Causal Semantics in Physics

exploring extra-mathematical constraints on physics equations

OUTLINE

Act 1:

Debating the role of causation in science

Act 2:

physics equations have syntax & semantics

Act 3:

causation semantically constrains physics equations

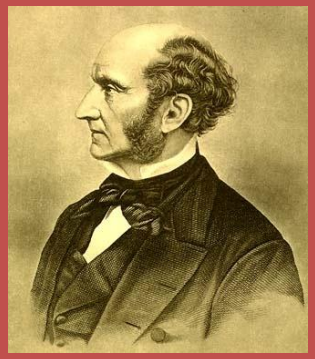
Act 1:

Debating the role of causation in science

Many folks in science believe that science relies upon causal notions

"The law of causation, the recognition of which is the main pillar of inductive science, is but the familiar truth…"

John Stuart Mill (1862)

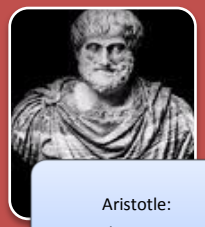


Many in education think science relies upon causal notions

"Both historically and for students, progress in scientific inquiry is characterized in part by a shift toward reasoning about causal mechanisms."

Russ & Scherr (2008)

Causation has proved hard to define



Aristotle:

An object acts in accordance with its properties

Hume:

where all the objects, similar to the first, are followed by objects similar to the second

Mackey:

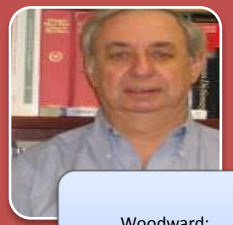
Insufficient but necessary part of unnecessary but sufficient conditions

Lewis:

Effects depend counterfactually on their causes

Cartwright:

Equations are laws of association; causal laws are effective strategies

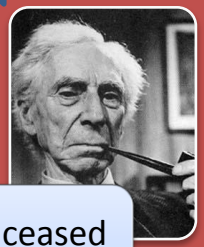


Woodward:

we can causally explain a situation when we can manipulate it

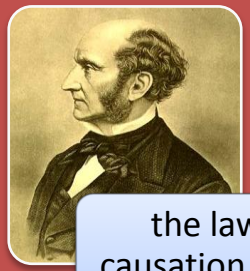
What role should causation play in science?

causal eliminitivism — causal fundamentalism



physics has ceased to look for causes ; there are no such things

Causation is folk science



the law of causation…is the main pillar of science

A fair compromise?

John Norton, (2003). Causation as Folk Science:

> At a fundamental level, there are no causes and effects in science and no overarching principle of causality. However, in appropriately restricted domains our science tells us that the world behaves just as if it conformed to some sort of folk theory of causation….

