Transforming the Radiological Interpretation Process: The SCAR TRIP™ Initiative

Katherine P. Andriole* and the SCAR TRIP™ Subcommittee: Richard L. Morin[a], Ronald L. Arenson[*], John A. Carrino[b], Bradley J. Erickson[c], Steven C. Horii[d], David W. Piraino[e], Bruce I. Reiner[f], J. Anthony Seibert[g], Eliot L. Siegel[f]

*Department of Radiology, University of California at San Francisco, San Francisco, CA 94143; [a]Mayo Clinic Jacksonville, Jacksonville, FL 32224; [b]Brigham and Women's Hospital, Boston, MA 02115; [c]Mayo Clinic Rochester, Rochester, MN 55905; [d]University of Pennsylvania, Philadelphia, PA 19104; [e]Cleveland Clinic Foundation, Cleveland, OH 44195; [f]Baltimore VAMC, Baltimore, MD 21146; [g]University of California Davis, Sacramento, CA 95817

ABSTRACT

The Society for Computer Applications in Radiology (SCAR) Transforming the Radiological Interpretation Process (TRIP™) Initiative aims to spearhead research, education, and discovery of innovative solutions to address the problem of information and image data overload. The initiative will foster inter-disciplinary research on technological, environmental and human factors to better manage and exploit the massive amounts of data. TRIP™ will focus on the following basic objectives: improving the efficiency of interpretation of large data sets, improving the timeliness and effectiveness of communication, and decreasing medical errors. The ultimate goal of the initiative is to improve the quality and safety of patient care. Interdisciplinary research into several broad areas will be necessary to make progress in managing the ever-increasing volume of data. The six concepts involved include: human perception, image processing and computer-aided detection (CAD), visualization, navigation and usability, databases and integration, and evaluation and validation of methods and performance. The result of this transformation will affect several key processes in radiology, including image interpretation; communication of imaging results; workflow and efficiency within the health care enterprise; diagnostic accuracy and a reduction in medical errors; and, ultimately, the overall quality of care.

Keywords: Large data sets, radiological image interpretation paradigm

1. INTRODUCTION

1.1 The problem

The Society for Computer Applications in Radiology (SCAR) TRIP™ Initiative grew out of discussions at a SCAR Research and Development (R&D) Committee retreat on July 12, 2002. Members began examining the increasing problem of the number of images making up current medical studies, the number of studies associated with each patient, and the number of patients seen per day in current electronic radiology practices. The discussions concluded that a paradigm shift in the radiological interpretation process will be necessary to carry out medical imaging in the health care environments of the future. At this retreat, the Medical Image Interpretation Paradigm Shift Subcommittee was formed by the R&D Committee to examine this issue of information and image data overload, and to provide a forum for discussion as well as an organizational infrastructure to seek solutions to this impending crisis. At a second retreat, held in February of 2003, activities of the effort were refined, and the initiative was renamed Transforming the Radiological Interpretation Process (TRIP™).

The SCAR TRIP™ Initiative aims to spearhead research, education, and discovery of innovative solutions to address the problem of information and image data overload. The initiative will foster inter-disciplinary research on

Medical Imaging 2004: PACS and Imaging Informatics,
edited by Osman M. Ratib, H. K. Huang, Proceedings of SPIE Vol. 5371
(SPIE, Bellingham, WA, 2004) · 1605-7422/04/$15 · doi: 10.1117/12.543741

technological, environmental and human factors to better manage and exploit the massive amounts of data. TRIP™ will focus on the following basic objectives:

- Improving the efficiency of interpretation of large data sets;
- Improving the timeliness and effectiveness of communication; and
- Decreasing medical errors.

The ultimate goal of the initiative is to improve the quality and safety of patient care.

It is the fundamental belief of the SCAR leadership that the current impending crisis in image data overload provides not only a problematic challenge but a wonderful opportunity to change the radiological interpretation process, improving both the quality of patient care and the efficiency of future radiologists and their electronic practice. This document is intended to outline the historical background to today's information overload, assess the literature that addresses challenges involved in finding solutions, provide specific indications of areas in which these solutions may lie, and briefly describe SCAR's efforts at identifying both immediate and long-term answers to the most pressing questions that will face radiology in the coming decades.

