Chance laws and quantum randomness

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Goals of this talk:

1. Explore the notion of an (irreducible, fundamental) probabilistic law of nature, and argue that we don't have a good grasp of what it would *mean* to postulate such a thing.

   Valerio Scarani: "What does it mean, a physical law that has statistical character?"

Goals of this talk:

1. Explore the notion of an (irreducible, fundamental) probabilistic law of nature, and argue that we don't have a good grasp of what it would *mean* to postulate such a thing.

2. Show that, by contrast, a probabilistic law that is grounded on underlying determinism can be grasped easily - and we have many good examples of such laws.

3. Offer some thoughts and questions in connection with the alleged certifiable 'intrinsic randomness' of QM.

Objective probabilities or ‘chances’

- Pr(Heads) = 0.5, flipping a ‘fair’ coin
- Pr(00) in throw of 38-slot roulette wheel = 1/38
- Pr(Pu^{241} decay in 1 year) = 0.05
- Pr(spin-z up | spin-x up earlier) = 0.5
  - … what kind of *facts* are these?
  - Can we make sense of them as *objective* and *ground-level* truths?

De Finetti on ‘probability’:

- “My thesis, paradoxically, and a little provocatively, but nonetheless genuinely, is simply this:

  PROBABILITY DOES NOT EXIST

  The abandonment of superstitious beliefs about the existence of the Phlogiston, the Cosmic Ether, Absolute Space and Time, . . . or Fairies and Witches was an essential step along the road to scientific thinking. Probability, too, if regarded as something endowed with some kind of objective existence, is no less a misleading misconception, an illusory attempt to exteriorize or materialize our true probabilistic beliefs.” (p. x)

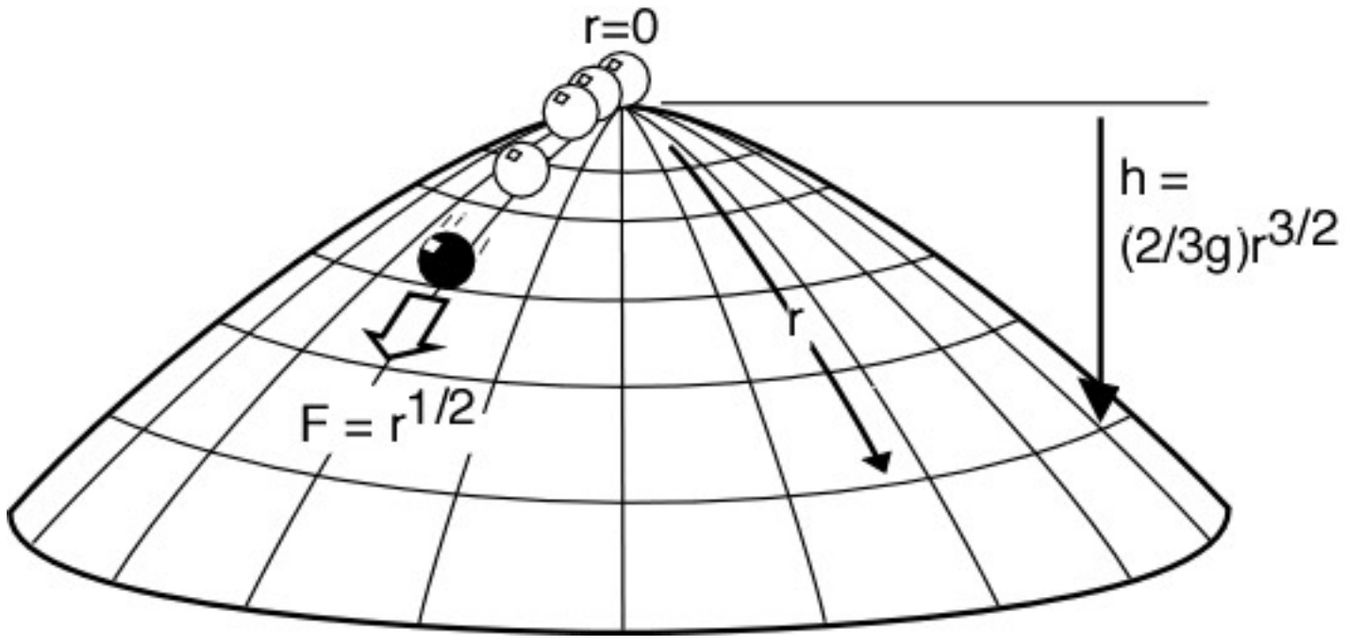
Distinctions and notations

- indeterminism = ¬ determinism
- indeterminism *vs* random behavior
- indeterminism *vs* probabilistic laws

Non-random indeterminisms

- Classical Mechanics (CM):

  – Space Invaders (5-particle system in *t*-reverse)
  – Norton's Dome (& other symmetry-breaking situations)



Non-random indeterminisms

- General Relativity (GR):

  – Naked singularities (e.g. “white holes”)
  – Other types of ‘hole’
  – models with no Cauchy

- What all these CM and GR cases have in common:

- *No* involvement of probability; indeterminism as simple breakdown of determinism.

