual environments deals with mobility or cognitive skills in spatial or mental structures.
- Communication can be enhanced using gesture recognition, input/output through touching, sign-to-speech or speech-to-sign translation and special methods of speech recognition.
- Rehabilitation is possible in the context of physical therapy - a recovery of manual skills or learning how to speak or listen to sound can be targeted.
- Access to educational systems is facilitated via dual navigation elements like earcons, icons or haptic devices.

Our idea is to support the visually or hearing-impaired in building conceptual models of real world situations in the way that seeing or hearing users do. Our approach is comparable to the one introduced by Zajicek et al. [27].

We can identify four important common elements and aspects in the modeling process for systems concerning blind and hearing-impaired persons:

1. **The Conceptual model** results from mapping the real or fictive world situation into a computer model which may use all digital media by applying adequate modeling languages.
2. **The Perceptual model** is created by developing a perceptual model and a script for the dynamic changes of the model. It can be perceived by the learner using only those information channels which are available to him and respects the disabilities of the user group. With the perceptual model, it is important to provide surprising elements to provoke attention in order to enhance the perception process. The computer model description should be based on text. Explanation of graphic objects should be given in caption form. This text can be presented for the blind by using a text-to-speech plug-in or a Braille display, for the deaf by converting it from speech to text. Intuitive correspondences between graphic and aural objects must be defined. Attention must be paid to the fact that only a small number of sounds can be memorized. Also, melodies that help to identify the objects should be used.
3. **The implementation design -** Icons and earcons should be provided in parallel. If sound or speech is used, written dialogue for hearing-impaired people should be provided. If there are animated image sequences or videos with sound, subtitles or moving text-banners should be used. Sound provides a rich set of resources which complement visual access to a virtual world. The four types of audio examined by Ressler and Wang [11] are ambient background music, jingles, spoken descriptions, and speech synthesis. Ambient music can play and vary as the user moves from one room to another, providing an intuitive location cue. Jingles or small melodies should characterize special objects and control elements. Spoken descriptions of objects can play as the viewer moves closer to an object. Speech synthesizers can read embedded text from the nodes in a scene graph representation. Recent WEB-languages provide Anchor node descriptions, EnvironmentNodes or World-Info nodes. Internet accessible speech synthesizers supply easy access to text-to-speech technology.
4. **The implementation tools -** Special editors or languages like Java, Java3D, OpenGL, or VRML should be used. VRML defines a standard language for representing a directed acyclic graph containing geometric information nodes that may be communicated over the Internet and animated and viewed interactively in real-time. VRML 2.0 [22] also provides behavior, user interaction, sensors, events, routes and interpolators for interactive animation. User interaction, time dependent events or scripts can trigger dynamic changes in some properties of an object. VRML viewers are available not only as plug-ins to Internet browsers, but also as interactive ob-

jects that may be embedded into standard Office documents. However, the actual version does not yet support collaborative scenarios. This is only a succinct description of some tools that are currently available. There are, of course, many more, but we have focused on those that are platform independent and based on international standards.

Software architecture and tools for implementation

To support multi-modal interaction we propose an architectural model which consists of an interaction module supporting the input and output devices and allowing data input and representation of the feedback, a data representation module that transforms collected data into data types which will be managed by the model implementation on the server, and an application module that contains the task scheduler, student modeling and diagnostic subsystems.

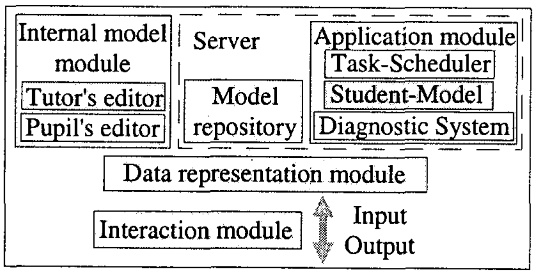

Figure 7: Architectural model

The internal model module: Special editors for tutors or pupils can help in the construction of an internal model. For hearing-impaired people models can be selected using drag-and-drop actions on nouns, icons or cartoons in a repository. Equivalent representations of these entities should be given in the form of text or phonetic transcription. Blind people choose elements from internal worlds by using sensitive boards, pointing or haptic devices. Each internal model designed can be coded as a VRML scene graph that is memorized in an appropriate database. It should be possible to add a user avatar and to render the graph with respect to the viewpoint of this representation.

