Let us start with a brief overview.
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Philosophy of Science
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Philosophy of Science
  • 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
The demarcations serve some purposes.
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But problems in philosophy are rarely isolated. Often, a problem can span a range of topics.
Example: the measurement problem of quantum mechanics
Example: the measurement problem of quantum mechanics

- 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
Another example: laws of nature
Another example: laws of nature

- conceptual connections to many general issues
  - possibility, necessity, counterfactuals, causation, production, determinism, prediction, explanation, induction
Another example: laws of nature

- 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
My personal experience, for what it’s worth:
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- started with general issues in philosophy of science (laws and chances)
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- that’s why I’m currently working on both at the same time
This lecture series is on laws of nature.
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- Lecture 1: Introduction [Today]
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- Lecture 1: Introduction [Today]
- Lecture 2: How Do Laws Govern?
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Overview of the Lecture Series

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- Lecture 5: Why Are Laws Simple?
We begin with some general remarks about laws:
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- What makes them interesting is their connections to a wide range of issues, such as **ontology**, **modality**, explanations, **counterfactuals**, **causation**, **time**, induction, determinism, chance, and fundamentality.
- We will incorporate the most recent progress in philosophy of physics.
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1. a fundamental ontology about what things there are in the physical world.
Ontology and Nomology

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1. a fundamental ontology about what things there are in the physical world.
2. a fundamental nomology about how such things behave. [laws]
Let us start with a first-pass definition of the fundamental ontology of a theory.
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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.
For a familiar example, consider a version of Newtonian gravitation theory. Its fundamental ontology has three components:

- **Fundamental material objects:** $N$ particles
- **Fundamental properties:** their masses, $(m_1, m_2, \ldots, m_N)$, and their trajectories in physical space, $(q_1(t), q_2(t), \ldots, q_N(t))$
- **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.
(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 $(q_1(t), q_2(t), \ldots, q_N(t))$, together with the mass values that do not depend on time. Call $Q(t) = (q_1(t), q_2(t), \ldots, q_N(t))$ a configuration of the universe.
It is often useful to consider other information, such as momenta of the $N$ particles, $(p_1(t), p_2(t), \ldots, p_N(t))$, 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, $X(t) = (q_1(t), q_2(t), \ldots, q_N(t); p_1(t), p_2(t), \ldots, p_N(t))$, which includes more information than the fundamental physical state, can still be regarded as a physical state.
(ii) *State spaces.* There are many possible states for the universe to be at any time. A space of all such possible states is a state space.
(ii) State spaces. There are many possible states for the universe to be at any time. A space of all such possible states is a state space. 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 $\mathbb{R}^{3N}$. 
When it is useful to consider momenta in addition to particle positions, as in classical mechanics, we may define a space of higher dimensions called the *phase space*.
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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.)
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The concept of physical histories does not presuppose a direction of time.
Next, let us define the fundamental nomology of a theory.
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**Fundamental Nomology** The fundamental nomology of a physical theory refers to the fundamental laws in the physical theory.
The fundamental laws of Newtonian gravitation theory can be represented by the following equations:

**Dynamical Law:**\[ F = ma, \] or equivalently\[ F_i(t) = m_i \frac{d^2 q_i(t)}{dt^2}, \] with \( G \) the gravitational constant.

**Force Law:**\[ F = \frac{GMm}{r^2}, \] or equivalently\[ F_i(t) = \sum_{N_j \neq i} \frac{G m_i m_j}{|q_i(t) - q_j(t)|^2}, \] for each \( i \)th particle.
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- The dynamical law: \( F = ma \), or equivalently \( F_i(t) = m_i \frac{d^2 q_i(t)}{dt^2} \)
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  F_i(t) = \sum_{j \neq i}^N \frac{G m_i m_j}{|q_i(t) - q_j(t)|^2}, \text{ with } G \text{ the gravitational constant}
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The collection of all such worlds permitted by physical laws forms the set of **nomological possibilities**.
More precisely, a nomologically possible world of theory $T$ is a logically consistent description of spacetime and its contents such that
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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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Let’s define the following:

A possible world \( w \): a spacetime and a distribution of material contents.

