

Qualitative Simulation Modelling

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May 4, 2007

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Goal: proposing a methodology for simulations. How can we gain scientific knowledge from simulation models?

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- Output of sciences: defining “knowledge”.
- Qualitative simulations: how simulations generate knowledge.
- Some features of simulation models in social sciences

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- 4 Collect experimental or observational data of the elements concerned.
- 5 Compare the theoretical results with those observed in nature.
- 6 Accept the theory that provides the closer data fitting and has the widest applicability.

The scientific methodology

Standard methodology assumes that the phenomenon to explain is perfectly represented by a vector of variables, whose values must be *explained* in terms of elaboration of independent variables.

$$\vec{Y} = f(\vec{a}, \vec{X})$$

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- **Structural stability.** Relevant properties of the entities in the real system are represented by a stable set of variables. Any event not reflected in their values is not part of the phenomenon.
- **Closed systems.** What we observe is not influenced by external events, but for noise uncorrelated with the phenomenon of interest.

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Any quantitative measure is ambiguous and potentially misleading: two quantitatively identical systems can actually be totally different, and similar systems can provide completely different measures.

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- **Structural dynamics.** Relevant variables representing system's properties change during the unfolding of the phenomenon.
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In these conditions the *format* of knowledge as mathematical relations among variables cannot even be conceived.

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Failure of providing quantitative theories in social sciences is not due to deficiency of the theorists, but to the fact that there are no quantitative invariances that can (or are worth to) be replicated by a theory.

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An example is biology. Its theories do not aim at describing exactly which species appears at any moment in time. Still, a large body of knowledge can be cumulated on how evolution takes place, how organism works, how the environment affects the objects of study, etc.

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We are very interested in understanding how these forces interact to shape empirical observations, and how they can be controlled to obtain desired results.

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This definition allows to assess certain properties of scientific knowledge supporting the use of computer simulations as the most general and rigorous format to embody scientific knowledge.

How do we know something?

Definition: Knowledge is a causal link, or explanation, for two states of the world:

$$A \xRightarrow{\mu} B$$

where μ is an explanatory mechanism.

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- Expertise and practices.
- Instruction manuals.
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- Evolutionary advantage of linking events;
- Knowledge as solution to problems. Observation of the same events can tell different things to different people.

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Furthermore, such definition allows refinements and qualifications, in order to generate narrower or more ample expressions by formalization or approximation.

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Knowledge extensions: Knowledge can be extended to form chains of causes, or explanations, in which the final state of an explanation is used as the initial state of the next:

$$A \xRightarrow{\mu} B \xRightarrow{\nu} C \xRightarrow{\phi} D \dots$$

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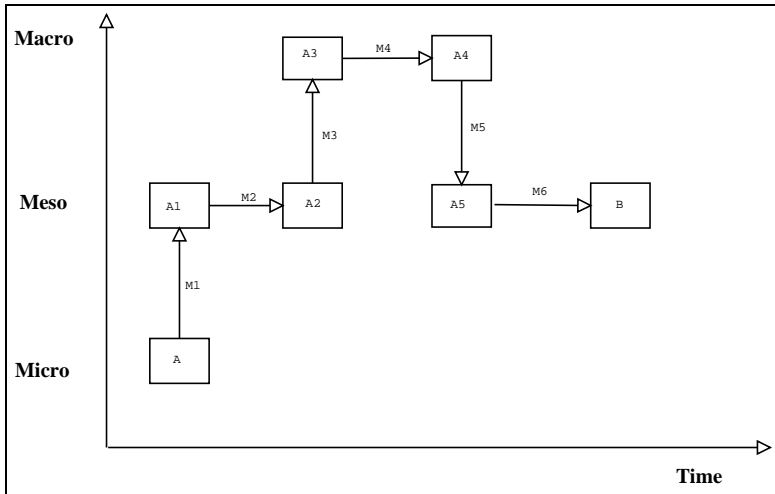
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- **Temporal:** the explanation consists in the passing time during which the elements comprising the state of the world A can be expected to produce B .
- **Aggregative:** elements at a certain level of aggregation explain the properties of elements at a different levels.

Most relevant explanations in the real world are a combination of explanations from both classes, though they need to be kept separated.

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Simulation models and knowledge as explanations

The next section suggests that simulation models are perfectly suited to embody knowledge, as defined here, provided that simulations are used in a correct form.

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In any case, *how* the model produces those results is not relevant for the evaluation of the model.

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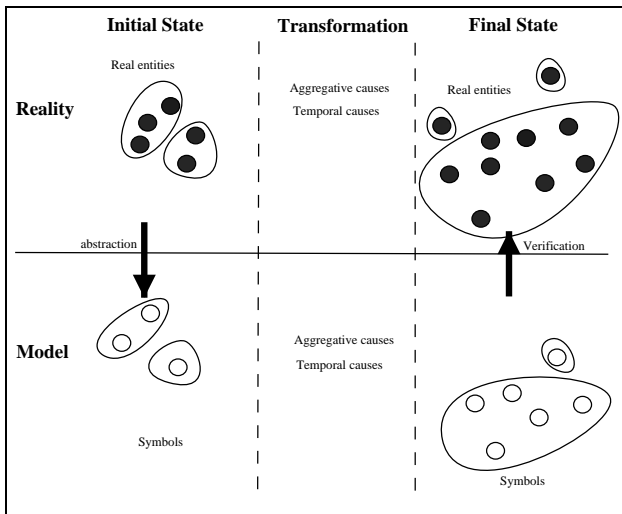
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Once such explanation mechanism becomes known, the model can be used for forecasting and normative purposes.