1.2 Historical perspective

Image overload may be the single biggest challenge to effective, state-of-the-art practice in the delivery of consistent and well-planned radiological services in health care today. Although this appears to be a relatively recent phenomenon, resulting from the inter-section of computing power and rapidly developing clinical modalities in the 1980s and 1990s, the problem is not entirely new.

Those who see image management as a very recent difficulty err by more than a century. When Wilhelm Röntgen's announcement of the "amazing new ray that could see through living human flesh" was sent out across Europe and North America in the first weeks of 1896, physicists, physicians, and even amateur photographers began experimenting with ways to capture the results on permanent images. More quickly than any new technique then or since, roentgenology (later radiology) would become an established part of health care.

By 1898, many hospitals had fledgling x-ray departments, and specialized journals soon appeared to address topics of concern in the developing field. These included problems with referring physicians, expanding areas of focus within the body, new imaging techniques, and the difficulties of image management: the same topics that dominate today's radiology literature. These problems today, however, will require very different, innovative interdisciplinary imaging informatics solutions.

The advent of the microchip—both in imaging and information processing technologies—changed the landscape of medical imaging forever. The problems of mass and volume skyrocketed, with new technologies that could provide hundreds of views as easily as one. Today new computer-enabled technologies that can image anatomy and function down to a cellular level have blurred the boundaries among imaging disciplines and between radiology and other image-intensive fields such as cellular biology, biochemistry, and pathology.

An informal study of the number of images acquired in the Department of Radiology at the Mayo Clinic Jacksonville, FL, determined that roughly 1,500 images were generated and stored per day in 1994. In that same practice in 2002, an average of 16,000 images were acquired each day. By extrapolating these volumes to the year 2006 with a similar increase in the number of images per study, the estimates conclude that approximately 80,000 images will be acquired per day. Assuming a radiologist can view approximately one image per second, the number of images generated in the future will require 22.2 hours per day to interpret using today's practice strategies. Clearly an image interpretation paradigm shift will be necessary in order for radiologists to perform their work effectively, efficiently, and accurately.

The challenge is to develop a completely new paradigm for looking at information and image data overload. It is a challenge that will require creative thinkers from a number of fields, a synergistic effort that the Society for Computer Applications in Radiology is calling Transforming the Radiological Interpretation Process, or TRIP™.

2. LITERATURE REVIEW

A search of the recent literature was performed to assess the availability and quality of published materials on the effects of growing amounts of image data on interpretation, management, and the general delivery of timely radiological diagnoses, as well as to determine whether viable solutions to these challenges had been instituted or proposed. The results of the search were both disappointing and revealing in that the topic of growing amounts of image data was frequently discussed, but rarely accompanied by proposed solutions. A number of concepts stood out, however, pointing toward specific questions that will need to be addressed in finding 21st-century solutions to the coming crisis in medical image management. These broad topics include research in human perception of images, design of radiology workstations, and enhancing visualization through image processing.

2.1 Image perception

The interplay among the radiologist's eye, the inherent knowledge or context obtained through training and experience, the physical circumstances of the viewing, and the quality of the image have long been recognized as sources of tremendous variability in diagnostic image interpretation. In 1960, Tuddenham[1] summarized for the referring physician readership of the *New York State Medical Journal* a range of potential problems associated with variability in image perception and interpretation. By the late 1980s and into the 1990s, a number of observers recognized that newly introduced algorithms for contrast enhancement, edge sharpening, noise smoothing, and dynamic range manipulation could provide additional information that could augment the interpretation process[2–7].

Computerized enhancements were being incorporated into a range of imaging modalities. But the methods lacked consistency across modalities and among manufacturers, meaning that radiologists often faced a changing landscape that might or might not suit their actual clinical needs. More importantly, little forethought was given to precisely what properties of radiological images were most useful in their interpretation or how these properties could be enhanced to improve diagnostic accuracy. How, for example, might color be added without distorting anatomical features? With these uncertainties left unaddressed, many radiologists gave a less-than-enthusiastic reception to image enhancement innovations.

Enthusiasts who had hoped that artificial intelligence would provide computerized consultants to assist with difficult diagnostic problems and computer vision systems to detect abnormalities in complex images were disappointed at the lack of advancement or acceptance at the clinical level. A few individuals proposed the development of less demanding computer aids that build on both human and machine capabilities[8–9].