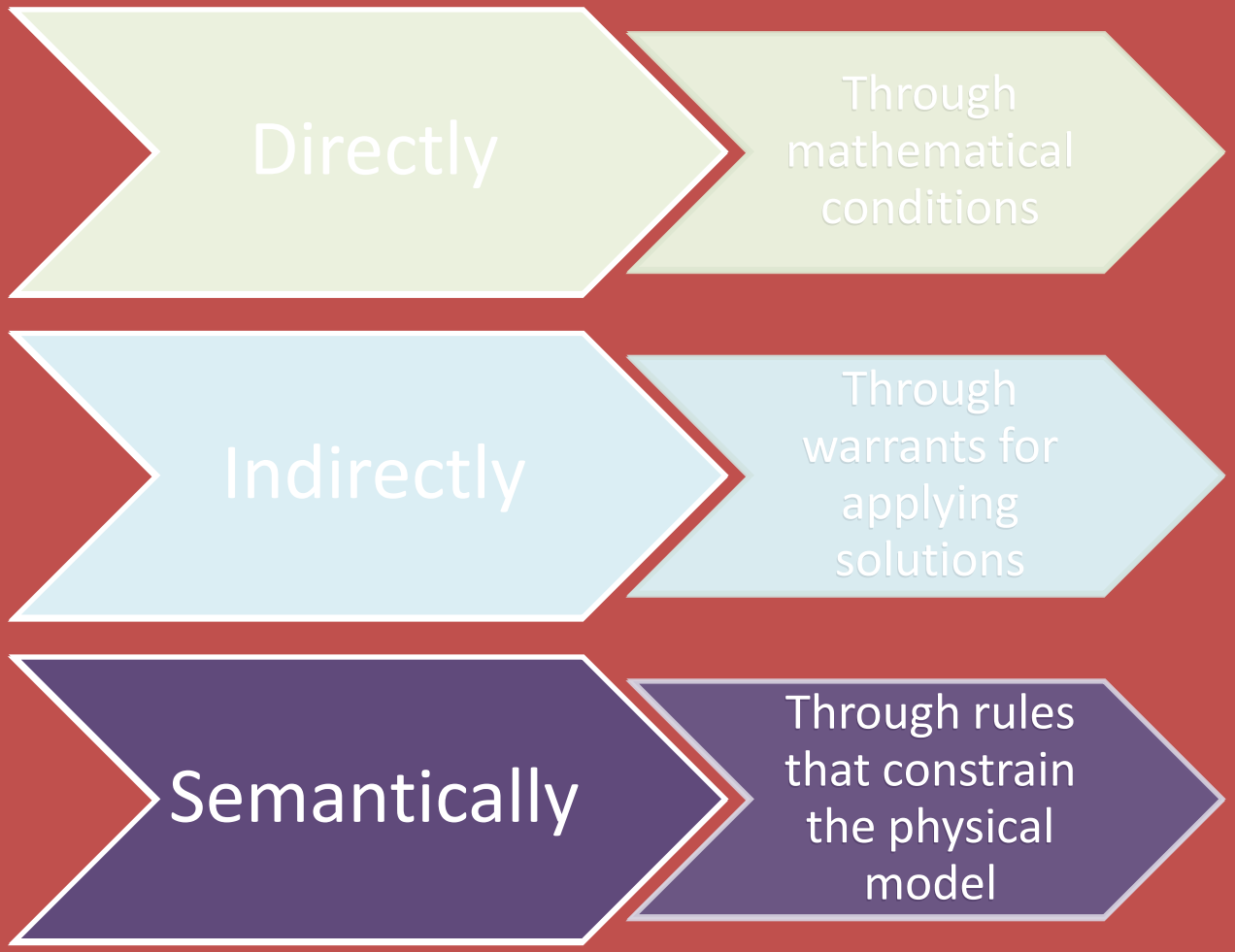
caloric

gravitational force

The Causal Fundamentalist's Dilemma

EITHER causation places restrictions on factual content of science…or it's just an empty honorific.

Causation *does* put factual restrictions on our physical theories



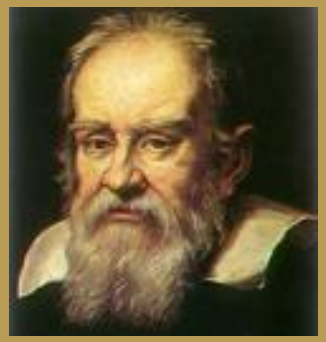
Act 2:

physics equations have syntax & semantics

Math is the language of physics

"Philosophy is written in this grand book, the universe, ... But the book cannot be understood unless one first learns to comprehend the language and read the characters in which it is written. It is written in the language of mathematics."

