Power Structuralism / Metaphysics of Entanglement
Reading group on *Causation and its Basis in Fundamental Physics* by D. Kutach
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Fundamental causation

— Chapter 2 handout —

> The goal of this chapter is to identify commonalities among paradigm fundamental theories to serve as a guide for what fundamental reality is like and to identify some causation-like relations that will hold for all such theories. Then, in the following chapters, we can use these fundamental causation-like relations to construct models of influence, probability-raising, causal regularities, and more. (p.56)

<u>Basic idea</u>: "What fundamentally connects causes with their effects is <u>terminance</u> [= a kind of probability-fixing]." (p.107)

> Terminants and contributors have a privileged ontological status and other kinds of causes exist only derivatively. [...] Terminants are the only entities that engage in those metaphysical relations that ultimately vindicate talk of causation. (p.116)

<u>Prelude</u>

RUSSELLIAN INTUITION: Science doesn't find directed graphs in nature that link mundane events to each other via some very special metaphysical relation.

ANTI-RUSSELLIAN INTUITION: "there are objective structures in the world that account for why reality behaves in paradigmatically causal ways, structures that call out for explanation." (p.54)

VERBAL DISPUTE: "Is causation real?"

REAL QUESTION: What underlying rules account for the fact that the world seems to behave causally?

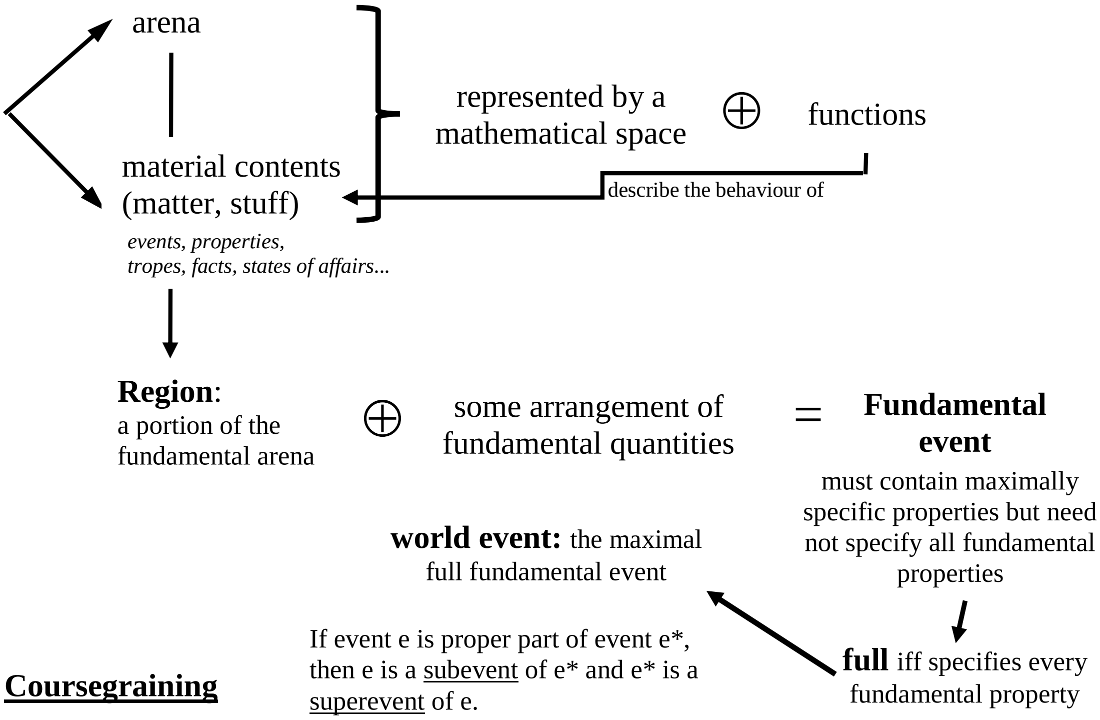
<u>Assumption: Fundamental reality = fundamental physics</u>

Might be false, but it helps see where this premise leads and it may act as a prolegomenon to considering whether the fundamental is wholly physical (or whether it is physical at all).

Current fundamental physics is disunified and parts of it may be false. But, again, it is methodologically useful to pretend that we have at least a rough idea about the true shape of (completed) fundamental physics.

