THE SILENT HISTORY OF CAUSE AND EFFECT

Every science that has thriven has thriven upon its own symbols
~Augustus de Morgan (1864)

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OUTLINE

- The Ubiquity of causal thinking in ethics and science, from ancient times to modernity.
- Why it kept silent till 1920.
- What prevented statisticians, economists, social and health scientists from answering causal questions in their respected fields.
- The causal revolution and its miracles

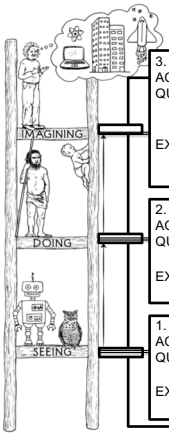
TYPICAL CAUSAL QUESTIONS

1. How effective is a given treatment in preventing a disease?
2. Was it the new tax break that caused our sales to go up? Or our marketing campaign?
3. What is the annual health-care costs attributed to obesity?
4. Can hiring records prove an employer guilty of sex discrimination?
5. I am about to quit my job, will I regret it?

* Unarticulatable in the standard grammar of science.

$$Y = aX \quad \text{vs.} \quad Y \leftarrow aX$$

3-LEVEL HIERARCHY

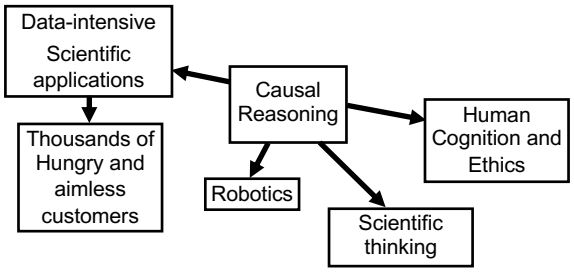


3. COUNTERFACTUALS
ACTIVITY: Imagining, Retrospection, Understanding
QUESTIONS: *What if I had done . . . ? Why?*
(Was it X that caused Y? What if X had not occurred? What if I had acted differently?)
EXAMPLES: Was it the aspirin that stopped my headache? Would Kennedy be alive if Oswald had not killed him? What if I had not smoked the last 2 years?

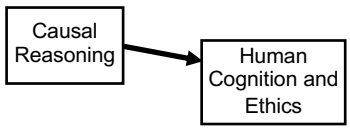
2. INTERVENTION
ACTIVITY: Doing, Intervening
QUESTIONS: *What if I do . . . ? How?*
(What would Y be if I do X?)
EXAMPLES: If I take aspirin, will my headache be cured? What if we ban cigarettes?

1. ASSOCIATION
ACTIVITY: Seeing, Observing
QUESTIONS: *What if I see . . . ?*
(How would seeing X change my belief in Y?)
EXAMPLES: What does a symptom tell me about a disease? What does a survey tell us about the election results?

THE UBIQUITY OF CAUSAL REASONING



THE UBIQUITY OF CAUSAL REASONING



Causal Explanation

"*She handed me the fruit and I ate*"

"*The serpent deceived me, and I ate*"

COUNTERFACTUALS AND OUR SENSE OF JUSTICE

Abraham:
Are you about to smite the righteous with the wicked?
What if there were fifty righteous men in the city?

And the Lord said,
"If I find in the city of Sodom fifty good men, I will pardon the whole place for their sake."
Genesis 18:26

HOW THE ANCIENTS VALUED CAUSAL THINKING

"I would rather discover one causal relation than be king of Persia"
Democritus (430-380 BC)

"Lucky is he who has been able to understand the causes of things"
Virgil (29 BC)

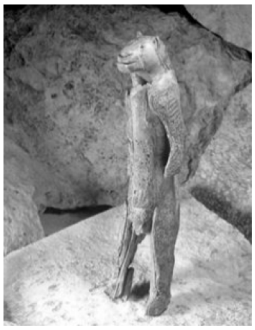
THUCYDIDES AND THE TSUNAMI IN EUBOEA (426 BC)

- ... what was once land is now sea;
- The cause, in my opinion, of this phenomenon must be sought in the earthquake.
- Without an earthquake I do not see how such an accident could happen.

CAUSAL MODELS AND THE COGNITIVE REVOLUTION

- 10,000 years ago, human beings accounted for less than a tenth of 1 percent of all vertebrate life on planet Earth.
  Today, that percentage, including livestock and pets, is in the neighborhood of 98!
  (Daniel Dennett, 2006)
- What Happened?
- What computational facility did humans acquire 10,000 years ago that they did not possess before?

