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Teaching Information Aesthetics as a Research Class in China

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Research has traditionally been conducted in one-to-one or one-to-few training or tutoring settings, similar to apprenticeships practiced in many other lines of work. Such a small-scale tutoring mode has been effective in producing great researchers, but it is extremely costly in terms of manpower utilization of experienced researchers and educators. Research-based instructional strategies (RBISs) have been applied to enhance student learning, typically in the STEM (science, technology, engineering, and mathematics) disciplines. Class time devoted to RBIS is limited,[1] however, and recent studies show that such classroom interactions and after-class discussions are still lacking.[2] Nevertheless, we believe that various RBISs could be utilized to teach students to conduct productive research through projects in a classroom setting.

This article reports on our experiences while attempting to scale up the research training in a typical Chinese class. Kang Zhang and Quang Vinh Nguyen jointly ran a research class in the School of Computer Software at Tianjin University, China, in the spring semester of 2013, with 41 undergraduate and master's students. The course research topic, information aesthetics, covered information visualization and generative art. Seven teams were set up to conduct seven different projects within the topic, and several were able to produce research papers published or accepted by journals and conferences (four publications out of the seven team projects).

As part of this process, we developed an innovative method for setting up project teams based on the strengths of individual team members. We also were able to instruct undergraduate students along with their graduate peers. The most important learning experiences in teaching this class were determining how to enable effective team work and maximize the students' research potential. We believe that our model is replicable for larger classes and equally applicable to other disciplines.

Class Setup and Requirements

Our research class had a regular course weight of 32 hours and two credits across 16 weeks, a typical master's course weight. It was offered in 2013 to both first-year master's students and third-year undergraduate students. The course was called "Visual Languages and Visualization," and it required full participation and attendance by the students, with a sign-up sheet.

The class syllabus included the following description:

> This course is research-oriented and targets students who are interested in research using graphs as a means for communication and problem solving, to represent program executions, and networked information. Topics in visual languages and information visualization will be discussed.

The desirable prior knowledge for the students included computer graphics, compilers, human-computer interfaces, and UML. Students were required to read papers on information visualization published in several recent journal issues and conference proceedings:

- *IEEE Transactions on Visualization and Computer Graphics*,
- *IEEE Computer Graphics and Applications*,
- *Journal of Visual Languages and Computing*,
- IEEE Conference on Information Visualization,
- IEEE Symposium on Visual Analytics, and

 Published by the IEEE Computer Society

- IEEE Symposium on Visual Languages and Human-Centric Computing.

We also required that they read a few relevant books.[3–7]

The assessable work for graduate students included program-solving projects using the programming language Processing[5] or Java, an innovative information visualization, a state-of-the-art survey of related areas, and technical presentations and discussions. Each project was assessed using student presentations, literature review and project proposal (10 percent of course weight) and final presentation (20 percent), and a 3,000-word scientific paper describing the project, formatted using the IEEE two-column format (40 percent). Class attendance was mandatory (10 percent) and active classroom discussion was strongly encouraged (20 percent). Students needed to devote considerable time to their chosen research projects. They were encouraged to collaborate to complement each other in pursuing relevant topics, with the goal of producing a publishable paper. The assessable work for undergraduate students was similar, except that the project presentations were Processing programming exercises (30 percent) and the scientific paper writing component was replaced with a final examination (40 percent).

The course's instruction language was English, and all classroom interactions had to be conducted in English. For many students, this language requirement was challenging, particularly with oral communications in English as well.

Student Backgrounds

All the students were computer science or software engineering majors in the School of Computer Software at Tianjin University. Twenty-one first-year master's students and 20 undergraduate junior students attended the class. Every MS student was required to conduct a research project, whereas the undergraduate students were only required to participate in the class, with an option to volunteer to take up a research project. Five to six master's students had limited research experiences, while most of them had helped their advisors with company-sponsored projects. Of the 20 undergraduate students, only one or two had prior exposure to research.

Instructional Formats

The course was designed with three different forms of instruction: PowerPoint lecture presentations given by the two instructors; student team presentations, including a project proposal and a final report; and inter- and intra-team discussions.