- Galileo Galilei

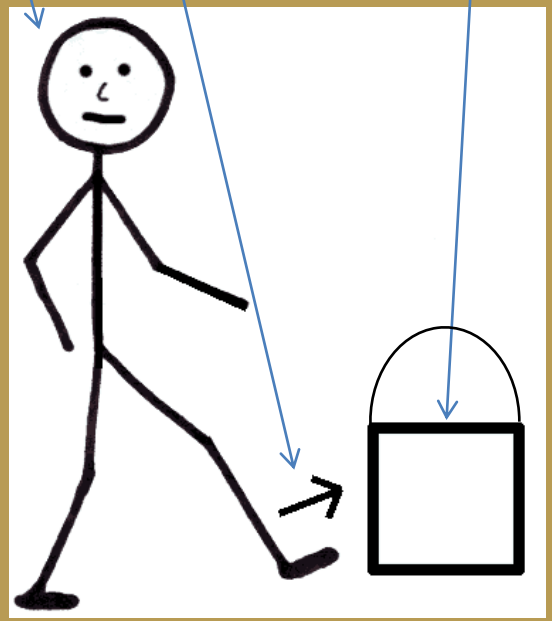


Syntax & Semantics in English

Syntax ≈ grammar

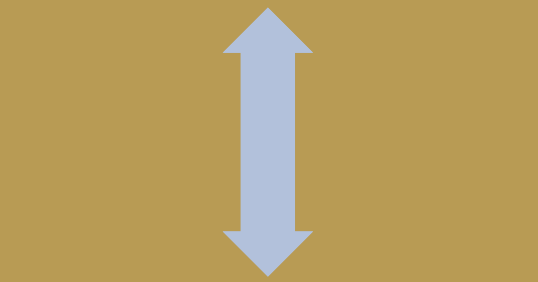
Semantics ≈ meaning

Bill kicked the bucket



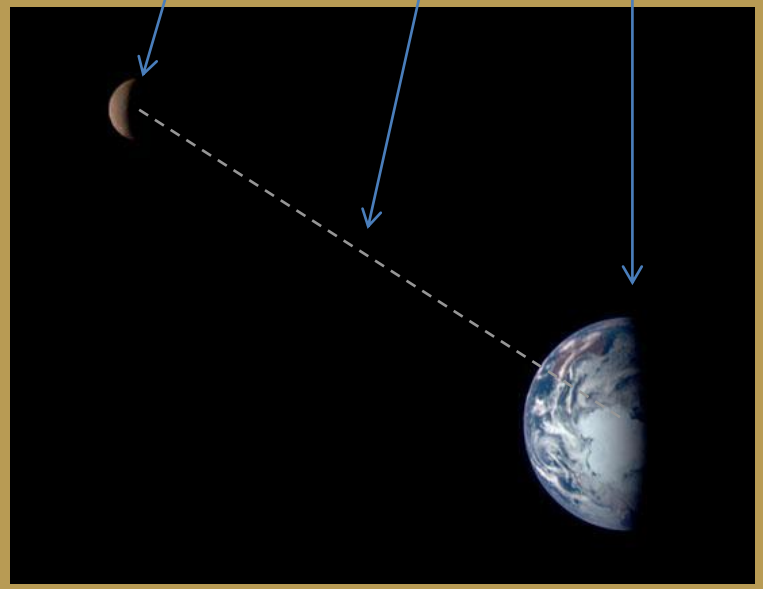
Syntax & Semantics in Physics

