Engaging an infrastructure of time production with international law

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This article explores international legal entanglements with the infrastructure of Coordinated Universal Time (UTC), a socio-technical construction that comprises the globally definitive measure of seconds, minutes and hours working in lockstep around the world. UTC is produced and maintained with international law, through international administration with social, political, material and technical dimensions. In analysing mutual entanglements of international law with infrastructural relations organized around UTC, the article assesses their imbrication in globalized governance routines and distributive patterns, instantiated here with reference to the field of finance. The article further considers ways to engage legal-infrastructural relations for material change in patterns of governance.

There are many sorts of time, and many ways of knowing and marking time to do different sorts of work. This article explores international legal entanglements with the infrastructure of a particular measure of time, namely Coordinated Universal Time (or UTC). UTC comprises the globally definitive measure of seconds, minutes and hours working in lockstep around the world. Other time scales notwithstanding, UTC represents a hegemonic time scale, produced and maintained by international law through international administration with social, political, material and technical dimensions. In short, UTC is a socio-technical construction.¹ Its scope is global, but the work it does is

¹ Cf. S Jasanoff and S-H Kim (eds), Dreamscape of Modernity: Sociotechnical Imaginaries and the Fabrication of Power (University of Chicago Press 2015).
varied and particular. In this article, I will take up the particular work that the production of UTC does in support of ‘lifeworlds’ such as Karin Knorr Cetina describes for global currency traders, focusing here on high frequency trading in the field of finance. But constitutive elements in an infrastructure for globally standardised time production do not make obviously productive targets for legal intervention. One aim for this study is to engage technical sites where the administration of standardised time is imbricated in governance routines and distributive patterns that are global in scope.

Benedict Kingsbury has pointed out that ‘infrastructural thinking [brings together] the technical (the designed and engineered physical and software elements), the social (the human and non-human actants in their intricate relations), and the organisational (the forms of entity, regulatory arrangements, financing, inspection, governance, etc.). Legal practice is implicated in each of these dimensions, and in reciprocal fashion: ‘Law may intervene in the technical, the social and the organisational, and each of these may be embedded in a particular environment of legal forms and relations.’ Paul Edwards, paraphrasing Langdon Winner, describes the action of infrastructures, which he calls law-like: ‘infrastructures act like laws. They create both opportunities and limits; they promote some interests at the expense of others.’ And Brian Larkin, addressing their governance dimensions, holds that infrastructures can be reverse engineered, at least in theory, to ‘reveal forms of political rationality that underlie technological projects and which give rise to an “apparatus of governmentality”’. I build upon parts of both quotes, Edwards’ and Larkin’s, while also pushing back on a similar aspect in each. Edwards helpfully makes plain the opportunities and limits produced by infrastructures, the way they can promote some interests at the expense of others, which will be a primary point of attention in the second and third sections following this introduction.

2 K Knorr Cetina and U Bruegger, ‘Inhabiting Technology: The Global Lifeform of Financial Markets’ (2002) 50 Current Sociology 389.
3 B Kingsbury, ‘Infrastructure and InfraReg: On Rousing the International Law “Wizards of Is”’ (2019) 8 Cambridge International Law Journal 171, 179. Kingsbury’s suggestion to take up ‘infrastructural thinking’ takes special urgency in the context of the emergence of infrastructural assemblages such as described by Gavin Sullivan in the context of global security practices. G Sullivan, The Law of the List: UN counterterrorism sanctions and the politics of global security law (Cambridge University Press 2020).
4 ibid.
5 P Edwards, ‘Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems’ in P Brey, A Rip, and A Feenberg (eds), Modernity and Technology (MIT Press 2002) 185, 191.
6 B Larkin, ‘The Politics and Poetics of Infrastructure’ (2013) 42 Annual Review of Anthropology 327, 328.
But I want to bracket the ‘law-like’ ascription, because I mean to observe law as part of the infrastructure, not something that exists independently of it. Likewise, Larkin’s quote helpfully points governance towards issues of governmentality, especially insofar as governmentality stands for governmental rationality, in which ‘the focal question of politics is . . . not so much the justification of state action as the governability of the social’.7 Governmentality in this mode comprises what it takes ‘for an individual, and for a society or population of individuals, to be governed or governable’.8 These issues of governance and governmentality will be a concern throughout this article. But I want to bracket the notion that an infrastructure can be reverse engineered to arrive at a governmentality that precedes it. I am interested instead in the ways in which governmentality associated with an infrastructure—like Edwards’ ‘law-like’ effects—is produced through and with the infrastructure at any given moment.

Like the time that it produces, the infrastructure for globally standardised time is a particular construction: one infrastructural assemblage for one class of time measurement. Even so limited, it can be put to work for innumerable purposes—but still it cannot and does not do just anything. It supports a particular timescale to do particular work, distinct from other possible timescale artefacts such as sundials, incense sticks, seasons, cigarettes, etc. As I will demonstrate in the three sections following this introduction, it has been built to do the work that it does based upon specific material and conceptual possibilities, developed on the basis of specific interests, and mobilised for specific purposes.

I have already gestured broadly at interests and purposes by reference to the ‘lifeworlds’ that Knorr Cetina has described with respect to the foreign exchange market, materialising out of the socio-technical conditions that enable time-based association in the field of global finance.9 Those lifeworlds are constituted with—and contribute to the construction of—a flow architecture, a contemporary facet of the infrastructure for globally standardised time comprising persons, screens, clocks and information (among other things).10

7 C Gordon, ‘Governmental Rationality: An Introduction’, in G Burchell, C Gordon and P Miller (eds), The Foucault Effect: Studies in Governmentality (University of Chicago Press 1991) 1, 34. In this Foucauldian register, governance refers to the conduct of conduct, by means of interventions in social behaviour, whereas governmentality refers roughly to a framework by which government comprehends one mode or rationale of governance to be preferable to another.
8 Ibid 36.
9 Knorr Cetina and Bruegger (n 2) 389.
10 K Knorr Cetina, ‘From Pipes to Scopes: The Flow Architecture of Financial Markets’ (2003) 4 Distinktion: Scandinavian Journal of Social Theory 7.
flow architecture described by Knorr Cetina constantly produces and reproduces, moment to moment, a temporalised economic reality, and thereby privileges a rationality of emergence that is capable of colonising other social domains, as I will address in the second section following this introduction. Among the lifeworlds that it supports, however, the interests and purposes at play are not always coordinated or even complementary. Moreover, the infrastructure for globally standardised time and the units of time that it produces are not closed, fixed artefacts. Though the material assemblage of this infrastructure is durable, it is also always changing. As I will demonstrate in the next three sections, the infrastructure for globally standardised time is contingent on constant and deliberate support and intervention: its operation and effects are inscribed with investments in (always ongoing) maintenance and support. These investments are steeped in law.

The Greenwich Meridian was once the site and product of an intense contest under international law to determine a global index for time,11 today the Greenwich Meridian is a relic, with little relevance to a global administration of time, also established under international law, which relies on and regulates iterative algorithmic sampling of hundreds of nuclear clocks kept around the world (the next section). I will look in the final section at examples of change associated with innovations in time control clocks. Such network investments in changing time technologies are driven by material interests and possibilities. These material interests and possibilities, however, are competitive in nature and not perfectly stable. The assemblage has been and remains a site of competing material interests to determine or capitalise on possibilities afforded by the infrastructure, and observing material sites of active investment indicates the stakes of globally standardised time production, as well as the interests in play. A securities trader capable of producing a timestamp to an extra decimal point, for example, can evade regulatory constraints by acting after a deadline but rounding to remain within it.12 This requires investment, and pushes the infrastructure to propagate the next decimal point in its production and distribution of standardised temporal units, with knock-on effects reaching also to actors incapable of exploiting the additional decimal point. For another example, the United States Department of Defense has committed large sums of money to develop stable, miniaturised nuclear clocks for military

11 ‘International Conference Held at Washington for the Purpose of Fixing a Prime Meridian and a Universal Day: Protocols of the Proceedings’ (October, 1884) <http://www.gutenberg.org/files/17759/17759-h/17759-h.htm#Page_13>.

12 K Birth, ‘While the West Sleeps: Deglobed Globalization and Its Consequences’ in P Huebner et al (eds), Time, Globalization and Human Experience (Routledge 2016) 109, 114.
deployment and strategic advantage.\textsuperscript{13} Such clocks change conditions of security, accessibility and mobility of authoritative measurements of standardised time, and alter the mix of other assemblages in which they are imbricated.

