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Illustrative Visualization for Medical Training

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Abstract

A system is presented that produces images that simulate pictorial representations for both scientific and biomedical visualization. It combines traditional and novel volume illustration techniques. We present examples to distill representational techniques for both creative exploration and emphatic presentation for clarity. More specifically, we present adaptations of these techniques for interactive simulation sessions being developed in a concurrent project for resident training in temporal bone dissection simulation. The goal of this effort is to evaluate the use of emphatic rendering to guide the user in an interactive session and to facilitate the learning of complex biomedical information, including structural, functional, and procedural information.

Categories and Subject Descriptors (according to ACM CCS): J.3 [Computer Applications]: Life and Medical Sciences

> "Culture is the epidemiology of mental representations: the spread of ideas and practices from person to person. " - Dan Sperber Cultural anthropologist [Pin03]

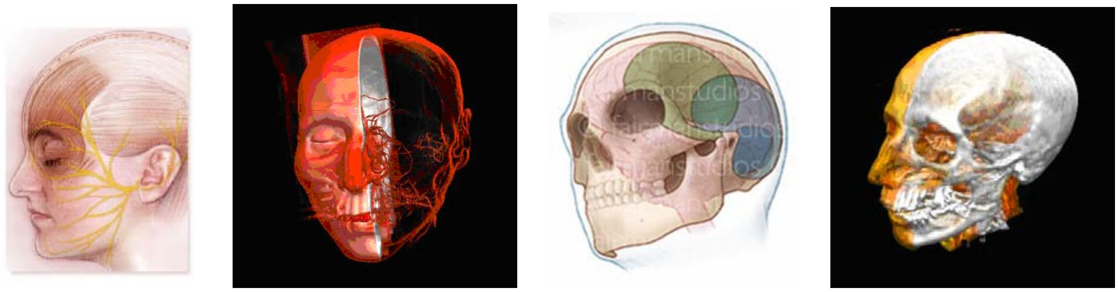
1. Illustrative Medical Visualization

The main goal of medical illustration, as that of visualization and rendering is to *effectively* convey information to the viewer. Computer-generated illustrative medical visualization is a powerful tool that can be applied for education and training of allied, nursing, and medical students, as well as surgical residents. This tool harnesses the power of traditional illustration techniques [Wol58, Hod03] and can be applied to actual patient data, instead of a canonical medical dataset. Patient specific data sets provide actual case studies in pathology and phenotypical variance. They are more relevant to clinical and research pursuits than paragons, and clinically can be exploited to demonstrate diagnosis and treatment options for patients and their families.

The focus of our research in illustrative volume visualization is not to replicate traditional media and techniques of medical illustrators, but to provide a new, extended tool set for the illustrator to effectively create informative illustrations from typical clinical data acquisitions, such as MR, CT, and PET datasets. For instance, the illustrations in Figure 1 show depictions of the human head acquired from CT that employ techniques not easily used in traditional illustration methods. By incorporating these techniques into an interactive visualization system, we can also allow the interactive variation of style and presentation of information during a training or exploration session, adjusting the complexity of the presentation to the expertise and experience of the user [BSSW01, SDS*05].

