Chapter 4

The Computer as Time-Critical Medium

CLOCKED LOGIC: THE COMPUTER

Time is a crucial criterion for media theory, as it provides insight into the being of technical media. The synchronization of signal flows, which is necessary for media to have an effect on humans, is based on a complex internal dramaturgy of time. In the digital computer, the classic cultural technique of timing becomes the literal “clocking” of chrono-logical sequences. This also applies to the networking of the computer itself; an entire hierarchy of time-critical operations is at work in the Internet (most importantly, the network time protocol for packet switching). When a defective computer produces a technological rhythm as it vainly attempts to access the hard drive and the internal synchronization ultimately fails, it becomes clear that the computer is relentlessly subject to the clock pulse of time. On the other hand, an intact computer enables signal and time axis manipulation in real time, as its operating system employs chrono-techniques like “pre-emptive multitasking” to anticipate the future and a “scheduler” to determine the optimal time window for computations. In this delicate temporal structure, informatics differentiates between “hard” and “soft” real time—a world that is oriented toward the human sense of time as well as signal processes themselves. Media-archeological analysis focuses on moments of digital time sensibility.

The concept of the computer as a time-critical medium includes key terms like stored programmability, cybernetic feedback, and recursion at the level of programming languages. Informatics speaks of the “semantic gap” between the computer and the programmer, which is simultaneously represented as a “temporal gap.” Discrete cycle, computing, and dead times constitute a micro-dramaturgy that deserves to be formulated as an epistemological object of genuine media temporality. However, this analysis only succeeds with the most precise electro-technical and computational knowledge of what actually transpires: a mathematically cool, electronically hot temporality. The strict media-archeological method thus corresponds to “a theoretically cool system for melancholically hot loops over limited time resources or thermodynamically time-limited computer hardware.”[1]

Time-critical symbol processing requires a much sharper focusing of the media analytical gaze than the general concept of “time-based media.” Computer architectures set the basic temporal conditions of the machine; operating systems, and especially the process of “time-sharing,” manage computing time for the quasi-parallel processing of incidental tasks; and signal-processing algorithms enable elaborate time axis manipulation. As the technical implementation of mathematics, the computer is not simply a symbol-processing machine; rather, its radical time-critical modes of operation also make it a complex time machine.

The so-called temporal logic of the computer serves as a model of its temporal modes in its branching sequences, transition relations, loops, and data access processes. During the development of hardware logic analyzers oscilloscopically visualize the individual computations of the computer in parallel channels. Such “monitoring” of process sequences in the computer for the purpose of optimization occurs as signal processing in real time, as a second order observation in accordance with the law of computing media. “Graphical data representation enables detailed understanding of dynamic processes on massively parallel systems,” reported *Vampir*, a tool for performance analysis and “in-depth event-based analysis of parallel run-time behavior and interprocess communication” based on the parallel storage of “event traces.”[2]

The digital computer does not have a problem with the processing of signals that are already symbolic and thus discretely coded, like alphabetical texts. The situation is quite different when the object of computer computation is supposed to be continuous physical time processes—in other words, the actual world with regard to the moorings of being and time. The computer only has a stake in temporal indexicality or real-world time at the level of its own time implementation. Discrete machines can hardly grasp this real-world time through digital signal processing, which is wired into the chips themselves. In the field of complex computations, “the need to treat clocked time discretely, which is associated with digitization, leads the hardware to determine the possibility or impossibility of a computation.”[3] At a fundamental and thus media-archeological level, however, the “halting problem” of the digital computer still exists: no program is able to determine in advance if another program will terminate in finite time. What is required here is not an abstract algorithm, but rather the actual implementation, the being-in-the-world (*in-der-Welt-Sein*) of the mathematical operation. “Because it is only possible to show that symbol processing has come to an end through its implementation, it is not sufficient merely to imagine the Turing machine; instead, it must be allowed to run."[4] The basic ontological questions of temporality thus flare up at the macro-time-critical level of "computing."

Counting itself is already an operative implementation and therefore a temporal form; Hermann Weyl calls for the iteration of the domain of natural numbers.[5] Arithmetic initially served to define time as the measurement of movement itself (Aristotle); analysis was then able to calculate the smallest movements as Δt (Leibniz's infinitesimal calculation); this was eventually followed by cybernetic time-series analysis and "linear prediction" (Norbert Wiener) as time-critical mathematics, which was implemented in the high-speed computations of the computer. The prerequisite for this was an increase in computation speed through electron tubes, which surpassed the electromechanical time limits that constrained Konrad Zuse's proto-computers Z1 to Z3.

Analog and digital computers calculate with fundamentally different temporal modes. Every Turing machine must always be implemented in real analog physics in order to be effective, even though its key feature lies in the fact that this material implementation is *ideally* not crucial for the information. In contrast to the virtually instantaneous parameterization of computing tasks in analog computers through current voltage, the execution of programs in digital computers is based on discrete, incremental time; algorithms form time sequences. The symbolic formulation of the program as a list spatializes the dynamics of a process in the two-dimensional field; however, the media-technical execution of a computer program displays this space in time, thus radically dramatizing the algorithm.[6] An algorithm f must be executed in physical time in order for its result $y = f(x)$ to become real. Every computational model of the world[7] is thereby subjected to a temporalizing imperative; otherwise it remains a simple "world picture" (*Weltbild*). This is the entire difference between pure mathematics and mathematized physics. "Mathematical structures (graphs, groups, topological spaces, etc.) do not change in time whereas computer science objects (databases, machines) often do."[8] The parameter of time initially remains external to mathematical models as such, yet the Turing machine as "abstract-state-machine" already "represents an . . . attempt at introducing dynamism into logic."[9]

Between numerically discrete computing time and the operative time of the analog computer, which equiprimordially acts as a simulated time process, a media-epistemological abyss opened up that has since been bridged by digital signal processing—that is, corresponding processors and algorithms.[10] In discrete signal processing, storage and time-critical moments are necessarily entangled; in discontinuous computing systems, scanning and storage are the most important operations.[11] In digital shift registers, capacitors are usually employed as buffers.

Unlike Vannevar Bush's differential analyzer from the 1930s, the Electronical Numerical Integrator And Computer (ENIAC) constructed in 1942 operated time-critically in its combination of tube technology and wiring. What is astonishing about this machine is not only its mathematical power, but also the fact "that it carried out such difficult tasks . . . in the shortest time." Galileo once had to measure the smallest fall times of bodies, and he employed an inclined plane to slow them down artificially. Electronic computing machines capable of feedback are able to measure the smallest intervals at lightning speed. Therein lies "*the special temporal relationship of this machine*: it operates in the microstructures or microprocesess of time, which cannot be utilized through human actions or thoughts"[12]—thus exceeding the human time window. This is a necessary condition for the chrono-technical effect called "real time." Media criticism must also differentiate processes in such delicate time domains.

Informatics recognizes the concept of concurrent behaviors in the computer: relative time windows *within* which an act is supposed to take place. Communication processes within computing architecture thus determine priorities and intervals. The clock pulse is not the only regulator here; rather, it involves a new kind of clockwork.[13] "The . . . distinguishing feature of the computer is its temporal creativity."[14] The computing machine here departs from the Newtonian universe, in which physical processes are reversible, and enters the realm of logical time. Indeed, the essence of the processual character of this subtle structure lies in the fact "that its being in time is not reversible but irreversible."[15]

Electronic media like radio and television and their methods of recording on magnetic tape are distinguished by the fact that their technical being is revealed in their implementation. Yet, the concept of technology only fully comes to the fore with the computer, as it represents the convergence of matter and mathematics, *techné* and *logos*. The computer is the medium in which the word becomes matter in the hierarchy of stored data from the bit to the "word." As imagined, the computer belongs to media theory; as a time-critical process implemented in the physical world, however, it belongs to media history—which, from the perspective of the computer, is inevitably time-bound and no longer necessarily historiographic. What distinguished Charles Babbage's analytical engine design in the 1830s from previous calculating machines was its time-critical element: it implied at the very least that the computational program could modify itself during the calculating process on the basis of temporarily stored results. In his description of a machine that was able to mechanically calculate everything that was mathematically calculable, Alan Turing emphasized the discrete conditions and thus the timing of the machine. John von Neumann also determined for the high-performance computer EDVAC that each step of data processing had to occur after another. The computer was thus described through its time behavior—up to asynchronous machines, the alternative to the Von Neumann architecture, which do not need to consider the slowest subcomponents.

