15. Laws of Nature

- *Common view*: One goal of science is to discover the laws of nature.

Newton's Laws of Motion

I. Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.

II. The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.

III. To every action there is always opposed an equal reaction.

Ohm's Law

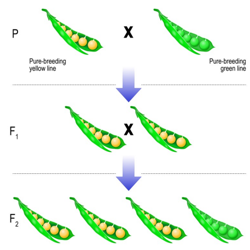
$V = IR$

Boyle's Law

$P \propto 1/V$

Mendel's Laws of Inheritance

1. *Dominance*: Recessive alleles will be masked by dominant alleles.
2. *Segregation*: When gametes form, alleles are separated so that each gamete carries only one allele for each gene.
3. *Assortment*: The segregation of alleles for one gene occurs independently to that of any other gene.

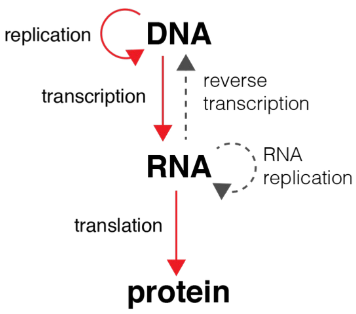


Moore's Law

The number of transistors on a microchip doubles every two years.

Central Dogma

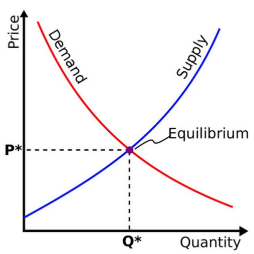
Genetic information can flow from DNA to RNA, and *vice-versa*; and from RNA to protein, but not *vice-versa*; and not from protein to protein.



Laws of Supply and Demand

A. *Supply*: At higher prices, sellers will supply more of an economic good.

B. *Demand*: At higher prices, buyers will demand less of an economic good.



Linus's Law

Given enough eyeballs, all bugs are shallow.

Newton's Law of Gravity

$$F = \frac{Gm_1m_2}{r^2}$$

What is a law of nature?

1. Preliminary Sketch

Claim: A law must
(a) Describe a regularity that holds universally.
(b) Support counterfactual statements.
(c) Support modal statements.

Counterfactual statement: An "if-then" statement with a false "if" clause.

Ex. If Abe Lincoln were alive today, then he'd be clawing at the lid of his coffin.

Modal statement: A statement that asserts a physical necessity or (im)possibility.

Ex. It is impossible to construct an enriched uranium sphere with mass > 100,000 *kg*.

Which are laws?

1. All the apples in my refrigerator are yellow. Not a law!
2. No gold sphere has a mass greater than 100,000 *kg*. Not a law!
3. No enriched uranium sphere has a mass greater than 100,000 *kg*.

- #1 does not satisfy (a).
- #2 satisifes (a), but not (b) or (c).
  - It doesn't support the true counterfactual statement, "If two gold spheres with masses 50,001 *kg* were put together, then they would form a sphere with mass > 100,000 *kg*."
  - It doesn't support the true modal statement, "It is possible to construct a gold sphere with mass > 100,000 kg."

1. Preliminary Sketch

Hempel, C. & P. Oppenheim (1948) "Studies in the Logic of Explanation"

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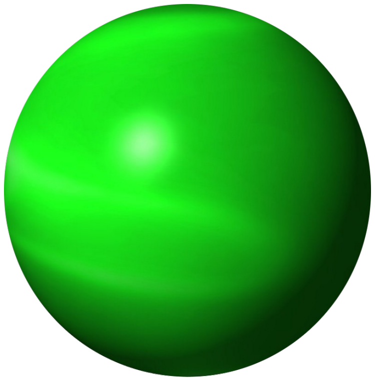
<u>Which are laws</u>?