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- randomness in general *vs* probabilistic-law-randomness
  - examples: cancer incidence, *vs* radioactive decay rate

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  - [*apparent* randomness *vs intrinsic* randomness]

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Outline:

I. The dialectics of primitive chance laws.

II. Chances from underlying determinism

III. QM, BM & intrinsic randomness

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Chancy fundamental laws?

(I.e., *intrinsic* randomness in nature?)

- Same idea as philosophers' *chance propensity*, but turned into *physical law*.

  - irreducible
  - bottom-level
  - no explanation of how individual chancy events turn out is possible

  - Possible examples: Born rule in QM, GRW localization law...
  - ... and that's about it!

When we ascribe a primitive (irreducible) chance propensity, or postulate intrinsically random/chancy fundamental laws of nature, *do we know what we're saying*?

- What is the content of such statements: what are their "truth conditions"? What do they say about the world?

What the content is *not*

- A claim about *actual* frequencies
  - because these always *can,* and usually *do*, differ from the ‘true probabilities’.
  - and “The frequency of *a*-events shall be *x.*” is no fit candidate for lawhood.
- A claim about *hypothetical ∞-long-run* frequencies
  - because these <u>also</u> can differ from the ‘true probabilities’.
  - ... and are unphysical ...
  - ... and can’t be inferred from any finite observation set.

What the content is *not*, cont'd

- A claim about *some agent's subjective beliefs*
  - *pace* De Finetti, Fuchs, Schack et al., that's just not what (most) quantum physicists are saying;
  - and there are no physical laws *about rational agents' beliefs.*
- A *primitive.*
  - I.e., one can not just assert that "Pr(A |conditions S) = *x* " is directly meaningful in a primitive sense, requiring no explication.

Det-laws *vs* prob-laws

- Deterministic law claims *vs* chance-law claims: on a par?
  - No: factual content of a Det-law claim is unproblematic, testable.
  - Key difference: *numerical strength* aspect of prob-law claims
- Primitive chance advocates admit: *any* frequency of outcomes is compatible with *any* chance-value;
- Without a clear explication of the numerical strength's meaning, we can't say what makes a claim like

  "Pr(spin-z-up | spin-x-up-earlier) = 0.5" different from

  "Pr(spin-z-up | spin-x-up-earlier) = 0.7"

Why does it *feel like* we understand prob-law claims??

- We tacitly bring in two key concepts associated with probability: *frequency;* and *expectation* (subjective)

- A false friend: the Law of Large Numbers

  $\Pr(|\text{Freq} - \text{Prob}| < \varepsilon)$ goes to 1 as $N \rightarrow \infty$, for any ε.

- We tacitly (and illegitimately!) invoke the chance-credence link, so we *know what to expect* if it is true that

  "Pr(spin-z-up | spin-x-up-earlier) = 0.5"

The chance-credence link (Principal Principle)

- PP: Cr(A|XE) = x where
  - A is some proposition specifying an outcome for a chance-process
  - X is a proposition stating that the objective probability P(A) = x
  - E is the rest of one's "evidence" or background knowledge
  - Cr(_|_) is a "rational credence function", i.e., subjective probability function of a fully rational agent

- Gives content to prob-law statement ***only*** if PP can be shown rational, for primitive/propensity probabilities. ✗

- Even if allowed, this makes the content of the prob-law claim intrinsically epistemic - about what agents' credences should be. ✗

Part 1 conclusion

- It's hard to say what the *content* of a putative chance-law statement could be.
- Believers in intrinsic randomness should help me understand what they are talking about!

