A Three-Generation Model for Teleradiology

Uwe Engelmann, Andre Schröter, Ulrike Baur, Oliver Werner, Markus Schwab, Henning Müller, Hans-Peter Meinzer

***Abstract*— This paper proceeds from the definition of teleradiology. It identifies three different generations of teleradiology systems and includes those systems that are not regarded as teleradiology systems by the authors. A list of requirements pertinent to users of first-generation teleradiology systems is introduced. Most of the requirements have been realized in a new generation teleradiology system called CHILI.**[1]

***Index Terms*—Biomedical communication, biomedical imaging, collaborative work, computer-assisted radiology, data security, image processing, picture archiving and communication systems, teleconferencing, telemedicine, teleradiology.**

I. Introduction

THE GERMAN Cancer Research Center and the Steinbeis-Transfer Center for Medical Informatics, both of which are located in Heidelberg, Germany, cooperatively developed the teleradiology system MEDICUS. This project ran from mid-1994 to mid-1996 and was funded by the DeTeBerkom, a subsidiary of the German Telecom. Since January 1996, the system has been in use in 13 medical institutions. More than 30 000 images have been processed with MEDICUS (as of March 1997).

We can see that many different research prototypes and products offer a varying degree of functionality in teleradiology. The users of existing systems have their own understanding of what constitutes a good teleradiology system. Requirements for a good teleradiology system are constantly in flux since the users are asking for more features and functionality all of the time.

To obtain at least a rough classification of the systems, we developed the simple three-generation model of teleradiology systems.

II. Generations of Teleradiology

A. What Is "Teleradiology?"

Radiologists and vendors of software and hardware in this field do not always share the same definition of teleradiology. Thus, it is probably necessary to point out that we are using the definition given by the American College of Radiology (ACR) [1]. This resolution includes an initial definition of teleradiology (besides goals, qualifications of personnel, equipment guidelines, licensing, credentialing, liability, communication, quality control, and quality improvement for teleradiology). The ACR definition of teleradiology states the following [1].

Teleradiology is the electronic transmission of radiological images from one location to another for the purposes of interpretation and/or consultation. Teleradiology may allow even more timely interpretation of radiological images and give greater access to secondary consultations and to improved continuing education. Users in different locations may simultaneously view images. Appropriately utilized, teleradiology can improve access to quality radiological interpretations and thus significantly improve patient care.

Teleradiology is not appropriate if the available teleradiology system does not provide images of sufficient quality to perform the indicated task. When a teleradiology system is used to produce the official authenticated written interpretation, there should not be a significant loss of spatial or contrast resolution from image acquisition through transmission to final image display. For transmission of images for display use only, the image quality should be sufficient to satisfy the needs of the clinical circumstance.

Since this standard should serve as a model for all physicians and healthcare workers who utilize teleradiology, we shall refer to it in this paper.

B. What Is "Not Teleradiology?"

A number of commercial products for video conferences or computer-supported cooperative work (CSCW) are on the market. The functionality of such products can be summarized as video telephony (see each other and talk to each other), working on a common work area or whiteboard [e.g., drawing, writing, display of images, manipulation of three-dimensional (3-D) objects] and application sharing. Examples of such products are ProShare and InPerson.[2] All of these lack domain-specific functionality for the processing of digital radiographic images. They do not support the medical image standards ACR/NEMA or Digital Imaging and Communication (DICOM) [2]. It is not possible to handle 12-bit images, and they have no specific functions for level/window manipulation or the analysis of gray values. Other functions for image analysis and processing are missing as well. Other drawbacks are that they are not integrated into the existing environment of a radiology department (connection with imaging modality; management of patient data and organizational data). Appli-

Manuscript received November 10, 1997; revised January 23, 1998.

U. Engelmann, A. Schröter, U. Bauer, O. Werner, M. Schwab, and H.-P. Meinzer are with Deutsches Krebsforschungszentrum, Abt. Medizinische und Biologische Informatik, D-69120 Heidelberg, Germany (e-mail: u.engelmann@dkfz-heidelberg.de).

H. Müller was with Deutsches Krebsforschungszentrum, Abt. Medizinische und Biologische Informatik, D-69120 Heidelberg, Germany. He is now with Daimler Benz Research and Technology North America, Portland, OR 97205 USA.

Publisher Item Identifier S 1089-7771(98)03560-2.

[1] CHILI is a registered trademark of the Steinbeis-Transfer Center for Medical Informatics, Heidelberg, Germany.

