Visual Storytelling for Science Popularization and Education: A Design Study of the Evolutionary Game Theory

Siqi Shen*
Fudan University, China

Yanda Li†
Fudan University, China

Zhibang Jiang‡
Parsons School of Design, U.S.

Siming Chen§
Fudan University, China

ABSTRACT

More and more attention has focused on data visualization for its ability of revealing stories within data. Particularly, visual storytelling can be applied as an efficient technique for science popularization and education. However, there is a lack of design space and implications for science popularization with visual storytelling of mathematical models, indicating a need to learn about how to design a visual storytelling for disseminating mathematical knowledge. Therefore, in this work, we summarize the design space for storytelling of mathematical models. Following the design space, we then propose a visual storytelling design for the evolutionary game theory.

1 INTRODUCTION

Historically, storytelling has always been considered as an efficient way of disseminating information and knowledge [3]. With the advent of modern information technology, the evolution of visualization techniques acts as a catalyst for visual storytelling. Wojtkowski et al. [6] defined visual storytelling as the one with three properties including well-constructed and presented effectively contents with reliable datasets, well-detailed performance similar to a story, and presenting in an attractive way to be well-understood by the audience. In 2008, Segel and Heer [4] provided a design space for visual storytelling, marking a guidance of applying visualization techniques for visual storytelling. Later in 2017, Brehmer et al. [1] raise an effective design space for the timelines of visual storytelling, improving the coherence of storytelling process. However, there is few published researches on design space for mathematical model visualizations for educational purpose. It remains unclear yet how to design a visual storytelling for disseminating mathematical knowledge to the general public. To fulfill the requirement, in the following sections, we will summarize a design space for storytelling of mathematical models, propose a visual storytelling for the evolutionary game theory and raise some implications for visual storytelling of mathematical models.

2 DESIGN SPACE

We summarize a design space for visual storytelling of complex mathematical models based on the theories of mathematical visualizations and education [7] and taking the researches of Segel and Heer [4] as the guidance for selecting suitable visualization techniques. Our design space contains three main divisions: (1) mathematical background level of audience, (2) narrative purpose and (3) types of data objects.

1. Mathematical Background Level of Audience Different levels of mathematical knowledge of the target audience directly affect how difficult a visualization can tell about the mathematical model. Thus, the first division identifies the background requirement of the audience involving their mathematical knowledge base. We divide it into three levels, which includes solving, perceptualizing and synthesizing. The first level, solving, only requires the audience to formulate, represent, and solve mathematical problem shown in the visualizations. the visualizations at the first levels are concrete and detailed that the audience do not need to imagine or summarize the knowledge. The second level, perceptualizing, means that the visualizations at this level provides some familiar examples applying informal mathematical cases including imagery, natural language, and metaphors [5]. the visualizations at the second levels contain more cases for the audience. The third level, synthesizing, requires rigorous proofing, high-order abstraction, reasoning, and generalization using formal mathematical language [2]. the visualizations at the third levels require the audience to conclude new concepts themselves and deduce the properties to construct new coherent and logical understanding.

Due to the direct influence from the audience, this division performs as the most critical factors determining the presentation of visual storytelling including its genres and narrative orders.

2. Narrative Purpose This division can be characterized as 2 types of visualizations for mathematical models, namely theory-driven and application-driven ones. Theory-driven visualizations indicate that the mathematical model depicted by the visualizations emphasize more on teaching the audience the meaning of the theories and formulas for the model. Meanwhile, application-driven visualizations mean that the visualizations focus more on teaching how to apply the mathematical models to explain the existing phenomenon.

3. Attributes of Data Objects The third division identifies the different types of attributes of data objects including categorical and quantitative ones.It is widely believed that that different types of diagrams work better for different data.Therefore, this division mainly influence the types of diagrams applying for visualize the data and the mathematical knowledge behind.

3 VISUALIZATION DESIGN

Based on the design space as the guideline, we propose a design for storytelling of the evolutionary game theory as an illustrating case for science popularization and education.

3.1 Dataset and Definition of Terms

The data is generated and collected from the simulation of an evolutionary game theory story we construct. Based on an interview with a domain expert in game theory, she states that: 1. The basic elements of evolutionary game theory require explaining at first. 2. The case we use for evolutionary game theory need to be basic and easy to understand. Therefore, the story we apply is one of the most classical one called "Hawk Dove Game", outlining the playing result of strategies of "Being Dove" or "Being Hawk" between two groups of birds. Additionally, we introduce some essential elements for presentation involved in our visualization, and definitions of them are given as follows.

Player: Players can be defined as the participants who choose strategies to maximize their payoffs during the whole playing process. In our story "Hawk Dove Game", players include groups of birds.

*e-mail: 20210980083@fudan.edu.cn
†e-mail: 823150785@qq.com
‡e-mail: zhibang.jiang@newschool.edu
§e-mail: simingchen@fudan.edu.cn

Strategy: Strategies can be defined as actions implemented by the players. In our case, strategies include “Being Dove” or “Being Hawk”. In terms of the evolutionary game theory, players, who initially adopt a diverse range of strategies, will eventually select a strategy of relatively higher payoffs, i.e. the strategies of the entire player population will stabilize over the evolutionary process. This evolutionary stable strategy require depicting in our visualization.
Payoff: Payoffs can be defined as the rewards of the two players from an individual game that depends the two players' strategies. In our case, the settings of payoff are interactive that are determined by the audience of our visualization. We hope that the audience explore the different results of evolutionary stable strategy based on their different settings.
Characteristics: Characteristics can be defined as strategy mechanisms, i.e. they decide which strategies to choose when faced with different ones. For instance, a player with “COOPERATE” characteristic will choose strategy “Being Dove” whichever players he plays with.
Generation: Generation can be defined as a process for players to play. After a generation ends, some players with lower payoffs will be eliminated and the same number of players, who emulate the characteristics of the one with highest payoffs in the generation, will be added in order to maintain the number of player population.

