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Essay Review

Material History and Imaginary Clocks: Poincaré, Einstein, and Galison on Simultaneity

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Peter Galison, *Einstein's Clocks, Poincaré's Maps: Empires of Time*. New York: W. W. Norton & Company, 2003, 389 pages. $23.95 (cloth).

Over the decades, students of physics as well as laypersons have wondered: how did Einstein's theory of relativity originate? Where did it come from? Accordingly, historians, philosophers, and psychologists have pursued various lines of inquiry and uncovered many significant roots. Nonetheless, fascination and puzzlement on the question has persisted, and thus many writers have advanced conjectures and plausible scenarios trying to reconstruct details of Einstein's creativity. Among such accounts, some have focused on Einstein's childhood, others on his philosophical interests, others on his wife and family, some on aesthetics, and still others on the physics. Now, in *Einstein's Clocks, Poincaré's Maps*, we find the most comprehensive study of the technological context in which relativity theory took form.[1]

Previously, it might have seemed rather fortunate that the young Albert Einstein succeeded in advancing the frontiers of physics even though he worked in a seemingly inappropriate and isolated location: not at a leading center of scientific research, but at the Federal Office of Intellectual Property in Bern, Switzerland. Snubbed by universities, Einstein had to settle for a job as a civil servant, evaluating patent applications for practical and commercial devices far removed from his interests in theoretical physics. But wait. Einstein based his relativity theory on a procedure for the synchronization of clocks – and *that* was a field of intense activity for engineers, clockmakers, telegraphy experts, and railroad workers. Switzerland was a center of innovation on timing technologies, clocks were a matter of national and cultural pride. Was it incidental that in his famous relativity paper of 1905, Einstein defined and illustrated the concept of time by writing about clocks and a train?

In *Einstein's Clocks, Poincaré's Maps*, Peter Galison traces connections between the technoculture of time coordination and the emergence of modern physics. His book is a nice introduction to the history of modern timekeeping practices, the unification of

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time zones, the establishment of standard metric measures, and the determination of longitude. It stems partly from much original research, as well as from earlier works in the history of science, and various works on the history of telegraphy, longitude, and timekeeping, such as Ian Bartky's *Selling the True Time: Nineteenth Century Timekeeping in America* and Derek Howse's *Greenwich Time and the Discovery of the Longitude*.[2] A few other writers had suggested or explored connections previously between Einstein's job as a patent officer and his formulation of special relativity, including Albrecht Fölsing and William R. Everdell.[3] Most recently, historian of physics Arthur I. Miller explored the subject,[4] and a year earlier, Galison published a preliminary study as well.[5] (Both claim their works are independent.) Now Galison's new book is, by far, the most extensive and systematic study of the matter.

We learn not only about the Swiss culture of clocks and the patent applications for electromechanical timekeeping devices that were processed at the office in Bern, but also about developments across Europe, America, and beyond. Astronomers in observatories sold time to cities and businessmen. The competing time measures of the French, British, and American empires stretched out along railroad lines and transatlantic underwater telegraphic cables. City times reached out to distant towns and colonies, chasing away "local times." Politicians and engineers labored to unify time. Meanwhile, in The Netherlands, the theoretical physicist H. A. Lorentz invented a mathematical fiction that he called "local time" to simplify his theory of the dynamics of electrons moving through the intangible ether. We find the prominent French mathematician Henri Poincaré moving from the depths of coal mines to the presidency of the French Bureau of Longitude as he labored to solve engineering problems and improve timekeeping conventions. Like peace and war, standards of length, weight, time, and electrical power were established by convention. Poincaré led attempts to decimalize time. Also, he interpreted Lorentz's fictitious local times as the actual measures of time given by conventional procedures of clock synchronization. Thus, Galison's narrative moves back and forth between concrete things, like iron railways and electrical machines, and abstract conceptions such as Einstein's relativity.

Galison has studied the subject of time coordination from a broad perspective. He explains that his exploration concerns the development of kindred conceptions of modernity at the crossing points of metaphysics and machines. But don't be put off, the book is rather light on metaphysics.[6] It is mainly about the entwinement of concepts and devices. Note also that the focus of the book is not the history of relativity physics. The author, Mallinckrodt Professor for the History of Science and of Physics at Harvard University, is quite capable of writing such a comprehensive book, but that was not his aim here.

Nevertheless, the book's contents pose a provocative challenge to our understanding of the origins of Einstein's theory. Having unearthed plenty of historical material to argue that the Swiss technocultural context was of importance comparable to other influences in Einstein's creativity, Galison yet abstains from estimating its relative importance. One reviewer of the book complains that, "The inevitable question is then to decide what weight to attach to these different factors, and Galison refuses to address the matter."[7] It is fine for any author to freely choose what main subjects to pursue; nonetheless, afterwards readers may want more, or even less: such as a plain accounting.

So we may ask the question: to what extent do we have evidence that the emergence of relativity theory was precipitated by technocultural factors?