Mathematical Representation

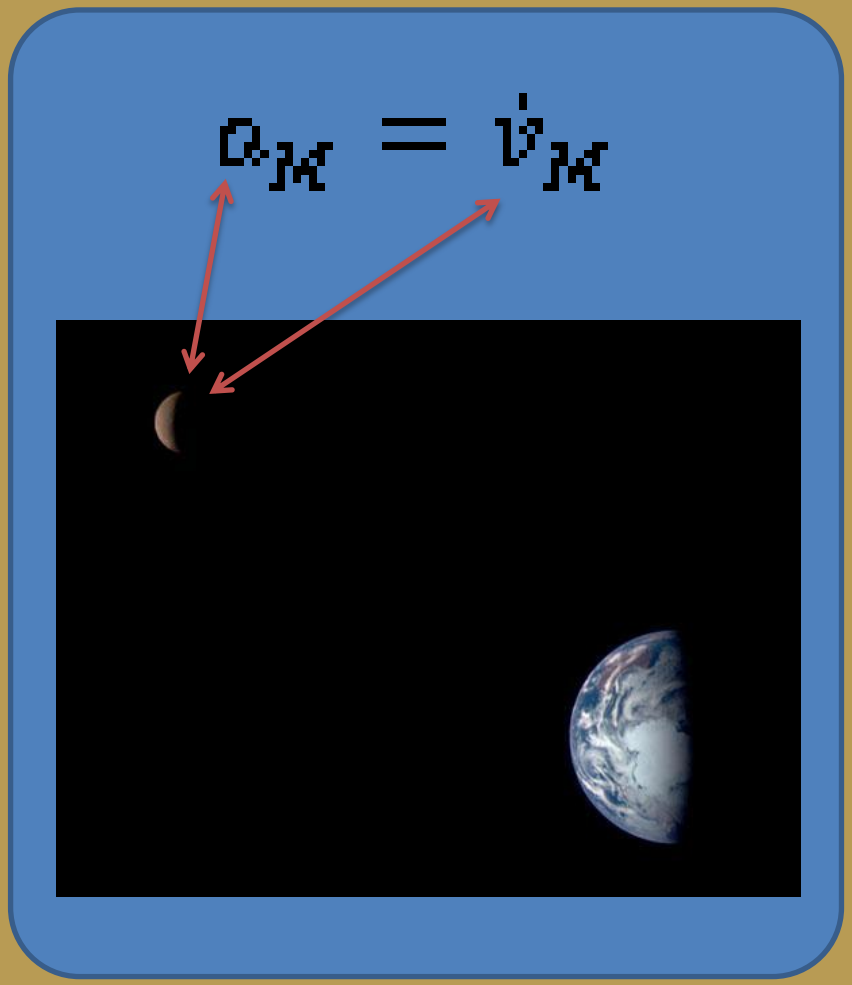


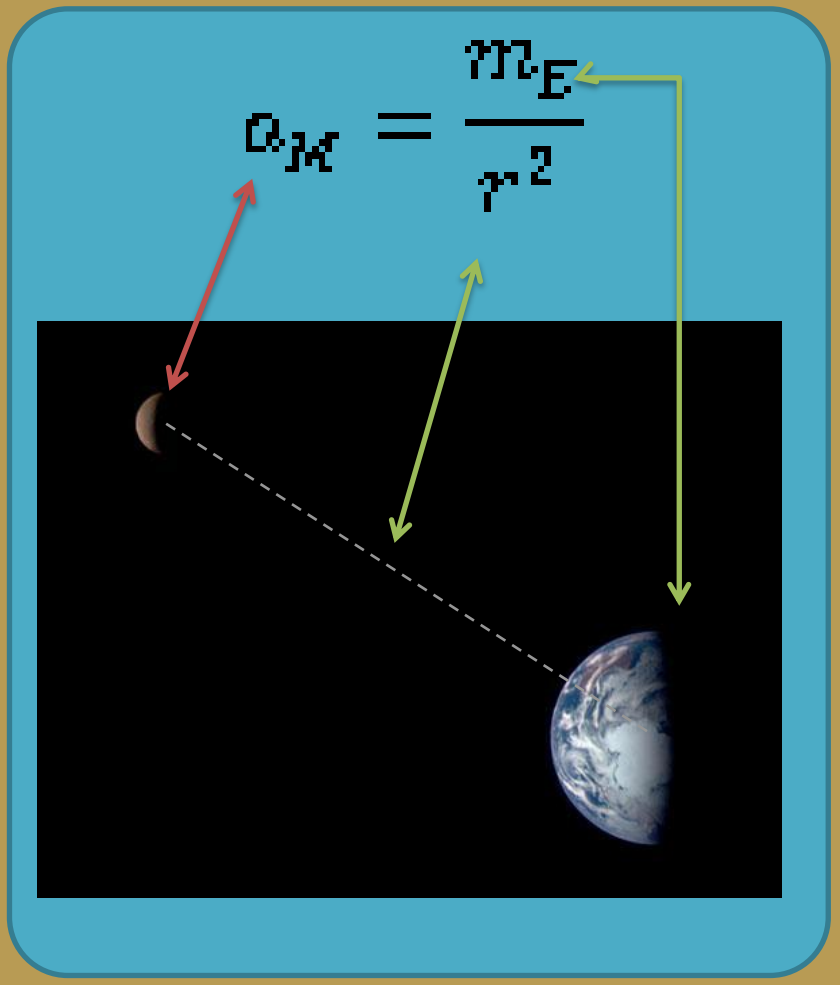
Physical System

$$a_M = \frac{m_E}{r^2}$$



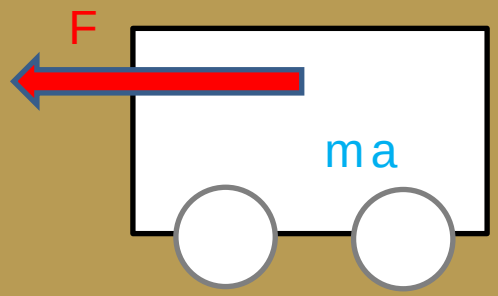
Syntactically equal doesn't mean semantically equal