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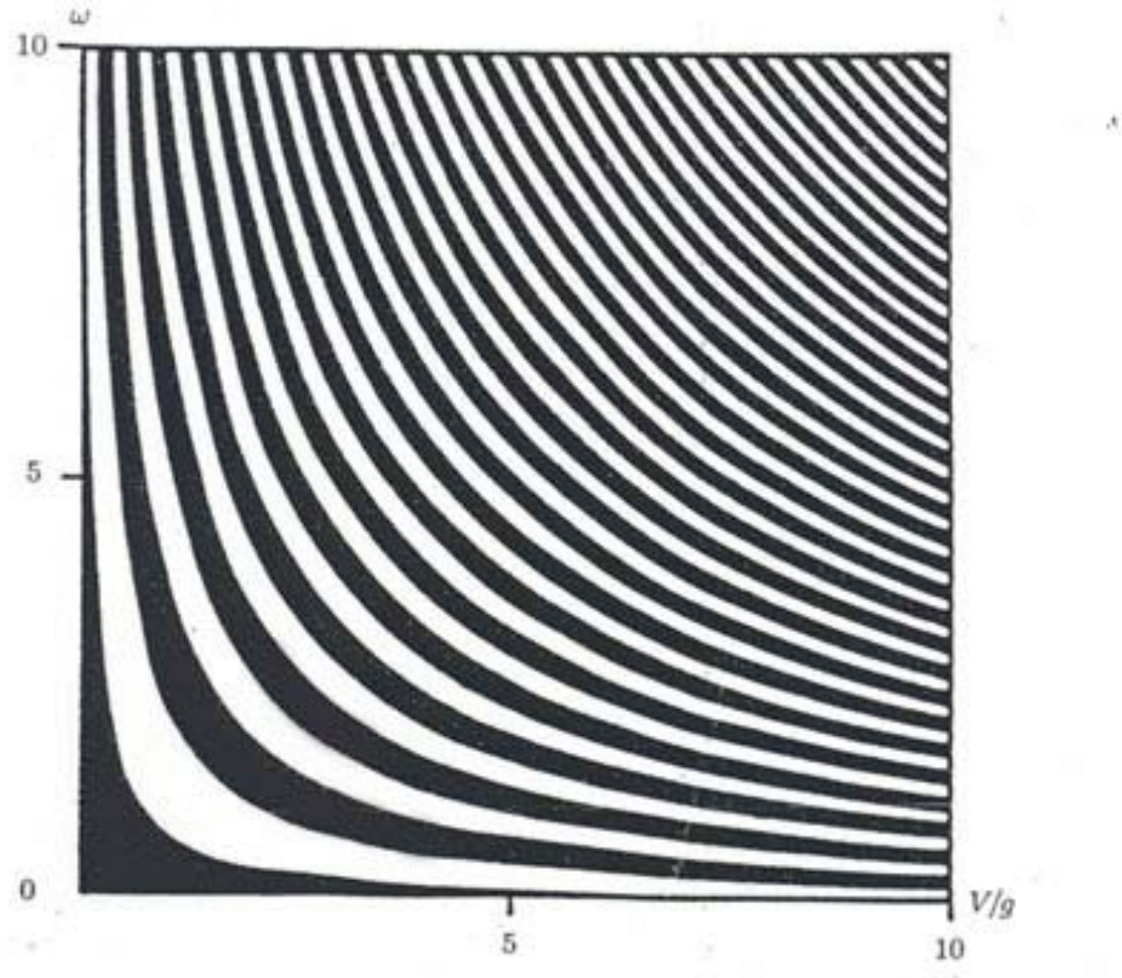
Chance from Determinism

Diaconis' coin-flip analysis



Vertical: rate of rotation Horizontal: initial upward velocity

Chance from Determinism

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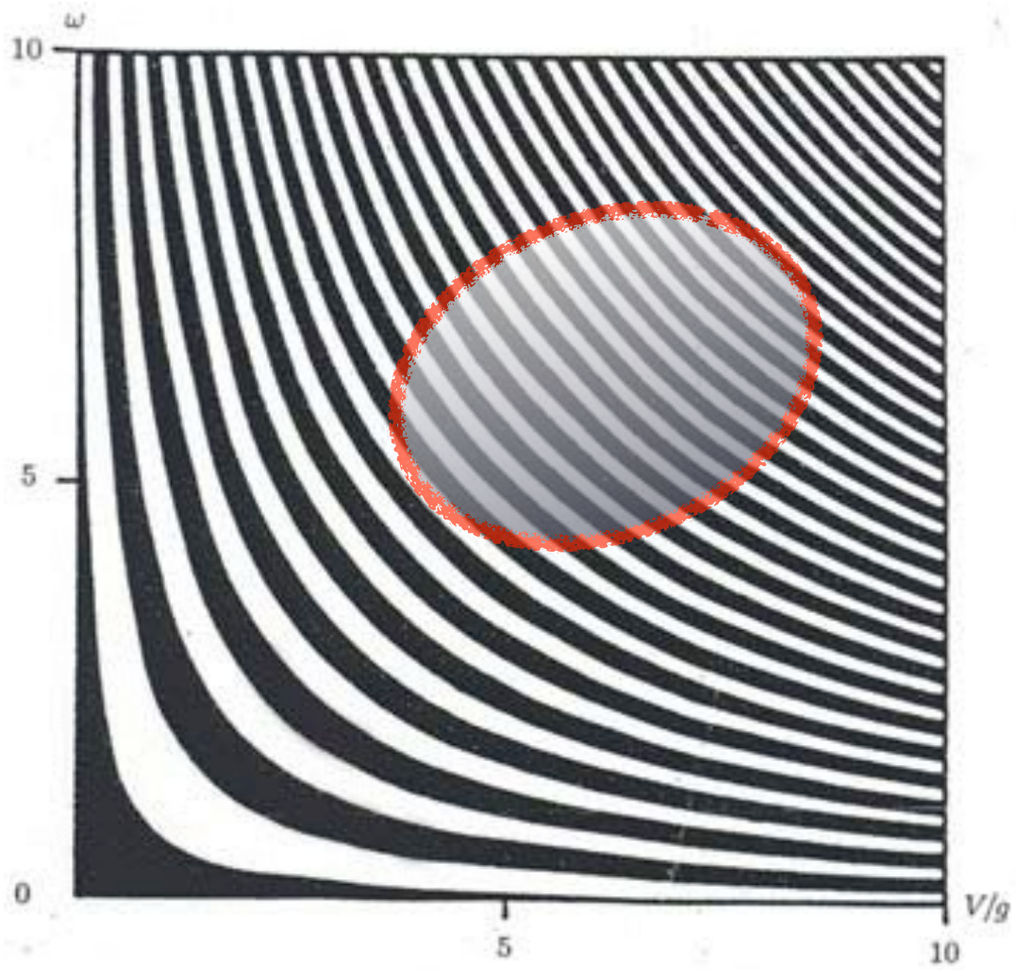
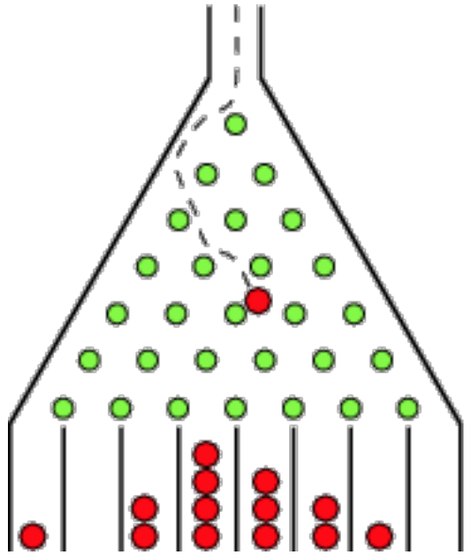