COUNTERFACTUALS: THE HOMOSAPIENS' SECRET

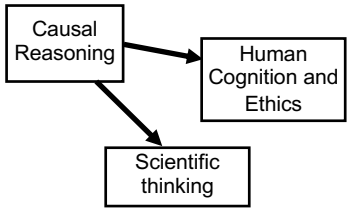


THE INVENTION OF COUNTERFACTUALS

- About 70,000 years ago, Sapiens from East Africa spread into the Arabian peninsula, and from there they quickly overran the entire Eurasian landmass, wiping out the native population.
- What was the Sapiens' secret of success?
- The ability to imagine things that do not really exist.
- You could never convince a monkey to give you a banana by promising him limitless bananas after death in monkey heaven.

(Harari, 2015)

THE UBIQUITY OF CAUSAL REASONING



WHY PHYSICS IS COUNTERFACTUAL

Scientific Equations (e.g., Hooke's Law) are non-algebraic

e.g., Length (*Y*) equals a constant (2) times the weight (*X*)

Correct notation:

~~*Y* := 2*X*~~	*X* = 1	~~*X* := ½*Y*~~ *X* = 3
X = 3 ~~:=~~	*Y* = 2	*Y* = *X*+1
Process information	The solution	Alternative

Had *X* been 3, *Y* would be 6.
If we raise *X* to 3, *Y* would be 6.
Must "wipe out" *X* = 1.

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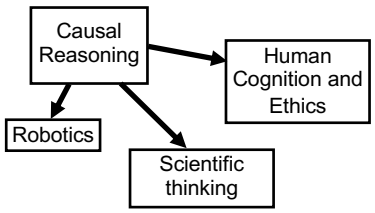
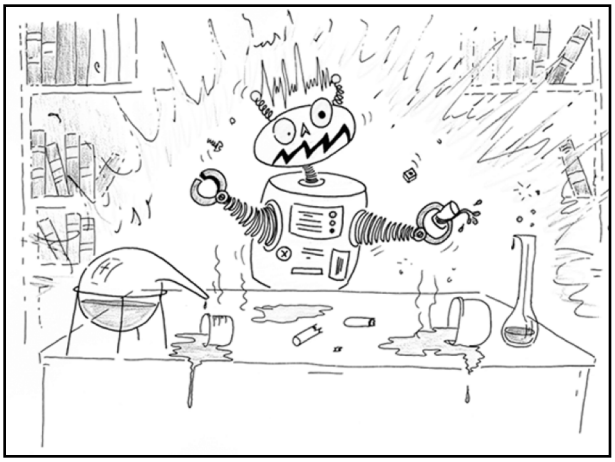
THE UBIQUITY OF CAUSAL REASONING





CAUSATION AS A PROGRAMMER'S NIGHTMARE

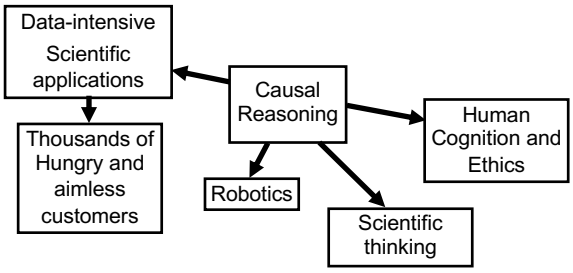
Input:

1. "If the grass is wet, then it rained"
2. "if we break this bottle, the grass will get wet"

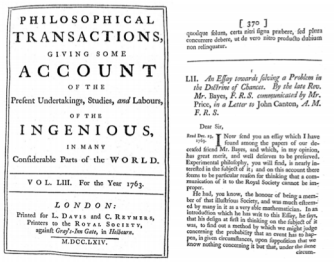
Output:

"If we break this bottle, then it rained"

THE UBIQUITY OF CAUSAL REASONING



STATISTICS FIRST ENCOUNTER WITH CAUSALITY BAYES THEOREM


PHILOSOPHICAL TRANSACTIONS,
GIVING SOME
ACCOUNT
OF THE
Present Undertakings, Studies, and Labours,
OF THE
INGENIOUS,
IN MANY
Considerable Parts of the WORLD.
VOL. LIII. For the Year 1763.
LONDON:
Printed for L. DAVIS and C. REYMERS,
Printers to the ROYAL SOCIETY,
against Gray's-Inn Gate, in Holborn.
M.DCC.LXIV.

