An analogical representation of liquids based on a physical mechanism.

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ABSTRACT

In this paper we discuss the advantages of an analogical representation for liquids evolving according to simple local rules. These rules embody the physical knowledge people use, when deducing the differential equations expressing physical laws. As an example we show how the phenomenon of wave propagation in liquids can be represented. We also discuss the possible use of such an analogical representation for certain types of problem solving.

1. Introduction.

Different approaches have already been proposed for the representation of knowledge about liquids. Naive physics, based on common sense behavior of physical systems, relies on first order logic as formalism for such a representation (Hayes 1985). Qualitative physics constructs a representation based on the qualitative equivalent of the quantitative physical laws which describe the system under study (DeKleer 84),(Forbus 84). Both approaches have their drawbacks. Naive physics does not always provide a correct answer to a given problem, because it relies only on naive observations of physical systems. Qualitative physics is not able to provide a unique answer to a given problem because, working qualitatively, one discards a lot of information which guarantees the uniqueness of the solution in the quantitative approach.

To overcome some of these difficulties, a new approach based on an analogical representation, has recently been proposed (Gardin 86). In this approach a liquid is modelled as an ensemble of interacting liquid particles. These particles do not directly correspond to molecules but rather to small macroscopic volumes of the liquid. They are made to interact according to local laws (i.e. between nearest neighbors), which are inspired from naive observations. In this way many physical processes involving liquids have been simulated.

In our work we adopt this molecular approach, but we propose to construct local interaction laws by reasoning along the same lines as physicists do, when deducing the differential equations of physics. They thereby rely on very fundamental ideas such as conservation laws, symmetry principles, and Newton's laws. Moreover, this type of physical reasoning is truely local in the sense that it expresses all the fundamental concepts and relations in terms of so-called infinitesimal quantities. Classical physics then attempts to integrate these equations in order to obtain macroscopical information about the evolution of the system (Feynman 1964). This step is traditionally approached with the help of mathematics. However, such an integration is often not possible and if it is, the qualitative content of the solutions is not obvious.**

We propose to circumvent this mathematical integration procedure and instead obtain the macroscopical behavior directly from the microscopical laws through simulation with an analogical representation. Our purpose is to construct a representation of liquids which can reproduce macroscopical qualitatively correct behavior of liquids.

A model like ours, based on simple local interaction laws, is well adapted to be implemented on a parallel architecture. We have built a software system on a small network of forty transputers, which allows experimentation with different types of interaction laws. All our experiments are done with this system.

2. The model.

For the time being we use a simple analogical representation: a two dimensional grid of liquid cells. These cells have to be considered as small volumes of liquid containing many molecules. In fact we will not take into account the molecular structure of a liquid. The cells in our model correspond to infinitesimal volumes in the sense of differential calculus. This means that within such a cell we can consider all quantities to be independant of the particular location in the cell.

In order to describe the state of a particular cell at a certain instant of time we introduce the following variables:

1- The *displacement* of the cell as measured with respect to a given equilibrium position.
2- The *density* of the liquid in a cell. It is expressed as mass per volume.
3- The *pressure* in the cell. It is related to the density through a phenomenological law which can be further explained only when one takes into account the molecular structure of the liquid. For our model we simply postulate such a law.

These three varaibles describe the state of a cell internally. Externally a cell is connected to four neighbours which we will call top, bottom, left and right for convenience. It is only with these neighbours that a cell can interact directly. This interaction is of a rather simple type: the values of the variables in the neighbours influence the evolution of the variables in the cell.

The second essential ingredient of our model is the dynamics governing the evolution of the cells. This dynamics has to be expressed in terms of some simple local interaction laws which implement a physical phenomenon. We have choosen to model one of the many aspects of liquid dynamics: wave propagation. Classically this phenomenon is described by the celebrated wave equation, which in one dimension looks like:

$$\frac{\partial^2 \chi(x,t)}{\partial x^2} = \frac{1}{c^2} \frac{\partial^2 \chi(x,t)}{\partial t^2}$$

where $\chi\ (x,t)$ denotes the displacement of a small volume of liquid centered around the point x at time t. The physical mechanism which lead to the deduction of this equation can be translated into the following three local evolution laws for liquid cells:

1- Each cell checks the displacements of its four neighbours. A difference between the displacements of its left and right neighbour or its top and bottom neighbour results in a change of volume of the cell. We assume conservation of mass and therefore this change in volume induces a change in density of the liquid.

