From Learning Theory to Particle Physics

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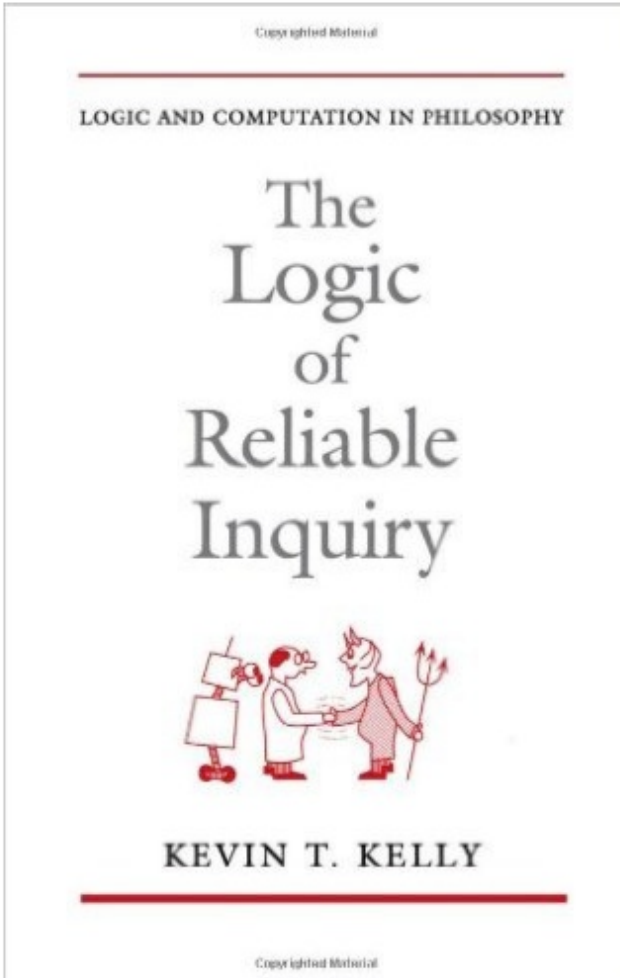
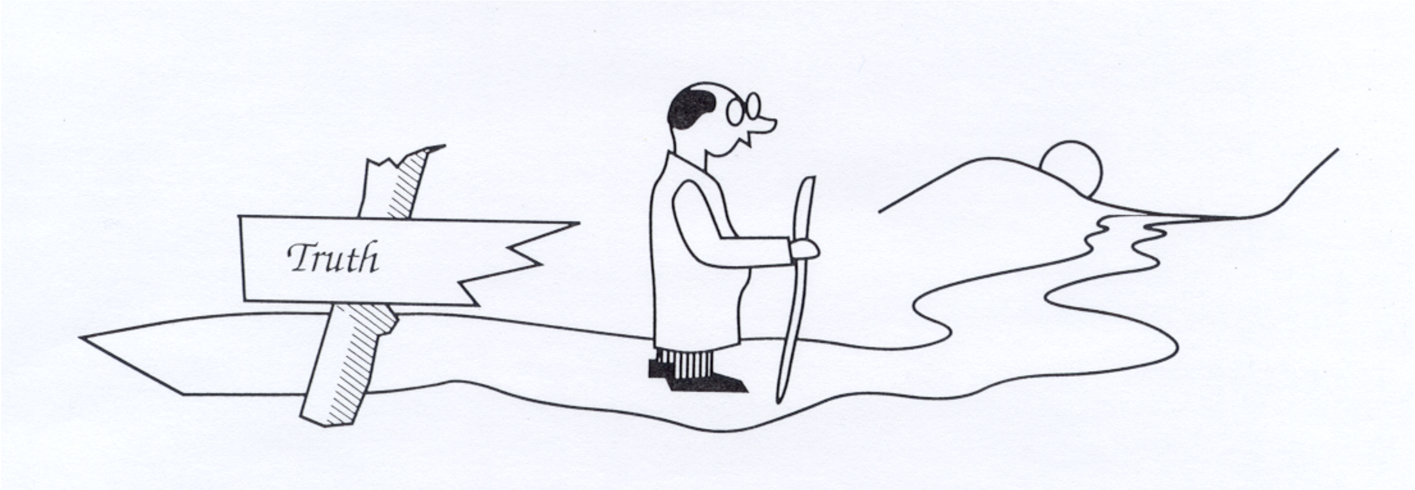
The Logic of Reliable Inquiry (ca. 1994)



Long-Run Reliability

- Key concept: Inquiry ought to settle on the right answer eventually, no matter what the evidence.

