Time, Temperature and its Informational Turn

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De-metaphorizing 'temperature' in terms and times of information media

Biased by the desire to de-metaphorize the notion of temperature when applied to contemporary digital culture, the media archaeological focus rests on the term *entropy* as much as on the relation between cold storage ('thermal' objects) and hot data processing ('thermal' events).

As it has been brought up repeatedly within 'media ecology' (see Fuller, 2005; Peters, 2015), dealing with temperature can be an infrastructural or environmental challenge (increasing heat within micro-processors, as well as energy costs for computing power). Nonetheless, the core operations of binary information processing is not a matter of energy, but an understanding of 'temperature' turned upside down: not physical thermodynamics (Boltzmann's entropy), but Shannon's informational entropy.

'Entropy' has been the measuring unit of the second law of thermodynamics in physics which declares that the energy disorder of any closed system tends to increase and points to a uniform equilibrium, providing the metaphysics of an 'arrow of time' with a scientific grounding: everything decays, since heat tends to irradiate and dissipate. For a communication media source, one can say just what one would also say of a thermodynamic ensemble: When this situation is highly organized, it is not characterized by a large degree of randomness or of choice – 'that is to say, the information (or the entropy) is low' (Weaver, 1949: 13).

According to Michel Serres in Hermes IV, humans are immersed in 'thermic noise' (1993: 278), while in technological media, thermic metaphors turn into processual statistics. Protagonist of cybernetic aesthetics' Max Bense's radio play from 1968 *Der Monolog der Terry Jo*, starts from 'thermal' noise: from a random distribution of alphabetic letters, a computer successively generates character sequences which approximate human speech. The actual case is a women found in a boat after a physically thermal catastrophe (a storm) on a beach in Florida: Terry Jo is unconscious, but continuously uttering meaningless speech (Bense & Harig, 1968; see Siegert, 2011: 112f). Once an artificial language is identified as a stochastic process which generates a sequence of symbols, Markov chains can gradually synthesize the symbolic order of 'the human' language, starting with memoryless first order Markov chains making a probabilistic prediction that depends only on the current state of letter or word sequences.[1]

Boltzmann entropy and / or Shannon entropy

The very term 'entropy' oscillates between thermic temporality and informational value, between physical 'medium' (such as liquids) and 'media' artefacts in the techno-logical sense. For communication engineering 'entropy' in transmission itself is not related to the physical temperature but to discrete sequences of impulses coded as zeros and ones. Norbert Wiener proposed the very term 'entropy' as measure of the mean probability of statistical binary decisions (bits). By simply correlating communication theory with thermodynamics, his student Shannon burrowed the term but turned it upside down. This informational 'entropy' then became central foundation of his *Mathematical Theory of Communication* and until today it remains the very condition of possibility for all digital communication media.

In the beginning, there was a demon, transforming the irreversibility of thermic time into informational a-temporality. Nineteenth century statistical mechanics, itself immersed within the clouds of industrial coal smoke, discovered the irreversible linear direction of physical time. Any intelligent observation of thermodynamic movements such as, e. g., gas molecules which might contradict this physical tendency by active informatized intervention (James Clerk Maxwell's 'demon') is energy consuming (see Parrondo et al., 2015; Szilard, 1929; Maxwell, 1872). Boltzmann entropy defines how distant a *physical* system is from thermodynamic equi-balance, while Shannon entropy in *communication* engineering defines how many bit-decisions, in the statistic average, are required for the recognition of a single character from a (limited) alphabet on the side of the sender. In statistical 'thermic' distribution over time, spatiotemporal islands emerge against the tendency towards 'heat death'. In contrast to the law of increasing thermodynamic entropy, this occasionally is called 'negentropic'.