In sum, the reproduction of the infrastructure for globally standardised time is driven by competitive distributive stakes. Competition, however, has not undone the construction, and here is one of the decisive contributions by contemporary legal practice to the ongoing construction of the infrastructure. As I will describe in the next section, legal practice stabilises competing interests around a consistent administrative architecture, enabling the sustained assemblage of a coherent infrastructure with consistent outputs despite competitive conditions. Competition to exploit the next decimal point, for instance, is enfolded with regulatory negotiations over the mix of clocks, algorithms and protocols in the overall assemblage for standardised time production under legal practice. Similarly, legal practice works to stabilise expectations, or coordinate expectation horizons within the assemblage,\textsuperscript{14} which will condition behaviour in any given site of activity—such as, for example, with the shared understanding that a specific commodity will not be readily transferable on the open market without good title (which will exhibit an orderly transfer of ownership recorded in linear time).

The relationship is reciprocal: legal practice stabilises the assemblage despite conditions of competition, and standardised time production stabilises the intelligibility of some legal practices, despite pressures associated with expansive economic conditions. Indexing ostensibly noneconomic events to standardised time facilitates their legibility for transactional purposes (the second section below), triggering a host of legal routines. Both time production and legal practice help to stabilise the hegemonic intelligibility of the other, including the particular sorts of expectations that may be recognised and communicated in practice. Thus, a related role for international law is to coordinate expectation horizons at the margins of networks, and from that vantage, to facilitate negotiations and translations of communications across bounded networks—such as when expectations generated in one network, for instance finance, can influence expectations in another system, for instance health care.\textsuperscript{15} I will return in the conclusion to law’s material contributions in the interoperation of multiple infrastructures. Each of these roles listed here—stabilising competition and

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  \item \textsuperscript{13} DARPA News, ‘Reducing Tics in the Tocks of Atomic Clocks: If GPS Goes Down, More Stable Atomic Clocks Could Save the Day’ CHIPS: The Department of the Navy’s Information Technology Magazine (29 December 2015) <https://www.doncio.navy.mil/CHIPS/ArticleDetails.aspx?id=7274>.
  \item \textsuperscript{14} N Luhmann, \textit{Law as a Social System} (Oxford University Press 2004).
  \item \textsuperscript{15} On the idea of legal regimes as the outcome of agonistic negotiations, see D Kennedy, ‘The Stakes of Law, or Hale and Foucault!’ (1991) 15 \textit{Legal Studies Forum} 327.
\end{itemize}
expectations, and working as a switching mechanism at points of interface—relies on mechanisms of institutional regulation established under international law. I turn to regulatory mechanisms in the following section.

**MAKING TIME: PRODUCING UTC TODAY**

Guaranteeing the authoritative production of globally standardised time today, in the form of UTC, is the responsibility of the Bureau International des Poids et Mesures (BIPM). That responsibility includes coordinating the different ‘universal’ times produced in laboratories around the world (which produce so-called ‘local realisations’), a responsibility taken over in 1987 from the International Time Bureau (BIH), which was formed at the 1912 Conférence internationale de l'heure radiotélégraphique, and made part of the International Astronomical Union at the 1919 Constitutive Assembly of the International Research Council (founded then by Belgium, Canada, France, Great Britain, Greece, Japan, and the United States). The BIPM, however, calculates the guiding UTC standard on the basis of another time standard, International Atomic Time (TAI). It calculates TAI by drawing on local realisations from a pool of more than 400 atomic clocks, maintained by more than 70 laboratories, or ‘timing centers’. In each of these national laboratories, a master clock takes readings from a number of atomic clocks to average out an accurate reading, though the readings for the individual clocks may be differently weighted for the average, and the algorithms for that weighted averaging calculation vary across the national laboratories. The BIPM, then, also applies a weighted average to the variety of averaged readings that it receives from the national laboratories. In other words, no one clock actually tells TAI, which is the product of multiple algorithms that together calculate a weighted average of weighted averages. After completing that process to produce TAI, the BIPM then converts from TAI to UTC by adjusting for leap seconds, which are only accounted for with the latter. Approximately one month after the initial readings at the national level have been taken, the BIPM will circulate the TAI and UTC that they helped to produce via a communication called Circular T. Just as no one clock ever tells TAI, none tell

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16 International Radiotelegraph Convention (signed 5 July 1912) [1913] UKTS 139, <http://handle.itu.int/11.1004/020.1000/5.19.61.en.100>.

17 A Blaauw, *History of the IAU* (Springer 1994).

18 Bureau International des Poids et Mesures, 'BIPM Annual Report on Time Activities' (vol 13, 2018) 49, <https://webtai.bipm.org/ftp/pub/tai/annual-reports/bipm-annual-report/annual_report_2018.pdf>.

19 BIPM, 'BIPM Technical Services: Time Metrology', <https://www.bipm.org/en/time-metrology>.
UTC, either, at least not in the present. A clock may be shown to have told UTC, but only after the fact, as a sort of confirmed coincidence, once the BIPM’s adjusted TAI calculation is communicated with Circular T (turning the title of the communication into a double entendre).20

The UTC production process makes clear enough that the construction is not made of clocks alone, but comprises a technological network that includes people (e.g., the scientists and cleaning personnel who maintain the various laboratories, together with the accountants and managers who determine the time and resources available to them), their techniques (e.g., for maintaining stables of atomic clocks, and the changing calculations for the weighted average times kept among them), and other things. Moreover, the people and techniques at the highest levels of UTC policy-making are part of a complex bureaucratic structure, reflecting a mix of political and technocratic dimensions. The BIPM, which administers the technological network, is an intergovernmental organization, established pursuant to the Metre Convention of 1875, with 58 states members to date.21 Its assumption of responsibilities formerly held by the International Time Bureau, established pursuant to a different treaty, has already been noted. In addition, the BIPM defers to the Radiocommunications Sector of the International Telecommunications Union (ITU-R), though ITU-R holds no formal power over the BIPM. The ITU-R, however, is a UN agency, reflecting ‘universal’ membership.22 Whereas the BIPM is made up of (nationally-appointed) metrology experts, the ITU-R is made up of political delegates. While the political delegates typically form working parties with experts closely associated with the BIPM, still the ITU-R represents political considerations in the construction of UTC. Kevin Birth, for example, reports on the possibility that the ITU-R has capped the level of influence that the United States’ clocks (maintained by the United States Naval Observatory, or USNO) can wield, below what the algorithms otherwise might provide, despite (or because of) the technological dominance of USNO clocks.23 In sum: there is tension between the experts, politicians, and machines in the reproduction of UTC,24 a tension that illustrates the politics and political possibilities of UTC, to which I return in the conclusion.

20 Bureau International des Poids et Mesures, ‘FTP Server of the BIPM Time Department’ <https://www.bipm.org/en/time-ftp>.
21 Convention du mètre (signed 20 May, 1875) <https://www.bipm.org/en/metre-convention>.
22 More precisely, the ITU, the parent organization, is the UN agency, and the ITU-R its sub-agency.
23 K Birth, ‘Time Standards and Rhizomatic Imperialism’ in C McGranahan and JF Collins (eds), Ethnographies of US Empire (Duke University Press 2018) 237.
24 T Quinn, From Artefacts to Atoms: The BIPM and the Search for Ultimate Measurement Standards (Oxford University Press 2012) 316.
In keeping with the embodied nature of time produced across a widespread infrastructure, the production of UTC and distribution of UTC does not stop with the BIPM and its coordinate institutions. The networks that communicate and distribute UTC are part of the production process. The communication of UTC contributes to its production, and so the infrastructure for globally standardised time in its productive capacity also comprises the networks by which UTC is communicated and distributed. Once, some readers will recall, these sites of communicative/productive authority would have been identified with examples such as the telephone number, maintained by the telephone company, that would announce an automated reading of the time when called. Today, these sites include the times told by computing devices, including personal computers, smart phones, tablets, etc. To communicate this time, each computing device counts on the reliability of the product of the interactions administered by the BIPM. Moreover, the time that computing devices communicate is also an integral part of their overall operation, in the form of timestamping. Computers rely on timestamps to communicate intelligibly, both internally as well as networked. This is because communication among computing devices occurs by means of one or more commands: the proper sequencing among commands—and the legibility of that sequencing—is essential to their intelligibility. As a result, the deep integration of time and widespread computing processes is now part of the infrastructure for globally standardised time.

