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by Till Aldinger, Stephan Kopf, Nicolai Scheele, Wolfgang Effelsberg

Participatory Simulation of a Stock Exchange

Till Aldinger, Stephan Kopf, Nicolai Scheele, Wolfgang Effelsberg
Dept. of Computer Science IV, University of Mannheim, Germany
{aldinger,kopf,scheele,effelsberg}@pi4.informatik.uni-mannheim.de

Abstract: In this paper, we present a participatory simulation of a stock exchange. It was designed for master's students in business administration to improve their understanding of finance theory and especially of the pricing of stocks and bonds. Users taking part in the computer-based simulation become private investors who are able to buy and sell stocks, bonds or stock options. The simulation facilitates the understanding of the complex system of a stock market and increases the motivation and learning intensity of students. The stock exchange simulation is based on the WIL-MA architecture (Wireless Interactive Learning at the University of Mannheim) that was developed at our institute to support interactive lectures with mobile devices. It provides a basic client/server functionality as well as an administrator tool. This technology has so far been used to support interactivity in university lectures by providing different services like hand-raising, feedback or quiz sessions. We have extended the WIL-MA technology to support participatory simulations in general and implemented the stock exchange scenario as a first comprehensive example.

Keywords: participatory simulation, interactive learning, new learning technologies

Introduction

Many new approaches based on emerging network technologies were presented in recent years, which support the learning of pupils and students in lectures. A participatory simulation is a new concept where students take an active role in a computer-based simulation. The system maps a dynamic and complex problem of the real world to a model with a fixed number of rules. Students observe that system and make decisions to discover and understand the impact of their activities. They learn in the simplified model of the simulation the processes of complex systems.

A major advantage of participatory simulations is the fact that the activity of the individual is very high even in large groups. A teacher starts with an introduction where he or she explains the relevant theoretical parts of the complex problem. The students should understand the possible activities, which are available in the simulation. The exchange of experience and a discussion in small groups within or after the simulation help to increase the understanding of the simulated system.

We have developed a client/server based system that enables students to participate in such a simulation. The participants can connect a mobile computer or hand-held device by means of WLAN or the Internet. Therefore, it is possible that the students participate in the simulation during the lecture, on the campus or from home. Very short simulations with a length of a few minutes can be integrated in the lecture, but it is also possible to start a simulation at the beginning of a term and work with the same simulation for several weeks. The students choose their time to participate and the teacher can discuss and visualize specific features in the lecture.

In this paper, we present a participatory simulation in form of a stock exchange that was designed for master's students in financial theory. The complexity of the simulation can be reduced (e.g., by decreasing the number of parameters or securities), so that it is even suitable for high schools. The participants get market information and have the possibility to trade different kinds of securities, so each student manages a securities account and tries to increase its value compared to other students. The simulations thus aims to increase the understanding of the pricing of stocks, bonds and options.

The economic competition is a major factor for the motivation of the students. They have to be active to increase their profit and can benefit from analyzing market information and understanding basic factors about the pricing. Although the users can see the success of their investment strategy on the changing value of their portfolio, the more profound experience gain is based on a discussion of their strategies in groups. An administrator defines market, company and security data before starting the stock exchange simulation. He can also influence the market or specific company data during the simulation.

The paper is structured as follows: In the next section, we present related work in the scope of participatory simulation. Section 3 gives an overview of the WIL-MA system and Section 4 describes relevant factors from the financial theory that influence the pricing of securities. The implementation and functionality of the system is illustrated in Section 5. In Section 6, the evaluations and experimental results are presented and the participatory simulation based on the WIL-MA architecture is compared to a second stock exchange simulation with NetLogo/HubNet. Section 7 concludes the paper.

Related Work

The idea to study complex problems of the real world is part of the system dynamics or system thinking research (Chen and Stroup, 1993; Senge, 1990). A participatory simulation is a role-playing activity that helps to explain the coherence of complex dynamic systems. Global patterns emerge in participatory simulations from local interactions of users. New teaching methodologies like participatory simulations are required, because many students have great problems in understanding the behavior of complex dynamic systems (Kahnemann et al., 1982; Mandinach and Cline, 1994; Resnick, 1995).

