Content

Epistemological machines and protocomputing

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In early 2012, a group of researchers attracted wide attention by showing that the logical components of digital computing could be realized using swarms of soldier crabs. The work implements a theoretical "ballistic" model of computing, where logic is enacted through idealized physical interactions, but intriguingly replaces notional billiard balls with swarms of living crustaceans [Gunji et al., 2012]. Aside from the mad poetry of its central premise – a computer made from crabs – this work strikes a popular chord because it addresses a disjunction that we encounter every day. While the computing machines we spend our lives attached to are on the one hand clearly material things – slabs of glass, plastic and electronics – the process of computation itself is completely obscure and apparently immaterial. The comedic spark of a computer made from crab swarms is a product, we suggest, of short circuiting this disjunction, demonstrating computation happening in the world with us, rather than in some hidden abstract realm.

Ralf Baecker's computational machines address this same question; of how computing happens, and in particular how it operates in the world with us. Like the crab-swarm experiment, Baecker's artworks resemble no familiar computer: instead of screens and keyboards we encounter strange mechanical contraptions, warbling crystals and networks of strings and levers. As they work these machines enfold us in tex-

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tures of movement and sound – perceptual traces of a distributed process. Working at a sculptural scale, Baecker emphasizes the physical presence of computing machines; and, in our increasingly digital culture, this is a point worth making. But, as we will argue below,Baecker's machines also go much further in investigating and transforming computing as we know it.

What kinds of machines are these? If they are in some sense computers, then what can they say about computing? Baecker offers one possible answer, citing the influence of early mechanical automata – what he describes as theatrical, philosophical or epistemological devices [Baecker, 2013a, 2013b]. These are machines for thinking with, devices that demonstrate, enact or provoke forms of knowledge. Baecker contrasts this reflective function with the "utilitarian" computers of our everyday experience; though this is not to say that our familiar computers are any different in their operation. Following Foucault, Jussi Parikka [Parikka, 2013] argues that all media are "epistemological machines" – that they "participate in creating regimes of knowledge across arts and sciences". We are immersed in a regime of knowledge that our machines reinforce, and so it becomes transparent to us. By physically transforming the computer – and ultimately also transforming computation itself – Baecker's work prompts us to reflect on these machines and their grasp on the world.

Rechnender Raum

In Konrad Zuse's 1969 *Rechnender Raum* – "calculating space" – he posits the notion of a computational universe; that space itself is a computing machine with finite, discrete states [Zuse, 1969]. In adopting Zuse's concept for his own *Rechnender Raum*, Baecker creates a literal, sculptural "calculating space": an open latticework of strings, pulleys and levers manipulating a strange elastic "display" at its core (Figs. 1–3). This computer is literally transparent; the state of the machine is stored in the positions of the mechanical levers arrayed on its outer surface. These levers are linked into modules that form logic gates – the elementary units of digital computing, combining discrete input states into outputs. Where integrated circuits run at millions of cycles per second, this machine updates its state at a more human time scale, once every few seconds. *Rechnender Raum* thus makes computation physically apparent, "zooming in" on the logical and symbolic operations that underpin our everyday digital computing.

This "open", mechanical computer recalls some twentieth-century epistemological machines; and these in turn offer some useful counterpoints to *Rechnender Raum*. The Digi-Comp I and its successor the Digi-Comp II were mechanical computing devices manufactured in the 1960s and sold as toys "to demonstrate the apparatus hidden within the circuits of the giant brains of today" ("Electronic Computer Brain" [E.S.R., 1963]).

Fig. 1. Ralf Baecker, *Rechender Raum*, Trinitatiskirche Köln, 2007.

Fig. 2. Ralf Baecker, *Rechender Raum*, detail, 2007.

Fig. 3. Ralf Baecker, *Rechender Raum*, installation view, Moltkerei Werkstatt Köln, 2007.

Like *Rechnender Raum*, the Digi-Comp I makes a virtue of being open "so complete operations can be viewed". The Digi-Comp II was a programmable binary calculator that used marbles and mechanical gates to methodically process input into output. Advertising for these toys reflects their historical and social context, as well as a specific notion of the role and value of computation. "You will be able to add, subtract, multiply – solve problems – solve riddles … think how amazed all your friends will be when you solve problems of missile countdown, satellite re-entry and missile checkout" ("Electronic Computer Brain" [E.S.R., 1963]). The Digi-Comp II (c. 1967) "shows how computers solve math, business, science & other problems" including bookkeeping, summing fractions and "population explosion" ("Digi-Comp II" [E.S.R., 1967]). While this space-age celebration of computing seems charmingly old fashioned, these machines illustrate some foundational characteristics of contemporary computing. The notion of task or problem is fundamental, and the cultural and epistemological value of the computer is linked to the space-age problems it solves. This emphasis is reflected in the spatial and temporal organization of these open machines. Computing here involves providing a "problem" – a set of inputs and a program or logical configuration – and working through a kinetic process that terminates at a solution.