Paradigms considered here: classical gravitation, electromagnetism, general relativity, non-relativistic quantum mechanics.

Basic structure of fundamental theories:

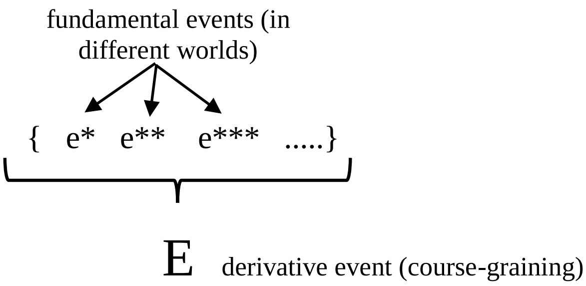


<u>Coursegraining</u>

Derivative events:

> When we refer to the first moon landing, we often have in mind a conception of reality that is insensitive both to the spatial extent of the event and to its many microscopic details. (p.60)

Basic idea:



> Each coarse-graining Ei of e is a set of fundamental events that includes e as one member. One coarse-graining, E1, might allow for very slight microscopic alterations of e to count as the same moon landing by including fundamental events that are just like e except for a small shift of a few atoms. Another coarse-graining, E2, might allow for there to be an extra screw attached to the lunar lander by including such a fundamental event. Another coarse-graining, E3, might count the possibility of Buzz Aldrin stepping on the moon as the same moon landing event but not the possibility where Elvis steps on the moon. (p.62)

Assumption: the derivative events we'll deal with are composed of fundamental events that have the same size and shape (p.61)

Laws: two conceptions

Laws are what's common to a privileged set of worlds (namely, to those that are nomologically possible) (p.64)

- real entities/structures that govern events or are instantiated by them
- "privileged summary of the layout of material contents"

talk of fundamental laws is meant to be neutral b/w these options

Law facts vs. material facts: e.g. Maxwell's equations vs. the whole history a classical electromagnetic arena.

Laws ground counterfactuals:

> When evaluating what would have happened if C had happened, we hold the fundamental laws fixed, fill in some supposition about how C is instantiated by fundamental stuff, and then evaluate what would have happened using only the fundamental laws. (p.65–6)

If it turns out that there are no fundamental laws, then (i) either there is no causation at all in reality, or (ii) some non-Kutachian theory of causation is true. However, this is, in the end, a verbal dispute, because it boils down to "a terminological decision about whether to identify 'causation' with whatever it is that ultimately accounts for putative instances of causation". (p.66)

Laws in the special sciences may or may not be derivative. One sign that they might be is that (1) they are temporally asymmetric, which, on Kutach's account, follows from fundamental physics, and (2) they are ceteris paribus (p.67).

Terminance

> A fundamental event c determines a fundamental event e iff the occurrence of c nomologically suffices for the occurrence of e (with e's location relative to c being built into this necessitation relation). (p.67)

Note: determination is reflexive, transitive, and may be symmetric.
Trivial determinants: c determines c and subevents of c.

> [Determination relations] are genuine relations of singular (and actual) causation in the sense that they are the components of the actual world that bind various happenings causally. The determinants (and their chancy counterparts) are "doing all the causal work," all of the pushing and pulling in the actual world. (p.68)

A contextualized event $\underline{E}$ is a course-grained event with probabilities attached to all its members, adding up to 1: $E = \{e_1, e_2, e_3...\}$, such that $\exists\, x_1\, x_2...$: $P(e_1) = x_1$, $P(e_2) = x_2$, ...etc. and $\Sigma x_i = 1$. This structure, as a whole, is the contextualized event $\underline{E}$. (The e_i's might have to be enlarged a bit before we can assign probabilities to them.) (p.69)

A fundamental event *c* <u>fixes</u> a contextualized event <u>*E*</u> iff *c* suffices for the probability distribution that <u>*E*</u> represents (p.70)

c is a **<u>terminant</u>** of *e* iff, for some <u>*E*</u> fixed by *c*, *e* is a member of *E*.
(*c* and *e* are worldmates) (p.72)

c is a <u>parterminant</u> of *e* iff *e* only fixes probabilities for some segment of an <u>*E*</u> that e is part of. E.g. "the laws specify what could happen in *e*'s region for two-thirds of the probability distribution, but fails to imply anything about what happens for the other one-third of the probability distribution" (p.72)

c is an <u>indeterminant</u> of e iff c is a terminant of e but not a determinant of e, i.e. iff c fixes a less than 1 probability for the occurrence of e.

