NEW DIRECTIONS IN SCIENCE

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The Santa Fe Institute was founded about 12 years ago by a group of scientists who, for one reason or another, had come to the conclusion that something was really very broken in the practice of science in the American university. Individual disciplines dominated the research agenda to the exclusion of almost all interdisciplinary work, and the research agendas of these disciplines were narrowing to an alarming extent. The Santa Fe institute was organized to be a entirely visiting institution, a place where people could come on sabbatical or for extended workshops and not be constrained to the rigid requirements of department life, or worry about publishing yet another unread paper to insure the proper number of refereed publications the tenure committee might require for permanent appointment. On the whole, this experiment has been quite successful, and I think that we can point to a number of cases where ideas generated in the give and take of interdisciplinary discussion have become almost mainstream in academic circles. Several of these are in the Social sciences, and today I would like to talk a bit about computer simulation, and the challenges we all face in introducing simulation techniques from the physical sciences into the realm of cultural and economic problems.

The cultural and economic sciences seem to be ready made for extensions of the Monte Carlo techniques so prevalent in the design and analysis of High Energy Physics and Accelerator experiments. These problems almost always consist of large aggregations of individuals or organizations which interact as time progresses in a sequence of encounters, with themselves or with their environment, leading to a statistical distribution of effects which can characterize the development of the system. But things are never as easy as they might seem.

Simulation is used in the Physical sciences to investigate the really hard problems where analytical methods cannot give adequate description to the interactions involved. In the case of particle accelerator physics, beam interaction and space charge effects are almost always handled via simulation techniques. Simulation is more prevalent in the design and analysis of high energy physics experiments, where Monte Carlo simulations of event signatures, spectrometer acceptance, and background rates are almost always required by the program committee before beam time is allocated. Simulations are often required in the analysis of the experimental results, again for geometrical acceptances as well as detector efficiencies, etc.. Of course, the most complex of the simulations in the physical sciences is probably in the codes which are used to design and analyze nuclear explosions, which combine particle transport with hydromagnetic and radiation effects in a extremely complex way.

Moving to the biological sciences, including ecology and evolution, we see a more complex system, and thus more difficulty in applying simulations accurately. In the Social sciences, the interacting entities can think, plan ahead, make mental models of their domain, evolve in time, learn, and in general introduce innumerable complications into the interactions. Social sciences such as economics, anthropology, organizational theory, psychology, and even philosophy and history may be amenable to simulation if we can only learn how to do it. The problem is learning how to do science with simulations such that meaningful insights emerge from the exercise, leading to deeper understandings of the problems, if not predictability as is the case in the physical sciences.

What are some of the characteristics of cultural or social investigations? Usually, the universe of the problem is made up of many “agents”, e.g. individuals, firms, countries, villages, or similar. This is in analogy to the particles being transported in typical monte carlo simulations for particle physics. Collisions between agents and other agents or the environment occur as time unfolds, producing the dynamics of the situation. Typically, the fate of individual agents is “path dependent”, history does count. At this point, analogies to the physical sciences become less clear. A major part of the environment in which social simulations unfold is generated by the actions of the agents themselves. This feedback, or coupling between individual and group behavior, is what makes such studies scientifically interesting, and often mathematically intractable. This can be said to capture the point where simplicity becomes complexity. The behavior of the entire assemblage of agents “emerges” in a highly nonlinear manner from the behaviors of the individuals. The agents themselves can be highly complex, and their interactions with the environment can modify their individual behaviors. To be realistic, in contrast to simulations in the physical sciences, agents must also be able to learn, modify behavior, and in general optimize their performance. Hierarchical stratification of organization should be possible in the simulation. There must be a mechanism for individuals to organize into groupings, for example families, firms, countries, etc. And finally, it is clear that the entire simulation is very path dependent, this is not only do to individual agents histories depending critically on chance encounters during the passage of time, but the emergence of a “world” is historically path dependent. Any simulation must allow “today”, the sum of past evolution and emergence of a society, the sum of culture, superstitions, myths, institutions, and the like must be insertable at certain points.

Making simulations with all of these features is a very tall order. Can it be done? The problems are much too important for science to duck — we must try even though it seems extremely daunting. The World in which we live is made of the collective decisions of millions of agents acting under the rules, both cultural and legal, set up by our organization of society. Can such a world be modeled using simulation techniques?. It certainly has not been done yet — but just as in the physical sciences simulations are essential to experimental investigations, as computation becomes cheaper much more complex simulations of human organization and behavior will become important.

With this as background, I would like to describe a simple first attempt to bring this type simulation into the scientific arena. I will give in what follows some results from a study of the formation of financial markets by a simulation program which incorporates some of the features of social simulation mentioned above. This work has been done by a collaborative group of visitors at the Santa Fe Institute, and consists of Brian Arthur, an economist and demographer, John Holland, a computer scientist and psychologist, Blake LeBaron, a economist, Richard Palmer, a physicist, and Paul Tayler, a stock trader.

A persistent puzzle in finance is why academic theorists and market traders should view financial markets is strikingly different ways. Standard economic theory assumes homogeneous investors who share rational expectations of an asset's future price, and who instantaneously and rationally discount all market information into this price. It follows that the market is efficient in that no opportunities are left open for consistent speculative profit, that technical trading (using patterns in past prices to forecast future ones) cannot be profitable except by luck, that temporary price overreactions - bubbles and crashes- reflect rational changes in assets' valuations rather then sudden shifts in investor sentiment. It follows too that trading volume is low or zero, and that indices of trading volume and price volatility are not persistent or serially correlated in any way. The market, in this standard theoretical view, is rational, efficient, and mechanistic. Traders, on the other hand, often see markets as offering speculative opportunities. Many believe that technical trading is profitable, that something definable as a "market psychology" exists, and that herd effects unrelated to market news can cause bubbles and crashes. Some traders and financial writers even see the market itself as possessing its own moods and personality, sometimes describing the market as "nervous", or "sluggish", or " jittery". The market in this view is psychological, less than efficient, and organic. From the academic viewpoint traders with such beliefs — embarrassingly the very agents assumed rational by the theory — are irrational, wrong, superstitious. From the traders viewpoint, the standard academic theory is unrealistic, alien, not borne out by their own perceptions. To quote one of the most successful traders, George Soros: "this efficient market theory interpretation of the way financial markets operate is severely distorted. It may seem strange that a patently false theory should gain such widespread acceptance."