[2] Proshare is a trademark of Intel Corporation. InPerson is a trademark of Silicon Graphics Inc.

cation sharing systems have the drawback that the submission of a complete image series (up to 30 MB) over narrowband telephone lines, such as ISDN with two channels of 64 KB/s each, is too slow for efficient interactive teleconferences.

C. Teleradiology: Generation Zero

From our point of view, teleradiology systems can be divided into at least three different generations. Generation zero *cannot* be regarded as being true teleradiology systems, according to the definition of the ACR. These systems can only submit images to another site. Synchronized teleconferences are not possible. Nevertheless, more than 50 vendors at RSNA'96 claimed to have a teleradiology solution, although they could not present teleconferences.

D. First Generation

Among others, examples of first-generation teleradiology systems are KAMEDIN [3] and MEDICUS [4]. The development of both systems has been funded by the German Telecom. Both systems are able to submit images to another location and establish teleconferences with synchronized images and functions on both sides.

The ACR resolution also requires that the data transfer be conducted via the DICOM standard. This includes the DICOM file format and the communication protocol. The user should have access to the images via a patient database. MEDICUS is able to submit images to another location and establish teleconferences with synchronized images and functions on both sides. Furthermore, MEDICUS can read DICOM files and receive images via the DICOM protocol (as C-Store Provider). A patient database gives access to the available image data.

The main disadvantage of first-generation systems is that they emphasize the teleradiology component, but experience shows that a strong teleradiology solution must include more than this.

E. Second-Generation Teleradiology

Based on the experience of first-generation users, it is possible to specify a list of requirements for the next generation. Such requirements have been collected from different sources; the most important ones originate with users participating in the MEDICUS field test [8]. Additional requirements were obtained from a German study [12].

We started with the basic feature set of the MEDICUS system of the first generation. This cannot be repeated here, but specifics have been published by Engelmann *et al.* [4]. Additional system features of the second generation can be divided into several groups.

DICOM Functionality

- DICOM is the basic communication protocol and image file format for receiving images from the imaging modalities.
- Images can be sent to imaging modalities, film printers, and other devices via DICOM.

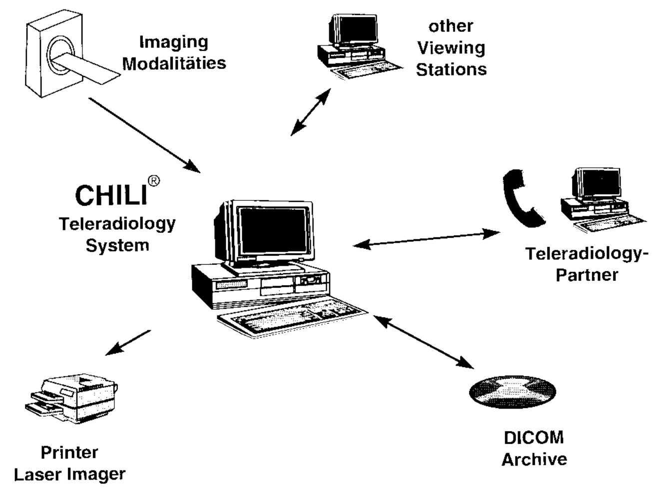

Fig. 1. Second-generation teleradiology system CHILI in the context of radiology.

- DICOM protocol should also be used for the distribution of images to other teleradiology systems.
- Query and Retrieve functions are available to get images from modalities and digital archives.
- Image printouts on film and paper are supported (via DICOM as well).

Viewing Functionality

- Second-generation system is based on a general purpose radiology image workstation that can be used for reporting and viewing images, is connected to imaging modalities, and has access to a digital image archive. Fig. 1 shows the system in the context of a radiology department.
- Ergonomic user interface is based on results obtained in human computer interface research. The interface supports both inexperienced beginners and skilled experts who use the system in their daily routine [11].
- Data and functions are synchronized during teleconferences. The communication partners cursor is also visible on the screen. Both users have full access to all viewing functions.
- Advanced review/viewing functionality, including image analysis and annotations with graphics, text, and sound are available.
- Basic image manipulation functions are interactive level/window functions, magnification, inversion of gray values, image rotation and flipping, and linear measurements.
- Series of two-dimensional (2-D) images can also be displayed as cine sequences.
- Modularity: Since different users have different needs, the systems should be modular in the sense that a user can configure (and pay for) only the software modules he/she needs.
- As much screen space as possible is available for images.
- Database interface is easy to use both for query/retrieval of local data on the workstation and for external data in digital archives or imaging modalities.

