Introduction to Laws of Nature

Eddy Keming Chen

Department of Philosophy.
University of California, San Diego

www.eddykemingchen.net

Laws of Nature: Lecture 1

Let us start with a brief overview.

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Philosophy of Science

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- General Philosophy of Science

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Philosophy of Science

- General Philosophy of Science
- Philosophy of the Specific Sciences

General Philosophy of Science

General Philosophy of Science

- Laws of Nature
- Explanation
- Confirmation
- Induction
- Realism
- Theoretical virtues
- Counterfactuals and causation
- Determinism, indeterminism, and chance
- Decision theory
- History of science
- Science and values
- Science, technology, and society

Philosophy of the Specific Sciences

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- Philosophy of Physics
- Philosophy of Chemistry
- Philosophy of Biology
- Philosophy of Psychology
- Philosophy of Cognitive Science
- Philosophy of Neuroscience
- Philosophy of Climate Science
- Philosophy of Medicine
- Philosophy of Economics
- Philosophy of Probability and Statistics
- Philosophy of Mathematics

Philosophy of Physics

- Philosophy of Classical Physics
- Philosophy of Quantum Physics
- Philosophy of Statistical Physics
- Philosophy of Relativity

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But problems in philosophy are rarely isolated. Often, a problem can span a range of topics.

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- draw knowledge about a range of topics
- laws, explanation, confirmation, realism, theoretical virtues, determinism / indeterminism, history of science, scientific metaphysics, probability
- philosophy of quantum physics, classical physics, statistical physics, and relativity

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- conceptual connections to many general issues
    - possibility, necessity, counterfactuals, causation, production, determinism, prediction, explanation, induction

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- conceptual connections to many general issues
  - possibility, necessity, counterfactuals, causation, production, determinism, prediction, explanation, induction
- science presents many examples of laws that stretch our intuitions, requiring us to update and refine our accounts of lawhood
  - much discussed in philosophy of physics: laws about spacetime, principles of least action, non-locality, time-reversal symmetry

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- that's why I'm currently working on both at the same time

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- Lecture 5: Why Are Laws Simple?

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- We will incorporate the most recent progress in philosophy of physics.

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2. a fundamental nomology about how such things behave. [laws]

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Fundamental Ontology The fundamental ontology of a physical theory refers to the fundamental material objects, their fundamental properties, and the spacetime they occupy, according to that theory.

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- Spacetime: 3-dimensional Euclidean space, represented by the Cartesian coordinate space $\mathbb{R}^3$, and 1-dimensional time, represented by $\mathbb{R}^1$

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For simplicity, let us assume that all N particles have equal mass $m = 1$ in the chosen unit.

Ontology and Nomology

(i) Physical states. The fundamental physical state of the universe at time t is the instantaneous state of the fundamental ontology at t, i.e. the arrangement of fundamental material objects and their properties at t.

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In the example above, the state of the N-particle universe at time t is a list $(q_1(t), q_2(t), ..., q_N(t))$, together with the mass values that do not depend on time. Call $Q(t) = (q_1(t), q_2(t), ..., q_N(t))$ a *configuration* of the universe.

It is often useful to consider other information, such as momenta of the N particles, $(p_1(t), p_2(t), ..., p_N(t))$, alongside positions. If we understand momenta as velocities (changes in positions) multiplied with mass, then momenta need not be fundamental properties of the particles.

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A state description with both positions and momenta, $X(t) = (q_1(t), q_2(t), ..., q_N(t); p_1(t), p_2(t), ..., p_N(t))$, which includes more information than the fundamental physical state, can still be regarded as a physical state.

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The space of all possible configurations is called the *configuration space*. Each point in the configuration space corresponds to a possible value of $Q(t)$, a possible list of the positions of N particles in $\mathbb{R}^3$. The configuration space is represented by $\mathbb{R}^{3N}$.

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Each point in the phase space corresponds to $X(t)$, a possible list of the positions *and momenta* of N particles in $\mathbb{R}^3$. The list $X(t)$ is twice as long as $Q(t)$. The phase space is represented by $\mathbb{R}^{6N}$.

(iii) Physical histories. We can consider a physical history of the N-particle universe in terms of physical states and state spaces. The most intuitive way is to represent the physical history as N curves in physical space.

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The physical history of the entire universe corresponds to a single curve in the high-dimensional configuration space, representing the configurations at different times. (It also can be represented as a single curve in phase space.)

The concept of physical histories does not presuppose a direction of time.

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Fundamental Nomology The fundamental nomology of a physical theory refers to the fundamental laws in the physical theory.

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- The force law: $F = GMm/r^2$, or equivalently $F_i(t) = \sum_{j \neq i}^{N} \frac{G m_i m_j}{|q_i(t) - q_j(t)|^2}$, with G the gravitational constant

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- A possible world can be represented in multiple ways discussed above, with N curves in physical space or spacetime, or a single curve in a high-dimensional state space.
- The collection of all such worlds permitted by physical laws forms the set of **nomological possibilities**.