From a time-critical point of view, the computer truly becomes accessible to media archeology through its micro-dramatic configuration. This perspective deciphers processes and events matter-of-factly as time series, while the historical discourse treats them as narrative elements. The era of the computer is written not simply as another chapter in media history, but rather as "Turing time."[16] In terms of media archeology, this requires new modes of representing temporal processes, as it makes available the entire history of technology up to the present. It is as important to write continuous and discrete conditions as they are technically signalized.

THE TIME OF THE FLIP-FLOP: 0/1 SWITCHING

The concept of chronology, which is so familiar in our culture, depends on the technical processing of binary signals. The object of switching algebra is logical and thus not time-dependent connection, but the relations between input and output signals in delay and memory circuits as well as frequency multiplication are especially relevant in their temporality.[17] The optimization of electronic data processing requires not only increasing the packet and integration density of the components on semiconductor plates, but also "reducing the delay times of an individual structure in an integrated circuit."[18] "Delay time" is the essence of binary time, as it refers to the switching time of bipolar transistors that elapses between a control signal and the point at which the collector current researches 10% of its maximum value. Digital media are fundamentally time-critical, as the basis of binary signal processing—the flip-flop circuit—divides time and thus recalls the etymological core of "time" itself: partitioning. Paradoxically, the same circuit simultaneously functions as the smallest binary storage for a "bit"; in such circuits, capacitors store the current state of both electron tubes, hence the name "decision circuit." The change of state itself is a change in current, which is triggered by a small, critical event moment.

The recoding of the notion of time as flow into a notion of time as discrete and nonlinear appears in Augustine's discussion of meter in prosody, which is critically connected to Aristotle's equation of time and counting. With the advent of the geared clock, this time-discrete aesthetic became technical at the level of measuring; in quantum physics, the world ultimately makes nothing but spontaneous time leaps. The nonlinear and nonchronological temporal modes of media are not founded on philosophy, but rather on their technical *a priori*: the discrete time of alternating current and binary signal processing.

The digital computer not only radically reformatted the concept of time *in* the twentieth century, but it also reformatted the concept of the "twentieth century" itself, as the "year 2000 problem" manifested in the last second of the last century. The "millennium bug" was a rare moment when people became aware of the time of the computer on a massive scale. The computer game "Little Computer People," which playfully dramatizes software errors, was itself affected by the Y2K bug, thus revealing the entirely unhistorical temporality of the computer.[19]

The specific temporality of the digital computer, which consists of discrete oscillatory clock pulses, transformed time itself into information. All preceding technical media were characterized by a material discursivity. For example, photography depicted a moment fixed on paper and cinematography presented an imaginary perceptual sequence through a succession of images on celluloid. On the symbolic side, vocal alphabetic writing and book printing brought about a temporally linearized cultural technique of reading.[20] However, the digital computer liquidates the material temporality of representational states in favor of a purely logical though electronically implemented code. At the operative level, the computer is constituted by radical time critique—namely, discrete scansions. At the hardware level, different successive stages of time—the linearities of past, present, and future—implode in a discrete electronic time. The computer thus proves to be a permanent media archeologist, which preserves the time-critical chrono-aesthetic of World War II.

Norbert Wiener conceptualized a computing machine to calculate the trajectories of enemy aircraft; John von Neumann constructed a machine capable of performing calculations far beyond the computing capacity of humans. Computing media are at the same time systems and procedures, techno-mathematics and implementation. The results of this simultaneously logical and operative time can resolve any kind of event. All of the binary-coded operations in the digital computer proceed according to the time-discrete sequentiality of the "on/off," from which is derived all higher (program) structures right up to the narrative effects they produce through human interfaces. In such a way, the implementation of alphanumerically coded symbol sequences is able to simulate any kind of chronology and the cultural phantasms of past, present, and future better than literary narratives. If the metaphysical tradition envisages time as a continuous series of present moments, then this present becomes impossible in discrete and thus kairotic time. The relation between the moments of symbolic time in the digital computer is no longer a relation between substantial elements that can each be ontologized (as the Pythagorean mathematical aesthetic presupposes), but rather a radically different interrelatedness—the temporal essence of the binary units of information 0/1, implemented in worldly technics. Systems theory also identifies the time-critical moment that is involved in every binary circuit. The form of a statement as a border separates two sides such that only one side can be observed and the other side cannot be reached "unless the border is crossed—that is, unless time is expended."[21] The clear distinguishability of two conditions does not occur in the abstract realm of ideas, but rather necessarily in the world and thus in time, such as the flip-flop circuit as the time-critical core of binary information processing. Niklas Luhmann emphasizes "that marking must be temporalized, and therefore all calculus makes use of time. . .. The 'marks' . . . are juxtaposed and superimposed according to definite rules. . .. But they only function as a sequence of operations, and thus only in time."[22]

THE CLOCK SIGNAL

According to Lewis Mumford, the clock ranks above the printing press in the list of factors that influenced the mechanization of society. "The clock, not the steam engine, is the key-machine of the modern industrial age."[23] Yet, digital culture did not begin media-epistemologically with the clock. In a genuinely media-archeological intensification of Mumford's argument, McLuhan pointed out in *Understanding Media* that clock time first became conceivable against the background of the enduring practice of alphabetic writing, which divided the flow of spoken language into smaller units that remained below the semantic threshold and whose literally elementary symbols encouraged scientific analysis. "Mumford takes no account of the phonetic alphabet as the technology that had made possible the visual and uniform fragmentation of time. Mumford, in fact, is unaware of the alphabet as the source of Western mechanism."[24] The development of clock time, time-based work organization, and time-critically implemented algorithms thus paralleled the typographic "Gutenberg Galaxy"—right up to the typewriter, which depended on the timing mechanism of the clock for the forward movement of the ribbon. In a "mechanical notation" to his analytical engine, Charles Babbage blurred the distinction between real machine and written sign by proposing a symbolic machine, which would enable not only the abstract analysis of the time behavior of the arithmetic unit in the form of a table, but also its actual reproduction as a time event—a diagrammatic simulation. "The table divides the time of a complete period of the machinery into any required number of parts; and it exhibits in a map, as it were, that which every part of the machine is doing at each moment of time."[25]

Digital computing machines deploy a calendaric of their own proper time; cultural perception is here confronted with the simulacrum of a self-referential time. The electronic computer as a contemporary condition of economic, informational, and cultural communication has no continuous time consciousness; rather, it is based on discrete hardware, pulse frequencies, and algorithmically programmed software. "Uniquitous computing" encourages an entire era to conceive of time processing in discrete steps. In the digital realm, "time axis manipulation" is spoken of differently than with classic analog media like phonograph, film, and video. The text-processing environment LibreOffice calls for the two-digit year dates in the document vault to be "interpreted" as years between 1930 and 2029, but this setting is individually variable. It is thus no longer mandatory for a computer-century to be based on the Christian calendar; rather, it transforms into an adjustable interval—a radical tempo-spatialization in computing space. Jacques Derrida defined *différance* for the culture of writing, but it has now expanded to the alphanumeric field.

The connection between time and number, which Aristotle defined theoretically, returns mechanically in the geared clock and electronically in the computer clock. However, this does not represent a recursion in a cultural-*historical* sense, but rather a superimposition. The epistemological characteristic is the quantization of time—an essential feature of the digital.

> Because microprocessors are complex structures of combinational and sequential logic, they require a clock pulse whose duration represents the smallest period for all of the processes executed in it. Through the internal time schedule controller, the *pulse generator* is thus in charge of all the processes controlled in and from the processor. In practice, quartz-controlled generators are employed. . . . For less stringent requirements . . . simple RC rectangle generators are sufficient. . . . With every cycle the microprocessor performs a partial operation step and then moves to the next condition. Consecutive operation steps constitute a *machine cycle*.[26]

Depending on the command, more machine cycles are necessary; the first is called the command read cycle ("instruction op code fetch"); a time diagram shows an entire command read cycle and diagrammatically facilitates orientation in (machine) time.

The goal of Alan Turing's symbol processing machine was to treat time discretely; it is informed not by the historical-continuous concept of time evolution, but rather by the media-theoretical (thus encompassing logic and engineering) insight into the necessity of discrete conditions T1, T2, etc. for the machinic mastery of numerical mathematics.[27] The Turing machine is a finite state machine that is always in an actual present.