A major idea of participatory simulations is the concept of *learning through doing*. It is strongly related to role-playing games, which have been used in many disciplines (Resnick and Wilensky, 1997). Students participate in an active way, analyze available information, make decisions and see the outcome of their actions. This increases the motivation and the learning success improves (Kafai and Resnick, 1996; Papert and Harel, 1991). Another goal of participatory simulations is to encourage creative thinking (Asselt et al., 2001).

Simulations were realized with paper and pencil in the past, but the technological advances made a complete new type of simulation possible. Hardware devices were developed to support participatory simulations. A physical interface called *System Blocks* (Zuckerman and Resnick, 2003a,b) was developed for young children to get a first understanding of dynamic systems. Each block is made of wood with some electronics and has a specific functionality (e.g., it plays a sound). The blocks can be connected with other blocks and it is possible to create dynamic systems like a feedback loop by connecting only a few blocks. Another participatory simulation is based on the so-called *Thinking Tags*, small name-tag sized computers that communicate with each other (see Andrews et al., 2003; Borovoy et al., 1996; Colella et al., 1998). The tag communicates with other tags, exchanges data and visualizes similar preferences of two persons.

Early software-based simulations were implemented with *Stella* (Roberts et al., 1983) or *StarLogo* (Resnick, 1996, 1995). *NetLogo* (Tisue and Wilensky, 2004a,b) in its current version 2.1 is a mature environment for the development of participatory simulations for PCs. A major advantage of this technology is that simulations can be re-played, analyzed and compared with previous simulations. With the rapid development of networking technologies, the NetLogo system was extended to support the participation of several human players. The extension is called HubNet (Wilensky and Stroup, 1999), which supports PCs and mobile devices for input and output. Mobile phones can also be used for participatory simulations (Lonsdale et al., 2004). Special channels for the communication are text messages, which trigger events or give additional information. A typical example of a simulation that was developed with Net-Logo/HubNet is called *Gridlock* (see Wilensky and Stroup, 2000), which simulates the traffic situation in cities. The goal is to understand the complexity of traffic, the cause of traffic jams or accidents, and the effect of traffic lights in cities.

Beside the education of pupils and students, participatory simulations were used in the area of software engineering to support the development of complex software systems (Ramanath and Gilbert, 2004). In these experiments, the end users of the system were much more involved through all phases of the software development process.