To sequence each next command or communication, every action of a computer is stamped and identified with time, marking the moment of each command’s articulation and execution. Moreover, this process occurs at multiple scales: a singular command within a singular program of a singular computer is timestamped, a peer-to-peer communication is timestamped, an email is timestamped, a blockchain hash function is timestamped, and so on. A closed system of communication might be able to rely on its own time source for its own purposes, but a complex multiplicity of systems calls for a reliable, global source, which is the role assumed by UTC, as produced by the BIPM in consultation with the ITU-R. Because UTC is only ever actually produced after the fact, however, its reproduction and operationalization in computer networks entails still more layers of mediation. For computers and other devices to apply digital timestamps that produce a consistent result across networks, and in so-called real time, they rely on synchronization among linked machines, all running their nearest approximation of what UTC will have been confirmed to be. That synchronization requires consistent protocols. The dominant protocol for the purpose has been Network Time Protocol (NTP), formulated roughly in 1981 by David Mills, a veteran of the US Department of Defense’s Advanced Research Projects Agency (now known as DARPA).
Mills is one of the early architects of the Internet, about which he states plainly: ‘Having the wrong time could completely destroy the network.’ Communication among machines via the internet (or otherwise) would not be possible as we know it without reliable temporal sequencing for each piece of information to be transmitted. To enable that coordination, NTP functions according to a hierarchy among linked computers, servers and clocks. The most dominant servers and clocks belong to the USNO, but the NTP hierarchy includes up to 15 levels of stratification, with multiple clocks and servers at each level. NTP selects among the available linked and stratified devices by means of an algorithm to ascertain the closest approximation of UTC in the network. In other words, NTP is an algorithm that fashions a weighted average out of an approximation of a time that itself is a weighted average of weighted averages, the results of which will only be circulated after the fact. Linear it is not, but precise it is. It is able consistently to produce time units with apparent systemic consistency of roughly within 10–100 nanoseconds.

NTP, however, is no longer the most accurate available protocol. A relatively new protocol, called Precision Time Protocol (PTP), aspires to synchronise time to within one nanosecond of accuracy. The Institute for Electrical and Electronic Engineers (IEEE), a non-governmental body, issued PTP in 1997. PTP achieves its greater accuracy on the basis of several distinctions from NTP. To summarise broadly the distinctions that are relevant here, PTP applies best to systems with their own atomic clocks and a small number of connections, featuring symmetrical architecture among them. This has two consequences. First, PTP tends to prioritise the time distributed by the USNO, thus giving greater weight to US time technologies (apparently at odds with the ITU-R). Second, PTP can be extraordinarily expensive, especially if it is applied in a network of any size or geographic scope, where a closed, reliable and symmetrical loop of cables and connections becomes a prohibitively difficult feat of engineering. As a result, it is only deployed in situations

25 D Kukich, ‘Where Timing is Everything’ 11 (2002) University of Delaware Messenger <http://www1.udel.edu/PR/Messenger/02/1/where.html>. See also D Mills, “‘A Maze of Twisty, Turney Passages”—Routing in the Internet Swamp (and Other Adventures)” (18 May 2005) <https://www.eecis.udel.edu/~mills/database/brief/goat/goat.pdf>.
26 Birth (n 12) 109, 114.
27 D Mills, ‘NTP Precision Time Synchronization’ (5 July 2008) <https://www.eecis.udel.edu/~mills/database/brief/precise/precise.pdf>.
28 National Institute of Standards and Technology, 'IEEE 1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems' (26 January 2021) <https://www.nist.gov/el/intelligent-systems-division-73500/ieee-1588>.
29 Birth (n 12) 114–15.
where it is worth the enormous expenditure, and in those cases, it is only deployed by those who can afford it. This reality drives home the point emphasised earlier: that the infrastructure for globally standardised time is a particular construction, with particular interests invested and embedded in its material build. With respect to the cutting edge of time-keeping technologies today, there are a limited number of practices in which PTP’s level of accuracy is worth the expenditure, which include select data mining operations and what is known as fintech.

I turn next to fintech practices of algorithmic trading. Before I do, however, consider the production of UTC in comparison with both its imaginary predicates and ultimate outputs. Its imaginary predicates describe an ideal linear procession of identical units progressing simultaneously and in lockstep; its ultimate output is a practical and precise approximation of the same. The production of UTC, however, is quite different. Every machine involved in the production of UTC tells a unique version of it, none of them operate in actual lockstep, and simultaneity is impossible to attain. The production of UTC proceeds recursively rather than linearly, with what might be analagised to crocheting, or a loop-and-stitch pattern: to determine the present, the BIPM regularly loops back to tell past time, while computers stitch the future (the point at which the authoritative time will retroactively be told) together with the present by approximating each next loop-back. In short, the production process matches neither its uniform, linear idealization, nor the commodified version of that idealization, the artefactual output. I raise this disjuncture to make clear that the complex architecture of the system cannot be explained by natural or intuitive inevitability, and its internal inconsistencies discount any singular truth in its operation—the infrastructure for globally standardised time and the globally hegemonic standardised time that it produces do not exist on any transcendent basis; rather, the infrastructure exists because it works. This raises the simple question: what does it work for?30 There is not one answer to this question, but different answers will point to different investments in the assemblage for different purposes. The next section offers one example.

**TRADING TIME: TIME IN FINANCE AND HIGH FREQUENCY TRADING**

The previous section addressed the ways in which institutions of international law, including the BIPM and ITU-R, regulate the infrastructure for globally

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30 Cf. G Gordon, ‘Transnational Time’ in L Boer and S Stolk (eds), Backstage Practices of Transnational Law (Routledge 2019).
This section addresses entanglements of this infrastructure with the world of finance, including the sort of work that the two do for and with one other, as well as how legal practices are implicated in their interactions. I focus on activities known as high frequency trading, an application of algorithmic trading. Algorithmic trading today relies on artificial intelligence to process enormous amounts of data to leverage information and trade for profit. In the case of high frequency trading, algorithmic calculation is used to make rapid and constant trades with massive sums, to generate profits from what are typically small movements in financial devices such as commodities, securities, and derivatives. Once controversial, these practices have become routine, whereby money is ‘made’ or ‘lost’ according to a race among competing analyses and bids measured in nanoseconds but involving massive sums.31

I focus here on high frequency trading because it allows me to foreground the dimension of speed and, with it, matters of time, but it is important to keep in mind that the production (and product) of time is deeply implicated in financial practices beyond quantitative finance.32 High frequency algorithmic trading is possible by virtue of a mutually implicating relationship between finance and time as that relationship is and has been materially, technically and legally constituted—it is endogenous, at least in part, to each of these vectors of practice, not some external in(ter)vention with respect to any of them.33 A fundamental connection between finance, time and technology is clear already in volumes two and three of Marx’s Capital, which describe the tendency towards increasing volume and speed in the circulation of finance capital as a systemic feature of capitalism.34 In contemporary practice, finance is constituted in part out of trade in temporal units, according to practices enabled and conditioned by law. In this situation, UTC is both an object and agent of financial speculation: it is exchanged as a commodity, as abstract equivalents and objectified units of value, while simultaneously driving the

31 S Patterson and G Rogow, ‘What’s behind High-Frequency Trading’ Wall Street Journal (New York, 1 August 2009) 44.
32 See, eg, E Gilbert, ‘Common Cents: Situating Money in Time and Place’ (2005) 34 Economy and Society 357; K Knorr Cetina, ‘How are Global Markets Global? The Architecture of a Flow World’ in K Knorr Cetina and A Preda (eds), The Sociology of Financial Markets (Oxford University Press 2004) 38; M Pryke and J Allen, ‘Monetized Time-Space: Derivatives—Money’s “New Imaginary”?’ (2000) 29 Economy and Society 264.
33 F Pasquale, ‘Law’s Acceleration of Finance: Redefining the Problem of High-Frequency Trading’ (2014) 36 Cardozo Law Review 2085.
34 Karl Marx, Capital: Volume II (2nd edn, 1893) <https://www.marxists.org/archive/marx/works/1885-c2/index.htm> and Capital: Volume III (2nd edn, 1894) <https://www.marxists.org/archive/marx/works/1894-c3/index.htm>.
technologies that perform the exchange of commodified value and make it legible.