Electronic 'temperature': the thermionic tube

According to Wiener's *Cybernetics* (1948), the essence of binary information is neither matter nor energy which differentiates computation from energy-transforming machines in the 19th century. But the actual Turing-machine embodies both. Information is a specific measure of probabilities (where 'low probability means negentropy' (Brillouin, 1951: 337), conceptualized in the *bit* and electronically embodied first in flip-flop circuits by means of cross-related thermionic tubes. By its electronic clouds, communicational Shannon entropy is enabled from within the physical vacuum as thermal Boltzmann entropy. Temperature becomes non-metaphoric when detected within the core device of electronics itself: the Schrot effect in what is appropriately called 'thermionic' tubes, culturally objectifying the natural wonders of thunder and lightning (see Wiener, 1948: 40-56). All technical, even digital 'information' media are physical channels; here, thermal noise in the physical sense (so-called *Schrotrauschen*) interferes. The thermionic tube as the essential non-human agency of electronics (which means intelligent modulation of electricity by minimal voltage) translate energetic work into micro-energetic 'temperature', the streams and clouds of electron flow within the vacuum. Especially the triode liberated technical media from mechanical constraints, thus from erasure in usage. Still, the tube or its subsequent functional equivalent, the transistor in semi-conducting matter, are subject to physical and chemical decay over time themselves; therefore 'we are the first culture to experience our own archaeology on a daily basis' (DeMarinis, 2011: 211). The electronic triode tube which had been developed for telegraphic, telephonic and radio signal transmission, has been mis-used as a binary switching device in early electronic computing, forcing clouds of electron temperature (the physical real) into binary symbolic order.

The switching moment between 'on' and 'off' was called by Wiener – in an intuitive moment of epistemological poetry at a Macy conference – the 'time of non-reality' (see Pias, 2009). But even if – in theory – binary information is independent from physical entropy, in each concrete implementation, this time of non-reality is actual material aging and energy-absorption. In a truly media-archaeological operation of slowing down this moment to the extreme (von Baer), the binary switching reveals its entropic *tempoReal*.

'Sonic' time and temperature with Fourier

Different from cultural or historical narratives, the computer literally counts the world procedurally. In an algorithmic operation, Fourier-transformation identifies the individual frequencies constituting any mixed signal – an implicitly musical analysis indeed, revealing the time-based essence of any physical signal. It had been a thermal hallucination indeed which initiated such kind of analytics. Joseph Fourier got its initial impulse for developing his *Theory of Heat* as a member of the scientific task force attached to Napoleon's Egyptian mission (see Siegert, 2003: 249). Fourier's analysis turned implicitly 'sonic' heat conduction into cold, silent (techno-)mathematical calculation. His decomposition of temperature into harmonic sine waves reaffirms the occidental epistemology of a world ordered by Pythagorean ratios, but this time in a time-based, dynamic way, and resulted in an over-profiled separation of sound from noise (for the pleasure of aesthetics). An apparently continuous thermal, that is: physical configuration is transformed into discrete computability by mathematical *analysis*. Non-periodic functions in fact cannot be derived from Fourier series. The real challenge to this harmonic order therefore is thermal noise and thermodynamic stochastics.

Weather as data (clouds)

Media-mathematical analysis concentrates on the non-discursive (non-cultural) articulations and is therefore radically de-metaphorizing temperature. In 1922, Lewis Fry Richardson proposed weather prediction in numerical calculation by human 'computers', calculating incoming data from weather stations around the globe which are telegraphically transmitted almost in real time. A human media theatre: 'Imagine a large hall like a theatre' (1993: 219), directed by a man in charge 'to maintain a uniform speed of progress in all parts of the globe. [...] he is like the conductor of an orchestra in which the instruments are slide-rules and calculating machines', a parallel architecture for real time computing. Senior clerks were planned to collect 'the future weather as fast as it is being computed [...] coded and telephoned to the radio transmitting station' (ibid.). A transformation of thermic energy into information takes place in this 'computing theatre' (ibid.).