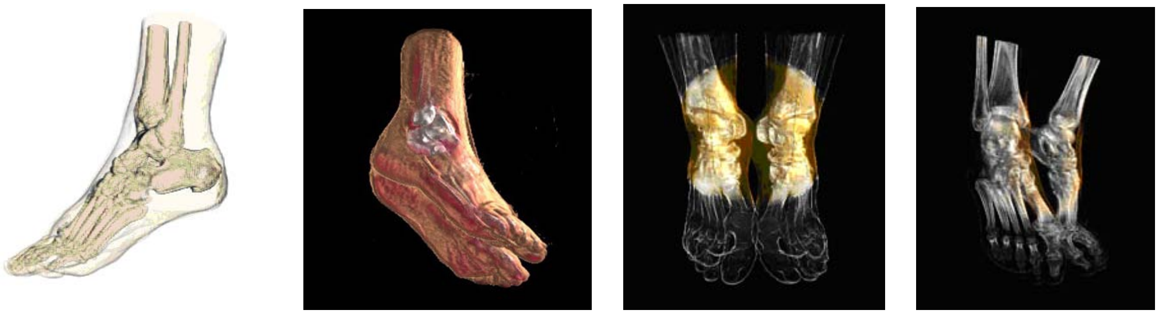
2. User Variance

We have developed an interactive illustrative volume visualization system that utilizes principles from perception and illustration to facilitate the emphasis and de-emphasis of information from a medical dataset based on the application and the user's expertise and perceptual preferences [SE03, SES05]. Our system easily allows one to focus or highlight information, through lighting, color, complexity, and subjugate contextual detail. Examples are shown in Figure 2. Sketching and silhouetting are used in the contextual regions to provide references that facilitate the orientation of the viewer. We utilize variances in multiple attributes and distributed regions to emphasize or de-emphasize form, using a repertoire of volume rendering enhancements, such as



(a) (b) (c) (d)

Figure 1: *Traditional medical illustrations of (a) the various approaches to forehead lifts, facial anatomy and (c) the anatomy of the cranial base with specific locations for cranial base surgery. Illustrations printed with permission: Copyright Fairman Studios, LLC 2005. Two illustrative renderings (b, d) of a CT head dataset showing the variety of new illustrative techniques that are possible with illustrative volume visualization. (b) Shows the sinuses and skin outlined on the right portion of the image, while (d) shows the skin rendered on the left half and the bone rendered on the right half of the head.*



(a) (b) (c) (d)

Figure 2: *Illustrative renderings for anatomical explanation and surgery simulation: (a) shows a more traditional anatomy illustration of a foot CT dataset, while (b) shows a subjective surgical view of the tarsal joint, with (c) and (d) highlighting the same dataset through the use of focus of attention and illustrative sketching.*

stipples, lines, continuous shading, as well as illumination and contrast.

This variance of presentation is a key advantage of our interactive illustrative visualization system. The appropriate presentation of information varies based on the expertise of the user and their preference for processing information (e.g., form dominant). Perceptually, we are not all wired the same. Some people are form dominant, some color dominant, some movement dominant, some with high proficiencies in all three, say, and some with low in all three, and every infinite possibility in-between. The issue is relevant to aesthetics. If we are hard wired for color dominance, then it is highly probable that we will find imagery that is focused in color pleasing. That is not to say we cannot appreciate form. Therefore, this approach uses the trainee's level of expertise as a basis for the level of representation, also referred to in this paper as motif classification. Figure 4 shows three levels of representation of micro CT data used in our temporal bone surgery simulator for novice (left two images), intermediate (middle image), and expert training (right image).

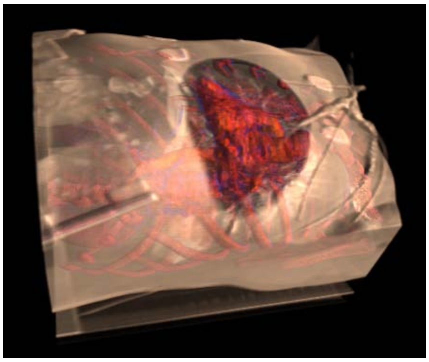


Figure 3: *Illustrative renderings for anatomical explanation and surgery simulation for a cardiac surgical view of an abdominal CT dataset.*

Figure 4: Left to right*: one novice, one intermediate, and one expert visualization for temporal bone surgery simulation.*

Novices are frequently overwhelmed by the quantity and complexity of data presented. Therefore, for novice surgery simulation, a zone of interest is placed in the surgery target area (Figure 5). We use a silhouetted context for subjugation of details outside of the zone, while an illustrative rendering with color cues is used inside the zone, as shown in Figure 2. In contrast, an expert has the necessary experience to subjugate the data details that provide context and can quickly focus on the specific portion of the data and relevant structures. Thus, for expert surgery simulation, we provide more detailed rendering with the selective choice of color and illumination enhancements for structure identification (Figures 3, 4, 6). However, even if an expert is introduced to new information (outside of their own expertise), they may need to start at either the schematic or intermediate level to facilitate integration into their mental representation of the regional anatomy. Therefore, we also need the ability to switch from novice to intermediate to expert levels of representation (Figure 6).