The interface module: We have seen that the common procedure for developing interfaces for blind people consists in trying to transform the graphic output into a haptic or an audible format or the latter into a text or graphic format through which the user navigates. We believe that in many cases it is more appropriate to model the interface first and then try to represent this as a logic structure using auditory or haptic resources. This idea was first proposed by Savidis et al. [21] and Ressler and Wang [11], who developed a methodology for making synthetic virtual worlds accessible to the visually and physically impaired.

The addition of embedded text, sounds, and further assisting devices, such as speech recognition systems and data gloves all contribute to more accessible virtual worlds. Virtual environments (VE) organize objects in hierarchical data structures. Designers wishing to make their virtual worlds generated by modeling languages like VRML more accessible to blind people should think about the possibility of enhancing the syntactic node elements within the graph structure by

- adding WorldInfo node textual descriptions, both for the entire world and for individual objects,
- using varying sounds depending on distances described in the EnvironmentNode,
- using the description field of Anchor nodes, to implement links to other scenes or objects,
- associating sound nodes to specify the orientation, intensity, and localization of sounds including spoken descriptions of objects of interest,
- creating large control areas for alternative input devices.

CONCLUSION

In this paper we have given an overview of the state of the art in the field of existing educational systems for people with disabilities such as blindness or deafness, especially focusing on transferring the real world into appropriate computer representations; then we introduced a unified methodology for modeling the real world for these people, and finally we illustrated important tasks for defining error measures and adapted output formats.

A critical mass of educational systems have already been developed for disabled people, which allows some generalizations and recommendations to be made. The development of systems for people with disabilities should not longer appear as isolated handcrafted efforts; instead, efforts should be made to systematize the construction of these types of systems. Recent advances in hardware and software developments support our idea and provide hope that the technological foundation for such systems has already been laid.

ACKNOWLEDGEMENTS

This research and common multi-media software development for the disabled (AudioDoom for blind people and Whisper for postlingually deaf people) are being carried out by the authors in the course of a current German-Chilean project funded by the German ministry BMBF and the Universities of Duisburg and (Santiago de) Chile. We thank Dr. M. Mühlenbrock and Dr. D. Willett for their valuable suggestions and our collaborators Dr. W. Otten and C. Wans for their persistent valuable support during the development and evaluation of Whisper, discussing the ideas and supplying the material of their research for our purposes.

REFERENCES

1. Alonso, F., de Antonio, A., Fuertes, J. L., and Montes, C. Teaching Communication Skills to Hearing-Impaired Children. *IEEE Multimedia*, Vol. 2, No. 4 (1995), 55-67.

2. Baloian, N., Luther, W. Visualization for the Mind's eye. *Proc. Dagstuhl, Software Visualization* 2001, LNCS 2269, St. Diehl ed., Springer, Berlin (2002).

3. Colwell, Ch., Petrie, H., Kornbrot, D., Hardwick, A., Furner, S. Haptic Virtual Reality for Blind Computer Users. *The Third Annual ACM Conference on Assistive Technologies*, April 15-17, 1998, Marina del Rey, California, USA, 92-99. Available at http://www.acm.org/pubs/articles/proceedings/assets/274497/p92-colwell/p92-colwell.pdf

4. Gräfe, J. Visualisierung von Sprache und Erkennung sprechtypischer Parameter und ihre Veränderung bei Spätertaubten. Diploma-Dissertation, Duisburg (1998).

5. Hobohm, K. Verfahren zur Spektralanalyse und Mustergenerierung für die Realzeit-visualisierung gesprochener Sprache. PhD-Dissertation, TU Berlin (1993).

6. ISAEUS. Speech Training for Deaf and Hearing-Impaired People (1997). Available at http://www.ercim.org/publication/Ercim_News/enw28/haton.html

7. Lumbreras, M., Sánchez, J., Barcia, M. A 3D sound hypermedial system for the blind. *Proc. First Europ. Conf. on Disability, Virtual Reality and Associated Technologies*, Maidenhead, UK (1996), 187-191.

8. Lumbreras, M., Sánchez, J. 3D aural interactive hyperstories for blind children. *International Journal of Virtual Reality* 4 (1) (1998), 20-28.

