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TEACHING INTRODUCTORY SIMULATION IN 1996: FROM THE FIRST ASSIGNMENT TO THE FINAL PRESENTATION

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ABSTRACT

Rapid developments in computing and simulation are providing continuing challenges for the design and delivery of courses in discrete-event simulation. Such courses not only need to keep up with relevant developments, but also have the potential for taking advantage of some of the developments in the structuring of the courses. For example, animation can be the topic initially taken up in a course that covers both simulation and animation. We report here on a teaching approach in which a simulation course starts with the topic of animation, then introduces the programming-language subset of a modeling language to support animation at a fundamental level, then returns to animation to introduce more sophisticated aspects of that material, then goes back to the modeling language to investigate the modeling of queuing networks, and so on. Introducing animation first has the effect of capturing intense student interest and dedication at the outset of the course and has the additional benefit of helping students visualize and deal with parallel processes of the type they will be studying and modeling later in the course. Recent technological developments are further reflected by including a World Wide Web-based support system in the course.

1 FACTORS INFLUENCING THE TEACHING OF SIMULATION COURSES

The teaching of simulation is influenced by factors both external to and internal to the subject itself. Some of these factors are indicated below.

1.1 External Factors

The *audience* consists of people with differing backgrounds in computing, statistics, stochastic processes and practical work experience. Members of the audience often have a wide range of interests, from the general to the highly specialized. The audience can consist of undergraduate or graduate students majoring in such areas as engineering, computer science, business, health care, and public policy studies, and can include on-the-job professionals.

The available *time* for teaching a simulation course varies from one or several hours for a self-contained tutorial to one or two full-semester courses for students specializing in simulation.

The available *software* ranges from general programming tools to highly developed simulation and animation software with graphical user interfaces.

The available *hardware* ranges from standalone PCs to workstations with access to a global network of computers.

The skill and experience of the *instructor* is another factor that bears importantly on the teaching process.

1.2 Internal Factors

Internal factors involve topics intrinsic to the subject of simulation. Some of these internal factors are indicated below, in no particular order of importance.

Random Numbers are basic components of most discrete-event simulation models. The simulation specialist should know how random numbers are generated, tested, and transformed.

Event Handling with suitable algorithms and data structures is central to discrete-event simulation. It is easy to understand how a "future events list" is managed. It is not as easy to understand such things as the way time-tied events are resolved during the course of a simulation.

Input Modeling requires some skill in statistics and is a pre-requisite for building valid models.

Model Construction is as much an art as a science. The process of model construction is strongly supported by some simulation systems, less so by others, and the instructor has to decide what degree of support to make available to the students.

Verification and Validation of simulation models must be understood to support interpretation of modeling results in the context of real systems.

Experimental Design is an important skill for problems in which even a moderate number of experimental parameters is involved.

Output Analysis involves mathematical statistics and is an essential component of a simulation study.

Result Presentation is an area of increasing importance. Presentations typically include graphs and animations.

Simulation Software is available for supporting various phases of a simulation study. An understanding of the types of simulation software available and the development of operational capabilities with representative software is central to the study of simulation.

Simulator Construction is a subject appropriate for computer science students studying simulation.

The preceding topics, although not all inclusive, do reflect the content of representative simulation textbooks. Individual textbooks each seem to have their own bias, however, covering some of the topics in depth and providing only brief or no treatment of other topics.

Apart from textbooks, the teaching of simulation has also been the subject of discussion in some recent Winter Simulation Conferences, e.g. Romeu 1995; Withers et al. 1994.

2 TECHNOLOGICAL INFLUENCES OF THE LAST DECADE

The last decade has witnessed major new developments and trends in simulation methodology, in computing and communication, and in economic and business processes. Which technological trends impact simulation and should be reflected, included or exploited in a simulation course? Which trends are only of transient interest? We comment on these matters in the following subsections, while remaining open to constructive discussion and debate in this regard.

