An Interactive Augmented Reality System for Learning Anatomy Structure

Chien-Huan Chien, Chien-Hsu Chen, Tay-Sheng Jeng

Abstract—**Anatomy, the study of the structure of the human body, is fundamental to medical education. In recent years, the hours devoted to anatomy are declining from the medical curriculum. This decline includes the reduction of course hours and an emphasis on early clinical experience. To adapt to those changes in anatomy education, various complementary methods with technology of three-dimensional visualization have been tried, and the explosion of image technology during the last few decades and this has brought anatomical education into a new world. In this study, we aim to use augmented reality (AR) technology to create an interactive learning system, which help medical students to understand and memorize the 3D anatomy structure easily with tangible augmented reality support. We speculate that by working directly with 3D skull model with visual support and tangible manipulate, this AR system can help young medical students to learn the complex anatomy structure better and faster than only with traditional methods.**

Index Terms— **Anatomy, augmented reality, spatial memory.**

I. Introduction

Anatomy is a cornerstone of medical education. The history of anatomy started from Egypt (approximately 500 B.C.E.) and Greece (between 3000 and 2500 B.C.E.) In Renaissance, it was the exploration of life, suffering, and death. Today, anatomy is still one of the most important courses in the medical education, but it is at a crossroads. In recent years, the hours devoted to anatomy are declining from the medical curriculum [1]. This decline includes the reduction of course hours and an emphasis on early clinical experience. To adapt to those changes in anatomy education, various complementary methods have been tried and changed over the nature of anatomy education. The explosion of image technology during the last few decades has brought anatomical education into a new world.

The examples of image technology range from magnetic resonance imaging and computed tomography to other three-dimensional (3D) visualizations. Together with newly emerging technology, 3D visualizations have opened up a new view for anatomical education. The new media have become widely used tools in medical instruction today. Augmented reality (AR) technology integrates the computer generated objects into the real word. AR offers an innovative learning space by merging digital learning materials into the physical space. We think of an interactive augmented reality anatomy learning system as a learning material helping young medical students to learn the complex anatomy structure better.

C. H. Chien is with the Institute of Creative Industry Design, National Cheng Kung University, Tainan, Taiwan (corresponding author to provide phone: +886-6-757575 53360; e-mail: claymo@ gmail.com).

C. H. Chen is with the Institute of Creative Industry Design, National Cheng Kung University, Tainan, Taiwan.
(e-mail:chenhsu@mail.ncku.edu.tw).

T. S. Jeng is with the Institute of Creative Industry Design, National Cheng Kung University, Tainan, Taiwan (e-mail: tsjeng@mail.ncku.edu.tw).

Anatomy plays an important role in the medical education. The three main approaches to studying anatomy are regional anatomy, systemic anatomy, and clinical anatomy. The approaches above reflect the body's organization and the priorities. Regional anatomy considers the organization of the human body as segments: a main body, head, neck, trunk, paired upper limbs, and lower limbs. It also recognizes the body's structure by layers: skin, subcutaneous tissue, muscles, skeleton, and cavities. Here we restrict the scope of the study to skull only, which has the most complex structure.

This research uses AR technology to create an interactive learning environment, which allows students to understand the 3D skull structure with visual support. With a clear pop-up labeling and interactive 3D model, students can easily get the relative position of each bone in different angle. In addition, the augmented reality skull model enables users to disassemble, assemble, and manipulate the 3D AR skull with two hands intuitively.

The structure information is important to learn anatomy, and AR anatomy learning system presents visual anatomy information clearly and provides student a tangible interactive interface enhancing spatial memory. We speculate that by working directly with 3D skull model with visual support and two-hand manipulation, this system can help young medical students to learn the complex anatomy structure better and faster than only with traditional methods.

II. Related Works

A. Anatomical education

In recent years, anatomy curriculum has been slowly squeezed from the medical education [2]. In the previous studies from Leung describe the reduction in hours of gross anatomy [3]: a survey in medical schools in 1902 showed an average of gross anatomy teaching is 549 hours, but the mean teaching hours had been dropped to 330 by 1955 (Blake, 1980). However, a survey on 126 U.S. medical school anatomy departments in 1991 showed the average of gross anatomy teaching was reduced to 190 hours, and the number dropped down to 165 hours in 1997. These changes include

ISBN: 978-988-17012-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

the reduction of course hours, the additional usage of problem-based learning, and an emphasis on early clinical experience. However, medical students today need to learn more, but the total time required for medical study is the same. That is, the course hours of Anatomy decreased dramatically.