3. Some Guiding Principles for Designing A Useful System

In addition to accommodating user variance into the system design, good aesthetics and design are crucial for creating a system that is effective and that people will use. As Norman [Nor93] points out, "Attractive things work better." To make something attractive, Wooldridge and Jenkinson [WJ04] suggest that reducing the information presented leads to clarity, that visual complexity should be limited, when appropriate, and that visual elegance is achieved from iterative development and refinement.

Creating an effective system with a natural user interface can be achieved by following principles for effective visual communication based on cognitive psychology and human visual perception. Several useful principles proposed by Norman [Nor93] and Tversky [TMB02] that we have used in designing our system for medical training include the following:

- **Appropriateness principle** [Nor93] - The visual representation should provide neither more nor less information than what is needed for the task at hand. This is in agreement with the views of Wooldridge and Jenkinson that additional information may be distracting and make the user's task more difficult.
- **Naturalness principle** [Nor93] - Experiential cognition is most effective when the properties of the visual representation most closely match the information being represented. This principle supports the idea that new visual metaphors and representations are only useful when

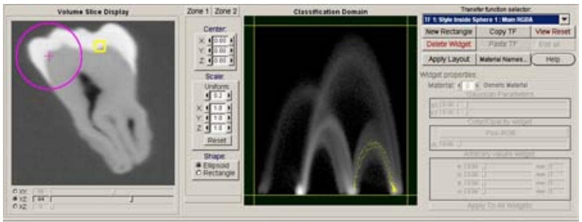


Figure 5: *Part of the expert-level system interface- Left side shows the cross-section window with the zone of interest (purple circle) and a probe (yellow square). Right side shows the low-level interface with transfer function editor with a map of the classification domain and widget controls. The classification domain map shows the probing result (yellow dots).*

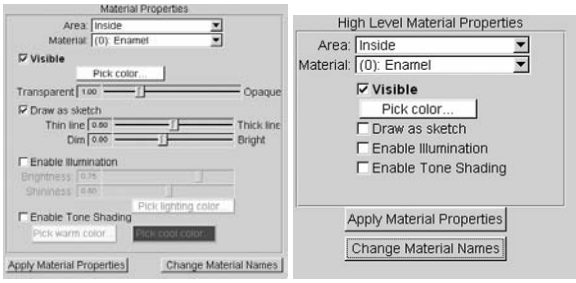


Figure 6: *The mid-level (left) and high-level (right) system interfaces.*

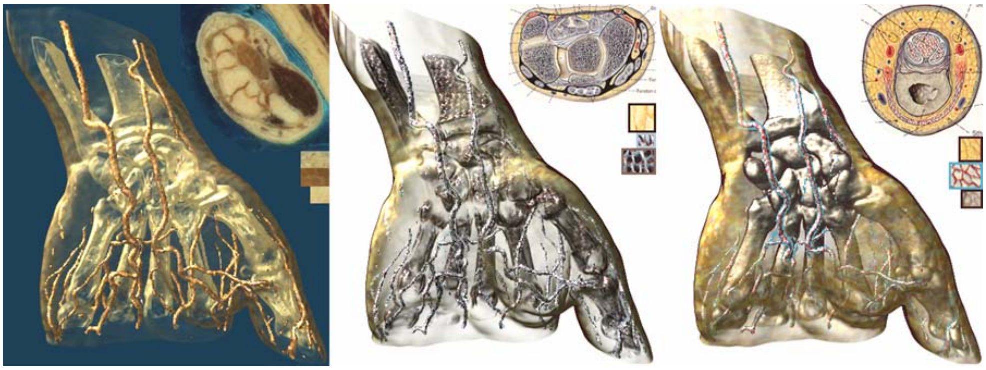


Figure 7: *Example-based volume illustration of a hand CT dataset, where the color and texture examples are shown in the upper right portion of each image. (a) used a photographic slice of the visible man as the input texture, whereas (b) and (c) use two different medical illustrations as their source for color and texture.*

they match the user's cognitive model of the information. Purely artificial visual metaphors can actually hinder understanding, making the system difficult to use. As described in the next section, we have found that even the choice of labels on menus affect the naturalness of the system to various users, which is why we have developed different interfaces and menus for different classes of users.

