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Visualization of Complex Systems –The Two-Shower Model

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ABSTRACT

This paper addresses ongoing research into visualization of system dynamics models to help the understanding of complex systems. The paper discusses a prototype under development named “The Two-Shower Model”. This collaborative interactive learning environment presents learners with a seemingly simple task: to reach a pleasant temperature in two showers that share the same hot water resource. This is however an example of a complex nonlinear system that may be difficult to control. Both particpants must reach an understanding of how the system works in order to be able to control it together. The paper discusses how visualizations may assist the participants in that process.

Keywords: *Visualization; Complex Systems; Collaboration; Interactive Learning Environments; Prototype Design.*

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1. Introduction

We are surrounded by complex problems that can better be understood through a study of the complex systems of which they originate. Complex systems are generally difficult to understand and control. They are nonlinear which makes it hard to predict their future behavior based on experience. System dynamics is a method that is used to study complex systems by way of computerized modeling and simulation. The simulation models, however, tend to grow large in size and complexity, and may be difficult to understand for those who lack a background in system dynamics. Research within visualization and the field of computer supported collaborative learning may be utilized in order to communicate the characteristics of complex systems.

Interactive learning environments (ILEs) may be used to aid people in learning to understand and control complex systems. In an interactive learning environment, characteristics of the system structure and behavior may be visualized in order to

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explain to the participants what is happening in the system. In addition, the visualizations may provide a basis for communication of the decisions and conditions to participants who are collaborating, and thereby support them in the process of developing a mutual understanding of the system.

We are currently developing a collaborative interactive learning environment where we aim to develop new ways of visualizing complex systems that may help participants develop a better understanding of such systems. The interactive learning environment is called “the Two-Shower Model”, and describes two showers that share a common hot water resource.

Imagine the following scenario:

> *You arrive at a hotel for the night, and tired from an exhausting journey you long to take a refreshing shower. The bathroom looks OK and the shower as well – until you turn on the water. You struggle to find the right temperature, turning the tap more and more desperately towards hot or cold with no immediate results. The temperature of the water keeps shifting from scolding to freezing. Finally, you realize that a little patience, waiting for the temperature to change before you turn on even more hot or cold water, helps more than cursing. Then you hear the shower in the next room being turned on, and it is the same story all over again. What happened?*

Although controlling the temperature of a shower is probably not a large problem for most people, it is still an example of an everyday encounter with a complex, nonlinear system. The decision maker is herself part of the system, and her decisions (changes in tap setting) feed back and change her situation (the temperature at the showerhead) after some time. The shower example is used in the interactive learning environment that we are currently developing. It is a two-user system where the participants are located next to each other, however on separate computers. They each control a shower and are encouraged to discuss what is happening in the model in order to find a solution of how the model works.

The Two-Shower Model is developed as a prototype of a visualized complex system. Before describing the model in more detail, we will present the theoretical framework and background for the prototype design. In sections 2 and 3 we will briefly explain what complex systems are and why they can be difficult to understand. In sections 4 and 5 we discuss visualization and grounding in relation to the understanding of complex systems.

2. Complex Systems

A complex, dynamic system is a system whose structure consists of variables that influence each other through causal relationships. These variables form feedback loops, which are coupled with other feedback loops (see figure 1, an extract of the relationships in the simulation model that we are using in the two shower model). The interaction between the feedback loops is nonlinear, which implicates that an identical change in one variable will not always result in the same system behavior. This is because the state of the system changes over time, thus changing the impact of the controllable variable. In the case of the shower, using the same tap setting does not always result in the same shower temperature, because the effect that the tap setting has on the shower temperature changes over time based on the pressure of the water (which again is determined by other variables). This will be further explained in section 6.