Like the Digi-Comp, Baecker's *Rechnender Raum* renders the logical elements (Fig. 4) of digital computing – binary gates – in mechanical form, and exposes computation as a legible, kinetic process. However, there are some striking contrasts in the

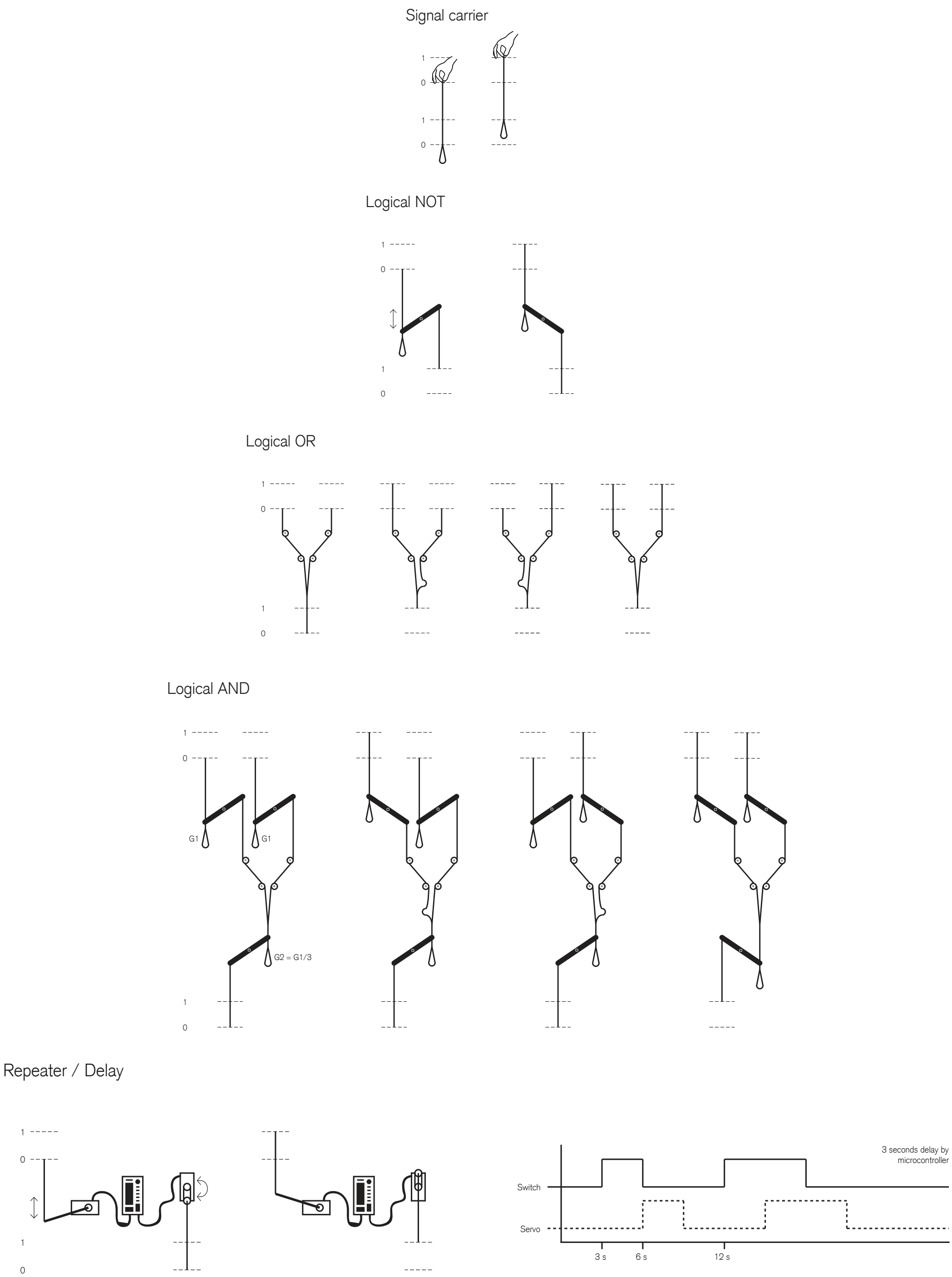

Fig. 4. *Rechender Raum*, diagram of elementary logic elements, 2007.

models of computation at work here, evident in the spatial, temporal and logical structures of these machines. The Digi-Comp machines have a spatial structure that mirrors their input–output configuration. In the Digi-Comp II the rolling marbles enact this transition, trickling through the machine before coming to rest to present the result of the calculation. *Rechnender Raum*, on the other hand, is in the form of an enigmatic ring; it never offers a human-facing "front" but constantly turns away, and inward, towards itself. Its "output" – a cylindrical net of elastic cords – is kept at a distance, in the core of the ring. As Baecker [2007] writes, "the results of its computations are sent inwards … they are not intended for the viewer.". Just as it has no front or back, *Rechnender Raum* never starts or stops: it seems to only carry on, quietly whirring and flipping, strings tightening and becoming slack.