1. All the apples in my refrigerator are yellow. *Not a law!*
2. No gold sphere has a mass greater than 100,000 *kg*. *Not a law!*
3. No enriched uranium sphere has a mass greater than 100,000 *kg*. *A law!*

- #1 does not satisfy (a).
- #2 satisifes (a), but not (b) or (c).
- #3 satisfies (a), (b) and (c).
  - It supports the true counterfactual statement, "If two enriched uranium spheres with masses 50,001 *kg* were put together, then they would not form a sphere with mass > 100,000 *kg*."
  - It supports the true modal statement, "It is impossible to construct a sphere of enriched uranium with mass > 100,000 *kg*."



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Accidental generalization: A true generalization that satisfies (a), but not (b) or (c).

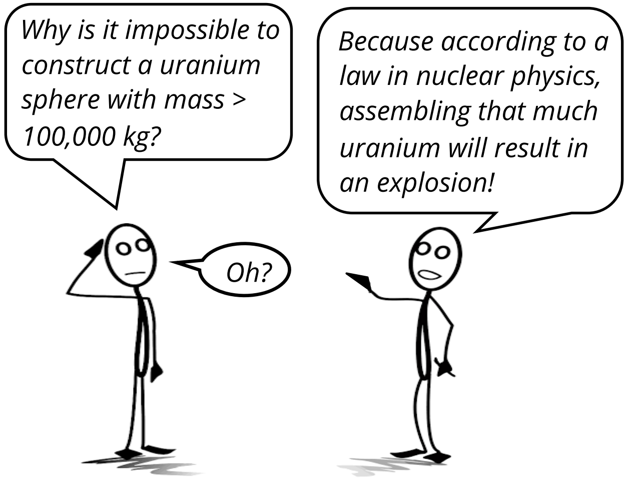
Law: A true generalization that satisfies (a), (b), and (c).

<u>*Problem of Circularity*</u>

- Under this preliminary account, a law differs from an accidental generalization solely on its ability to support counterfactuals and modal statements.

- <u>*But*</u>: Why do we think certain counterfactuals and modal statements are true in the first place?

  - *If it's because we think there is a law of nature that makes them true, then we can't use them to define what we mean by a law.*



- <u>*So*</u>: The preliminary account only works if we *already* have a theory of counterfactuals and modal statements that is *independent* of the notion of a law.

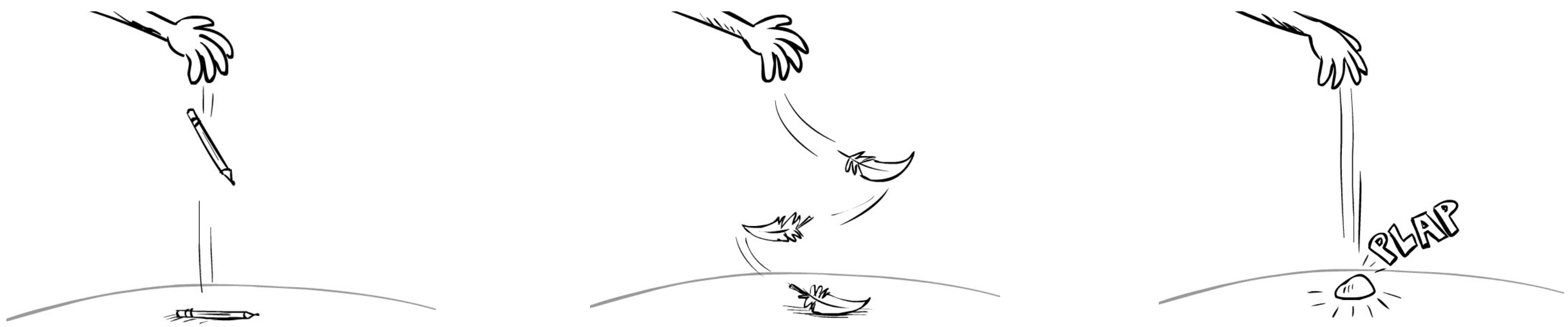
  - *Such a theory would determine which counterfactuals/modal statements are true and which are false, and then we could adopt the preliminary account's definition of a law.*

2. The Simple Regularity Account

Claim: A law is a regularity.