The mutual implication of time, technology, finance and law has exhibited a particularly visible character since the early 1970s, when the demise of Bretton Woods portended the ascent of speculative finance and the increasing commodification of debt. Under Bretton Woods, national currencies were maintained in a fixed price relationship to one another. With the collapse of Bretton Woods, the prices of national currencies were allowed to ‘float’, or vary up or down relative to one another, as with other commodities. In the post-Bretton Woods landscape, the market for exchanging foreign currencies led the ascent of speculative finance on a global scale. At the same time, national and international regulatory initiatives provided banks with more ways and means to sell debt, expanding the commercial market for debt products as well as products based on the assignment or expectation of transactions and changes in designated values at designated times. In a relatively small amount of time, the amount of debt circulating in financial markets, in the form of bets on future behaviour (of whatever sort, monetised for market purposes), outstripped by far the amounts of liquid currency and domestic product. By the International Monetary Fund’s (IMF) measurements, private side debt (so-called) has tripled since 1950, and government debt, which had been in decline until the mid-1970s, has gone up sharply ever since. As a result, the number of temporally-indexed objects and instruments of speculative financial interest multiplied. The rise of temporally-indexed speculative instruments brought with it a new practice community in the economic world of

35 S Strange, Casino Capitalism (Manchester University Press 1997); S Strange, 'The New World of Debt' (1998) 230 New Left Review 91.
36 Knorr Cetina (n 10).
37 A Campbell and E Bakir, 'The Pre-1980 Roots of Neoliberal Financial Deregulation' (2012) 46 Journal of Economic Issues 531; R Felder, 'From Bretton Woods to Neoliberal Reforms: International Financial Institutions and American Power' in L Panitch and M Konings (eds), American Empire and the Political Economy of Global Finance (Palgrave 2008) 175.
38 Cf. G Teubner, ‘A Constitutional Moment? The Logics of “Hitting the Bottom”’ in P Kjaer, G Teubner and A Febbrajo (eds), The Financial Crisis in Constitutional Perspective: The Dark Side of Functional Differentiation (Bloomsbury 2011) 3–4.
39 S Mbaye and M Moreno Badia, 'New Data on Global Debt' (IMFBlog: New Insights on Economics and Finance, 2 January 2019) <https://blogs.imf.org/2019/01/02/new-data-on-global-debt/>. The IMF's Global Debt Database, from which these numbers are taken, is available online: IMF, 'Global Debt Database' <https://www.imf.org/external/datamapper/datasets/GDD>. Cf. S Mbaye, M Moreno Badia and K Chae, 'Global Debt Database: Methodology and Sources' (IMF Working Paper No 18/111, 14 May 2018) <https://www.imf.org/-/media/Files/Publications/WP/2018/wp18111ashx>. The World Bank documents three waves of growth in debt since 1970, highlighting especially marked growth since 1980. M Kose, P Nagle, F Ohnsorge and N Sugawara, Global Waves of Debt (World Bank Group 2020).
investment, and new ‘lifeworlds’, in the language of Knorr Cetina. Those lifeworlds are temporal ones, constituted by roughly simultaneous engagement in the constant flux of speculative market prices. They correspond with emergent governmental rationalities that exhibit a tendency to colonise other social domains, as I will discuss below.

After the demise of Bretton Woods, the loosening regulatory environment and multiplying ways of extracting profits from changes over time created the conditions for what Susan Strange called ‘casino capitalism’, emphasising the element of speculation. Three aspects of the changes that followed the collapse of Bretton Woods are pertinent here. For one, the speculative movement of information and capital have created temporally-defined economic lifeworlds of global scope, exhibiting what Knorr Cetina describes as a ‘flow architecture’. In that flow architecture, scopic technologies allowing the observation and projection of information combine with time measurements to enable economic practices attuned to the moment, as I will further describe below. Two, the flow architecture has enabled speculative economic activities to reach and condition what had been considered non-economic domains—this is the colonial capacity to which I have alluded, and to which I will return. Finally, the common unit for exchange or special currency moving within this flow architecture is time.

As a unit of exchange enabling diversification of potential vehicles for debt, time has been widely observed to enable debt as an instrument of speculation delinked from production. Derivatives are illustrative, representing bets on the value of a commodity or commodified index at a designated moment, in which the point is neither production nor possession. The investor in derivatives rarely if ever engages in production or takes any possession. Only the exchange value of the chosen index at the programmed time counts. Barbara Adam makes clear the central value of time to these post-Bretton Woods economic practices: ‘most money is made on the speculative market that trades not with goods but with time. This involves bets on future prices of the stock market, currency prices, interest rates, even on the entire stock market indices. The trade in time [in 1995] equal[ed] the entire stock of

40 Knorr Cetina and Bruegger (n 2).
41 Strange (n 35).
42 W Hope, ‘Time, Communication and Financial Collapse’ (2010) 4 International Journal of Communication 649, 650–2; W Hope, ‘Global Capitalism and the Critique of Real Time’ (2006) 15 Time and Society 275, 276–7.
43 D Bryan and M Rafferty, ‘Financial Derivatives as Social Policy Beyond Crisis’ (2014) 48 Sociology 887.
productive fixed capital of the world’, and it has grown since. By 2018, the International Monetary Fund estimated that global debt, including both ‘government and private sides of borrowing’, totalled $184 trillion, outstripping global GDP by 225 per cent. This is wealth (and debt) accumulation on the basis of wagers indexed to time. Debt instruments enable trading in time for economic profit. A unitary time scale is necessary for the purpose: there must be an agreed set of temporal markers—and agreed means to generate and confirm those markers—to manage expectations under law. This will have ‘downstream’ temporal consequences for the object of the bet, including any production and distribution processes involved, which will now be linked by its financing to the time scheme of the speculative instrument such as the derivative. Downstream consequences reach all the way to the bodies of workers, obligated to labour according to a time and pace determined by massive and fast-moving flows of speculative debt.

The trade in time also has consequences that spread out horizontally. If one consequence is downstream effects on the object of speculation, including the bodies of workers occupied with it, this second consequence is the cross-stream effect, whereby multiple potential objects of speculation are comparatively assessed for the relative profit they might yield once translated into commodified temporal terms. The potential return on each speculative wager can be notionally measured against the potential return of any other speculative possibility intelligible to potential speculator-investors. This is one way in which speculative economic activities have reached and conditioned what had been considered non-economic domains, by indexing them to common temporal markers under law for speculative economic purposes. The only ‘horizontal’ limit on trade in time concerns the intelligibility of the potential wager—can it intelligibly (and so actionably) be translated as an object of speculation? The language of intelligibility thus begins with temporal markers

44 B Adam, ‘The Gendered Time Politics of Globalization: Of Shadowlands and Elusive Justice’ (2002) 70 Feminist Review 3, 22.
45 Mbaye and Moreno Badia (n 39); IMF (n 39).
46 Cf. M Feher, Rated Agency: Investee Politics in a Speculative Age (Zone Books 2018).
47 Cf. K Dorry, ‘Strategic Nodes in Investment Fund Global Production Networks: The Example of the Financial Centre Luxembourg’ (2015) 15 Journal of Economic Geography 797; D MacKinnon, ‘Beyond Strategic Coupling: Reassessing the Firm-Region Nexus in Global Production Networks’ (2012) 12 Journal of Economic Geography 227.
48 I cabin here for reasons of space the biopolitical dimensions of the infrastructure for globally standardized time, to focus within limited space on select socio-technical dimensions of its construction, but it must be clear that its inscription on and in bodies is a material part of the overall assemblage, not some mere externality.
49 Feher (n 46).
to make dynamics of duration and differentiation amenable to speculation. An infrastructure for globally standardised time distributes general intelligibility to enable the expansive and colonising speculative possibility. It incorporates a combination of regulatory, technical and material components to ensure comparability, consistency and predictability across speculative transactions. Here the role of temporal units not just as objects but also as agents is apparent: temporal units here are not solely units of currency for speculation, but are instrumental in the construction of the legibility that makes speculative transactions possible. In this socio-technical system, every act and transmission must be digitally timestamped. Birth describes the importance of the timestamp:

Global capitalism relies on accurate timestamps. All messages include a timestamp generated by the exchange on which the order is posted, and a collection-point timestamp where the order could be executed. For a traded security, every time its price is adjusted, it receives a new time stamp. Some orders also have expiration times. Together, these collected times constitute what is called ‘transaction time’. Transaction time does not represent a moment in time, but a duration of a piece of data in a database—in this case, an offer in an exchange’s trading sequence.

The timestamps that constitute transaction time allow the representation of the sequence of activity pertaining to each order and offered security. This is important because trading volumes are greater than servers can process in real time, so the transaction time system charts the sequence of orders, quotes, and price changes. The rapid global circulation of capital then unfolds in two times—the real time as experienced by people, and a representational time as generated by the sequencing of timestamps.

The two times that Birth describes are evident in what I called the ‘downstream’ effects, in which the transaction time for capital (including the fictitious capital of leveraged debt) will outpace and so pressurise the time on the job as experienced by workers in the labour of production.

Both the crucial role of the timestamp and the disjuncture from time as experienced by people are especially clear in the example of algorithmic trading practices today. Algorithmic trading includes bulk trades in stocks and other financial instruments as a bet on movement in their short-term values.