- The system is capable of displaying small-matrix images (CT, MRI, ultrasound, nuclear medicine, digital fluorography), large-matrix images (e.g., digitized radiographic films or computed radiography), and image sequences (e.g., cardiac image sequences).
- High-resolution images (e.g., digitized radiographic films or computed radiography) must be supported by both the software and the screen resolution.
- Different monitor options should be available to match the actual requirements of the application scenario.
- Monitors should offer sufficient luminance (at least 50-ft lamberts). Multiple monitor configurations should be available where necessary. A flexible concept allows the user to select the monitor that is appropriate to his actual needs (e.g., reporting, reviewing, presentation).
- Video capture: The system should be able to capture videos from connected video cameras or other video sources. It should be possible to capture and transmit video images during teleconferences. It is only necessary to capture still images. The transfer of live video images is not important for teleradiology [4], [12].

Patient Database

- Patient database includes at least patient name, identification number, date, type of examination, and type of images. These data are extracted from the DICOM files.
- Order of the data fields and the sorting order of the data should be customizable by the end user.
- Database should be based on the SQL standard to be able to use database management systems from different vendors. Support of the ODBC database standard, which is an emerging standard in the Microsoft world and in the World Wide Web, should also be considered.

General System Features

- Client/server solutions should prove possible in a local area network, where one workstation can act as a central server for data storage and distribution and a number of smaller clients can access the central server for viewing and teleconferences without prior image distribution to the conference partners.
- Multiple platforms: The system supports the UNIX world as well as the PC world (MS Windows, Windows 95, and Windows NT). Image transfer and teleconferences are possible across both worlds.
- Extensibility: New modules (plug-ins) can be added for additional software functions [e.g., dynamic MRI, 3-D reconstruction, etc.]. A developer toolkit allows the users (or other software vendors) to write their own plug-ins.
- Internationalization: The teleradiology systems of the second generation are customizable for different countries, with respect to languages, data representation, and specific cultural differences.
- Good user documentation is a key feature of a good software system. The European tecom requirements can serve as a good guideline for user documentation because they take into account international (ISO), national (ANSI, DIN), and industry standards for user documentation [13].

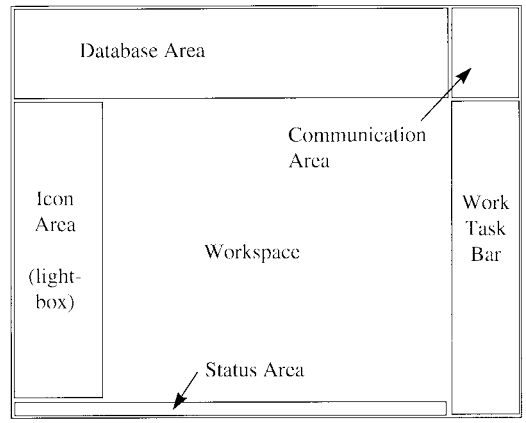

Fig. 2. Layout scheme of the GUI of CHILI.

Security

- Systems should provide network and software security protocols to protect the confidentiality of the patient images and data. National laws must be respected.
- DICOM does not fulfill all security needs. Initial discussions about security concerns have now begun in the ACR and the NEMA.
- Technical, educational, organizational, and software requirements must be taken into account when formulating security concepts. A good guideline in Europe is the Information Technology Security Evaluation Manual of the Commission of the European Union [5], [6]. An example of an already realized security concept has been developed and implemented as part of the MEDICUS project [7].

Future Challenges

- Software development process should be certified by the ISO 9000 standard to guarantee the quality of the software production process.
- Cross-System Communication: Future teleradiology systems should permit communication between systems from different vendors.
- Interfaces to RIS/HIS have to be realized (although the users of a German study indicate that it is less important to them [12]).

III. CHILI: SECOND-GENERATION SYSTEM

How far away are we from a running second-generation system? By mid-1996, the Steinbeis-Transfer Center for Medical Informatics began developing such a system, as described above, in cooperation with the German Cancer Research Center (see Fig. 1). System design and development were based on the concepts and experiences of the MEDICUS project. The requirements for the second-generation system have been carefully collected and integrated into the new concept. CHILI is a completely new implementation; the

Fig. 3. User interface of the second-generation teleradiology system CHILI.

data model has been changed to be as DICOM compliant as possible. The result is a modular architecture of components that can be integrated into packages for the specific needs of users.