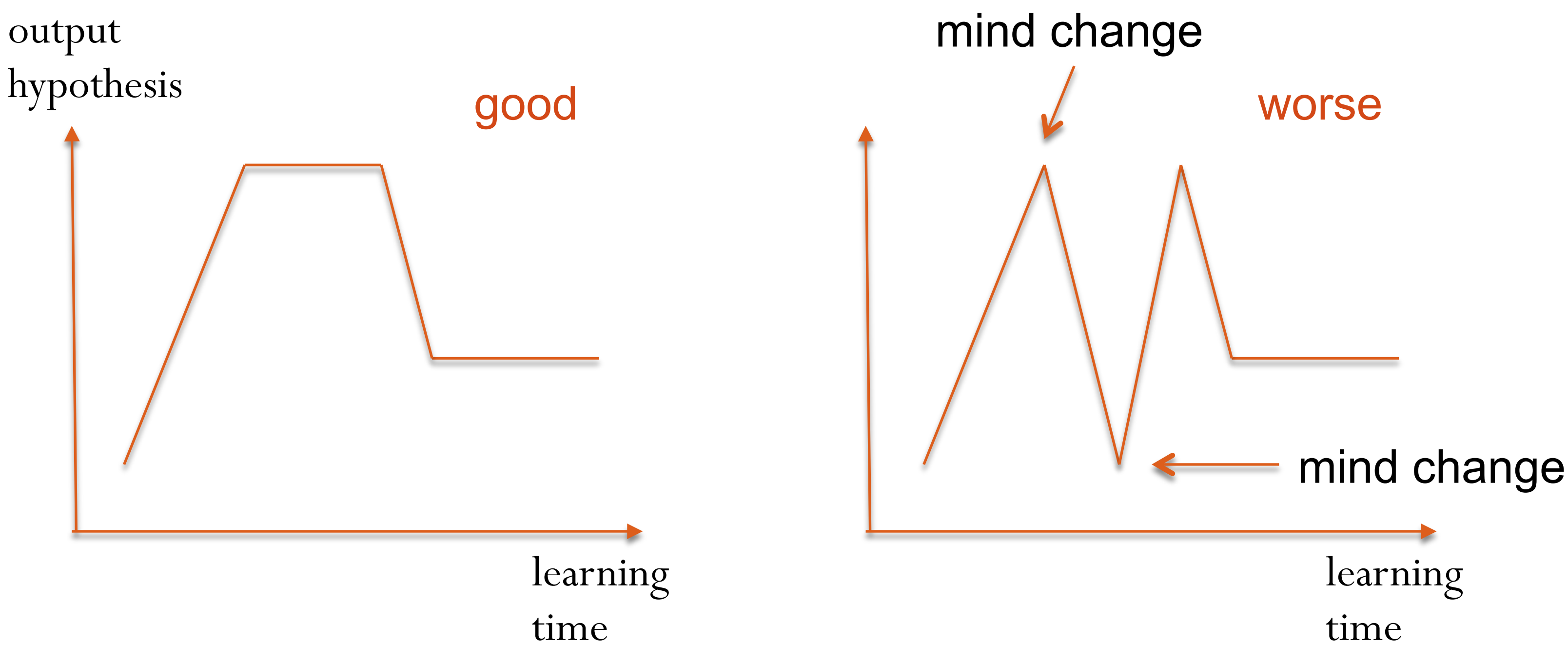


The Long Run in the Short Run?

- Reichenbach's pragmatic vindication of induction: a version of long-run reliability for estimating probabilities.
- Salmon's critique: Long-run reliability does not constrain the short run.
- Kelly's suggestion: What if we add success criteria *in addition to* long-run reliability?