> Nevertheless, a problem arises as soon as the past of the system is relevant in any way. In stateless systems no past actually exists in the system. . ., yet a

> changing state exists outside the system in its output and input values. The function *sin*(*kt*), for example, generates one value for every input value *k* to every point in time *t*; time is thus nevertheless located as linear progression outside the system.[28]

From a cultural-studies perspective, a long path of historical development lies between the macrotemporal *computus* used in medieval calendars and the clock signal used in computers (the inner time of the computer), yet media archeology reveals another path: the short circuit between eras and the compression of macro-historical distance to Dirac delta or impulse function intervals. The clock signal is functionally installed within the proper world of the computer and this is the very condition of its proper time, which cannot be compared to an external time. This time-critical aspect is crucial for the concept of the medium in implementation. As Charles Babbage wrote in 1855: "In order to perfectly understand a machine, it is imperative to have precise knowledge of the following: (1) The form. (2) The different parts. . . . (3) The precise moment when all of the different parts are set in motion, as well as the duration of the motion. This is the *cycle*."[29] In complex circuits, which depend largely on the synchronization of the electronic data stream, the measuring device of the logic analyzer serves not the quasi-philosophical function of verifying the validity of propositional logic, but rather the time-critical function of orchestrating virtually parallel pulse sequences. In the computer, the clock signal helps the circuits with reciprocal data synchronization in the temporal domain; therein lies the essence of the computer as a time machine. What the clockwork escapement mechanism initiated in the early modern period is evident here, too: periodic, rhythmic timing as the tuning of mathematics. Through the clock signal, the analog is articulated to the digital as the extreme compression of a dynamic process; at times, the apparently binary signal is itself composed of sine waves.

With the internal clock supply of the computer (and its antecedent, the feedback of electron tubes in the Meissner circuit), logic becomes not only mechanically operative, as in the scholastic mechanisms of Raimundus Lullus, but also time-critical. In order to construct master frequency clocks, a negation function is time-critically employed:

> Instead of drawing further conclusions from the results, as in logic, the negation leads back to the signal input, where the out-of-phase signal arrives with an infinitesimal delay due to the finite transmission rate and thus generates the inverse initial state, which reacts to the input again, and so forth ad infinitum. The negation of negation—albeit in the rather non-Hegelian domain of time—thus gives rise to a clock pulse that allows all other free-run input signals to be cut up in the microsecond rhythm.[30]

A DEFINITION OF DIGITAL MEDIA THROUGH TIME: CLOCK PULSES IN THE COMPUTER

The computer is realized through hardware, and its worldliness sets limits. The physically implemented Turing machine distinguishes itself from the ideality of its logical model through actual, not only linguistically formulated time. “Time never occurs in logic.”[31] Every binary circuit built in the real world is not a purely logical function, but rather always also a time function. “Symbols are created in continuous dynamical time, and are only preserved in discrete, arbitrary structures.”[32] Sampling always requires time- and value-discrete buffering; in this sense, everything that happens in the computer already represents an intermediate archival condition with respect to the world. In contrast to the purely symbolic order of the static archive, however, electrotechnically discretized relations possess a dynamic operativity and are thus temporally connected to the world.

The digital first occurs *in time-discrete implementation*, and thus as a genuine techno-mathematical operation. The basis of precise digitization is periodic timing, which introduces discreteness to computer time and relies on intermediate time, or strictly speaking the intermediate time of the clock pulse. Many digital gates operate at different speeds; the clock pulse is therefore needed to order these times and make them mathematically concurrent.

> Through the clock pulse time is microscopically quantized into computing time and rest time. For time-economic reasons, rest time is actually minimized as much as possible, but it is nevertheless indispensable to the secure exchange of information. . . . It also serves the performance-economy, such as battery run-time, because in contemporary semiconductor technology no electrical output is recorded during rest time. Looking deeper into digital circuit technology: before every time change, such as 0 -> 1, a “set up” time is defined up to which all gates must be finished—and they will be if the design is correct.[33]

This organization of time is an important criterion for stability, as it ensures that digital data processing is not only logical but also time-critical—that is, it can take place in the real world.

DOES TIME COUNT? THE DIGITAL, THE COMPUTER, AND THE SUBLATION OF MEDIA HISTORY

The time of the digital, insofar as it is based on relays and switches, permits approximation. “Therefore at any given time the circuit between any two terminals must be either open (infinite impedance) or closed (zero impedance).”[34]

This variable is explicitly "a function of time."[35] But what does time mean in this context? "Time *is* not. There is, It gives time. The giving that gives time is determined by denying and withholding nearness."[36] Shannon himself calls this 0/1 alternative the "hindrance" of the circuit. However, intermediate time itself (which Norbert Wiener defined as the "time of non-reality") does not count. "Between 0 and 1 there is no time. . . . It is the withdrawal of the real, through which the symbolic emerges."[37] Techno-mathematically discretized time only exists in the *ideal*, and this is the entire difference between calculating machines as theory and as actual technical event. An entire time world lies between theoretical and technical informatics:

> Because automaton theorys works with abstract concepts, this transition from one state to another in the theory occurs without intermediate stages. Automaton theory thus does not question how such a transition is actually technically executed by an automaton. It is only interesting, for example, that a flip-flop transitions from one stable condition to another within a certain period of time.[38]

In the digital mode, the signal is negotiated no longer as a continuous physical event, but rather as information. This paradigm shift in the concept of communication was introduced through the combination of electrotechnics and mathematics. It becomes plastic at the moment when amplifiers in communication lines (for which, in the case of the telephone, Robert von Lieben developed the electron tube), which had always also amplified interference, were replaced by the "regenerative repetitor," which was able to amplify the binary-coded signal to a large extent without errors because intermediate and boundary values were omitted. Logical time takes the place of physical transmission time.

The digital computer was more than the sum of all previous media, as it "represented a more refined and more effective intervention in time structures, as well as . . . the synthesis of various existing technologies."[39] In this respect, the temporal modes of all previous media were (in Hegelian terms) *sublated* in the computer. This was possible because it made the stream of time concretely discretized and thereby algorithmizable as software. The transmission of "streaming media" in the Internet (video, speech, and music) requires effective compression if the time window is supposed to remain close to real time. So-called "codecs" thus encode and decode signal streams.

Is the history of all previous media also sublated in the computer? On the contrary, the computer actually reconfigures the categories of media history itself. There were good reasons for distinguishing cultural techniques like counting and writing from technical apparatuses, in which processes are automatized and detached from human intervention. Technical media in the narrow sense were thus first introduced with photography, followed by phonography and cinematography. Such high-tech media completely broke away from traditional cultural techniques. Fully electronic media (which were not simply electrically augmented mechanical media) represented a new media episteme; they constituted a world in its own right, which was actually a product of cultural knowledge but which was entirely informed by the laws of logic and physics. The concept of media (besides its spiritualist derivatives) as discursively and scientifically formative was first due to this escalation in the form of electronic media, culminating in the moment when the concept of *media* was thematized outside the physical sciences. However, the definition of the computer as the combination of symbolic practices and high-tech or electrotechnical apparatuses results in a unique situation that defies the evolutionary model of media history. Apart from electronic media like radio and television, the computer practices a form of alphanumeric *symbol* processing that overturns the analog-technical world of continuous or discrete *signals*. It is thus very near to the fundamental operation of historiography itself in so far as it is based on discrete writing, which was so foreign to the time world of analog signal storage (like phonography). In view of the computer—in other words, from a media-archeological perspective—knowledge of the genealogy of Western symbol systems is as relevant as the knowledge of electrophysical technologies. The computer is the first true techno-logy, as it represents the alliance of *techné* and *logos* (as formulated by the ancient Greeks) or electrotechnics and mathematics (as formulated in media studies). While the history of the alphabet did not play a significant role for the concept of electronics, it is unexpectedly central for the *anamnesis* of the digital computer. McLuhan's expansive approach to the concept of media thus obtains a new media-theoretical relevance. On the one hand, he ushered in the concept of media with the title of his 1964 classic *Understanding Media*, thereby establishing media studies; on the other hand, he always kept the concept of the medium open to new connections and couplings that may still be yet to come. Part of the unique nature of media studies is that its object of study is constantly metamorphosing (unlike sciences with temporally closed subject areas, like ancient philology and classical archeology). The computer thus not only contains all of the temporal modes of previous media, but it also involves an emphatic time (or another macrotemporal time-relation) that is different from all previous media—the sublation of mathematical time in the computer.