The semantics of equations are hinted at by how we talk

Brookes, D. (2007)



F = ma

Force *acting on* cart

mass, acceleration *of* cart

Living entity

Container metaphor

`Twas brillig, and the slithy toves
Did gyre and gimble in the wabe:
All mimsy were the borogoves,
And the mome raths outgrabe.

Act 3:

causation can semantically constrain physics equations

Foregrounding directs your attention

"The building is behind the garden."

"The garden is in in front of the building."

Foregrounding in English: "Jim hit Bill."

Foregrounding Jim	Foregrounding Bill
Q: Who hit Bill?	Q: Who was hit by Jim?
A: *Jim* hit Bill.	A: *Bill* was hit by Jim.

Foregrounding in Physics: F = ma

Foregrounding the force

Q: How hard must an elevator pull up to make me feel 2g's

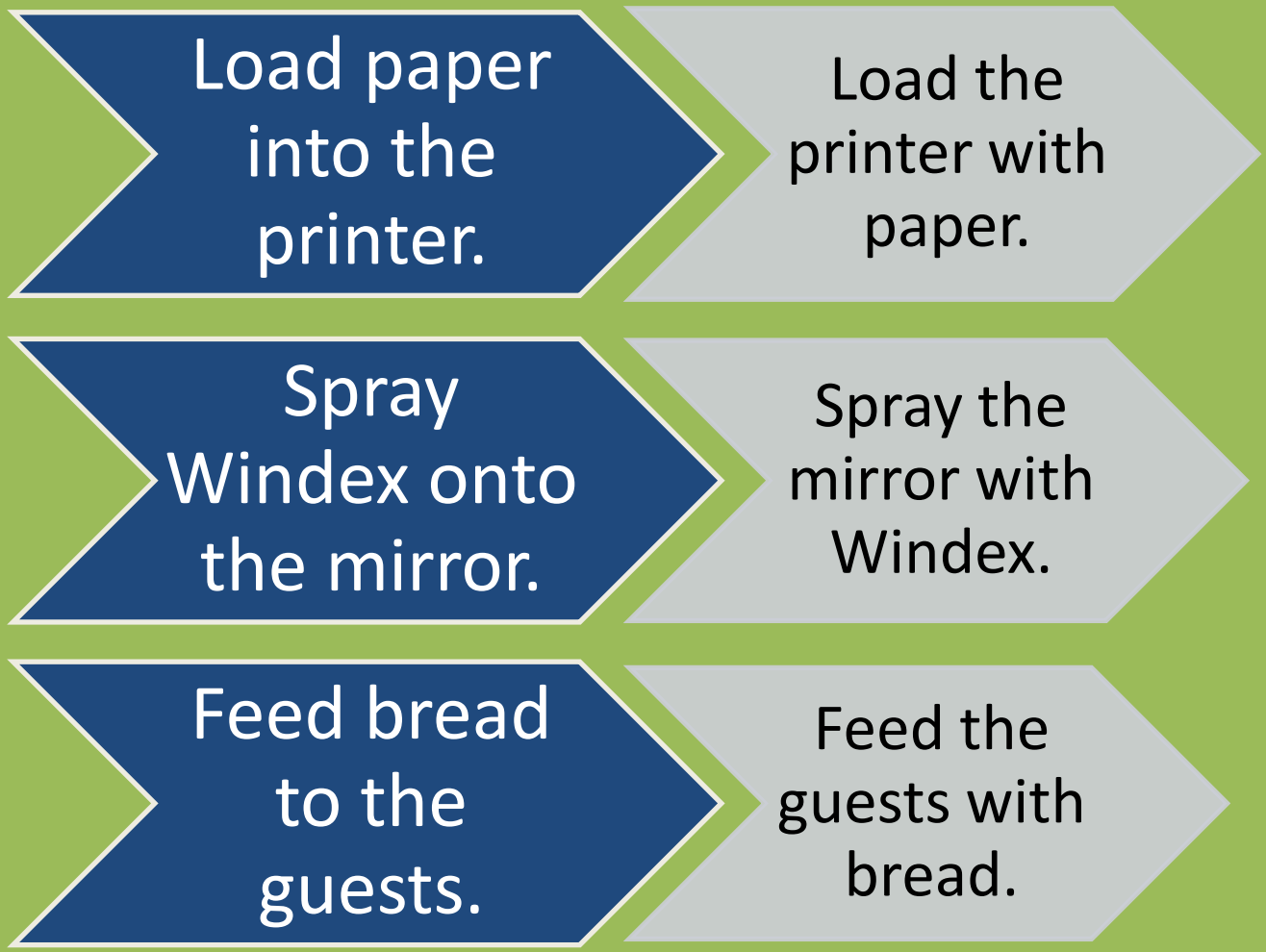