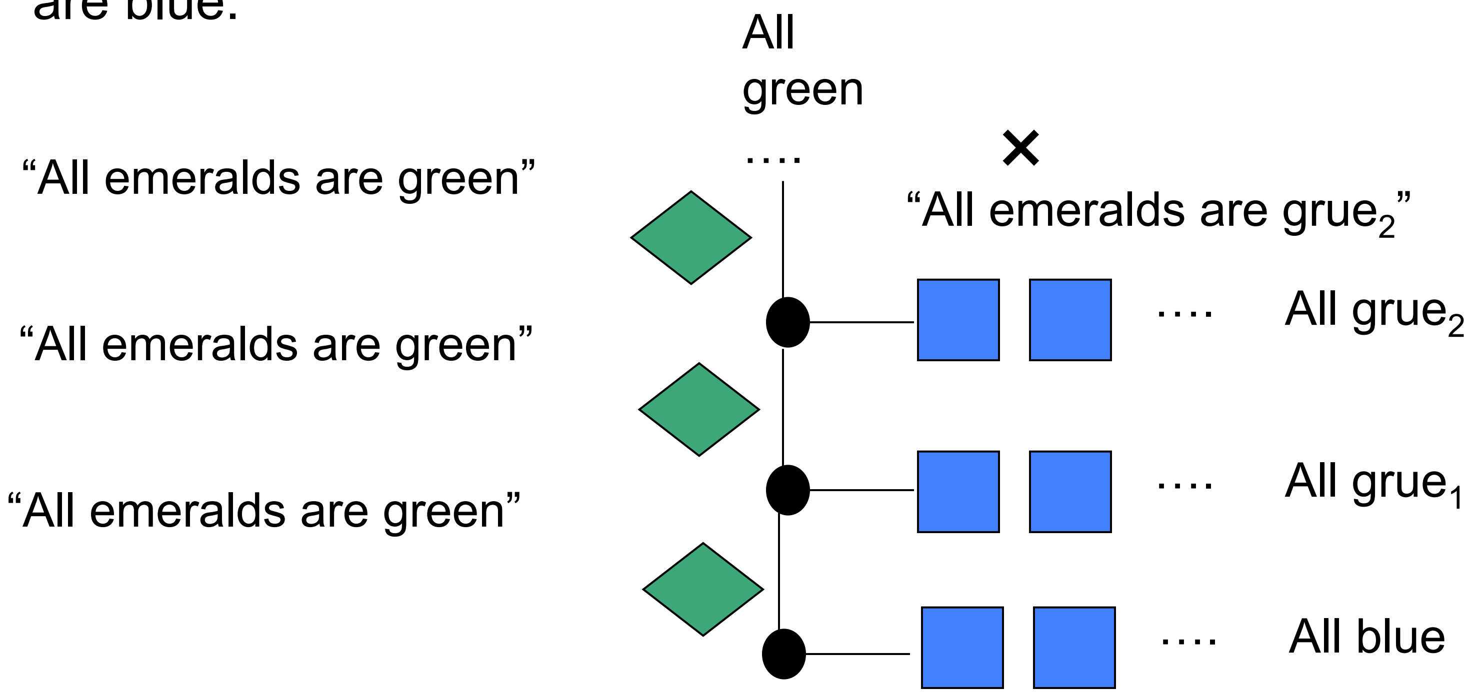
Hans Reichenbach,"The Theory of Probability", 1949, *UC Press*.
Glymour, Clark and Eberhardt, Frederick, {Hans Reichenbach", *The Stanford Encyclopedia of Philosophy* (Fall 2014 Edition).
Wesley Salmon, "Hans Reichenbach's vindication of induction", *Erkenntnis* 1991.

Learning and Steady Convergence



The New Riddle of Induction

Goodman (1983). "Grue applies to all things examined before t just in case they are green but to other things just in case they are blue."



Schulte, O. (1996), 'Means-Ends Epistemology', *The British Journal for the Philosophy of Science 79(1), 141--147.*