These structures come together in the logical architecture of the machine. The torus of *Rechnender Raum* is made up of nine wedge-shaped modules, each containing three submodules – mechanical gates that process inputs into outputs (Fig. 6). Each submodule is connected to both its neighbouring modules and the core "display", in an interwoven cascade of logical operations. The process has no edge or end; the structure wraps around on itself, and the bottom-most submodules feed into the top (forming a true torus, in the topological sense). In formal terms, this is a digital computer: binary elements store the state of the whole system; its state changes in a series of discrete time steps, as determined by a fixed, logical "program" and a network of connections. But as a model of computing – as an epistemological machine – it is less conventional. Where the Digi-Comp machines make an earnest effort to reveal the functional power of computing, *Rechnender Raum* has an ambivalent relationship to its human audience. As Baecker says, it is both open and closed: completely transparent and strictly self-contained. It suggests a form of computing quite independent of human agency; a computer that is not for us – in fact not for anything: it solves no problem, it has no task and it delivers no answer. Yet nor is it idle – it works slowly, tirelessly, in a never-ending process.

In this sense *Rechnender Raum* and *Irrational Computing* (see below) are forms of performance: staged actions for us to interpret. The "function" of *Rechnender Raum* is not to solve a problem, but to perform. Baecker recognizes the theatrical dimension of early mechanical automata, and echoes it in these works. Andrew Pickering's study of cybernetics proposes the notion of *ontological theatre*: he argues that the experimental machines of cybernetics – such as W. Grey Walter's Tortoise and Ashby's Homeostat – stage a "nonmodern" ontology, a particular model of the

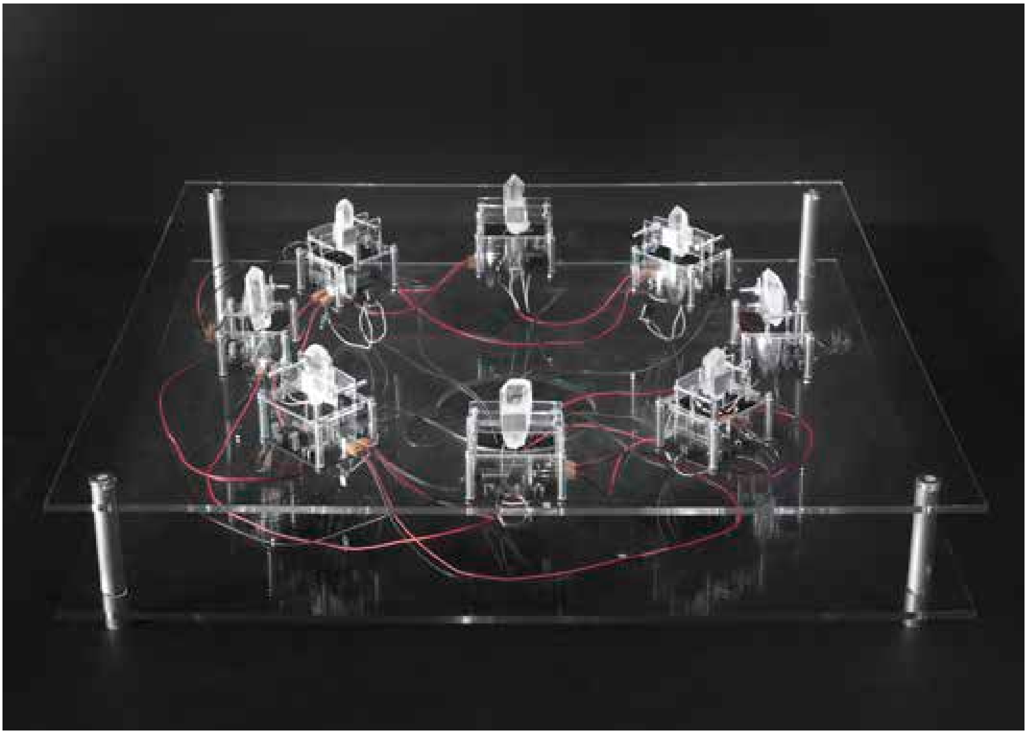

Fig. 5. Irrational Computing, phase-locked loop, 2011.

world focused on action and performance rather than knowledge and interpretation [Pickering, 2010, p. 21]. This theatre both outlines an ontological model – a vision of the world – and actually enacts or performs that ontology. In just the same way Baecker's *Rechnender Raum* is ontological theatre. It both describes and enacts a reconfigured computing: one that rejoins us at a human scale, legible and open but at the same time obscure. With the sticks and strings of *Rechnender Raum* Baecker reminds us, reassuringly, that computers are physical machines; but at the same time he suggests how readily computation peels away into an independent, nonhuman process.