2.1 Presentation: Graphics and Animation

Graphical presentation of results has long been an essential aspect of simulation. Pseudo graphic presentation of simulation results dates back to simulation systems of the 1960s. In 1976 the PC appeared on the scene, but even by 1986 most PCs still provided only an alphanumeric display. Now in 1996 it is perhaps impossible to buy a PC without graphical display capabilities. And it is almost impossible to conduct a simulation study that does not include graphical presentation of results.

Animation is intimately involved with simulation. Animation depicts simultaneously moving objects and simultaneously running processes, and so animation algorithms are closely related to the basic underlying concepts of simulation. In fact, animation can be regarded as a sister or a child of simulation. Animation is a favorite candidate for inclusion in a simulation course.

2.2 Visual Interactive Modeling

The increased graphics performance of computers has been the basis for establishing Visual Interactive Modeling, which is "the use of icons on the screen to represent the system in a way that closely resembles the physical system" (Seila 1995), and involves an approach to modeling in which icons are linked together to represent network flows.

If a modeler has a VIM simulator with the predefined classes of objects needed in a particular model and with simple connections between the instances of the classes, then it can be relatively easy to build a model and still have time remaining to work on other aspects of a simulation project. VIM simulators can work well for specialized applications and can promote fast modeling of standard situations. They seem however not to be well suited for a general simulation course: they are not really *general* simulation systems and they hide essential parts of model behavior by hiding the supporting internal processes. A general simulation course should (we believe) promote understanding of these internal processes.

2.3 Multi-Purpose Models

Computer performance is growing by a factor of 10 every 7 years. That is a factor of about 1000 in the last 20 years! However, the increasing sophistication and complexity of simulation software might mean that in some cases simulations take more time to execute than in the past, despite the dramatic increases in computer performance. Nevertheless, fast simulators do exist and it is appropriate to ask: "How we can take advantage of fast, efficient simulators to enhance the quality of simulation modeling?"

One potential answer to this question lies in the possibility of building multipurpose models with a scalable degree of detail. Rather than following the old paradigm of simply "building models as detailed as necessary for a special purpose," we now have enough computing and modeling power to build models which answer not only predefined questions but also other (future) questions which cannot be foreseen by the model developer.

There is a general tendency in the technology toward more multipurpose hardware and software. But most simulation models are still only single-purpose. They could alternatively be multipurpose and be equipped with features that might be needed for a range of special-purpose uses. For example, a given multipurpose model could be useful for gaining insight into characteristics of the modeled system, for presenting aspects of system behavior to a variety of interested parties, and for training people who work within the system.

2.4 Business Processes and Global Economy

The last decade and probably to a much greater extent the next decade was/will be characterized by global operating organizations, global products and global markets. That fact should influence the content of simulation models and studies.

Material flow in a single factory is typical of the type of problem on which simulation has focused in the past. In contrast, the global flow of material and information might be a central subject of current and future simulation models. Should simulation courses include study of large scale and global models?

2.5 Communication Networks

Communication networks are growing dramatically. The Internet has already started to influence our entire society. How should the simulation community react to this? Where are there new ideas forthcoming for simulation software and simulation applications involving the World Wide Web? How should the Web be used for teaching support and how should it be included in a simulation course?

2.6 The Challenge

How should developments such as those listed above be reflected in simulation courses? It is clear that there are more questions at this time than there are answers. Over time it will be necessary for many simulation educators and practitioners to help contribute answers to questions impinging on future simulation instruction.

3 AN EXAMPLE OF ONGOING COURSE EXPERIMENTATION

This section describe procedures and experiences resulting from a teaching approach that is being developed and used to seek constructive responses to some of the preceding questions and issues. The approach is one that has been followed in three settings:

1. A one-term course offered in 1995 to computer science undergraduates at the University of Wisconsin at Stevens Point;
2. A one-term course offered in 1995 and 1996 to computer science graduate students at the University of Magdeburg; and
3. Tutorials on "Simulation and Animation" offered at EUROSIM '95 in Vienna; at a 1996 conference at the University of Magdeburg (Lorenz and Schriber 1996); for industrial people in Wisconsin in 1995; and for upper high school ("Gymnasium") instructors in Nordrhein-Westfalen (Germany) in 1996.