COMPUTER TIME

The timing of the everyday flow of time through the geared clock and its escapement represented a mechanical precursor of the chronotechnical practice of discrete time coding. The clock pulse of the computer "enables us to introduce a discreteness into time, so that time for some purposes can be regarded as a succession of instants instead of a continuous flow. A digital machine must essentially deal with discrete objects."[40] Timing thus functions as the foundation of the *operative*, as the digital itself is implemented in real physics. Christopher Burton programmed a simulation of the Pegasus computer in the late 1950s. Time behavior separates replicas, simulations, and emulations of historical computers. "The simulation is . . . a bit-level simulation, that is, it is implemented at the logical equivalent of the molecular level of the machine. It replicates the behavior of the operating system exactly and animates the on-screen console in response."[41] The ancient Greek vocal alphabetic was a sub-semantic simplification of language; however, prosody first gave poetry its rhythm. Is this rhythm now migrating into computer algorithms? The difference between clock pulse and rhythm lies in the accuracy of time-critical *chronoi*—as defined by Aristoxenus on the basis of ancient Greek prosody[42]—which at the same time also distinguishes humans from machines as signal processing beings. Rhythm is imprecise, which is also inherent to the analog computer in contrast to the digital computer. "No analogy machine exists which will really form the product of two numbers. What it will form is this product, plus a small mechanism and the physical processes involved."[43] Accurate timing is a condition of digital precision as soon as it is performed by high-speed machines and not simply by people with pencils on graph paper. In his definition of "clocking," Turing added a note concerning his automatic computing engine (ACE): "All other digital computing machines except for human and other brains that I know of do the same."[44] In opposition to all of the reductions of neuronal signal processing to binary circuits, John von Neumann also noted that the brain communicates on the basis of chemistry. In place of accurate timing, the brain is dominated by neuronal "summation time," which corresponds to the integrator in the analog computer rather than the binary time-discreteness of the digital computer.[45] Neuronal oscillators actually differ from their technical equivalents in digital computers through internal phase shifts. Julian Bigelow emphasizes that the digital conceals the "forbidden ground in between" like an abyss in the real. "It does not seem to me enough to describe a digital process as being one in which there are two or more discrete levels in which you are only interested in saying whether you are at level A or at level B. I think it is essential to point out that this involves a forbidden ground in between and an agreement never to assign any value whatsoever to that forbidden ground."[46] In digital computers, it is understood that the value of this forbidden ground should never be written. The psychologist John Stroud thus recommended handling these transitions in practice as if they simply did not exist, and the logician Walter Pitts agreed to ignore continuity in the present.[47] However, this third exists in the domain of time—a special kind of ternary logic. Counting and computing are not simply functions of temporal operations, but rather they also make the concept possible in the first place; the consciously ignored intermediate time of binary conditions is the condition of possibility of the logical operativity of digital computers. McCulloch adds: "We have still a flavor of the continuum. When the probability of the Zwischen state is zero or negligible, we think chiefly in other terms."[48] The "forbidden ground in between" and the "Zwischen state" constitute the media-archeological level of media-technical temporal modes.

The computer is able to practice highly differentiated, discrete rhythms, whereas people physiologically perceive or cognitively assume simply continuous time—a rupture between actual signal processing and its perceptual effects. In early fully electronic computers, the timing rate was still in the audible frequency range up to 20000 Hz. In practice, as with the Z 22 of the Zuse KG, this was used by engineers as a form of conscious sonification to determine if a program was running regularly or in endless loops, thus crashing. The technicity of the medium, which otherwise remained hidden behind its contents, only manifested in moments of rebelliousness, interruption, and temporal accidents.

The time counted by the computer does not refer to actual clock time, but rather to the time that has passed since the computer was switched on; these time signals are derived from an internal piezoelectric crystal, and they thus represent an articulation of proper time. The delay time of a program constitutes a machine-sovereign temporal mode, which makes it autonomous of calendar, cultural, and historical time: the autopoiesis of media time. The circuit boards of processors now include battery-buffered real-time clocks, which continue to count after the computer is switched off; as a result, the internal counter immediately inputs the current time whenever the computer is switched on, and the computer thus conforms to global time. The time connected to the computer is always necessarily machine time, which replaces the previously merely symbolic order of calendar time. With the rise of machine time, calendar time collapses. With the positing of its own time base and the circulation of time signals as information, the system in the digital computer forms its own micro-temporal cosmos, which struggles with the entropic time of physics. "This clocking . . . must keep the pulses in step as well as prevent degeneration of the pulses over a number of cycles."[49]

THE IMPLEMENTATION OF MATHEMATICS AS MEDIA TIME

Technical knowledge relations not only pass through the people who create media but are also further developed and thus processed by them;

conversely, the proper names of thinkers and inventors almost negentropically outlive their mortal, historical biographies. Alan Turing also received the highest honor, as his name was bestowed on a logical machine—the Turing machine—which surpassed the individual person. In his 1936 essay "On Computable Numbers," Turing described how a person in the moment of computation (either mentally or on paper) is in a machine condition and thus in a transsubjective state. The Turing machine is a provocation of the historical foundation of mathematical knowledge in people. From a technical-historical or media-material perspective, the computer follows the series of electronic media like radio and television in a linear fashion. However, in a media-archeological sense—that is, deciphered as a technology in a broader sense of the word—it is not only an electrotechnical, but also a logical machine, which thus unexpectedly and nonlinearly calls for an entirely different, ahistorical state of mathematics and symbol processing. Inhuman and already predetermined evidence appears in mathematical objects (in geometry and arithmetic); they are thus also outside historical time. "Platonists are certain: every intelligent species inevitably develops the same mathematics as us, as it must be created from the same world of ideas."[50]

After World War II brought about a massive boost to innovation in the field of telecommunications, cybernetics no longer questioned individual media, but rather the systematic connection of their signal processing function. This epistemology did not evolve in the sense of the history of ideas, but rather it was the result of an inherent logic, a *logical proper time* of media technologies themselves. The waves and rhythms of media knowledge develop asynchronously in each historical context, and thus they are articulated not exclusively in the verbal written language, but rather in techno-mathematical argumentation. "When Shannon explicitly says that we have no need for a communications system for eternal truths . . . because such truths must be continuously reproducible at different times and places without technical transmission, it becomes abundantly clear how the essence of media diverges from our everyday concept of faith."[51] Media-archeological records are apparently not passed on in the mode of history, but rather in the repeated attempts of a genuinely techno-logical knowledge; roughly a century after Leibniz proposed a dual computer, for example, the engineer-captain Johann Helfreich Müller returned once again to this still unknown idea that a machine is capable of dual computations.[52]

The syllogistic mental operation as the primal scene of all logical machines—logic implemented in the real—is already played out in time through the quasi-medial necessity of an intermediate state (*medius terminus*). The conflict of logic versus time appears to be sublated. With the memory-programmable computer, logical calculus—reduced to Boolean logic statements with true/false values technified as one/off switching—is brought into the material world and thus becomes "real time." "Once we have the possibility of embodying this 0, this 1, the notation of presence and absence, in the real, embodying it in a rhythm, a fundamental scansion, something moves into the real."[53] A mathematical rather than metaphorical concept of media archeology then comes into play.[54] What is at work here is the calculating medium of the computer. "It is unique in human history that a culture should attempt to calculate and master the world with real numbers."[55]

The temporality of mathematics lies not in the realm of ideas, but rather in the worldliness of its media-technical operations—whether in the form of the "intermediate storage" of interim results in the registries of the central processing unit (CPU) of an electronic computer or in the classic form of the mathematical gesture on paper (and between them the overwriting sequences of the Turing machine on a tape loop).

> Every operation is almost completely sublated by a trace or . . . every operation virtually coincides with its grapheme-calculated trace. The most recent contribution of mathematics always also emanates a historical amnesia due to the fact that mathematics constantly overwrites and equalizes its history at the moment of its operation.[56]

The internal temporality of mathematics lies in its modes of implementation, but it is largely invariant with respect to external historical time. The temporal mode of mathematized media is thus likewise defined. As a condition of its essential *modus operandi*, circuit algebra can be functionally abstracted and raised above its concrete worldly implementation—like the concept of the virtual machine in the programming language Java. Even when an era of historical time elapses and this computer architecture is housed in a new physical form, its algebraic sense of time remains invariant.[57] In the foundational crisis of mathematics around 1900, "intuitionism placed a spatial continuum under the primacy of time. For Brouwer, therefore, mathematics had to prove itself solely through its activity, whereas for Hilbert it had to prove itself on paper."[58] Both of these modes—the abstract mathematical space of signs and machine activity—are entangled in the computer. Time lies here in the operative. While second order cybernetics later noted that every act of differentiation (what Spencer-Brown called "drawing a distinction")—in other words, the constitution of an observer difference—produces a microtemporal interval, L. E. J. Brouwer already pointed out that every mathematical operation has an irreducible temporality that precedes pure symbolic demonstration as an act of thought in the sense of operative diagrammatics. The thinking machine, the computer, exceeds this essential temporality in the field of symbolic manipulation itself—the time of the digital.