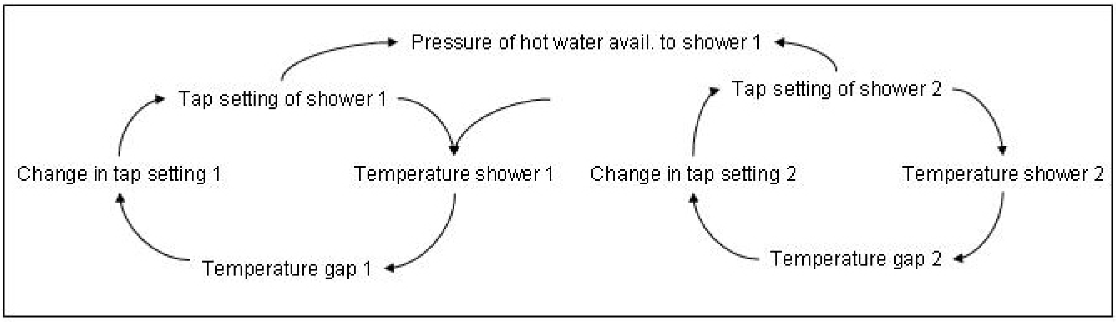

Fig. 1. An example of causal relationships (an extract of the relationships and causal loops in the two-shower model).

A study of complex systems typically involves more significant issues than that of controlling the temperature of a shower. There is a need for analysis of complex systems within a variety of disciplines. What are, for example, the causes of population and economic growth and decline within a city? Which forces drive the fluctuations of the labor market? How will the aids epidemic spread? What are the processes that influence inflation? How do environmental factors affect human migration? What are the economic forces that drive the fluctuations of commodity prices? These are examples of questions that we may try to obtain a better understanding of through an investigation of complex systems.

3. System Dynamics

Our studies of complex systems are based on the system dynamic method. System dynamics is a method that is used to identify, understand, and utilize the relationship between structure and behavior in complex, dynamic systems (Jay W. Forrester, 1961). In short, use of the system dynamic method always starts with the need to examine some problem. The problem is thought to be influenced by causal influence between variables within a complex system over time. The system and the variables are studied in order to map the structure that is believed to influence the problem. A simulation model is made, based on the findings. The model is then studied, and policies for how to solve the problem are tried out in the model before implemented in a real setting.

The system dynamic approach utilizes computerized simulation models in the analysis of the complex systems. Most existing system dynamic models are presented by equations, stock- and flow diagrams, and simple graphs, which make a thorough understanding of the system difficult to acquire even for experienced mathematicians and system thinkers (Moxnes, 2000; Sterman, 1989, 2002). Figure 2 shows the structural relationships of the two-shower model, and is an example of a stock-and-flow diagram. Figure 3 shows the behavior that is generated by the structural relationships in figure 2. For people who lack experience in reading these graphs it may be difficult to understand the relationship between the underlying structure and behavior. The purpose of our project is to find new ways of visualizing such systems in a manner that may help people get a better understanding of complex systems. The goal is for the visualizations to aid the users in the process of developing an understanding of the system, and thus be able to obtain control of the system.

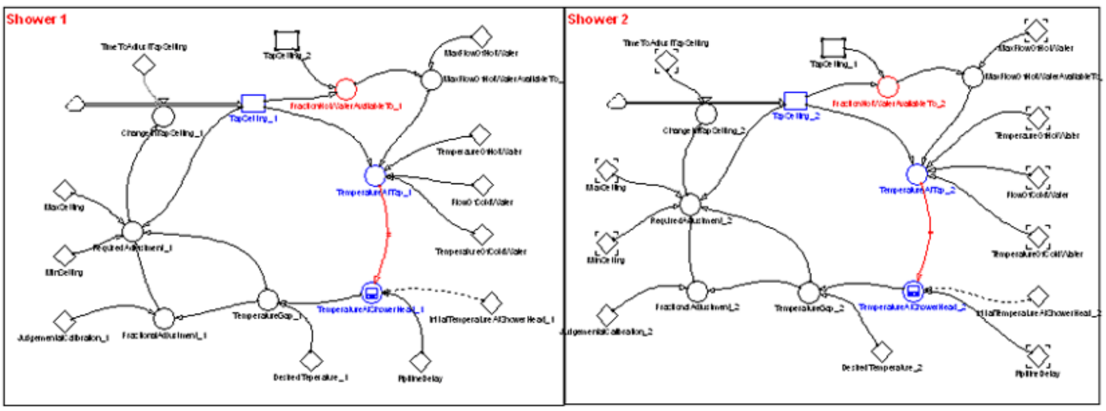

Fig. 2. Stock-and-flow diagram of the two-shower model.