Hydrodynamics had been the ultimate mathematical challenge for John von Neumann, such as the nuclear fusion for the atomic bomb, resulting in more speed-efficient computing: the stored-program EDVAC architecture. Computing thermic systems belongs to the ultimate challenges of the Turing-machine itself. With Turing-machines, humanity dares to approximate the real physical world by computational analysis and synthesis (while at the same time defining the limits of such computation). Mathematical machines since Charles Babbage's design of an Analytic Engine aim to compute continuous dynamics discretely, with a set of real numbers, based on the mathematical tools of the infinitesimal calculus (Newton, Leibniz).

Data temperature is sublime, and the new 'weather' clouds are invisible: be it Ionospheric 'weather' conditions determining the signal-to-noise ratio of short wave radio communication (and electro-smog), or nuclear pollution. The digital machinery retreats into algorithmic opaqueness since nuclear testing has been substituted by the almost incomprehensible power of computational simulation.

In its interactive virtual environment "Dialogue with the Knowbotic South" (1994), the media art collective Knowbotic Research once created a three-dimensional data cloud transmitted by the measuring stations in the Antarctic; digital communication media and measuring devices produce thermic information that nature never produced itself – computed nature (Huebler, 1996). The Antarctic as informational space actually happens outside the polar region, as artificial nature in data representations of measuring and sensor instruments covering the area and producing, every second, a stream, a flood of data (see Wesemann, 1995). The data body of this Cyber-Antarctica is based on temperature data and ozone values – scientific material which has lost any deep meaning, conforming with Shannon's mathematical transformation of thermodynamic entropy into informational probabilities through communication channels. Nowadays, terms like 'cloud computing' are literally obscuring the techno-mathematical theory of information communication.

Temperature degree zero: 'cold' technological storage

Transmission and storage in media communication is conventionally kept apart. Such distinct operations, under the perspective of the temperature/energy/time equivalence, turn out as two extremes of one process: fast (hot) and slowed down (cooled) signal transfer. Endurance of matter is linked to deep freeze (as expressed by the very term 'permafrost' in Siberia), since the elementary molecules do not vibrate any more. Freezing signals is an extreme slowing down, an ultimate delay of signal transmission over a channel. While a 'thermal' theory of signal (and data) transmission has been expressed in communication engineering, this approach can be extended to storage as well (see Winkler, 2015), resulting in a generalized model of cultural tradition. The technologies and -logics of tradition relate to both the physical and the informational notion of 'entropy' – which, in turn, allows to describe *tradition* without using the noun 'time' at all, dis- and replacing it by more precise *termini technici* of operative tempor(e)alities.

Applied 'entropology' of storage media

Hidden behind the user interfaces of so-called 'social media', there is the regime of a physical infrastructure of data centers and the energy amount to cool such facilities; 'a single data center can require more power than a medium-size town' (see Holt & Vonderau, 2015: 82f).

According to the '8 degree rule', such an increase of the temperature shortens the endurance of data storage about one half. For digital storage, information is not completely unlike energy when it comes to storage: for the storage of one bit a minimal energy is necessary. Here, we come close to the 'Boltzmann constant'. Time vs. energy: Longer storage endurance for digital data carriers can be achieved by lower temperatures.

In a refrigerator at around 10 degrees Celsius the data endurance of a typical flash memory (e. g. a USB stick) is secure for millenia.[2] But in millenia ahead, the heating of the refrigerator will have increased the earth's entropy to a deadly degree. An alternative less vulnerable to thermic conditions is the recent development of optoelectronic storage media (e. g. nanostructured glass). Such records might even survive the so-called 'anthropocene' as an evidence of human civilization. But in future millenia, probably no being will be able to decipher a frozen electrostatic storage unit as a symbolic bit.

