Computer Simulations

A practical approach to simulation

Semra Gündüç

`gunduc@ankara.edu.tr`

Ankara University Faculty of Engineering,

Department of Computer Engineering

Computer Simulations

- Computer simulation was pioneered as a scientific tool in meteorology and nuclear physics in the period directly following World War II, and since then has become indispensable in a growing number of disciplines.
- The list of sciences that make extensive use of computer simulation has grown to include
  - astrophysics,
  - particle physics,
  - materials science,
  - engineering,
  - fluid mechanics,
  - climate science,
  - evolutionary biology,

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- ecology,
- economics,
- decision theory,
- medicine,
- sociology,
- epidemiology, and many others.

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- There are even a few disciplines, such as chaos theory and complexity theory, whose very existence has emerged alongside the development of the computational models they study.

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- After a slow start, philosophers of science have begun to devote more attention to the role of computer simulation in science. Several areas of philosophical interest in computer simulation have emerged:
  - What is the structure of the epistemology of computer simulation?
  - What is the relationship between computer simulation and experiment?
  - Does computer simulation raise issues for the philosophy of science that are not fully covered by recent work on models more generally?
  - What does computer simulation teach us about emergence? About the structure of scientific theories? About the role (if any) of fictions in scientific modeling?

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What is Computer Simulation?

No single definition of computer simulation is appropriate

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- In its narrowest sense, a computer simulation is a program that is run on a computer and that uses step-by-step methods to explore the approximate behavior of a mathematical model.
- Usually this is a model of a real-world system (although the system in question might be an imaginary or hypothetical one). Such a computer program is a computer simulation model.

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- Sometimes the step-by-step methods of computer simulation are used because the model of interest contains continuous (differential) equations (which specify continuous rates of change in time) that cannot be solved analytically—either in principle or perhaps only in practice.
- This underwrites the spirit of the following definition given by Paul Humphreys: “any computer-implemented method for exploring the properties of mathematical models where analytic methods are not available” (1991, 500).

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- But even as a narrow definition, this one should be read carefully, and not be taken to suggest that simulations are only used when there are analytically unsolvable equations in the model.
- Computer simulations are often used either because the original model itself contains discrete equations—which can be directly implemented in an algorithm suitable for simulation—or because the original model consists of something better described as rules of evolution than as equations.

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- More broadly, we can think of computer simulation as a comprehensive method for studying systems.
- In this broader sense of the term, it refers to an entire process.
- This process includes choosing a model; finding a way of implementing that model in a form that can be run on a computer; calculating the output of the algorithm; and visualizing and studying the resultant data.

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- Both of the above definitions take computer simulation to be fundamentally about using a computer to solve, or to approximately solve, the mathematical equations of a model that is meant to represent some system—either real or hypothetical

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- Another approach is to try to define “simulation” independently of the notion of computer simulation, and then to define “computer simulation” compositionally: as a simulation that is carried out by a programmed digital computer. On this approach, a simulation is any system that is believed, or hoped, to have dynamical behavior that is similar enough to some other system such that the former can be studied to learn about the latter.

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For example, if we study some object because we believe it is sufficiently dynamically similar to a basin of fluid for us to learn about basins of fluid by studying the it, then it provides a simulation of basins of fluid. This is in line with the definition of simulation we find in Hartmann: it is something that “imitates one process by another process. In this definition the term ”process“ refers solely to some object or system whose state changes in time” (1996, 83).

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Hughes (1999) objected that Hartmann's definition ruled out simulations that imitate a system's structure rather than its dynamics. Humphreys revised his definition of simulation to accord with the remarks of Hartmann and Hughes as follows:

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System S provides a core simulation of an object or process B just in case S is a concrete computational device that produces, via a temporal process, solutions to a computational model . . . that correctly represents B, either dynamically or statically. If in addition the computational model used by S correctly represents the structure of the real system R, then S provides a core simulation of system R with respect to B. (2004, p. 110)

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(Note that Humphreys is here defining computer simulation, not simulation generally, but he is doing it in the spirit of defining a compositional term.) It should be noted that Humphreys' definitions make simulation out to be a success term, and that seems unfortunate. A better definition would be one that, like the one in the last section, included a word like "believed" or "hoped" to address this issue.

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Purposes of Simulation

- There are three general categories of purposes to which computer simulations can be put. Simulations can be used;
  - for heuristic purposes,
  - for the purpose of predicting data that we do not have,
  - and for generating understanding of data that we do already have.

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Computer simulations can be used for both of these kinds of purposes—to explore features of possible representational structures; or to communicate knowledge to others. For example: computer simulations of natural processes, such as bacterial reproduction, tectonic shifting, chemical reactions, and evolution have all been used in classroom settings to help students visualize hidden structure in phenomena and processes that are impractical, impossible, or costly to illustrate in a "wet" laboratory setting.

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- Another broad class of purposes to which computer simulations can be put is in telling us about how we should expect some system in the real world to behave under a particular set of circumstances. **Loosely speaking: computer simulation can be used for prediction.**
- We can use models to predict the future, or to retrodict the past;
- we can use them to make precise predictions or loose and general ones.

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- With regard to the relative precision of the predictions we make with simulations, we can be slightly more finegrained in our taxonomy. There are
- a) Point predictions: Where will the planet Mars be on October 21st, 2300?
- b) "Qualitative" or global or systemic predictions: Is the orbit of this planet stable? What scaling law emerges in these kinds of systems? What is the fractal dimension of the attractor for systems of this kind? and...
- c) Range predictions: It is 66$\%$ likely that the global mean surface temperature will increase by between 2–5 degrees C by the year 2100; it is "highly likely" that sea level will rise by at least two feet; it is "implausible" that the thermohaline will shut down in the next 50 years.

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- Finally, simulations can be used to understand systems and their behavior.
- If we already have data telling us how some system behaves, we can use computer simulation to answer questions about how these events could possibly have occurred; or about how those events actually did occur.

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Simulation and Experiment

- Working scientists sometimes describe simulation studies in experimental terms.
- A simulation that accurately mimics a complex phenomenon contains a wealth of information about that phenomenon. Variables such as temperature, pressure, humidity, and wind velocity are evaluated at thousands of points by the supercomputer as it simulates the development of a storm, for example. Such data, which far exceed anything that could be gained from launching a fleet of weather balloons, reveals intimate details of what is going on in the storm cloud. (Kaufmann and Smarr 1993, 4)

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- The idea of “in silico” experiments becomes even more plausible when a simulation study is designed to learn what happens to a system as a result of various possible interventions:
  - What would happen to the global climate if x amount of carbon were added to the atmosphere?
  - What will happen to this airplane wing if it is subjected to such-and-such strain?
  - How would traffic patterns change if an onramp is added at this location?

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- Philosophers, consequently, have begun to consider in what sense, if any, computer simulations are like experiments and in what sense they differ.
- A number of views have emerged in the literature centered around defending and criticizing two theses:

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- The identity thesis. Computer simulation studies are literally instances of experiments.
- The epistemological dependence thesis. The identity thesis would (if it were true) be a good reason (weak version), or the best reason (stronger version), or the only reason (strongest version; it is a necessary condition) to believe that simulations can provide warrants for belief in the hypotheses that they support. A consequence of the strongest version is that only if the identity thesis is true is there reason to believe that simulations can confer warrant for believing in hypotheses.