The class lectures covered the following topics:

- Introduction to Visual Languages
- Introduction to Processing Programming
- Graph Grammars and Visual Language Generation
- Visual Language Applications in Web Transformation
- Information Visualization
- Aesthetic Computing and Computational Aesthetics
- Computer Generated Art
- Software Visualization
- Graph Drawing
- Scientific Paper Writing

For many students, the English language requirement was challenging, particularly with oral communications in English as well.

The last topic, scientific paper writing, specifically focused on how to write a quality computer science paper in the ACM/IEEE required form. It covered the requirements and pitfalls in different parts of a paper, analyzed several anonymized papers, and explored why they were rejected by a past IEEE conference. Common mistakes among Chinese authors were highlighted and corrected during the analysis.

Projects in Information Aesthetics

The instructors provided several choices of projects for the student teams to choose from, all in the general areas of information aesthetics, including information visualization, tree drawing, and generative art.

Project 1: Visualizing Large Trees

Research in tree visualization can be classified into two main streams:

- *Connection:* This is a natural way to draw tree structures in a node-link diagram. A set of visible graphical edges are drawn in the diagram to link nodes from parents to their children. Nodes represent data while edges represent relationships among data items. Example techniques are cone tree,[8] hyperbolic tree,[9] radial view,[10] and classical hierarchical tree.[11]

- *Enclosure:* Unlike the connection approach, the enclosure approach uses enclosed areas to represent a tree structure. Typical examples of this type of tree visualization techniques are tree maps.[12] A comprehensive list of current tree visualization techniques is available online.[13]

This project investigates "new" or "enhanced" interactive visualization techniques or algorithms for visualizing large tree-type data. There is no fixed solution regarding which approach to use to draw the tree or on how to use it. Creativity is particularly encouraged.

We aimed at forming several student teams, each consisting of four members ideally equipped with one of four skills.

Project 2: Interactive 3D Hyperbolic Visualization

Hyperbolic geometry has been used to provide 3D interactive visualization of large graphs or hierarchical structures.[9,14] This approach constructs the hierarchy in hyperbolic geometry and then maps that structure onto an ordinary Euclidean plane. The algorithm produces a nice visualization inside a disc or sphere. Although a 2D hyperbolic browser provides an excellent context-and-focus navigation, 3D hyperbolic browsers have limited success in navigation and interaction.

This project takes 3D hyperbolic visualization to the next level by providing a new, yet efficient way to navigate information in a 3D hyperbolic space, from inside a spherical universe to the outside of the visualization sphere.

Project 3: Generating Pollock's Drip Style

This project aims at automatic generation of the Jackson Pollock style of abstract paintings using the programming language Processing. The first phase involves an analysis of Pollock's paintings based on his artwork downloadable from the Web. His style typically includes aesthetic presentations of dripping paint or liquid.

The second phase is to find relevant mathematical functions and then choose appropriate colors and their combinations. The project team was instructed to follow and compare Richard Taylor's earlier work.[15–17]

The third phase is implementation and evaluation. The first painting should be generated based on one of Pollock's most well-known paintings, and then randomness and patterns of graphic elements are added to generate different paintings that look like Pollock's paintings but that differ from any of his originals.

Project 4: Visual Analytics of Port Logistics

Ports are the main components of container logistics, responsible for managing the transfer and transportation of goods. Interactive visualization techniques can be used to intuitively convey commodity flows, showing ports and states, modes of transport, facilities and their capacities, operational characteristics, intermodal operations, and parameters required to calculate system efficiency, benefits, and costs.

Based on the design of the original interactive visualization system for visual analysis of multidimensional port data in the logistics domain, this project requires redevelopment of the system with a Web-based architecture for easy access and a context view of the port performance, in a time series of quarters and years. In addition, this project also considers enhancements on its interaction and visualization.