The content and the concept of the courses indicated under 1 and 2 above and their underlying teaching approach are called the *Reference Course* here. The following subsections are closely related to this Reference Course, which is based on a course duration of about 14 or 15 weeks.

3.1 Starting with Animation

A simulation course might reasonably start by explaining goals, terms, history and applications, and by giving introductory examples. But what comes next?

Historically, many simulation courses have then continued with the topic of *random number generators*. But this topic is now often deferred to a later course position (and moved to later chapters or even to appendices in textbooks) and might only be given very brief treatment or no treatment at all in a first course.

An alternative approach is to proceed with *basic algorithms and data structures* for simulation, explaining alternative control approaches, e.g., polling; related waiting; and so on.

A third possible approach is to proceed with *animation*. Moving the shapes of various objects around on a computer screen is a new experience for most students. Arranging for the smooth movement of objects along paths involves using a polling algorithm with small time steps and this goes hand in hand with basic aspects of simulation.

Proof Animation software (Henriksen et al. 1995) is well suited for this phase of a simulation course. Working with Proof Animation, the following basic concepts of animation can be introduced and explained:

1. Drawing or importing and using a scene or background or layout;
2. Defining classes and objects (which in turn provides a possible starting point for object-oriented programming and simulation);
3. Using the animation clock;
4. Creating objects, placing them on the layout, and moving them; and
5. Creating, writing and reading animation trace files and layout files.

No more than one lecture is needed to explain these basic concepts and bring students to the point of being given a first assignment. Here are examples of potential Assignment #1 exercises:

1. Objects are to be placed on the screen at various starting positions and then moved smoothly to final resting positions. Plan and implement the sequential creation and simultaneous movement of the objects.
2. Display a triangle using three different types of dots for the three sides.
3. Trace out a sine curve in a coordinate system.
4. Place 100 objects taken from five different object classes into a square.
5. Trace out a circle with small objects from a variety of object classes.
6. Build a chessboard, using red and white squares.
7. Make up your own assignment involving the movement of objects!

Some students come up with really good ideas when given a chance to compose their own Assignment #1. They often devise better exercises than those suggested by the instructor. For example, Figure 1 shows a snapshot taken from the animation of the assembly of a jigsaw puzzle developed for Assignment #1 after the first animation lecture. (Figures shown here look much better in their original color than in the black and white of the Winter Simulation Conference Proceedings.)

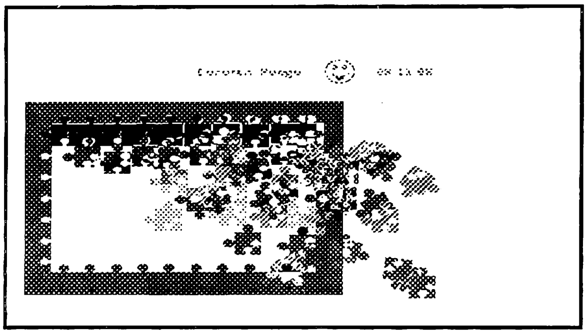

Figure 1: An Example from Assignment #1 - "Jigsaw-Puzzle Assembly Animation" (Carsten Poege, Magdeburg, Germany, 1995)

Starting with animation not only has methodological and educational advantages. It also has the advantage of exciting a high level of student interest and involvement with the material early in the course. Most students react very favorably to lectures on animation and look forward with anticipation to doing their animation homework.

In the first assignment the students learn to use software to create and write animation trace files. It is useful in lecture to show examples for trace file generation with a variety of tools: with a text editor, for example, and with Basic and/or Pascal and/or C++. *But it is recommended that students also use whatever software the instructor has chosen for building simulation models later in the course.* A simulation system with elementary algorithmic and file handling capabilities is needed to support Assignment #1.

