WHY SPACETIME IS NOT A HIDDEN CAUSE: A REALIST STORY

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"Spacetime acts on matter, telling it how to move" (Misner et al. 1970 p. 5; Taylor et al. 1991 p 275).

Abstract: Spacetime realism requires that it is not hidden and not a cause. Its style of explanation is geometrical.

1 Introduction

How does – how *could* - spacetime act on matter or tell it how to move?

The best short argument against realism runs like this: if spacetime is a real entity for General Relativity (GR) then surely the acting and the telling must be a causing - a *hidden* causing. But, equally surely, spacetime is the wrong kind of thing to *make* matter move. That's bad physics and bad metaphysics. But if spacetime causes nothing, it explains nothing either. So weed it out of the ontology of GR and settle for a codification – whatever *that* is.[2] [DiSalle 1994, 321-8 1995, 275-7. Brown 2005, pp. 24-5, Brown and Pooley 2004, Torretti 2006 p. 3n. For doubts about codification (in another context) see Nerlich 2005 §2.1, 3.1]

The argument goes astray from the start. Realism doesn't need and can't admit spacetime as causing matter to move. Spacetime is not a hidden cause because not a cause.[3] Yet spacetime explains what matter does under pure gravitation. It does so rather straightforwardly. It exploits various direct identities. That is misunderstood, widely I think, perhaps because the search for causes clouds the issue.

Familiar thoughts motivate this paper. Gravity makes no sense as action across a distance by some massive things on others. It is not a force, not a cause. GR makes sense only as a local theory: it demands proximal explanation. In lots of pure gravitation situations, the *only* proximal feature available to explain anything is local spacetime structure. But surely it can't explain matter's motion by causing it. So a style of *geometrical* explanation both local and acausal surely looks at least worth consideration. Of course the idea is frightening. Ontologists abhor spacetime just as nature, it was once supposed, abhors a vacuum.

Apart from its last step, the premises of this paper's argument rest on common ground; indeed, they make up the simplest, basic ideas of GR. The step to the conclusion is no less simple and direct. Further, there are simple examples already to hand of non-causal geometrical explanation. The handedness of hands depends on whether their containing space is orientable or not. Roughly, they are handed if *there exist no paths* in the space that will smoothly map an asymmetrical object onto its mirror image, and not handed if *such paths exist*. This isn't causal explanation – space *does* nothing to hands. That is some sort of *existential* explanation. The shape of spherical space explains why there are no similar shapes of

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[1] This paper was delivered at the Ontology of Spacetime Conference, Montreal, 2008. Forthcoming in Petkov, V (2010)

[2] For doubts see Nerlich 2005 § 2.1, 3.1.

[3] And not hidden either; see Nerlich 1994, 38-43.

different sizes in that space - why it has no similarity geometry. For triangles with greater perimeters there is more space, more area, that they must contain That, too, is somehow existential. It's about *how much space there is*.

What follows in this paper is familiar and obvious too. So much so, that it continues to puzzle me why it needs to be said. But that is a dangerous state of mind in which to approach the problem. I suspect that the main difficulty lies in the horror of spacetime realism. Dispelling the horror is the hard part of this work, but it is not closely examined here.

I start with some prehistory of inertial motion.

2 Cause and classical inertial motion

Confusion once reigned as to what keeps an arrow flying. Galileo's giant stride towards clarity turned on the relativity of motion and the composition of velocities. He saw that "What keeps the arrow flying?" is the wrong question. Instead, ask what causes it ever to stop. Then there are genuine causal answers: e.g. gravity pulls it down to earth, or it hits something. A more precise message was fogged by the great Italian's preoccupation with circular (including horizontal) motion. This obscured the role of linearity in free motion. (Chalmers 1993).