Arthur et. al. Have constructed a simulation of a simple market, with features which make possible the study of some of the questions raised by this fundamental puzzle in economic science. In this market N agents decide on their desired asset distribution between a risky stock paying a stochastic dividend and a risk free bond. The individual agents formulate their expectations independently, but are identical in other respects. Except for the heterogeneity of agents, the market is neoclassical in all respects. Each trader has access to information on the state of the market in the form of time series of past and current prices and dividends. In the model they do not use the raw time series, but these data are summarized into a set of binary descriptors, which for example, could be the running average of the stock dividend, or the price trend for the last pre determined number of periods, or other statistical information generated from the raw price and dividend data stream. Using these descriptors the individual agents predict the price for the next period, and decide to buy or sell the stock depending upon their current position in the market. Descriptors are combined into hypotheses which are reinforced or discarded according to the success or failure of the individual hypotheses to accurately predict the price. Each agent has its hypotheses stored on a "genome", a bit string which encodes the present set of hypotheses with which the agent trades. This bit string is modified by the success or failure of the trades the agent performs, as well as is modified by mutation and crossover which brings new hypotheses to the action. A standard genetic programming approach is used for the evolution of strategies, as well as the discard of unsuccessful hypotheses. The price of the stock then varies according to the aggregate of the buy and sell orders presented. Further, hypotheses can be classified into classes, those which reflect fundamentals, (such as price to dividend ratios), and technical trading indicators, such as price trends.

Clearly, this model incorporates in a rudimentary way several of the criteria discussed for simulations in social situations. In incorporates learning, path dependence, and strong feedback where the agents generate their own environment. Arthur et al have conducted a series of experiments using this model, and have gained considerable insight into the observed behaviors of real markets in real world situations. First they investigated the operation of the market in the homogeneous rational expectations regime. As expected, if the hypotheses were limited to the calculation of fundamentals and bids were determined using this data only, the rational expectations model was replicated, price followed fundamentals very closely, and volume was low. Even small admixtures of technical hypotheses rapidly converge back to the rational expectations result, and technical hypotheses tend to die out in the models used by the agents for trading. There clearly is a natural, weak attraction to the rational expectations model. As initial heterogeneity is increased, increasingly the market does not converge to the rational expectations regime. Instead, complex patterns form in the collection of beliefs, and the market falls into a regime that differs materially from the rational expectations behavior. Bubbles and crashes occur, and suggest that technical trading, in the form of buying or selling into trends, may have emerged in the market. Once into the rich psychological regime the volume increases substantially, and in other respects mimics very closely several of the statistical features of a real market which are not reproduced in the rational expectations regime. In particular, statistical correlations between price volatility and volume observed in real markets, called GARCH (Generalized Autoregressive Conditional Heteroscedastic time series) behavior is seen clearly. Other observations in the behavior of the market which track with the observations in real markets include the dynamics of recovery from dividend or price perturbations and the income distributions of participants in the market. And finally, it is clear that the environment for trading is bootstrapped by the individual traders. A very successful trader at one time, if frozen in its trading hypotheses, will do very poorly at a different time, as the environment has evolved around it into different competition. They have even seen strategies evolve to corner the market!!! It is clear that real stock markets operate in the rich psychological regime.

Thus it seems clear that for this case real insight into market behavior can be extracted from simple simulations of learning and adaptation of agents in a market environment. Clearly this simulation cannot be used for application into a real market to predict behavior — particular stock prices on the New York Stock Exchange for example. But as a tool for economics research simulations may be the wave of the future. No less a critic than Robert Solow, Nobel prize winner from MIT, has written in Science magazine that this type simulation may be the future in some aspects of economics research.

As should be apparent, programming these type problems is a very technical and demanding task. Even in the Physical sciences typical Monte-Carlo simulations are usually handled by utilizing library programs which take care of the graphical output, geometrical parameters, and so on. There are no equivalent libraries of programs available to the social scientist in consistent use at the present time, and up until recently each simulation was essentially started from scratch. About three years ago a team of visitors at SFI held a series of meetings to evaluate what was available to the community for applications of these kinds, and developed a set of goals for a programming language, or platform, which could be developed to support agent based simulations. Out of this effort a collaborative group of computer scientists and others have developed a programming platform called SWARM which is available to any group wishing to do simulations of this kind. This platform utilizes many individual pieces from the overall simulation community and also significant extensions in power not utilized previously. Interestingly, industry participation in this collaborative team has been significant, both in the input phase and in the implementation of actual code. Swarm is multi-agent software platform for the simulation of complex adaptive systems. In the Swarm system the basic unit of simulation is the swarm, a collection of agents executing a schedule of actions. Swarm supports hierarchical modeling approaches whereby agents can be composed of swarms of other agents in nested structures. Swarm provides object oriented libraries of reusable components for building models and analyzing displaying, and controlling experiments on those models. Swarm is currently available as a beta version in full, free source code form. It requires the GNU C Compiler, Unix, and X Windows. More information about Swarm can be obtained from the World wide web,

http://www.santafe.edu/projects/swarm/ .