In the mid-1990s, Zonneveld and colleagues published a series of articles that surveyed the past decade's developments in three-dimensional imaging[10–12], noting that what was at the time primarily a research tool was sure to gain clinical acceptance. The group identified three key areas that should be assessed before the number of images and the variety of ways to display them became unmanageable. The areas included image analysis, surgical navigation, and stereoscopic and volumetric display.

In 1995, H.L. Kundel[13] proposed that the only solution to the snowballing problems of image perception in a changing digital landscape was to think proactively about the information needed to find a solution. He suggested five priorities for research in the area:

- Develop psychophysical models for the detection of abnormalities in medical images;
- Improve understanding of the mechanisms of perception as they apply to medical images;
- Develop aids for enhancing perception by use of approaches that provide interactions between vision and display;
- Study perceptually acceptable alternatives to sequential slices for viewing images from cross-sectional imaging examinations; and
- Perform methodological research aimed at improving the evaluation of medical imaging systems, and alternatives to standard methods for measuring observer performance.

Although these and similar recommendations have been widely discussed[14–15] and a number of research studies have been completed, few researchers have gone on to propose methods by which the data derived can be used to support new approaches to digital image perception.

E.A. Krupinski has written extensively on the topic of image perception as it is affected and enhanced by digital image acquisition and associated computer driven softcopy displays[16–18]. Her research into the topic has emphasized the need for perceptually based standards for image quality based on quantifiable data that define the optimal presentation parameters (e.g., size, luminance levels, and spatial and contrast resolution). Her work has also confirmed some of the problems inherent in current computerized images, including decreased viewing time with specially processed images and decreased use of functions such as window and level, zoom, and other tools. She has pointed out that although image enhancement and computer-aided diagnosis show great promise, they must be accompanied by experience-based standards and user-targeted innovations, such as linearized perception models, that will improve workflow and increase diagnostic accuracy.

2.2 Workstation design

One way of addressing the challenges posed by image overload is to look at the physical interface between the radiologist and the image and associated data, that is, the workstation. A considerable body of literature exists, much of it based on the experience of specific groups of radiologists in academic and private practice settings. In 1990, Beard[19] laid the groundwork for many ensuing discussions of workstation design when he described a study performed at the University of North Carolina. This study directly addressed issues of navigation, evaluation techniques, and the physical displays themselves.

In the same year, Arenson and colleagues considered the psychophysics, physics, and engineering of the radiology workstation[20] with a focus on the fundamental perception of contrast in detail and on human perception of findings in medical images. The authors also discussed possible effects of workstation variability on physician workflow and imaging practice. Other authors have reviewed the existing literature and studies on interactive workstation configuration and assessed the general requirements for spatial resolution, contrast resolution, image processing, user software, and architecture for a number of modalities[21].

2.3 Image processing

The use of digital image processing to optimize the appearance of images has received extensive coverage in the literature, particularly as applied to images in other fields outside of medicine. A number of studies applied specifically to medical imaging evaluated the accuracy of interpretation using images processed by different irreversible compression techniques. Although several of these point to specific solutions, such as wavelet compression to reduce file size and optimize data delivery and storage, most also agree that the central problem of radiology data volume is that it continues to grow faster than storage space and network speed capabilities[22–23], and that ultimately image processing and analysis will be needed to optimize the delivery and appearance of the image for medical diagnosis.

In addition, increasing image detail and contrast at acquisition is reaching a point of diminishing returns. Many radiological abnormalities are in fact recorded on the image with today's technologies but are not perceived by the observer. Processing must be applied to optimize recognition of these abnormalities. Further, most medical imaging technologies today take into account only one of a variety of attributes by which objects can be recognized in an image, attributes such as gray scale, color, texture, relative motion, and depth. Image displays using multiple simultaneous attributes should be evaluated for their potential effectiveness.

2.4 Summary

This review of the literature continues to raise several philosophical questions that ultimately will impact the future practice of medical imaging. How will the nature of the human–machine interface change in order to address the coming crisis in image data overload? Will more routine chores be relinquished to the computer, allowing the physician to perform the more difficult tasks that require judgment and comprehension? Might the radiologist's workstation of the future incorporate simple computer-based aids to help the radiologist read more effectively and better manage the increasingly complex choices of imaging parameters? Will workstations support adequate monitoring and supervision of machine reading? How will imaging informatics concepts be incorporated to support the radiologist's expanding functions in teaching and research? Radiology needs answers to these questions to deal effectively with the coming crisis.