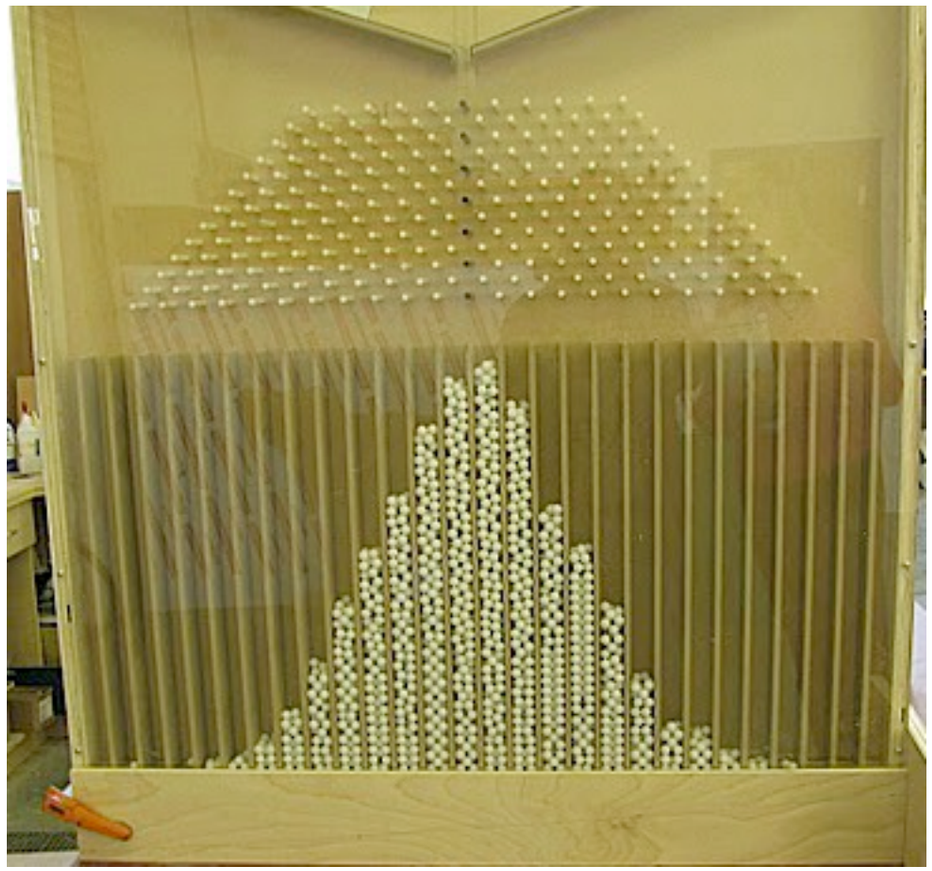
Vertical: rate of rotation Horizontal: initial upward velocity

Recent proponents:

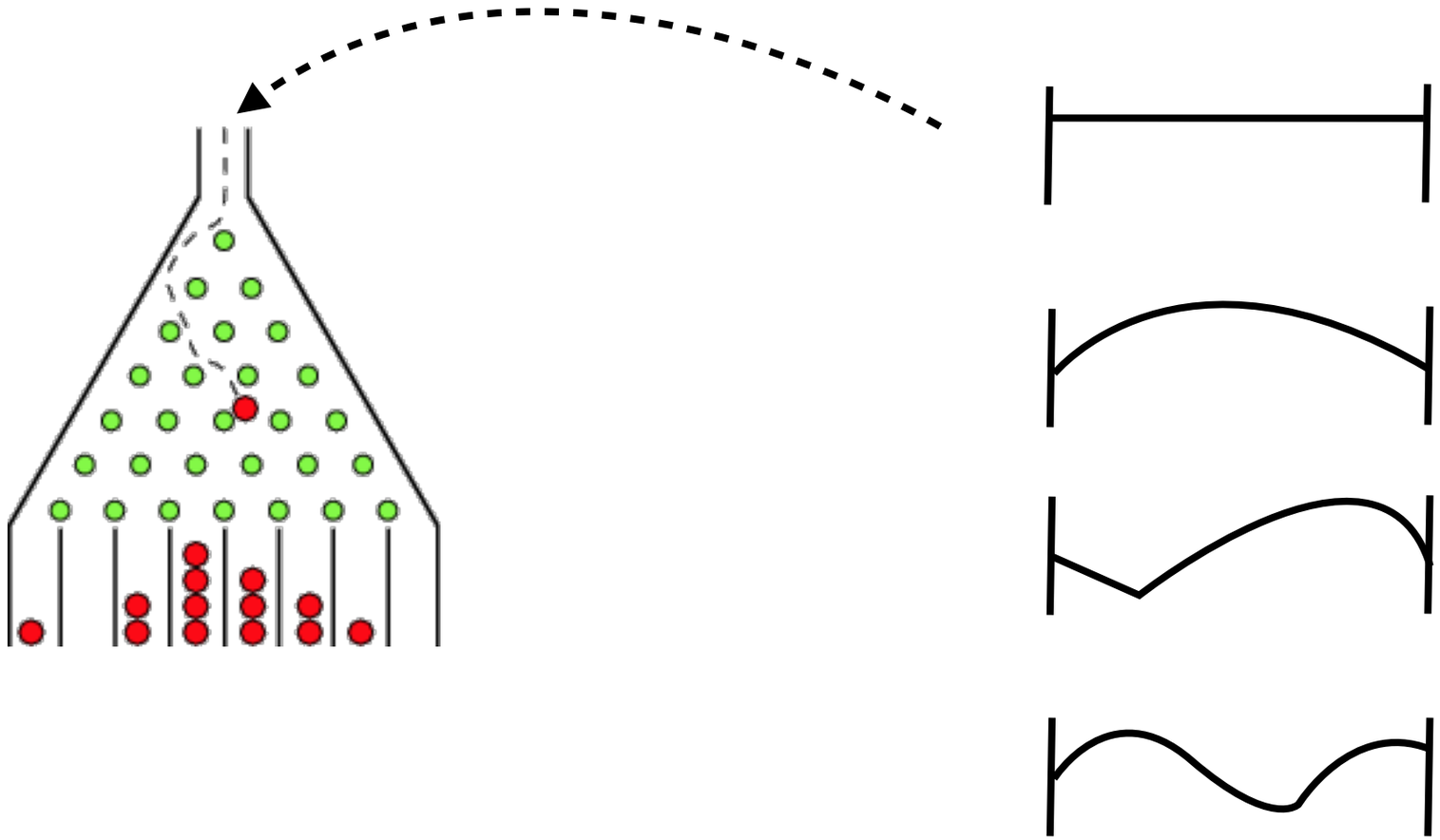
- M. Strevens - *Bigger than Chaos*
- W. Myrvold (Stat Mech)
- T. Maudlin (Galton board example)
- Hoefer (2007): *stochastic nomological machines*