'Arctic' storage and the metaphorical risk: De-freezing and delayed transfer

The vocabulary of storage media is 'very much a language of temperature' (Frank *et. al.*, 2013).[3] Low temperature has become less a metaphor for eternal memory than for delay: rather an equivalent to the electric condenser than to the archive. The time-critical counterpart of 'archival' long-time preservation is condensed time in frozen water indeed; instead of endurance, we confront what Wendy Chun in terms of dynamic computer memories calls 'the enduring ephemeral' (Chun, 2011). In terms of technological media analysis, there is a correlation between time and temperature, speed, and heat, which is not just metaphorical. Storage is a 'cooled', slowed-down event – 'freeze frame' (see Diekmann & Gerling, 2010; Hámos et al., 2010). In the cinematographic 'moving still', endurance and processual media time are interlaced (see Green & Lowry, 2006). Recording is a temporal 'cooling', slowing down, or even freezing, of an otherwise transient signal. Friedjof Nansen's photos from his arctic expedition still addresses events beyond his own death.

The 'record' is usually associated with a crystallization or steady inscription, ranging from a paleolithic fossils to the archival textual document, and photographic chemistry or phonographic signal engraving (Genz, 2002: 234f). But there are *transitory records*, traces of a physical elements like the electron left on the screen on its measuring instrument (the oscilloscope), and dynamic memory by constant regeneration like the mercury-tube based acoustic delay line discussed by Alan Turing for electronic computer memory. A critical problem with such a system has been thermal indeed: 'the electronics required to perform the modulation, demodulation, amplification, and reshaping of the pulses was constructed mainly of vacuum tubes, and the heat given off by them would adversely affect the temperature stability of the delay lines' (Williams, 1997: 309). As a variation of the delay line for dynamic short-term storage of digital pulses, even air as memory was tested by mounting a loudspeaker on one wall of a room and a microphone on the other wall – rediscovered later in media art performance, by Alvin Lucier's notorious tape-based acoustic loop installation from 1970 *I'm sitting in a room*. A. D. Booth in Britain after the Second World War, due to the lack of suitable material for electronic devices, 'was forced to experiment with almost every physical property of matter in order to construct a working memory' for digital computing such as thermal memory: a drum whose surface was capable of being heated by a series of small wires which would locally heat a small portion and, as the drum rotated, these heated spots would pass in front of a series of heat detectors. 'When a hot spot was detected, it was immediately recycled back to the writing mechanism which would copy it onto a clean (cool) part of the drum' (Williams, 1997: 303).

Entropy in / as memory in computing

With digital memory there are no institutionally stable record repositories but dynamic *archives in motion* (see Røssaak, 2010) – a new condition which has been anticipated by the very technological nature of early digital computer working memories (RAM) for the intermediary storage of coded signals such as the mercury-based 'acoustic delay line'. Such instant memories were based on delay lines for the intermediary storage of coded signals, finally leading to the more enduring latency of magnetic core memory. Practically speaking, storing digital data carriers in ultra-low temperatures (be it a refrigerator or an iceberg) exponentially increases the probability for undamaged preservation. What has started as a 'thermic' metaphor ('Arctic' freeze for storage), returns within the mechanism of storage itself. Frozen water is a metaphor for slowing down the dynamic present; not yet memory, it is rather a delayed present: an equivalent to the electric condenser in its function as micro-storage. Permanence and endurance is not achieved in the traditional way anymore (which has been monumental fixation, *stasis* so far), but by dynamic refreshing, reminiscent of the resonant circuit in electronics, consisting of a wire spool and a capacitor which in delayed phase store and transmit energy as magnetic state and as electric dynamics.

Just like the phonographic record waits for the mechanic player to de-freeze its analog signals in a kind of technological re-enactment, there is a thermodynamic metaphor to express the relation of software to hardware in digital culture as well: '[t]he analogy between a computer program and a musical score – once described as 'frozen music' needing only an orchestra to melt it' (Campbell-Kelly, 2000: 399). What looks like a seduction by thermal metaphors, is here – in terms of a twin 'entropic' analysis in both its physical *and* informational sense – actually justified.