Note that no simulation-specific features, functions or capabilities are needed to carry out Assignment #1

3.2 Intermediate Animation and Basic Simulation Tools

The next segment of the Reference Course deals with intermediate animation and basic simulation tools. Intermediate animation involves the dynamic display of messages, bars and plots. On the simulation side, the items of choice for providing information to be animated can include random number generators and procedures for the transformation of uniform random numbers into random numbers sampled from theoretical or empirical distributions.

Assignment #2 can then be an exercise in using simulation and animation tools of the indicated kind. First, all students are given the preliminary assignment to write their name and the current date on the screen and display a running analog clock (with hour and minute hands). Individual problems of the following type are then assigned, one for each student:

1. Generate exponentially distributed random numbers over time and display the relative frequencies of realized values in a dynamically changing histogram as well as in a table. Ask the user for a random number seed, a sample size, and the end points of the frequency class intervals.
2. Repeat 1, but with alternative theoretical or empirical distributions.
3. Display the plot and the corresponding tabled values for a trigonometric function of choice. Ask the user for the range of angles to be covered and the angle increments to be used.
4. Display the plot and the corresponding tabled values for a specified polynomial. Ask the user to provide the domain of the function to be displayed and the size of argument increments to be used.

Figure 2 shows a snapshot from a student solution to a typical Assignment #2 problem.

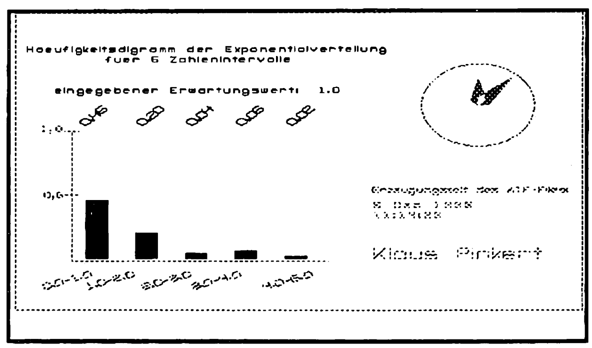

Figure 2: An Example from Assignment #2 - "Frequency Histogram, Exponential Distribution" (Klaus Pinkert, Magdeburg, Germany, 1995)

The objective in Assignment #2 is to gain practice in displaying plots and histograms while using the algorithmic capabilities of the simulation software to produce the information being animated. After completion of the assignment, students are familiar with operational aspects of handling the animation and simulation software. They are then ready to jump into a more traditional area of discrete event simulation: the simulation of queuing systems and networks.

3.3 HTML-Based Lecture Notes (WWW Support)

Customized materials developed and written by an instructor to support a course are traditionally produced on paper and distributed to students in that form. A relatively new alternative to this approach is to use HTML (the HyperText Markup Language) to make such materials available to students on the World Wide Web. Some of the considerations involved in taking this approach have been articulated by Antchev et al. 1996.

HTML-based lecture notes and course materials are used in the Reference Course. The course support system can be found at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/docs/welcome.htm

German and English versions of these HTML-based lecture notes are under continuing development. The support system is intended to escort and guide students throughout the entire course. Above and beyond completely replacing the former paper-based course materials, the HTML-based course support system has these characteristics:

1. It is easily accessed and handled by students, providing them with needed course materials and updates at low (or no) cost.
2. It is a hypertext system with links between related subjects.
3. It facilitates easy and timely modification, extension, and correction of materials by the instructor.
4. It is a tool for providing a suite of graduated simulation models that reflect increasing degrees of modeling complexity. The models are provided for more than viewing purposes. These models can be freely edited *in situ* on their WWW page and simulations can be performed with the models without leaving the Web browser.
5. The materials can be easily and inexpensively enhanced with colored pictures, experimental frames, and so on.

Among the Web support materials, for example, is the full text of all assignments that exist to date for the Reference Course. These assignments are in German at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/docs/assign.htm

and can be found in English at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/edocs/assignmt/ass.htm

Currently the simulation models provided as part of the support materials are based on GPSS/H (Banks et al. 1995; Schriber 1991) as a general purpose simulation system. But other text-based simulation systems could be used as alternatives. Good choices for using the Web are those simulation modeling systems that have a complete alphanumeric interface.

