

EXPERIENCING NATURAL PHENOMENA WITH VIRTUAL, CONSTRUCTED AND MATHEMATICAL MODELS

Stephan Diehl
Carsten Görg

FR 6.2 Informatik
Saarland University
66041 Saarbrücken, GERMANY

ABSTRACT

In this paper we discuss how different kinds of models can be combined in an educational setting to enable students to experience natural phenomena, here earthquakes. Different tools enable students to manipulate virtual models, construct physical models and formulate mathematical models. Ideally, the modelling processes and the resulting models complement each other to some degree. Virtual and physical models can then be driven by real data as well as mathematical models of the phenomena.

1 INTRODUCTION

The ideas presented in this paper are under development in a current research project (COLDEX, EU-FP5 Project IST 2001-32327, <http://www.coldex.info>) with the goal to develop and use new computational tools to foster scientific experimentation, modelling and simulation in distributed collaborative settings. It focuses on visual and other perceptual phenomena, including astronomical and seismic measurements.

In this paper we consider earthquakes as an example of natural phenomena. Earthquakes are caused at a spot deep below the surface, which we call its hypocenter. The point above the hypocenter on the earth surface is called the epicenter. With the help of seismographs the waves of an earthquake are recorded at different measuring sites. In particular, seismographs record two kinds of waves. Both kinds of waves propagate straight from the hypocenter to the measuring site. Primary waves create a back and forth movement of the rocks through which they travel, while secondary waves produce a side to side motion.

2 MODELS AND SIMULATION

The term *model* is used in various ways in computer science and science in general. Etymologically, model means *small measure* (from the Latin *modus*). This gives rise to a first

characterization of models. Models are not small scale copies of reality, but reduced in the sense that they allow to measure less properties.

As Noam Chomsky said in an interview (Chomsky and Cockburn 1994): “If you study the planets, for example, it helps to think of them as points which have mass and move in elliptical trajectories around other points. Of course, the planets are not points – a point has no dimensions – but if you treat them as such, you can predict and understand the solar system more clearly. That is a model.” So by using models we abstract from or simplify reality to be able to predict and understand natural phenomena.

In a more general way Cellier defines models and their role for simulation (Cellier 1991). “A system is a potential source of data. An experiment is the process of extracting data from a system by exerting it through its inputs. A model for a system and an experiment is anything to which an experiment can be applied in order to answer questions about a system. A simulation is an experiment performed on a model.”

The descriptions above are all about the purpose of models, but not about their representation or the medium they are encoded in. We will look at three different representations in the rest of this paper: virtual (here: 3D graphics), physical and mathematical (in the form of equations or formulae).

Note, that this is different from sets of models as for example in UML or a multimodel (Ören 1991) which is a network or hierarchy of models. There models represent systems at different levels of abstraction or granularity. This is not necessarily the case for the models we are looking at, although, typically, the different media lend themselves to different aspects and different levels of abstraction for the same system to be modelled.

In our educational settings modelling processes and not ready made models are crucial for active learning. Thus we will also focus on the modelling processes here.