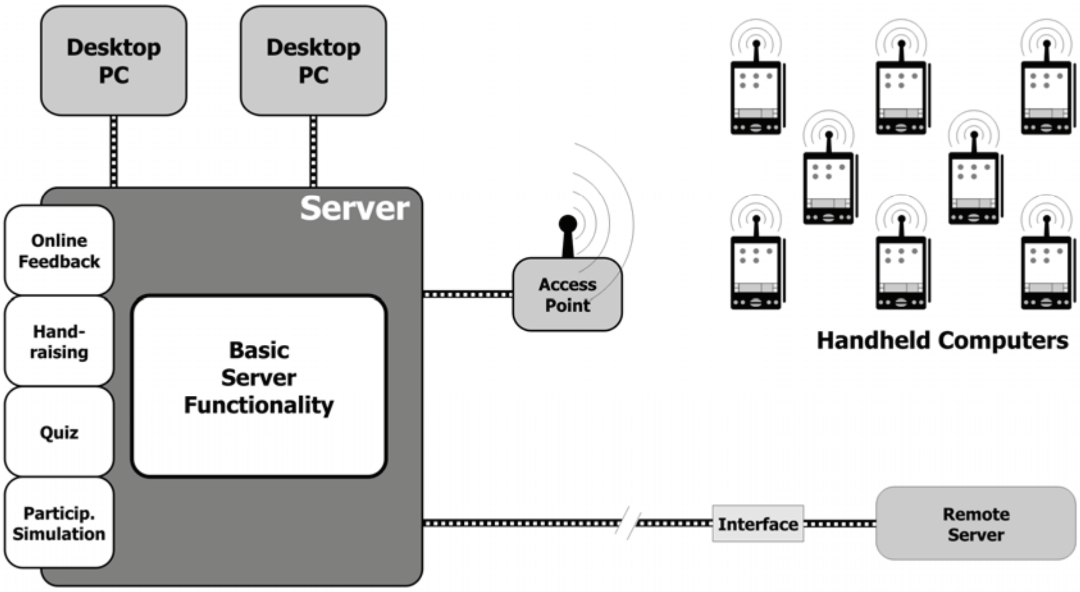

Figure 1: Overview of the WIL-MA system

Overview

The WIL-MA architecture (see Scheele et al., 2003, 2004, 2005) basically consists of three components: a server, an administrator and a client. The main task of the *server* is the communication between the clients and the administrator and the aggregation and analysis of incoming data. All users log on to the server to participate in a service (clients) or to start and manage one (administrator).

The *administrator* tool configures the services and starts the sessions. The preparations can be done without connection to the server, but to start a session, the administrator has to be connected. The *clients* are the actual user front-ends, which can not be used offline. Depending on the services that have been started by the administrator, the client provides a menu for each running service. Figure 1 shows a possible setup of the WIL-MA system. The clients run on desktop PCs or laptops as well as on PDAs with a Java Virtual Machine. It is possible to use all device types simultaneously in the same session.

Financial Theory

Different approaches and parameters can be selected to calculate the prices of the securities. The teacher should think about the educational objective and the complexity and length of the simulation. He/she decides which securities (stocks, bonds or options) are available and defines the number of companies in the market. An objective could be to understand the idea of supply and demand or to recognize the influence of general market factors like oil price or exchange rate (US-Dollar/Euro) on the prices of stocks. Different models from the financial theory are used to calculate the prices.

The calculation of *stock* prices is based on the single factor model (see Haugen, 2001). An index is computed and the direction of the index is influenced by two mood factors and random components. Further factors like oil price and exchange rate influence the stock price, based on the company properties defined by the administrator. However, the random movement of these secondary factors does not have any deterministic direction, unless the administrator changes the absolute value of a factor manually.