[370]

LII. *An Essay towards solving a Problem in the Doctrine of Chances. By the late Rev. Mr. Bayes, F.R.S. communicated by Mr. Price, in a Letter to* John Canton, *A.M. F.R.S.*

Figure 3.1. Title page of the journal where Thomas Bayes's posthumous article on inverse probability was published and the first page of Richard Price's introduction.

PRICE INTERPRETATION OF BAYES' ARTICLE

- The purpose I mean is, to shew what reason we have for believing that there are in the constitution of things fixed laws according to which things happen, and that, therefore,
- the frame of the world must be the effect of the wisdom and power of an intelligent cause;
- and thus to confirm the argument taken from final causes for the existence of the Deity.

REV. BAYE'S POOL TABLE

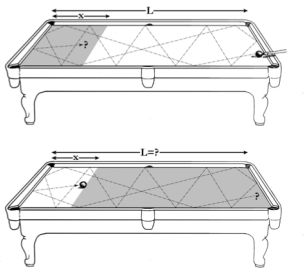


Figure 3.2. Thomas Bayes's pool table example. In the first version, a forward-probability question, we know the length of the table and want to calculate the probability of the ball stopping within x feet of the end. In the second, an inverse-probability question, we observe that the ball stopped *x* feet from the end and want to estimate the likelihood that the table's length is *L*.

BAYES 3-TIER DICTUM (L.I. SAVAGE)

- How a definition $P(A|B)=P(A,B)/P(B)$ made Bayes famous?
- It is silly to ignore what we know
- It is natural and useful to cast what we know in the language of probabilities
- If our subjective probabilities are erroneous, their impact will get washed out in due time, as the number of observations increases.

STATISTICS 2ND CHANCE AT CAUSALITY

Sir Francis Galton demonstrates his "Galton board" or "quincunx" at the Royal Institution. He saw this pinball-like apparatus as an analogy for the inheritance of genetic traits like stature. The pinballs accumulate in a bell-shaped curve that is similar to the distribution of human heights. The puzzle of why human heights don't spread out from one generation to the next, as the balls would, led him to the discovery of "regression to the mean."

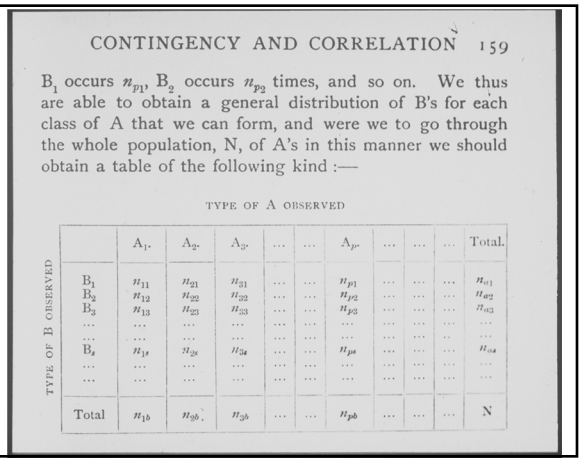
KARL PEARSON – "THE BUCANEER" "BROADER THAN CAUSATION"

Figure 2.5. Karl Pearson with a skull from the Paris Catacombs.

PURGING CAUSALITY FROM SCIENCE (STATISTICS)

Karl Pearlson (1911)

- "Beyond such discarded fundamentals as 'matter' and 'force' lies still another fetish amidst the inscrutable arcana of modern science, namely, the category of cause and effect."
- "Such a table is termed a contingency table, and the ultimate scientific statement of description of the relation between two things can always be thrown back upon such a contingency table....
- "Once the reader realizes the nature of such a table, he will have grasped the essence of the conception of association between cause and effect."



CONTINGENCY AND CORRELATION 159

B_1 occurs n_{p1}, B_2 occurs n_{p2} times, and so on. We thus are able to obtain a general distribution of B's for each class of A that we can form, and were we to go through the whole population, N, of A's in this manner we should obtain a table of the following kind :—

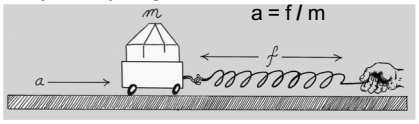
TYPE OF A OBSERVED

TYPE OF B OBSERVED	A_1.	A_2.	A_3.	...	...	A_p.	...	...	...	Total.
B_1	n_{11}	n_{21}	n_{31}	...	...	n_{p1}	...	...	...	n_{a1}
B_2	n_{12}	n_{22}	n_{32}	...	...	n_{p2}	...	...	...	n_{a2}
B_3	n_{13}	n_{23}	n_{33}	...	...	n_{p3}	...	...	...	n_{a3}
...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
B_s	n_{1s}	n_{2s}	n_{3s}	...	...	n_{ps}	...	...	...	n_{as}
...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
Total	n_{1b}	n_{2b}	n_{3b}	...	...	n_{pb}	...	...	...	N

PURGING CAUSALITY FROM PHYSICS?