Fig. 3 shows the GUI of CHILI. The different areas of the screen are explained in Fig. 2. The center of the interface is the workspace where the current data (e.g., images) are displayed. The upper left box is the flexible database area where patient, study, series, and modality data are presented. The order of the data fields and the order of the contents can be sorted in different ways with drag-and-drop functions by the user. The icon area (respectively, Lightbox) shows an overview of all data in the current data set (e.g., iconified images). These icons can be used to navigate in the data. The right-hand box is the work task bar, which is used to switch between work tasks (e.g., image display, preparation of a data transfer, system configuration). The lower area displays status messages like warnings and errors. The upper right area of the user interface is the communication area where the user can accept/deny an incoming teleconference request or activate a teleconference to a communication partner. This design is based on the results of research in cognitive psychology and a style guide for medical applications [11]. As a result, all areas always remain at the same position on the screen. Only the size of the different areas can be changed. This is important to adopt the layout to the current needs of the user. No pull-down menus are used, and the number of pop-up windows is avoided as much as possible. Thus, the user interface is very static and the user can easily remember where the different functions and data are located.

Realizing the future challenges requires a great deal of time and effort. Cross-system communications for teleconferences especially demand the participation and cooperation of many vendors and institutions. Existing standards must be extended. They are the subject of a work that is still in progress.

IV. Summary

A three-generation model of teleradiology has been introduced. The requirements for the second-generation system are discussed in detail. CHILI is a second-generation teleradiology system that meets most of the user requirements for a second-generation teleradiology system. It is an open and portable system. At the core of the system is a general radiological workstation that possesses additional functions for teleradiology. The system is fully DICOM oriented and is, in fact, more of a general radiological viewing station than a pure teleradiology system.

References

[1] American College of Radiology, ACR Standard for Teleradiology, Res. 21-1994; http://www.acr.org/standards.new/teleradiology_standard.html.

[2] American College of Radiology, National Electrical Manufacturers Association, "Digital imaging and communications in medicine (DICOM): Version 3.0." in ACR/NEMA Committee, Working Group, ACR/NEMA Standards Pub. PS3.

[3] H. Handels, C. Busch, J. Encarnacao, C. Hahn, V. Kühn, J. Miehe, S. Pöppl, E. Rinast, C. Roßmanith, F. Seibert, and A. Will, "KAMEDIN: A telemedicine system for computer supported cooperative work and remote image analysis in radiology," *Comput. Methods Program Biomed.*, vol. 52, pp. 175–183, 1997.

[4] U. Engelmann, A. Schröter, U. Baur, A. Schroeder, O. Werner, K. Wolsiffer, H. J. Baur, B. Göransson, E. Borälv, and H.-P. Meinzer, "Teleradiology system MEDICUS," in *CAR '96: Comput. Assist. Radiol., 10th Int. Symp. Exhibit.*,, H. U. Lemke, M. W. Vannier, K. Inamura, and A. G. Farman, Eds. Amsterdam, The Netherlands: Elsevier, pp. 537–542.

[5] Information Technology Security Evaluation Criteria, ITSEC, Brussels and Luxembourg, Belgium, 1991, DGXIII, ISBN 92-826-3004-8.

[6] Information Technology Security Evaluation Manual, ITSEM, Brussels and Luxembourg, Belgium, 1994, DGXIII, ISBN 92-826-7087-2.

[7] H. J. Baur, F. Saurbier, U. Engelmann, A. Schröter, U. Baur, and H. P. Meinzer, "Aspects of data security and privacy in teleradiology," in *CAR '96: Computer Assisted Radiology, 10th Int. Symp. Exhibit.*, H. U. Lemke, M. W. Vannier, K. Inamura, and A. G. Farman, Eds. Paris, France, and Amsterdam, The Netherlands: Elsevier, pp. 525–530.

[8] U. Engelmann, M. L. Bahner, A. Schröter, U. Baur, A. Schroeder, O. Werner, H. J. Baur, and H. P. Meinzer, "Practical and clinical experiences with a teleradiology system," in *Proc. EuroPACS'96 14th Int. Meeting*, S. Orphanoudakis, Ed. Hellas, Heraklion, Greece: Inst. Comput. Sci., Foundation Res. Technol., pp. 78–82.

[9] U. Engelmann, A. Schröter, U. Baur, O. Werner, M. Schwab, H. Müller, M. L. Bahner, and H. P. Meinzer, "The German teleradiology system MEDICUS—System description and experiences in a German field test, *Eur. J. Radiol.*, to be published.