It is a law that F's are G's *if and only if* all F's are G's.

- Let F be the property of "being in free fall near the surface of the Earth".
- Let G be the property of "experiencing an acceleration of 9.8 m/s^2".
- *Then*: Newton's Law of Gravity consists (in part) of the collection of all instances of objects exhibiting both F and G.



A pencil that possesses both F and G. A feather that possesses both F and G. A rock that possesses both F and G.

Newton's Law of Gravity = particular observed regularity that consists (in part) of all objects that possess the properties F ("being in free fall near the surface of the Earth") and G ("experiencing an acceleration of 9.8 m/s^2").

Two Problems

1. Not all regularities are laws.

- An accidental generalization is not a law.

$F =$ "being an apple in my refrigerator"

$G =$ "being yellow"

2. Not all laws are regularities.

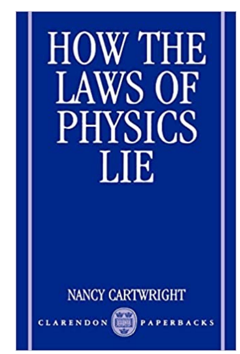
Ex. 1: No-instance laws

- The ideal gas law: $P = kT/V$
- Newton's 2nd Law: $F = ma$

> *Claim*: These are applicable only under ideal conditions that never actually occur.

- *Thus*: There are no real instances of them.
- *In other words*: The regularities that we do observe are not precisely characterized by them.

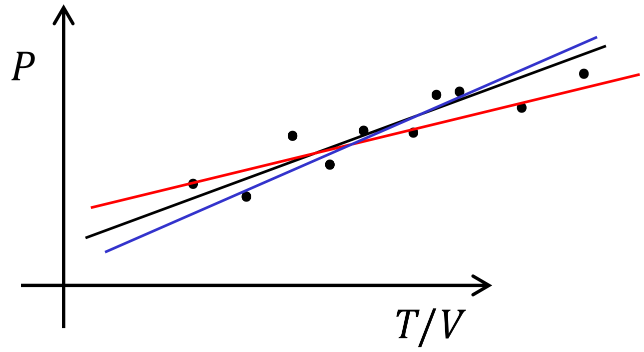
Radical Claim: *All* laws in physics are no-instance laws.



Cartwright, Nancy (1983)
How the Laws of Physics Lie

Ex. 2: Functional laws

- Laws expressed as functions that can take a continuum of values, more than the finite number of instances that can be observed in nature.
- *Consider again*: The ideal gas law $P(T, V) = kT/V$.
  - *P takes a continuum of values; more than those that actually occur as regularities displayed by actual gases (under conditions approaching ideal conditions).*
  - *So: The law is more than just a summary of its actually occurring instances.*



- *Instances (data points) of the law don't pick out a unique function (graph).*
- *There are distinct graphs that fit the data.*

- *Note*: A functional law gives us information about instances that have not yet been observed.
  - *Allows us to infer what would be the case if certain conditions hold.*
  - *Thus: Supports counterfactuals!*

Ex. 3: Probabilistic laws

- A law that states that F's have a certain probability of being G's.
- *Example*: All F's have a probability of 1/2 of being G's.
  - *Let*: F = "being a nucleus with a half-life of 100,000 years"
    G = "decaying after 100,000 years"

Claim: A probabilistic law cannot be considered just a summary of its instances.

- *Why*? Because a probabilistic law describes an average distribution of a property (G) over a population of individuals (F's).
  - *So*: An individual might not have the property but still be governed by the law.

Ex: Any particular nucleus with a half-life of 100,000 years may not have decayed after 100,000 years.

- The law just says "On average, half the population will have decayed after 100,000 years".
- *But*: We still want to say that all such nuclei are governed by the probabilistic law.

Ex: Any particular flip of a coin may come up tails.

- *But*: We still want to say that all coins are governed by the probabilistic law of coming up heads with probability 1/2.

Possible response

- There are two ways to interpret probabilities:

Epistemic View: Probabilities are a measure of our ignorance.