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- (1) the fundamental objects and properties are restricted to those kinds mentioned by the fundamental laws in T, and
- (2) their arrangement is compatible with those laws. In other words, a nomologically possible world of theory T is a model of the laws of T.
- This definition can be specialized to the actual physical laws. The actual world is a very special one—the spacetime with the actual arrangement of objects and their properties.

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Note that $\Omega_\alpha = \Omega^T$ only when T is the actual theory of the world, i.e. the axioms of T correspond to the fundamental laws governing α.

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The choice of a fundamental nomology selects a special subclass of histories as corresponding to the nomologically possible histories, which are also called **physical possibilities**.

Counterfactuals and Causation

Let's turn to issues about counterfactuals and causation.

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In a counterfactual, the consequence does not follow from the antecedent as a matter of logic; they are joined together by laws.

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Hence, it is not logic alone that renders C1 true and C2 false.

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But why laws in particular, but not just general facts of the form "every match that is struck in oxygen rich, dry, and no-wind condition is lit?" Generality is not sufficient, and lawfulness is crucial.

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To support a counterfactual, the non-logical fact needs to have nomological necessity, corresponding to a law.

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- If another machine were built, it would require energy to do work.
- If another person came into this room, they would have seen the movie *Oppenheimer*.

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C6 If the polarizer were oriented at 30 degrees from the median line, 25% of the pairs of photons would have passed.

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- For C5, we consider the nomologically possible worlds with a ninth planet orbiting around the sun and check whether it has an elliptical orbit.
- There are conceptual nuances and technical challenges in spelling out the exact nomic algorithms for evaluating such counterfactuals.

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- These further suggest the practical relevance of knowledge of counterfactuals and physical laws.

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For example, Suzy throws a rock at a window and the window breaks. Her throw causes the breaking of the window, because if she had not thrown the rock at the window it would not have broken.

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- Nevertheless, counterfactual dependence seems to capture an important aspect of causation.
- The central idea is also preserved in contemporary structural equation models of causation.

Dynamic Production and the Direction of Time

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- Laws govern the universe by dynamically producing the subsequent states from earlier ones;
- an event is explained by appealing to the laws and the prior events that produce it.

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- Examples include Newton's $F = ma$, Schrödinger's equation, and Dirac's equation, but not Einstein equation, Gauss's law, or boundary-condition laws.
- Moreover, for dynamic production to make sense, the temporal development should be directed only from the past to the future.

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- they are (essentially) time-reversal invariant in the sense that for any nomologically possible history going in one temporal direction, its temporal reverse is also nomologically possible.
- Where does the direction of time come from?
- A natural idea, on this picture, is to make the direction of time a fundamental feature of the universe.

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Dynamic Production Laws explain by producing later states of the universe from earlier ones.

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Only FLOTEs: The only kind of fundamental laws are fundamental laws of temporal evolution (FLOTEs).

(2) a commitment to dynamic production as how laws explain:

Dynamic Production: Laws explain by producing later states of the universe from earlier ones.

and (3) a metaphysical posit about the direction of time:

Temporal Direction Primitivism: The direction of time is a fundamental feature of the universe.

Dynamic Production and the Direction of Time

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> *The universe, as well as all the smaller parts of it, is made: it is an ongoing enterprise, generated from a beginning and guided towards its future by physical law. (p.182)*

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- It may be a useful heuristic picture to start out with,
- but once we see more examples of candidate laws and appreciate the explanations they provide, it is natural to replace the picture with something more flexible (allowing non-FLOTEs to be laws) and without a commitment to dynamic production or a fundamental direction of time.

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- Given the Past Hypothesis as a nomic constraint, it is plausible to expect that most solutions to the dynamical equations will be ones that relaxes towards the thermodynamic equilibrium (maximum entropy) in the direction away from the temporal boundary where the Past Hypothesis applies.
- Hence, almost all the nomological possible worlds are such that they will display an entropy gradient, giving rise to an emergent (non-fundamental) direction of time.

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- Still, we may sometimes prefer FLOTEs, but the preferences are not grounded in metaphysical prohibitions about the forms of laws,
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- As I shall argue in the next lecture, the alternative approach is better suited for accommodating the variety of kinds of laws in modern physics and understanding the explanations they provide.

Other Connections

- Determinism
- Indeterminism
- Chance
- Strong Determinism
- Prediction
- Explanation
- Induction
- Exactness
- Fundamentality

My Book

Laws of Physics

- Cambridge University Press, forthcoming
- Draft available online:
- Chapters 1-2

Concluding Remarks

- General philosophy of science and philosophy of specific sciences are inseparable.
- The topic of laws of nature is a good example.
- Laws are intimately connected to a wide range of issues.
- We will investigate some of them in the next few days.

I look forward to our discussions.

Thank you! The end.