2- The density in a given cell is related to the pressure in that cell through a phenomenological law. We assume that there is a linear relation between the excess* density and the excess pressure. The coefficient in this relation is a parameter controlling the compressibility of the liquid.
3- After the new values of the pressure have been calculated in all the cells, every cell updates its displacement according to Newton's law. This means that a difference in pressure in the left and right neighbour results in an acceleration of the cell towards the neighbour with lowest pressure and therefore in a new displacement.

These three steps are then repeated to calculate the next step in the evolution.

3. Results

Although we have only introduced local interaction laws between nearest neighbours, we obtain global behavior which is in accordance with observation. Starting from an initial equilibrium state, where all the cells have the same value for their variables, and introducing a small perturbation in one of the cells** we observe the propagation of this perturbation as a wave. This wave is reflected when it hits the border, thus creating interference patterns between the incident and reflected waves. These patterns correspond to those one can observe when dropping a stone in a pound.

We also did a double slit experiment. This consists of creating a wave which impinges on a screen with two narrow holes. Our model reproduces the correct behaviour consisting of a reflected wave and two smaller secondary waves behind the screen. These two secondary waves form interference patterns similar to those one observes when dropping two stones at the same time in a pound.

The advantage of opening up the mechanism behind wave propagation, instead of working with the wave equation itself, becomes clear when we want to modify this mechanism. Introducing viscosity requires no ingenuity. A simple friction term in Newton's law will do. It is also easy to experiment with compressibility in order to model different types of liquids. We have observed that changing the compressibility of a liquid has an effect on the velocity of wave propagation. Also in this aspect our representation is in agreement with real liquids. We want to emphasize that all these properties of liquids are recovered as macroscopical features. They are so to say implicitly contained in the local interaction laws between adjacent liquid cells.

In the following section we demonstrate the use of our model for problem solving. Finding the way in a maze can easily be done by exploiting a metaphor involving a viscous liquid.

4. Application

Suppose we want to find the shortest route from entrance to exit in a maze of arbitrary complexity. It is enough to note that if a maze were totally filled with a nearly incompressible liquid and if some more liquid were introduced under pressure

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* By excess we mean the difference between the actual value and the equilibrium value which corresponds to no evolution.

** e.g. a small displacement from equilibrium position at the entrance, because of the almost incompressibility and the conservation of matter, an equal amount of liquid must flow out at the exit. The liquid molecules which moved during this process automatically trace the shortest path from source to sink. It is as if the liquid which fills the maze, blows up the obstacles until only the free way through them remains.

We have done this experiment using the analogical representation of liquids we have constructed. Instead of actually tracing the moving liquid molecules we simply put a pressure source at the entrance of the maze and a pressure sink at the exit. Thanks to the propagation mechanism a pressure gradient is established and this corresponds to the path the molecules follow. We have observed that this gradient indeed coincides with the shortest path from entrance to exit. Moreover, the system can dynamically cope with modifications of the maze. The pressure gradient can quickly adapt to any alteration of the arrangement of obstacles. We want to emphasize the importance of using the true physical laws. Only in this way can we be sure that a liquid in our analogical representation behaves in accordance with a real liquid.

This solution of the maze problem is an illustration of the use of analogical representations for problem solving in the domain of common-sense. By translating a problem into a carefully choosen analogical representation it becomes possible to solve the problem in a most natural way (Steels 1988).

4.1. Conclusion.

Analogical representations combined with local evolution laws obtained from physically well understood mechanisms, provide an alternative to symbolic knowledge representation for physical systems. Most knowledge is implicit and can be made explicit by running a simulation. These lead to physically plausible predictions about the behavior of the systems one wants to store knowledge about. As a consequence, these representations lend themselves perfectly for certain types of problem solving by exploitation of physical metaphors. We believe this approach is a valuable complement to the traditional symbolic way of representing knowledge and problem solving.

5. References

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