9. Lumbreras, M., Sánchez, J. Interactive 3D Sound Hyperstories for Blind Children. *CHI '99*, Pittsburg PA, USA (1999), 318-325.

10. Paciello, M. Making the Web accessible for the deaf, hearing and mobility impaired. *Yuri Rubinsky Insight Foundation* (1998). Available at http://www.yuri.org

11. Ressler, S. and Wang, Q. Making VRML Accessible for People with Disabilities. In *Proceedings of ASSETS '98, the Third Annual ACM Conference on Assistive Technologies*, Marina del Rey, California, USA (1998), 144-148.

12. Ressler, S., Antonishek, B. Integrating Active Tangible Devices with a Synthetic Environment for Collaborative Engineering. *Proc. 2001 Web3D Symposium*, Paderborn, Germany, Febr. 19-22 (2001), 93-100.

13. Roth, P., Petrucci, L., Assimacopoulos, A., Pun, Th. Concentration Game, an Audio Adaptation for the blind. *CSUN 2000 Conf. Proceedings*, Los Angeles, USA. Available at http://www.csun.edu/cod/conf2000/proceedings/gensess_proceedings.html .

14. Sánchez, J. 3D interactive games for blind children. *Proceedings of Technology and Persons with Disabilities, CSUN 2000 Conference Proceedings,* Los Angeles, USA.

15. Sánchez, J. Interactive virtual environments to assist the cognition of blind children. Proc. *VII Iberoamerican Scientific Conference, CYTED*, Panama (2000).

16. Sánchez, J. Interactive virtual environments for blind children: Usability and cognition. *Proceedings 4th Iberoamerican Congress on Informatics and Education, RIBIE 2000*, Viña del Mar, Chile.

17. Sánchez, J. Usability and cognitive impact of the interaction with 3D virtual interactive acoustic environments by blind children. *CP&B 2000* (in press).

18. Sánchez, J. Interactive virtual acoustic environments for blind children. *Proceedings of ACM CHI '2001*, Seattle, Washington, April 2-5, 2001, 23-25.

19. Sánchez, J., Lumbreras, M. Virtual Environment Interaction through 3D Audio by Blind Children. *Journal of Cyberpsychology and Behavior, CP&B* 2(2) (1999), 101-111.

20. Sánchez, J., Lumbreras, M. Usability and Cognitive Impact of the Interaction with 3D Virtual Interactive Acoustic Environments by Blind Children. *3rd Int. Conf. on Disability, VR and Assoc. Technologies*, Alghero, Sardinia, Italy (2000),. 67-73.

21. Savidis, A., Stephanidis, C., Korte, A., Crispie, K., Fellbaum, K. A generic direct-manipulation 3D-auditory environment for hierarchical navigation in non-visual interaction. *Proc. ACM ASSETS 96*, 117-123.

22. VRML Consortium. VRML97 International Standard Specification (ISO/IEC 14772-1 :1997). Available at http://www.web3d.org/Specifications.

23. Wans, Cl. ILSE: Ein Interaktives Lehr-/Lernsystem für Spätertaubte. In: Ch. Herzog (Hrsg): *Beiträge zum 8. Arbeitstreffen der GI-Fachgruppe, 1.1.5/7.0.1 "Intelligente Lehr-/Lernsysteme"*, Blaue Reihe München, TUM-INFO-08-I9736-150/1.-FI (1997), 133-144.

24. Wans, Cl. An Interactive Multimedia Learning System for the Postlingually Deaf. *Proceedings of ITiCSE'98, 6th Annual Conference on the Teaching of Computing, 3rd Annual Conference on Integrating Technology into Computer Science Education*, ACM, New York, Oxford (1998).

25. Wans, Cl. Computer-supported hearing exercises and speech training for hearing-impaired and postlingually deaf. *Assistive Technology Research Series*, Vol 6 (1), IOS Press (1999) 564-568.

26. Willett, D. Beiträge zur statistischen Modellierung und effizienten Dekodierung in der automatischen Spracherkennung. PhD-Dissertation, Gerhard-Mercator-Universität Duisburg (2000).

27. Zajicek M., Powell C., and Reeves C. A Web Navigation Tool for the Blind. *Proc. of ASSETS'98, the 3rd ACM/SIGCAPH on Assistive Technologies*, Los Angeles, USA (1998), 204-206.