Untranslated appendix to *Philosophie der Raum-Zeit-Lehre*

"Weyl's Extension of the Riemannian Concept of Space and the Geometrical Interpretation of Electricity". (1928)

Has never been translated into English.
→ worse: the German text has not been in print for over 70 years!

Topics:
- o A critical assessment of Weyl's unified field theory;
- o The use of an antisymmetric affine connection, i.e. torsion;
- o Torsion employed in a new attempt to geometrise electromagnetism;
- o The relation between visualisability and geometrisation;
- o … .

I rely heavily on work (2021) by Marco Giovanelli, who reintroduces the Appendix to the English-speaking world.

Anhang.

Die Weylsche Erweiterung des Riemannschen Raumbegriffs und die geometrische Deutung der Elektrizität.

§ 46. Problemstellung. Wir geben im folgenden eine Darstellung der Weylschen Erweiterung des Riemannschen Raumes, da dieser Gedankenkreis eine große Bedeutung für die Weiterführung der Relativitätstheorie erlangt hat. Diese Darstellung wird sich insofern von der Darstellung dieses Buches unterscheiden, als sie den mathematischen Aufbau etwas ausführ-

Hans Reichenbach (1928). "Anhang: Die Weylsche Erweiterung des Riemannschen Raumbegriffs und die geometrische Deutung der Elektrizität." In *Raum und Zeit,* pp. 331-373.
Giovanelli, Marco (2021). "'Geometrization of Physics' vs. 'Physicalization of Geometry.' The Untranslated Appendix to Reichenbach's *Philosophie der Raum-Zeit-Lehre*."

Unified field theory and geometrisation

Reichenbach's geometrisation of electrodynamics

But what could be the body under the cloak?

Reichenbach's factual dynamical approach

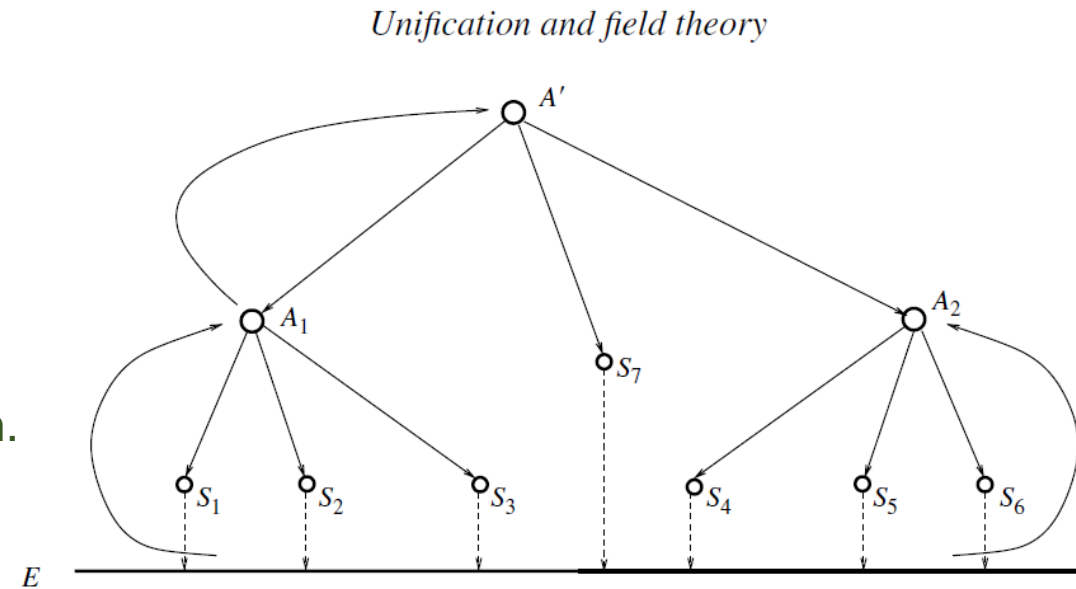# Geometrisation and the unified field theory programme

Einstein's success with general relativity (GR): gravity not seen as a **force**, but as a manifestation of **curvature.**

This prompts a 1920s research programme to **geometrise the electromagnetic field.**

These are the first attempts at a unified field theory.

