Title: The art of the possible in reconstructing quantum theory

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Abstract: The methodology employed in reconstructing quantum theory involves defining a general mathematical framework that frames a landscape of possible theories and then positing principles that uniquely pick out quantum theory. In contrast, many traditional interpretations of quantum theory consider only quantum theory, not a larger space of possible theories. I will defend the modal methodology used in reconstruction by tracing the historical roots of Einsteinâ€™s distinction between principle and constructive theories. Einsteinâ€™s principle theories (exemplified by thermodynamics and special relativity) are often cited as inspiration for reconstructing quantum theory. The concept of a â€œphysics of principlesâ€• emerged at the end of the nineteenth century in the context of the application of Lagrangian mechanics to electromagnetism. This case is an intriguing historical precedent for reconstructing quantum theory. I will also offer some reflections on how the application of a similar modal methodology in axiomatic QFT plays out.
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The art of the possible in reconstructing quantum theory

Doreen Fraser

Department of Philosophy, University of Waterloo

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Context

Examples of Reconstructions:
Hardy's (2001) five reasonable axioms; Masanes and Müller (2011) axioms; Chiribella, D'Ariano, and Perinotti (2011) axioms
(not "device-independent" approaches)

"The goal is to find a compelling set of axioms that singles out quantum theory from among all possible theories."
- Chiribella and Spekkens (2016)

Modal Methodology

Step 1: General mathematical framework

- landscape of possible theories
- e.g., GPT framework: *operational* (preparation, transformation, measurement)

Step 2: Formulate physical principles

Step 3: Formulate axioms based on the physical principles that uniquely pick out quantum theory within the general framework

Alternative to the Modal Methodology

Roughly: We are warranted in believing that our current best theories give approximately true descriptions of the *actual world* in restricted domains. Theorizing about possible worlds in which our theories are exactly true or imagining possible worlds in which alternative theories are true misconstrues the nature of our scientific knowledge.

"Why the quantum?" is not a question that needs to be answered

What recommends the modal methodology?
In the past, the modal methodology was successfully applied in the development of new theories.

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Einstein's (1919) distinction

Constructive theory	**Principle theory**
Ex: kinetic theory of gases	Ex: thermodynamics
synthetic method: "attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out"	analytic method: principles "not hypothetically constructed but empirically discovered," describe "general characteristics of natural processes," and **"give rise to mathematically formulated criteria which separate processes or theoretical representations of them have to satisfy"**
advantages: completeness, adaptability, clearness	advantages: logical perfection, security of foundations

Historical roots of principle-constructive distinction

- Poincaré (1904): "physics of principles" (e.g., theories of analytical dynamics of Lagrange, Poisson, Hamilton, Jacobi, and others, Fourier's theory of heat, Hamilton's and Cauchy's optics, as well as Maxwell's theory of electromagnetism)—in contrast to "physics of central forces" (e.g., Laplace's celestial mechanics)
- Maxwell's methodological reflections on electromagnetism (and development of Maxwell's theory of EM by Lorentz, Helmholtz, Fitzgerald)

Maxwell's early constructive approach to EM

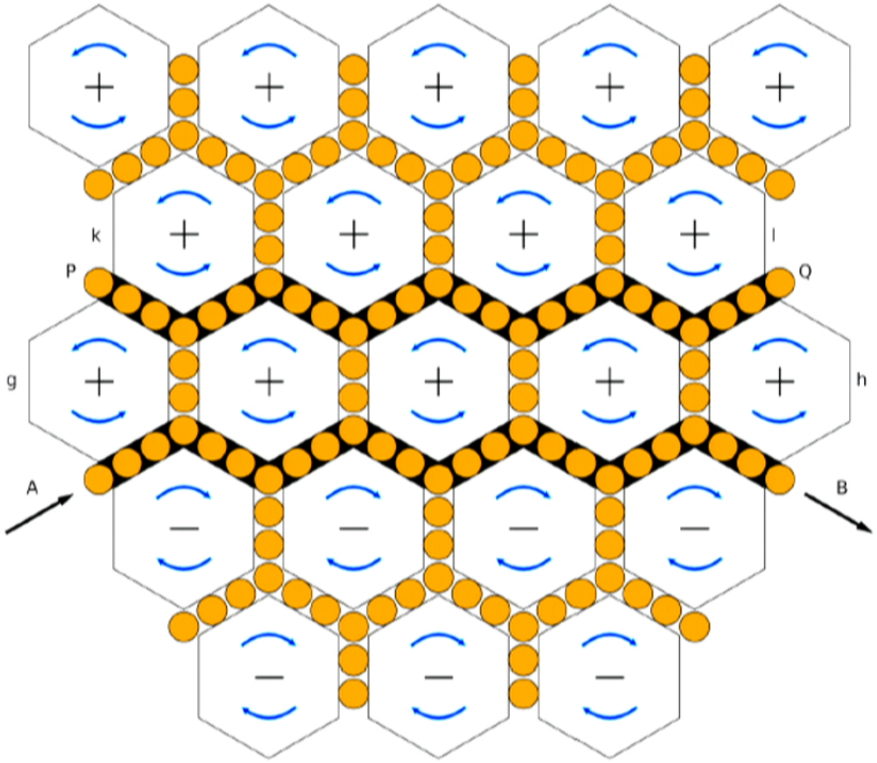

Image: https://sites.google.com/site/perennialphysics/

Maxwell's methodological reflections on the honeycomb model

The conception of a particle having its motion connected with that of a vortex by perfect rolling contact may appear somewhat awkward. I do not bring it forward as a mode of connexion existing in nature, or even as that which I would willingly assent to as an electrical hypothesis. It is, however, a mode of connexion which is mechanically conceivable, and it serves to bring out the actual mechanical connexions between the known electro-magnetic phenomena...

i.e., Maxwell believes that EM phenomena are produced by the motions of ether

Maxwell's methodological reflections on the honeycomb model

"The nature of this mechanism is to the true mechanism what an orrery is to the solar system" (Letter to Tait, 1867)

Maxwell's methodological reflections, *Treatise* (1873)

The mechanism required to establish a given species of connexion between the motions of the parts of a system always admits of an infinite number of solutions. Of these, some may be more clumsy or more complex than others, but all must satisfy the conditions of mechanism in general.