Galison himself is not very interested in old-fashioned questions of priority and historical causation. He would much rather have us focus on how physical, technological, and philosophical perspectives converged on the problem of the coordination of time. Indeed, what interests him most about the historical episode on the coordination of time is the stage at which ideas and materials from diverse fields interact mutually in many directions. In an interview, as in person, he points out, for example, that by 1899 Poincaré was simultaneously concerned with the concept of simultaneity in all three fields: physics, philosophy, and technology, in such a way that none of the three drove the others.[8] So it might then seem that in the case of Poincaré, and for Einstein as well, these diverse avenues of influence intersected simultaneously.

But we must be careful, at any rate, not to infer that in the mind and work of any individual the diverse fields of influence converged, by coincidence, at the same time. In the case of Poincaré, the extant evidence doesn't support that inference. Rather, it suggests a sequence of developments wherein knowledge from one field was transposed to another. Poincaré begins to act as member of the French Bureau of Longitude in 1894, and is thus closely exposed to the kinds of discussions about clock synchrony that appeared often in the *Annales du Bureau des Longitudes*. Only later, in 1898, does he publish a somewhat philosophical paper on the problem of measuring time, in the *Revue de Métaphysique et de Morale*. And only afterwards, in 1900, does he begin to publish on the interpretation of Lorentz's local time as the time given by moving clocks synchronized with light signals. So, the chain of influence, at least on the evidence reviewed by Galison, seems to go clearly *from* technological problems, *to* abstract philosophical considerations, *to* specific applications in theoretical physics.*

More generally, regarding clocks, we have to assume that both Poincaré and Einstein must have become acquainted with the everyday practical matter of synchronization, at very early ages, before they even wandered to physical or philosophical discussions about time. So there is a sense in which the technological question of synchrony presumably entered their minds first. But this is of course negligible because it happens in this way with almost anyone.

The argument that Galison makes, by contrast, is strong: that both Poincaré and Einstein were in positions that gave them a privileged and intense acquaintance with questions of timing technologies, alongside questions of time in physics and philosophy. And this is certainly a good argument. It is indeed remarkable that the two most important individuals in the genesis of special relativity (aside from Lorentz) were both well

* We care about causal sequences because part of the historical effort to understand the past consists in trying to identify factors, notwithstanding our predilections, that contributed to or deterred the evolution of concepts, practices, and works. Without trying to clarify such chains and webs of influence, one may foster the illusion that certain key events transpired by coincidence, by some sort of noncausal convergence. Incidentally, this kind of explanation was explored by the psychologist Carl Jung, who called it "synchronicity." But if we can infer historically, at least to some extent, how events triggered one another, one need not settle for opaque coincidences, nor posit paranormal connections.

positioned in what Galison calls the “triple conjunction” of technology, physics, and philosophy. It thus seems that their conceptual innovations regarding the plasticity of the notion of time incorporated and responded to concerns in each of three fields.

The notion that time is determined by conventions, in Poincaré’s works, clearly flowered under the joint influence of mathematical, technological, physical, and philosophical concerns, and Galison does a good job of tracing such interconnections. Poincaré was engaged in discussions about conventional aspects of mathematics, especially pertaining to the validity of non-Euclidean geometries. He was at home with discussions about physical time, both in general discussions about the foundations of mechanics, and in the specific works on electrodynamics of Lorentz and others. And yes, he was involved in philosophical and engineering circles that pondered questions about time both abstractly and concretely.

Some of Galison’s arguments, however, can be polished a bit further. For example, consider the question of the significance of the delay of electrical transmissions, in Poincaré’s works. Galison was surprised to find, contrary to his expectations,[9] that the transmission delay of telegraphic signals was not just a *theoretical* necessity for exact timekeeping, as explained by Poincaré in his 1898 paper, but was actually taken into account routinely by surveyors and mapmakers in the late 1800s. Galison argues that Poincaré must have been acquainted with such practices owing to the reports at the Bureau of Longitude. After all, in his paper of 1898 he specifically mentioned the telegraphic determination of longitude. But note that in that connection Poincaré immediately commented that, “In general, the duration of the transmission is neglected and the two events are regarded as simultaneous. But, to be rigorous, a little correction would still have to be made by a complicated calculation; in practice it is not made….”[10] So, the correction in question appears explicitly in Poincaré’s account less as a practical than a theoretical concern. Nevertheless, Galison rightly highlights the intimate connection between Poincaré’s conventional-theoretic notion of time and the practical chronometric questions of the day.

Galison’s parallel argument, regarding Einstein, is less effective. On the one hand, Galison locates the emergence of Einstein’s special relativity in the triple intersection of physics, technology, and philosophy; so it would seem that all three had roughly equal importance in that development. On the other hand, the great bulk of Galison’s line of research, and hence his book, focuses on the technocultural dimension. Thus there is an uneasy tension between the centrist perspective and the drift of the narrative.