Project 5: Multidimensional Information Visualization

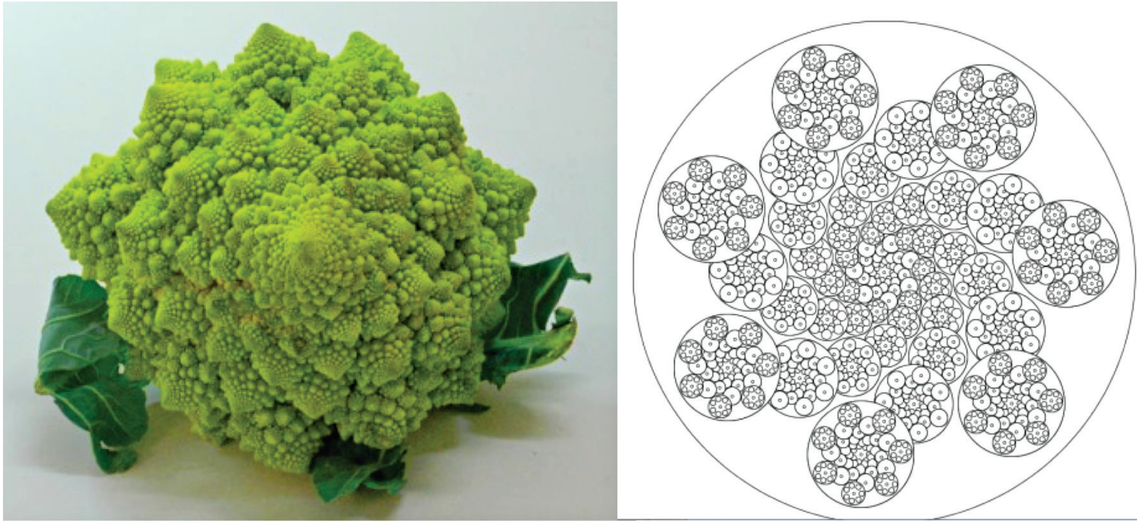
Real-world data is usually large and complex, so scalability and high-dimensionality problems remained a challenge in information visualization[18] and visual analytics.[19] For example in the medical field, Microarray and single nucleotide polymorphisms (SNPs) datasets have complex data structures with several thousand genes (and/or probes) and cross-referenced interconnections in each record.

This project investigates efficient and effective methods for visualizing and navigating multidimensional data, beyond the capacity of the display space. For example, a dataset may include 100 items, each having 10,000 attributes. The program must be run in real time using a desktop computer. Optimization in the algorithms, memory resource, and so forth have to be considered in the development. Interaction can be enabled using a 2D fisheye view.

Team Setup and Project Selection

In the first class meeting, the students received a questionnaire that asked them to provide their own assessments of their competence levels in four categories:

- oral English,
- written English,
- programming skills, and
- art and design skills.



(a) **(b)**

Figure 1. Broccoli Tree visualization. (a) The visual structure of Romanesco broccoli was used as a model (b) to visualize hierarchical and ordered gross domestic product data.

The questionnaire form used a scale of one to four (one being the most competent). We aimed at forming several teams, each consisting of four members ideally equipped with these four skills.

Based on the students' returned self-assessment forms, we considered both the gender balance as well as equal distributions of the most competent students from each category when placing them into different teams. For every team of four members, we were able to allocate one student strongest in oral English, one strongest in written English, one or two strongest in programming, and possibly one strong in art and design.

One master's student insisted on conducting a project by herself (as a solo team) and a team of four undergraduate students volunteered to do a project. By the end of the second week, three teams selected Project 1 (Visualizing Large Trees) but challenged themselves to come up with their own innovative, yet distinctive ideas on tree drawing. Two teams liked generative art projects; one selected Project 3 (Generating Pollock's Drip Style) and the other (the solo team) chose to generate Kazimir Malevich style abstract images. One team selected Project 2 (Interactive 3D Hyperbolic Visualization) and another selected Project 4 (Visual Analytics of Port Logistics). None of the teams selected Project 5 (Multidimensional Information Visualization), possibly due to its complexity and because is it less intuitive than the other projects.