The actual world \( \alpha \): the actual spacetime and the actual distribution of material contents.

Material contents: material objects and their qualitative properties.

\( \Omega_T \): the set of possible worlds that satisfy the fundamental laws specified in theory \( T \).

\( \Omega_\alpha \): the set of possible worlds that satisfy the actual fundamental laws of \( \alpha \), i.e. the set of all nomologically possible worlds.

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 \( \alpha \).
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We may think of a choice of a fundamental ontology as pinning down abstract *state spaces* that tell us what kind of physical states are available.
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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*. 
Let’s turn to issues about counterfactuals and causation.
Laws *support* counterfactuals. A counterfactual is a conditional of the form “if A were the case, then B would be the case.”
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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.
For example, consider:

C1  If this match had been struck, it would have lit.
For example, consider:

\[ \text{C1} \quad \text{If this match had been struck, it would have lit.} \]

\[ \text{C2} \quad \text{If this match had been struck, it would not have lit.} \]
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Suppose C1 is true and C2 false.
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Suppose C1 is true and C2 false.

For either one, the consequent and its negation are logically compatible with the antecedent. [Note about truth-functionality.]
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Suppose C1 is true and C2 false.

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Hence, it is not logic alone that renders C1 true and C2 false.
What non-logical fact is needed? Many agree that it involves some laws.
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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.
Suppose every coin in my pocket is silver.
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Nevertheless, the following counterfactual is false:

C3 If this coin were in my pocket, it would have been silver.

The problem is that the general fact \textit{every coin in my pocket is silver} is accidental.
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The problem is that the general fact *every coin in my pocket is silver* is accidental.

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

More examples:

All machines are such that they require energy to do work; that is, there are no perpetual motion machines of the first kind. All people in this room have seen the movie *Oppenheimer*. 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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- 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*. 
To see this more clearly, consider counterfactuals about physical systems:

C4 If this ice cube were placed in a cup of hot tea, it would have melted 30 seconds later.

C5 If there were one more planet orbiting around the sun, it would have an elliptical orbit.

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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To evaluate such counterfactuals, we need knowledge of the relevant laws (in thermodynamics, classical mechanics, and quantum mechanics).
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For C4, we can consider the nomologically possible worlds where this ice cube were placed in a cup of hot tea, and check whether the ice cube is melted 30 seconds later in all (or most) of them. If the answer the yes, then C4 is true.
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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.
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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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Roughly speaking, event A causes event E if and only if the following two counterfactuals are true:
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C7 If A were the case, then C would be the case.

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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The central idea is also preserved in contemporary structural equation models of causation.
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- For some people, dynamic production is constitutive of how laws govern and explain.
- 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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The emphasis on dynamic production is often associated with an emphasis on dynamical laws and the direction of time.

If dynamic production is how laws govern, perhaps laws should be dynamical laws that evolve the states of the universe successively in time.

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Moreover, for dynamic production to make sense, the temporal development should be directed only from the past to the future.
However, the laws in modern physics are blind to the past-future distinction;
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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.
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Where does the direction of time come from?
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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.
We may summarize this package of ideas as (1) a restriction of the form of laws:

**Only FLOTEs** The only kind of fundamental laws are fundamental laws of temporal evolution (FLOTEs).
Dynamic Production and the Direction of Time

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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.
Many people accept the package because it seems intuitive. Some build it into their theories of lawhood.
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*The universe started out in some particular initial state. The laws of temporal evolution operate, whether deterministically or stochastically, from that initial state to generate or produce later states.* (p.174)
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*This sort of explanation takes the term initial quite seriously: the initial state temporally precedes the explananda, which can be seen to arise from it (by means of the operation of the law).* (p.176)

*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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Dynamic Production and the Direction of Time

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- We should understand the direction of time and dynamic production as important but derivative features of the physical world, partly explained by a boundary-condition law called the Past Hypothesis.

- The direction of time should be understood in terms of an entropy gradient that arises from a new law—at one temporal boundary, the universe is in a low-entropy state.
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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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but in methodological and epistemic reasons that certain dynamical laws offer simple and compelling explanations of observed phenomena.

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
Laws of Physics

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