Einstein’s crucial thoughts seem to originate in the concrete technologies around him, as Galison claims that Einstein “constructed his abstract relativity machine out of a material world of synchronized clocks.”[11] Galison seems to imply that the technocultural influence was preeminent in turning Einstein’s interests to the question of time: “Before he stepped into the patent office [in June of 1902], he left not the slightest clue that he had any interest in clocks, time, or simultaneity.”[12] Oh, but note, we know some things about Einstein’s earlier interests. For example, he had already read Ernst Mach’s *Die Mechanik*, a book recommended to him by his friend Michele Besso, which he greatly enjoyed. There Mach insistently criticized the ordinary concept of time and denounced absolute time as a useless metaphysical conception. Also, even earlier, Einstein's favorite philosopher had been Immanuel Kant, who had written much about the notions of temporal succession, duration, and simultaneity. Kant denied the absolute existence of time, contra Newton. Moreover, Einstein also was acquainted with works of Arthur Schopenhauer, another philosopher who likewise denied the absolute existence of time, emphasized its subjective origins, and made significant use of the notion of simultaneity. Such examples suggest that perhaps Einstein could have had some interest in the question of time prior to his job at the patent office.[13]

Besides, Einstein himself left no written statement even implying that he became increasingly interested in time because of any timing technologies at the patent office. By contrast, he explicitly acknowledged the crucial influence of Mach and the philosopher David Hume. So what? Does it now seem that Einstein's early interests in questions about time may have stemmed first from philosophy? Likewise, consider one clear early influence in the case of Poincaré, also in a Kantian vein. Galison himself reminds us that in the middle 1880s Poincaré was encouraged, by Auguste Calinon, to ponder the importance of relying on sensations to judge the simultaneity of events. So it then seems that both for Einstein and Poincaré we have good reasons to suspect that their early interests in questions about time in general, and simultaneity in particular, stemmed from, say, abstract psychophysical or philosophical literature.

Still, a narrower question about the genesis of relativity theory concerns the extent to which Einstein's ideas in 1905 were precipitated by technocultural factors. It is plausible to surmise that Einstein's active functions in a work environment that involved some analysis of contemporary timing technologies helped to move him in the direction of analyzing the notion of time. Galison develops this conjecture by highlighting several significant points. For example, Einstein acknowledged, in hindsight, that his work at the patent office provided a stimulus for physical thoughts. Also, during his years on the job, the number of patent applications for electrically controlled and coordinated clock systems grew (as did applications in other electrical technologies). In 1904, for example, fourteen such patents were approved at Bern, and some may well have lingered on Einstein's desk. Meanwhile, some innovators in Europe and America explored and discussed the transmission of time by means of wireless signals. As Einstein walked around Bern everyday he would have noticed public clocks displayed prominently. Clocks at train stations marked multiple times. By emphasizing such points just immediately prior to discussing Einstein's relativity breakthrough, Galison's narrative fosters the impression that Einstein's conceptual search culminated thanks to his Swiss electrotechnical environment.

Before telling us about Einstein's breakthrough moment, Galison mentions that Einstein moved to a residence "outside Bern's zone of unified time."[14] Did he have to adjust to a new time? No, by "unified time zone" Galison refers merely to the network of city clocks that were coordinated by electrical signals; other nearby clocks also marked the same time, though they were not wired to the network. Besides, that Einstein moved is irrelevant, because he moved after having his breakthrough moment (we have an account from Einstein himself stating that when relativity theory emerged he still lived in the heart of Bern).[15] In any case, when Einstein first conceived the relativity of time, he promptly told his friend Michele Besso. That we know. Now Galison tells us that right then, in May 1905, Einstein excitedly explained the synchronization of clocks to Besso, as they stood on a hill to the northeast of downtown Bern, by pointing at a clock tower in Bern and to the clock tower of the nearby town of Muri. This anecdote is particularly significant because it connects Einstein's breakthrough moment to the material and public technological world around him. Galison mentions it four times, and includes a map locating the hill where Einstein and Besso stood,* as well as an illustration of the church steeple at Muri to which Einstein pointed.[16] Unfortunately, this anecdote is a mistake, a misapprehension; there is no evidence that it ever happened.

Galison footnotes two sources: a biography of Einstein by Albrecht Fölsing, and the book *Einstein in Bern* by Max Flückiger.[17] Fölsing's account seems to confirm the anecdote:

> He [Einstein] was observed gesticulating to friends and colleagues as he pointed to one of Bern's bell towers and then to one in the neighboring village of Muri. Michele Besso was the first person and Josef Sauter the second to whom he explained in this manner that the synchronization of spatially separated clocks represented a problem which, properly understood, must lead to profound changes in the concept of time.[18]

But Fölsing wasn't there in 1905, so his account is not a primary source. He gives only one reference for it: a passage in Flückiger's book (the same one cited by Galison). In it, there is an account in the words of Josef Sauter, a coworker at the Bern patent office. It is a recollection voiced in 1955, when he was 84 years old, in which he recounts, among other things, how Einstein once illustrated his new definition of clock synchrony: "to pin down the ideas, he told me, let's suppose that one of the clocks is atop a tower at Bern and the other on a tower at Muri (the ancient aristocratic annex of Bern)."[19] Presumably, their conversation transpired in 1905 shortly after Einstein made his breakthrough, though we do not know for certain. But notice, no mention of Besso.

Regarding Einstein's *overall* formulation of relativity theory (not merely the definition of synchrony), Sauter claimed that Einstein said that Sauter was the second person to whom he had conveyed it. Writers thus have readily concluded that Sauter was indeed the second person to whom Einstein told of his initial discovery, while Besso was the first,** since we have an independent account by Einstein himself concerning Besso (with no mention of clock towers, by the way).[20] Moreover, Sauter inferred that Einstein first told another friend, Maurice Solovine.[21] Rather than simply disregard old

* The map of the region of Switzerland showing Bern and Muri is upside-down, so that south seems to be north, so is the hill that Galison refers to not northeast but southwest of downtown Bern? See Galison, *Einstein's Clocks* (ref. 1), p. 254.