Key figures: Weyl, Eddington, Cartan, Einstein – and Reichenbach.

But Reichenbach is skeptical about the realistic interpretation of 'geometry' – but not for the well-known reasons

Unification and field theory

Vizgin, Vladimir P. (1989). "Einstein, Hilbert, and Weyl: the genesis of the geometrical unified field theory program."
van Dongen, Jeroen (2010). *Einstein's unification.* (Figure from p. 60, the combination of two Solovine schemas).

"Do not mistake the cloak for the body"

Reichenbach: "The geometrical interpretation of gravitation is merely the visual cloak *[anschauliche Gewand]* in which the factual assertion is dressed. It would be a mistake to confuse this cloak with the body it covers; rather, we may infer the shape of the body from the shape of the cloak which it wears. After all, only the body is the object of interest in physics. Anything beyond that is added by the imagination and constitutes picture-thinking. "*

* Appendix, pp. 353-354: […] die geometrische Deutung der Gravitation ist nur das anschauliche Gewand, in welches die Tatsachenbehauptung gekleidet wird. Man darf nicht das Gewand für den Körper halten, der darunter steckt; sondern man darf nur aus der bestimmten Form des Gewandes auf die Form des Körpers schließen, der es trägt. Aber erst dieser Körper ist das Objekt der Physik. Alles Weitere ist Zutat der Phantasie, ist Veranschaulichung.

"Do not mistake the cloak for the body"

Reichenbach: "The geometrical interpretation of gravitation is merely the visual cloak *[anschauliche Gewand]* in which the factual assertion is dressed. It would be a mistake to confuse this cloak with the body it covers; rather, we may infer the shape of the body from the shape of the cloak which it wears. After all, only the body is the object of interest in physics. Anything beyond that is added by the imagination and constitutes picture-thinking. "*

Giovanelli's take: Reichenbach sees Einstein's General Relativity not as the start of a programme to "geometricise physics", but as the end of a "physicalisation of geometry".

How does Reichenbach argue for this?
→ Straightforward option would be: *de-geometrise* GR
→ But no! Reichenbach takes the option to *geometrise* electrodynamics

Goal: show that differential geometry is just mathematical reformulation:
a *cloak* covering the physical goings-on!

Following Weyl's attempt to geometrise electrodynamics, but
  i.   via torsion
  ii.   not via metric incompatibility
  (Note the parallel with modern-day "Geometric Trinity of Gravity".)

Reichenbach successfully reproduces the electromagnetic force. Thus:

"The operation or displacement therefore offers nothing but a geometrical presentation of this Law, i.e. a visualisation, not a new physical idea."*

Slightly artificial: a different affine connection per value of electric charge.

$$\mu \frac{du^\tau}{ds} = -\begin{Bmatrix} \mu\nu \\ \tau \end{Bmatrix} u^\mu u^\nu - \rho f_\nu^\tau u^\nu .$$

charge

$$g^{\mu\nu} f_\nu^\tau = f_{\mu\nu}$$

Christoffel symbols

electromagnetic field strengths

Giovanelli, Marco (2021). "'Geometrization of Physics' vs. 'Physicalization of Geometry.' p. 14.
Giovanelli, Marco (2016). "'…But I still can't get rid of a sense of artificiality': The Reichenbach–Einstein debate on the geometrization of the electromagnetic field."
* Appendix, p. 365: Die Verschiebungsoperation ist also lediglich eine geometrische Einkleidung dieses Gesetzes, eine Veranschaulichung also, aber kein neuer physikalischer Gedanke.

Not Newton's gravitational field! → GR makes novel predictions.

Is Reichenbach hinting at an unconceived/underdeveloped alternative?

