A Philosopher Looks at Effective Field Theories

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Motivation

- The goal of this talk is to address some methodological and epistemological questions related to and inspired by effective field theories in physics.
- This can be done in three different ways:
  - (i) Start with a philosophical explication of central concepts (such as explanation, reduction, or confirmation) and confront the practice of science with them. → No!
  - (ii) Examine the practice of science and collect case studies. → No!
  - (iii) Take the practice of science seriously and develop philosophical ideas in interaction with the practice. → Yes!
- The third approach mimicks best how the sciences proceed.

Overview

1. EFTs and the Structure of Science
   - Which role do EFTs play in science?
   - Develop a coherentist account
2. EFTs and Reductionism
   - How do EFTs relate to other theories?
   - Discuss a reductionist account of intertheoretic relations
3. Open Questions

Some Questions

- The following questions can be asked:
  1. How is science organized as a whole?
  2. How is one particular science organized?
  3. How is a scientific subdiscipline (such as CMP) organized?
  4. ...
- Various answers to these questions are possible: hierarchical structure ("the unity of science"), ..., pluralism ("the disunity of science")
- Philosophers have mainly defended the extreme positions.
- However, these positions fail ...
- Let's examine why.

The Unity of Science

- Driving intuition: One important goal of scientific theorizing is to come up with a single (ideally simple) unified theory.
- Two well-known proposals:
  1. Oppenheim and Putnam's (1958): pyramid structure of the sciences, ontological and epistemological reduction, unification as a heuristics
  2. Nagel (1961): model of reduction employing biconditional bridge laws and subsequent deduction of the reduced from the reducing theory

. . . and Its Problems

- Both proposals focus on *deductive relations* between theories. This turns out to be too strong a requirement, and so it is no surprise that . . .
- there are hardly any cases that fit these models.

However:

- Disregarding the main intuition behind the unity-of-science movement altogether is like throwing out the baby with the bath water.
- For example, there might be weaker relations between theories that are epistemically relevant.

The Disunity of Science

- Driving intuition: There is no hierarchy of theories (and sciences), "all theories are equal", and all of them are indispensable.
- Supported by case studies from "messy" science (lasers, superconductivity, ...). We find many theoretical approaches, none of them is fully satisfying, but all of them illuminate some aspect of the phenomenon in question.
- Cartwright: "Theories and models are only connected as they relate to the same empirical reality." There is no deeper relation between them beyond that.

. . . and Its Problems

- This claim is too extreme as it disregards the evident interrelatedness (and mutual support) of theories (and models) as well as scientists' (often successful) ambition to come up with unified theories.
- No argument is given why this interrelatedness is not epistemically relevant. It should not be neglected.

Upshot

- While the unity of science stresses the goal to present a single simple theory that accounts for everything (but often fails to account for much), the disunity of science stresses our goal to account for as many empirical phenomena as possible.
- While some unified theories do well on both counts (e.g. Maxwell's theory), there is (often) a tradeoff between the two goals. They pull in different directions.
- My hypothesis: Coherent networks of interrelated theories and models provide the best tradeoff between the two goals.

A Bayesian Analysis

- Give a Bayesian account of the unity-of-science debate.
- Bayesianism brings in a normative dimension according to which various proposals can be assessed.
- Bayesianism in a nutshell: propositions, probability distribution defined over it, learning, updating, confirmation, Dutch books
- Criterion for theory acceptance? Confirmation vs. **high probability of the whole knowledge system**

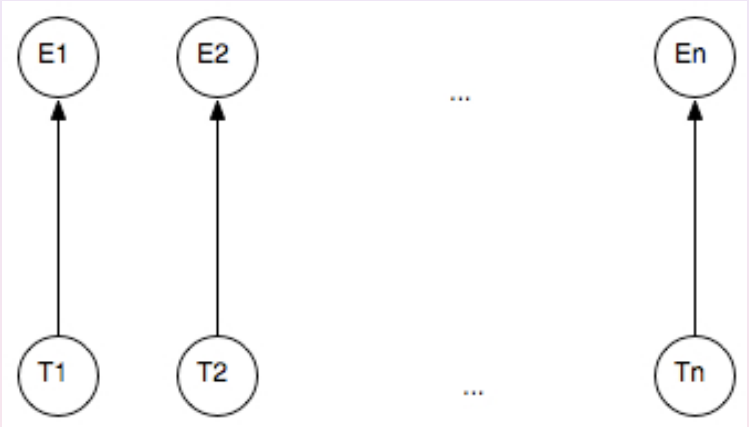
The Unity of Science from a Bayesian Point of View