Maxwell's later principle approach to EM

The belfry analogy

Can use Lagrange's equations to predict motion of ropes when acted upon by specified forces, given initial values of shifts, velocities

assume: ropes collectively determine motion of hidden mechanism

empirically accessible quantities: KE, PE as functions of coordinates, velocities

Maxwell's later principle approach to EM

Analogously, use Lagrange's equations to derive Maxwell's equations

assume: EM system (conducting circuits, space, etc.) possess KE, PE

assume: currents, positions of conductors, etc. collectively determine motion of hidden mechanism

empirically accessible quantities: KE, PE as functions of currents, positions of conductors, etc.

Why was the principle theory approach successful?

- "black boxing" the details of the mechanism was a good strategy because the details differed between domains (e.g., EM, simple machines, hydrodynamics)
- the assumption that all theories shared structural properties turned out to be correct

Abstract principles more likely to survive in new theories than *concrete* assumptions about systems

Maxwell's later principle approach to EM

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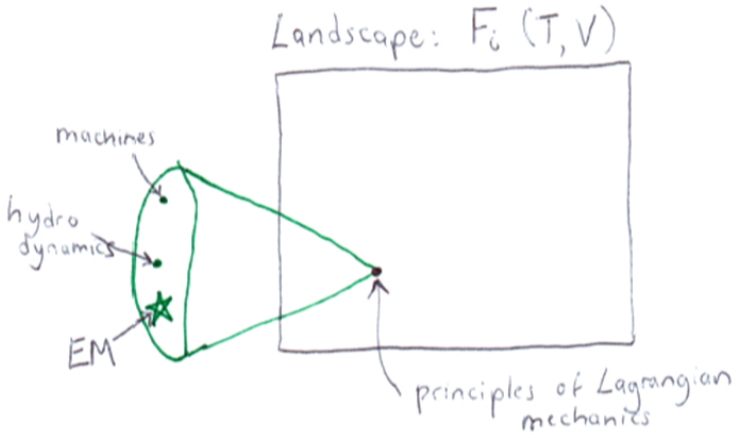
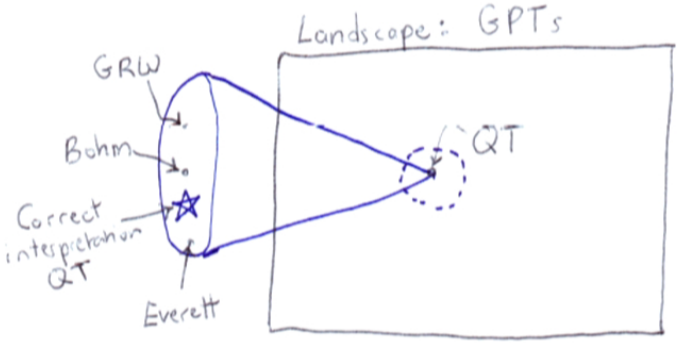
Application of the modal methodology to EM



Analogous modal methodology for QT?



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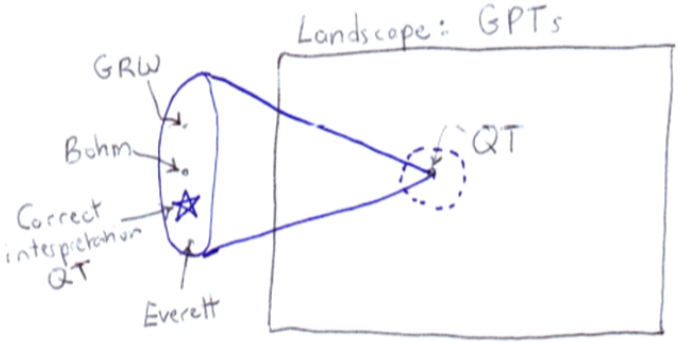

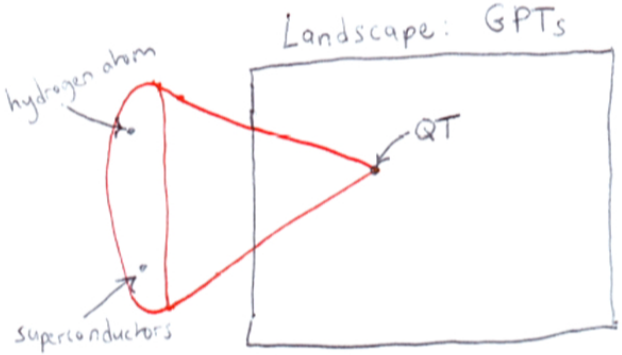

What kinds of principles?

Principles of Lagrangian mechanics

- abstract: capture general features common to a set of concrete theories

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  operationalist? NO
  - principles are not about measurement operations

Responses to Fuchs' (2016) criticisms of reconstructions of QT

1. Principles from which QT has been reconstructed lack "shock value" when juxtaposed, like principles of special relativity

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2. We will know that we have a successful reconstruction when principles satisfy Wheeler's desideratum:

   Wheeler: "If one really understood the central point and its necessity in the construction of the world, one ought to be able to state it in one clear, simple sentence."

   Response: Principles of Lagrangian mechanics do not satisfy this requirement