- "A nucleus has a probability of 1/2 of decaying after 100,000 years" means "We can't predict with certainty whether it will decay after 100,000 years, but there is a determinant fact of the matter whether it will or will not".

Ontic View: Probabilities refer to intrinsic probabilistic properties.

- "A nucleus has a probability of 1/2 of decaying after 100,000 years" means "The nucleus has an intrinsic probabilistic property: there is no determinant fact of the matter as to whether or not it will decay after 100,000 years".

- The Ontic View allows for instances of probabilistic laws.
  - Such instances are individuals with instrinsic probabilistic properties.
  - *So*: A probabilistic law is just a "normal" law (All F's are G's) in which the G is an intrinsic probabilistic property.

"All F's have a probability of 1/2 of being G's"

- *Where*: F = "being a nucleus with a half-life of 100,000 years", and G = "decaying after 100,000 years".

really means

"All F's are G's"

- *Where*: F = "being a nucleus with a half-life of 100,000 years" and G = "decaying with prob 1/2 after 100,000 years".

3. The Best System Account

Claim: A regularity is a law *if and only if* it appears as a theorem or axiom in that true *deductive system* which achieves a best combination of *simplicity* and *strength*.

"theory"

least number of axioms

information content

Motivation

- Laws *systematize* facts; they don't *just* report them.
- *How to systematize facts*: Construct a theory in which they can be embedded.
- *To identify laws*:
  - Write down the simplest and strongest theory that accounts for the phenomena.
  - The laws will be the basic principles (theorems or axioms) of this theory.

Advantages

1. *Allows distinction between* **accidental generalizations** *and* **laws**.
   - Accidental generalizations will not figure into the simplest and strongest systematization of the facts.

2. *Allows distinction between* **fundamental laws** *and* **derived laws**.
   - *Ex*. Kepler's 3 laws of planetary motion can be derived from Newton's law of gravity.

Kepler's Laws

1. The orbits of the planets are in the form of ellipses.
2. The orbits of the planets sweep out equal areas in equal time intervals.
3. The ratio D^3/T^2 is constant for all planets ($D =$ ave. distance from sun, $T =$ period).

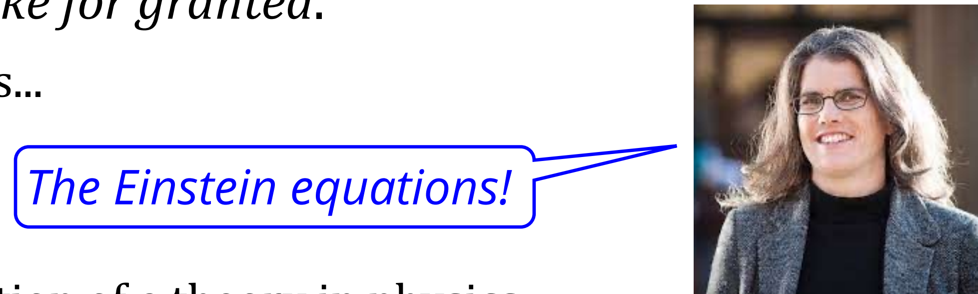
Newton's Law of Gravity

$$F = \frac{Gm_1m_2}{r^2}$$

   - The Best System Account claims that, in the best system, Newton's law of gravity will appear at a lower level, while Kepler's laws will appear at a higher level.
   - The Simple Regularity Account can't make this distinction: it makes no distinction between fundamental *vs* derived regularities.

3. *The account that (most) scientists take for granted*.

- Ask a physicist what a law of nature is...