Candidates:
- **Teleparallel gravity?** Using a flat but torsionful connection → but also geometric;
- **Whitehead (1922) gravity?** Gravitational time-delay → but today falsified;
- **Spin-2 gravity?** Expand around a Minkowski metric and interpret h as dynamical:

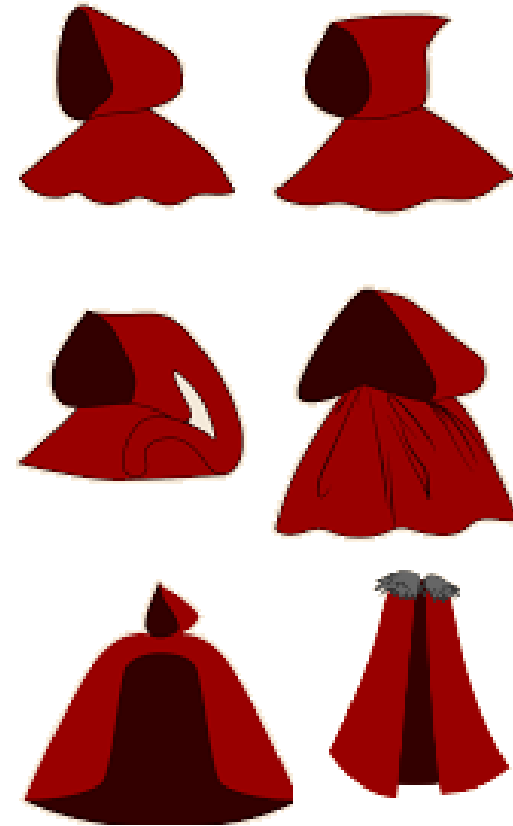$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \,, \qquad \|h_{\mu\nu}\| \ll 1 \,.$$

Rather:
- ➢ choose by convention a flat background;
- ➢ then use the (in)famous universal forces from Reichenbach's own approach.

In line with Giovanelli (2021): Appendix puts "relativity of geometry" approach into context.

But it prompts the question: why bother with this at all? My answer:
    (A) Reichenbach identifies **explanatory power** in the dynamics;
    (B) The visual *a priori*: tricks to *train* geometric **visualisation**.

Different cloaks betraying different bodies

Not Newton's gravitational field! → GR makes novel predictions.

Is Reichenbach hinting at an unconceived/underdeveloped alternative?

Candidates:
- **Teleparallel gravity?** Using a flat but torsionful connection → but also geometric;
- **Whitehead (1922) gravity?** Gravitational time-delay → but today falsified;
- **Spin-2 gravity?** Expand around a Minkowski metric and interpret h as dynamical:

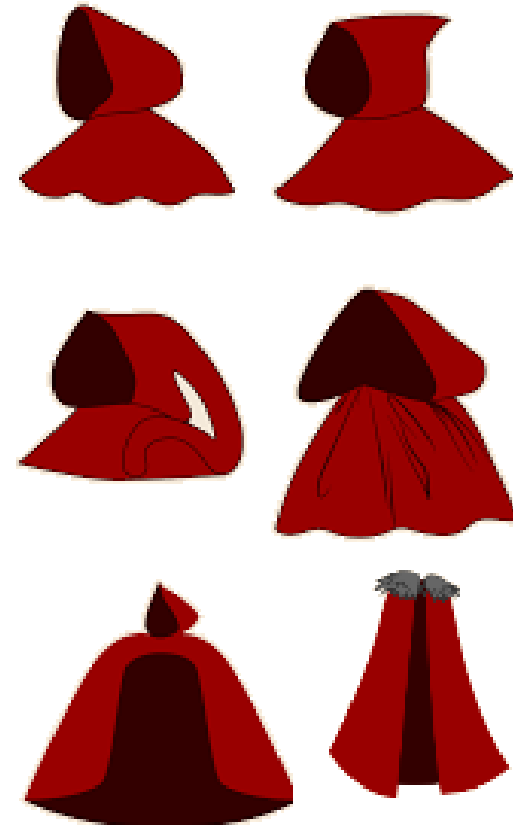$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} , \qquad \|h_{\mu\nu}\| \ll 1 .$$

Rather:
➢ choose by convention a flat background;
➢ then use the (in)famous universal forces from Reichenbach's own approach.

In line with Giovanelli (2021): Appendix puts "relativity of geometry" approach into context.

But it prompts the question: why bother with this at all? My answer:
    (A) Reichenbach identifies **explanatory power** in the dynamics;
    ~~(B) The visual *a priori*: tricks to *train* geometric **visualisation**.~~

Different cloaks betraying different bodies

Dynamicism vs. Geometricism (1/2)

What explains relativistic effecs? For example the twin effect?