The three teams that selected Project 1 proposed three different ideas of tree visualizations, individually mimicking diamonds, drawers, and Romanesco broccoli in their tree structures (as discussed and illustrated in the next section).

Individual Projects Contributions

This section summarizes the ideas and main contributions of all seven team projects, with illustrations. For the purposes of this discussion, we assigned the teams the following names based on their selected project:

1. Diamond Tree visualization,
2. Drawer Tree visualization,
3. Broccoli Tree visualization (undergraduate team),
4. Pollock Style generation,
5. Malevich Style generation (solo team),
6. 3D Hyperbolic visualization, and
7. Port Logistics visualization.

The Broccoli Tree team proposed an interesting model to visualize hierarchical and ordered data that mimics the visual structure of Romanesco broccoli (see Figure 1a). The size and depth of the filled color of circles correspond to the numeric value of the data. The layout of sibling nodes from inside out represents the order of the data (Figure 1b). The nodes at different levels are displayed by zooming in and out and represent the hierarchical levels of the data. The team came up with an idea of fast navigation by providing a specific view according to the user's need. The visualization provides a good context-and-focus view for large datasets, offering an easy comparison of relationships among the given data. The Broccoli Tree model was applied to the visualization of the gross domestic product (GDP) data.

The Diamond Tree team proposed a tree visualization model that looks like a diamond to visualize the organization and relationships of

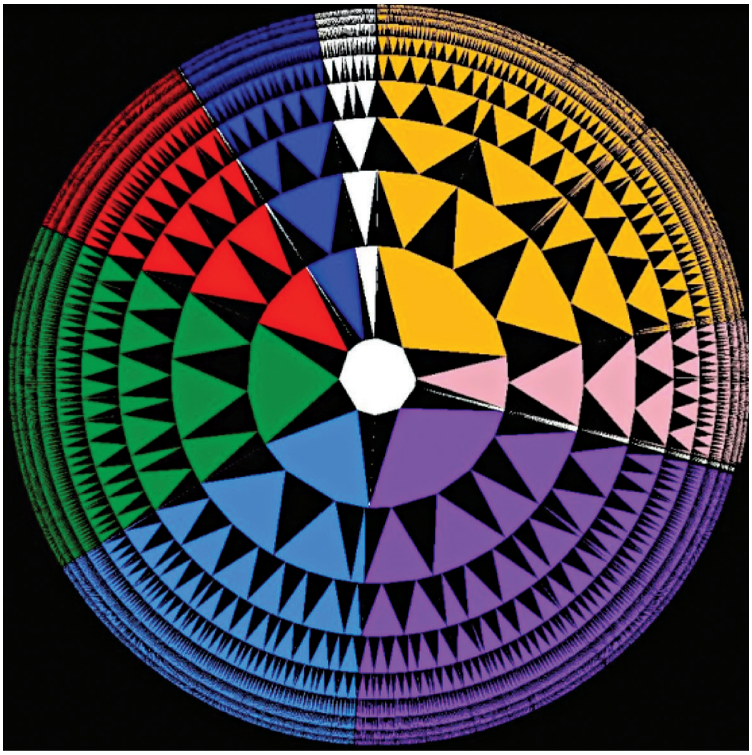


Figure 2. Diamond Tree visualization. The team designed a diamond-like spatial layout of the Tianjin University website (19,279 pages).

hierarchical data (see Figure 2). They designed a spatial layout using the geometry theory, starting with a simple design and continually improving it until reaching the design that makes the best use of the screen estate. They demonstrated the diamond tree method by visualizing and analyzing the structure of the entire Tianjin University website (www.tju.edu.cn), including 19,279 pages. This work was presented at the IEEE/ACIS International Conference on Computer and Information Science (ICIS) 2014.[20]

The Drawer Tree team proposed a tree visualization model that can be used to present the structure, organization, and interrelation of big data. The "drawer" is a metaphor that helps the user associate the visualization structure with a set of hierarchical drawers. By utilizing the display space with traditional node link visualization, the team was able to devise a method to visualize tree structures with millions of items.