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Moreover, given the strong importance of historical events, we have little hope (and, eventually, no interest) in replicating a few of the ever changing states of an economic system.

Instead, we can investigate the mechanisms of complex dynamical systems, which can provide intuition of future likely directions and the possibility to influence them.

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The output of research consists in providing *one of* the explanations for the phenomena. Competing explanations can be put to test, but **deeper** and **broader** explanations will always continue to be requested.

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Simulation models allow to exactly individuate the mechanisms of simulated emergent properties. It is such mechanisms that needs to be tested in the real world.

Simulation models' elements

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 - **Dynamic:** based on past values;
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- **Data:** num. of objects, parameters' values, etc.

Any specification of the above elements determines the same model and must provide the same results.

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- B : the generation of results by a given model can be rigorously assessed.
- μ : the intermediate steps or mechanisms arising during a simulation run can be analysed, tested and documented.

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- 4 Test that the model generate a phenomenon equivalent to those observed.
- 5 Inspect the model to fill the originally missing knowledge concerning how the elements generate the phenomenon.

Sources of knowledge

Modelling provides new knowledge from the following activities:

- **Learning by coding:** the need to represent computationally a system forces to think how real systems actually work. A model is a simulated universe, with the same logical constraints as the real one. Apparently obvious representations turn out to be inconsistent or incomplete once put into code. Finding the right way to express with a formal language a synthesis of a real system provides a lot of insights on the system itself.

Sources of knowledge

- **Learning by plotting:** analysing the results (across time and/or different initializations) provides evidence of the model's behaviour. Controlling that your model produces realistic phenomena generates new understanding of the real cases, their characteristics and other properties non-obvious from the observation of the real world.

Sources of knowledge

- **Learning by debugging:** linking logically the model description with the results produced by simulations provides surprising insight, showing non-obvious consequences of the model structure. These explanations embody the ultimate knowledge on the simulated system, hopefully valid for real ones, too.

Sources of knowledge

- **Learning by erring:** Mistakes in simulations have a built-in system of recovery. Erring when using simulations means that the explanation provided to explain the simulated phenomenon cannot explain one of its purported real counterpart. The mere acknowledgment of the error provides at least hints of how to fix the error, i.e. which part of the model was wrong and how it should have been implemented.

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- **Applications:** simulations are, by themselves, immediate tools to transfer theoretical knowledge to applications, like forecasting or policy planning.

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- 6 Publish!

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True, but computers help to understand exactly the implications of your code. Think, for example, of models of weather forecasting. The basic physics is trivial, but the aggregate, non-linear dynamics is impossible to treat, and computers help to fill the gap between our hypothesis (e.g. basic physics) and their implications in time and aggregations.

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- *Random models/models with many parameters must be adequately tested for the robustness of results.*

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False. Economic events are not necessarily the most likely. In some cases, the only interesting result stems from the peculiar, exceptional result that highlight the basic mechanism at work. Simulation models, as well as economic systems can frequently be understood by studying the exceptions, as much as doctors understand how the human body works by studying sick patients.

People say that ...

- *Better a good theorem than a hundred simulations.*

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True. Mathematics is a wonder of compactness, representing many (infinite) cases by one single line of symbols. However, non-linear aggregations and dynamics are poorly managed by mathematical tools, while computers can easily do both: simulations can replicate (though inelegantly) results embodied in theorems, but, in general, theorems cannot contain the knowledge provided by models.

People say that ...

- *Programming simulations is difficult, don't want to waste my time learning how to program.*

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False. Writing programs is difficult, writing code for simulations is not. Most of simulation models' code is made of trivial, IF-THEN-ELSE statements and simple arithmetic operations. Arranging the model's code in a computer program is very difficult, particularly because you need sophisticated interfaces to investigate model's behaviour.

However, endowing a model with the necessary interfaces is a technical problem, that technicians can help to solve. But, crucially, the model must be constructed and used by the theorist.

People say that ...

- *Data confirm your results?*

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Futile. Data replication is utterly useless without understanding their meaning. Moreover, a model replicating one set of data can miserably fail to replicate another one, irrespective of its correctness.

People say that ...

- *Then, for you empirical analysis is useless...*

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- *Then, for you empirical analysis is useless...*
False. Statistical analysis, descriptive or inferential, provides the crucial information on what is going on in such complex entities like economic system. Only, we need constantly to take into account that quantitative measures are a very fuzzy shadow of the systems that produced them.

Conclusions

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- 1 Social sciences (among others) lack the structural stability and concern open systems: replications of observations is impossible and, ultimately, useless.
- 2 A weaker, more general format of knowledge is called for: explanations $A \stackrel{\mu}{\Rightarrow} B$
- 3 Simulations are the best format to represent any kind of knowledge, meant as explanations of what happens in a simulated world.

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“What we cannot speak about we must pass over in silence.”

L. Wittgenstein, “Tractatus Logico-Philosophicus”