3. INTERDISCIPLINARY RESEARCH

SCAR aims to foster interdisciplinary informatics research in the areas of technological, environmental, and human factors that impact on medical imaging and the crisis of data overload. Interdisciplinary research into several broad areas will be necessary to make progress in managing the ever-increasing volume of data. The six concepts involved include: human perception, image processing and computer-aided detection (CAD), visualization, navigation and usability, databases and integration, and evaluation and validation of methods and performance.

3.1 Human perception

Research in human perception will be required to develop a standard for image quality as well as for display standards. Objective methodologies for optimal image presentation and criteria from which to determine optimal presentation parameters will need to be developed based on diagnostic performance measures. Psycho-physical models for detection of abnormalities will need to be defined by understanding what is desired by an image observer, what properties of radiological images are most useful in their interpretation, and how these properties can be enhanced to improve accuracy of interpretation.

3.2 Image processing and computer-aided detection

Research in image processing and computer-aided detection will be needed to develop computer aids for feature perception and to design the radiology workstation of the future, focusing on the human–machine interface. Future radiology display applications will have to implement computer aids, such as cueing, overlays, and annotation, into a broadly supportive workstation. Assists, including decision support, simple reminder techniques to help avert errors of omission, data mining capabilities, and access to reference libraries, will be incorporated. Human–machine systems for image-based diagnosis will need to take advantage of both human and machine capabilities, creating a system which as a whole will be greater than the sum of its parts.

3.3 Visualization

Medical data visualization has been gradually transformed with the advent of digital imaging and the maturation of computer tools. Medical images were originally displayed in static form on film. This process migrated to dynamic display with softcopy viewing of digital images. Image manipulation, including modification of contrast and brightness, magnification, and different presentation formats, became possible. Interpretation of cross-sectional modalities evolved from viewing images tiled across the monitor, to stack or cine modes, to linked stack mode for 3D correspondence, all of which have now become routine visualization modes. Newer visualization techniques include multi-modality image fusion, maximum intensity projections, multiplanar reconstructions, 3D surface and volume renderings, and virtual reality representations. Exploration of new visualization techniques, perhaps adapted from other fields such as the entertainment industry, could prove useful in medical imaging.

3.4 Navigation and usability

Intuitive easy-to-use tools for navigation through medical image data sets may include increasing use of 3D and motion, virtual reality fly-throughs, and hand–eye cueing instruments. Hand-held devices will become more widespread for more efficient point-of-care delivery of information. Context-matching and voice- activated tools may also be further developed for the clinical arena.

3.5 Databases and integration

Advances in databases and integration will be essential and may require open standards, continued evolution of the American College of Radiology–National Electrical Manufacturers Association Digital Imaging and Communications in Medicine standard, and increased adoption of the framework Integrating the Healthcare Enterprise (IHE) in imaging systems. Greater acceptance of IHE concepts will facilitate the integration of hospital and radiology information systems with picture archiving and communication systems (PACS) as well as speech recognition systems. Real-time image processing at the PACS display and Web-based systems will be possible through better integration and database richness.

3.6 Evaluation and validation

Research in evaluation and validation will involve developing objective methodologies for radiological imaging as well as standard datasets for testing, comparison and collaborative research.

For progress in the transformation of the radiological interpretation process to be made, the interplay of concepts from each of the aforementioned areas of research will need to be explored. The result of this transformation will affect several key processes in radiology, including image interpretation; communication of imaging results; workflow and efficiency within the health care enterprise; diagnostic accuracy and a reduction in medical errors; and, ultimately, the overall quality of care.

4. Actions

In an arena in which everyone agrees a crisis is approaching, SCAR leadership and members identified specific areas in which the Society will focus its efforts:

Defining the problem: Little data is available on the volume of images read by a “typical” imaging specialist, on the specific challenges that growing image loads bring to different modalities and subspecialities, or on likely changes in the near future.