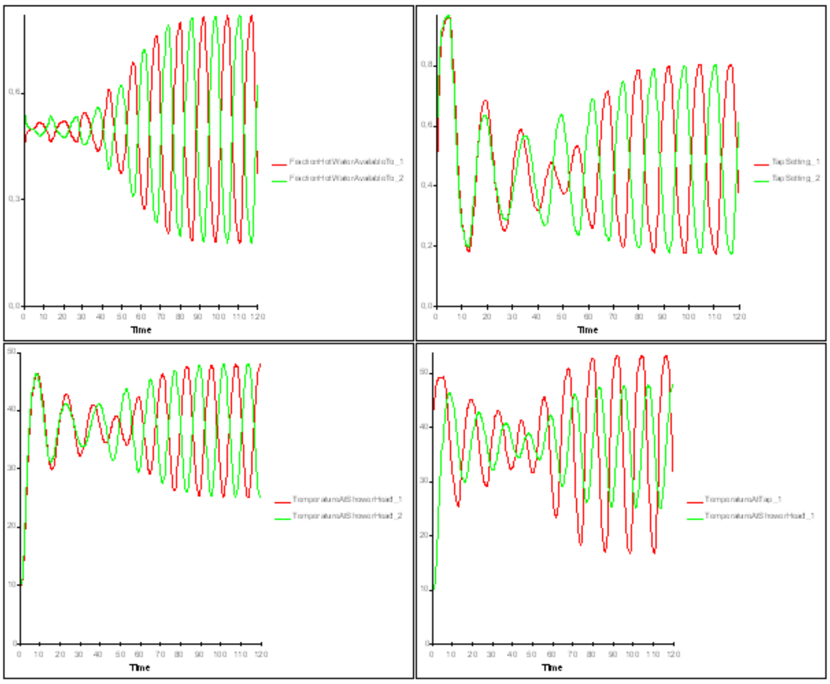

Fig. 3. Behavior graph of the two-shower model.

4. Visualization

The visualizations are developed with the purpose of creating a base for communication for the participants and thereby help them collaborate in the process of understanding the system. Through the visualizations, the important characteristics of the system are highlighted. The system must be analyzed thoroughly before the visualizations can be developed. Based on the analysis the important structural and behavioral characteristics are gathered, and these are used as a base for creating visualizations of the system.

The visualizations must portray what is happening in the system, how the structure causes the behavior and how the behavior feeds back and alters the structural relationships in the system. According to Tufte (1997, p. 9) "to understand is to know *what cause provokes what effect, by what means, at what rate*". Tufte analyzes various visual representations of dynamics created by cause and effect relationships, and discusses how knowledge about such concepts can be represented graphically. He emphasizes the importance of making a close link between cause and effect as well as time in visual representations of data[4]. He emphasizes the importance of being able to communicate graphically. Our attempt to create new visualizations of complex systems, also require a consideration of the need to visualize the causal relationships

[4] Tufte claims that graphics that lacked a link between cause and effect was the reason for communication problems that lead to the Challenger accident (Tufte 1997:42-50).

within the system. If the participants do not understand these, they will probably not be able to control the system.

Tufte (1997) also discusses how a visual display where the order of events is unclear, also distorts the links between the causes and effects as these occur in time. It is impossible to determine the direction of a causal relationship unless it can be placed in time. Tufte uses an example of a graph that represents the cholera deaths during a cholera outbreak in London in 1854. In the original graphs made by John Snow, it seemed that the removal of a water pump ended the epidemic. Taking a closer look at the data, however, disclosed that the epidemic was already in decline before the pump was removed. The original graphs did not link the incidents to time properly, thus displaying a causal relationship improperly. The issue of time is important in our project as well. It will not be possible for the participants to understand the causality between variables without placing their behaviour over time. The main challenge when trying to communicate what is happening in a complex system visually is then to develop a representation of the causes and effects in the system, and how these relationships occur and change over time.

Both the model structure and behaviour must be visualized. When creating visualizations of the model structure, important characteristics that are common for complex systems are considered. Examples are nonlinearities and delays in the system. A delay means that it takes time from a decision or change is made until a response is seen in another variable. The visualizations must represent this. The changes in behaviour must be visualized by displaying how the variables change over time.