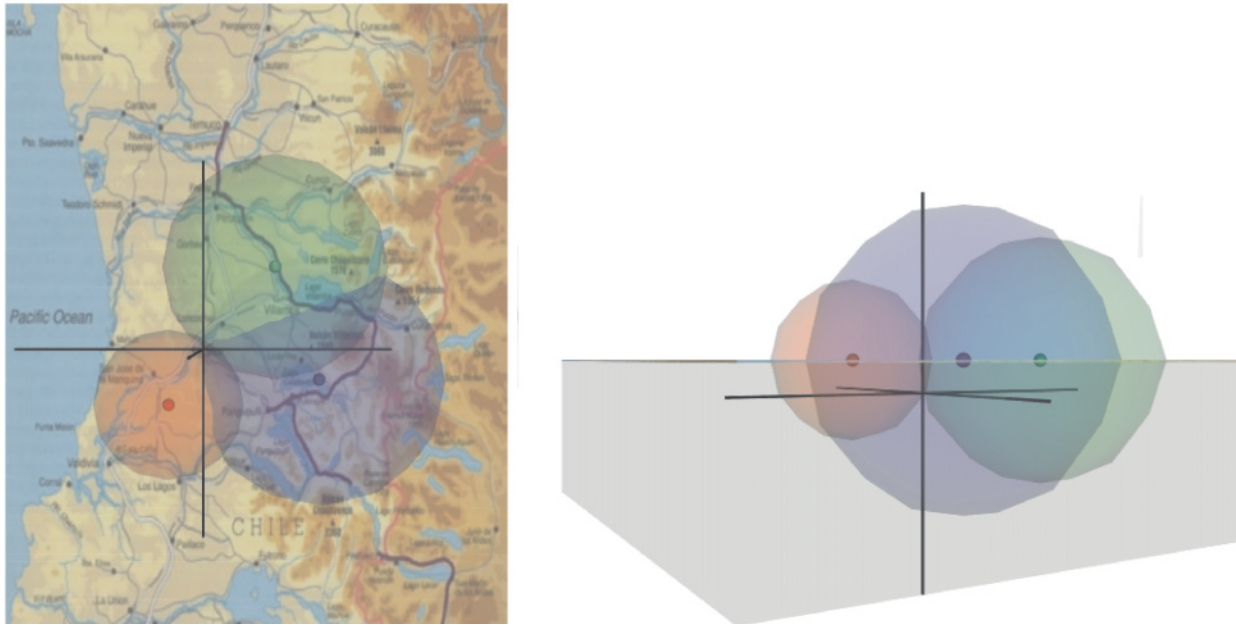


Figure 1: Detecting the Hypocenter in 3D

3 VIRTUAL MODELS

Often virtual models are developed in a way to imitate reality as much as possible and achieve photorealism. In educational contexts virtual models are used primarily for another reason (Diehl 2002): Virtual models can show properties and relations which are invisible in reality. For example, exaggerated scaling allows to fit objects, which are far from each other, on the screen. In Figure 1 a 3D model is used to visually detect the hypocenter of an earthquake. The radius of the spheres is the distance of the measuring site from the hypocenter. The user can interactively place the graticule within the intersection of all three spheres.

3.1 Tools

X3D (eXtensible 3D) is the next-generation open standard for 3D on the web (<http://www.web3d.org>). It replaces VRML, but also provides compatibility with existing VRML content and browsers. Extensibility means that X3D can be used to make a small, efficient 3D animation player, or to support the latest streaming or rendering extensions. By supporting multiple encodings and APIs, it can easily be integrated with web browsers through XML or with other applications. X3D is also used to provide 3D support within MPEG-4. There exist a variety of open-source as well as commercial authoring tools that generate X3D.

4 CONSTRUCTED MODELS

Models are built by hand and can be manipulated (from the Latin word *manus*, meaning "hand") providing a firsthand

experience. Thus constructed models use the tactile sense in addition to the visual sense. Looking at science we also find that historically scientists used to build their own instruments and from this tool building got additional insights into the phenomena they wanted to study (Resnick, Berg, and Eisenberg 2000).

In our educational earthquake scenario students can build their own seismograph or a motion platform with a toolkit basically using two motors to tilt and lift the platform. Figure 2 shows the platform in use (left) and the motors below the platform (right). On top of this motion platform students can put different things, including towers built with Lego bricks, to see how stable they are.

4.1 Tools

The RCX is the programmable "brain" for robots which can be created with the Lego Mindstorms(tm) construction kits (<http://mindstorms.lego.com>).

The RCX brick contains a processor and 32kb of RAM, has 3 output ports for motors, 3 input ports for sensors, a speaker, four buttons and a small LCD. In most cases programs are downloaded onto the RCX via infrared and then the robot works autonomously.

lejos (<http://lejos.sourceforge.net>) replaces the firmware of the Lego Mindstorms RCX brick with a reduced Java Virtual Machine and thus allows to program Lego robots with Java.