Irrational Computing

With *Irrational Computing* (Fig. 8) Baecker mounts a work of ontological theatre that seeks out the edges and origins of computing machines; once again the result is not so much an exposition of computing, as a reconfiguration. The prerequisite for this reconstruction is a deconstruction, a stripping down; we can see this in *Rechnender Raum*, where Baecker implements logic gates with levers, weights

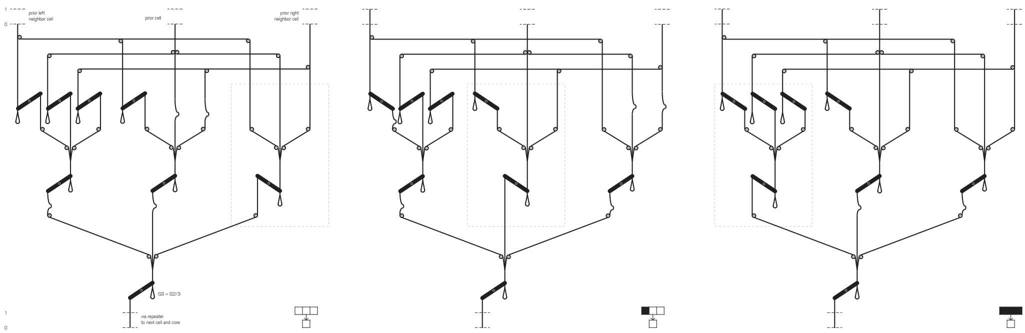

Fig. 6. *Rechender Raum* rule 110 (Wolfram) cellular automaton implementation (matching patterns), 2007.

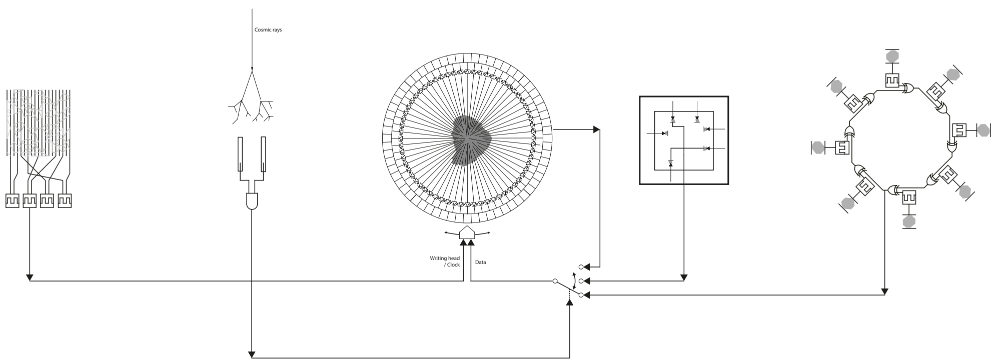

Fig. 7. Irrational Computing, Schematic, 2011.

and strings. In *Irrational Computing* Baecker turns to crystals and electronics – the mineral and technical substrates of conventional computing – but seeks out their idiosyncrasies and instabilities. He creates modules based on fundamental digital components such as transistors and clocks, but at a sculptural scale: a scientist's workbench on which a weird, emergent system – a not-quite- or not-yet computer – sits talking quietly to itself.

Irrational Computing is made up of five "modules" (Fig. 7) – transparent constructions of electronics and crystals, glimmering, clicking and buzzing. Each of the modules in the work is an independent electromineral unit; these are interlinked to form the chaotic ensemble of the work as a whole, which Baecker terms a "primitive macroscopic signal processor". At the centre of the installation sits Module I – the "display": a dark lump of silicon carbide encircled by probing arms. (Fig. 10) An array of 64 iron electrodes applies pulses of current to this crystal, triggering tiny flashes and clicks, like sparks of lightning within a thunderhead.

