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Formal Models of Explorative Experiments

Jan-Willem Romeijn
Faculty of Philosophy
University of Groningen

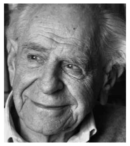
1 Justification versus discovery

The logical empiricist or analytic style (Fagot-Largeault, this conference) in philosophy of science has concentrated on

1. science as characterised by its method;
2. the rationalisation of scientific method by formal means;
3. a restriction of scientific method to theory evaluation.

Deviating from two or more of the above, social constructivists and new experimentalists have proposed alternatives to the logical empiricist view on the philosophy of science.

A package deal?
In a caricature of logical empiricism, the three above tenets go hand-in-hand.



As reviewed by Niiniluoto (this conference), there is room for formal models of theory change. In particular, such models may show how theory change is driven by both theoretical and empirical considerations.

A new perspective on discovery
In this paper I present such a formal model. I believe it improves on earlier work because contains a number of new ingredients.

- Experimental interventions as catalysts of theory change.
- Bayes-nets as a formal means to represent interventions and theory.
- Cognitive psychology to understand the investigative strategies of researchers.
- Statistical tools to supplement Bayesian networks with conceptual change.

2 Explorative experiments

I have two reasons for focusing on experimental interventions.

- Conceptual change is often ispired or forced by surprising experimental findings (Franklin, Morgan, Radder, Steinle).
- Scientific concepts are often fixed or stabilised in experimental procedures, not just operationally but also theoretically (Van Dyck, this conference).

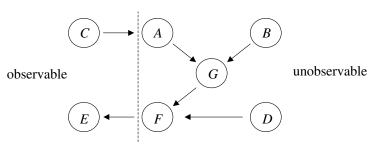
Philosophical schizofrenia

Formal and historical philosophy of science are far apart. I hope that this research will bring them somewhat closer together.

$$\begin{array}{l} H \wedge A \rightarrow E \\ \neg E \vee E' \\ A' \rightarrow \neg E' \\ \hline H \end{array}$$

3 Bayes-nets and experimental interventions

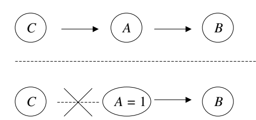
An experimental situation may be captured in a set of variables (Leuridan, this conference).



A theory consists in causal, logical and probabilistic relations between these variables, summarised in a Bayesian network.

Experimental manipulation

If we interpret the Bayesian network causally (Pearl 2000, Woodward 2005), then it tells us what an intervention on one of the variables amounts to.



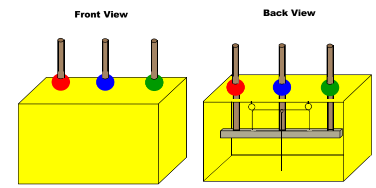
We can model experimental interventions formally (Korb 2006), in terms of a test after the alternation of a network structure.

Informative interventions
The knowledge state of a researcher may consist of a set of such probability assignments, represented by a collection of Bayesian networks, and a second-order probability distribution over the assignments.

- The entropy of the latter distribution expresses the degree of uncertainty about the experiment.
- Tong and Koller (2001) provide a measure for the expected information gain, or entropy decrease, of an intervention.

4 Cognitive psychology of science?

Bayesian networks are already used to make statistical analyses of intervention behaviour in cognitive and developmental psychological experiments.



Natural-born researchers
Steyvers et al. (2003) argue that we are particularly skillful in choosing the most informative interventions. Also, following Gopnik (2001) we seem to acquire these skills at very early age.

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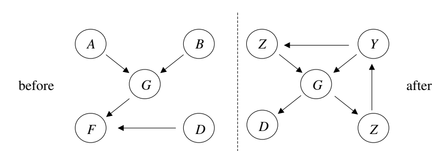
Note the contrast with other logical and probabilistic reasoning tasks, e.g. Wason's card task and Tversky and Kahneman's results on probabilistic inference.

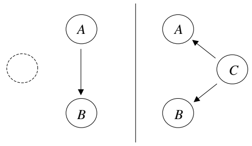
5 A formal model of conceptual change

All of the above is concerned with the reconfiguration of conceptual material that is already given.



Can we also give an account of arriving at brand new concepts?

Factor analysis
We can supplement Bayesian networks with additional statistical tools. One of them is exploratory factor analysis, a well-known technique from psychometrics.

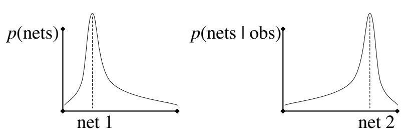


EFA allows us to add latent variables, or hidden nodes in the network, as commom cause or mechanism behind correlations between observed variables.

Underdetermination and indeterminacy of EFA
Unsurprisingly the introduction of hidden nodes leads to an underdetermination problem.

- To some extend, the use of intervention data can resolve the underdetermination of factor analysis (Romeijn 2008).
- Sometimes interventions reveal a poor model fit. In this case the intervention data directs us to adding yet other nodes to the network (Romeijn and Williamson, manuscript).

Revolutionary conceptual changes?
We may also describe conceptual change in terms of the dynamics of second-order probability distribution over credal networks. The introduction of restrictions on this second order distributions may lead to wild changes in network structure.



6 Concluding remarks

- Models of conceptual change seem more feasible with recent developments in statistics and psychology.
- Investigating conceptual change with formal means may provide a bridge between different sides in the philosophy of science.
- The issue is whether applications of the formal machinery to historical examples will convince historians of science.
- Another issue is whether the results can be used to improve automated discovery, e.g. in the construction of Bayesian networks for large data sets.