** At the time Sauter made his statement in 1955, apparently nobody contested or confirmed it – by then Einstein and Besso had died. For slightly more on Besso and Sauter in the early days of relativity, consult an account by a leading biographer of Einstein who corresponded with them all, Carl Seelig, *Albert Einstein und die Schweiz* (Zurich, Stuttgart, Wien: Europa-Verlag, 1952), pp. 73, 75–76.

Sauter's inference, we should note that his claim of being second refers to Einstein having given him a draft of his relativity paper and specifically to the moment when Sauter read and understood it, not explicitly to any initial conversation between the two. In any case, what matters here is that there is no evidence in Flückiger's book to even suggest that at the time of discovery, as Einstein conversed with Besso, that he excitedly pointed to clock towers while standing on a hill northeast of downtown Bern.

But then why did Fölsing write that Einstein "was observed gesticulating to friends and colleagues as he pointed to … bell towers"? Perhaps it was an artifact of the biographer's attempt to construct a narrative based on his notes. A passage in Flückiger's book mentions that Einstein sometimes visited his "Freund und Kollegen" Besso, as well as Sauter, and also a coworker who lived in Muri, Friedrich Blau.[22] Flückiger also noted that it is interesting that Sauter mentioned the bell towers.[23] Perhaps as Fölsing read Sauter's account, he may have translated the gist of it from Sauter's French into German, writing that Einstein illustrated a point by referring to towers, which Fölsing later misconstrued. What may have been originally just a handwaving illustration then becomes, in subsequent interpolation, gestures pointing towards specific towers.

In any case, the apparent anecdote becomes more definite in Galison's account. The conversation now seems to transpire between Einstein and Besso according, allegedly, to Besso's own reminiscence (by the way, there is nothing in the Besso-Einstein correspondence that even suggests anything of the sort).[24] The incident seems to happen at a definite place and at the key historical moment. Subsequently, the story seems to become even more crucial, as it evolves into the kind of "Eureka!" moment of which Galison himself is weary.[25] Namely, hundreds of thousands of people can read in the Book Review section of *The New York Times* that

> In May 1905, on a hill from which he and his friend Michele Besso could see both the electrically synchronized clocks of Bern and the as yet uncoordinated clock tower of suburban Muri, Einstein realized in a flash that….[26]

Thus impressions seem to become historical facts. Who knows, maybe it all happened. But without any documentary evidence it is merely a plausible fiction.

Still, that in 1905 a church steeple in Muri was not connected to the centralized electrical time network of Bern, as Galison notes, is a somewhat interesting point. It is also interesting that on the same street as one of the houses in which Einstein lived in 1905 there is an imposing clock tower,* as pointed out by Fölsing,[27] Galison, and others. And yes, these factoids become more suggestive in light of Sauter's recollection. A couple of years ago, another writer, Dennis Overbye, influenced by Galison's initial ideas, commented that, "It would be pretty to think" that maybe Einstein's breakthrough happened one day as he walked with Besso under the great clock tower in Bern near Einstein's house.[28] Likewise, perhaps it might be pretty to imagine that Einstein had his great idea while looking at clocks at a train station. Likewise, some writ-

* The *Zytglogge* (or *Zeitglockenturm*) is a major tourist attraction of Bern, as it is as much a symbol of the city as the bear. The tower was constructed in the early 1200s, rebuilt in the 1400s, provided with an intricate clock mechanism in 1530 that still operates today, and refurbished with Baroque embellishments in 1770–1771.

ers have entertained the pretty imaginative idea that Einstein got all of the key ideas for relativity theory from his wife. But we should be careful, as Overbye does well to warn (paraphrasing a classic statement by Poincaré): "hypotheses are what historians lack least."[29]

The question is: what can we really say about Einstein's creative step?

For almost a century, philosophers, physicists, and historians of physics often have noted that one of the key roots of Einstein's special theory of relativity was his analysis of the concept of simultaneity. Einstein was distinguished by having been just about the only person to highlight the physical importance of the concept, the only other one to have done so previously, and quite similarly, being the prominent mathematician Henri Poincaré. By contrast, Galison argues that the question of simultaneity was widespread and pervasive. This is a major conclusion of his researches. Clockmakers, engineers, surveyors, astronomers, navigators, railroad officials, patent officers, and others were all concerned with the question of the synchronization of clocks. In 1905 Einstein "defined" the meaning of the concept of simultaneity in terms of a procedure for synchronizing distant clocks using light rays and taking into account the transmission delay of these signals. Similarly, Galison tells us that, in earlier years and decades, squadrons of engineers, technocrats, and plain practical men had labored to establish procedural meanings of simultaneity, involving distant clocks, astronomical observations, pneumatic pulses, electrical signals, and even wireless electromagnetic signals; often even taking account of transmission delays.