Newton's first law of motion is clear on linearity:

> *Every body persists in its state of rest or of moving uniformly straight ahead, except insofar as it is compelled to change its state by forces impressed.* (Newton 1999, 416)

Thus Newton straightened out Galileo's story, but only to the extent of Corollary V

> *When bodies are enclosed in a given space, their motions in relation to one another are the same whether the space is at rest or whether it is moving uniformly straight forward without circular motion.* (Newton 1999, 423)

Notoriously, the rest or motion of the 'given space' is absolute. Perhaps this is why Newton hinted at the older thought[4] that a "force of inertia" ("vis insita" or "vis inertiae") causes the arrow's flying on. [5] This still leaves something to be desired but it is not the thought that *space* could cause anything.

The released bowstring pushes the arrow and causes it to fly. There, cause is force. If we look for a cause why the arrow *keeps on* flying, we look for a cause of inertial, free-fall motion: we look not for an initiating cause but for a proximal one. That a thing is moving inertially at some velocity now might be because it *was* just moving at that velocity. However, the earlier state doesn't force the later one, despite being a distinct, preceding state. A force is needed to *change* it. The structure of space is plainly no such cause even though its straights are the privileged paths.

But doesn't the preceding inertial motion, the conserved momentum, *cause* the present inertial motion? Not if we accept both the first law and the relativity of inertial motion. An adroit frame-swap can transform any state of free motion to a state of rest. The effect vanishes and the cause with it. That is because the 4-acceleration vector is **0** so no force recognised in GR can be at work. Any further search for a cause of inertial states must look for an account

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[4] Compare Buridan and Benedetti. See *Wikipedia: the free encyclopedia* article 'The Principle of Inertia 2.1.1.

[5] See 'A Guide to Newton's *Prtincipia'* by Bernard Cohen, Chapter 4, 4.7 esp. p. 98 *in* Newton 1999).

of why things endure. I grant, more for the sake of getting along than from conviction, that it will be a causal story (e.g. Tooley 2001, 398). Even if there is one, space (spacetime) has no part in it. There is no need to ask why an object at rest in an inertial frame stays put; for any object in uniform motion there is a frame in which it is at rest. The thing merely endures. This is *satisfactory:* questions can rest at this point.[6]

It's remarkable that the first law says nothing at all about the causal powers of any body to which it applies. It says nothing about what causes anything to endure. The second law requires that all bodies have mass; the first mentions no property whatever. Remarkably, too, we have good *classical* reason to think that no body ever actually does escape the (gravitational) causal net or persists in its state of rest or uniform motion (although there might be some bodies on which the resultant of forces is zero, briefly or not). This suggests that the law is about *trajectories*, spatio-temporal entities, not about what might occupy them. It tells us nothing of how any such trajectory ever comes to be occupied. It need say nothing about why an occupant remains on the trajectory, but it does explain why causes are needed to drive it off. It is about the importance for dynamics of the default case: the non-causal trajectory in which there is zero acceleration. The default, in pre-spacetime talk, is rest-or-uniform-motion. I will call these *Galileo trajectories*. Their importance emerges in the relativity of motion and the composition of velocities, which, in turn, depend on the spatial and temporal symmetries of classical mechanics.

The first law really is first. It is conceptually simpler and theoretically deeper than the 2nd. Once we can decide simply when forces are on or off, we can identify the required frames of reference (candidate rest states). Inertial motion is not defined by laws of motion: rather it is a rather direct observational truth as to what trajectory is found as forces approach zero. To a large extent, Newton decided this by seeing free motion as free from *impressed* forces (impacts, pushes and pulls) and gravity. This laid a groundwork: candidate forces should have (i) observable sources, and (ii) regularities governing (a) *when* and (b) *how* they are at work. This rules out arbitrary, conventional postulations of force. Only when we have the right frames of reference and, by implication, the right transformation group, may we explore accelerations relative to them in a comprehensive way; only then can forces be quantified and oriented. Then you can formulate the 2nd law and verify that 2nd derivatives are at the core of dynamics. That the 2nd law entails the first does not rob the first of first place.