Geometricists:

- Spacetime structure explains observable physical effects.

- Frame-dependent notions are suspect, not explanatory.

- 'the stationary twin is on a straight trajectory, while the traveling twin is on a bent trajectory.'

Spacetime structure ——— Explains? ———→ Dynamical laws

Constructive explanation?

Behaviour of physical bodies

Read, James (2023). *Special Relativity,* p. 62.
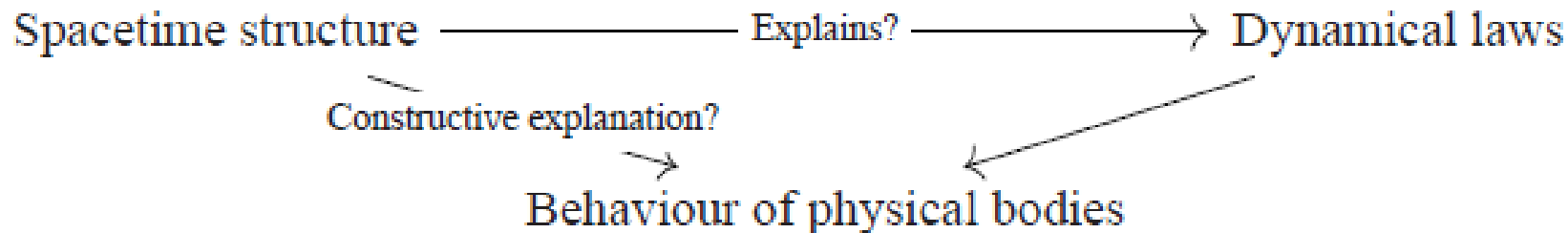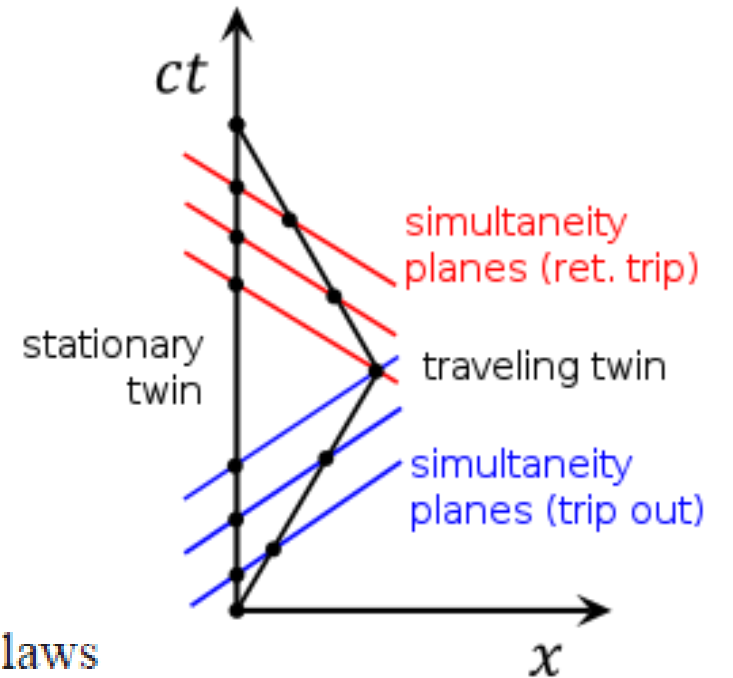
Dynamicism vs. Geometricism (2/2)

What explains relativistic effecs? For example the twin effect?

Dynamicists:
- Spacetime is merely a codification of dynamical symmetries of matter.

- Frame-dependent explanations are valid, even though they look differently in different frames.