- **Matching principle** [Nor93] - Representations of information are most effective when they match the task to be performed by the user. Effective visual representations should present affordances suggestive of the appropriate action. This very basic principle of user interaction greatly improves the acceptance and use of the system.
- **Principle of Congruence** [TMB02]- The structure and content of a visualization should correspond to the structure and content of the desired mental representation. Therefore, in our system we try to ensure that the visual representation of the data represents the important medical domain and task information.
- **Principle of Apprehension** [TMB02]- The structure and content of a visualization should be readily and accurately perceived and comprehended. We have used this principle to guide our adaptable system design to vary the visual representation based on the user's expertise and task.

4. Interface Requirements

For adoption and use of a visualization and training system, it is crucial that the system is interactive and easy to use. For our applications, the system needs to generate images at 5 (anatomical education and explanation) to 60 frames per second (stereoscopic surgical simulation) to maintain the interactivity requirements of the task.

For actual deployment of our system, we also need to provide appropriate interfaces for three classes of users. Therefore, the interface incorporates three levels of interaction: an expert level, a mid-level, and a high-level. The expert user-level is for the software developers, experienced illustrators, and system builders. This level allows access to all controls used to generate the styles of the visual rendering in terms of data characteristics (values, gradients, second directional derivatives) and spatial characteristics (orientation, specification of focus region). This level (and the mid-level) also allows creation of illustration motifs and adjustment to the high-level interface. The mid-level interface is for illustrators and experienced end-users that want to make adjustments once they understand the controls. This interface provides higher-level, more conceptual menus with labels that are more appropriate for an illustrator or technically-adept medical professional. The high-level interface is designed for the end user, and in our current application focus, it would be for medical students, surgeons, and surgical residents. This interface mainly allows the change of simple sliders to adjust for inter-patient dataset variation and user personal preferences in depiction. Finally, for the simplest specification, the user can simply load predefined motifs (e.g., expert temporal bone surgical style).

5. Task and User Adaptation

Our illustration motifs are designed to allow the variation in presentation based on both the user and the task. For anatomical education (e.g., Figure 2 (a-c)), we provide the traditional subjective view of the data and allow the rendering style to simulate traditional anatomical text renderings (Figure 2(a)) or to provide illustrative renderings that focus on the primary element of interest (e.g., the tarsal joint in Figure 2 (b) and (c)) using focus plus context techniques where we change the rendering style to capture the viewer's attentive focus to the appropriate location, while providing enough anatomical context for understanding. Figure 2(d) shows an example of a surgical motif for the same foot dataset, where a subjective "surgeon's eye" view of the data is used and the rendering style is more realistic, although enhancements such as making the skin semi-transparent can help in surgical training, as in Figures 2 and 3. This task adaptability is crucial to provide the most effective presentation of information.

As mentioned previously, we also provide variance in rendering to accommodate for the user's visual dominance and experience level, as illustrated in Figure 3. The addition of structural cognitive aids into the rendering to clarify confusing structures, as shown in Figures 2 and 4 for novices can increase their learning. Removing visual clutter and enhancing the rendering to focus visual attention is also useful for novice users. In our system, we allow the setting of various rendering styles according to the user expertise to be used in the training process and will allow the blending between levels to provide a seamless training process.