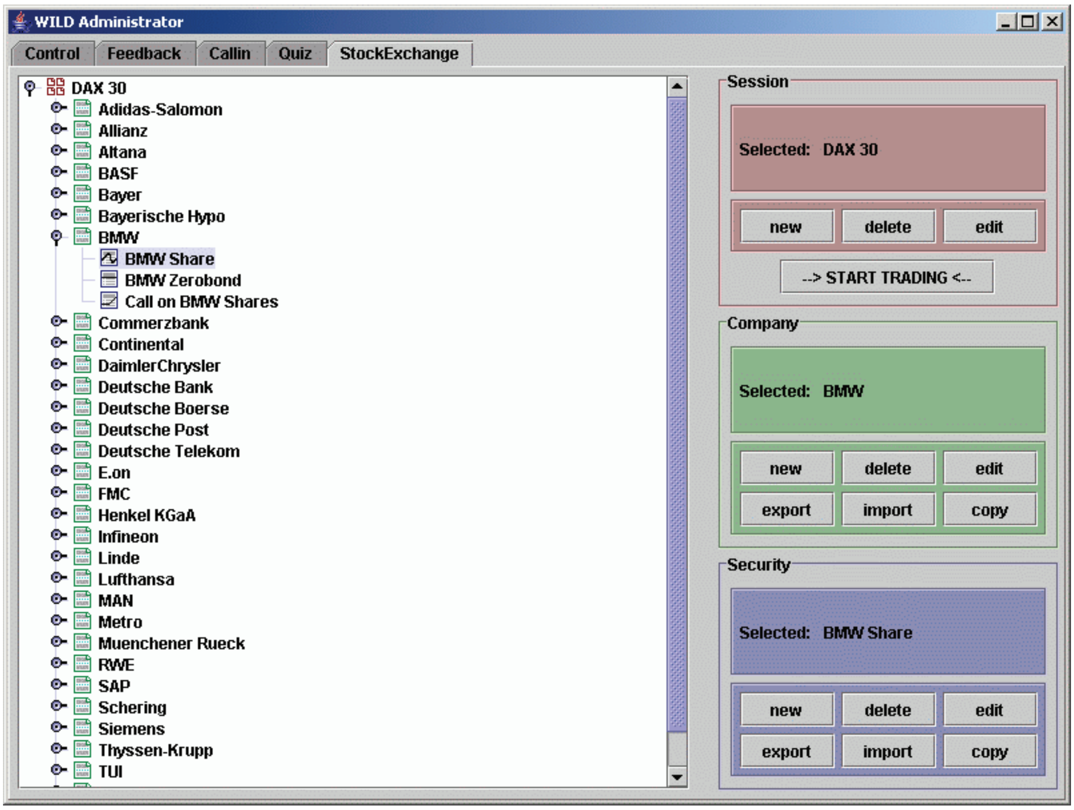

Figure 2: Administrator menu of the simulation

Bond prices follow a simple present value calculation, where a flat yield curve (see Fabozzi, 2000) is assumed. Company ratings may lower the bond prices to compensate the risk of default. Finally, the pricing of *stock options* is based on the Black/Scholes formula (see Cox and Rubinstein, 1985) for European-style calls or puts. American-style options are not implemented.

Implementation

The simulation's structure follows the general structure of the WIL-MA system and therefore provides server, administrator and client functionalities. The task of the *administrator* is to configure the general simulation data like market state or available securities.

The administrator's main menu of the stock exchange module is illustrated in Figure 2. On the left-hand side, the available companies and securities can be seen. The right-hand side provides the administrator with the sub menus where he or she can create new companies or securities, or modify existing ones. This menu cannot be accessed during a running simulation to avoid data inconsistencies. Instead of that, a smaller interim menu is made available, so that the administrator can modify market and company data to make index or security prices move into a certain direction. Optionally, a message can be broadcasted with a modification which informs the participants about market or company news. That way, the students can immediately see the effect of the new information on the security prices. Figure 3 (left) illustrates possible modifications for companies.

The WIL-MA *server* accepts requests from any number of participants and administrators. By starting the simulation, a server process is initiated which is responsible for simulating the stock exchange based on the configuration that has been set up by the administrator. During the simulation, the server repeatedly computes new market data and security prices. This is done in three steps. In the *first step*, the general market data is modified.

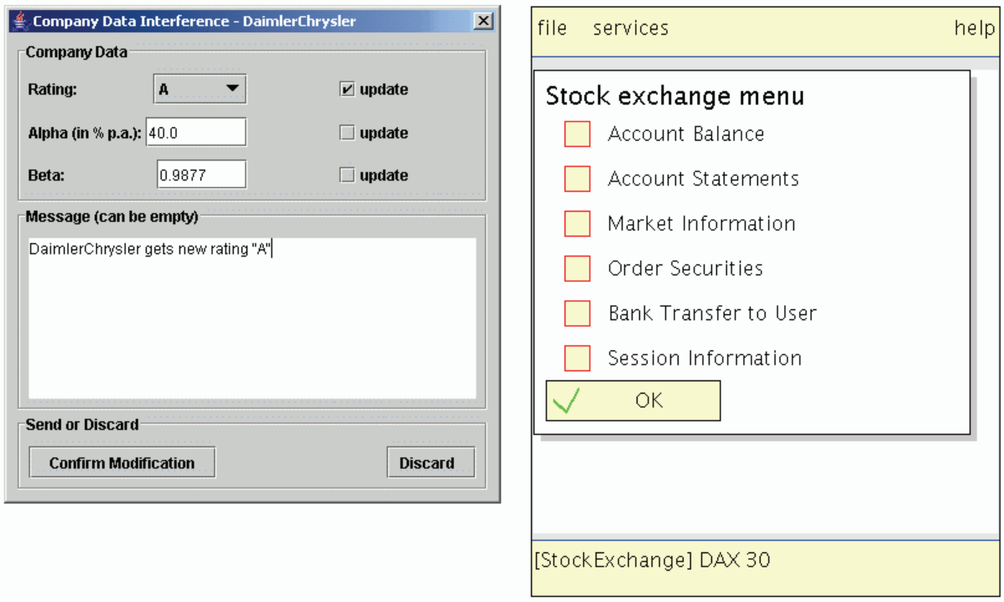

Figure 3: Left: Company interference menu for DaimlerChrysler. Right: Client menu of the simulation.