The versatility of the construction kit allows to use it in various and very different learning situations. In our context students can build functional, simplified models of real devices like telescopes or seismographs. Although

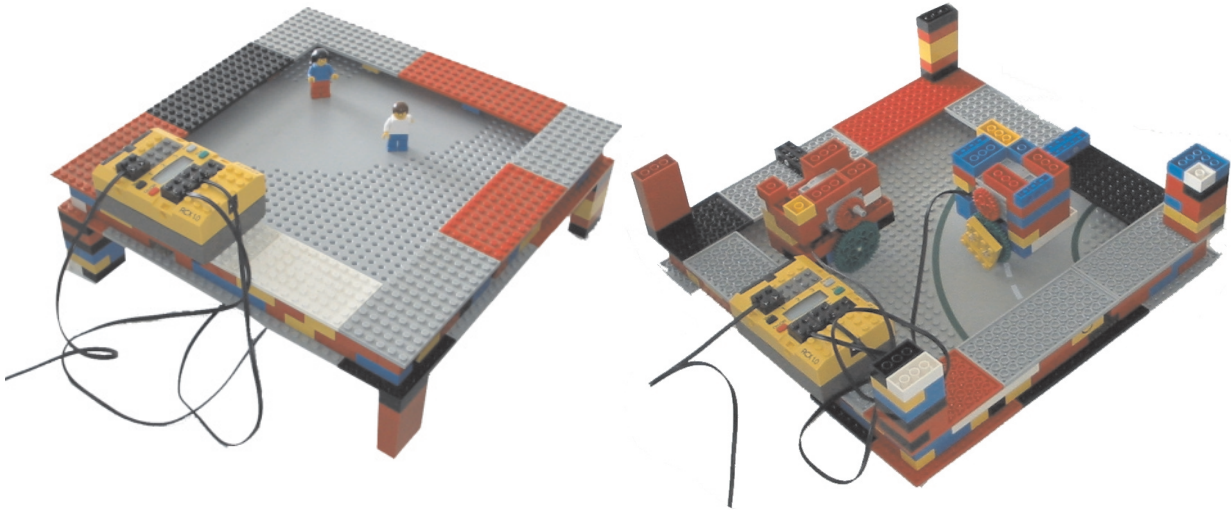


Figure 2: Motion Platform

programming the RCX is very simple with the visual programming environment provided by Lego, it can be too demanding for some students to require that they program the RCX. In these cases RCX programs have to be provided for the specific modelling task at hand.

5 MATHEMATICAL MODELS

A mathematical model is an equation or set of equations used to describe some real phenomenon. Some of the variables in these equations represent properties of real objects. A typical application of such a model is that the values of some of the properties are known and the equations are solved thus that the values of other properties can be computed.

In countries like Chile where earthquakes are part of everyday life, students learn mathematical models of wave propagation at school and use them to compute the hypocenter. More precisely they use the wave data measured at three different sites. For each site they measure the time lag between primary and secondary waves, see Figure 3.

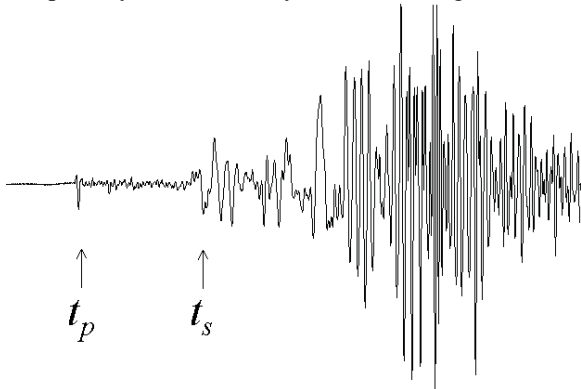


Figure 3: Primary and Secondary Waves

A typical problem with respect to earthquakes is how to model waves and their propagation through the earth. Assume that the earthquake occurs at time t_0 and that the primary wave travels with speed v_p and arrives at time t_p at the measuring site (analogously, v_s and t_s for the secondary wave). Then the distance Δ is

$$\Delta = (t_p - t_0)v_p = (t_s - t_0)v_s \quad (1)$$

At the measuring site we only measure the time lag $t_s - t_p$, so by transformation we get $\Delta = \frac{(t_s - t_p)v_p}{v_p - v_s}$. Assuming a certain speed of propagation of these waves the epicenter is calculated by triangulation.

For modelling we can also look at the inverse problem. Given the *strength* of an earthquake, a hypocenter or epicenter, and a measuring site (distance to hypocenter) provide a model of wave propagation which can be used to predict the waves observed at the measuring site.