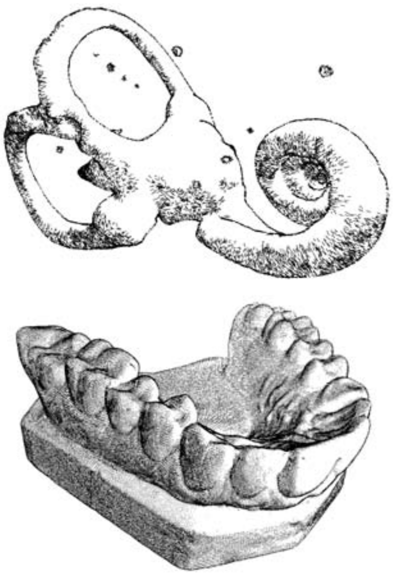


Figure 8: *Inner ear and dental arcade rendered with line and stipple marks, respectively [SFWS03, SSB04].*

6. Our Illustration Goals

One goal of our work is not to simply replicate the techniques used by medical illustrators but to create a new toolkit for illustrators to easily and effectively use for visual communication. By incorporating general illustration principles and styles and interfaces that are designed to be used by illustrators, we can provide a powerful new tool that has unique advantages compared to other illustration media. Our system's goal is not to just replicate their styles but to also incorporate their aesthetic and their techniques into an appropriate, usable system.

We are continuing to extend our system capabilities and have recently explored developing techniques to semi-automatically adapt the colors/textures of a traditional illustration to patient datasets (e.g., MR and CT) [LE05]. Figure 7 shows an example of applying colors and textures from the Visible Human photographic dataset (a) and two different medical illustrations of a hand (b and c) to a segmented hand dataset. These examples show that some basic characteristics of illustrations can be semi-automatically transferred to volume datasets to increase the richness and set the style of the data presentation.

7. Implications and Challenges: From Universal to Conventional to Personal Aesthetics

In addressing the question of whether or not aesthetics are personal or universal [Ren88], we would claim that they are both. Natural settings, such as sunsets are universally appealing due to subtle cues of detailed form, coloration, and movement. We all share, for the most part, similar circuitry that allows us to appreciate the beauty of a sunset. More conventional aesthetics, such as images created with stipple or line, were driven by collective techniques designed for print media (see Figure 8). And then there are our own personal aesthetics, such as how we decorate our bodies, offices, and dwellings, especially with belongings that have personal or "sentimental" value. Most importantly, our personal aesthetics encompass imagery that we are drawn to, that we seek out, and that we create. Our use of imagery, appropriated or self-made, helps express our identity, including how we see the world. These personal aesthetics can be "adopted" by others, and emerge again as conventional aesthetics.

Albeit our primary interest is the pragmatic issue of whether or not information is clearly communicated to the user, obviously the quality of our images is also important. Images that are not interesting to look at do not engage the viewer, and thus are antithetical to learning. By adopting approaches that follow basic principles of human perception, such as selective use of contrast, symmetry (see Figure 2), along with cueing the user's focus with brightness, color, complexity, we can follow a more general, or universal aesthetic. However, by allowing titration of the image qualities in subtle ways to the viewer, we allow a more precise, personal aesthetic to evolve.

These personal aesthetics have subtle variances from both genetic and environmental influences that are manifest in perceptual levels such as form dominance and color dominance. Furthermore, genetics and experience play a modulating role on the conceptual processes. Where basic perceptional systems elucidate what and where, conceptual systems modulate these systems and impart who, how and why. For instance, a religious drawing, albeit a simple line sketch, may hold immense meaning and context for an individual of that faith. Context, imparted from associative processing is essential to how representations are used.

As the techniques for manipulation of NPR images evolve, ultimately, our goal is to allow the user control over how the information is presented that makes the most sense to them at the time they are learning the information. Clearly our "tastes" or "aesthetics" change over time with context, especially as associative cortical regions impart subtle emphases as the user moves from perceptual learning (what and where); to the integration of what is there, where it is; towards the more conceptual, towards what does the structure do, what is its role in the system, and how does its configuration affect its function. Ultimately it would be advantageous to employ NPR techniques to allow user's to synthesize information, such as creating multimedia, into presentations that demonstrate their comprehension of subject matter. By allowing the user to manipulate the emphasis and deemphasis of information, it would provide a window on how the user is assimilating the information and allow us a better window to judge the more subtle levels of comprehension as they increase their expertise. This would serve two purposes: 1) to identify advanced comprehension, and thus challenge the individual, or 2) more precisely define where the individual is confused, and thus more appropriately intercede to bring them to their full potential.