- BERTRAND RUSSELL (1913):
  In advanced sciences the word "cause" never occurs. Causality is relic of bygone ago.
- PATRICK SUPPES (1970):
  "Causality" is commonly used by physicists

The symmetry enigma: f = m a
a = f / m



SEWALL WRIGHT – CAUSALITY'S FIRST FORMAL VOICE

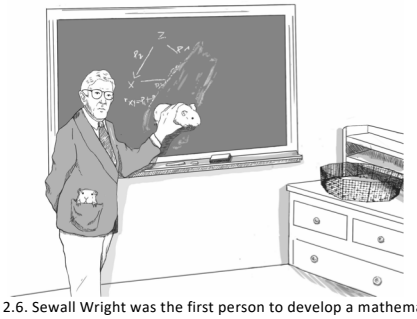


Figure 2.6. Sewall Wright was the first person to develop a mathematical method for answering causal questions from data, known as path diagrams. His love of mathematics surrendered only to his passion for guinea pigs.

SEWALL WRIGHT – CAUSALITY'S FIRST FORMAL VOICE

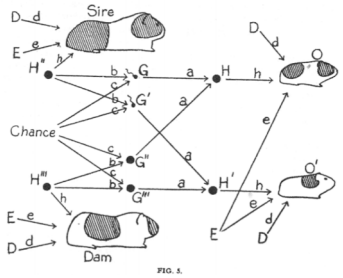


Figure 2.7. Sewall Wright's first path diagram, illustrating the factors leading to coat color in guinea pigs. D = developmental factors (after conception, before birth), E = environmental factors (after birth), G = genetic factors from each individual parent, H = combined hereditary factors from both parents, O, O¢ = offspring. The objective of analysis was to estimate the strength of the effects of D, E, H (written as d, e, h in the diagram). (Source: Sewall Wright, Proceedings of the National Academy of Sciences [1920], 320–332.)

WHAT IS AN ECONOMIC MODEL? (Haavelmo, 1943)

"We have in mind some actual experiment, or some design of an experiment, which we could at least imagine arranging." (Haavelmo, 1944)

His example: $y = \underline{a}x + \varepsilon_1$

$$x = by + \varepsilon_2$$

$$\underline{a}x \neq E(Y \mid X = x)$$

What information did the modeler intend $\underline{a}$ to carry in Eq. 1 and what information would $\underline{a}$ provide if we are able to estimate its value.

Perhaps $\underline{a} = g[P(x,y,z...)]$?

There is no such $g[\ ]$.

Later notation

$$\underline{a} = \frac{\partial}{\partial x} E(Y \mid do(x))$$

CLINGING DESPARATELY TO AN OLD ORACLE

Fifty-two years later (1995):

"I am speaking, of course, about the equation:

$$\{y = a + bx + \varepsilon\}.$$

What does it mean?

The only meaning I have ever determined for such an equation is that it is a shorthand way of describing the conditional distribution of $\{y\}$ given $\{x\}$."

(Holland, 1995, p. 54)

"Beneath all multiple equation models, there is only a set of conditional distributions."

(Richard Berk, 2004, p. 196)

ECONOMISTS CLINGING TO THE OLD ORACLE

Sixty-four years later (2007):

"A state implements tough new penalties on drunk drivers: What is the effect on highway fatalities?...
[This effect] is an unknown characteristic of the population joint distribution of X and Y."

(Stock and Watson, 2007, Introduction to Econometrics, Chapter 4, pp. 111)

Sixty-eight years later (2011):

"An econometric model specifies the statistical relationship that is believed to hold between the various economic quantities pertaining to particular economic phenomenal under study."

(Wikipedia – "Econometric Models," 2011)

WHAT CAN OUR NEW ORACLE DO?

Haavelmo: Provide policy advice.

"to predict consumption,… under the Government policy,... we may use the `theoretical' equations obtained."