Thus, in Galison's words, mapmakers were "always" concerned with a "question of distant simultaneity," astronomers and train supervisors "cared about the rapid dispersal of simultaneity," telegraphers working on chronometry were "simultaneity men," time reformers worked on "the geography of simultaneity," railroaders and telegraphers determined "the electric enforcement of simultaneity," local time zones and standards constituted "competing simultaneities," the Atlantic Ocean was "wired for simultaneity," Naval Officers and surveyors risked their lives to "pin electrical simultaneity to the shores of the Americas, Asia, and Africa."[30] French geographers in Ecuador, trying to help measure the shape of the Earth, are described by Galison as "the simultaneity team" and "the forces of simultaneity," and likewise, Swiss clockmakers took part in "the worldwide project of electric simultaneity."[31] Therefore, simultaneity was not just the intellectual property of Poincaré in 1898 and Einstein in 1905, because long before, engineers, cartographers, physicists, and astronomers "were creating simultaneity every day of the week."[32]

Despite their suggestive power, there is something peculiar about all of these expressions. In the first place, all of these expressions are anachronistic; they are retrospective labels. For example, telegraphers in the 1800s did not describe themselves as "simultaneity men," and neither did anyone else. So what's going on? Galison systematically treats time as a fluid substance of modern cities, a commodity like water, steam, electricity, and even sewage: simultaneity was engineered, produced, advocated, negotiated, sold, dispersed, and transmitted at ever larger scales. For instance, on May 23, 1910, the Eiffel Tower "began broadcasting simultaneity," says Galison.[33] Thus before 1900 as well as after, simultaneity did not just interest a very few physicists, it was a widespread concern of many people. Wherever people struggled to establish standards of time and to synchronize distant clocks, Galison sees an active practical enterprise to establish simultaneity.

But wait. Is all talk about time and simultaneity about synchronized clocks? Are synchrony and simultaneity the same thing? The problem is precisely that they are not. The simultaneity of distant events can be determined or established without using clocks at all. Einstein himself demonstrated that one can formulate a definition of simultaneity, that is, a procedure by which to decide whether to call two events "simultaneous," without employing clocks. In his 1917 book on relativity, he argued that an observer positioned exactly midway between two distant events may identify them as simultaneous if both are seen to occur at the same time.[34] Such a procedure can be employed to verify the synchrony of distant clocks, and accordingly to adjust them. But the question of simultaneity is independent and prior to the question of clock synchrony. For example, the pointing of one clock's hour hand to three and the pointing of another clock's hour hand to twelve can be simultaneous events even though such clocks are not synchronized. A broken clock that continually happens to mark 12:34 shows the same time simultaneously with a working twelve-hour clock twice a day, yet they are not synchronized. Hence, one perhaps might say that all talk about synchrony is about simultaneity, but not *vice versa*.

Therefore, the claim to which Galison ascribes the central importance in physics, philosophy, and technology, that, "*To talk about time, about simultaneity at a distance, you have to synchronize your clocks*,"[35] is not rigorously quite right. Rather, what Einstein argued since 1905 was that all of our judgments about time are judgments about simultaneous events.[36] Since synchrony involves simultaneity, Galison tends to tighten the relationship; he tends to equate the two concepts such that whenever people tried to synchronize clocks, they appear to be investigating simultaneity. Galison follows Einstein in seeing questions of simultaneity wherever there are practical questions of clock synchrony. But whereas this can be done as an epistemological exercise, it is not the same in a historical argument. Specifically, just because people in the 1800s struggled to synchronize clocks precisely, using procedures and conventions, it does not necessarily mean that they thought that simultaneity itself had to be stipulated, created, or constructed.

Before Einstein's theory, most people thought that there exist objective, univocal matters of fact regarding simultaneity and the order of all events in time. Simultaneity or succession were relationships to be discovered or ascertained, not relationships to be stipulated by conventional deliberations. Synchrony of clocks could be established by convention, but regardless, there was supposed to be a truth of the matter about any question of whether two events are truly simultaneous, irrespective of whatever we do with our clocks or what they indicate. The distinction, as drawn by Isaac Newton and others, was between True Time and apparent, practical, approximate measures of time. Regarding the notion of simultaneity, the distinction was made clearly, for example, by a civil engineer and physicist, absent in Galison's narrative. James Thomson was the older brother of William Thomson (Lord Kelvin), and was Professor at the University of Glasgow and President of the Institution of Engineers and Shipbuilders in Scotland. In 1884 he presented a paper on the "principle of chronometry" at a meeting of the Royal Society of Edinburgh. He argued that there are ambiguous difficulties in trying to ascertain or specify the simultaneity of distant events. He admitted that the transmission time for any signal employed to coordinate times "involves an imperfection in human powers of ascertaining simultaneity of occurrences at distant places. It seems, however, probably not to involve any difficulty of idealising or imagining the existence of simultaneity."[37] Thomson realized that there was something problematic about the exact determination of true simultaneity, yet he did not conclude that this ambiguity constituted a fundamental problem for physics. Clocks could well be synchronized, approximately so, even if one did not know exact and true simultaneity.

In the late 1800s, and for centuries before, experts and laypersons who synchronized clocks were attempting to establish practical measures of time. Hence, to make sense of Galison's expressions, we may say that such people were working to establish *practical* simultaneity, and to make it correspond as closely as possible to true simultaneity.