3 GR space, time and spacetime

Here's my strategy in a nutshell. In pure gravitation examples, GR explains what matter does by extending the idea of Galileo trajectories to 4-geodesics (straights[7]) in spacetime even though these often have no rest-or-uniform-motion image relative to frames of reference (space and time representations). Roughly, that a worldline is a Galileo 4-trajectory explains why its occupant is innocent of causal dependence, guidance etc. beyond its mere endurance (the mere extension of its worldline). It merely falls (floats) freely – free of causes and forces.

[6] If all that is sound, then there is a classical non-causal process, a changing of spatial distance between two suitably inertially moving things. The motion of neither is an effect, since it vanishes under frame swaps. The changing distance between them is a covariant quantity of the Galilean (Lorentz) group: it is a real change. The change is uncaused. If so, it is odd that this was never cited (at any rate it never caught on) as an obvious exception to the rule that all changes are caused.

[7] I write 'straight' where you might expect 'geodesic'. Geodesics just are straights of whatever space they are in The shorter term reminds us of what matters about them for this paper.

Of course, the object has causal power to interact with other bodies and with force fields! However, the images of these Galileo 4-trajectories in space and time often *do* call up causal and dynamical stories about their occupants since, in that setting, they breach the first law.

This is well illustrated by Einstein's familiar example of a rotating disk in Minkowski spacetime. (Einstein 1920 Ch. XXIII, Einstein et al.1923; 115-7) Suppose an inertial frame F in which the disk's centre is at rest. Relative to F, a particle in uniform motion crosses the centre of the disk. Its 4-trajectory is Galilean. Yet, relative to a frame co-moving with the disk, the particle follows an outward spiral at varying speed. It accelerates. The first law demands the postulation of a force field throughout the frame. It will vanish at the centre of the disk and vary as a function of its radius. Relative to that frame, the particle's motion is said to be forced and caused. Plainly the path and speed of the particle are not uniform. Yet, in the spacetime representation, the 4-trajectory remains straight and Galilean. There is no force on the particle and no cause of its continuing motion-or-rest. The structure of spacetime explains how the trajectory is Galilean; it does not cause anything.

I place two conditions on cause: (i) if x causes y, then not (x = y); (ii) for mechanics, causes are forces.

The explanatory role of spacetime in the behaviour of freely falling matter is twofold. It explains (as illustrated) how the apparent gravitational dynamics of free-fall particles in general frames of reference vanishes into the mere kinematics of geodesics in flat or curved spacetimes. It explains also by citing several *identities*. Suppose the trajectory of a cloud of test particles through flat spacetime projects it into a region of curved spacetime. There may be immanent causes for the persistence of the particles: they explain how the cloud *gets into* the curved region. Nothing in this implicates spacetime causally. The flatness of the region of spacetime does not cause the curvature of the neighbouring region that the cloud traverses. The change in shape of the cloud, the deviation of its point-parts, *is* the deviation of geodesic worldlines and not caused by it.

(i) Free fall in a purely gravitational field

I'll enlarge that simple GR example in which the geometric structure of spacetime fully explains an observable behaviour of matter. Let's begin with an idealised cloud of matter-points (pressure free dust): it is spherical at t_0, falling freely ("under gravity alone") towards a massive object. To delete any influence from local matter, assume dust points with negligible mass, ignore gravitational forces between them, and assume there is no other interaction among the points. "Gravity" from the *distant* source is not erased; it is the curvature of spacetime. The cloud will change shape.

The origin of a space-and-time frame of reference (not inertial) floats freely at the centre of the cloud. A point at rest there will remain at rest with zero gravitational force on it. The cloud changes shape round that central point which is at rest in the frame. In the direction of the distant source, the cloud gradually stretches out fore and aft, but it contracts across the orthogonal section – it gets longer and thinner. This closely approximates classical gravity, where it has a causal, dynamical explanation. Clearly, the non-central points move, indeed accelerate in the frame. The more distant points acquire larger 3-velocities in it: some move towards the centre, others away. What accelerates them is a force demanded by the 1st law, a tidal gravitational "force".

A similar tale may be told selecting any point in the cloud as at rest.