Anatomy has an established value in medical education and is supported by students, clinicians, and the general public. The recent changes in the reduction of course hours, integration of clinical courses, abandoning of cadaver dissection, introduction of new educational methods, emphasis on self-directed learning, computer-assisted learning, and problem-base learning [4]. The debate about how to teach anatomy has arisen.

Conventional anatomy

A traditional, conventional anatomy education is based on the dissection of human body. It has become synonymous with traditional courses. The general assumption is that dissection allows haptic, and the process of dissection provides students with important three-dimensional views of the human anatomy structures, which cannot be replicated by an atlas [5]. In addition, dissection also gives an opportunity to appreciate the range of variability presented in real human body that is difficult to capture in a textbook and specimen [6]. Most medical students have the experiences that they were astonished by how the images in atlas differs from textbook and dissection.

Despite the many advantages, there are some obvious problems with dissection such as cadavers storing, issues of morality, and public perception. Dissection may be a way to introduce students to death and their role as medical professionals in death, but many students have the natural abhorrence and feel upset during dissection. Besides, the quality of dissection and the learning outcomes depend on different factors such as the quality of material and sometimes the limitations in the number of cadavers, emotional concerns, prior knowledge, time spent on dissection, number of teachers, and self-instruction time [7].

Computer-supported anatomy

We live in the time of the continuing evolution of computer-based multimedia technology. In the revolution, medical sciences have taken advantage of the power of these tools. Molecular biology, manuscript preparation, data manipulation, Medline searches, the images of diagnosis, the sequence of the human genome, etc., there are hundreds of examples. Anatomical education has also taken advantage of these inventions and has applied them in teaching and visualization of the complex structures [8]-[10].

The knowledge of anatomy has developed from what we can see with naked eyes down to molecular level. During the last few decades, there is an explosion of new techniques for image and media. The Examples of image technology range from magnetic resonance imaging, computed tomography, to other three-dimensional visualizations [11]-[13]. The new media have become widely used tools in medical instruction today.

As we apply new virtual technology to anatomy teaching, the challenges are different from teaching gross anatomy, since virtual anatomy is much more complex, it requires three-dimension views. However, developments in image technology and anatomy knowledge offer much more opportunities for realistic and valuable anatomical education than ever before. New technology permits the manipulation of realistic three-dimensional models with options for displaying complex context.

In particular, Virtual reality (VR), which includes interactive 3D objects that has been used as a tool to teach anatomy, can provide users an interactive learning environment with 3D computer-generated objects in computer and it has made a significant contribution to medical education and training. For instance, the virtual temporal bone system provides a 3D anatomical model of the human temporal bone and allows students to manipulate the model with natural haptic [14]. “Visible human body” [15] and “touch simulator” [16] both provide the students with a 3-D graphical brain model and a multimodal interactive environment. Another example is the Learning Resources Center of the University of California, San Diego, School of Medicine has explored an educational applications of Virtual reality. It provides 3D models of human anatomy with multimedia medical learning resources (images, animations, and video, etc.). Recently, Argosy Publishing has produced “the Visible Body®”. It is a virtual human anatomy visualization tool with interactive 3D model including anatomical structures, major organs and systems of the human body.

Another technology that has been used to help medical students to learn anatomy is QuickTime, which is a multiplatform digital media that commonly employed for video programs. The development of multimedia technology has produced QuickTime virtual reality (QTVR), supported by Apple's QuickTime. QTVR features can be used to produce photorealistic, interactive “non-linear movies” which moves the photographic image from the flat 2D world into the 3D virtual world with a mouse on a normal computer screen. For anatomical structures education, QTVR can be used to prepare virtual anatomy specimens that can be reversibly dissected, layer by layer [17]. Another example is “Yorick—the VR Skull.” Users can use the computer mouse to scroll across these images that can be freely positioned with 360° views [18]. In addition, Hardin Library for the Health Sciences provides ‘‘The Bones of the Skull ’’ on their web site. It is an interactive 3D learning tool for the anatomy of human skull featuring interactive QTVR anatomical models integrated with tutorial content. As technology developed, there are new ways to improve anatomical education, augmented reality provide the novel and direct way.