Galison rightly points out that Poincaré and Einstein should not be seen as having invented synchrony procedures that were essentially quite common, and, we may add, readily conceivable. Nevertheless, distinctions must be clearly drawn to highlight what precisely was distinctive about the contributions of Poincaré and Einstein. Simply put, Poincaré argued that simultaneity is conventional not just in practice but *in principle*. Why? Because to ascertain the simultaneity of distant events we need to know the speed of a signal transmission, and to measure that speed we need to know simultaneity (say, by having synchronized clocks). Awareness of this logical circularity between the concepts of speed and distant simultaneity distinguished Poincaré from all those who assumed that they could know and "take into account" the delay of a signal transmission. Einstein took this insight a step further, by realizing that observers *in relative motion* may disagree about the simultaneity of distant events. Thus Einstein's key conceptual discovery was, precisely, the relativity of simultaneity.

Galison, however, writes as though Einstein's big breakthrough was the procedural definition of clock synchrony. He calls it "the last piece of the relativity puzzle," and he writes that "the recognition that synchronizing clocks was necessary to define simultaneity was the final conceptual step that led him [Einstein] to conclude his long hunt."[38] He calls clock synchronization "the crowning step in Einstein's development of the theory."[39] By the way, Einstein himself described his key contribution as "the step."* But the novel and distinctive step was not that Einstein employed a procedural definition of synchrony, but that he realized that simultaneity cannot be defined absolutely, that therefore it is relative, since it can vary among observers in relative motion.

Perhaps it is worth mentioning that the only instance where the expression "relativity of simultaneity" appears in Galison's book is in a quotation where Einstein himself characterized it as "the 'most important theorem' of the theory" of relativity.[40] The word "theorem" might suggest that the relativity of simultaneity was not a starting point of Einstein's new conception, but a consequence logically derived from the the-

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* According to Abraham Pais, "When I talked to him [Einstein] about those times of transition, he expressed himself in a curiously impersonal way. He would refer to the birth of special relativity as 'den Schritt,' the step." See Abraham Pais, *"Subtle is the Lord…" The Science and the Life of Albert Einstein* (New York: Oxford University Press, 1982), p. 163. Notice that Einstein's statement does not single out the synchronization of clocks.

ory afterwards. In textbooks, the relativity of simultaneity is indeed often and properly presented as a theorem. But we know from several sources that for Einstein the ordering of axioms, definitions, and theorems in the finished theory did not correspond to the order in which he conceived or adopted them. For example, in his seminal 1905 paper, Einstein demonstrated that simultaneity is relative in an argument that served as the transitional rupture between the classical notion of time and his new concepts, *before* deducing the core equations of his theory. Likewise, in his 1917 book, where Einstein presented his ideas "on the whole, in the sequence and connection in which they actually originated," he demonstrated the relativity of simultaneity as the critical juncture that entails the new theory.[41]

Summing up, technologies that synchronized *stationary* clocks, varied and widespread as they were for centuries, are not obviously connected to the relativity question, partly because one must consider systems in relative motion. Moreover, even when scientists or navigators considered bodies in motion, such as a ship transporting chronometers, the relativity of simultaneity did not obviously follow; far from it, since most anyone would imagine that under perfect circumstances such transported clocks would keep the same time as clocks at rest.[42] Only by conceiving of determinations of simultaneity as determined by electromagnetic signals in empty space did Einstein realize that he could dispense with the traditional notion of an invariant simultaneity.

And what about trains, railroad tracks, and stations? Essential in Einstein's theory are systems in uniform rectilinear motion (that is why the theory is called "special" or restricted), and appropriately, not only did he mention a train in his 1905 paper, but he sometimes used the illustration of trains when presenting the theory later, especially in his book of 1917. It seems reasonable to infer that the imagery of trains was an early and useful staple in Einstein's thought processes. And the Bern train station was just a short walk away from the patent office. Was that a material origin of Einstein's ideas? Who knows, perhaps it helped. What we do know for certain is that actual trains were not the only source from which a physicist might be led to employ trains in his arguments. Just as *physicists* often referred to clocks, they also referred to trains by the late 1800s. This must be noted because otherwise it might seem entirely outstanding that Einstein mentioned a train in his new kinematics of 1905. But the imagery of trains was already quite common, especially in the science of motion. In particular, in plenty of presentations of kinematics, the train had replaced the age-old image of a ship cruising on calm waters as a key way of illustrating both uniform rectilinear motion and the relativity of motion.