That language, that array of theoretical concepts, is appropriate if we conceive of the frame (as we conceive of ourselves) as a spatial thing enduring in time. Spacetime is nowhere in this image. ‘Spacetime’ is not among the concepts in which the space and time explanation may be requested or provided.

Here the changing shape of the cloud needs an explanation. It’s explained by the curvature of the spacetime 4-region. The explaining facts must be distinct from what they explain if the explanation is causal. But they are the same facts.

Each enduring point is an extended worldline. Spacetime doesn’t explain the particle’s extension along the straight nor what causes the straight to be occupied (and thus a worldline). Yet Galileo’s insight remains – don’t seek a cause for simplest dynamically-default states. That’s *satisfactory* because the straight has a zero acceleration vector at every point. That’s what a straight *is.* No acceleration, no force, no cause. That spacetime straights are the worldlines of simple endurance/extension is *satisfactory* for the same old reason – nothing to explain.[8] Here’s where question and explanation may halt.

What spacetime explains is why a 4-straight should be the dynamical default state. It can’t explain why anything is in that state.

The *identity* of the state of affairs differently presented in these descriptions explains what happens to the cloud, so long as there is a cloud. It tells us why the trajectories of the points change the shape of the cloud: the worldlines of different points lie on different straights, and these straights deviate in curved spacetime. The deviating straights project down into accelerating space and time trajectories, among them those that happen to be trajectories of particles. The deviation doesn’t cause the acceleration. It’s what the acceleration *is*; it *is* the change in shape made up by the trajectories of the points. The identities forbid a causal tie.

In turn, the deviation of the worldlines is not *caused* by the curvature of spacetime, since it *is* the curvature; curvature is the deviation of *all* geodesics. Flat spaces are those admitting parallels, so ‘curved space’ simply *means* ‘space in which straights deviate’.

Spacetime doesn’t cause material worldlines to lie on straights. If you like, spacetime doesn’t fully explain all of this because it doesn’t explain the endurance of the test particles. But the endurance doesn’t cause the change in shape. Spacetime explains it through identities, not causes.

In 1908 (Minkowski) and 1915 (Einstein) this style of explanation through various spacetime identities was without precedent and remains unique in science, both physically and metaphysically. Thus it shows the ontic type and role of spacetime as without parallel. That’s its metaphysical importance.

Finally, to parody Quine - no identities without entities. Only a realist can tell this story.

(ii) Light bending

Eddington confirmed the bending of light rays near the sun as predicted in GR. The immediate observation was of dots on (several) photographic plates of the sun at eclipse. The grouping of the dots was caused by a grouping of photons. Our question is about their *separation* and how spacetime structure explains it.

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[8] It’s not so satisfactory that I assume that we will never find a deeper explanation for it or that the deeper explanation will be consistent with the one made out here. There is no explanation within General Relativity.

To say that light rays bend round the sun is to say that in the 3-space of some frame[9], light rays do not move along straights of *that 3-space*. A tidal force, gravity, bends them, in this story.

That's causal. The story is a kind of fiction.

Once more, spacetime is nowhere in this picture. 'Spacetime' is not among the concepts in which the space and time explanation may be requested or provided.

In this case, too, the motion of photons translates up into lightlike straight worldlines. The mapping between space-and-time, and spacetime, representations is an *identity*.

The structure of spacetime *explains* why the dots on the photographic plates are separated as they are. The explanatory structure is the curvature. Spacetime curvature consists in the deviation of its straights, including lightlike ones. That, in turn, explains the separation of dots on the plate. That's how the photographic surface intersects the deviating luminal 4 straights, independently of whether the plate is there or not. Curvature does not *cause* the deviation because it *is* the deviation. The curvature tensor simply *analyses* and *measures* the deviation – an identity not a cause.

Again, flat space is, unique in having parallels. The failure of parallels *is* the curvature: it *is* the deviation of straights.

That completes the explanation. It is not causal; it is realistic – no identities without entities.

4 About matter

I've told my story with some idealised bit-players – test particles. My cloud of dust was misrepresented as made of massless particles each of which tracks a straight in a structure unaffected by these contents. But real dust is made of small but extended specks, not particles. Even specks have some mass that will constrain spacetime structure; clothed with specks, spacetime doesn't have the same straights as it has naked.