ISBN: 978-988-17012-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

B. Augmented reality

The term "augmented reality (AR)" is believed to be coined by Thomas Caudell in 1990. It is a technology that uses computers to overlay virtual information on the real world. In the system, users can handle the virtual objects in the real world at the real time, thus virtual objects and real objects coexist in the same space-time. By merging digital learning materials, AR offers an innovative learning space. It is therefore conceived that AR opens new perspectives in teaching and learning.

AR creates a new interface and it has been applied to surgical training [19]-[24], AR model has been used as a training tool in endoscopic ultrasonography, chest-tube insertion [25], and laparoscopy [26], [27]. Generally speaking, AR would be useful for training, because the information is presented ''just-in-time'' and ''just-in-place.'' Moreover, how to enhance students' spatial memory will be an important issue in this study.

Spatial memory

In daily life, we encode objects' spatial positions to retrieve objects and remember their places. Mandler et al. established that encoding objects' spatial locations is an unintentional and automatically process [28]. The general question is how to explore human spatial capabilities. Previous research shows that realistic 3D environments allow a more direct connection between virtual and real world [29]-[31]. There are some evidences supporting that 3D can improve spatial memory. Robertson et al. showed that when using their 3D Data Mountain, task times and error rates were lower than using the standard 2D 'Favorites' mechanism, the authors also suggested the role of spatial memory in the 3D environment [32]. Tavanti and Lind compared the effectiveness of spatial memory in 2D and 3D displays. The results show a positive effect on memory in 3D over 2D. The authors concluded, "A realistic 3D display better supports a specific spatial memory task, namely learning the place of an object" [33]. Those are experimental evidences showing that 3D ecological displays enhance subjects' spatial performances, the results give a positive expectation that augmented reality could enhance students' spatial memory and help them to memorize the structure and corresponding location of skull.

Tangible User Interface

Instead of 2D interface input devices such as keyboard and mouse, 3D interaction techniques provide a more intuitive interface to user. Tangible User Interface (TUI) is a more intuitive and effective interface in virtual environments [34], [35]. In a natural and intuitive interface, users can manipulate virtual 3D objects by simply handling physical objects. Compared to virtual tools, virtual objects with physical devices can be manipulated in more direct ways. It allows users to manipulate computer-generated 3D object freely and naturally just as if they were performing with physical objects in the real world.

In 3D virtual environments, user must be able to select target object so they can then manipulate and interact with it. There are several selection techniques which have been developed in 3D environment: Ray-casting, Depth Ray, Cone-casting, Shadow Cone, Aperture selection, and Image Plane selection techniques et al. To interact more naturally, hand-based input devices were developed, such as data gloves, which allows direct mapping between real and virtual hand motion.

In AR, Virtual Hand techniques can be implemented by tracking the user's fingers, or through a tracked handheld tool. As we introduced before, AR offers a way to merge virtual objects with the real world in real time. Kato et al. described a concept of Tangible Augmented Reality (TAR,) it combines TUI with augmented reality. TAR usually requires users to wear hand-mouth display (HMD) to view the augmented reality overlay on the real world. Tangible interfaces are tightly connected input devices to the output of user interactions. In our interface, we use two hands to manipulate virtual objects. Users can handle input tools with a great degree of freedom and easily map it to virtual objects. Thus, TAR is a powerful tool for displaying and manipulating virtual objects in the real world.

Tasks in Virtual Environments

When user need to interact with a 3D computer-garnered object in the virtual world, the motions can break down into several levels of steps, such as selection, manipulation, translation, navigation, rotation or scaling. Gabbard classified those tasks in virtual environment into three groups [35]: navigation and locomotion, object selection, and object Manipulation. Particularly, selection is an important one because it precedes most other manipulation and navigation actions. In the virtual environments, users need to select a target object, then they can manipulate the object and have other interactions with it.

To be more intuitive and natural to use, the techniques have to allow users to use like performing daily activities. Therefore, as they act in the real world, the system allows user to arrange objects with two-hand.