Return now to the question of the intersection of physics, technology, and philosophy. Did Einstein really solve the conceptual puzzles of electrodynamics and optics owing to an expert acquaintance with new timing technologies? Someone might imagine that perhaps he did, but there is just too little evidence to confirm the conjecture. In an interview, Galison himself admits that:

> Material relations do not eject ideas or produce ideas like ripples on the surface of deep-flowing currents. And here coordinated clocks did not cause Einstein to introduce the synchronizing procedure. Telegraphic longitude mapping did not force Poincaré to the simultaneity procedure.[43]

Still, we can further extend the circumstantial evidence that Galison has assembled, by identifying additional bits.* For instance, in 1921 Einstein's first biographer reported that for Einstein there existed "a definite connection between the knowledge acquired at the patent office and the theoretical results which, at that same time, emerged as examples of the acuteness of his thinking."[44] Interesting. Consider also Einstein's good friend, Besso. Galison mentions him in only six pages of his book, four of which each separately state the apparent anecdote that Einstein explained clock synchrony to Besso by pointing to clocks on the towers of Bern and Muri. Instead, good use can be made of Besso to advance the technological argument. For example, Galison could well have emphasized that Besso was a coworker at the patent office with Einstein (the only point in the entire book when this even comes up is at the very end, in a quotation by Einstein pertaining to Besso's death, where the reader may infer that they were coworkers). Likewise, Galison could have stated that Besso had studied at the Polytechnikum in Zurich (like Einstein), and that he there trained as a mechanical engineer. Also, Besso soon had gained professional experience as a consultant on electrical engineering. Moreover, Besso later claimed that it was he who, "as an electrotechnician," originally highlighted to Einstein the importance of electromagnetic induction for the questions of relative motion.[45] Accordingly, Galison would have done well to mention that Einstein thanked Besso, and only him, in his 1905 paper. (Thus, a historical fact that writers often throw into accounts of the birth of special relativity, like a bit of trivia, acquires a greater significance in the context woven by Galison.) Hence, one might perhaps say that the midwife of special relativity was, say, neither a physicist nor a philosopher, but an engineer and expert colleague at the Swiss patent office. Moreover, Galison's centrist agenda is even helped by noting that though Besso was an engineer by profession, he had strong and active physical and philosophical interests. In sum, whereas some of Galison's arguments may erode by paying closer attention to historical details, others can be strengthened.

But despite such limited bits of evidence, there remain additional and necessary considerations that undermine any presumed crucial importance of the technocultural factors. For example, in his seminal 1905 paper Einstein explicitly described his clock syn-

* In "searching" for any historical evidence one must be very careful. Expectations can bias interpretations. One must be especially careful when relying on translations. For example, the original German of Einstein's 1905 paper uses only the word *Uhr* for clock, whereas Arthur I. Miller's English translation, for example, uses two words, "watch" and "clock," suggesting more technocultural texture than there is in the original; see Arthur I. Miller, *Albert Einstein's Special Theory of Relativity: Emergence 1905 and Early Interpretation 1905–1911* (Reading, Mass.: Addison-Wesley, 1981), p. 393. Likewise, Galison repeatedly refers to a train station when discussing Einstein's thoughts and his 1905 paper, whereas the word "station" is absent from the original paper; it is but an inference from Einstein's mention of the arrival of a train. As another example, in the English translation of the biography by Fölsing we find repeatedly that Einstein fondly remembered his days at the "temporal monastery" of the patent office; see Fölsing (ref. 3), pp. 102, 105, 220. Does the expression "temporal monastery" suggest that Einstein viewed the patent office as a place where he studied timing technologies religiously? No, it is a mistranslation of Einstein's expression *weltliches Kloster*, which literally means "worldly cloister" or, say, "secular monastery," a secluded place where employees worked on mundane technical things.

chrony procedures as "physical (thought) experiments."* If he had taken them from actual contemporary practices, then why did he not present them as such? Also, Einstein once reminisced to Besso as though their discussions at the workplace were rather separate from their official duties: "I can find nothing wrong in that, in the office, once in a while, sensible things were discussed, for which the State had not directed its resources."[46] Likewise, Sauter too spoke as though Einstein's theoretical activities were somewhat separate from his patent duties: "Happily, the fulfillment of his daily duties at the federal Bureau did not prevent Einstein from dedicating his nights to the scientific researches for which he was born."[47] Such points are subtle. But above all, neither Einstein nor his colleagues wrote about any connection between his formulation of his theory and any timing technologies.

Throughout the decades, Einstein made many comments and declarations concerning the origins of relativity theory. He was interviewed by biographers, psychologists, historians, physicists, journalists, and others. He voiced many details to friends, family members, and even to the public at large. We also have letters and recollections by his colleagues and contemporaries. Thus, we know of so many clear-cut influences that it would take us too far afield to review them here. To mention just a few as examples, some of the major influences, among many others, were: Lorentz's work on electrodynamics, the ether-drift experiments, a key experiment by Fizeau, the admittedly crucial writings of Hume and Mach, and to some extent, those of Poincaré.

And hence we return to Poincaré. Whereas we lack evidence to claim that Einstein's insights stemmed from his technocratic functions, we know at least that he was acquainted with some of Poincaré's relevant writings. And Galison has made a strong case that Poincaré's notion of time as conventional grew partly in connection with his role at the French Bureau of Longitude, especially in relation to the question of timekeeping procedures. If we had no plausible connection between Einstein and the writings of Poincaré, one perhaps might be more inclined to suspect the patent office as a likely candidate for moving Einstein's interests to questions of procedural timekeeping, for lack of other plausible influences. The case also would be somewhat stronger if Einstein were the only physicist to interpret time in electrodynamics as determined by clocks synchronized with light signals. However, Einstein was not the only one, since others, such as Emil Cohn, Max Abraham, and even Lorentz interpreted time in that manner, all following the example of Poincaré. Thus it seems plausible to infer that Einstein, just like his contemporaries working in the same field, adopted Poincaré's procedural interpretation of time. Poincaré's key paper in this line of inference is a paper of 1900, specifically on electrodynamics, where he employed a procedure of signal synchrony to account for time in *moving* systems. As Galison and other historians before him (in particular Olivier Darrigol) have highlighted, Poincaré's paper of 1900 was widely read by experts on electrodynamics, and likely by Einstein as well.[48]