> Indetermination is different from traditional probabilistic accounts of causation. On the latter, probability-fixing can occur without between nonfundamental events (e.g. the cue ball makes the 9ball's movement probable). In the present framework, the smallest relevant event is a slice of the backward lightcone of the 9ball's hitting the hole (p.74).

<u>Contribution:</u>

c <u>contributes</u> to *e* iff

∃c*: c* is a terminant of e and c* minus c is not a terminant of e. (p.75)

c* minus c = c* minus the material content of c

Difference between contributors and Mackie's INUS conditions:

> The most noteworthy differences between an inus condition and my conception of a contributor are that (1) contributors can exist by virtue of fundamentally chancy relations whereas inus conditions require determination, (2) contributors exist only as fine-grained events characterized using fundamental attributes and so are not as general as Mackie's "conditions," which include absences and (arguably derivative) macroscopic happenings, and (3) contributors only contribute by virtue of fundamental laws whereas Mackie imposes no such restriction. (p.76)

<u>The arena of classical gravity and electromagnetism</u>

Both Galilean spacetime and Minkowski spacetime are (1) infinite,
(2) homogeneous (the geometrical structure of the neighbourhood of points is the same everywhere), (3) connected (any two points are related).

There are <u>spacelike</u> and <u>timelike</u> connections.

A <u>spacelike surface</u> is a three-dimensional region the points of which are spacelike related.

A <u>time-slice</u> is a maximal spacelike surface.

A <u>global state</u> is a full event whose region is a time-slice.

<u>Basic principle</u>: "The fundamental laws disallow space-like terminance." p.81

(Space-like terminance occurs, roughly, if *c* and *e* are spacelike related. Precise def on p. 81)

Classical gravitation (CG)

Arena of CG: Galilean spacetime: separate objective metrics for spacelike and timelike separations. As a result, there is an objective difference between accelerated and unaccelerated motion.

Material contents of CG: corpuscles, represented by differentiable paths in the arena, known as world lines.

CG has determinants (non-probabilistic terminants). Its determinants are

- any time-slice iff there are instantaneous states of motion (velocities)

  Interestingly, anything smaller than a time-slice fails to determine anything (except, trivially, its parts). p.81

- any extended time-slice iff there are no instantaneous states of motion

  As a result, this sparse variant of CG has no minimal terminants

There is arbitrarily fast contribution in CG (for any finite timelike distance *d*, a global state at *t* determines everything at *t* + *d*). But there is no instantaneous (spacelike) contribution, at least in the standard versions. If acceleration were a fundamental property, then there would be (p.88).

Relativistic electromagnetism (RE)

Arena: Minkowski spacetime.
Unlike Galilean spacetime, it has a single spatiotemporal metric.
Time-like, space-like, and light-like paths. There are continuum-many different time-slices that contain an arbitrary point *p*.

Content: corpuscles + electromagnetic field. The field obeys its own dynamical laws so it cannot be eliminated like the gravitational field in CG.

Full events contain: (1) field values at each point, (2) mass, charge and trajectory of particles.

> Some global states determine everything throughout the future and past. However, there are also global and non-global events that serve as non-trivial determinants of more limited regions. (p.91)

Any full event that cuts across the entire light cone of *e* is a determinant of *e*.

Content completeness: “in order for an event *c* to termine everything that happens at the location of *e*, it must include a complete specification of all the fundamental attributes in the fundamental ontology.” p.93 (rules out cases where different laws, through different fundamental properties, termine the same event) Content completeness holds in both CG and RE.

Content independence holds iff whether c fixes e is independent of c’s material content and depends only on c’s shape, size, and location relative to e. (p.94) Content independence holds in both CG and RE.