In a typewritten memorandum from April 23, 1942, on "digital computation for a. a. directors," which was written in the context of a conference on electronic fire controls in air defense, George R. Stibitz distinguished between analog and discrete-numerical computation. "Computing mechanisms have been classified as 'analog' or as 'pulse' computers. The latter term seems to me less descriptive than the term 'digital.'"[59] Stibitz added that "digital computers introduce a consideration not found in kinematic analog computers, namely the ordering of computation steps in time." He was referring here to the "number train" of 0 s and 1 s. "Digital computation is dynamic in character," and the digital computer is thus more than a traditional calculating machine; it is a genuine media-technical temporal mode born from the marriage of mathematics and logic.

From a media-archeological perspective, the computer operates in ahistorical conditions. For the nineteenth-century protocomputer designed by Babbage, the question of its proper temporalization arises: Should it be treated media-archeologically or historically? The core of the Difference Engine No. 1 was actually built (based on the techno-mathematical principle of *finite* differences) and presented at the 1862 London Exhibition; the detailed blueprint of the Difference Engine No. 2 only existed as a paper machine, however, until the arithmetic unit was finally realized in the London Science Museum on the occasion of Babbage's 200th birthday in 1991—"a modern original of an old design."[60] The trusted media-temporal concepts of museum curators and restorers of antique media here become confused. Unlike traditional kinds of technical drawings, digital computers as *per definitionem* symbolic machines represent a new type of paper machine whose temporal mode is removed from classic media history, as it can be replicated without loss at a material level (and as software). "Logical simulation as a virtual object in some respects survives the forensic test of historical utility."[61] It simulates a literary experiment as conscious anachronism: the conjecture that the computer would have already prevailed in Victorian England as the model medium. This results in asymmetries between social discourses and technical actuality.[62]

Turing's symbol-processing machine strictly requires that the time parameter be treated as *discrete*; it is based not on a historical-continuous concept of the evolution of time, but rather on a media-archeological conception of sequences of states. And yet each present of a finite state machine is the logical function of its past. "A current *state* is determined by past states of the system. As such, it can be said to record information about the past, i.e. it reflects the input changes from the system start to the present moment."[63] Turing's design of the principles of a symbol-processing machine was the answer to the problem of computable numbers, as his symbolic technology handled uncountable infinities in countable finite quantities. The clock, as

Turing wrote in 1936, introduces technically concrete "discreteness into time, so that time can for some purposes be regarded as a succession of instants instead of as a continuous flow. A digital machine must essentially deal with discrete objects."[64] This resembles Aristotle's approach to time: an apparently infinite differentiable flow is made countable through scalar measurement; time and clock go hand in hand.

In November 2007, veterans in the Nixdorf computer center in Paderborn and at the finally rebuilt "Colossus" in Bletchley Park successfully reenacted the encoding and decoding of intelligence using Enigma and Lorenz machines from World War II. For a series of operative moments, therefore, the museumized media were once again implemented, and within the framework of operative time, which sublates historical difference, they were in an equiprimordial rather than historical state. This was also true of the syllogistic machines of the early modern period. In contrast to Turing's automatic machine, which was programmed with tables, Llull's *Ars Combinatoria* was a system that depended on active reader participation and thus involved "cold" calculation (in McLuhan's sense).[65] And it required not only logical but also massive theological participation. The operation carries a historical index as vector, but the machine is also combinatorially operable without any historical context. It was also widely received—minus the discursively concrete impetus, that is—because it operates at the level of syllogistics, which was considered more or less invariantly valid from Aristotle to the twentieth century (via Boole and Shannon) and through all cultural-historical relativization, like a phase shift.

"The computer is not entirely realized in its own prehistory," Georg Christoph Tholen notes regarding the archeology of control media (rolls and chimes, calculators, punched cards, as well as calculus and logical machines).[66] The culture of nonlinear information processing in computers is not only an era of media history but also a challenge to the historical model itself. Vilém Flusser (who still wrote media histories) emphasizes that the "processual, historical . . . consciousness" is replaced by a "formal, calculatory, and analytical consciousness."[67] This was from the beginning (*en arché*) the media-archeological alternative to narrative.

THE MASTER FREQUENCY CLOCK

The more complicated the algorithms, the more rhythmic they are. The equalizing of parallel signal streams is time-critical and requires delicate synchronization. In the computer, 0 and 1, low and high, are time states or time values; the indeterminate zone cannot become operative in discrete time intervals. A logic analyzer registers each now-state and the immediate post-history of such signals. The timing mechanism in the computer does not display time, as the geared clock once did; rather, it generates a self-referential and thus idiosyncratic time world:

> The inner game of the machine is a constant clocked conversion of symbols. The rhythmic pattern of state transitions thereby follows strict formal rules. A fundamental property of computers is that future states only depend on the current state . . . and the inputs. . . . The *inner current state* is detached from the outer world. The computer thus only retains *the past in the present*.[68]

The distinction between clock pulse and rhythm, as thematized in ancient Greek music theory[69] and the neuronal oscillators in humans, comes into play here.

Konrad Zuse's electromechanical computer Z1 still operated with a clock pulse rate of 1 Hz, the Z2 with 3 Hz, and the Z3 already with 5–10 Hz. The fully electronic ENIAC rapidly increased the clock pulse rate to 100 Hz, and modern computers have long operated in the gigahertz range. This does not simply represent a quantitative increase, but it also changes into a new quality. Within the framework of complexity theory, time is no longer specified in absolute seconds, but rather it is relative to input size. The attention of time-optimized programming demands a chronotechnical view of process control. The concept of *algorithmic depths* thus also includes the elegant time complexity of an algorithm as a measure of information content.

John von Neumann's "First Draft of a Report on EDVAC"[70] stated that the acceleration of computing power required the analysis of time-critical processes, which was not yet possible with traditional computing times. This included above all shock wave equations in connection with hydrogen bomb explosions. "Neumann's computer concept inaugurated a paradigm shift in the concept of time. It describes a complex machine whose runtimes ideally tend towards zero but are in fact randomly minimal/maximal. Its paradigm is the atom bomb, whose momentary flash breaks all traditional concepts of time in the macrocosmos of the world."[71] Neumann's computer concept, with his principle of strict sequentiality in data processing, required an extreme minimization of the time intervals of calculation steps. As soon as the system started up it already needed the mastery frequency clock for its internal time control. It is important here to differentiate between machine clock pulses and machine cycles (for different operations). In the computer, the discretization of time through "clocking" is virtually complete: "extremely close moments, which are only separated by a few nanoseconds."[72] The sublime dissimulation of the temporality generated in the digital computer through quartz crystals lies in the fact "that it can separate a second of analog time with a divisor, which is beyond our powers of imagination."[73] Only chronotechnical media still understand such a time.

INTERRUPT: THE TIME-CRITICAL COUPLING OF COMPUTER AND WORLD

Interfaces between humans and machines, as well as machine-to-machine, constitute a coupling with time. Informatics calls this—notwithstanding the historiographic concept—an *event*. During the Cold War, US radar monitoring of airspace fed signals over telephone lines into the "Whirlwind" supercomputer. The processing of these signals in real time required a discrete dialogue between input and processing, which resulted (in the media-archeological sense) in the "foundational" (Claus Pias) introduction of an interrupt signal that was able to interrupt processing at regular intervals and sensorially perceive the environment. This engineering solution resulted in the rotating magnetic drum, which could temporarily store data until a predetermined time when processing power would again be available.

> Communication between input, computing, and output units thus raised a time-critical question concerning the issue of a collective and yet at the same time differentiated systemic rhythm. The triggering of communication through an interrupt had little to do with the clock pulse of the central computing unit; rather, it was the most economical common denominator for peripherals with different amounts of data.[74]

It also enabled a critique of uniform techno-beats.