Figure 3 shows a snapshot of the introductory simulation model included in the support materials for the Reference Course. This is a model for the one-line, one-server system known as Joe's Barbershop. Anyone and everyone can see, modify, and run this model at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/docs/sa4/sa41/welcome.htm#model

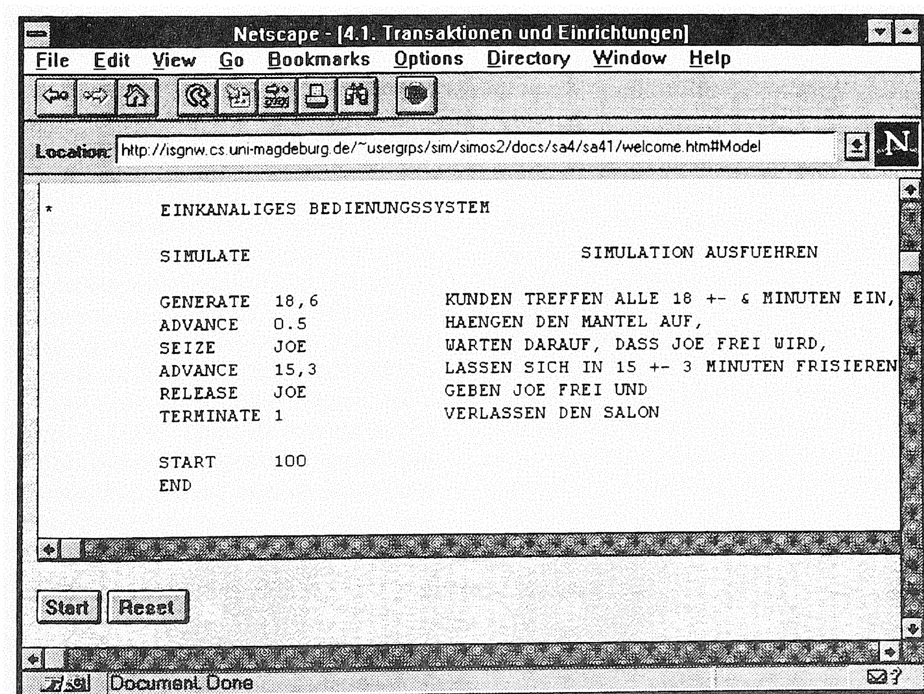

Figure 3: A Snapshot of a Web Page
Showing the Introductory Editable and Executable Simulation Model

Joe's Barbershop is the first in a series of about 20 simulation models currently included in the Web materials for the Reference Course. Entree to these models is provided at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/docs/appendix/progexpl.htm

The Reference Course does not have full WWW-based support for *animation* as of this writing (July, 1996). Ongoing developments in Web technology lead to good expectations for the near future in this regard, however (Dorwarth et al. 1996).

3.4 Modeling Queuing Networks

As suggested above, simulation of queuing networks is introduced in the Reference Course with Web-based accompaniment of live exercises. The students by now have experience in using the algorithmic statements of the simulation software. This means they only have to learn a few simulation-specific object classes and statement types at this point to move into queuing-network simulation. And, thanks to their earlier work with animation, when students leave their first lecture on queuing system simulation they already have specific operational insights into techniques for animating such systems.

The WWW-based course support does currently contain an example of a single-server animation to reinforce and extend student insights into animation. The example is available at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/docs/sa4/sa41/singlpr.htm

Taking the single-server model as a starting point, students build models for more interesting queuing networks in Reference Course Assignment #3. Here are typical examples of Assignment #3 problems:

1. Modify the model of Joe's Barbershop by including one of the following conditions:
   a. One barber (for men only) and two hairdressers (for women only) work in the shop. Women do not wait for a particular hairdresser.
   b. In a shop with one barber and two hairdressers, the men can be served by the hairdressers too.
2. A fast-food drive-in has three windows. The first window is for placing orders. The second is to pay for the food and the third is to pick up the food. Between consecutive windows there is enough room for five cars. Cars arrive every 4 +/- 3 minutes. It takes 2 +/- 1 minutes to order, 1.0 +/- 0.5 minutes to pay for and 3 +/- 2 minutes to pick up the food. How many cars arrive in a day? What can you say about the queues in front of each window?
3. A cable car moves between two points to take people up and down a mountain. The car holds 20 people. It starts moving only if it contains at least 15 people. The trip takes 15 minutes each way. How often does the cable car move in a day if people arrive every 4 +/- 2 minutes at one point and every 6 +/- 3 minutes at the other point?