> Whether content independence holds for the actual world is questionable because it is violated by the standard interpretation of general relativity, where the structure of the arena depends on how material contents are situated. (p.95)

General Relativity (GR)

> [T]he standard interpretation of GR postulates a space-time that is similar to Minkowski space-time on an infinitesimal scale but differs by permitting spatio-temporal curvature, including the relative tilting of the light cone structure at different points. [...] The signature feature of general relativity is that its space-time structure is dynamically responsive to the distribution of a world's material contents. (p109–10)

(Note that this creates problems for coarse-graining events, p.110.)

Content independence fails, but there is determination.

Problems for determination: inside of a black hole, white hole, timelike loops (p.110)

(Nonrelativistic) Quantum mechanics (QM)

Involves two "spaces": a Galilean spacetime
configuration space (3N-dimensional if there are N particles)

Wave function: Ψ: configuration space → complex numbers
Ψ(*t*) = "quantum state at *t*"
Ψ(*t*) evolves as a wave in configuration space

Global states: the quantum states + whatever fundamental properties are instantiated in spacetime, if any.

The fundamental arena can be identified with (1) spacetime, or (2) spacetime + configuration space.

Bohmian mechanics

Corpuscles with determinate trajectories in spacetime, obeying a deterministic guidance equation. The velocity of any given corpuscle at *t* depends on Ψ(*t*) plus the positions of all the other corpuscles at *t*.

Determinants:
- Ψ(*t*) determines the whole of Ψ
- Ψ(*t*) plus the corpuscle position at *t* together determine the whole history

The Ghirardi-Rimini-Weber interpretation (GRW)

> [T]he quantum state evolves according to the same deterministic rule as in Bohmian mechanics, except for special violations [when] the quantum state makes a discontinuous, fundamentally chancy transition to a new quantum state. (p.114)

There are two sources of indeterminism:
• a fundamental constant that sets the frequency of collapse
• the standard quantum-mechanical probability distribution that constrains the outcome of the collapse.

Indeterminants:
• any $\Psi(t)$ plus the time-slice at t is an indeterminant of all later events

Global states partermine past events:

> Regarding c's relationship to past events, the fundamental collapse rate fixes, for any duration Δt, some positive probability for the possibility that state c is not preceded by any collapses within the most recent span of time, Δt. However, there is no probability distribution for what states preceded a collapse, even when taking into account which particle was selected for collapse and the post-collapse state. (p.115)

<u>Flashy version of GRW</u>

> [F]lash interpretations of quantum mechanics postulate fundamental entities known as flashes that each occupy a single point of spacetime. [...] The event c, consisting of the quantum state at some initial time t_0 and a complete specification of all flashes in space-time from t_0 until some time t, fixes a probability for whether there will be a flash in any chosen space-time region at t, and that probability matches the probability dictated by the traditional spontaneous collapse interpretation. (p.115)

<u>Other interpretations of QM</u>

> Almost every interpretation of quantum mechanics either resembles (1) Bohmian mechanics, by relying entirely on relations of determination in the fundamental dynamical development, or (2) the spontaneous collapse interpretations, by supplementing the deterministic dynamical laws with some fundamentally chancy violations of the default deterministic rule. For all such theories, the structure of terminance will be largely the same as in these two interpretations. (p.116)

<u>Terminance, infuence, and timelike paths</u>

c's <u>domain of terminance</u>: sum of events that c termines

c's <u>domain of influence</u>: sum of events with some part that c contributes to

c-path ≈ a differentiable worldline ("an everywhere differentiable path whose tangents are nowhere space-like and are well-defined and non-space-like in any mathematical limits along the path" p.96)

c's <u>domain of dependence</u>: set of all points *p* such that every maximal c-path through *p* intersects *c*

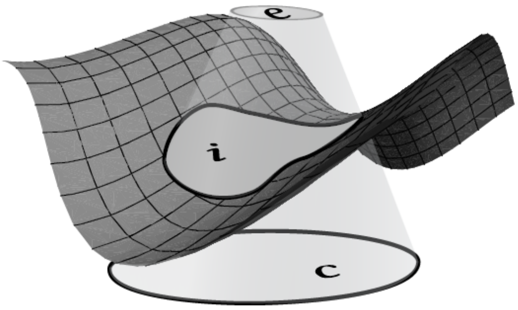
<u>GR + RE + CG:</u>
" • A point *p* is in *c*'s domain of terminance iff *p* is in *c*'s domain of dependence.
• A point *p* is in *c*'s domain of influence iff *c* is c-connected to *p*." (p.97)