An index yield is computed, which is the main influence on stock prices because of the single factor model. The direction of the index movement is mainly influenced by two mood factors, the first representing the general market mood (bullish or bearish). After that, oil price and exchange rate (US-Dollar/Euro) are modified randomly.

The *second step* operates on the company level. Each company has a certain dependency of each market factor (e.g., whether or not a rising oil price affects profits). Based on the three factors computed in the first step, a yield for each company is calculated. It mainly depends on the company properties that have been set up by the administrator. In the *third step*, the specific security prices are modified. *Stock* prices depend on the company yield resulting from the first two steps. To simulate the effect of supply and demand in the participatory simulation high volume orders also influence the stock price, so that many buy orders lead to a rising price. *Bond* prices depend on the market interest rate and the rating of the issuer. The prices of *stock options* are calculated based on the price of its underlying stock and its volatility.

The *client* provides an interface, which allows the users to act as a private investor. Figure 3 (right) shows the basic client menu with all the available options. Viewing the account balance, users can see their cash amount and a list of securities that are currently in their portfolio, including their amount and total value. In the account statements, all the security transactions are listed, such as orders, dividend or coupon payments and maturity payments. The market information option provides the user with all the information available about the market, specific companies and their associated securities. The information given should be the basis for the order decisions of every user. Viewing the information about a security, the user can directly switch to the next main menu option and trade the security. That way, the security ID is already filled in. The users can decide whether to buy or sell the security and what amount they would like to trade. If all order data is correct and the server accepts the order, the transaction is processed.

The idea of bank transfers is to introduce a group component to the simulation. By permitting bank transfers to other users, it is possible to play in teams, where the players have to maximize the team's performance, not necessarily their individual portfolio value. By limiting the tradable securities for specific users, team play can be forced. This can be done by a risk class setting associated with each security and a maximal risk class for each user. The last menu point provides some general static session information, like session name, transaction fee settings, and the users maximal risk class. At the end of the simulation, a ranking is sent to all users, showing all participants with their current portfolio value.

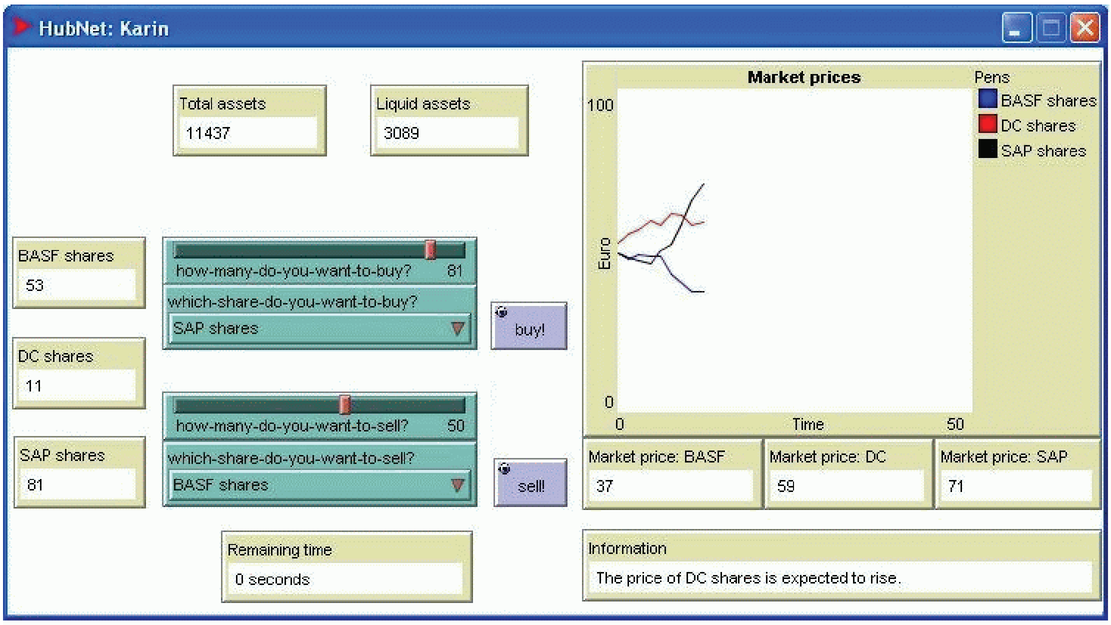

Figure 4: NetLogo client of a stock exchange

Evaluation and Results

Our WIL-MA technology, which is available under the Open Source license and free for download (LectureLab, 2005), was developed to support interactive lectures with mobile devices. Different services like hand-raising, feedback, a quiz tool or the participatory simulation are available. Many improvements and extensions were added in the last years and have produced a mature product.