- Highly unified theories are often too complicated to be applied. They only account for a few phenomena.

$$\begin{aligned} P(T, E_1, \ldots, E_n) &= P(T, E_1) \cdot P(E_2, \ldots, E_n) \\ &= P(T, E_1) \cdot \prod_{i=2}^{n} P(E_i) \approx 0 \end{aligned}$$

The Disunity of Science from a Bayesian Point of View

- Highly disunified theories also have a very small joint probability:



$$P(T_1, \ldots, T_n, E_1, \ldots, E_n) = \prod_{i=1}^{n} P(T_i, E_i) \approx 0$$

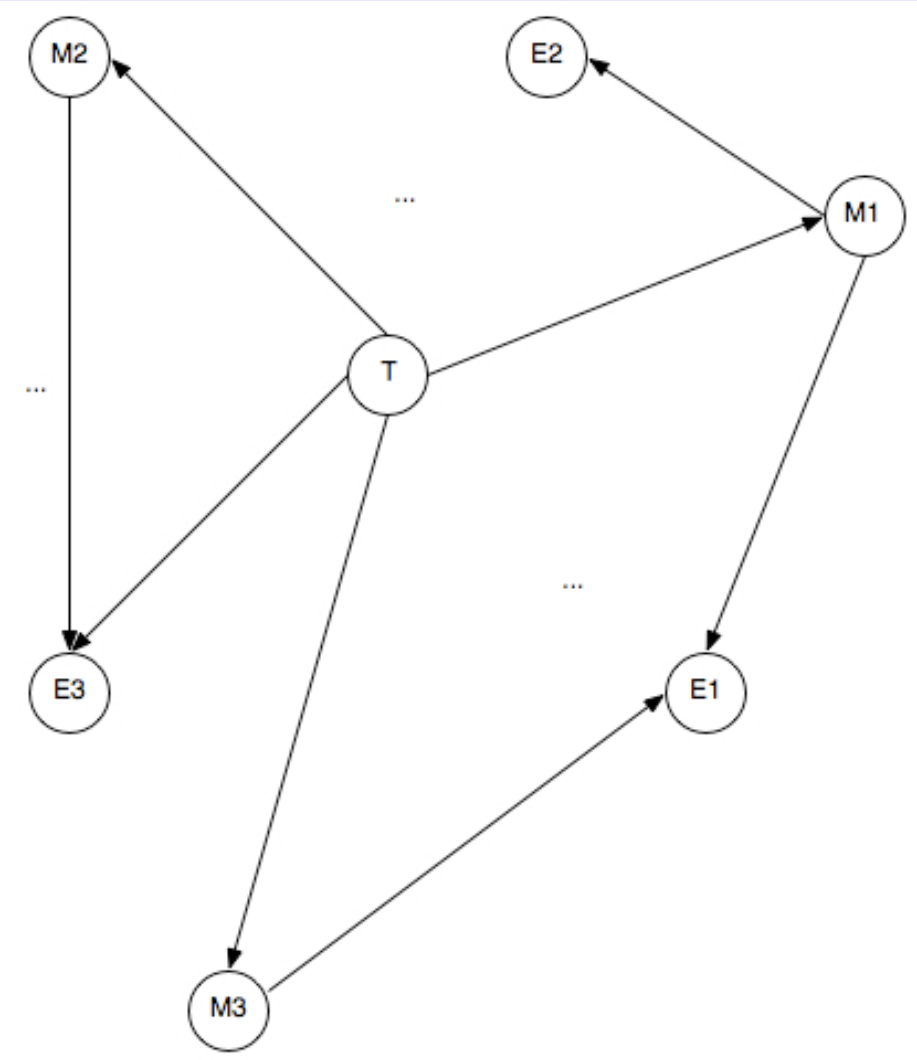
Coherent Networks of Theories and Models

- Interrelated networks can have a sufficiently high probability.
- The joint probability $P(T_1, \ldots, T_k, M_1, \ldots, M_l, E_1, \ldots, E_m)$ can be written as a product

$$P(T_1|T_2, \ldots, E_m) \cdot P(T_2|T_3, \ldots, E_m) \cdots P(E_m)$$

- This expression is sufficiently large if the conditional probabilities in question are large (deductive relations are best, but scarce).
- This is the case if the various theories, models and pieces of evidence in the network support each other well.