Module II is the *coincidence detector*: two parallel glass tubes (Geiger Müller tubes) sit atop exposed electronics; four tiny light-emitting diodes (LEDs) blink and chirp intermittently. Here Baecker recreates a device invented in the late 1920s to detect the incidence of cosmic rays. In 1930 Bruno Rossi (see [Bonolis, 2011]) improved the design by adding an electronic circuit to automatically detect coincidences between the two tubes. In doing so, Rossi also invented the first electronic AND circuit – a key element of binary digital logic, and one of the four types of Boolean logic gates now packed into integrated circuits in their millions. So, Baecker rebuilds the first electronic AND gate; but here it acts not as a logical controller, but a random signal generator. Functional, digital computing goes to great lengths to insulate itself from its physical environment, to maintain the integrity of its internal logical states; by contrast, Baecker here cracks his "irrational computer" open, extracting binary data from the surrounding cosmic flux.

In Modules III and V, the *Crystal Field Oscillator* (Fig. 9) and the *Phase Locked Loop* (Fig. 5), Baecker exploits the piezoelectric attributes of some crystals: they generate electrical current when subjected to pressure and, conversely, physically deform when subjected to a current. These attributes play a central role in conventional computing hardware: stable vibrations in quartz crystals provide a "clock" signal, slicing time into discrete steps for the organized execution of digital logic. In the *Crystal Field Oscillator* crystals of Rochelle salt (potassium sodium tartrate) are clamped onto a flat surface and strung over with copper wires. Rochelle salt was used in the first ever crystal oscillator, devised by Alexander M. Nicholson at Bell Telephone Laboratories in 1917. Here Baecker elaborates the elementary crystal oscillator into an unruly macroscopic field: "the crystals are stabilized/amplified by a resonator circuit with an inverted Schmitt trigger. It is the same circuit you need to drive the quartz crystal of a microcontroller or central processing unit. This circuit kind of jumps into the resonant frequency of the connected crystal, but it is

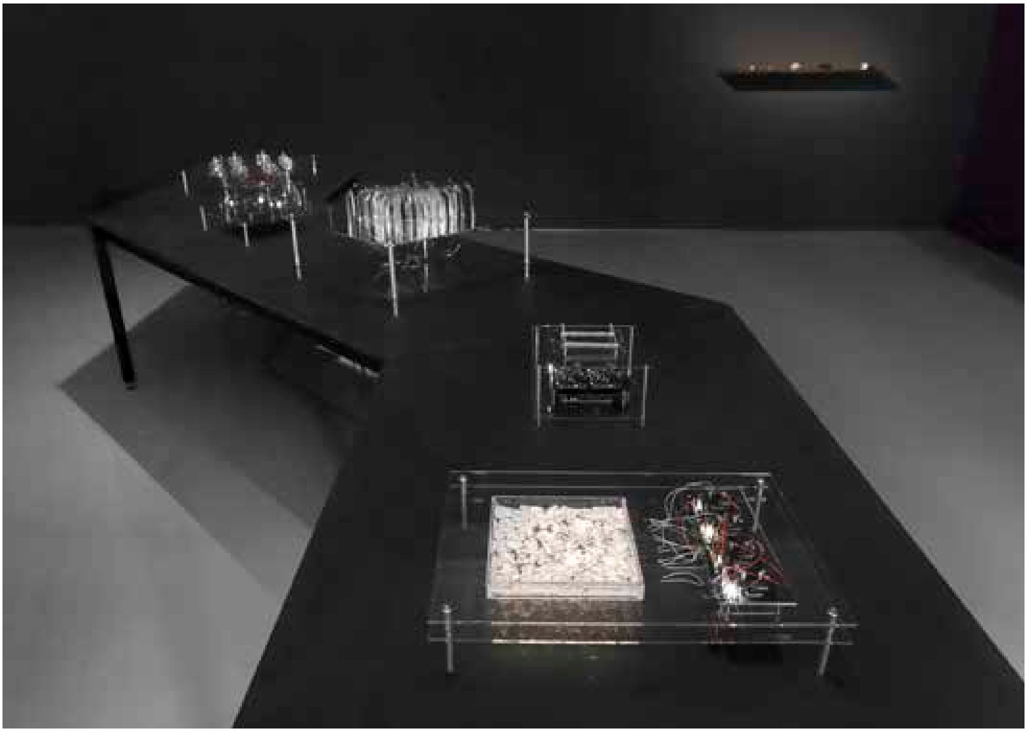

Fig. 8. Irrational Computing, installation view, Schering Stiftung Berlin 2011 (photograph: Roman März).

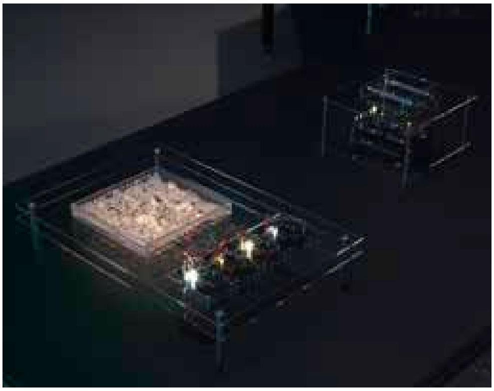

Fig. 9. Irrational Computing, Crystal Field Oscillator, 2011 (photograph: Roman März).