F = ma

Foregrounding acceleration

Q: How fast will I accelerate if the elevator pulls with 20,000 N of force?

a = F/m

Foregrounding is syntactical



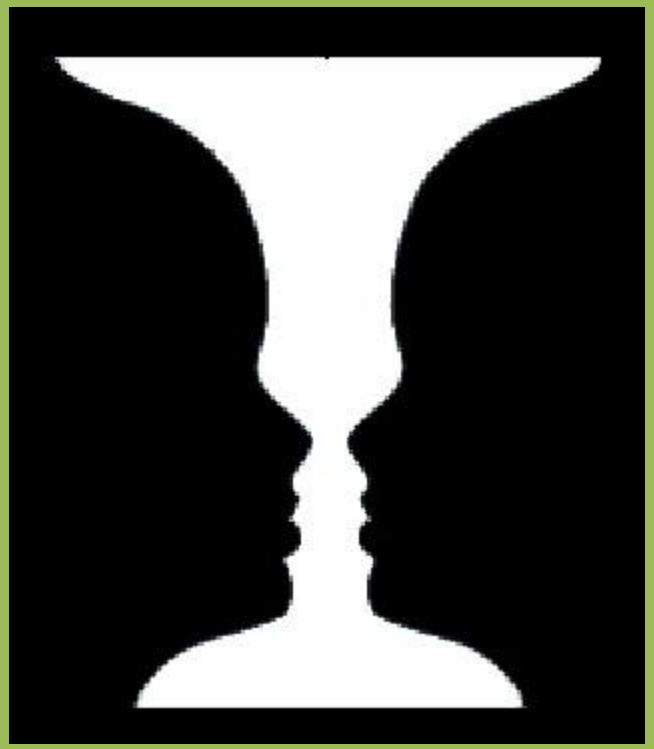
Foregrounding is semantically constrained (Pinker, 2007)

I riddled Capone with bullets.	~~I riddled bullets into Capone.~~
I dripped water onto the floor.	~~I dripped the floor with water.~~
I poured Pepsi into the glass.	~~I poured the glass with Pepsi.~~

Semantic structures make a syntactical difference!

"A" structure:

- Agent
- Causes
- Change in state
- of container



"B" structure:

- Agent
- Causes
- Change in trajectory
- of object

Semantic "Frame Shifts" in English

"Load the printer with paper."

printer is foregrounded

printer's *state* is changed

"Load paper into the printer."