Galton board



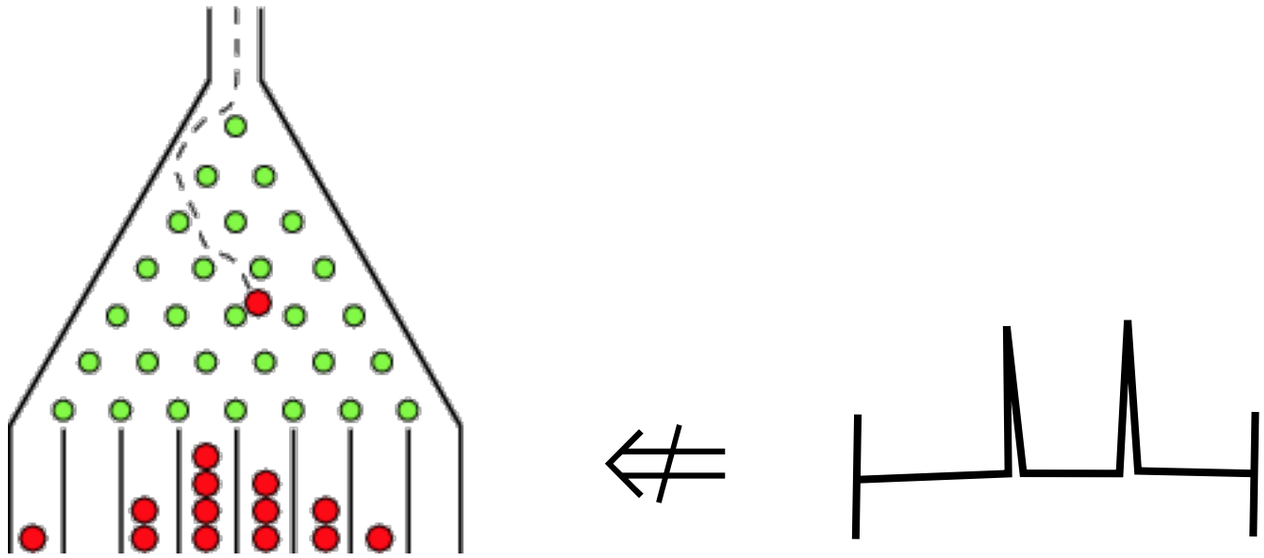


Galton board & IC distributions



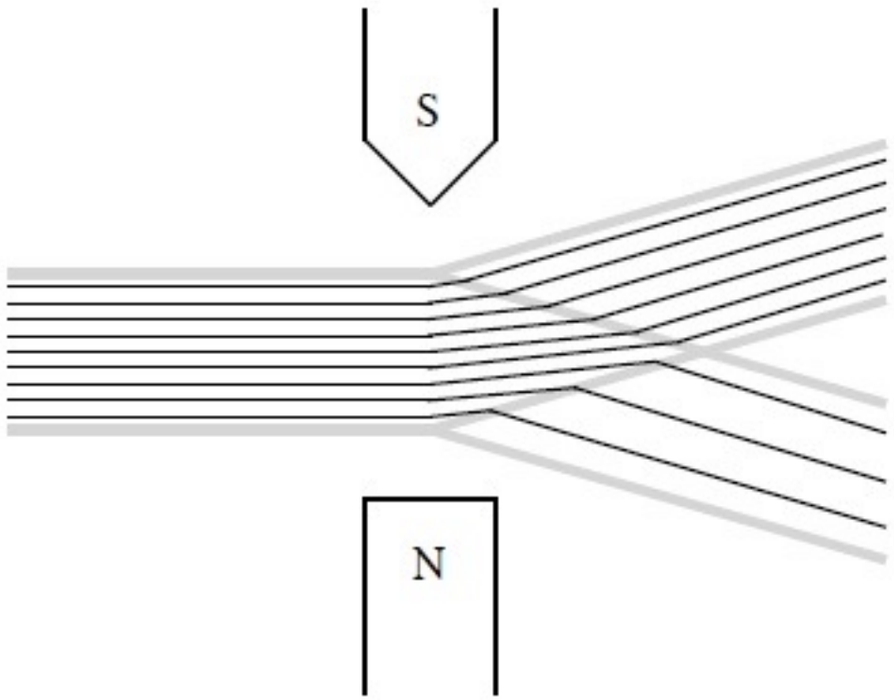
Any of these IC distributions leads to the same *statistical* outcome pattern.

Galton board & IC distributions



Some possible IC distributions however do not give ‘right’ results

Bohmian mechanics: spin-measurement



Norsen (2013): how Bohmian particles get distributed (unequal weight state)

Dialectics finished

- Some will say: believe in probabilistic fundamental laws, it is the *best explanation* of the random behavior we see in many experiments. (*inference to the best explanation*, IBE)

- But we saw: status of *explanation* was dubious

  - No acceptable explication of the *content* of prob-law claims ⇒ can't explain actual frequencies, nor our subjective expectations.

- Now status of *'best'* undermined too: underlying Det can explain chancy phenomena better!

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QM & intrinsic randomness. . .

What about Bohmian Mechanics?

- In order to say we have *certified* randomness from quantum phenomena, we have to rule out BM and similar Det hidden variable theories. . . How?
  - BM allows free choice of measurement settings in Bell experiments
  - BM is a no-signalling theory
  - BM involves no conspiratorial super-determinism
- . . . so the standard criteria for excluding HV theories seem ineffective.

QM & intrinsic randomness. . .

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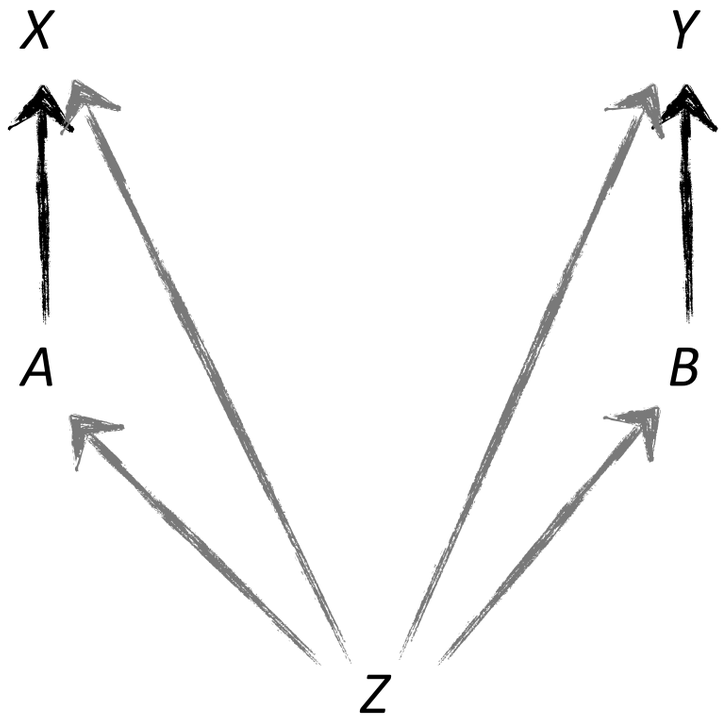
Causal structure of EPRB experiments