> A system was no longer dominated by a collective rhythm, but rather a variety of rhythmic interruptions. As a result, anything that was not available to the system at a certain location and time or was not temporarily buffered did not exist. Continuities, such as the tracking of a moving target, were thus only an effect of an extremely rapid yet ineluctably discontinuous triggering.[75]

The intrusion of world time into the model medium of the present, the computer, occurs in different ways. Interrupt processing gives microprocessors the option to interrupt a running program through a control signal in order to allow another program to run first, after which the initial program continues.[76] Through such incursions of the external world (like sensors), the computer is "informed" in the sense of mathematical communication theory, especially in the case of bidirectional communication. The interrupt reacts almost instantaneously to an external event. Certain processors are microprogrammed in such a way that the code regularly calls the analog-to-digital converter if it is necessary to react to changes. As hardware, this chrono-logical responsiveness to time signals has been entirely "made flesh."

The so-called "masked interrupts" in computer programs enable interruptions that can be approved or refused by the programmer through corresponding orders. "During the execution of a time-critical program part, for example, interrupt approval is blocked."[77] An example is the weather forecast, which is continuously reevaluated on the basis of actual weather that the forecast itself cannot influence. In contrast to the thermodynamic world of the weather, the world of technological media represents a culture of the second order. The everyday success of media-technical operations is constant proof of its claim to validity. Turing's theoretical machine in 1936 defined computability as a continuous approximation of real processes. Temporal continuities called "world" are not entirely comprehensible from the machine itself, which operates with discrete symbols; informatics responded to this with algorithmic recursions as a mathematically operative time figure.

TURING'S MACHINE TIME: CLOCK PULSES AND SAMPLING

The operativity of finite state machines constitutes a linear sequence of events in time. "These events occur only at discrete 'moments'—between which nothing happens. One may imagine these moments as occurring regularly like the ticking of a clock, and we identify the moments with integers—the variable for time, *t*, takes on only the values 0, 1, 2, . . ."[78] Time thus becomes a property of computer numbers. A human observer "may think of the machine as operating continuously, and of our moments as corresponding to the instants at which he takes a sequence of 'snapshots' of the machine's condition"[79]—a perception that is familiar since chronophotography. The deterministic machine is always in a particular temporal state. The Turing machine operates not in a timeless space, but rather time-critically. "At any moment there is just one square . . . which is 'in the machine'"[80]—that is, on the endless tape underlying the model. This introduces a new concept of data not simply as abstract information, but rather as a temporal condition.

Being-in-the-world means being-in-time. The central theme in the algorithmic modeling of the Turing machine is the concept of finitude (the "halting problem"). A computing machine is always in a definite and thus discrete state due to the temporal clock pulse. In Turing's essay "On Computable Numbers," time also plays a technical role in the succession of processing steps in the machine clock.[81] The complex synchronization of data processing in the computer is modeled on industrial clock systems with master and slave clocks. Without such clocks, the computer would also be unable to process the available information in precise increments. The master frequency clock sets the start, end, as well as sequence and frequency of its calculation steps.[82] Yet, the computer as time machine does not actually fit into the technical-historical continuity of time devices:

> Computers thoroughly differ from clocks. Thanks to their capacity, which seems capable of managing everything all at once, they make time disappear rather than calling attention to it. The symbols they use to express time are not "analog," like the continuously advancing hands of mechanical clocks, but rather alternating "digital" signals that flash on demand in chopped lines.[83]

If digitization is the translation of the environment into the drama of information processing, then the time-critical constitutes its operative core. The Nyquist–Shannon sampling theorem defines the substitutability of a constant signal through a finite number of values—computable numbers. With a sampling rate of 44.1 kHz a value in the sonic range is time-discretely calculated such that it can be faithfully reproduced without any audible deterioration. If all of the intermediate values were relevant at every point in time, this process would have to run analog; in contrast, algorithmic filtering operates discretely. This practice is implicit in Turing's symbolic machine design; accordingly, time must be viewed—in a complete realization of its Aristotelian definition—as a succession of moments instead of a continuous flow. "If data can be represented in the computer through pulse sequences per unit of time, then conversely the computer can also extract data from all real pulse sequences per unit of time . . . and thus infinitely sample what can be finitely sampled."[84]

Such high-tech operations could obviously only exist in a culture that was discursively familiar with these kinds of negotiations of timing and disciplining. Foucault's *Discipline and Punish* not only analyzes the panoptic *dispositif* but also draws attention to the genealogy of *time planning*, which was gradually refined to calculations in seconds and which occurs today in the architecture of the computer. The digital computer itself does not understand time in the cultural sense; it evades the emphatic concept of time in favor of a purely signified tempor(e)ality in the form of timing and rhythm. Mechanical clocks determined the timing of industrial society; atomic clocks do the same for the post-industrial information age. Their accuracy is the condition of possibility for the operation of highly sensitive time-critical electronic communication and navigation systems. Dynamic systems (whether technological or natural) involve the execution of temporal processes, so their state can be indicated at any given moment. This time axis proceeds mostly in one direction and is understood as a continuum. In order for the digital computer to be implemented and placed in a medial state, an operative combination of current, voltage, and logic is required—in other words, an alignment of computation and temporality, which leads (in contast to Heraclitean becoming) to a radically discrete concept of time:

> In contrast to this [continuous concept of time], it is convenient to study discrete-action devices in terms of a hypothetical discrete time. Let us imagine that the continuous time axis can be divided into an infinite number of finite

> intervals, not necessarily of equal length. Moving along the axis from $t = 0$ toward $t = \infty$, we mark the points separating these intervals by characters t_0, t_1, t_2. . . These points then constitute a countable set. Let us further agree to represent the characters t_0, t_1, t_2. . . by a series of positive integers 0, 1, 2 . . . . . . The time instants t_0, t_1, t_2 . . . now denoted by numbers 0, 1, 2 . . . shall be called *discrete moments*.[85]

An essential protagonist on the computer motherboard is the timer, which counts electrical pulses. The pulses can come from any source, like an external quartz crystal that yields a certain number of pulses per second. The medium of time processing is not narrative, but rather counting.[86] The timer—in technical jargon it is occasionally called the "real time clock"—can also be addressed by the program itself, as its own form of time allocation. The timer in the Commodore 64 was thus operatively calculated in order to generate arbitrary numbers by the RND command, which resulted in (pseudo) randomness.[87]

In the early phase of the electronic-digital computer, the timer also had the additional function of refreshing the data stored in RAM, as memory chips were incapable of retaining electronic data in the time window of their existence for more than a few milliseconds. Another function of the timer in the computer was "the production of sounds."[88] To turn the argument around, this means that acoustic processes of time behavior in the computer—in other words, its essence as a time-based medium—could be perceived by the senses.

Leibniz's concept of the world as composed of monads already required timing. Monads "keep time with one another like separate clocks, so that they appeared to communicate with one another; but this appearance is merely a deceptive consequence of their synchrony."[89] This also applies to logical automata and their high-tech mode of implementation.

> In order to understand the function of a microprocessor, we must disentangle ourselves from what we previously learned in electrical engineering. There is no continuous current flow, as for example in a lightbulb. . . . In the microprocessor individual current paths are always connected for very short periods of time, so the time in which the current actually flows is determined by the *timer*, which is part of every microprocessor system. It sends . . . a clock pulse to the microprocessor. . . . A certain combination of switches then triggers a desired activity.[90]

The difference between logical abstraction and actual implementation in hardware comes into play here. The synchronization of discrete microelectronics requires strict sequentiality and the time-critical coupling of logical instructions and the processing of singular data in the same world of bits. Sequential data processing in the Von Neumann architecture of the computer embodies the thermodynamic arrow of time (entropy) of the physical world in a time-logical sense. "There must be some irreversibility to ensure that calculations go forward (from inputs to outputs) and not in reverse."[91] Within this microcosm, however, every specific computer architecture has its own temporal properties, as in the configuration of *asynchronous* processors. The individual components do not wait for a central clock signal; rather, they work at maximum speed as soon as they are addressed. The acquired time depends on the skilful control of the flow of data in order not to impede reciprocal communication—the becoming-intelligent of chronotechnical time.

The momentariness of digital signal processing is intensified in the elementary unit 0/1, thus *materially* in the flip-flop. Binary logic as a time-critical process is operative in this circuit, and *it thus resonates with Bergson's notion of the musical sense of time in humans*. "This reduction of the spatialization of duration to nanoseconds simulates the vibrations of pure perception more precisely than analog time. The higher the frequency of this rhythm, the more it can be compared to a wave, even if this wave consists of the most discrete elements."[92] Mathematics first gains knowledge of the world in implementation through the act of time (mediamatics). As infinitesimal calculus, the cuts produced by time-discrete sampling and discrete calculation steps are able to foster the illusion of reality as continuity. This implies, however, that reality is perhaps not a becoming at all, but rather a nonlinear fabric of time.