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50 M Pryke and J Allen, ‘Monetized Time-Space: Derivatives—Money’s “New Imaginary”? ’ (2000) 29 Economy and Society 264.

51 Birth (n 12) 115–16.
In the case of high frequency trading, agents typically unwind every position by the end of every 24-hour cycle, thus never maintaining an ownership interest for long. To turn a profit on such short-term movement, however, algorithmic, high frequency trading involves massive purchases or sales in constant succession on the order of nanoseconds. The practice also includes a vast number of trades that do not (and are not meant to) happen, offers that are made and revoked nearly instantaneously to game the market. The combination of extreme speed, precision and repetition is crucial for these purposes. Further, these attributes are also indicative of the flow architecture that Knorr Cetina describes. Knorr Cetina’s flow architecture includes a discontinuity ‘between the spatial or physical world we usually conceive of, and that of a timeworld.’ Whereas the spatial world as Knorr Cetina describes it is mapped and made navigable with symbolic structures that endure, the timeworld established by flow is distinct and more immediate: ‘In a timeworld or flowworld . . . the content itself is processual—a “melt” of material that is constantly in flux, and that exists only as it is being projected forward and calls forth participants’ reactions and contribution to the flux.’ The flux relies on scopic technology, which Knorr Cetina describes as ‘reflexive mechanisms of observation and projection.’ Scopic technology is also information technology, which further explains the phenomenon of flow: ‘the material on [the financial practitioner’s] screen can disclose itself as information only in as far as it is new compared to earlier material. The new is “presenced” as-things-happen and vanishes from the screens as newer things come to pass. This sort of reality is inherently temporal, which is what [is also meant by] “flow.” Information managed according to a specific regime of time measurement and distribution enables the melt and flux that gives casino capitalism its radical immediacy and expansive potential. The faster the succession of new information, the more ‘liquid’—the fuller and more dynamic—the flow.

Thus, the fuller and more dynamic the flow of temporalised information, the greater the colonising capacity to subject seemingly unrelated social domains in the spatial world to the emergent governmentality of the financial lifeworld. The growth in that capacity is charted by the rising volume and

52 M Chlistalla, B Speyer, S Kaiser, and T Mayer, ‘High-Frequency Trading’ (2011) 7 Deutsche Bank Research <https://secure.fia.org/ptg-downloads/DBonHFT2-11.pdf>.
53 Knorr Cetina, (n 32) 39.
54 ibid 40.
55 ibid.
56 ibid 43.
variety of debt instruments since the demise of Bretton Woods. Contemporary time technologies, including timestamps and nuclear clocks, today combine to enable a constant succession of volumes of information in nanoseconds, producing flows of financialized information exhibiting extreme, self-reflexive dynamism. The ultimate limits on that movement of information and capital in algorithmic trading markets are technological limits on the communication of timestamped computations. Trading firms deploy algorithms to mine data, rapidly processing an enormous and constantly changing mix of information, organised by timestamp. The same algorithms then automatically produce bets on the products of their data mining activity, the bets registered by timestamp technologies capable of sequencing transactions at astronomical speeds. Returning to a point raised above, the cost and sophistication of the technologies that are necessary to this practice become a sort of gatekeeper. Only those who can afford it—whether individuals, firms, governmental entities, etc.—invest actively and substantially in the design and operation, and then only to ends perceived by some metric to offset the costs. As Birth puts it, ‘[a]ccess to timestamp precision becomes a subtle creator of stratification embedded in the production of timestamps’. 

Because algorithmic trading occurs in competitive markets, the twin requirements of speed and precision become the subject of intense technological competition. Competing algorithms process countless data points for patterns in the market value of any given equity or commodity. The data points can come from popular media, specialist databases, insider communications, and so on: the ‘winning’ algorithm will be the fastest to access and sift enough information to approximate closely the movement in price—which movement will include the effect of the winning bid, as well as the effects of the countless unsuccessful bids, including unsuccessful bids that are meant to game the price, rather than to win the wager. In short, the financial practices to predict prices according to temporal markers also co-produce them by means of the same practices and technologies. The result is orders placed and revoked in nanoseconds, with positions typically not lasting much longer

57 M Lazzarato, The Making of the Indebted Man (Semiotext(e) 2011).
58 Chlistalla et al (n 52).
59 Birth (n 12) 115.
60 Cf. M Mazzucato, The Value of Everything: Making and Taking in the Global Economy (Hachette 2018); and A Cartea and J Penalva, ‘Where is the Value in High Frequency Trading?’ (2012) 2 Quarterly Journal of Finance.
61 For extended insights in this vein, see D MacKenzie, F Muniesa, and L Siu (eds), Do Economists Make Markets? On the Performativity of Economics (Princeton University Press 2007).
than that, representing vast sums of money in constant speculative movement. That movement charts a fluid stream of values that condition distinct, downstream value-producing practices, and have cross-stream repercussions as well. Contemporary time technologies play a central role by enabling vastly accelerated and expanded practices for potential wealth accumulation by speculation.\(^{62}\)

In this new material environment, however, the notion of finance as an enterprise and the regulatory regime adapted to it have been destabilised.\(^{63}\) The speeds involved are approaching a hard limiting condition, namely the speed of light, which places special stresses on regulatory mechanisms and systemic coherence generally: the horizon of relativity (at light speed) challenges systemic demands for consistency and coordination.\(^{64}\) The stress is prompting a radical reconsideration of time within the field of financial regulation. James Angel, reviewing the coordination challenge from a regulator’s perspective, has called to revisit and reconstruct basic intuitions of time for legal governance purposes.\(^{65}\) Angel’s concern underscores the entanglement of financial regulation with the conduct that it would conduct: ‘intuitions—and regulations—gained from low-speed markets also need to be modified as trading approaches the speed of light.’\(^{66}\) The governmental posture here is closely attuned to the dilemmas that market behaviour creates for market participants, and the ways in which mutual participation breaks down from use of time technologies in practice. ‘As trading speed increases, physical issues and lessons from physics become more important for regulators and practitioners alike’ because ‘a market participant [will] not really know if a published “firm” quote is actually alive (can be traded on) or dead without actually submitting an order to trade against it.’\(^{67}\)

Pulling back the lens, Wayne Hope observes the overall operation of information and communications technology (ICT) behind algorithmic, or high frequency trading capabilities:

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62 L Adkins, *The Time of Money* (Stanford University Press 2018).

63 S Omarova, ‘Dealing with Disruption: Emerging Approaches to Fintech Regulation’ (2020) 61 *Journal of Law and Policy* 25; S Omarova, ‘New Tech v. New Deal: Fintech as a Systemic Phenomenon’ (2019) 36 *Yale Journal on Regulation* 735; R Buckley, ‘Reconceptualizing the Regulation of Global Finance’ (2016) 36 *Oxford Journal of Legal Studies* 242.

64 M Lenglet and J Mol, ‘Squaring the Speed of Light? Regulating Market Access in Algorithmic Finance’ (2017) 45 *Economy and Society* 201.

65 JJ Angel, ‘When Finance Meets Physics: The Impact of the Speed of Light on Financial Markets and Their Regulation’ (2014) 49 *Financial Review* 272.

66 ibid 272.

67 ibid 279, 276.
ICTs generally have become the nervous system of globalizing capital. Thus, computers, microchips, satellites and cable networks shape the reach, velocity and supervening power of global finance. As governmental control over exchange rates and capital movements diminished, private financial institutions were able to generate multiple units of credit and currency... Special satellite and internet linkups have enabled stockbrokers, institutional traders and personal investors to buy and sell shares concurrently in different stock exchanges. Barbara Adam’s observations about ICT time are pertinent here; the globally networked drive towards instantaneity and simultaneity is a constitutive feature of financial profit making...

The technological regime that Hope describes is not a neutral one. It works better for and with some interests than others. Only a select, capitalised few can compete for the profits that it yields. Among the many who are not so privileged, labour suffers on multiple fronts: the infrastructure favours the movement of temporalised information and things that can move in the form of information (such as money and capital) in a way that it does not privilege the movements of labour (in multiple senses, including the movements required in physical labour and the movement of workers in pursuit of jobs dislocated pursuant to financial mandates). The disadvantage is not arbitrary. The temporal infrastructure predicated on UTC has been built into an especially profitable partner for those capable of harnessing ICT power. Finance capital, consisting of transactions in time-based information delinked from actual goods, is one example. Thus, finance is an exemplary answer to the question posed earlier: the infrastructure for globally standardised time works for finance capital. For the same reason, finance capital is specially invested in continued, competitive development of the infrastructure in order to master self-reflexive markets in temporalised information, with particular distributive consequences.