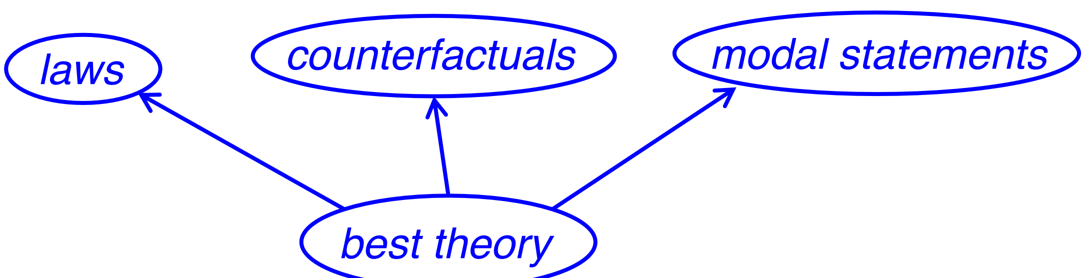


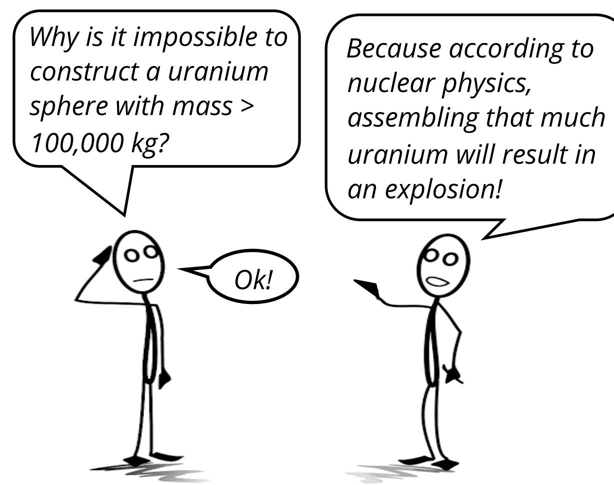
Andrea Ghez
2020 Nobel Prize in Physics

- A formula that appears as the foundation of a theory in physics.
- *But*: What about fields like biology or psychology?

4. *Accounts for the link between laws and counterfactuals/modal statements*.

- What we take to be true counterfactuals and modal statements is based on what we know about the world...
- *And*: What we know about the world is given to us by our best theories.
- *So*: Laws, counterfactuals, and modal statements have their basis in our best theories.





Problems

1. *Refers to subjective standards of simplicity and strength*.
   - Laws are supposed to be *objective* features of nature: Why should we think nature is simple?

2. *What if there is more than one best system?*
   - *Concern*: If so, then there is no fact of the matter as to what the true laws of nature are.

3. *What if the best system has accidental generalizations as its axioms and theorems?*

- Assumedly, this would be the case if the best system's axioms/theorems are generalizations that do not support counterfactuals or modal statements (recall the Preliminary account of laws).
  - *Ex*. No gold sphere has a mass > 100,000 kg.

- *But*: Under the Best System Account, what we take to be true counterfactuals and modal statements is determined by our best system.

> *In particular*: If it's an axiom or theorem of the best system that "No gold sphere has a mass > 100,000 *kg*", then, assumedly, the world in which the best system is true is a world in which it is false that "If two gold spheres of mass 50,001 *kg* each were combined, then we would have a gold sphere with mass > 100,000 *kg*".

- *In other words*: Under the Best System Account, the laws are *by definition* the axioms/theorems of the best system, and the accidental generalizations are generalizations that do not support counterfactuals/modal statements whose truth is determined by these laws.

4. The Necessitarian Account

Claim: It is a law that *F*'s are *G*'s if and only if Fness *necessitates* Gness.

universal

relation between universals

universal

Assumes metaphysical distinctions between:

2nd order property
(a property of a property)

necessitation

1st order property
(a property of an individual)

Fness, Gness

individual

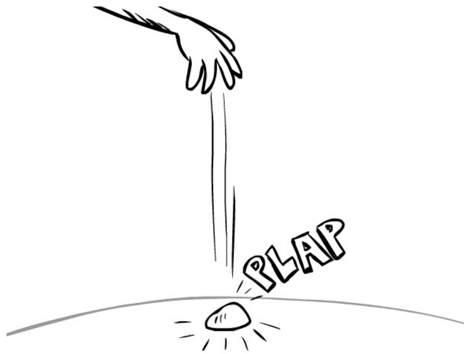
The Necessitarian Account says:

A law is a relation of *necessitation* (2nd order property) between two universals (1st order properties).