[10] M. L. Bahner, U. Engelmann, H. P. Meinzer, and G. van Kaick, "Design necessities for future teleradiology systems—Conclusion from a field test," *Eur. J. Radiol.*, vol. 7, p. S17, 1997.

[11] E. Borälv, B. Göransson, E. Olsson, and B. Sandblad, "Usability and efficiency. The HELIOS approach to development of user interfaces," *Comput. Methods Programs Biomed.*, vol. 45 (Suppl.), pp. 47–64, 1994.

[12] M. Walz, R. Bolte, K. J. Lehmann, T. Hothorn, C. Brill, L. Hothorn, and M. Georgi, "ANARAD: Requirements to teleradiology from German users' point of view," in *CAR '97: Comput. Assist. Radiol., 11th Int. Symp. Exhibit.*, H. U. Lemke, K. Inamura, and M. W. Vannier, Eds. Berlin, Germany, and Amsterdam, The Netherlands: Elsevier.

[13] Hoffmann, Hoelscher, Erfolgreich beschreiben—Praxis des Technischen Redakteurs, VDE-Verlag GmbH, Berlin and Offenbach, Germany, ISBN 3-8007-1987-8.

Uwe Engelmann received the M.Sc. and Ph.D. degrees in medical informatics from the University of Heidelberg, Heidelberg, Germany, in 1983 and 1990, respectively. He received the certificate medical informatics from Gesellschaft fuer Informatik (GI) and Deutsche Gesellschaft fuer Medizinische Informatik, Biometrie und Epidemiologie (GMDS).

He was a Ph.D. Student at the German Cancer Research Center, Heidelberg, from 1983 to 1990, where he worked on medical imaging and artificial intelligence. From 1985 to 1986, he served as a Consultant to BMW, Munich, Germany. He was an Associate Professor at the Fachhochschule des Landes Rheinland-Pfalz, where he taught information theory and coding theory from 1984 to 1987. From 1986 to 1992, he was the CEO of his own company, Interactive Systems GmbH, which developed PC-based image analysis systems. Since 1991, he has been a Senior Research Scientist at the German Cancer Research Center, where he is the Head of the research group "clinical applications and tool." He has been Project Leader of several national and international projects in the fields of medical image analysis, artificial intelligence, software engineering, and telemedicine. Additionally, he is working as a Consultant in the field of teleradiology and is an Associate Professor for telemedicine with the medical faculty of the University of Heidelberg.

Dr. Engelmann received, along with his team, the German Medical Software Prize of the MEDICA e. V. for the teleradiology system MEDICUS and in 1997, the European Information Technology Prize of the European Commission (ESPRIT) and EuroCASE for the teleradiology system CHILI. He serves as a reviewer for the International Medical Informatics Association IMIA and the German Medical Informatics Association GMDS. He is a member of ACM, GMDS, GI, DRG, BVMI, and FGK.

Andre Schröter received the degree in informatics from the Mannheim University of Applied Sciences, Mannheim, Germany, in 1995.

He has been with the German Cancer Research Center, Heidelberg, Germany, since 1991. From 1991 to 1994, he worked on two European projects on distributed image processing components in object-oriented software engineering environments. He designed and developed the kernel components of two teleradiology systems: MEDICUS and CHILI. He is also working as a Consultant at the Steinbeis-Transfer Center for Medical Informatics, Heidelberg, in the field of teleradiology. His major research interests are client/server architectures for image processing, graphical user interfaces, medical image formats, communication protocols (DICOM), and telemedicine.

Mr. Schröter received, along with his team, the German Medical Software Prize of the MEDICA e. V. for the teleradiology system MEDICUS and in 1997, the European Information Technology Prize of the European Commission (ESPRIT) and EuroCASE for the teleradiology system CHILI.

Ulrike Baur received the M.Sc. degree in medical informatics from the University of Heidelberg, Heidelberg, Germany, in 1993.

She has been with the German Cancer Research Center, Heidelberg, since 1990. Until her M.Sc. thesis, she worked on two European projects, where she worked on compiler and parser generators and on middleware architecture for distributed image processing in an object-oriented software engineering environment. She has been a Research Scientist since 1994. She developed the middleware services and several kernel components of the teleradiology systems MEDICUS and CHILI. She is currently working on plug-in mechanisms for radiology workstations. Furthermore, she is working as a Consultant in the field of teleradiology.