The ascendance of financial speculation and finance capital has also created other conflicts, arguably opening up fissures within capitalism itself. The sheer volume of finance capital circulating independent of production has created a set of incentives and ends that are not entirely consonant with dynamics traditionally associated with capitalist institutions. This is sometimes characterised as a tension between the ‘finance economy’ and the ‘real economy’.69 But the tension perhaps goes farther, exposing weaknesses in foundational

68 Hope, ‘Global Capitalism and the Critique of Real Time’ (n 42) 277.
69 Cf. S Hall, ‘Geographies of Money and Finance III: Financial Circuits and the “Real Economy”’ (2013) 37 Progress in Human Geography 285.
economic notions, including the definition of value that yields measures such as gross domestic product, or GDP. The tension between modes of economic practices, keyed to the use of time technologies, has also been described by heterodox and interdisciplinary economic observers as a potential source of hope for transformation. Among them, there is a specific current of hopeful critique that sees in the deployment of time as a speculative instrument of profit, a technology that has over run the ambitions that made it useful as an instrument of capital in the first place. Robert Hassan, reviewing the high-speed time techniques of financial networks, puts it this way: 'In the name of “efficiency”, neoliberalism has abrogated social control to both “market forces” and computer networks of automation. [But e]ven those “in control”, those in the boardrooms and cabinet offices of the great and powerful are essentially “out of control”’.

Birth, in turn, refers to the consequences as part of a rhizomatic empire of time. By rhizomatic, Birth means roughly that the consequences of decisions by figures in cabinet offices and board rooms exceed the intent behind them. This corresponds with Angel’s observation that the field of finance is destabilised for regulators and traders alike by competitive deployment of time technologies. The result, following Birth, has been a loss of directed, institutional control: ‘The rhizomatic nature of this empire of time emphasises international coordination even as it diminishes the ability of any one interest to control the empire. Yet, what is given up in terms of control is gained in the ability to move information and capital quickly and audit such movements precisely.’

Though the system of standardised time that Birth describes is not a directed one and is not amenable to unitary control in any conventional sense, it bears keeping in mind (pace Hassan) that limited classes of people continue to benefit disproportionately from its operations in a field such as finance. These observations underscore the stakes of law, to constitute new possibilities for coordination and control under competitive conditions, for instance as called for by Angel. They also point to new opportunities to engage the material complexity of the infrastructure under conditions of unsettled design. I take this up further in conclusion. First, however, I turn to one technology

References:
70 Mazzucato (n 60); J Gertner, ‘The Rise and Fall of the GDP’ New York Times (13 May 2010) <https://www.nytimes.com/2010/05/16/magazine/16GDP-t.html>.
71 K Dorre, S Lessenich, and H Rosa, Sociology, Capitalism, Critique (Verso 2015).
72 R Hassan, ‘Network Time and the New Knowledge Epoch’ (2003) 12 Time and Society 226, 238.
73 Birth (n 23) 242.
74 Cf. D van den Meerssche, ‘International Organizations and the Performativity of Measuring States: Discipline through Diagnosis’ (2018) 15 International Organizations Law Review 168, 174.
that has factored historically into that design, namely timestamping, as it was first practiced on factory floors with analogue time control clocks. The description to this point of systemic characteristics of the infrastructure for globally standardised time risks giving the impression of an inevitable or automatic technological development, but it is not that—though neither is it arbitrary. The brief, relatively narrow historical detail that follows, concerning one example of technological development, aims to demonstrate how the infrastructure is amenable to particular interventions that contribute to change over time.

**STAMPING TIME: THE TIME CONTROL CLOCK AND MATERIAL INNOVATION IN THE INFRASTRUCTURE FOR GLOBALLY STANDARDISED TIME**

The development of the infrastructure for globally standardised time has not been the product of black boxed intervention(s) from beyond. In the first section, I examined the iterative and recursive structure of the legal-technical administration of the infrastructure. In the previous section, I pointed to select practices by which financial practices have been actively implicated in the development of the infrastructure. In this section, I offer a historical example of material innovations in the infrastructure. The example includes the mutual implication of economic and legal-regulatory practices. Timestamps have already come up repeatedly, as they have played a role in each of the prior sections. I focus here on an analogue precursor to the digital timestamp. Analogue timestamping is not the same technology as its contemporary digital counterpart. The analogue timestamp is a mode of social and temporal control associated with the factory floor and time control clocks rather than mainframes and motherboards. But as will be clear, it was the pioneers in time control clocks and analogue timestamping who became pioneers in digital timestamping. Analogue timestamping formed part of the technical imagination and matrix of possibility for the development of digital timestamping.

This history of timestamps begins with time control clocks, clocks that synchronise and record events, originally to determine workers’ time on the job by stamping a designated clock time (typically synchronised to some other authoritative time source) on a card or paper to record presence and absence, activity and inactivity. Charlie Chaplin spotlighted the practice in *Modern Times*, in a scene in which Chaplin the worker is so routinised to time control that he stops to ‘punch’ his time card while running from the cops.75 The first

75 *Modern Times* (C Chaplin dir, 1936).
influential analogue time control clock is generally credited to Willard le Grand Bundy, and invented, patented and produced by the Bundy Manufacturing Company in the late 1880s.\(^{76}\) By 1900 Bundy was already aggressively pushing operations overseas, including licensed production in Germany for Bundy time clocks built in the Württembergische Uhrenfabrik in Schwenningen, and distributed by the Continentale Bundy-Gesellschaft, founded in Stuttgart on 7 April 1900.\(^{77}\) Bundy’s time clock utilised a key mechanism: each worker was assigned a key that triggered wheels to stamp the time on a paper tape.

Two other competitors at the time were Alexander Dey’s dial recorder, and Daniel Cooper’s Rochester Recorder. Cooper invented the Rochester Recorder in the late 1890s, then sold the patent and production rights to the Willard and Frick Company. The Rochester Recorder worked by timecard, with workers punching times of arrival and departure on a pre-printed card. This became the iconic image of factory and work-place time discipline and control. In 1900, Willard and Frick merged with the Bundy Manufacturing Company, as well as another competitor, the Standard Time Stamp Company. Following the merger, the company was aptly renamed the International Time Recording Company, and given the motto: ‘Safeguarding the minute’. The merger was orchestrated and overseen by George W Fairchild, who had joined the Bundy Manufacturing Company in 1896 as an investor and director. From 1907 onwards, while still with the company, Fairchild also served as congressman for New York for six terms, sitting on the Committees of Foreign Affairs and Ways and Means, becoming the ranking Republican on the latter and thereby playing a substantial role financing the US war effort in World War One.\(^{78}\)

Alexander Dey invented his machine in Glasgow. His brother, living in the United States, had opened a company with him in 1893. Once sales took off, Alexander joined his brother in the US in 1903, and by 1904 they had founded the Dey Time Register Company. Their main clientele included railways and the Post Office, both involved in the propagation of standardised time that would become UTC.\(^{79}\) Dey’s dial recorder was named for its large dial with workers’ numbers (in place of names) on it, to be selected by pointer.

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\(^{76}\) IBM, ‘IBM Highlights, 1885–1969’ (2001) 2, <http://www-03.ibm.com/ibm/history/documents/pdf/1885-1969.pdf>.

\(^{77}\) G Kopf, Zeit-Ordnung: Eine Geschichte der Stechuhr (PhD dissertation, Bauhaus-Universität Weimar, 2002) 19.

\(^{78}\) J Sullivan (ed.), The History of New York State (Lewis Historical Publishing 1927) 321–3.

\(^{79}\) G Gordon, ‘Railway Clocks’ in J Hohmann and D Joyce (eds), International Law’s Objects (Oxford University Press 2018) 387.
A separate, smaller wheel had six markings, indicating arrival in the morning, break for lunch, return at noon, quitting in the evening, extra time at work, and extra time off. A worker selected the identification number on the dial, the time-work status on the smaller wheel, and triggered a stamp on paper kept within the machine. The stamp was marked in green or red ink, by means of a two-toned ribbon patented by Dey, with green indicating punctuality and regular working hours, and red indicating a late arrival, early departure, overtime or time off. Repairs and maintenance were complex, but the paper record was simple to read and efficient for accounting purposes, which made the machine popular. In 1907, the International Time Recording Company purchased the Dey Time Register Company. By this point, the International Time Recording Company was far and away the dominant factory time control technology producer internationally. In 1911, following a series of further mergers, the company was renamed again, becoming the Computer-Tabulating-Recording Company. The Computer-Tabulating-Recording Company changed its name once more, in 1924, to its current name, International Business Machines, or IBM. IBM, of course, has gone on to become a dominant company in computing, as what began with time control clock innovations developed through generational change into global computing and business management interests.