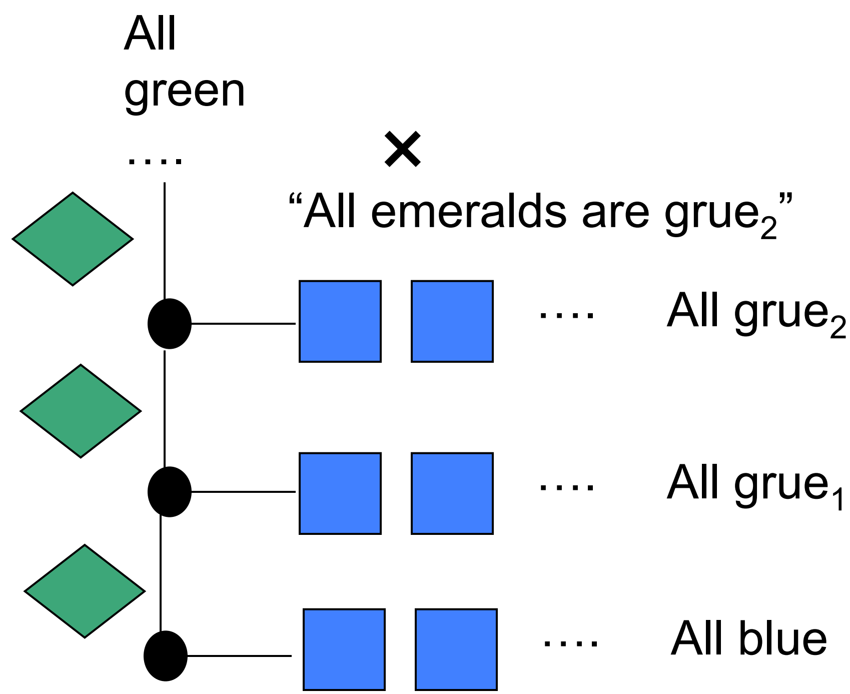
Unnatural Generalizations May Lead to Two Mind Changes

Goodman (1983). "Grue applies to all things examined before t just in case they are green but to other things just in case they are blue."

"All emeralds are green"

✕ "All emeralds are green"

"All emeralds are grue$_1$"

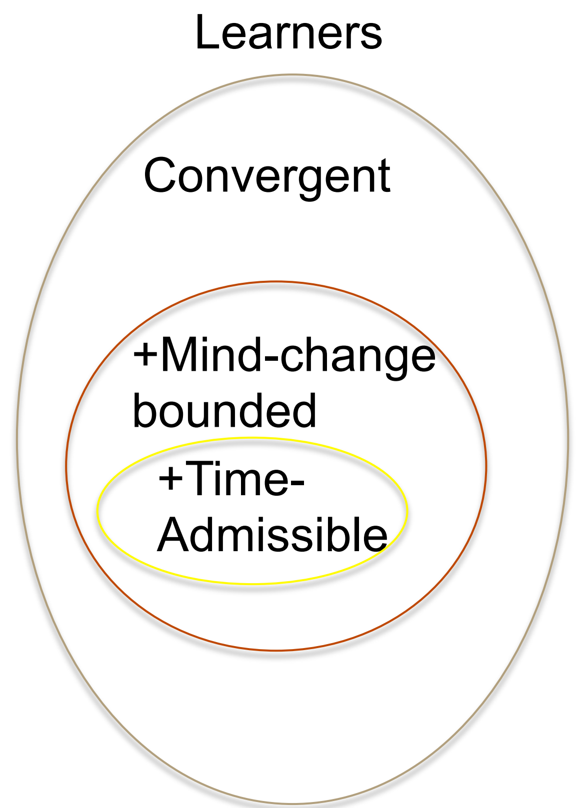


Solution to the New Riddle

Proposition

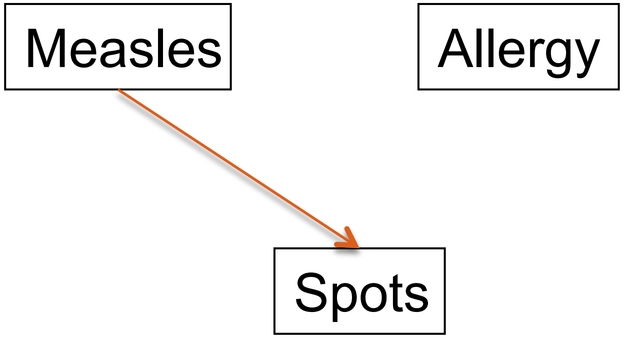
The natural projection rule is the only inductive method that

1. is guaranteed to arrive at the right generalization about emerald colors.
2. changes its generalization at most once.
3. minimizes convergence time (time-admissibility)



Other Applications

- Causal graph learning:
  - output the graph that explains the observed correlations with the *least number of edges*.



- Discovering molecular structure of chemical substances.
- Learning conservation laws in particle physics.