Coherent Networks: An Example



Coherentism

- The coherence of a set is then used to justify it ("coherence theory of justification").
- There are various proposals for measures of the coherence of an information set (see Bovens and Hartmann 2003).
- With these measures, one can explore under which conditions coherence is truth-conducive.
- N.B.: These judgments are relative to a (subjective) probability distribution, so that the word "truth" is somewhat misleading.
- The Bayesian framework is, however, neutral with regard to the interpretation of probability and a more objectivist account might eventually be defended.
- But does this account make sense on descriptive grounds?

Indispensability

- In a developed subdiscipline, such as CMP, we find theories, EFTs and models.
- They all have different functions:
  - Theories provide the ontology, the language to talk about things, and a unified framework.
  - EFTs capture the physics at a given scale by identifying the relevant degrees of freedom and their interactions.
  - Models are used to study aspects of a theory, to simplify an account, to get understanding and to pump intuitions,...
- All three approaches are required and complement each other.

Interrelatedness

- Note that there are typically no strict deductive relations between them.
- However, there are interesting other relations between them:
  a. Approximate deductions
  b. Deductions with the help of additional assumptions
  c. One can tell a story that makes the model's assumption plausible given the theory (e.g. the MIT Bag Model)
  d. ...
- All this fits nicely in the Bayesian picture. Dependencies between theories, for example, can be modeled by conditional probabilities.

A Proviso

- The picture I suggested needs to be amended.
- I suggested to probabilify only those theories and models that relate directly to phenomena. Call this the *empirical part* of the theory.
- Additionally, there is a *heuristic part* of a theory that comprises toy models, general laws (like the Schroedinger equation) that are not probabilified.
- It will be interesting to study the relation between these two parts.

Upshot

1. The coherentist picture seems to be preferable to alternative accounts on (i) descriptive and (ii) normative grounds.
2. The Bayesian framework is appropriate to model the (epistemically relevant) dependencies between theories, models and EFTs.

The Nature of Intertheoretic Relations

1. I take it to be an empirical question what the relations between theories are. (I am only committed to the claim that everything that is epistemically relevant about them can be model probabilistically.)
2. It is therefore interesting to study what these relations are and meetings such as this a a wonderful opportunity for philosophers to learn more about them.
3. In this context, Bob Batterman has pointed out that singular limits are important in many cases. But there are others.
4. In the remainder of this talk, I'd like to point out that EFTs provide examples of a modified version of Nagel's model of reduction.

Nagel Schaffner Reduction

- Basic idea: When we reduce one theory to another, we deduce the laws of one theory from the laws of the other theory.
- **Proviso 1:** If the two theories have different vocabularies, we need to translate the two vocabularies into each other (example: temperate and kinetic energy).
- **Proviso 2:** The deductions may only be approximate and (ideally innocent) additional assumptions have to be made.
- This procedure is in line with much of what is going on in physics (e.g. Statistical Mechanics).
- Deduction from a more fundamental theory may not always be the main goal of inquiry – we saw that it is difficult enough to come up with a good model. However, there would be a problem if a model *contradicted* a more fundamental theory (such as QED).