(1943, p.12)

Skeptics:

"How can anyone predict outcomes of experiments that where never performed?"

Haavelmo:

"this is only natural, because now the Government is, in fact, performing `experiments' of the type we had in mind when constructing each of the two equations."

(1943, p.12)

HOW CAN OUR NEW ORACLE DO ALL THAT? (THE ALGORITHMIZATION OF INTERVENTION)

"Assume that the Government decides, through public spending, taxation, etc., to keep income, r_t, at a given level,... the only change in the system being that, instead of

$$r_i = u_i + v_i$$

we now have

$$r_i = u_i + v_i + g_i$$

where g_i is Government expenditure, so adjusted as to keep r constant, whatever be u and v,..."

(1943, p. 12)

Haavelmo "surgery":

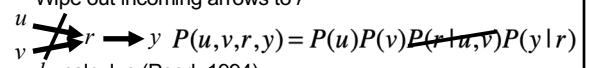
Modify an equation by adding an adjustable force g_i, while keeping all other equations in tact.

HAAVELMO'S THREE INSIGHTS

1. An economic model is a set of hypothetical experiments, qualitatively encoded in a system of equations.
2. An economic model is capable of answering policy intervention questions, with no further assistance from the modeller.
3. There is a formal way of taking an arbitrary model, combining it with data, and derive valid answers to policy questions.

THE EVOLUTION OF CAUSAL CALCULUS

- Haavelmo's surgery (1943)
  Add adjustable force $(+g_i)$
- Strotz and Wold surgery (1960). "Wipe out" the equation $r_i = u_i + v_i$, and replace it with $r_i =$ constant
- Graphical surgery (Spirtes et al., 1993; Pearl, 1993).
  Wipe out incoming arrows to r



$P(u,v,r,y) = P(u)P(v)\cancel{P(r \mid u,v)}P(y \mid r)$

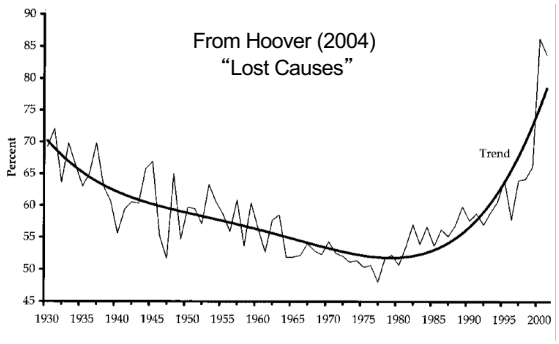
- *do*-calculus (Pearl, 1994)
  $P(Y = y \mid do(r))$ New operator $\neq P(Y = y \mid r)$
- Structural counterfactuals (Balke and Pearl, 1995)
  $Y_r(u) = Y(u)$ in the r - mutilated model
- Unification with Neyman-Rubin $Y_x(u)$ and Lewis (1973)

WILL HAAVELMO'S LEGACY SURVIVE?

Two attempted hijackings

1. The regressionism assault (1975 - 2000)
   Economic model is a parameterized family of joint distributions.

THE CAUSAL RENAISSANCE: VOCABULARY IN ECONOMICS



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1. The regressionism assault (1975 - 2000)
   Economic model is a parameterized family of joint distributions.
2. The "instrumentalism" assault (1995 -)
   Economic analysis needs instruments, not structure.
3. The structuralist defense
   Finding an instrument requires structural assumptions. The "experimentalists" choice of language deprives them from making those assumptions transparent.

THE CAUSAL REVOLUTION AND ITS MIRACLES

"More has been learned about causal inference in the last few decades than the sum total of everything that had been learned about it in all prior recorded history."
(Gary King, Harvard, 2014)

THE SEVEN MIRACLES OF THE CAUSAL REVOLUTION

1. Encoding causal information in transparent and testable way
2. Predicting the effects of actions and policies
3. Computing counterfactuals and finding causes of effects
4. Computing direct and indirect effects (Mediation)
5. Integrating data from diverse sources.
6. Recovering from missing data
7. Discovering causal relations from data

Paper available: http://ftp.cs.ucla.edu/pub/stat_ser/r475.pdf
Refs: http://bayes.cs.ucla.edu/jp_home.html

THANK YOU

Joint work with:
Elias Bareinboim
Karthika Mohan
Ilya Shpitser
Jin Tian
Many more . . .

Time for a short commercial

For a trailer, click WHY on my home page.