The drawer tree method can be used to visualize big hierarchical data. The team showed an example of the entire directory structure of a local system hard drive, including 305,800 files and folders, as Figure 3 illustrates. This work was presented at the ACM Symposium on Applied Computing (SAC) 2014.[21] Further enhancements on both the layout and color designs, plus more quantitative evaluations, were also reported in a subsequent paper.[22]

The Malevich project team (one student) first classified different styles of Kazimir Malevich's paintings. She then analyzed the reasons why some colors were chosen by the artist. The classified styles and analyzed colors were then incorporated into a parameterized and flexible production process to

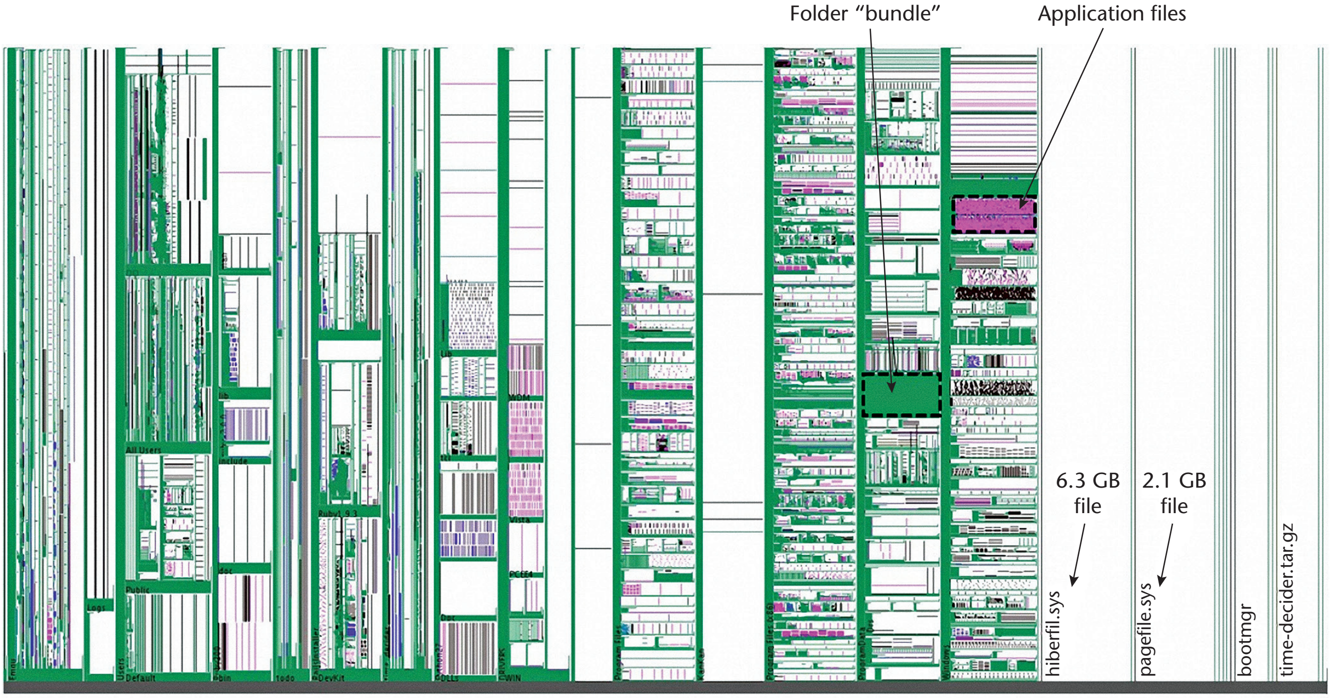


Figure 3. Drawer Tree visualization. Using a drawer metaphor, the team was able to visualize 305,800 files and folders on a local system hard drive.

generate the style of images mimicking the abstract artist's work. The generated results using the basic components in the artist's style based on his art theory were demonstrated. Figure 4 shows an example generated image modeling Malewich's *Suprematism* (1916). This work was also presented at ICIS 2014.[23]