Two-handed interactions

3D virtual technologies aim to provide a natural interface. However, to explore an intuitive and natural interactive interface is not easy. To improve the interaction, some techniques allow user to directly interact with the virtual environment. One of the solutions is using both hands. The non-dominant hand is used to select the object and to bring the object close to the dominant hand. The non-dominant hand's movements are low in spatial, and its task starts earlier than the dominant hand's movement. The main benefit of

ISBN: 978-988-17012-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

using both hands is intuition: in our daily life, we always use our non-dominant hand to bring objects into position in order to manipulate them with the dominant hand. This result suggests a new way for TAR.

Boeck [37] developed the “Object in Hand” metaphor allowing the user’s non-dominant hand to grab a selected object into a comfortable position for the manipulation of the dominant hand, and the user can interact with the object as they usually do in their everyday in the real world. They can arrange, rotate, and locate the objects with two-handed operation, which is very intuitive and natural [38]. Proposed by Pierce et al., another example is the “Voodoo Dolls,” which allows user to manipulate a doll with user’s both hands [39]. Those tangible user interfaces with two-handed operation have been applied in various application domains to manipulate objects. For example, TUIs have just been used in navigation, such as museums, multimedia stories, and scientific 3D data.

III. Materials and methods

A. System design

We aim to use AR technology to create an interactive learning environment, which allows students to understand the 3D skull structure with visual support. The system is based on a complete structure of the skull which can be decomposed and reassembled. To be an effective training tool, the system has to provide correct information to the students, the skull includes zygomatic bone, temporal bone, sphenoid bone, mandible, maxilla, ethimoid bone, parietal bone, frontal bone, occipital bone, nasal bone, lacrimal bone, palatine, vomer, and inferior nasal concha. With a clear pop-up labeling and interactive 3D model, students can easily get the related position of each bone in different angle.

Besides, we also design a platform which has an extra window to show detail information of each label. Thus, when students use the AR skull model, they do not need to check textbook or other recourse to get the detailed information. That means they do not get distracted. We use AR anatomy learning system as the supplementary materials to help medical students to do their self-direction learning.

User requirements

We interviewed five medical students to understand user requirements. They indicated that they were astonished by how the images in atlas of textbook differs from dissection, and the main challenge they face is after class they need to memorize all the positions of bones. However, human body is complex, and it’s hard to comprehend the 3D structure with textbook or other 2D atlas in a short time. After a brief introduction of AR and 3D model, they pointed out several requirements, such as the model is easy to manipulate with 360° views, can be disassembled, and has pop-up label et al. Anatomy can take the advantage of advanced learning tools because human body structure is complex, it is hard to reach the 3D structure concept by atlas only. Especially, brain is known to be one of the most complex organs in the human body in terms of structure, function, and appearance.

We designed an interactive augmented reality system of skull providing a computer-generated 3D skull with clear label to help medical student to learn anatomy. The augmented reality model enables users to disassemble, assemble, and manipulate the 3D AR skull intuitively.

B. System equipment

In this study, users only need a computer with webcam and a marker.

C. Experiment

Subjects

Participants are 30 medical students from the Kaohsiung Medical University. All of them have never taken the anatomy class. We separated them into Group A, B, and C randomly. Each group has 10 students.

Student trial

The students in Group A are asked to use an atlas to memorize the 31 parts of the skull in 40 minutes, students in Group B use virtual reality system as an assist system to learn the position and the name of the 31 parts of skull in 40 minutes, and students in Group C use augmented reality system as an assist materials to learn the position and the name of the 31 parts of skull in 40 minutes. After 40 minutes’ self-learning, students in each group are asked to take a quick exam on the physical skull model.

The purpose of the anatomy AR learning system is to examine how medical students learn and interact with a computer-garnered 3D skull in the augmented reality system that helps them to identify the related position of skull and to memorize the skull’s structure.

During the trial, students have to memorize the related position of each part of skull. This trial presented three activities. The first one is navigation, by having a global view of the skull to help the students get used to our system. The second part is to identify the 17 main parts of skull. The students are asked to use both hands to accomplish the selection. The third part is manipulation, by decomposing and reassembling each part of skull to familiarize with the 3D structure.