Figure 4 shows an animation snapshot taken from an animation produced by a student for Assignment #3.

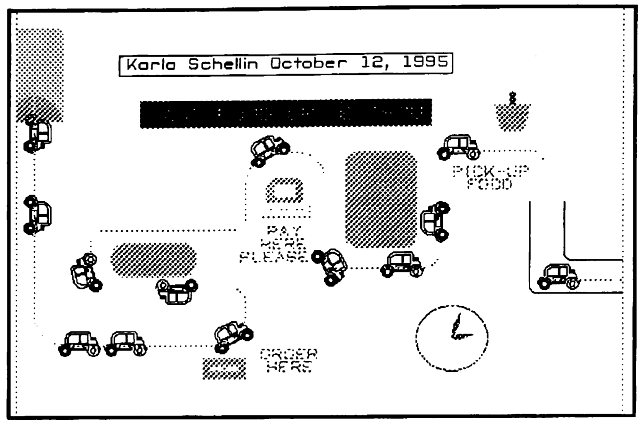

Figure 4: An Example from Assignment #3 - "Fast-Food Drive-Thru"
(Karla Schellin, Stevens Point WI, 1995)

3.5 Final Presentation

After finishing Assignments #3, the students are prepared to begin work on their Final Presentation (final assignment) in the Reference Course. The Final Presentation is a simulation project. The students are entering the last segment of the Reference Course at this point and are poised to learn how to model more complicated queuing situations and use animation to demonstrate system operation. There is strong student motivation now to absorb the content of the concluding lectures to support work on the Final Presentation.

The lectures in this last segment of the course provide an introduction to modeling complex control strategies and the corresponding control mechanisms and underlying logic provided by the simulation software. This insight into "how simulation software works" (Schriber and Brunner 1995) is important for correctly capturing the logical complexities of the real or envisaged system in the associated simulation model and animation.

Work on the Final Presentation is demanding. The students have to be innovative and imaginative and "fill in the gaps" in terms of material that has not been given explicit treatment in the Reference Course. The following text is a lightly edited extract from the Web-based specifications for the Final Presentation. The full text can be found at:

http://isgnw.cs.uni-magdeburg.de/~usergrps/sim/simos2/edocs/syllabus.htm

The following collection contains exercises. You can select one of these exercises as the subject of the Final Presentation. (See "Grading Policy" in the Syllabus.) You must build a simulation model with an animation for the Final Presentation.

The Final Presentation will be evaluated as follows:
1. *Simulation and animation models (60%)*
2. *Written documentation (20%)*
3. *Verbal presentation (10 minutes; 20%)*

The main criteria for evaluating the models are the correctness of mapping the given system into the model, readily comprehensible code, and the visual quality of the animation.

Every Final Presentation has to include the following:
1. *A Proof Animation presentation file that describes the system being modeled, the input data, the running processes and the results.*
2. *A display of current simulated time on an animated clock.*
3. *A title page with your name, a title for the assignment, and the date of the presentation.*

If work on the Final Presentation is limited to the points mentioned above, the work will be evaluated with a maximum grade of "C." At least two additional components taken from the following are needed for the maximum grade to be a "B":
1. *The source code must be well documented by building easily-read comments into it.*
2. *Multiple experimental runs must be specified in an experimental frame that provides values for model parameters and random number seeds.*
3. *A report file presenting the results in an easily readable format must be included.*