The Pollock team came up with a layered approach to model Jackson Pollock's paint dripping style. Having analyzed fractal-based algorithms and observed the details of Pollock's paintings, they designed a layered modeling approach that divides Pollock's artwork into four layers from the bottom up: background, irregular shape, line, and water drop. The layers are drawn sequentially and independently, forming the desired Pollock style. The parameters of their program can be randomly generated or tuned by the user, enabling high flexibility and effectiveness. Experimental results show that their layered modeling approach can systematically generate images resembling Pollock's dripping style. Figure 5 shows an example image modeling Pollock's *Number 8* (1949). Their work has been accepted by the *Visual Computer Journal*.[24]

The 3D Hyperbolic team utilized the Walrus tool (www.caida.org/tools/visualization/walrus/) to map and visualize a tree structure on a 3D space using hyperbolic geometry. Multiple interaction techniques were added into the visualization to enable the exploration of details, including a detailed information display on a selected node, the ability to change the focus point as well as track focus points during exploration, animation between transitions to maintain the user's mental map during the interaction, and the ability to zoom in and out on the visualization. The integration of various interaction functions on the original 3D hyperbolic visualization enhanced its effectiveness for visual analysis of large hierarchical datasets. Figure 6 shows an example interactive website visualization.

The Port Logistics team came up with a three-tiered system: MySQL by converting spreadsheet data into a database, PHP for processing on the server side, and HTML5 with JavaScript for presenting the port-data visualization on most modern Web browsers. The team also provided an overview of the performance for the entire record or a particular period. Using an iconic design, a simplified visualization for both land-side data (truck performance and TEU [twenty-foot equivalent unit] performance) and wharf-side data (ship performance and vessel working rate) were provided for easy comparison between quarters and years (see an example in Figure 7). The presentation of icons, such as style, size, number, and colors, was carefully chosen to ensure a simple, authentic design and seamless interactive visualization usable by logistics professionals.

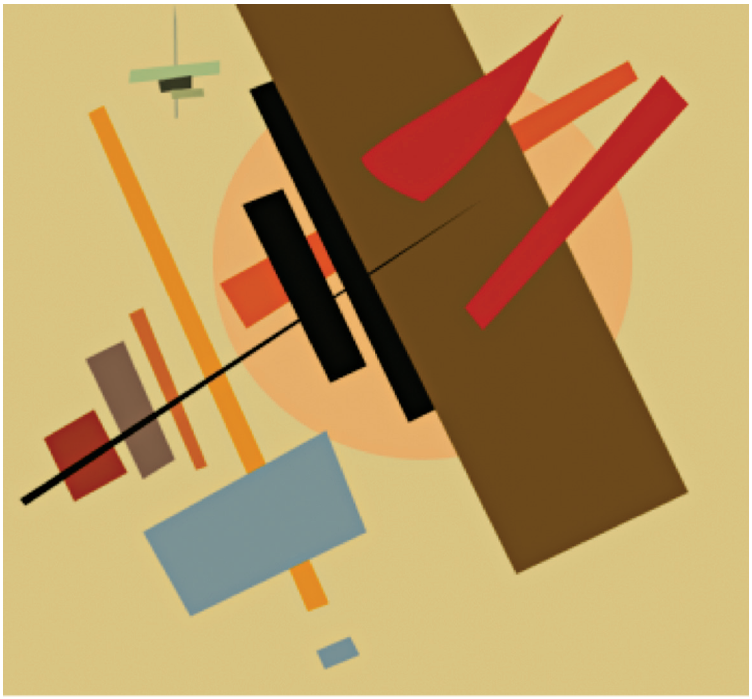


Figure 4. Malevich Style generation mimicking Malevich's *Suprematism* (1916). After classifying the artist's styles and analyzing his colors, the student incorporated them into a parameterized and flexible production process to generate this image.

Figure 5. Pollock Style generation mimicking Pollock's *Number 8* (1949). The team designed a layered modeling approach that divides Pollock's artwork into four sequential and independent layers.