The particular assemblage of the time control clock and the pervasive industrial practice of timestamping that it enabled contributed to change in the valence of standardised time in daily life, as chronicled by E P Thompson, who referred to practices of time control under industrial capitalism as time- and work-discipline. Time discipline entailed an entanglement of daily rhythms that is already apparent on the face of Dey’s time wheel, marking the morning, evening and lunch. Thompson described the development as ‘one of increasing rationalization in the service of economic growth’. Rationalization was also a key term in the colonial expansion of globally standardised time, as part of a rhetoric of science and civilization. In the cotton mills of colonial India and England alike, time control clocks imprinted the units of globally

80 Kopf (n 77) 21.
81 By 1958, IBM had expanded and sold off its Time Control Equipment division to the Simplex Time Recorders Company. By that time, time control clocks had become ubiquitous in the control of labour, and had begun to extend beyond the factory. And while IBM had divested from its roots in time control technologies aimed at the factory floor, it had moved into the next generation of timestamping technologies, inside computers: IBM (n 76) 5–6, 21.
82 EP Thompson, ‘Time, Work-Discipline, and Industrial Capitalism’ (1967) 38 Past and Present 56.
83 ibid.
84 G Gordon, ‘Imperial Standard Time’ (2018) 29 European Journal of International Law 1197.
standardised time on factory work and factory workers, who carried it beyond the shop floor, multiplying its reach alongside other technologies such as the wristwatch. The expansion was a bitterly contested one, occasioning strikes and violence. But legal regulation of the working day ultimately helped to stabilise the contest around the competence of the time control clock and its timestamps, until they became ubiquitous in still more working contexts, including physical spaces from professional offices to motherboards. Since the heyday of the analogue timestamp and the time control clock, time notations printed with ink on paper have been succeeded by electronic processes to produce digital timestamp records, and the deployment of time as an instrument of value extraction on the factory floor has expanded to countless other (digital) contexts. In sum, the assemblage of the time control clock and the practice of timestamping were enrolled into an expansive socio-economic program associated with rationalization, imperial governance, colonial practices, and legal-regulatory policy.

This brief history of factory time control clocks and timestamps illustrates the sort of material qualities and contingencies that have gone into the development of the infrastructure for globally standardised time. Some of the material elements can be generalised: timestamping was developed on the basis of making specific temporal information both mobile (transferable across people and machines in the form of a paper record) and legible (readable on its face, using numbers and colours for specific purposes). The relative ease of mobile legibility facilitated the success of the technology as it was enrolled into expansive economic programs, materially supporting the development of corporate information management practices. On this socio-technical basis, what Thompson called time discipline has continued to expand and evolve in ever more expansive networks of people and things; the use of time discipline to extract value in economic contexts has both expanded (in keeping with the ‘cross-stream’ movements described in the previous section) and become more intense (in keeping with the down-stream effects also described there). Writing in the tradition of Thompson, David Harvey has famously described the result as time-space compression. Organizational innovations involving mechanical stamps and paper, numbers, time and clock became predicate for successive innovations.

85 D Mumby, Organizational Communication: A Critical Approach (Sage 2012) 59.
86 Cf. S Wolcott, ‘Strikes in Colonial India, 1921–1938’ (2008) 61 Industrial and Labor Relations Review 460 (with thanks to Ntina Tzouvala for this reference).
87 D Harvey, The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change (Blackwell 1989) 284.
There is a startling similarity in the role played by the analogue timestamp with that played by the price ticker and ticker tape in the formation of the flow architecture observed in the foreign exchange market by Knorr Cetina. The ticker tape, in which prices were inscribed on a running band of paper as they were communicated in linear time, ‘temporalised the complexity of earlier market transactions’. 88 By ‘sequentializ[ing] and display[ing] past market activities’, Knorr Cetina argues, the ticker tape can be seen ‘as a first step toward’ the temporal lifeworlds associated with computer-based scopic systems.89 The ticker ‘initiated a trend that pre-cast some aspects of scopic systems: it sequentialised the market, initiating a price-and-volume flow that became at the same time an information flow.’90 Like the ticker tape, the analogue timestamp was precedent to an emergent temporal regime that developed with the heightened speed and capacity enabled by digital technologies. The materials of the time control clock and timestamp together registered data to order the workplace by regulating flow (of workers) with temporal information. In this capacity, the assemblage of the time control clock was enrolled into the industrial program of the factory, and contributed to its becoming. In turn, the time control clock as an element in the (work flow of) the factory became a key part of an integral grid of cultural, economic and technological intelligence—such as was built up over time at what became IBM—by which additional techniques of time control became knowable and exploitable in other material embodiments and socio-economic spaces. Similarly, the assemblage of the time control clock exhibits the merged economic, technological and regulatory imaginaries of information communication for management purposes that were concretely developed and propagated by IBM, leading a once-emerging market in business management now global in scope.

The foregoing developments in which the time control clock was implicated did not cause or create the explosion in financial practices in the late 20th century. They did, however, contribute materially to the conditions for its possibility. In the 1970s, time control devices worked together with legal and regulatory interventions to stabilise expectations for a radically new set of market practices, as described in the previous section, keyed to temporal speculation and bringing economic ‘rationalization’ to new frontiers. In the 1990s and 2000s, technical advances in time control and its communication enabled

88 K Knorr Cetina and A Preda, ‘The Temporalization of Financial Markets: From Network to Flow’ (2007) 24 Theory, Culture and Society 116.
89 ibid 117.
90 ibid 123.
the expansion of algorithmic trading. Digital timestamps are not simple reproductions of analogue timestamps, and their development has not been part of some automatic history or comprehensive plan. Rather, they were produced by a contingent and peculiar but historically intelligible assemblage of interests, agencies and things.

CONCLUSION

In conclusion, I want to focus on the conditions by which the infrastructure for globally standardised time may be favourable (or not) for transformation, and to consider the efficacy of legal practice at those junctures. There are at least two material indices in the episode of timestamping that point to possibilities. In that example, mobility and legibility were key. By rendering units of standardised time legible in mobile form—with numbers and metal wheels, paper ribbons and coloured stamps, among other things—the time control clock also produced greater possibilities for translating units of standardised time into other programs, enrolling time into new programs (such as workplace control beginning with the factory floor) and reciprocally enrolling new programs and policy concerns into the infrastructure. Similar material innovations in mobility and legibility apply with respect to the generations of information and communications technologies that have replaced the analogue timestamp, innovations such as are at work in the domain of fintech. The first section above makes apparent at least one material development resulting from contemporary innovations in mobility and legibility: multiplication and distribution of vanishingly brief units of time. The flow architecture of global finance described by Knorr Cetina was primed by the temporality of the ticker tape and time control mechanisms, but did not fully come into being until still more thoroughly temporalised communications, updating at briefer intervals, became industry standard.91

Once, the nanosecond was only an abstract possibility; today, it is a concrete part of embodied operations of global finance. The latter is more than the teleological fruition of the former: the embodied unit enjoys a reality distinct from the abstract one. The embodied unit is also more than a mere incremental addition to or by the technology. Its utilization contributes to new practices and relationships in time and with time, and in so doing contributes to a changed temporal order, in which even the valence of pre-existing units like seconds and minutes changes with the incorporation of the nanosecond into governance routines. As the temporal order changes, governmental

91 ibid.
rationalities change with it. As described in the first and second sections, the relationship is circular: material units of temporal order play a constitutive role in the production of governmental rationalities, even as governmental rationalities condition and instrumentalise material units of temporal order. In part, this is because the temporal order is not autonomous. As the temporal order interact with other domains, such as the economic—as its material units of time are translated into programs operating in these other domains, and as those domains invest in the production of its material units—it becomes mutually implicated in the interests and rationalities associated with them.

Fleur Johns has recently called to ‘reactivate’ competing notions of time ‘as political questions of the first order’ under international law. \(^{92}\) Her call points to the need for new ways of recognising and engaging the productive power and political character of time technologies and temporal regulation. \(^{93}\) Engaging the productive power of time technologies and temporal regulation today means intervening in the flow architecture described by Knorr Cetina, and the in-the-moment register of governance that it promotes. In other work, addressing international development and humanitarian law, Johns describes the growing reliance among international institutions generally on ‘a succession of rapid-fire snapshots resulting from automated dives into vast and shifting oceans of data’ \(^{94}\). That reliance enables ‘an open-ended, opportunistic, now-oriented [governmental] disposition’, such as the flow architecture that the financial world supports. \(^{95}\) Similar temporalization is evident in everything from border control installations and institutions of war to food supply chains. \(^{96}\) Against this backdrop, Johns has called for a critical practice to grasp ‘the pattern and formula, storage and transmission’ of ‘the increasingly self-organising streams of digits and “stuff” shaping global affairs’. \(^{97}\)

\(^{92}\) F Johns, ‘The Temporal Rivalries of Human Rights’ (2016) 23 Indiana Journal of Global Legal Studies 59–60.