- 'there is a double effect of time dilation with respect to the stationary twin's rest frame: outbound trip and return trip.'
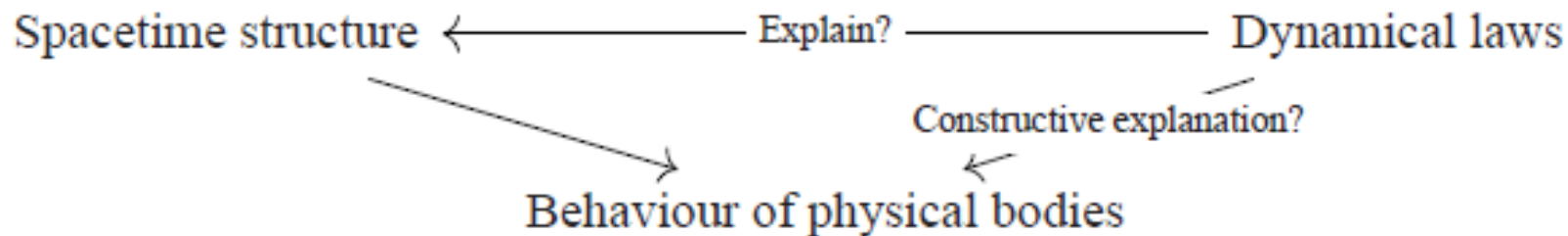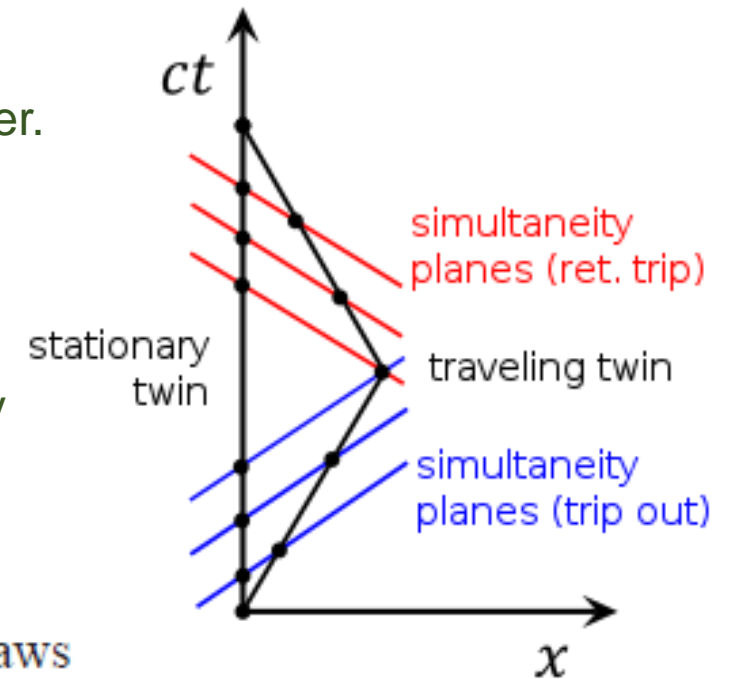
Read, James (2023). *Special Relativity,* p. 62.

Reichenbach accepts geometry as real…

"The geometrical interpretation of gravitation is [...] the expression of a real state, [an expression] for the actual influence of gravitation on measuring rods and clocks; therein lies its physical value." *

"If we think of a Riemannian space and with its special relations of congruence, instead of thinking of a field of force, this is a permissible representation of the gravitational field. But one cannot say it is a necessary one." **

…but denounces geometry as explanatory: a mere visual cloak.

➢ A codification of dynamical fact?

Strikingly different from Weyl (1921), who takes the differential geometry to reflect the "World Geometry".

Einstein even more of a deflationist about 'geometrisation' (cf. Lehmkuhl 2013): even 3-vectors count!

* Appendix, pp. 352: Die geometrische Deutung der Gravitation ist also der Ausdruck für einen realen Sachverhalt, für den realen Einfluß der Gravitation auf Uhren und Maßstäbe; darin liegt ihr physikalischer Wert.
** Appendix, pp. 352-353: Wenn wir, anstatt in ein Kraftfeld zu denken, uns einen Riemamischen Raum mit seinen besonderen Kongruenzverhältnissren vorstellen, so ist dies eine erlaubte Darstellung des Gravitationsfeldes; aber man kann nicht sagen, daß sie notwendig ist."."
Lehmkuhl (2014). "Why Einstein did not believe that General Relativity geometrizes gravity."
Einstein, Albert (1921). "Geometry and Experience."