Results and Follow-Up

During the 10-minute project proposal and 15-minute final presentations, one member from

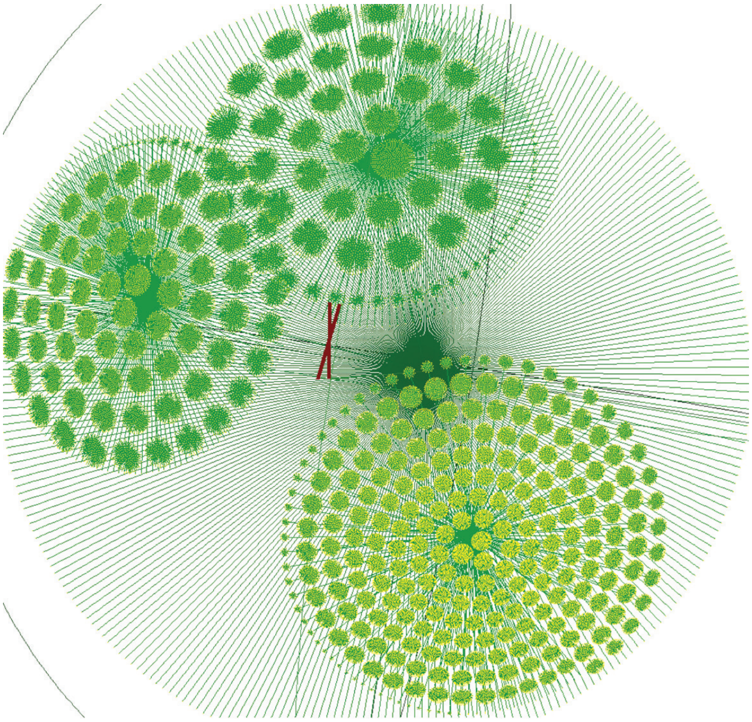


Figure 6. 3D Hyperbolic visualization. The University of Western Sydney website contains more than 170,000 pages in three levels.

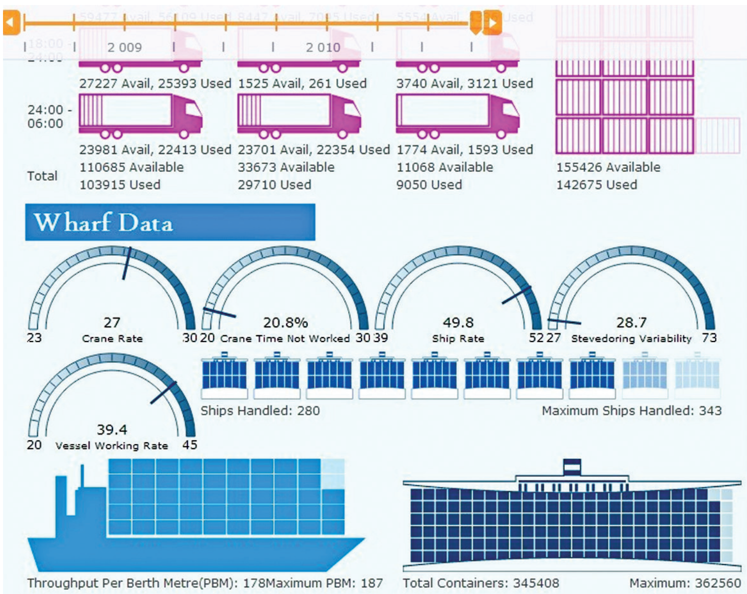


Figure 7. Port Logistics visualization. The presentation of icons was carefully chosen to ensure a simple, usable design that visualizes port performance across quarters and years.

each team presented its work, and only the other members were allowed to answer follow-up questions in a subsequent five-minute period. The assessment for the two presentations (the project proposal and final report) was conducted by the students themselves. Every student in the class was given a ranking sheet to rank both the presentation (between 1 and 6) and project quality (between 1 and 6) for every other team's presentation. After the final report presentation, the overall score S was obtained by averaging the project proposal and final report presentations, incorporating their respective weightings:

$$S = \frac{0.1\sum_{1}^{N} Rp + 0.2\sum_{1}^{N} Rf}{0.3 \times N}$$

where N is the total number of students who participated in the scoring process, Rp is the sum of the presentation rank and project quality rank for the proposal presentation (weighing 10 percent), and Rf is the sum of the presentation rank and project quality rank for the final presentation (20 percent). The seven projects were then ranked based on the calculated scores, as depicted in Figure 8. The final grade of each student was calculated by adding 40 percent for paper writing and 30 percent for classroom participation to the above score.