Micro-temperatures in time processing: the oscillating clock

The Long Now Foundation in the US installs a clock meant to keep time until the next Ice Age (in around 10000 years) driven by a mechanical oscillator (see Mackenzie, 2001: 255, note 1). But the wheel-driven mechanical clock as developed in the Benedictine monasteries of the late Medieval age is no ideal periodic oscillation, since there is an entropic dissipation implied in its material mechanism. There is no ideal pendulum, it always suffers from friction; that is why Huygens aimed at isolating (relieving) the time-giving oscillation (the pendulum's isochronism) from the actual technical realization. ‘Through isochronic oscillation the pendulum can exist as the autonomous embodiment of natural or physical time’ (Mackenzie, 2001: 244), different from the radio-controlled clock which periodically synchronizes to a reference clock elsewhere. But there is always loss of energy in subdued oscillation: the moment of contact between the suspended pendulum (as designed by Christiaan Huygens to achieve an isochronism) and the actual clockwork. This momentum asks for a description in strictly thermodynamic terms, as a dissipative system. The motions of the pendulum and the moments of its contact with the escapement convert potential energy to kinetic energy, and energy to discrete information to answer the clock-related question of actual time. The interlacing of time and temperature becomes tight in time-keeping mechanisms with their delicate and temperature-sensitive metal elements. Physical entropy, informational entropy and the (ir-)reversibility of the time arrow are interrelated in a trifold way. While the clockwork has served as model of the universe since late medieval times, it has been succeeded by the theory of the universal computer (in its double sense), where the clocking returns from within. Every discrete step in computing requires only sub-critical thermic costs. A further escalation in this infinitesimal, itself ‘temporal’ effort has been the *thermocompensated* piezoelectric quartz watch. Being a most exact resonator, the tuning-fork shaped quartz is still subject to an entropic ‘aging as phenomenon in which the vibrational frequency of the oscillator slowly changes over time’, and micro-ergodic ambient temperature changes (the coefficient of thermal expansion). For most exact laboratory timekeeping, the mechanism itself might be sheltered by temperature against environmental ‘temperature moods’ (*temperare* in the Baroque sense): the oven-controlled crystal oscillator. Another strategy is to install two crystal oscillators within one watch, with an analog compensation circuit which compensates for temperature-induced variance of frequencies by negative feedback. Here as well, the energy / information trade-off (neg/entropy) finally arrives: a major step in thermocompensation has been ‘the digital count adjustment method’, where the crystal frequency is allowed to drift with temperature, but an independent sensor (a *thermistor*) is used to measure the exact temperature of the crystal (Reding & Palasti, 2017). Minimal variances are thereby rectified; thermic metaphors are exorcized by techno-logical *analysis* of time.

Such a media archaeology of time-keeping directly links to Google’s alternative method of synchronizing time across cloud-based peripherals by chrono-thermically ‘smearing’ leap seconds to compensate for the gap between non-human International Atomic time (ATI) and the established cultural technique of Coordinated Universal Time (UTC); 'instead of one 'massive' jump backward of one whole second, Google sought and realized a long, dispersed leap that became a chronological coating or frosting, a smear' (Genosko & Hegerty, 2018).[5]

Coda

Discursive thermic metaphors are exorcized by techno-logical analysis, when the term technology is taken in its literal sense: referring to both the material existence of technical devices (with their physical entropy), and its conceptual regime in terms of mathematical communication engineering (Shannon's information entropy). Once more, the core media-theoretical question arises: how the symbolical, coded, algorithmic regime (vulgo 'digital') is implemented in the physical, worldly (vulgo 'analog') real. Once this relation is conceived not only as structural but as processual, a kind of epistemic thermodynamics of the machinery of media culture comes into sight.

Notes

1. In 1950, Claude Shannon wrote a paper on 'Prediction and Entropy of Printed English'.

2. As articulated in the journal Chip 5/2012: 128

3. As expressed in the thematic draft for the conference Archives of the Arctic. Ice, Entropy and Memory, Humboldt University, Berlin, September 18 to 21, 2013

5. With gratitude the author owes this link to the anonymous peer reviewer of this essay

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