Through visualization, important characteristics of the system may be communicated to the participants. Rather than displaying the mathematical equations of the model, they are represented by images that are easier to conceive. In the two-shower model we have chosen to use color, animation, and photos to portray the system. Red and blue colors are utilized to indicate the difference between hot and cold water, because these colors are used to distinguish between hot and cold within many cultures. Motion and changing colors and photos are used in an attempt to communicate the changing states of the variables of the system. The participants can thus monitor and try to interpret the system behaviour as it unfolds. According to (Bartram, 1998) motion is useful for displaying complex information because of its pre attentive and interpretive perceptual properties. It may thus help the user to follow the changes that occur in the system. Photos/slideshows are used with the intention of promoting user involvement.

The purpose is to encourage participants to identify with the feelings that the people in the photos reveal, as well as communicate the conditions of the other participant.

To understand complex systems it is important to be aware of how variables are interconnected and how the relation between them is dynamic and changes over time. In The Two-Shower Model the visualizations may enable the participants to monitor each other and help them realize that the effects of their decisions are connected. Their actions are displayed on both screens simultaneously, and this may help them control whether something that was said was understood by the other participant. The purpose of the visualizations is to assist the participants in the process of developing a common understanding of the system. Before describing in further detail how The Two-Shower Model is designed to help this process, we will briefly discuss aspects of collaborative learning relevant to the prototype design and clarify our use of the term grounding.

5. Collaboration and Grounding

When learning about complex ideas and concepts, collaboration has certain advantages over individual learning. Complex concepts may be simplified when explored and explained by an individual, and there are often misperceptions when multiple processes occur concurrently (Feltovich, Spiro, Coulson, & Feltovich, 1996; Koschmann, Kelson, Feltovich, & Barrows, 1996). Following this, we argue that the use of collaborative interactive learning environments may support the understanding of complex systems. An important aspect of the collaborative process is that the actors develop a shared understanding of the system or topic. This is often referred to as grounding.

Grounding is the process by which participants in collaborative learning construct and maintain some degree of mutual understanding (Baker, Hansen, Joiner, & Traum, 1999). Common ground does not necessarily refer to the internal knowledge that the participants have in common, but to something that is actively negotiated and re-negotiated during the communication process (Arnseth & Solheim, 2002). Similarly, a recent paper (Koschmann & LeBaron, 2003) critique the constructs of common ground and grounding. They argue that in CSCW literature “common ground” has tended to be treated as an abstract but measurable entity. Analyzing a fragment of interaction from the operating room at a teaching hospital, Koschmann and LeBaron argue that Clark’s contribution theory of discourse – which the grounding theory arises from – fails to explain important aspects of the collaboration process. When interaction is analyzed as a goal-oriented process of establishing common ground, researchers may ignore the ambiguities and dynamics of everyday conversation and collaboration (Koschmann & LeBaron, 2003).

In this paper we continue to use the terms grounding and common ground. By applying these terms, or the term "shared understanding", we do not imply that the participants are expected to acquire some mutual mental model of the system (the two showers) that they will be able to express in words, but only that they have reached a sufficient understanding to be able to control the system together.

The need for tools in collaborative learning depends on the setting. We intend that the participants should be located in the same room to enable face-to-face communication. Grounding through oral and written linguistic utterances may be limited by the participants' abilities to communicate their ideas and conceptions of the system, and their ability to interpret the utterances of other participants. The grounding process may be improved by a tool that enriches the linguistic utterances. We assume that grounding may be supported by providing visualizations of the conditions that each participant experiences during collaborative learning. Visualization of complex, dynamic systems may thus be used as a tool to support the grounding process and aid the participants' development of an understanding of a complex, dynamic system.

6. The Two-Shower Model

The following describes an initial attempt of visualizing a complex system. A small simulation-based interactive learning environment is developed. 'The Two-Shower Model' is a simple model of two showers that share a common hot water resource. The reason for selecting this particular model as a starting point is that it consists of a simple structure, yet is sufficiently comprehensive to encompass the main characteristics that make complex, dynamic systems difficult to understand and control. The model describes a problem that many people have experienced in some way, and it may therefore be easier for participants to relate to the problem, communicate about the problem, and develop an understanding of how the system is constructed.