Additional considerations used to evaluate the animation are these:
1. *Have plots and bars been used for the presentation of results?*
2. *Does the presentation file show a variety of animation views?*
3. *Does the presentation includes images (PCX files)?*

The written documentation must contain these sections:
1. *Assignment*
   This section contains the description of the assignment. This section should also indicate the requirements for animating the model.
2. *Analysis of the input data*
   The given input data must be analyzed and statistically fitted. How did you transform the input data into computer-readable form? In case no input data is given, you have to create your own data by e.g. observing the system.
3. *Model conception*
   This section provides the description of the model. Describe the mapping of the real objects to object classes in GPSS/H.
4. *Model description*
   This section contains a listing of the GPSS/H model and explains the structure of the model.
5. *Animation description*
   This section describes the mapping of model elements into animation system object classes and objects.
6. *Description of the experiment*
   In this section the content and organization of experiments are to be described.
7. *Evaluation and discussion*
   The results of the experiments are to be discussed and evaluated here.

A snapshot taken from the animation for a Final Presentation is shown in Figure 5.

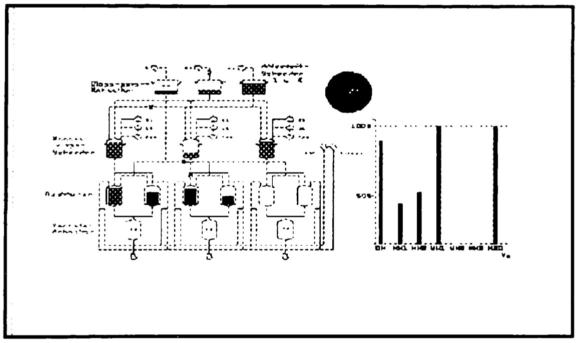

Figure 5: An Example from a Final Presentation - "Polymerization Reactors in a Chemical Plant" (Marcel Goetze, Magdeburg, 1996)

4 BENEFITS OF STARTING A SIMULATION COURSE WITH ANIMATION

Some of the benefits realized from starting an introductory simulation course with animation are summarized here.

The benefits for the instructor include these:
1. Intense student interest and dedication is captured from the very beginning of the course.
2. Animation provides a straightforward and interesting way for the instructor to gain a preliminary impression of a student's work.
3. A high level of student interest develops in the possibility of taking an advanced simulation course.

Among the benefits for the student are these:
1. The slope of the simulation/animation learning curve in the course is flattened substantially.
2. Knowledge and insights about the *visualization* of concurrent processes are gained.
3. Valuable experience is obtained in the *presentation* of systems, models, and processes.

5 ADVANCED COURSES

The graduate of the Reference Course has worked intensely on model construction and animation and is capable of building simulation and animation models at an intermediate level. But s/he lacks knowledge about the theoretical foundations of simulation. Many approaches and techniques have been explained and learned strictly by example, without benefit of a general or theoretical foundation. A student coming out of the Reference Course is poised to take an advanced simulation course. The student has been primed for such a course, having encountered many questions that could not be answered precisely (for lack of time) during the Reference Course.

Included among potential advanced-course topics are:

1. How do *Random Number Generators* work? What are the measures of generator quality? Which quality attributes might influence the validity of a model?
2. How can Real System Data can be transformed into *Input Model Data?* Which statistical methods and which programming tools are available for modeling input distributions?
3. What approaches and what body of experience can be brought to bear on *the construction of large, multipurpose models* of complicated systems?
4. What methods are available for *Verification and Validation* of simulation models?
5. How can *experiments best be designed and conducted* to investigate system behavior with models characterized by large numbers of parameters?
6. What methods and tools are available for the *Analysis of Output*?

6. CONCLUSION

The pattern experimented with in structuring an introductory discrete-event simulation course that starts with animation and then alternates between simulation and animation topics has been described. Experience gained in teaching such a course has been reported, and glimpses of several examples of student work produced in such a course have been presented. Inclusion of a World Wide Web-based support system for such a course has been described. The success of this teaching approach has been so encouraging that continued offerings of introductory courses along this line are planned.

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