Fig. 10. Irrational Computing, Silicon carbide display, 2011 (photograph: Roman März).

not very stable. The frequency sometimes jumps out ...” [Baecker, correspondence]. Baecker wrings a sort of unstable stability from this field of crystals, as they push and squeeze each other, inducing and responding to the surrounding current.

The *Shot Noise Generator* of Module IV is another chaotic signal generator built from predigital electronics. Here the units are “cat’s whisker” detectors – each a galena crystal with a fine, springy electrode touching its surface. This component, used in early (crystal) radios, is a point-contact diode: the junction between wire and crystal conducts electricity in only one direction. In fact, this device is the first ever semiconductor, dating to the early 1900s. Baecker uses six of these crystal diodes, in two roles: three act as noise generators, according to the principle of “shot noise”. This phenomenon relates to the discrete or particular nature of electric charge; in very large numbers, electrons can be abstracted into a single homogeneous flow – but this flow consists of billions of randomly fluctuating particles. At very low levels of current, where only a few particles pass, this randomness becomes relatively significant. Like the *Coincidence Detector* the galena diodes here act as noise sources, amplifying the random flow of electrons into binary fluctuations. This noise is then “computed” by three more crystal diodes acting as an AND gate, switching on only when all three noise sources are in agreement.

Irrational Computing hints at something like “protocomputing” – unearthing the precursors of digital computing, in parallel with a literal mining of the mineral substrates of the contemporary computer. I mean “proto” not only in the sense of a preceding form, but with the sense of unknown potential of the prototype, the germinal or not-yet-fully formed. For, after winding the computer back to this archaic state, Baecker is able to imagine it anew, to stage an ontological performance of a very different computing machine.

Baecker’s computing is first of all radically materialized. This is already evident in *Rechnender Raum*, where the computing machine explodes into a tangible lattice of timber and string. Yet, like a digital computer, *Rechnender Raum* is also independent of its material substrate. We could replace the timber struts with metal, for example, and while the sculptural presence of the work would change, its computations would be the same. The physical substrates of digital computing are carefully engineered to be stable and consistent: to faithfully bear and transmit the symbolic marker of the bit. Digital computing rests on what Will Schrimshaw calls an “indifference” to matter [Schrimshaw, 2012]; the computer holds the flux and chaos of its own material – and the world outside – at a distance, in order to function. Irrational Computing, on the other hand, actively tunes in to the instabilities of matter; it engineers complex networks of feedback and interaction and opens the machine to the surrounding world, using the random spikes of incident cosmic rays to switch (or "program") the modular architecture. What's more, the piezoelectric quirks of these specific crystals and the springiness of these particular wires all play a role here; to substitute different materials would be to reprogram the machine.

The implications of this attunement are radical because they go beyond simply affirming the presence of a material substrate. Such a "grounding" of digital computing is a vital strategy: it highlights the material substrates and infrastructures that are glossed over in what Felix Stalder called the "ideology of immateriality" underpinning the digital economy [Stalder, 2000]. But *Irrational Computing* suggests that to be thoroughly "grounded" involves embracing matter as active, a generative element rather than a neutral substrate. This in turn radically undermines models of computing based on explicit instruction and control. Instead of human "programmer" and "programmed" machine *Irrational Computing* suggests collaboration and negotiation, a process of coaxing, amplifying and steering material and environmental agencies.

Computing in the world

One of the catchcries of west coast digital capitalism is Marc Andreesen's declaration [Andreesen, 2011] that "software is eating the world" – a celebration of the disruption unfolding as digital products and services transform western economies. But this image – of computing as voracious and all consuming – also speaks to a heightened discourse around the relationship between computing systems and the physical world. In the mid 1990s Nicholas Negroponte trumpeted bits over atoms [Negroponte, 1996, p. 11]; George Gilder had earlier announced that "the central event of the twentieth century is the overthrow of matter" [Gilder, 1989, p. 17]. Yet more recently technofuturism has taken a decidedly material turn. In 2010 *Wired* magazine editor Chris Anderson flipped Negroponte's formulation around, promising that "in the next industrial revolution, atoms are the new bits" [Anderson, 2010]. Digital fabrication technology – in particular 3D printing – offers a digital mastery of matter at a bargain price, enabling paradigm shifts such as mass customization and on-demand manufacturing. Ubiquitous computing (ubicomp), or the "internet of things" – the pervasive integration of computing, sensors and networks into the fabric of our physical environment – is another locus of excitement. Where fabrication offers the digital manipulation of matter, ubicomp portrays a material and spatial world threaded through and “enhanced” or animated by the digital. While computing no longer seems “immaterial” here, fabrication and ubicomp in fact continue the story of our triumph over matter, and our desire for ever more powerful and pervasive control over our world.