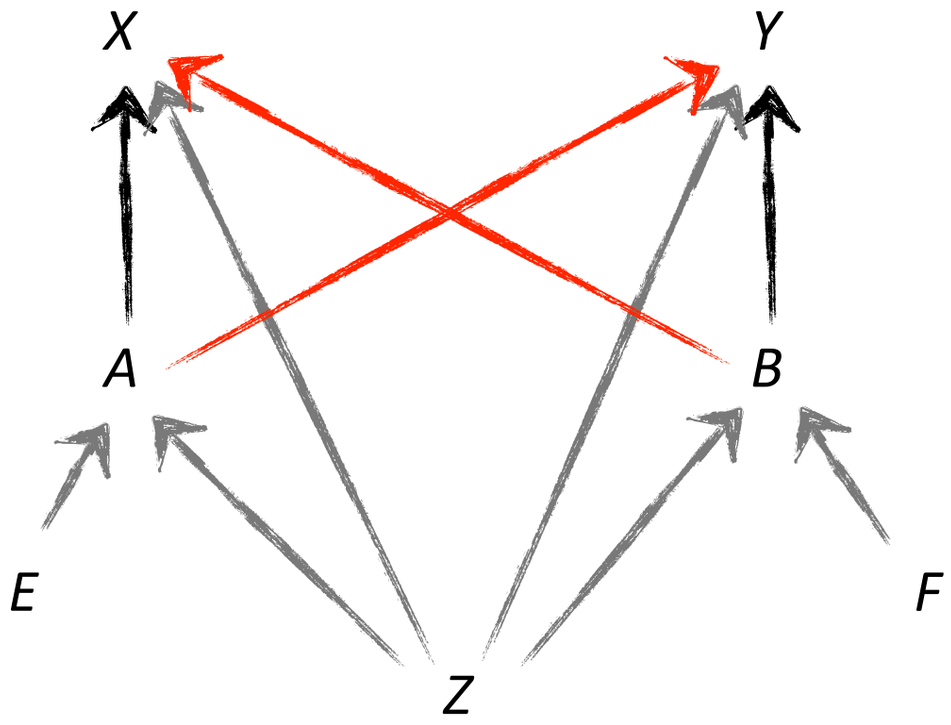
- Causal structure to which Colbeck & Renner (2013) argument applies



Causal structure of EPRB experiments (for Bohmians)

- Determination of *A, B* can be from photons from opposite sides of the galaxy if you like.

- No conspiracy needed



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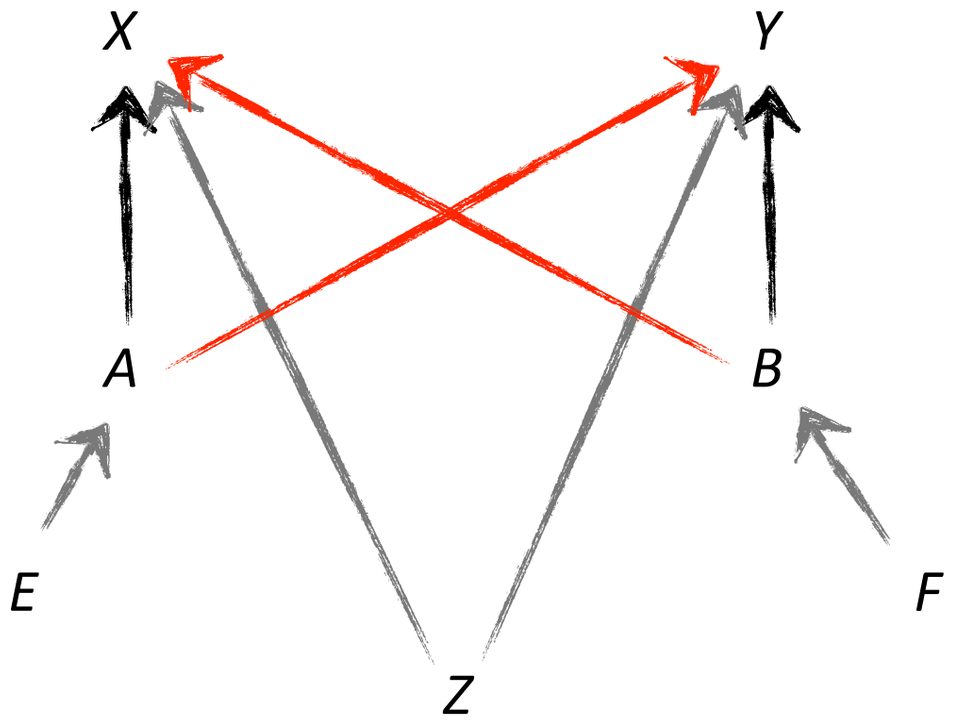