Any spacelike cross section of a speck will be intersected by more than one timelike straight. Since these deviate in curved spacetime, the causal story within any speck is not trivial. Elastic forces inside resist the deviation of the speck's smaller parts: internal stresses, distortions, will arise in it. As elastic wholes, specks won't lie on G-trajectories.

The causal story about specks is exhausted in the play of electromagnetic forces engaged in resisting the distortions and in any immanent causes of speck endurance. As before, spacetime explains the deviation of geodesics that change the electromagnetic forces, but it does not cause the forces. It continues to explain as before the causal-default part of the story - why this trajectory needs no cause for any geometrically simple extended thing to lie along it**.** At each point, its space-like acceleration vector is zero. The spacetime story is about the cause-free status *of the trajectory*. That explanation does not encroach on any theory of matter. An occupying point is irrelevant *save as an illustrative fiction*. [10]

Yet we do accept *exactly that explanation* in real if approximate cases. The orbit of Mercury is calculated treating the planet as a point (among other approximations). The observed advance of the planet's perihelion, famously, is very close to the GR-predicted Galileo-trajectory along which the idealised planet would extend. The orbit is a spacetime straight. Unknown stresses within the planet, and unobserved imperfections in its straight 4-

[9] Not an inertial frame, since spacetime is curved and lacks parallels. Only in the limit is spacetime flat and inertial frames locally available.

[1010] Nerlich 1979 §4; Nerlich 1991 §3 and 4.

trajectory are ignored. We fully understand why the orbit is the one we see: it's virtually a geodesic. As an illustration, it *traces* the structure of spacetime. The structure is not a hidden something (not concealed, obscured, not too small, not too fine). It is observed with highly non-trivial precision, even though we know that we see an approximation and that the unoccupied straight itself is not a visual object.

For similar reasons, in illustrative explanations, we may ignore the epicycle of feeding the small masses of the specks back into the T tensor. That will simply generate a new set of straights and these will be causal-default trajectories as before; the geometric explanation exploits just the same feature of the revised spacetime structure and its straights. It wasn't really ever about the properties of matter.[11]

5 A parody of 'hidden cause'

I turn to a lively and very explicit satire on the hidden cause part of the argument in the first three sentences I began with; it is given in Brown and Pooley 2004 §1 and repeated in Brown 2005, p.24. It will be clear that it contrasts sharply with the story just told. It amusingly parodies geometric explanation as causal. In a geometrical explanation, they suggest, matter must follow something like "*grooves*" or "*gutters*" in spacetime along which spacetime "nudges" them. (Brown 2005, p.24, p.161 for "nudge"). The thought is that the grooves *force* things to follow them. Clearly, this geometric story is causal.

I have no quarrel with the parody – but does anyone hold the view it attacks?[12]

Despite their calling this view popular, I can think of no *published* versions of anything like it, although it sometimes – too often – comes up in discussion. It is quite unworkable; how could it yield the crucial result that the geodesic followed in free fall is independent of the mass of the falling body? But something makes this mistake easy; it is exactly what makes the argument I mentioned at the beginning of the paper so plausible. Doesn't geometric explanation just *have* to be some kind of causal explanation?

Two interesting points arise: (i) the parody rests on the presupposition that test bodies would be doing *something else* if the nudge along spacetime's grooves did not turn them from it. Without that presupposition, the gutters, the nudges and the parody itself have no intelligible point. (ii) this never-mentioned something else would either be a state without external cause or have such a cause. If it is uncaused, some causal default state is tacitly recognised as necessary and intelligible: why not the groove-free state - the 1st law - we began with? If it is an externally (e.g. electromagnetically) caused state, then GR tells us that the trajectories

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[11] Compare (Brown 2005 p.24) that "… world-lines [of test 'particles'] follow geodesics *approximately* and then f*or quite different reasons*" from anything to do with the nature of test particles (his italics). Apart, of course from their natural tendency to persist. That leaves the story told here untouched.