The Two-Shower Model supports grounding through visualization of the participants' decisions and the conditions on which these decisions are based. The underlying simulation model is based on an existing system dynamic model that illustrates the consequences of mutual dependency of decision-makers in relation to resource allocation (Morecroft, Larsen, Lomi, & Ginsberg, 1995). The Two-Shower Model simulates two showers that share a common hot water resource. The participants must develop an understanding of how the underlying structure (the pipe system) renders control of the temperature difficult. There is a delay from a change is made in the tap setting until the water with the new temperature reaches the showerhead. Eager to obtain the right temperature, the participant may exaggerate the changes in the tap setting, disregarding the delay in the system. In addition, the pressure of the hot water resource depends on the tap settings of both showers. If one participant turns the tap extremely high, the other participant's access to the hot water pressure is restricted, and her temperature sinks. This participant will then turn her tap setting up, which again influences the hot water pressure of the first participant. Controlling the system based on previous experience is difficult, because the same tap setting will not always result in the same temperature. An enduring comfortable temperature for both showers is only feasible when the participants are aware of each other and the reactions of the other and the system structure are taken into account when changing the tap setting. A shared understanding of the underlying structure and its effect on the behavior of such a system is therefore necessary in order to control it.

6.1 The Interface of the Two-Shower Model

The user interface of the two-shower model has two layers. In 'the shower room', only a few of the structural and behavioral characteristics of the system are visualized (fig. 4). The user controls the temperature of the showerhead by manipulating the tap setting. Feedback is provided in the form of slideshows of a person showering (see fig. 5). Based on the shower temperature, the facial expressions of the person will change, together with the background color, and the color and scale of the thermometer. The participants can open a window with a slideshow of the conditions of the other participant. At this stage the participants receive only limited information about the underlying structure of the system, but hopefully sufficient as basis for discussion.

If the 'pipe' button is clicked the second interface, 'the pipe system' appears. This is a more thorough explanation of the system structure and behavior (fig. 6). The pipe structure is presented by animations of how the pressure of the hot water in the tank changes, and how hot water flows through the pipes (to see an animated version of the interfaces described and presented in fig. 4 and 6, open this link to a screen capture video of the model in use).

When an 'information' icon is activated, a series of explanations of the relationship between structure and behavior of the system is triggered. The effects of a change in tap setting on the other shower, and how this makes the other participant change her tap setting, is explained in words (a model-generated narrative of the events and their cause and effects) and graphics. It may thus be possible to trace the effect of a change through the system, and see the reactions of the other participant. The interfaces are developed with the purpose of controlling the degree of complexity displayed. Assisted by these visualizations, the participants may develop a shared understanding of the system, and thereby collaborate to maintain a stable, comfortable temperature for both showers.

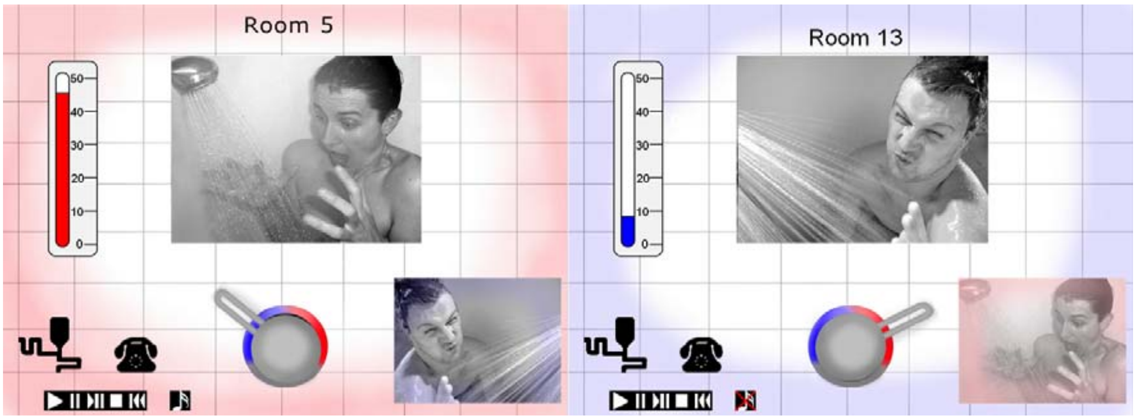

Fig. 4. The shower room (participant 1, left, participant 2, right).


Fig. 5. Example of photo sequence with changing temperatures.