Ex. Let: *F*ness = "being in free-fall near the surface of the Earth"

*G*ness = "having an acceleration of 9.8 m/s^2

individual = a rock that I just dropped



A rock that possesses both *F*ness and *G*ness, which themselves stand in the relation of *necessitation* to each other.

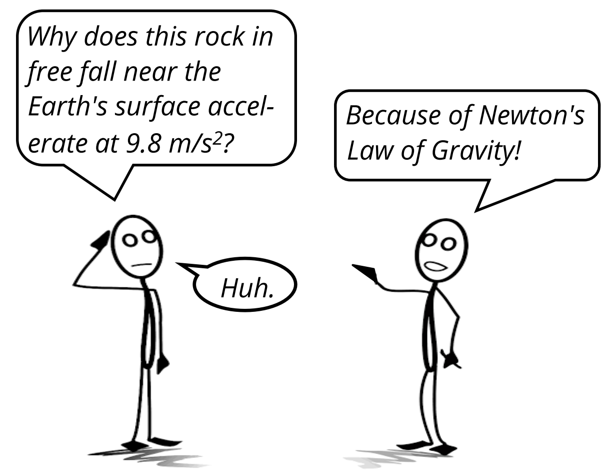
- The rock (individual) has both the 1st properties *F*ness and *G*ness.
- These properties also stand in the 2nd order relation of *necessitation*: *F*ness necessitates *G*ness.
- *This is a manifestation of Newton's Law of Gravity*: The law *just* is the relation of *necessitation* between "being in free fall near the surface of the Earth" and "having an acceleration of 9.8 m/s^2".

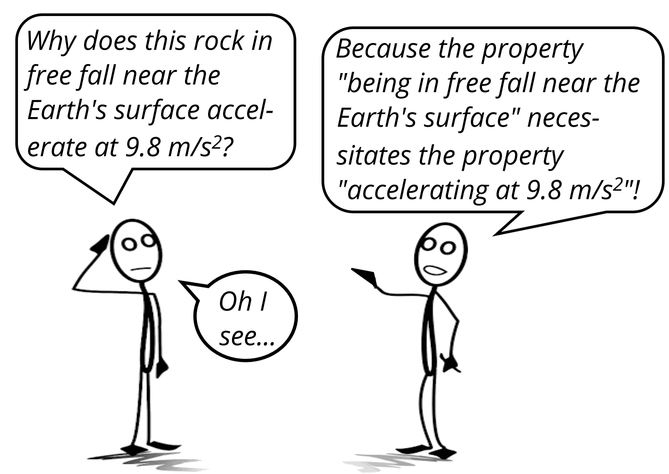
Why get so mumbo-jumbo metaphysical with it?

<u>*Advantages*</u>

1. *Allows a distinction between* **accidental regularities** *and* **laws**.
   - All laws are regularities; but a regularity doesn't have to be a law.
   - Only those regularities that exhibit the 2nd order property of necessitation are laws.

2. *Allows a law to* **explain** *its instances*.
   - Simple regularity and best system accounts both claim a law is a regularity.
   - <u>*And*</u>: What explains an instance of a regularity is something that explains the regularity itself; and a regularity cannot explain itself.
   - Necessitarian account says a law is more than a regularity: it's a regularity that exhibits the necessitation relation!
   - <u>*And*</u>: The necessitation relation explains the instances of the regularity.