At the same time what might be called the material price of computing is attracting increasing attention. Energy-hungry data centres; low-paid workers in Chinese factories; the toxic residues of e-waste. Despite the ephemeral imagery of “the cloud”, we are reminded that computing remains awkwardly intertwined in our troubled relationship with the earth, and that our mastery over matter is distinctly limited. If we consider the power of the computer as a model of knowledge, as well as a physical force in the world, the stakes are even higher. Digital computers both enact and reinforce a particular way of thinking, knowing and being in the world; Bowers calls them “the epistemological machines of … technologically oriented middle-class culture” and as such “a totally inadequate technology for addressing the deeper cultural roots of the ecological crisis” [Bowers, 1995, pp. 89–90]. One way to begin unpicking this knot would be to reimagine the computer, to strip it for ontological parts and rebuild it anew, so that instead of holding matter at arm’s length it operates in and with the world. Such an epistemological machine might model complex embeddedness and collaboration, rather than control; what Jane Bennett calls a “distributive” agency of living and nonliving things [Bennett, 2009, p. 23]. Baecker’s work offers a provocative glimpse of what such a machine might be.

The poetics of digital materiality

Irrational Computing investigates material, aesthetics and potential of digital processes. The basic raw materials of our surrounding information technology are semiconductor crystals such as silicon, quartz or silicon carbide, which, thanks to today’s advanced microtechnology and extremely sophisticated procedures, are processed into transistors or integrated circuits (ICs), with the materiality of modern microprocessors having long since ceased to be graspable. The extreme miniaturization and the black-box setup elude visual interpretation. The installation’s circuit runs counter to the developments in information technology, representing the system in a dimension that is enlarged many times over. The project thus corresponds to an extreme zooming in on the smallest “physical” units of digital processes.