Luo, W. & Schulte, O. (2006), 'Mind Change Efficient Learning', *Information and Computation 204, 989--1011.*

Learning Conservation Laws in Particle Physics

Conserved Quantities in the Standard Model

- Standard Model based on Gell-Mann's quark model (1964).
- Full set of particles: $n = 193$.
- Quantity ⟷ **Particle Family** (Cluster).

	Particle	Charge	Baryon#	Tau#	Electron#	Muon#
1	Σ^-	-1	1	0	0	0
2	$\overline{\Sigma}^+$	1	-1	0	0	0
3	n	0	1	0	0	0
4	$\overline{n}$	0	-1	0	0	0
5	p	1	1	0	0	0
6	$\overline{p}$	-1	-1	0	0	0
7	π^+	1	0	0	0	0
8	π^-	-1	0	0	0	0
9	π^0	0	0	0	0	0
10	γ	0	0	0	0	0
11	τ^-	-1	0	1	0	0
12	τ^+	1	0	-1	0	0
13	ν_τ	0	0	1	0	0
14	$\overline{\nu}_\tau$	0	0	-1	0	0
15	μ^-	-1	0	0	0	1
16	μ^+	1	0	0	0	-1
17	ν_μ	0	0	0	0	1
18	$\overline{\nu}_\mu$	0	0	0	0	-1
19	e^-	-1	0	0	1	0
20	e^+	1	0	0	-1	0
21	ν_e	0	0	0	1	0
22	$\overline{\nu}_e$	0	0	0	-1	0

The Learning Task (Toy Example)

Given:
1. fixed list of known detectable particles.
2. Input reactions

Not Given:
1. # of quantities
2. Interpretation of quantities.

Reactions

$$\mu^- \rightarrow e^-$$
$$p + p \rightarrow p + p + \pi^0$$

Reaction Matrix *R*

$$\begin{pmatrix} 0 & 0 & 1 & -1 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

Learning

Output

Quantity Matrix *Q*

$$\begin{pmatrix} 1 & 1 \\ 0 & 0 \\ 0 & -1 \\ 0 & -1 \end{pmatrix}$$

Cols in *Q* are conserved, so *RQ* = *0*.

The Mind-Change Optimal Method

- **Proposition** The mind-change optimal method selects a set of conservation laws that rule out as *many unobserved reactions as possible*.
- aka Gell-Mann's Totalitarian Principle: 'Anything which is not prohibited is compulsory'.
- Ford's Plentitude Principle (1963): "Everything which *can* happen without violating a conservation law *does* happen."

Matches Standard Model!

Discovering Neutrinos

- Extend mind-change optimality to discovery conservation laws + *unobserved entities*.
- In some cases, positing unobserved neutrinos helps to rule out unobserved reactions.
- Well-known example: if $\nu_e = \nu_{\bar{e}}$, then
  the neutrino-less double beta decay
  $n + n \rightarrow p + p + e^- + e^-$
  should be possible.
- Elliott and Engel (May 2004):
  "What aspects of still-unknown neutrino physics is it most important to explore? …it is clear that the absolute mass scale and whether **the neutrino is a Majorana or Dirac particle are crucial issues** (ie $\nu_e = \bar{\nu}_e$?).

Discovering a New Critical Experiment

- The mind-change optimal method for finding unobserved particles can be implemented using the Smith Normal Form.

➢ Compute from actual accelerator data:

If $\nu_e = \bar{\nu}_e$, then the reaction
$Y + \Lambda^0 \rightarrow p + e^- + \mu^+ + \mu^-$
should be possible.

- But this reaction fails another constraint: Conserving fermion number mod 2.

- Thanks to Matt Strasser

Schulte, O. (2009), Simultaneous Discovery of Conservation Laws and Hidden Particles With Smith Matrix Decomposition, *in '(IJCAI-09', pp. 1481--1487.*

Summary: Theory

- Mind-change optimal learning: converge to a correct hypothesis with a minimum number of theory changes.
- If a mind change bound exists, there is a *unique* time-admissible method that attains it.
- Applications solve for this method.
  - Riddle of Induction: conjecture "all emeralds are green" until blue one is observed.
  - Causal graphs: conjecture simplest graph consistent with observed correlations.
  - Learning conservation laws: rule out as many unobserved reactions as possible. Possibly with neutrinos.

The End

- Thank you!