We may well say that talk of clock synchronization in theoretical electrodynamics was implemented by Poincaré, and that perhaps that contribution derived partly from his acquaintance with conventional chronometric procedures. By itself this suffices to

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* *(gedachter) physikalischer Erfahrungen…*; see Einstein, "Zur Elektrodynamik" (ref. 36), p. 894.

argue that a basic part of the theory of relativity was rooted in a widespread techno-culture. What importance one gives to this factor in the genesis of Einstein's theory depends on what importance we attribute to the theory's various elements. Aside from clock synchronization, the theory involves other essentials (which, by the way, are usually granted a greater importance): the principle of relativity, the principle of the constancy of the speed of light, the relativity of simultaneity, the rejection of the concepts of ether and absolute rest, the algebraic formalism, and the rejection of the addition law of velocities. Galison focused on one aspect that he located in the intersection of physics, technology, and philosophy. In conversation, Galison explains that since different physicists construed relativistic electrodynamics in various ways, and even the interpretation of Einstein's formulation has varied, that it is appropriate to identify the theory as a family of concerns. Indeed, far too often have people neglected and underestimated the important contributions of Lorentz and Poincaré because of a narrow-minded compulsion to focus exclusively on what was distinctive in Einstein's work.[49] Thus Einstein always received what he himself regarded as more than his share of the credit. From this perspective, at least, we do well to highlight the importance of clock coordination in the body and roots of relativity theory.

Galison has rescued facets of Poincaré's long-neglected role in the emergence of modern physics. We already knew that Poincaré's contributions included: the emphasis on simultaneity and its conventional definition, the procedural interpretation of Lorentz's local time, the denial of absolute time, the emphasis on the principle of relativity, the characterization of the constancy of the speed of light as a postulate, and the introduction of a four-dimensional spacetime. Now Galison has uncovered subtle aspects of how Poincaré influenced the advancement of the physical imagination, especially in relation to material experience. The attitude that one often identifies with the young Einstein, a reticence to invoke elements that are not given by observation, was employed and advocated maturely by Poincaré. For example, he did not contrast time as we know it with time as it ultimately exists; rather, he analyzed time as that which can be intelligibly and systematically measured. He optimistically focused on the objective relations among things, rather than on obscure metaphysical notions.* He carefully worked to acknowledge and reconcile the contributions of various physicists. Poincaré exhibited a thoughtful appreciation of the heuristic value of traditional concepts, some of which, by contrast, the young and reckless Einstein was all too ready to abandon. Yet with advancing years, Einstein came to increasingly appreciate and even rescue old concepts that he had dismissed earlier. He complained that few physicists appreciated the continuity between his special relativity and earlier theories. His misfortune was that by then his initial brash attitude had infected many young theorists who, to his dismay, readily rejected extraordinarily useful traditional concepts (such as causality). Moreover, we find in Poincaré values that were later increasingly and unfortunately neglected by many physicists. He conscientiously labored to elucidate intelli-

* For Poincaré, so-called "objective" knowledge consisted of the parts of knowledge that are common to many thinking beings and can be shared by all; it was for him the only attainable truth. See, for example, his Introduction to *The Value of Science* (ref. 10), pp. 208–209.

gible explanations. He actively participated in fields of both abstract theory as well as practical endeavors.

In writing history of physics, Galison has likewise labored to bring to light the conjunctions of the concrete and the abstract, and equally important, to make them intelligible to a broad audience. His attempts to place the emergence of special relativity in the material culture of Switzerland and Europe at the turn of the century seem to be driven by the realization that our present divisions among the fields of knowledge are unfortunately very great. Despite the cautions and shifts of focus that we continually make regarding the origins of Einstein's theory, an old lesson remains intact: that the intersections of the disciplines are fertile fields for the advancement of knowledge. It reminds us of a point emphasized by another historian of relativity, John Stachel: that our parochial focus on single areas of specialty, such as physics or philosophy or history, are often sterile vanity, and that the center of attention should be not the straightjacket of any one professional discipline, but rather, the problem under study.

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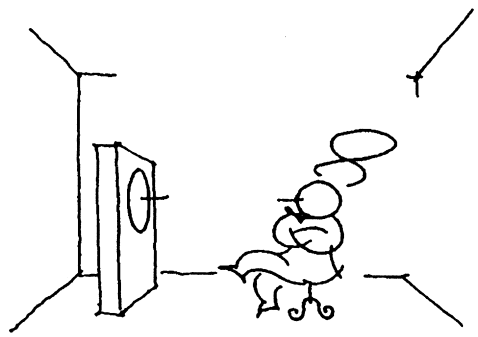

TIME

Does time exist?
I gravely doubt it.
But gosh, what should we do
without it?

Piet Hein