\(^{93}\) Cf. F Johns, ‘From Planning to Prototypes: New Ways of Seeing Like a State’ (2019) 82 Modern Law Review 833.

\(^{94}\) ibid 850.

\(^{95}\) ibid.

\(^{96}\) D van den Meerssche, ‘Virtual Borders: International Law and the Elusive Inequalities of Algorithmic Association’ forthcoming in European Journal of International Law; M Liljefors, G Noll, and D Steuer (eds), War and Algorithm (Rowman and Littlefield 2019); J Allen and S Lavau, “Just-in-Time” Disease: Biosecurity, Poultry and Power’ (2015) 8 Journal of Cultural Economy 342.

\(^{97}\) F Johns, ‘On Dead Circuits and Non-Events’ (UNSW Law Research Paper No 19-80, 2019) <http://dx.doi.org/10.2139/ssrn.3469325>. 
How, then, to engage such temporal assemblages that shape global affairs with self-organising streams of information? In a different register, Nick Seaver writes that ‘infrastructure is a trap in slow motion’. Seaver posits the trap in counterintuitive but provocative ways. Drawing on anthropological studies of traps and trapping, he defines the trap as more than a single-faceted object to contain a victim. Traps involves persuasion as much as coercion; they ‘are not just devices of momentary violence, but agents of ‘environmentalization’.’ In this latter capacity, infrastructures, likes traps, are ‘making worlds for the entities they trap.’ The world-making operation is social as well as material: ‘a trap is not simply the unilateral application of technical force, but rather a fundamentally uncertain effort to relate to others which thereby produces a world.’ Though not exactly benign—the infrastructure remains characterised as a trap, after all—neither is it merely sinister. The world-making character that Seaver observes is productive, and if the infrastructure trap is not the sort that allows escape, its productive potential might still be materially recalibrated in order to effect different worlds. In Seaver’s words, we might ‘move beyond denouncing entrapment and toward reconfiguring our captivating social infrastructures.’ No trap, Seaver emphasises, is all encompassing, nor can a trap exist independent of the environment in which it must entrap its intended captive. Any one infrastructure is itself caught up in other infrastructures. The elements of the infrastructure for globally standardised time are enrolled and enfolded in other networks and infrastructures—fintech, in the example considered here, GPS-driven security regimes in another—with each assemblage incorporating and contingent on material parts of another.

Interconnectedness points up the indeterminate and variable condition of infrastructures, but it also helps to explain their durability. Interconnectedness in this sense brings with it the design principle that makes the decentralised network a resilient one. The infrastructure for globally standardised time is caught up with and stabilised by other traps or infrastructures, other social and material assemblages, each of them actively stabilised by a variety of other things and assemblages, none of them final or fixed. The factory

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98 N Seaver, ‘Captivating Algorithms: Recommender Systems as Traps’ (2019) 24 Journal of Material Culture 432.
99 Ibid.
100 Ibid.
101 Ibid.
102 Ibid.
floor has been one material site of interconnection, where economic control of
the mode of production is inserted into the daily rhythms of workers; the
cloud server is another contemporary site. But while the multiplicity of
intersections helps to explain overall durability, they also present sites of mar-
ginal change, where the shifting assemblage of one infrastructure may induce
reciprocal movement in another. Moreover, each interconnection may also
present a tactical site for intervention, where translation exercises from the
one network to another may be contested precisely as the communication
‘switches’ from one systemic orientation to the other. Points of intercon-
nection and places of translation are also the moments when legal practices typic-
ally play a material role in the assemblage, stabilising the borders of
interpenetrating domains and the interests among them. The mix of atomic
clocks that determine the time standards for global financial transactions are
debated at the ITU-R; while the urgency to stabilise and exploit global posi-
tioning systems, which run on time signals, incentivises the production and
military deployment of miniaturised atomic clocks. In such complex condi-
tions, these constellated social and material points of interconnection and the
legal elements of their interoperation are potential sites for strategic engage-
ment and intervention, whether directed at the infrastructure for globally
standardised time, or at the other networks and infrastructures with which it
is mutually implicated. In addition, fissures among the particular economic
interests implicated in the infrastructure for globally standardised time point
to an instability in the socio-technical hegemony of its operation and repro-
duction. Such fissures present other openings for new interests and (counter-)
engagement in its reproduction.

The constellated points of interconnection between the infrastructure for
globally standardised time and other networks and infrastructures are ripe for
reactivation as political concerns. Time technologies operating near the speed
of light underlie sensationally destabilising developments not limited to high-
speed financial transactions, just as the increasingly material imaginary of
quantum computing points to other opportunities for transformation. The
destabilising character of these developments underscores a moment of possi-
bility—for reactivation, in Johns’ words—in the world-making character of
time technologies at work. But as Kingsbury has stated, ‘the international legal
framework for much of this is at present scanty, woefully lagging, and in

103 Cf. L Amoore, Cloud Ethics: Algorithms and the Attributes of Ourselves and Others (Duke University
Press 2020).
104 DARPA News (n 13).
urgent need of construction. 105 Economic investments have determined some of the most powerful technologies incorporated into the infrastructure for globally standardised time, in the service of Knorr Cetina’s ‘lifeworlds’, but that does not mean that finance capital enjoys a final or univocal power over the assemblage. Reactivation, however, is not limited to framework-style regulation of cutting-edge technologies. It may mean opportunistic engagement with the sort of temporalised flow that the infrastructure for globally standardised time produces. 106 Equally, even at its most technologically advanced horizons, the infrastructure remains constituted in no small part by everyday engagement and popular imaginaries. Working up from everyday materialities can make the possibilities for engaging the infrastructure more apparent by making them more concrete. Fintech firms buy land to build servers adjacent to the walls of trading centres, or construct closed transmission systems capable of relaying information at maximum speeds: they take up space in cities, and are reached or reachable daily by cleaning and construction crews as well as brokers, bankers, lawyers, mathematicians and security services. Johns points to the Equinix NY5 data centre in Secaucus, which hosts volumes of high frequency trading. 107 Data mining operations also set up shop in areas with cheap energy, cool temperatures and favourable regulatory regimes. Every one of these spaces includes legal relations and legal practices, among other things at work in the overall assemblage. And the traps and infrastructures of which they are a part are constituted out of other traps and infrastructures, each circumscribed and materially supported by law. In the context of lethal autonomous weapons systems, also bound up with time technologies, Sara Kendall has demonstrated how attention to material conditions can point to old fashioned means of getting ahead of the ‘blink’, or the vanishingly small moment for intervention in a system predicated on a rapid flow of constantly changing information, pointing to the power of labour to pre-empt production. 108

105 Kingsbury (n 3) 181.
106 Cf. A Bastani, Fully Automated Luxury Communism (Verso 2019); N Srnicek and A Williams, Inventing the Future: Postcapitalism and a World without Work (Verso 2015); A Williams and N Srnicek, ‘#ACCELERATE MANIFESTO for an Accelerationist Politics’ (Critical Legal Thinking, 14 May 2013) <https://criticallegalthinking.com/2013/05/14/accelerate-manifesto-for-an-accelerationist-politics/>.
107 Johns (n 97).
108 S Kendall, ‘Law’s Ends: On Algorithmic Warfare and Humanitarian Violence’ in M Liljefors, G Noll, and D Steuer (eds), War and Algorithm (Rowman and Littlefield 2019) 114. Kendall draws the ‘blink’ from the work of Brian Massumi: see B Massumi, Ontopower: War, Powers, and the State of Perception (Duke University Press 2015).
A critical step to engage processes of change or transformation, whether with respect to the infrastructure for globally standardised time itself or some other implicated assemblage, includes knowing the myriad, mutual implications of time and law as material indices of intervention, and thereby to reconstitute the reality of the infrastructure as a political vector. None of these sites can simply be reimaged as something entirely other than what they are currently known to be—their durability militates against this. But they can be re-engaged and reconfigured in as many ways as there are points of connection among the social and material agents by which they are known to exist, across which legal practices play stabilising but contestable roles in myriad material forms. The constitutive action of the infrastructure for globally standardised time has been apparent here in its capacity to promote expansive expectations for lifeworlds in fields of global finance. But I close with the argument that the corresponding expansion of the infrastructure is also an ambivalent basis for renewed engagement and intervention in legal practice.