Scenario

Experiment combined with user-trial experiences. Participants from medical school are asked to fill out a questionnaire that consists of 2 parts in different phases: the first part is the demographics about their personal information and anatomy background knowledge before

ISBN: 978-988-17012-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

testing; the following is a general introduction and demonstration of the AR anatomy learning system, and then subjects perform the user-trial experience. During the trial, students are encouraged to speak aloud regarding their feelings about the system (VR and AR) and any problems they have. After the trial, they were required to fill in another questionnaire including a fill-in the blanks exam and user feedbacks.

IV. CONCLUSION

In the future, anatomy still plays an important role in the medical education. All medical schools around the world will maintain anatomy as a core subject in their curricula. As we know, anatomy in medical curriculum has been declined. As digital tools have become very important learning and teaching aids in medical instruction today, integration of new technology will encourage students' interest and retention of anatomical knowledge. The structure information is important to learn anatomy, and AR anatomy learning system presents visual anatomical information clearly and provides student an interactive environment. This system will not only assist students to learn anatomical detail but also provide the appreciation of 3D structure which cannot be replicated by an atlas. We speculate that by working directly with AR 3D objects with visual support, this system can help young medical students to learn the complex anatomy structure better and faster than only with traditional methods. Finally, the feedbacks and suggestions highlighted the system's advantages and shortcomings that provide the references for future work, including the development of AR training model and anatomical education.

REFERENCES

[1] McCuskey, R. S., S. W. Carmichael, et al. (2005). "The Importance of Anatomy in Health Professions Education and the Shortage of Qualified Educators." Academic Medicine 80(4): 349-351.
[2] Reidenberg, J. S. and J. T. Laitman (2002). "The new face of gross anatomy." Anat Rec 269(2): 81-8.
[3] Leung, K. K., K. S. Lu, et al. (2006). "Anatomy instruction in medical schools: connecting the past and the future." Adv Health Sci Educ Theory Pract 11(2): 209-15.
[4] McKeown, P. P., D. J. A. Heylings, et al. (2003). "The impact of curricular change on medical students' knowledge of anatomy." Medical Education 37(11): 954-961.
[5] Snelling, J., A. Sahai, et al. (2003). "Attitudes of medical and dental students to dissection." Clin Anat 16(2): 165-72.
[6] Turney, B. W. (2007). "Anatomy in a modern medical curriculum." Ann R Coll Surg Engl 89(2): 104-7
[7] Trelease, R. B., G. L. Nieder, et al. (2000). "Going virtual with quicktime VR: new methods and standardized tools for interactive dynamic visualization of anatomical structures." Anat Rec 261(2): 64-77.
[8] Paalman, M. H. (2000). "New frontiers in anatomy education." Anatomical Record 261(2): 47-47.
[9] Maldonado-Zimbron, V. E., R. E. Elizondo-Omana, et al. (2006). "An Interactive Tool for the Human Anatomy Laboratory." Int. J. Morphol 24(3): 377-382.
[10] Petersson, H., D. Sinkvist, et al. (2009). "Web-based interactive 3D visualization as a tool for improved anatomy learning." Anat Sci Educ 2(2): 61-8.
[11] McLachlan, J. C., J. Bligh, et al. (2004). "Teaching anatomy without cadavers." Medical Education 38(4): 418-424.
[12] Shaffer, K. (2004). "Teaching anatomy in the digital world." N Engl J Med 351(13): 1279-81.
[13] Temkin, B., E. Acosta, et al. (2002). "Web-based three-dimensional Virtual Body Structures: W3D-VBS." J Am Med Inform Assoc 9(5): 425-36.
[14] Nicholson, D., C. Chalk, et al. (2006). "A randomized controlled study of a computer-generated three-dimensional model for teaching ear anatomy." Medical Education.
[15] Jastrow, H. and A. Hollinderbmer (2004). "On the use and value of new media and how medical students assess their effectiveness in learning anatomy." The Anatomical Record Part B: The New Anatomist 280B(1): 20-29.
[16] Panchaphongsaphak, B., R. Burgkart, et al. (2007). "Three-dimensional touch interface for medical education." Ieee Transactions on Information Technology in Biomedicine 11(3): 251-263.
[17] Malinowski, R. (2003). 3D K9: Using Quicktime VR to teach veterinary anatomy .
[18] Nieder, G. L., J. N. Scott, et al. (2000). "Using QuickTime virtual reality objects in computer-assisted instruction of gross anatomy: Yorick- The VR Skull" Clinical Anatomy 13(4): 287-293.
[19] Marmulla, R., H. Hoppe, et al. (2005). "An augmented reality system for image-guided surgery." Int J Oral Maxillofac Surg 34(6): 594-6.
[20] Magee, D., Y. Zhu, et al. (2007). "An augmented reality simulator for ultrasound guided needle placement training." Med Biol Eng Comput 45(10): 957-67.
[21] Yao, Y., X.-x. Pang, et al. (2008). Augmented Reality Interactive Interface for Defective Bone Repair System. 7th Asian-Pacific Conference on Medical and Biological Engineering: 733-736.
[22] Sakellariou, S., B. Ward, et al. (2009). Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study. Virtual and Mixed Reality: 605-614.
[23] Shuhaiber, J. H. (2004). "Augmented reality in surgery." Arch Surg 139(2): 170-4.
[24] Hamza-Lup, F. G., A. P. Santhanam, et al. (2007). "Distributed augmented reality with 3-D lung dynamics--a planning tool concept." IEEE Trans Inf Technol Biomed 11(1): 40-6.
[25] Felix, G. H.-l., P. R. Jannick, et al. (2008). A Distributed Augmented Reality System for Medical Training and Simulation.
[26] Botden, S. M., I. H. de Hingh, et al. (2009). "Suturing training in Augmented Reality: gaining proficiency in suturing skills faster." Surg Endosc 23(9): 2131-7.
[27] Botden, S. M., F. Torab, et al. (2008). "The importance of haptic feedback in laparoscopic suturing training and the additive value of virtual reality simulation." Surg Endosc 22(5): 1214-22.