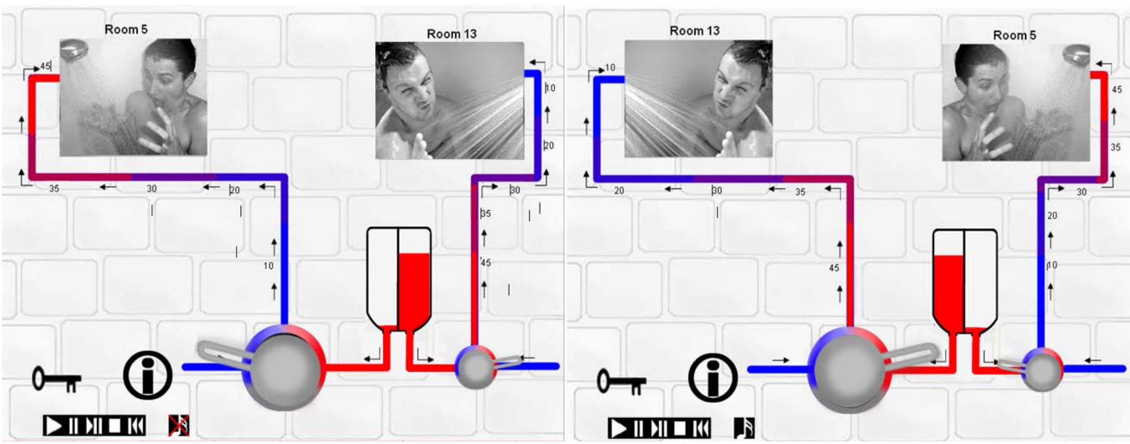

Fig. 6. The Pipe System (participant 1, left, participant 2, right).

7. Further Research

The Two-Shower Model has not yet been studied empirically. Video analysis of the interactive learning environment in use will be performed. The goal of this research project is to create tools that can be used to create similar learning environment dealing with other examples of complex systems.

In collaboration with our research group (Viste, Skartveit, Davidsen, Goodnow, Frotjold and Djupvik at the Department of Information Science and Media studies), we are currently working on a second visualized system dynamic model. This model is more complex and describes issues related to urban development of the UNESCO-listed city of Quito, Ecuador. The dynamics of cities is a prevailing issue within the system dynamic community, as well as for city planners, government officials, and citizens of any city. Urban dynamics was first introduced to the field of system dynamics by Jay Forrester (Forrester, 1970). Forrester constructed a computer driven simulation model that represented a city as a system of interacting industries, housing and people. Urban development and related issues has since been a central problem analyzed by several practitioners in the field (Backus, Schwein, Johnson, & Walker, 2001; Mayo, Callaghan, & Dalton, 2001; Piattelli, Cueno, Bianchi, & Soncin, 2002; Sudhir, Srinivasan, & Muraleedharan, 1997)

In the Quito Model we use documentary video clips to illustrate the behavior of a simulated city (see (Skartveit & Viste, 2003). The user will play the role of a city-planner of the historic city of Quito. The interactive learning environment is supposed to help the user understand the challenges of managing a city for mixed use: The goal is to create a city for locals, tourists, different social groups, commerce, and housing. Like in the Two-Shower Model, the user can change the variables of the model to try out different policies. As the simulation unfolds, short running video clips (20-30 sec), called up from a library of clips, will pop up on the screen as feedback (in a similar way as the slide show of the showering persons). These model-generated sequences represent the actual conditions of the system. When, for example, pollution reaches a certain level, clips related to contamination will be triggered, such as a taxi driver complaining about smog during rush hour. The video clips will work as comments on the simulation results, showing for example what consequences the user's choices might have for the citizens.

In the development of the Quito Model we will use insights gained from testing and development of the Two-Shower Model. As discussed previously in this paper, the

Two-Shower Model has relatively few variables to be visualized, and it is therefore easier to develop a simple user interface including all the necessary information. In contrast, the Quito Model is more complex, containing a larger number of variables, and non-linear interactions between them. This typically results in a wider variety of potential patterns of behavior. In such a larger and more complex case, problems associated with the organization of the user interface, the visualizations, and the narratives must thus be handled differently than in the simpler case of the Two-Shower Model. The interface must support the generation of longer and more complex visual narratives involving a greater number of combinations of linked variables and behavior patterns. The issue of how a user should traverse the narratives also becomes more pressing.

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