Identifying desirable outcomes: Perhaps the greatest deficiency in dealing with computerized imaging has been the tendency of practitioners to react on an ad hoc basis to innovations rather than working collaboratively on techniques and tools that will provide useful and usable solutions to everyday clinical problems.

Building effective bridges among participants in digital imaging: End-users in radiology have been separated from re-searchers, industry, and from those in other medical and nonmedical fields who are faced with similar data overload challenges.

Sponsoring and encouraging research that provides durable solutions: Only research that arises from a solid understanding of long-term needs of radiologists, patients, and information systems can hope to provide durable solutions to the coming crisis in radiology.

Communicating urgent issues and new results: No single information source currently exists in which the wide, multidisciplinary audience interested in these issues can communicate.

Each of these areas will lead to specific action items to be identified in collaboration with other interested organizations and disciplines.

REFERENCES

1. Tuddenham WJ. Visual problems of roentgen interpretation. *N Y State J Medicine.* 1960;60:1234–1238.
2. Hendee WR, Wells PN. Visual perception as an opportunity for radiologic research. *Invesigative Radiology.* 1989; 24:575–576.
3. Cooper LA. Understanding complex images: perspectives from visual cognition. *Invesigative Radiology*. 1991;26:765–768.
4. MacCormac ER. Images: cultural, perceptual and computational. *Invesigative Radiology.* 1989;24:331–333.
5. Vannier MW, Rickman D. Multispectral and color-aided displays. *Invesigative Radiology*. 1989;24:88–91.
6. Seltzer SE, Cavanagh P, Judy PF, Swensson RG, Scarff L, Monsky W. Enhanced displays of medical images: evaluation of the effectiveness of color, motion, and contour for detecting and localizing liver lesions. *Academic Radiology*. 1995;2:748–755.
7. Vizy KN. The roles of film in an increasingly computerized world. *Invesigative Radiology*. 1989;24:503–506.
8. Ackerman L. Toward automated image analysis: Future possibilities and historical perspective. *Radiology Clinics of North America.* 1986;24:79–85.
9. Picket RM. Person-machine systems for image-based diagnosis. *Invesigative Radiology*. 1988;23:394-395.
10. Hemmy DC, Sonneveld FW, Lobregt S, Fukuta K. A decade of clinical three-dimensional imaging: A review. Part l. Historical development. *Invesigative Radiology.* 1994;29:489–496.

11. Zonneveld FW, Fukuta K. A decade of clinical three-dimensional imaging: A review. Part 2: Clinical applications. *Invesigative Radiology.* 1994;29:574–589.
12. Zonneveld FW. A decade of clinical dimensional imaging: A review. Part 3: Image analysis and interaction, display options, and physical models. *Invesigative Radiology.* 1994;29:716–725.
13. Kundel HL. Medical image perception. *Academic Radiology*. 1995;2(suppl 2):S108–S110.
14. Burgess A. Image quality, the ideal observer, and human performance of radiologic decision tasks. *Academic Radiology*. 1995;2:522–526.
15. Wang J, Langer S. A brief review of human perception factors in digital displays for picture archiving and communications systems. *Journal of Digital Imaging.* 1997;10:158–168.
16. Krupinski EA, Kundel HL, Judy PF, Nodine CF. Key issues for image perception research. *Radiology*. 1998;209:611–612.
17. Krupinski EA. Importance of perception research in medical imaging. *Radiation Medicine.* 2000;18:329–334.
18. Krupinski EA, Radvany M, Levy M, et al. Enhanced visualization processing: effect on workflow. *Academic Radiology*. 2001;8:1127–1133.
19. Beard D. Designing a radiology work-station: a focus on navigation during the interpretation task. *Journal of Digital Imaging.* 1990;3:152–163.
20. Arenson RL, Chakraborty DP, Seshadri SB, Kundel HL. The digital imaging workstation. *Radiology.* 1990;176:315–330.
21. Dwyer SJ III. Work station for soft copy reading. *Applied Radiology*. 1998; August.
22. Lee H, Frank MS, Rowberg AH, Choi HS, Kim Y. A new method for computed tomography image compression using adjacent slice data. *Invesigative Radiology*. 1993:28:678–685.
23. Erickson BJ, Manduca A, Palisson P, et al. Wavelet compression of medical images. *Radiology.* 1998;206:599–607.