paper is foregrounded

paper's *trajectory* is changed

Semantic "Frame Shifts" in Physics

Field Equation

field is foregrounded

Change the *state* of space

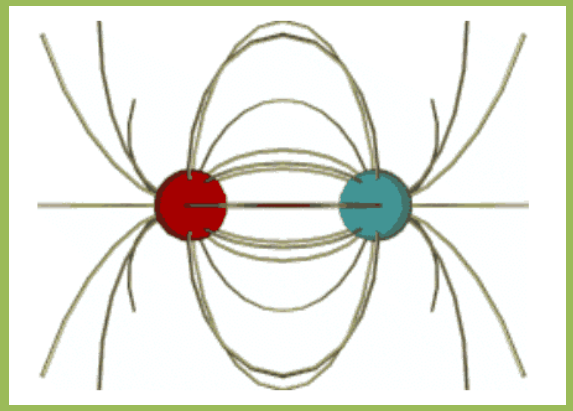
Equation of Motion:

particle is foregrounded

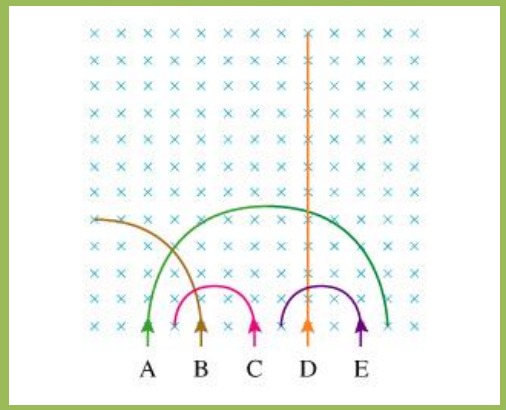
Change the *trajectory* of particle

Semantic Structures of Electrodynamics

Charge → Field



Field → Charge



“A-Problems”

“B-Problems”

Semantic “frame shift” comes with syntactic foregrounding

Given a charge distribution, what field is generated?

$$\nabla \cdot \mathbf{E} = \frac{\rho_f}{\epsilon}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu \mathbf{J}_f + \mu\epsilon\frac{\partial \mathbf{E}}{\partial t}.$$

Field → Source

Given a field, how does a charge distribution move?

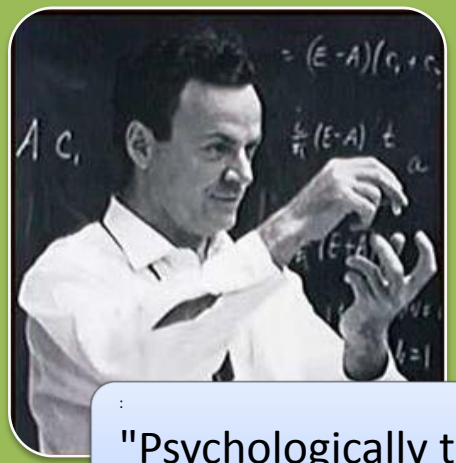
$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}),$$

Force → Field

Frame shifts have consequences

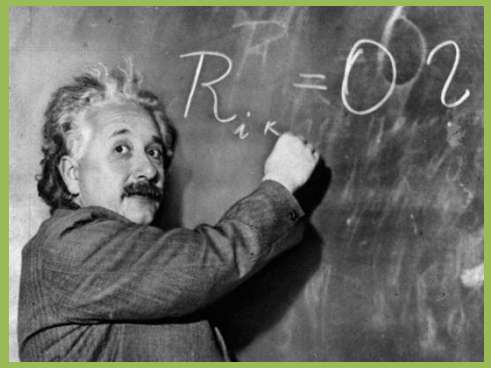
$$F_G = \frac{-Gm_1m_2}{r^2}$$

$$\nabla^2\varphi = 4\pi\kappa\rho \quad \Longleftrightarrow \quad \delta S = 0$$



"Psychologically they are… completely unequivalent when you are trying to guess new laws"

Semantic structures guide physics theorizing (Renn et al., 2007)



$$\nabla^2 \varphi = 4\pi\kappa\rho$$

OP(POTENTIAL)=SOURCE

Core Operator,
Entwurf Operator,
Ricci Tensor,
Einstein Tensor,
etc…

$$?\left(g_{\mu\nu}\right) = \bar{\kappa} T_{\mu\nu}$$

Causal frame shifts in physics

In classical physics a field equation must be complemented by an equation of motion. Their complementarity derives from the way in which interactions split into cause and effect in the Lorentz model.