TIME FUNCTIONS: SEQUENTIAL AUTOMATA AND MEMORY PROGRAMMABILITY

The limits and chances of the Turing machine manifest in time. It becomes comprehensible through the model of the endless paper roll (apparently inspired by the typewriter), which makes Cantor's concept of the "countably infinite" extremely concrete. The speed of computing routines in sequential architectures is a function of distance and time. Turing sought to access the stored records *quickly*.

> In general the arrangement of the memory on an infinite tape is unsatisfactory in a practical machine, because of the large amount of time which is liable to be spent in shifting up and down the tape to reach the point at which a particular piece of information required at the moment is stored. . . . One needs some form of memory with which any required entry can be reached at short notice. This difficulty presumably used to worry the Egyptians when their books were written on papyrus scrolls. It must have been slow work looking up references in them, and the present arrangement of written matter in books which can be opened at any point is greatly to be preferred. . . . Memory in book form is a good deal better.[93]

The intrusion of numbers into the alphabetic code (the page numbers in books) effectively made typographic memory addressable. This passive memory becomes active in the concept of memory programmability. John von Neumann defined its computational format in 1945. In the integrated program memory, commands and data are filed in the same format. The stored data thus potentially revises the current set of instructions; as a result, the diachronic is synchronously operative. Jacques Lacan's interpretation of the unconscious corresponds to Von Neumann's program memory and is thus inspired by media archeology (in the sense of a recursion rather than a historical causal chain).[94] Neuronal human memory is also not an emphatic archive in the sense of accumulation; rather, it is processual and dynamic in that it constantly converts incremental, impulse-like diachrony into synchronicity.

Memory programmability also requires the introduction of *dynamic* buffer storage for short-term values, which is realized in its most direct form in registers. This qualitative leap over previous computing machines was also accompanied by an exponential leap in the speed of computational processes, as the introduction of the electron tube permitted a maximum switching time of 200 operations per second.[95] For the memory programmable computer, "not only must the memory have sufficient room to store these intermediate data, but there must be provisions whereby these data later can be removed, i.e., at the end of the (t + dt) cycle, and replaced by the corresponding data from the memory."[96] This concept was dynamically realized in the early period of electronic computers in the form of delay lines for signal chains as circulating data words. A central temporal mode of high-tech media, the Δt, was actually implemented, and this chronotechnology made time itself obsolete. Contemporary storage technologies are able to write, read, and/or delete values at any time. "The typical computer program does not exemplify solely linear thinking. Programming is an activity that relies on both hemispheres of the brain. A program consists of doubling back, of loops within loops, of branching off in different directions. It is thus an apt symbol for contemporary temporality. . . . There are species of time which no longer progress."[97] The Turing machine "writes" and "reads" like humans—namely, in discrete sign sequences and saccades. "The fact that a sequence proceeds step by step in time and cannot be viewed at a glance in its entire infinite expanse is an immediate consequence of our situatedness in time. The task is therefore to examine the relationship between mathematical objects and temporality, this exquisite human moment of being (*Dasein*)."[98] Current computer architecture is dominated by temporal sequentiality instead of delicate parallel data processing; the rapid central clock pulse and the time management of the operating system compensate once again for this temporal disadvantage. Every modern operating system is actually characterized by multitasking or quasi-parallelism in data processing, which connects increasingly complex synchronization problems. The computer was never as time-critical as it is today. In the concept of memory programming, the necessary connections corresponding to the commands coded in working memory are only established when needed, which results in greater flexibility in the time-critical field. "Thus all sorts of sophisticated order-systems become possible, which keep successively modifying themselves and hence also the computational processes that are likewise under their control. In this way more complex processes than mere iterations become possible."[99] A true chronopoetics thus emerges.

TIME-CRITICAL PROGRAMMING

The programming of computers always also requires time-critical consideration of data synchronization. The so-called "profiler" finds out how long the machine is needed for each operation. This unique temporal dramaturgy effectively makes the machine a world unto itself, in so far as "world" is conceived as a temporal structure. What is attractive about programming in assembly language is the fact that it enables control of the operation of the computer "up to the final ticks of the system clock."[100] At the level of media archeology, the greatest possible proximity between human and computer lies in time-critical machine programming. The programmer is also closely oriented towards the working and temporal modes of the processor through the abbreviated process of so-called "mnemonics" in assembly programming, which allows every procedural step to be predetermined. Many time-critical applications are thus still programmed in assembly despite the user-friendly standard language.[101]

Time-critical *techné* manifested in ancient Greece with the playing of music.[102] This connection becomes evident as techno-mathematical reentry for the current era in the *Lexicon of Music Electronics*, whose entry on "machine language" emphasizes the time-critical element. The time-critical is here associated with hardware.

> A program written in M. can be immediately understood and executed by the central processing unit of the computer, which normally ensures a much faster execution compared to programs in a higher (but nevertheless easier to learn) programming language. For example, it is useful to program in M. for direct sound synthesis, . . . as many computational processes must occur in the shortest time.[103]

This time form thus reveals itself sonically "in the domain of sound synthesis, in which the time structure of processes is to some extent the only object."[104] For a long time, electronic images were also only representable as sequences of pixels in time and consequently as mathematical functions of the time axis, which virtually made them sonic events. However, current graphics memory no longer requires refresh cycles, which makes the temporal dynamization of the image nothing more than a media-archeological interlude.

In 1971, the programming language Smalltalk made it possible to rewrite a program "on the fly" during its runtime, which was previously only feasible in machine code. A relatively entangled temporal relationship emerges, especially with respect to sound objects—in other words, whenever the program refers to a process that takes place entirely in time. "For example, does an algorithm for sound synthesis refer to a sonic event or to the machine that created it?"[105] In the SuperCollider programming environment, signal processing enables the instrumentalization of the time parameter at the programming level for the composition of music. The processing of musical signals directly on the basis of their digital sampling requires the use of techno-mathematical intelligence. Signals are thereby conceived not semiotically as signs, but rather media-analytically as a time function. Pseudo-parallelism is achieved here through skillful synchronization. Complex signals result in chronotechnical complexity, and the concept of time shifts from a philosophically and culturally emphatic signifier to an operative signifier.

The MIDI standard of 1982 already implemented the temporal element in computer music by allowing the instruments to be detached from the source. This occurred even more completely in the "physical modeling" of the instruments themselves. This approach operates at the level of the acoustic real and links computing time directly to the sonic event rather than its musical-harmonic idealization in the Pythagorean sense. It is precisely the psycho-acoustic reality that stochastic calculus seeks to simulate. Concrete instruction codes in SuperCollider generate quasi-random sequences of numbers in order to produce frequentative imprecision, which is perceived by the ear as a signature of the natural rather than synthetic abstraction.[106] SuperCollider was developed for the composition of electronic music, and it therefore enables manipulation at the time-critical level. A cascade of time-critical operations structures time in the microtonal range. The "yield" command allows a smooth merging of the sound and thus a time-critical coincidence. With the "stream" command, the system overrides moments of waiting and pausing by providing a new value for every point in time. Such are the sonic temporal modes of informatics.

NOTES

1. Martin Carlé, comment from the seminar "The Computer as Time-Critical Medium," Helmholtz Center for Cultural Techniques, Humboldt University, Berlin, winter semester 2002–2003.

2. Developed by GWT-TUD GmbH, Dresden; see *Vampir 8.5*, http://www.vampir.eu.

3. Sybille Krämer, “Was haben die Medien, der Computer und die Realität miteinander zu tun?,” in *Medien Computer Realität. Wirlichkeitsvorstellungen und neue Medien*, ed. Sybille Krämer (Frankfurt am Main: Suhrkamp, 1998), 19.

4. Philipp von Hilgers, *Kriegsspiele. Eine Geschichte der Ausnahmezustände und Unberechenbarkeiten* (Munich: Fink, 2008), 171. Von Hilgers here refers to Gregory J. Chaitin, *The Limits of Mathematics: A Course on Information, Theory and the Limits of Formal Reasoning* (Singapore: Springer, 1998), 11.

5. Nils Röller, *Medientheorie im epistemischen Übergang. Hermann Weyls Philosophie der Mathematik und Naturwissenschaften und Ernst Cassirers Philosophie der symbolischen Formen im Wechselverhältnis* (Weimar: Verlag und Datenbank für Geisteswissenschaften, 2002), 83.

6. See Bruno Bachimont, “Formale Zeichen und digitale Computation,” in *Spektakuläre Experimente. Praktiken der Evidenzproduktion im 17. Jahrhundert*, ed. Helmar Schramm, Ludger Schwarte, and Jan Lazardzig (Berlin: Walter de Gruyter, 2006), 407.