[12] I do quarrel with their ascribing the view to me on the basis of a three-sentence quotation from my 1976 book in which I said (in terms of a familiar metaphor about antennae) that action at distance plays no role in GR. There is no hint of nudges, gutters, grooves or causes, There are 7 index items in the book under 'Geometric explanation'. Not one of them is mentioned by Brown or Pooley; all of them argue for, state or imply a *rejection* of the story pinned on me. No item refers readers to the passage they cite; it is about GR's being a local theory. I question whether any theory like the one parodied "has become very popular", and their citing a mere three sentences about something entirely different suggests some desperation in the search to find any that does; it also suggests that Brown's "it is one of the aims of this [his] book to rebut this and related views" is not an aim supported by significant research. Having trod what seems to me a solitary missionary path for 32 years, it is disappointing to find oneself cited as a leading spokesman for a supposedly widespread view that one has always opposed. Brown 2005 p. 23 includes the relevant claims.
After an amicable discussion, I can report that the authors have withdrawn the attribution to me.

won't be geodesical and the geodesical grooves would play a totally obscure part in the parody. I conclude that the parody depends on the tacit admission that causal default states are both essential and intelligible. I warmly welcome that, of course. It does presuppose the 1st law as causal default explanation, however.

But, really, how can Brown or Pooley admit this? The rejection of causal defaults, mere kinematics, is just what their constructivism weds itself to. Everything is dynamics. Deploring mere kinematics, Brown, for instance, writes of the 1st law as a conspiracy "among force-free bodies to move in straight lines while being unable … to communicate … It is probably fair to say that anyone who is not amazed by this conspiracy has not understood it." He asks "by what mechanism is the rod or clock informed … as to what this [spacetime] structure is?" (Brown 2005; p.8, pp.12-13) Again (24) "it cannot simply be in the nature of free test particles to 'read' the projective geometry, or affine connection…"

Of course not. If my earlier arguments are good, free rods and clocks know nothing, feel nothing, 'read' nothing, *do* nothing. Their natures are completely irrelevant. Were there unextended free fall (float) strict particles, they would do the very same thing in one spacetime as they do in any other: they stay put, do nothing. They simply endure. Their worldlines extend along zero acceleration, causal default, trajectories without benefit of nudge or communication. Spacetime structure relates Galileo trajectories to each other: curvature is their deviation. That the field equation entails the law of motion in GR is a significant *formal* result. But it can't tell us what guides the point particles, since nothing can guide them. These are zero acceleration trajectories and can't be steered, guttered or grooved.

Nothing in my discussion suggests that we should know the causal default state *a priori*. My colleague, Greg O'Hair suggested that it might have been a random spatial walk. It is an *empirical, theoretical* fact that the causal default is a spacetime straight. The identities cited before are also empirical and theoretic. That makes perfect sense within a contingent geometry and mechanics. I claim that it is *satisfactory*. It is not causal.

6 Conclusion

Finally, there are two bits of unfinished business. Identity arguments are powerless to settle two remaining problems. (i) They can't relate geometric structure in one spacetime region to that in another nearby region. But I do not think that is a causal relation either; (ii) Plausibly, if spacetime can't act causally on matter then matter can't act causally on spacetime. Identity arguments look impotent to tell us how matter is related to spacetime in that direction. The field equation is not an identity. Nevertheless, it is not causal either, but an equation of mutual constraint. (See Geroch 1978, p 174, 176). One aspect of the identity of gravitational with inertial mass is that GR need only consider inertial mass. The left hand side of the field equation need not be taken as a source term. This thought needs long and careful reflection on the relation between curvature of spacetime, gravitational potential energy and the mass of curved, empty spacetime and more. That is the topic of another paper – or two or three. Further, we can't set up matter and then see what happens to spacetime; nor vice versa. Indeed, it is perhaps more common to specify a metric, then look for a suitable matter tensor. So these things don't smell causal. But I hope there is something better to say about the problem than that.

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