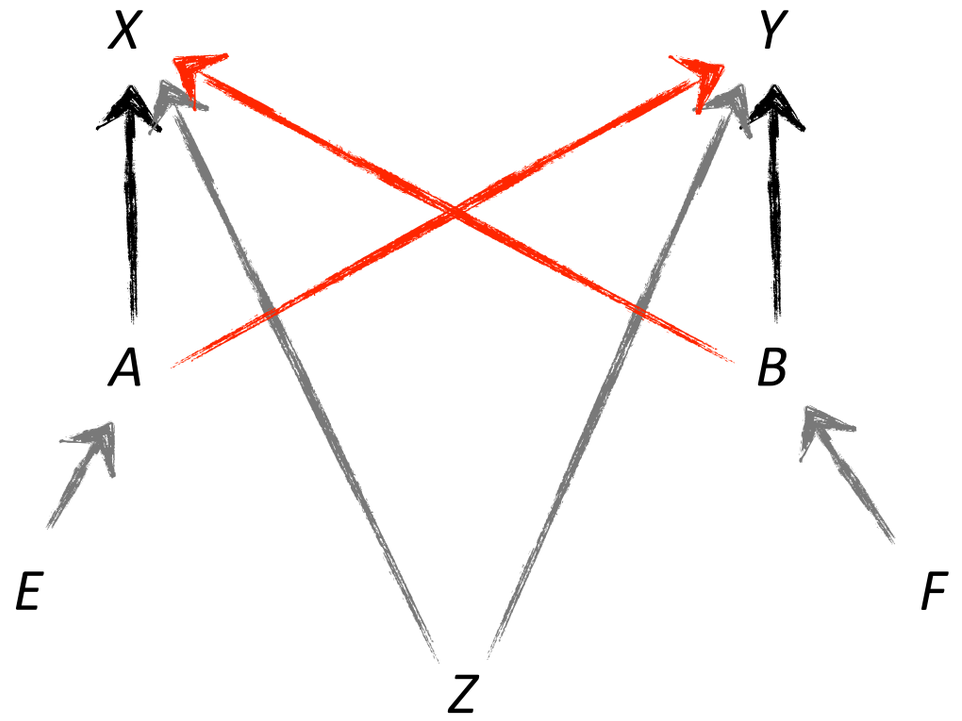
QM & intrinsic randomness. . .

What about Bohmian Mechanics??

- In order to say we have *certified* randomness from quantum phenomena, we have to rule out BM and similar Det hidden variable theories. . . How?
  - BM is supposedly a no-signalling theory

Causal structure of EPRB experiments (for Bohmians)

- Parameter dependence ≠ effective signalling
- Quantum equilibrium postulate ensures no *effective* signalling possible
- QEP ≠ conspiratorial initial conditions in the "superdeterminism" sense.



NB: *I am not endorsing Bohm's theory*

- There are reasons to be skeptical that BM is on the right track.
- But - violation of no-signalling (at the surface level, where we have reason to trust N-S), or of free choice, are not among those reasons
- Plus: where there's one theory, there may be more out there waiting to be discovered.

Contrast: properties of standard QM

- Non-local
- Contextual
- Parameter-dependence [Copenhagen]
- [arguable] causation at spacelike separation

Summing up

1. I argued that it's difficult to spell out what we mean when we postulate intrinsic randomness of the propensity or chance-law variety.

2. By contrast, I argued, we can understand objective probability claims if they arise from determinism + nicely-distributed initial conditions. Quantum "randomness" in Bohmian Mechanics is of exactly this sort.

3. I noted that while Bohmian QM has no *intrinsic randomness* (being deterministic), it satisfies no-signalling (in a pragmatic or effective sense). At the surface, it's a counterexample to randomness-certification arguments; but at the deep level one could say it *is* a "signalling" theory. But in this deep-level sense, we have no way to rule out that nature herself *is* signalling.

4. Distinction: certified [*effective*] randomness *vs* certified [*intrinsic*] randomness. BM is counterexample to latter, but not the former.

David Lewis on the challenge

- “It only remains for me to concede defeat, and agree that the chancemakers are not, after all, patterns in the arrangement of qualities. They are something else altogether: special chancemaking relations of universals, primitive facts about chance, or what have you. ... But I think there is no refuge here. Be my guest-posit all the primitive unHumean whatnots you like. ... But play fair in naming your whatnots. Don't call any alleged feature of reality "chance" unless you've already shown that you have something, knowledge of which could constrain rational credence.”