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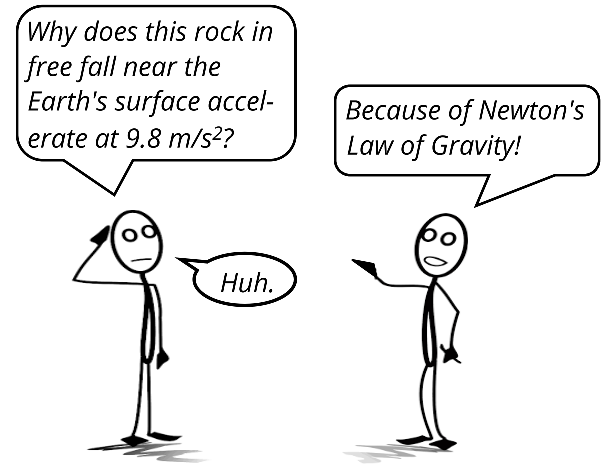
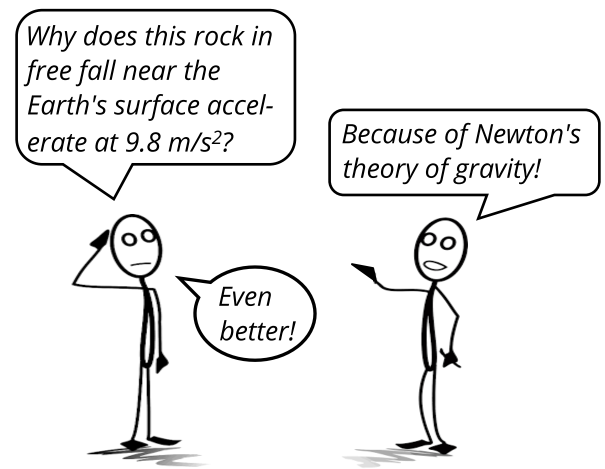
   - Simple regularity and best system accounts both claim a law is a regularity.
   - *And*: What explains an instance of a regularity is something that explains the regularity itself; and a regularity cannot explain itself.
   - Necessitarian account says a law is more than a regularity: it's a regularity that exhibits the necessitation relation!
   - *And*: The necessitation relation explains the instances of the regularity.
   - *But*: Doesn't the best system explain an instance of a regularity that is an axiom/theorem of it?

Maybe an instance of a law can be explained by something other than the law itself!





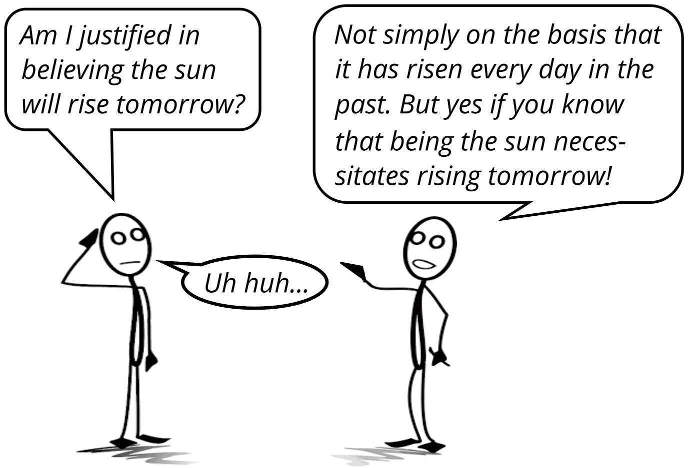
3. *Allows for a few instances to count as evidence for the existence of a law*.

- Some experiments are so constrained that just a few positive results will convince scientists of the truth of the claim being tested.
- If a law is associated with a (2nd order) property, as opposed to being a regularity, then just a single or very few instances may be enough to establish its existence.

Large Hadron Collider

4. *Provides a basis for* **induction**.

- Induction cannot be justified on the basis of a mere regularity.
- Induction *can* be justified if we know that the regularity is more than just a regularity; *i.e.*, there's something more to it that connects *F*ness with *G*ness.
- The necessitarian account tells us what this is.



Problems

1. *What is the necessitation relation?*
   - *Claim*: Any description of it fails to distinguish it from the best systems account.

2. *How is the necessitation relation known*?
   - It has to go beyond observable regularities (if we stop at observable regularities, we have the best system account).
   - It is an *in-principle unobservable* property.

Consider:
- Two worlds W_1, W_2 that agree on all observable regularities.
- The necessitarian must claim they could still disagree on what the laws of nature are.
- If the laws of W_1 and W_2 are different, how could we ever come to know this?