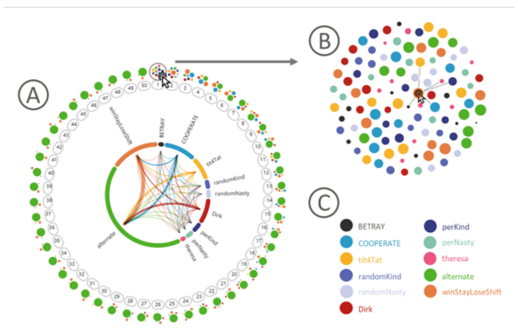

Figure 1: Our visualization is composed of (A) An visualization on the overview of gaming process; (B) An individual visualization of a specific generation; (C) The list of different preseted characteristics.

3.2 Design Process

Our visualization focuses on teaching the audience the meaning of the theories and formulas for the model as well as providing cases for the audience including imagery, natural language, and metaphors. From what we summarized in design space for visual storytelling for complex mathematical models, our mathematical background level of audience is designated as perceptualizing and narrative purpose as theory-driven one. Due to the complex mathematical model with many elements to be explained, we choose slide shows as our genre and linear order to introduce the concepts gradually, ensuring clearer explanations of the concepts.

The visualization design comprises four parts, including the descriptions of basic theoretical knowledge, those of complex knowledge, an visualization on the overview of gaming process, an individual visualization of a specific generation, and conclusions and some real-life instances with applications of the theory.

Part 1: The Descriptions of Basic Theoretical Knowledge

Our visualization begins with the a series of explanations of some basic theoretical knowledge for evolutionary game model, including the definitions of players, strategies and payoffs based on the story ”Hawk Dove Game”. The narrative of this slide is designed in a cartoon style for aesthetic purpose.

Here our design purpose is to introduce the elements including player, strategy and payoff before displaying our visualization

Part 2: An Visualization on the Overview of Gaming Process

This part depicts an overview of gaming process (Figure 1A). The visualizations include 5 layers. From outside to inside, the first layer is a series of scatterplots containing the proportions of players with various strategies in different generations with annotations for each generation in the second layer. The size of each dots represents the proportion of the characteristics distinguished by its colour. The third layer is also for annotations indicating the names of the corresponding characteristics in the fourth layer which is a donut chart depicting the the proportions of players with various characteristics from an overall perspective. The last one is a chordal graph depicting the results of comparisons between the corresponding characteristics at the two ends of the lines. The color of the line is determined by the characteristic that obtains higher payoff during the playing process of the players with the two characteristics.

Here our design purpose is to indicate the whole evolutionary game process and comparisons between two characteristics. Here we introduce the elements generation and characteristic, trying to inspire the audience that players are evolving generation by generation.

Part 3: An Individual Visualization of a Specific Generation

This part contains a network graph that indicates the different situation of each player in selected generation (Figure 1B). Each dot symbolizes a player with its colour implying its characteristic. Interactive functions in the slide are included to indicate the payoff history and the strategy of the player in the generation as well as click function to show the links of the dot which indicates the occurrence of gaming with the dot at the other end.

Here our design purpose is to emphasize on the game relationship between players. Thus, a network graph works best for our requirement. Here we introduce the elements payoff and strategy to explain the detailed gaming process to the audience.

Part 4: Conclusion and Some Real-life Instances with Applications

The final slide includes the situation that the strategies of the entire player population will stabilize as the generation proceeds, indicating the evolutionary stable strategy. Here also exists some real-life phenomenon that the evolutionary game theory can explain. The instances raised in the slide afford the application scenarios of evolutionary game theory and we hope it inspiring for the audience.

To be concluded, we construct a visual storytelling based on a specific case ”Hawk Dove Game” aiming to disseminating the knowledge of evolutionary game theory. The visualizations in part 2 and 3 respectively explain the knowledge of evolutionary game theory from macro and micro perspectives, providing a more comprehensive perspective that helps the audience to understand.

References

[1] M. Brehmer, B. Lee, B. Bach, N. H. Riche, and T. Munzner. Timelines revisited: A design space and considerations for expressive storytelling. *IEEE Transactions on Visualization Computer Graphics*, PP(9):1–1, 2017.

[2] U. Leron. Mathematical thinking human nature: Consonance conflict. Technical report, 2004.

[3] E. M. Lidal, M. Natali, D. Patel, H. Hauser, and I. Viola. Geological storytelling. *Computers Graphics*, 37(5):445–459, 2013. doi: 10.1016/j.cag.2013.01.010

[4] E. Segel and J. Heer. Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):1139–1148, 2010. doi: 10.1109/TVCG.2010.179

[5] D. Tall. Introducing three worlds of mathematics.

[6] W. Wojtkowski and W. G. Wojtkowski. Storytelling: its role in information visualization.

[7] Yeoh Hong Beng and A. S. B. M. Yunus. What to measure in the level of mathematical thinking among preuniversity science students? In *2015 International Conference on Research and Education in Mathematics (ICREM7)*, pp. 165–168, 2015. doi: 10.1109/ICREM.2015.7357046