Renn & Sauer 2007

Conclusion

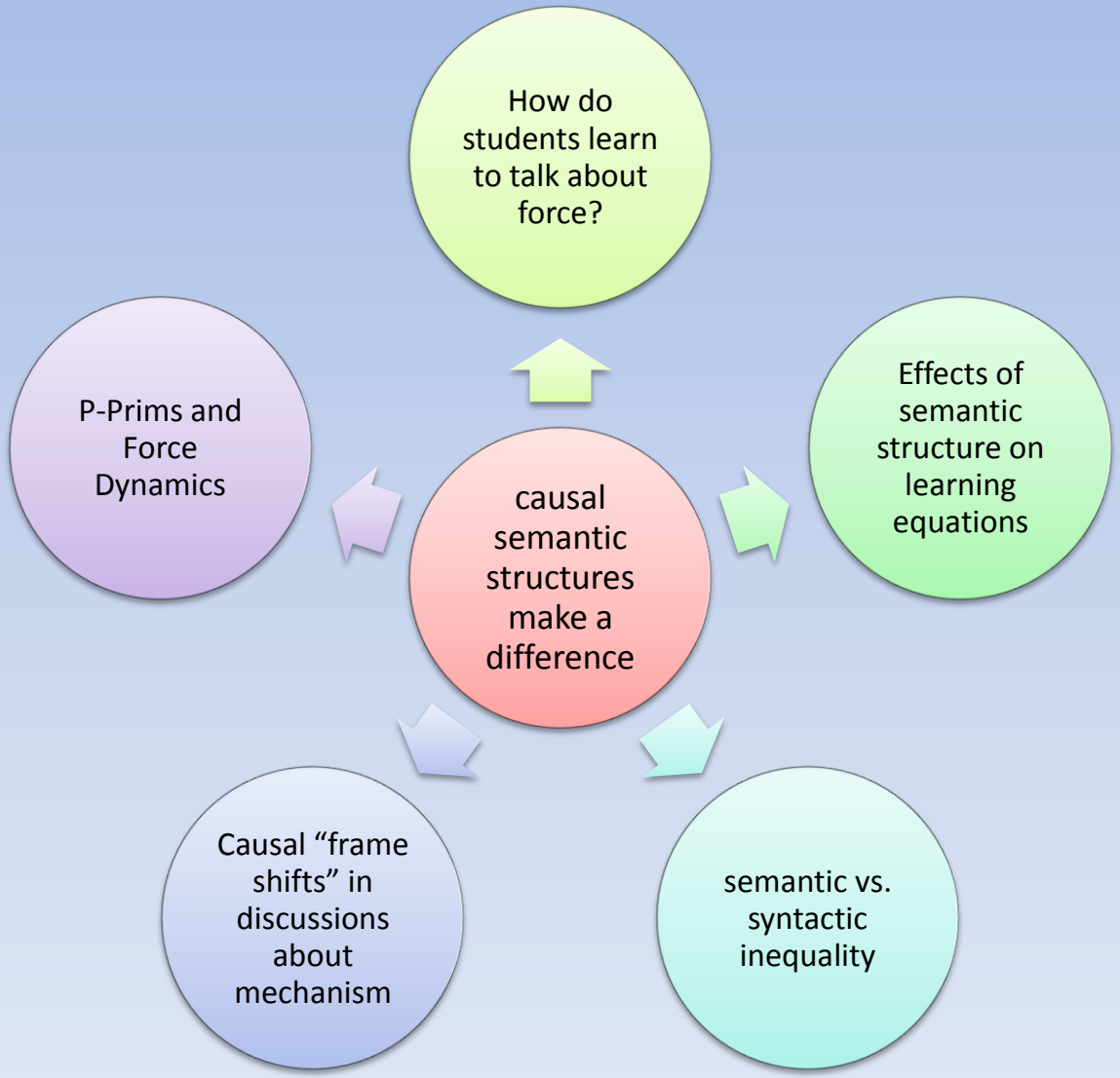
Semantic structures constrain syntax

Physics equations follow causal semantic structures

Causation can make a difference in science

We can still say science is about finding causal mechanisms!

Educational Implications



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