ISBN: 978-988-17012-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

[28] Mandler, J.M., Seegmiller, D., and Day, J., On the coding of spatial information. Memory & Cognition, 1977, 5, pp. 10-16.

[29] Belcher, D., M. Billinghurst, et al. (2003). Using Augmented Reality for Visualizing Complex Graphs in Three Dimensions. Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality, IEEE Computer Society.

[30] Siegl, H., M. Hanheide, et al. (2007). "An augmented reality human-computer interface for object localization in a cognitive vision system." Image and Vision Computing 25(12): 1895-1903.

[31] Cockburn, A. (2004). Revisiting 2D vs 3D implications on spatial memory. Proceedings of the fifth conference on Australasian user interface - Volume 28. Dunedin, New Zealand, Australian Computer Society, Inc.

[32] Robertson, G., M. Czerwinski, et al. (1998). Data mountain: using spatial memory for document management. Proceedings of the 11th annual ACM symposium on User interface software and technology. San Francisco, California, United States, ACM.

[33] Tavanti, M. and M. Lind (2001). 2D vs 3D, Implications on Spatial Memory. Proceedings of the IEEE Symposium on Information Visualization 2001 (INFOVIS'01), IEEE Computer Society.

[34] Sinclair, P. and K. Martinez (2004). "Adapting Information Through Tangible Augmented Reality Interfaces ".

[35] Kim, J.-S. (2005). "Tangible User Interface for CAVE based on Augmented Reality Technique."

[36] Joseph Gabbard and Deborah Hix. A Taxonomy of Usability Characteristics in Virtual Environments. Virginia Polytechnic Institute and State University, november 1997.

[37] Boeck, J. D., T. D. Weyer, et al. (2006). Using the Non-Dominant Hand for Selection in 3D. Proceedings of the 3D User Interfaces, IEEE Computer Society.

[38] Ware, C. and J. Rose (1999). "Rotating virtual objects with real handles." ACM Trans. Comput.-Hum. Interact. 6(2): 162-180.

[39] Pierce, J. S., B. C. Stearns, et al. (1999). Voodoo dolls: seamless interaction at multiple scales in virtual environments. Proceedings of the 1999 symposium on Interactive 3D graphics. Atlanta, Georgia, United States, ACM.

ISBN: 978-988-17012-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)