The WIL-MA software has been tested and evaluated in six mass lectures (computer science and psychology) with up to 240 students in each lecture until now. The students that used mobile devices had significantly better scores and their motivation was much higher. The software was also used in tele-lectures and in other Universities, e.g., in a joint project at the University of Stanford (WGLN, 2004; Kopf, 2005a). We developed a second stock exchange simulation based on NetLogo/HubNet to evaluate our system (Kopf, 2005b). The full functionality of the WIL-MA system could not be implemented, due to missing features in NetLogo like dynamic screens, menus or limited possibilities for interaction. Stocks can be traded by artificial or human agents. The administrator defines a specific strategy for each artificial agent based on the readiness to take risks. It is possible to select agents that get additional ”insider” information about the expected development of the prices of one stock. An example of the NetLogo client is depicted in Figure 4.

The behavior and the decisions of the artificial agents in NetLogo are analyzed first. 139 simulations with several artificial clients have been carried out. As expected, the standard deviation and the average total asset at the end of the simulation are higher for the agents that take higher risks. Artificial agents that receive (and use) insider information could increase their asset significantly.

The WIL-MA stock exchange simulation was developed for master’s students in business administration especially finance. The motivation of the students that tested the system was very high. We used an old PC as server (Pentium, 133 MHz) that was connected with DSL as server to test the functionality of the WIL-MA system and measure possible performance problems. Stocks, bonds and call options of 30 companies (DAX) were added to the system with prices and α/β-values, which are mandatory for the singe index model. During one simulation, nearly all prices of the stocks rose (bullish market). Students, which bought call options during the first part of the simulation, could increase their portfolio value significantly. If a great amount of credits was invested in bonds it was even possible that the total asset of some students dropped due to the transaction costs.

One of the major strengths of NetLogo is the interface builder. Elements of the client window can be arranged by *drag and drop* and it is very simple to add code to the elements. A graphical visualization for histograms or plots is integrated in the system and the network support for the clients works quiet well. A major disadvantage of the interface is its low flexibility. It is not possible, e.g. to visualize tables, use more than one window or change/rearrange the items in the window. The input on the clients is limited to sliders, choices or buttons. The internal use of lists and the missing exception handling is bothersome: The program crashes, e.g., if the administrator enters a character but the program expects a number.

The complexity of the stock exchange is very high. The functionality of NetLogo – especially the fact that everything must be visualized in one static window – is not sufficient to create simulations for these scenarios. An advantage of the WIL-MA architecture is that the administrator can make changes during the simulation, stop/pause or continue it, send messages to selected users or modify the value of market parameters. The effort to create a new simulation is much higher in comparison to NetLogo. We found out that the creation of the client window via drag-and-drop and the visualization of dynamic graphs or histograms are important features that are missing in the WIL-MA architecture.

The motivation of the students that used one of the simulations was very high, although the NetLogo simulation supports stocks only. Even before the final release of the NetLogo simulation was finished, several students tested the simulation and tried to develop strategies to maximize their assets. NetLogo is particularly useful if the number of parameters and interactions is not too large.

Outlook

The NetLogo/HubNet and the WIL-MA system are mature systems that are suitable to develop participatory simulations. The architecture of WIL-MA has proven to be very flexible and many other services to support new learning technologies have already been integrated into this system. A major advantage of participatory simulations is the fact that students learn to see patterns and understand coherences much easier. With all the technical advances it is of particular relevance to keep in mind only a part of the learning can be done with participatory simulations. The communication and discussion is always an essential part of the learning process. We believe that the emerging field of participatory simulations improves – especially in the case of complex systems – the learning success of students.

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