Reichenbach prioritises dynamics as the "actual effect" [*realen Einfluß*]:

> "The field of force of gravitation affects the behavior or measuring instruments. Besides serving in their customary capacity of determining the geometry of space and time, they serve, therefore, also as indicators of the gravitational field. The geometrical interpretation of gravitation is consequently an expression of a real situation; namely, of the actual effect of gravitation on measuring rods and clocks." *

What needs to be explained is the congruence of all measuring devices.
→ A force can serve as a common-cause explanation!

The key notion is **causality:** causal relations are not conventional, but factual.

Comparison:
- dynamicists reduce chronogeometric effects to symmetries of the dynamical laws;
- Reichenbach reduces chronogeometric effects to causal facts of the dynamics.

* Appendix, p. 352: Das Kraftfeld der Gravitation ist von Einfluß auf das Verhalten der Meßkörper; diese, die sonst zur Ermittlung der Geometrie von Raum und Zeit dienen, werden deshalb zugleich zu Indikatoren des Gravitationsfeldes. Die geometrische Deutung der Gravitation ist also der Ausdruck für einen realen Sachverhalt, für den realen Einfluß der Gravitation auf Uhren und Maßstäbe; darin liegt ihr physikalischer Wert.

Bibliography

Brown, Harvey R. **(**2005). *Physical Relativity: Space-Time Structure from a Dynamical Viewpoint*. Oxford: Oxford University Press.

Brown, Harvey R**.** & James **Read** (2021). "The Dynamical Approach to Spacetime Theories." In *The Routledge Companion to Philosophy of Physics*. Routledge. First edition. [Here]

Einstein, Albert (1921). "Geometry and Experience." In *Beyond Geometry. Classic Papers from Riemann to Einstein*, pp. 147-157. Edited by Peter Pesic. Dover Publications. [Here]

Giovanelli, Marco (2016). "'…But I still can't get rid of a sense of artificiality': The Reichenbach–Einstein debate on the geometrization of the electromagnetic field." *Studies in History and Philosophy of Modern Physics* **54**, pp. 35-51. [Here]

Giovanelli, Marco (2021). "'Geometrization of Physics' vs. 'Physicalization of Geometry.' The Untranslated Appendix to Reichenbach's *Philosophie der Raum-Zeit-Lehre*." In *From Philosophy of Nature to Physics: Logical Empiricism and the Natural Sciences*. Routledge. First edition (38 pages). [Here]

Lehmkuhl, Dennis **(**2014). "Why Einstein did not believe that General Relativity geometrizes gravity." *Studies in History and Philosophy of Modern Physics* **46**, pp. 316-326. [Here]

Maudlin, Tim (2012). *Philosophy of physics: Space and time*. Princeton University Press.

Mulder, Ruward & James **Read** (2023). „"Is spacetime curved?: Assessing the underdetermination of general relativity and teleparallel gravity." *Under review*. [Available on request]

Norton, John D. (2008). "Why constructive relativity fails." *British Journal for the Philosophy of Science* **59** (4), pp. 821–834. [Here]

Read, James **(2023).** *Special Relativity.* Cambridge Elements: Elements in the Philosophy of Physics. Edited by James Owen Weatherall.

Reichenbach, Hans (1928, 1957, 2014). *Philosophie der Raum-Zeit-Lehre*. Berlin and Leipzig: Walter de Gruyter. And *The Philosophy of Space & Time*. New York: Dover Publications. [Here]

Reichenbach, Hans (1928). "Anhang: Die Weylsche Erweiterung des Riemannschen Raumbegriffs und die geometrische Deutung der Elektrizität." In *Philosophie der Raum-Zeit-Lehre,* pp. 331-373.

Salimkhani, Kian (2020). The dynamical approach to spin-2 gravity. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* **72**, pp. 29-45. [Here]

van Dongen, Jeroen (2010). *Einstein's unification*. New York: Cambridge University Press.

Vizgin, Vladimir P. (1989). "Einstein, Hilbert, and Weyl: the genesis of the geometrical unified field theory program." In *Einstein and the History of General Relativity*. Edited by Don Howard & John Stachel. Birkhäuser.

Weyl, Hermann (1923, 2013). "World Metrics as the Origin of Electromagnetic Phenomena." In *Space Time Matter,* pp. 282-295. METHUEN & CO. Translated by Henry L. Brose.