It is interesting to note that the rankings in Figure 8 appear to be objective and accurate because they partly reflected the final publication qualities. As mentioned earlier, the Pollock Style work was accepted by the *Visual Computer Journal*;[24] the Drawer Tree paper was presented at ACM SAC 2014, for which the acceptance rate was 23.2 percent;[22] and the Malevich Style and Diamond Tree papers were presented at ICIS 2014.[20,23] For unknown reasons, the 3D Hyperbolic and Broccoli Tree teams did not follow up with complete drafts for submission.

Most of the students in the class had no prior experience writing scientific papers. This class offered them a unique opportunity to conduct cutting-edge research, hands-on project work, and paper writing. Of the seven teams, four were able to complete their writing for submission to two conferences and one journal. The instructors helped revise and improve the papers for several rounds before their submissions. We believe that the revision process itself is indispensable to the student learning quality paper writing. Those students with the accepted papers also had the experience of presenting their papers at an international forum.

Limitations

Although our overall experiences and results from this class have been extremely positive, there are inevitably a few limitations.

First, the contributions of individual team members were not distinguished, and all the members of the same team received the same grade. Team members' self-assessments—such as reporting the proportions of members' contributions—could be incorporated in their final grades. Intra- and inter-team collaboration could also be assessed for more accurate grading and encouragement for collaboration.[3]

Second, due to the nature of team work, individual team members brought their strengths to different phases of the projects and separately focused on project design, implementation, presentation, or paper writing. The students therefore did not individually get a full hands-on training in all aspects of research.

Finally, although the classroom discussion was an assessable component (20 percent), tracking down all the students who actively participated in the class discussions became a challenge. Neither the instructor nor the student had time to complete it. We ended up with a rough estimate and awarded a few highly active students.

This article has reported our experiences in teaching a research class on information aesthetics in China, focusing on hands-on training using team-based research projects and scientific paper writing. Our primary objective was to generate publishable work, measured by the final publication outcomes. The results have been encouraging, with one journal publication and three conference presentations. The feedback from the participating students was all positive and some of them have since been accepted as master's and doctoral students in highly ranked US and Australian universities.

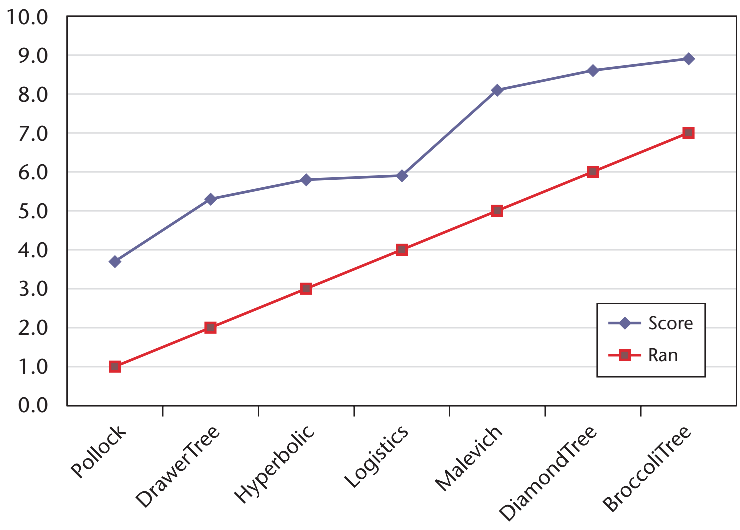


Figure 8. Scores and rankings of all the projects. The presentation rankings provided by the students closely mirror qualities of the final published papers.

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