5.1 Tools

Mathematical models are usually developed with pen and paper. For more complicated cases scientists will use tools for numerical and algebraic calculation like Mathematica (Wolfram Research Inc. 2003). For students visual modelling tools like Cool Modes (Pinkwart, Hoppe, Bollen, and Fuhlrott 2002) facilitate mathematical modelling by providing the possibility to define the relations between different entities as graphs. Information flows along the edges of these graphs and equations can process this information.

6 COMBINING MODELS

The different kinds of models discussed above are not developed in isolation, but they should complement each other to some degree. So students formulate models with graphical and mathematical modelling tools. These models can then be used for simulations which drive the virtual experiments.

Obviously the RCX could just produce random movements of a certain strength. But things become more interesting when the student is able to download real seismic data from the net and use this as input for the motion platform. With the same toolkit the learner can also build a simple seismograph using a light sensor to detect movements. Even more the output of the seismograph can be used as input for the platform.

7 MODELLING PROCESSES

Next we look at the key steps of the modelling processes for each of the kinds of models discussed above. In all three modelling processes steps 3 and 4 can be supported by tools.

Virtual Modelling

1. Identify relevant real objects and their behaviors
2. Find visual abstractions for these objects and behaviors
3. Define these visual abstractions of objects with X3D primitives
4. Define behaviors with X3D nodes or implement them as Java or JavaScript programs

Physical Modelling

1. Identify relevant real objects and their behaviors
2. Find simplified constructions for these objects
3. Build these constructions with Lego bricks
4. Implement behaviors mechanical or by programming the RCX

Mathematical Modelling

1. Identify relevant properties and relationships of the real world
2. Identify relevant mathematical areas (e.g. stochastics, geometry)
3. Encode the properties and relationships as a set of equations
4. Solve equations. Possibly implement them for experimentation

These modelling processes are usually extended by general problem solving strategies like iteration or divide&conquer. In an iterative approach the results of the model are compared with the behavior of the actual system. If they do not agree some of the steps have to be repeated.

8 CONCLUSIONS

Modelling is performed on different levels: physical, visual and conceptual. We expect that providing and combining modelling tools on all these levels helps to better understand natural phenomena.

REFERENCES

- Cellier, F. E. 1991. *Continuous systems modeling*. New York: Springer Verlag.
- Chomsky, N., and A. Cockburn. 1994, Fall. Models, nature and language. *Grand Street*.
- Diehl, S. 2002. Web3D. In *Handbook on Information Technologies for Education & Training*, ed. H. Adelsberger, B. Collis, and J. Pawlowski, International Handbook on Information Systems Series. Springer-Verlag.
- Ören, T. I. 1991. Dynamic templates and semantic rules for simulation advisors and certifiers. In *Knowledge-Based Simulation: Methodology and Application*, ed. P. A. Fishwick and R. B. Modjeski, 53–76. New York: Springer Verlag.
- Pinkwart, N., U. Hoppe, L. Bollen, and E. Fuhlrott. 2002. Group-oriented Modelling Tools with Heterogeneous Semantics. In *Intelligent Tutoring Systems, Proceedings of 6th International Conference, ITS 2002*, ed. S. Cerri, G. Gouardères, and F. Paraguaç, LNCS 2363, 21–30. Springer-Verlag.
- Resnick, M., R. Berg, and M. Eisenberg. 2000. Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. *Jour. Learning Sciences*, 9(1): 7–30.
- Wolfram Research Inc. 2003. Mathematica. <<http://www.mathematica.com>>.

AUTHOR BIOGRAPHIES

STEPHAN DIEHL is an Assistant Professor at Saarland University. Stephan Diehl studied computer science and computational linguistics at Saarland University, and as a Fulbright scholar at Worcester Polytechnic Institute, Massachusetts. He got his PhD from Saarland University as a DFG scholar working in the group of Prof. Reinhard Wilhelm. Stephan Diehl's research interests include programming languages and compiler design, internet technologies, educational software and visualization, in particular software visualization. He is a member of GI, ACM and the Web3D-Consortium. His e-mail address is <diehl@acm.org>, and his web page is <www.cs.uni-sb.de/~diehl>.

CARSTEN GÖRG is Research Assistant at Saarland University. His current research interests include software visualization and dynamic graph drawing. His e-mail address is <goerg@cs.uni-sb.de>.