7. See Konrad Zuse, *Rechnender Raum* (Braunschweig: Vieweg, 1969).

8. Juri Gurevich, *Logic and the Challenge of Computer Science* (New York: Computer Science Press, 1988), 4.

9. Matthew Fuller and Andrew Goffey, *Evil Media* (Cambridge, MA: MIT Press, 2012), 80.

10. See Morris Rubinoff, “Analogue vs. Digital Computers: A Comparison,” *Proceedings of the Institute of Radio Engineers* 41 (1953): 1254–62.na

11. A. Kley and G. Meyer-Brötz, “Analoge Rechenelemente als Abtaster, Speicher und Laufzeitglieder,” *Elektronische Rechenanlagen* 3.3 (1961): 120.

12. Max Bense, “Kybernetik oder die Metatechnik einer Maschine,” *Merkur* 5 (1951): 205–18; rpt. in *Ästhetik als Programm. Max Bense/Daten und Streuungen*, ed. Barbara Büscher, Hans-Christian von Herrmann, and Christoph Hoffmann (Berlin: Vice Versa, 2004): 57f.

13. See Christian Steininger, “Zeit als kulturwissenschaftliche Schlüsselkategorie,” in *Zeit in den Medien. Medien in der Zeit*, ed. Werner Faulstich and Christian Steininger (Munich: Fink, 2002), 9–44.

14. Marshall McLuhan and Eric McLuhan, *Laws of Media: The New Science* (Toronto: University of Toronto Press, 1988), 53. “While clocks are all set to the same exacting sequence, duration, and rhythm, the computer is free to manipulate all three of these temporal dimensions by merely changing the program.” Ibid. McLuhan here refers to David Bolter, *Turing’s Man: Western Culture in the Computer Age* (Chapel Hill: University of North Carolina Press, 1984), 38f. Bolter himself time-critically intensifies it. “In another sense, the computer processes time itself.” Ibid., 102.

15. Bense, “Kybernetik,” 59. Bense here refers to Wiener, *Cybernetics*, 30–44.

16. This was the title planned for the last volume of Friedrich Kittler’s *Music and Mathematics* series.

17. “In practice, logical and temporal links often co-occur.” Heinz Greif, *Messen, Steuern und Regeln für den Amateur* (Berlin: Deutscher Militärverlag, 1971), 197.

18. Otger Neufang, *Lexikon der Elektronik* (Braunschweig: Vieweg, 1983), v.

19. See Stefan Höltgen, "Vom Bug-on-a-chip zum House-on-a-Disc. 'Little Computer People' und die Archäologie des Computerfehlers," *Retro. Kulturmagazin für Computerspiele* 21 (Autumn 2011): 12–14.

20. See Walter Ong, *Orality and Literacy: The Technologizing of the Word* (London: Methuen, 1982).

21. George Spencer-Brown, *Laws of Form* (New York: Julian Press, 1972); qtd. in Niklas Luhmann, "Die Form der Schrift," in *Germanistik in der Mediengesellschaft*, ed. Ludwig Jäger and Bernd Switalla (Munich: Fink, 1994), 405f.

22. Niklas Luhmann, "Die Realität der Massenmedien. Niklas Luhmann im Radiogespräch mit Wolfgang Hagen," in *Warum haben Sie keinen Fernseher, Herr Luhmann? Letzte Gespräche mit Niklas Luhmann*, ed. Wolfgang Hagen (Berlin: Kulturverlag Kadmos, 2004), 68f.

23. Lewis Mumford, *Technics and Civilization* (London: Harcout, Brace & Company, 1934), 14.

24. Marshall McLuhan, *Understanding Media: The Extensions of Man* (New York: McGraw-Hill, 1964), 160.

25. Dionysius Lardner, "Babbage's Calculating Engine," *Edinburgh Review* 59 (July 1834): 314; qtd. in R. H. Babbage, "The Work of Charles Babbage," in *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery,* ed. Howard Aiken (Cambridge, MA: Harvard University Press, 1948), 15.

26. Manfred Krauß, Ernst Kutschbach, and Eugen-Georg Woschni, *Handbuch Datenerfassung* (Berlin: VEB Verlag Technik, 1985), 165.

27. See also Zuse's *Rechnender Raum*, in which the computer pioneer claims that the universe is calculable as a constant mutation of discrete states—namely, as a chain of pulse transmission relays.

28. Julian Rohrhuber, "Das Rechtzeitige. Doppelte Extension und formales Experiment," in *Zeitkritische Medien*, ed. Axel Volmar (Berlin: Kulturverlag Kadmos, 2009), 208f.

29. Qtd. in Bernhard Dotzler, *Diskurs und Medium. Zur Archäologie der Computerkultur* (Munich: Fink, 2006), 182.

30. Kittler, "Real Time Analysis," 193.

31. John von Neumann, "Probabilistic Logics and the Synthesis of Reliable Organisms from Unreliable Components," in *Automata Studies*, ed. Claude E. Shannon and J. McCarthy (Princeton, NJ: Princeton University Press, 1956), 44.

32. H. H. Pattee, "Discrete and Continuous Processes in Computers and Brains," in *Physics and Mathematics of the Nervous System*, ed. M. Conrad et al. (Berlin: Springer, 1974), 129. Pattee here refers to Emil Post, "Absolutely Unsolvable Problems and Relatively Undecidable Propositions: Account of an Anticipation," in *The Undecidable: Basic Papers on Undecidable Propositions, Unsolvable Problems and Computable Functions*, ed. Martin Davis (New York: Raven Press, 1965), 420.

33. Frank Winkler, message to author.

34. Claude Elwood Shannon, "A Symbolic Analysis of Relay and Switching Circuits," in *Collected Papers*, ed. N. J. A. Sloane and Aaron D. Wyner (New York: IEEE Press, 1993), 472.

35. Ibid.

36. Martin Heidegger, *On Time and Being*, trans. Joan Stambaugh (New York: Harper & Row, 1972), 16.

37. Siegert, *Passage des Digitalen*, 9.

38. Konrad Zuse, "Rechnender Raum," *Elektronische Datenverarbeitung* 8 (1967): 343.

39. Zielinski, *Deep Time of the Media*, 31.

40. Alan M. Turing, "Lecture to the London Mathematical Society on 20 February 1947," in *A. M. Turing's ACE Report of 1946 and Other Papers*, ed. B. E. Carpenter and R. W. Doran (Cambridge, MA: MIT Press, 1986), 111.

41. Doron Swade, "Virtual Objects: Threat or Salvation?," in *Museums of Modern Science*, ed. S. Lindquist, M. Hedin, and U. Larsson (Canton, MA: Science History Publications, 2000), 144f.

42. See Lionel Pearson, introduction to *Elementa Rhythmica: The Fragment of Book II and the Additional Evidence for Aristoxenian Rhythmic Theory*, by Aristoxenus (Oxford: Clarendon Press, 1990), xxxiv. Pearson elaborates: "One of the difficulties in reading Aristoxenus is to distinguish the special or technical use of a word from its general meaning."

43. John von Neumann, "The General and Logical Theory of Automata," in *Collected Works of John von Neumann*, ed. Abraham H. Taub (Oxford: Pergamon Press, 1963), 5: 293.

44. Turing, "Lecture to the London Mathematical Society," 111.

45. John von Neumann, *The Computer and the Brain* (New Haven: Yale University Press, 1958), 43f.

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47. Ibid., 186f. See also Claus Pias, "Time of Non-Reality. Miszellen zum Thema Zeit und Auflösung," in *Zeitkritische Medien*, ed. Axel Volmar (Berlin: Kulturverlag Kadmos, 2009), 267–82.

48. Gerard, "Some of the Problems Concerning Digital Notions in the Central Nervous System," 197.

49. T. K. Sharpless, "Mercury Delay Lines as a Memory Unit," in *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery,* ed. Howard Aiken (Cambridge, MA: Harvard University Press, 1948), 103–9.

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57. See Daniel Hillis, *Computerlogik. So einfach arbeiten Computer* (Munich: Goldmann, 2001), 33.

58. Von Hilgers, *Kriegsspiele*, 157. Von Hilgers here refers to Hermann Weyl, "Über den Symbolismus der Mathematik und mathematischen Physik," in *Gesammelte Abhandlungen* (Berlin: Springer, 1968), 4: 529.

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60. Swade, "Virtual Objects," 142.

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