Ms. Bauer received, along with the rest of her team, the German Medical Software Prize of the MEDICA e. V. for the teleradiology system MEDICUS and in 1997, the European Information Technology Prize of the European Commission (ESPRIT) and EuroCASE for the teleradiology system CHILI.

Oliver Werner received the M.Sc. degree in medical informatics from the University of Heidelberg, Heidelberg, Germany, in 1992.

He cofounded the PAIDOS software GmbH that developed a system for pediatric practice on behalf of the Professional Association of German Pediatricians. From 1992 to 1994, he supervised the development of the PAIDOS systems at DOCexpert, Bamberg, Germany. Since 1994, he has been a Ph.D. Candidate at the German Cancer Research Center, Heidelberg, where he performs research in the field of modeling and simulation of complex systems in biomedicine. He is currently developing a modeling environment for the intranet, which is implemented in Java. Beside his research activities, he is involved in the development and maintenance of databases for the EPIC study (European Prospective Investigation into Cancer and Nutrition). At the Steinbeis-Transfer Center for Medical Informatics, Heidelberg, he implements interfaces to diverse databases and DICOM services for the teleradiology systems MEDICUS and CHILI.

Mr. Werner received, along with his team, the German Medical Software Prize of the MEDICA e. V. for the teleradiology system MEDICUS and in 1997, the European Information Technology Prize of the European Commission (ESPRIT) and EuroCASE for the teleradiology system CHILI.

Markus Schwab received the M.Sc. degree in medical informatics from the University of Heidelberg, Heidelberg, Germany, in 1997.

He was with the Laboratory of Artificial Intelligence, Chambery, France, for six months, where he worked on a European research project on the evaluation of knowledge-based systems. Between 1995 and 1996, he was with the University of Applied Sciences, Heilbronn, Germany, on the analysis of ECG signals of heart transplant patients with wavelets and chaos algorithms. Since 1996, he has been a Researcher with the German Cancer Research Center, Heidelberg. He is also with the Steinbeis-Transfer Center for Medical Informatics, Heidelberg, where he is responsible for customer support of the teleradiology system CHILI.

Mr. Schwab received in 1997, along with his team, the European Information Technology Prize of the European Commission (ESPRIT) and EuroCASE for the teleradiology system CHILI.

Henning Müller received the M.Sc. degree in medical informatics from the University of Heidelberg, Heidelberg, Germany, in 1997.

He was with the Gesellschaft fuer Systemberatung im Gesundheitswesen from 1990 to 1997, where he worked on different research projects in the areas of hospital information systems and the economy of hospitals. Between 1995 and 1996, he was with the University of Applied Sciences, Heilbronn, Germany, where he worked on the analysis of ECG signals of heart transplant patients with wavelets and chaos algorithms. From 1996 to 1998, he was with the German Cancer Research Center, Heidelberg, where he finished his diploma thesis in 1997. He is analyzing the communication needs and developing different DICOM interfaces for a teleradiology system. He is now with Daimler Benz Research and Technology North America, Portland, OR, with a scholarship from the Carl Duisberg Society and the German Ministry of the Exterior. He is working with different communication protocols that are used in the car and truck business.

Hans-Peter Meinzer received the M.S. degree in physics and economics from University of Karlsruhe, Karlsruhe, Germany, in 1973 and Ph.D. degrees in medical computer science (formal languages) and habilitation (cell growth simulation) from the University of Heidelberg, Heidelberg, Germany, in 1983 and 1987, respectively.

He has been a Scientist at the German Cancer Research Center, Heidelberg, since 1974. Since 1983, he has directed a research team specializing in the 3-D visualization of 3-D tomographies. The team developed a ray tracing algorithm for medical 3-D data volumes. In this context, he works on neural nets, AI, human perception, cognitive texture analysis, morphology, and parallel computing concepts. His special interest lies in modeling and simulating tissues and tissue kinetics. He is also an Associate Professor at the University of Heidelberg, where he teaches medical informatics. Lastly, he founded in 1994 and now directs the Steinbeis-Transfer Center for Medical Informatics, Heidelberg, a software company specializing in telemedicine and teleradiology.

Dr. Meinzer was the recipient of scientific awards from the German Society of Heart Surgery in 1992, the German Society of Pattern Recognition in 1993, and the European Commission in 1997 (the European Information Technology Prize). He is a member of the Gesellschaft fuer Informatik (GI), Deutsche Gesellschaft fuer Medizinische Informatik, Biometrie und Epidemiologie (GMDS), ACM.