8. Conclusion

As reality is a construct of the brain, the shared reality we experience is the result of equivalencies in genetic makeup, and shared conventional schema for representations. In our shared perceptions and conceptualizations, the way we "see" the world represents the brain's way of creating representations from our existence that are meaningful and assist in sense making, and most importantly, are useful in communication. By creating imagery that mimics the way we see, we may augment the assimilation of new information. By developing referents that build on natural representations and shared perceptual experiences, we may be facilitating the sharing of information across disciplines, in a time where interdisciplinary research and investigations are critical to understanding rich and complex phenomena.

However, genetic makeup and experience is congruent only to a degree. Diversity is a powerful instrument of change, a mechanism for both collective and individual growth. By supporting and nurturing cognitive diversity through more advanced visualization techniques, we support the ability to see the world in new ways, not in how we perceive the world, but more importantly, in the way in which we think about the world. Emerging techniques in NPR provide methods by which to communicate information both efficiently and effectively, as well as supporting and nurturing cognitive diversity.

9. Future Directions

There are numerous issues directly related to our research that should be explored further to understand the value of applying illustrative visualization techniques in medicine.

9.1. Traditional illustration

Various levels of representation, from abstract to schematic to realistic, have been exploited for millennia to facilitate the transfer of information from one individual to another. Artists, from the earliest representations that emerged in the Aurignacian period [Whi89] to today, have exploited perceptual phenomenon through their astute applications in various media that elicit cues similar to those found in direct observation of nature.

The real power in the traditional arts and illustration came from their subtle understanding of how to effectively manipulate the media to create subtle cues to represent (abstract or realistic) and include ways to emphasize or de-emphasize information to effectively communicate various messages to their viewer.

9.2. Computer-generated medical illustration

The value of computer generated medical illustration is manifold. Through direct volume-volume rendering of patient specific data, actual case examples of phenotypical variation in anatomy as well as pathological variations can be presented. These data are more salient and relevant to clinical research and medical education. The value in patient education when employed to convey diagnostic and treatment plans to patients and/or their families is self-evident. Though the integration of NPR techniques, complexity inherent in multimodal image acquisitions, i.e., CT, MT, PET, etc, is easily reduced. This complexity would be extremely difficult to reduce through traditional illustrative techniques.

The combination of direct volume rendering and NPR techniques provide a rich and varied repertoire of traditional illustration techniques for use in various biomedical simulation and training scenarios.

9.3. Limitations of NPR systems

Most NPR systems are not flexible enough to allow informed presentation to the appropriate audience. These systems must support rapid iteration, so that various imaging representations can be tried: (a) rapid selection of region of interests, Euclidean, and irregular, (b) rapid lighting, (c) importing segmented systems. This is happening both through the development and maturation of "Interactive NPR" systems [Sch94] (traditional renderings produced partly by the system and partly by the user), as well as by technological developments such as the expansive capabilities of GPU's.

We do not advocate that an illustrator is the sole arbitrator of visual literacy and aesthetics. We would like to see the systems allow for a selection of styles and rapidly allow one to say "Take my data and make it look like this example". Our goal isn't to replicate what traditional media can be used for, but to provide a new tool for the illustrator with its own features and advantages.

9.4. Aesthetic challenges

Replicating the look of traditional illustration techniques and incorporating standard illustration conventions obviously can have an aesthetic quality since these techniques exist in our collective psyche, i.e., chalk drawings and the work of the Renaissance masters, stipple and engraving techniques borrowed from print techniques. However, simply replicating techniques previously developed for other media is not enough. The final question remains: Does the representation clearly convey the information to be depicted? And if it does, does the image also embody an aesthetic quality?

Most traditional techniques evolved by constraints with the media, i.e., early printing techniques could not reproduce continuous tone properly, so stipple and hatching, which evolved out of engraving techniques, became popular, because the engraving plates used for mass production reproduced the images with high fidelity.

We see a strong intermediate use by individuals who would like to select pictorial motifs from images that show various treatments. This would allow for a quick way to draw upon previous motifs that one finds both useful and aesthetically pleasing.