<u>Continuity of terminance and shielding of terminance</u>

Arguably, these two principles hold throughout fundamental physics. “The key idea behind continuity is that the fundamental interaction between events at separate locations is always mediated what happens in between” (p.98). The key idea behind shielding is that the mediators are themselves fixed by the distant cause. More precisely:

> <u>Continuity of Terminance</u>: For any possible fundamental event f (occupying region F) with any subevent e and any subevent c that termines e and any subregion R of F intermediate between c and e, there exists an intermediate terminant on the way from c to e occupying R. (p.99)
>
> (A region R is <u>intermediate</u> between c and e iff (1) every point of R is c-connected between some point of c’s region and some point of e’s region, and (2) there is a connected space-like subregion Q of R such that every c-path from a point in c’s region to a point in e’s region intersects Q. p.98)
>
> <u>Shielding of Terminance</u>: For any possible fundamental event f with any subevent e and subevent c that termines e, the probability any [terminant i of e intermediate between c and e] fixes for any coarse-graining E of e is equal to the probability fixed for E by any superevents of i that are termined by c and do not intersect i’s e-ward domain of influence. (p.99)
>
> Shielding can be thought of as the claim that as nature evolves dynamically in an ordered sequence or continuum of suitably large states toward the future, each of these states incorporates all the relevant information from its past for anything it fixes toward the future. (p.117)

FIGURE 2.6 *The event c termines e with an intermediate terminant i. The probability that i fixes for E is the same as the probability fixed by any of i’s superevents that are termined by c and do not inhabit i’s future domain of influence.*



Worlds without continuity and shielding:

> It is easy to imagine possible worlds where continuity and shielding do not hold. Suppose there are fundamental laws of magic such that waving a wand with the proper incantation determines that all rabbits will vanish after precisely one day. The state of the universe in the meantime is exactly the same as it would have been without the magical spell having taken place. In such a world, the spell does not have its effect on rabbits by way of something fundamental in the intervening times but does play a role in what happens one day later. (p.100)

Determinism

Basic idea: any global state fixes the whole history.

Two ways to define determinism: through unique propagation (how the laws evolve a state) and through possible worlds (if two worlds have duplicate time-slices, then they are duplicates).

Kutach prefers the unique-propagation view, because (i) it is more general: worlds with disconnected spacetime-components can be deterministic in the first sense while being indeterministic in the second sense, and (ii) it defuses the hole argument (p.102–3).

Determinism def ≈ For any nomologically possible full event c, c determines a unique full event throughout its future light cone via the laws of nature

Precise version: "For any nomologically possible full event c, c determines a unique full event throughout its maximal domain of dependence." (p.103)

> (A maximal domain of dependence for a fundamental event c is a region R produced by applying the fundamental laws to c (extending the arena if necessary) until R includes all and only those points that are definitive of c's domain of dependence: every point p such that every inextendible c-path intersecting p also intersects c's region. p.103)

Failure of determinism:

• stochastic fundamental theories ("A stochastic fundamental theory includes laws allowing fundamental events to suffice nomologically for a probability distribution over a set of possible events without determining which particular member of the set will be instantiated." p.104)

• nonstochastic indeterminism: space invaders, gremlins, Norton's dome.

Arguably, cases in the second group do not make the actual world indeterministic, because these situations never obtain. (p.108)

Bottom line

Basic idea: fundamental causation is about terminance (and its weaker cousin, contribution). "Terminance and contribution constitute the relations of singular causation that fundamentally bind various parts of the universe together." (p.116)

Basic facts about terminance:

• Terminants are big. "For relativistic theories, the only prior states that termine a full event e span at least the entirety of e's light cone. For paradigm non-relativistic theories, the only prior states that termine e span all of space." p.116

• Terminance is all-or-nothing: if you remove a little bit, terminance disappears.

• Interplay with arena structure: "many facts about terminance depend only on the arena structure." p.117

• Non-spatiality (terminance is timelike directed).

• No temporal asymmetry.

• Continuity: The fundamental laws disallow fixing relations that skip over intermediate regions.

• Shielding: Events incorporate all the relevant information about the past for the future events they fix.