Nagel Schaffner Reduction in a Nutshell

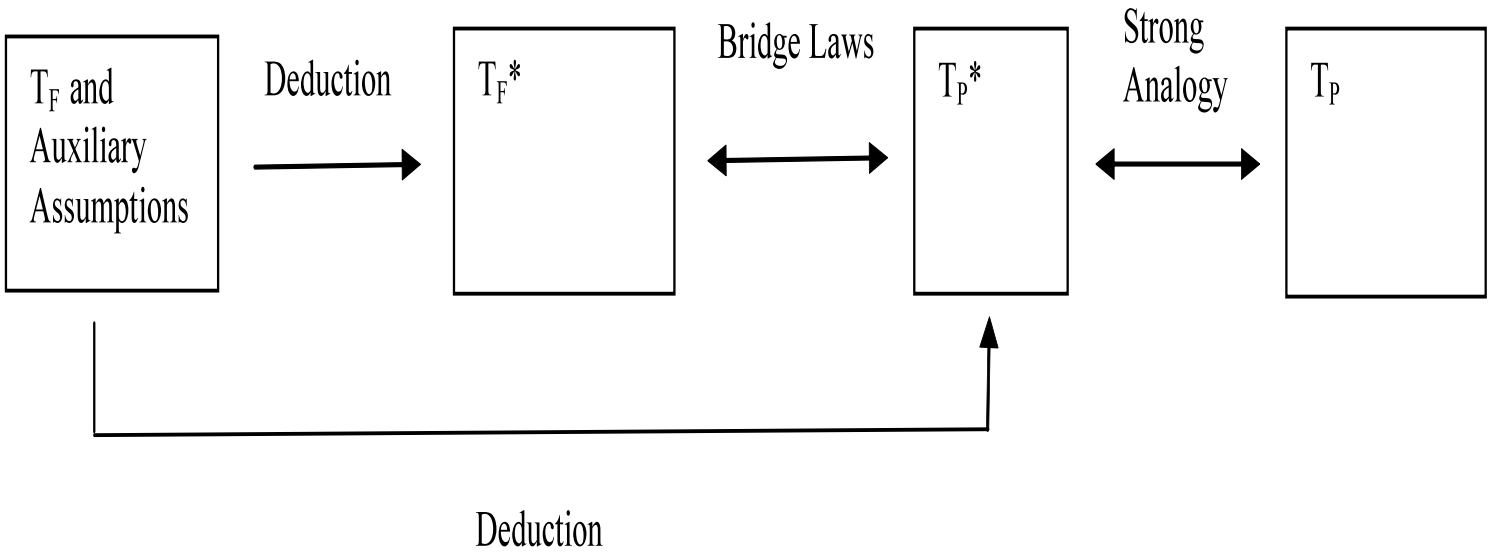


Illustration: EFTs Top Down

- Start with a renormalizable theory (such as QCD) and expand in momentum and mass.
- If one cuts off the expansion, one obtains an effective Lagrangians for a certain energy scale.
- Replace terms such as $\overline{q}\,\gamma_5\,\tau\,q$ by expressions such as π.
- Recover phenomenological models (e.g. the ones Roman Jackiw wrote a book about).
- For details, see my paper "Effective Field Theories, Reduction and Scientific Explanation", *Studies in History and Philosophy of Modern Physics* 32B, 267-304 (2001).

A Nagelian Reconstruction

- What is going on here?
  1. Associate entities with entities: Pions *are* composites of quarks.
  2. Associate properties with properties: Represent the pion field by $\overline{q}\,\gamma_5\,\tau\,q$.
- **Question:** Is it good or bad news that this procedure fits the Nagel Schaffner model?
- Note that the model has been severely criticized and basically abandoned in the philosophical literature.
- **Answer:** No, these criticisms can be met (see my recent paper with Foad Dizadji-Bahmani and Roman Frigg).
- **Conclusions:** There seems to be nothing wrong with attempting to NSR one theory to another, but *why* should one want to do this?

Why Reducing?

1. Traditional answer: Explanation: The reducing theory explains the reduced theory.
2. Consistency: Having two different stories to account for the same phenomenon may lead to a consistency problem: which story is right? However, if the is a reductive relation between the two theories, makes sure that they are consistent.
3. Confirmation and coherence: In many cases, the relation is stronger; confirmation flows from the reducing to the reduced theory (and vice versa). At the end, we obtain a coherent network of theories, models and EFTs
4. This also holds for weaker conditions and is another argument in favor of my coherentist account.

Reduction and Reductionism

- I do not want to defend reductionism *tout course* in the form the unity of science people had it in mind.
- I only want to stress that reduction is one type of intertheoretic relation that applies at least to some laws of some theories.
- However, there are other types of intertheoretic relations as well which philosophers of science should study.
- So I want to remain neutral about the question whether *ultimately* everything reduces to a fundamental theory (or whether there is such an ultimate theory).
- But even if this turns out to be so, we will need other theories, models and EFTs for pragmatic reasons (to account for phenomena) and for understanding.

Open Questions

1. How much coherence is good or productive? Does this depend on the field under investigation?
2. Should we conclude from the observation that energy levels largely decouple that ontological pluralism is right and that "all theories are equal"?