Again, the “prime directive” is to convey the information. However, we are forging into some new territory, because the titration of representations to an individual is counterintuitive to the notion of a “universal aesthetic”. We would posit that this is simply a level of degree. That most of representation falls into the “universal aesthetic” in that perceptual cues (developed) and expected by humans are provided (i.e. content “what”) However, individual preferences, in our case, is closely associated with subtle variations in genetic and experiential makeup that are manifest in subtle aspects of form, color, or motion dominance and preference, as well as “associative components”, i.e, contextual (level of experience, appreciation, etc.) as opposed to content.

9.5. Variance of expertise (novice, intermediate, expert)

Lintern has shown that simple graphics may be more helpful to novice pilots when using simulation to depict flying, and that simple representations for novices may actually reduce practice time by 15 percent [Lin92]. This work suggests that overly realistic displays may be too overwhelming for novices, because they do not have the mental representation to subjugate noise and process the most salient information in the scene, as would an expert. Experts, based upon extensive experience, use nuances subtlety and intuitively to effectively assess and interact with their environment. At one time consciously sought out and contextualized, as in initial learning, these cues are now subjugated and unconsciously processed. Again, this is mostly due to levels of association. Does the individual have the knowledge to associate aspects that provide a sense of aesthetics, i.e., an appreciation for a subtle variation, or novel attribute?

Within even an expert population, variations in types of learning may exist. These may include visual (imagery) dominant, verbal dominant (written, auditory), and kinaesthetic (touch movement) dominant. We will attempt to study these types of learners to see if there is any correlation in how they utilize the simulation. This will allow us to evaluate if they rate themselves focusing on visual, haptic, or auditory cues.

9.6. Long-term collaboration

An important question is how can we promote long-term collaboration between the medical illustration and computer graphics/NPR communities? A first step here would be to provide complete, user-friendly tools with an interface that is natural and useful for an illustrator. Most existing systems are research prototypes and not products ready to be used. We can create environments to promote this and nurture the possibility of interaction, or like us, find researchers with common ground and see how it goes. We would like to see illustrators get actively involved in promoting visual literacy. Incorporating standard illustration conventions into our systems should be a priority. We have identified three crucial factors on how to automate user adaptable presentation and guide a user to the most appropriate representation: (1) the interface (2) the use of appropriate terminology and (3) task adaptability.

9.7. Interactive simulation

Learning complex information, such as found in biomedicine, proves specifically problematic to many, and often requires incremental step-wise and multiple depictions of the information to clarify structural, functional, and procedural relationships. Spiro and Feltovich have demonstrated that generating alternate views of the same information under different organizational schemes and representations may reduce and prevent reductive biases and oversimplification which often occur in learning complex material [SFCA89]. Although the gradual increase in variability of task complexity and representation initially decrease a learnerŠs performance in training, it has been demonstrated to ultimately increase learning and transfer [FH84, PMJCG73]. Multiple depictions have been shown to facilitate self-evaluation and validation of oneŠs comprehension. However, even with extensive learning through text, images, and lectures, initial interaction to determine proficiency with either cadaver or live patients is often accompanied by high levels of anxiety.

The simulation of procedural relationships, especially those that involve user queries demand interaction. Emerging visualization techniques, such as non-photorealistic representations, coupled with advances in computational speeds, especially new graphical processing units, provides unique capabilities to explore the use and variation of representations in interactive learning sessions.

We are developing a surgical simulation environment that is being exploited to investigate the use of volumetric data to provide interactive levels of representation titrated to the level of proficiency of the user (see Figures 2, 3, 4). Our intention is to run controlled studies that compare traditional methods of learning anatomy, lecture, drawings, etc with simulations studies.

For the purposes of this study, we are employing a basic exploratory pre-test and post-test comparison of improvement in understanding temporal bone anatomy. The metrics to be collected will be based upon proper identification of structures and times to task. Our experimental design will measure a percent change in user's score regarding the use of the simulator as a supplemental learning tool compared to additional time in the anatomy lab.

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