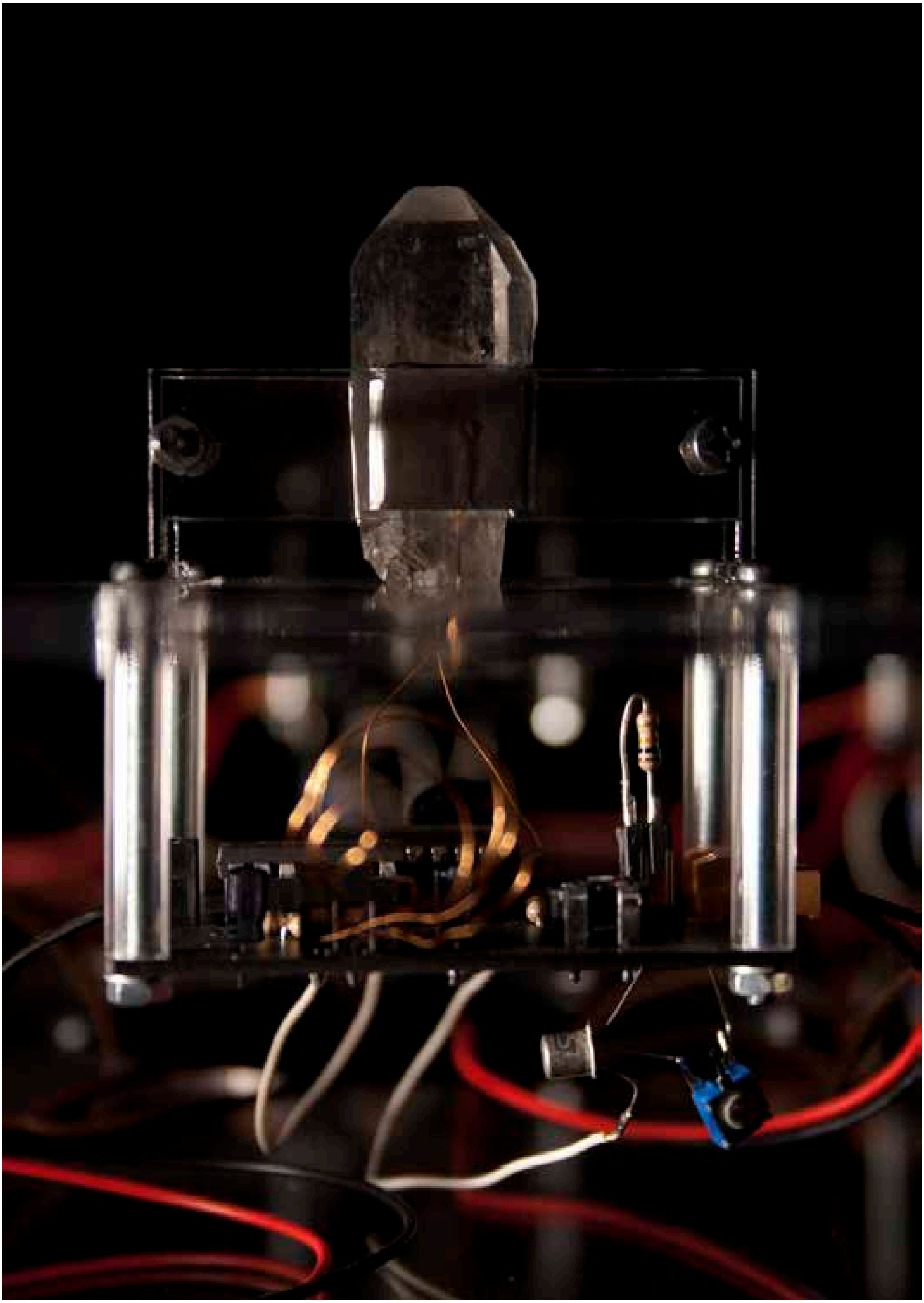

Fig. 11. Irrational Computing, Quartz Oscillator, 2011.

The installation consists of five interlinked modules that use the varied electrical and mechanical particularities and characteristics of crystals and minerals and, through their networking, form a kind of primitive macroscopic signal processor. The crystals used for the purpose are taken directly from nature, industrial waste products or have been especially cultivated for the purpose. A silicon carbide crystal, for example, is made to light up at numerous points with the help of electrodes (LEDs). On the crystal piece, there appears a kind of display, which is targeted by the data flows generated by other modules. At the same time, the crystal functions as a sound generator, since the electrical impulses change the surface of the crystal, causing it to vibrate. Via loudspeakers, these microscopic reverberations are made audible for visitors. Digital systems, in their function, are conceived logically and rationally. The lowest physical or electrotechnical level (crystals with semiconductor properties) is based, however, on quantum mechanical, i.e. statistical or unpredictable. processes. Modern computer technology has thus tamed and domesticated the chaotic, so to speak. In his work, Ralf Baecker comments on this paradox by examining the aesthetics of the materials from which has developed a global digital network. *Irrational Computing* is not supposed to "function" – its aim is to search for the poetic elements on the border between "accuracy" and "chaos".

Time of nonreality

> "Besides, it must be admitted that perception and anything that depends on it, cannot be explained in terms of mechanistic causation – that is, in terms of shapes and motions. Let us pretend that there was a machine, which was constructed in such a way as to give rise to thinking, sensing, and having perceptions. You could imagine it expanded in size (while retaining the same proportions), so that you could go inside it, like going into a mill. On this assumption, your tour inside it would show you the working parts pushing each other, but never anything which would explain a perception. So perception is to be sought, not in compounds (or machines), but in simple substances. Furthermore, there is nothing to be found in simple substances, apart from perceptions and their changes. Again, all the internal actions of simple substances can consist in nothing other than perceptions and their changes." [Leibniz, 1714, §17]

Rechnender Raum (Computing Space) is a lightweight sculpture, constructed from sticks, strings and little plumb weights. At the same time it is a fully functional logic exact neural network. Through its strict geometric and otherwise very filigree construction, the observer is able to track the whole processing logic from every viewpoint around the machine. This disclosure of the machine's core is enforced by an uncommon distribution of its constructing elements: a nine-angled architectural body forms a torus. In contrast to an ordinary alignment of a hidden logic and an outer user-facing display, its geometric basis is turned inside out. The core of the machine, with all its computing elements, is shifted outwards on the surface, while the "display" which indicates the results of the tasks is displaced into the centre of the system. Even though the tasks and their logic run directly in front of the viewer's eyes and even if one is long sinking into the interaction of the elements which is accompanied by a polyphonic but steady and reassuring buzz, it is not possible to follow the succession of the single conditions of the machine. On one hand by turning the machine inside out its function is completely transparent, on the other hand a strict self referentiality and ignorance to the viewer is realized. The machine turns away from the visitor and carries out its computations only for itself. Without depending on interaction or requesting it, it goes through its own states endlessly. The results of the computations are sent inwards – into its own centre – they are not intended for the viewer. So, an interesting paradox appears: while the machine opens up everything it closes it at the same time, as if it has a secret.

Rechnender Raum is set in motion, by pulling one of its over 200 levers; it will try to compensate the inserted disturbance. But with every try one will generate further disturbances. The program, inscribed into the configuration of its levers, weights and lines, forces the machine to process all its possible states (Zustandsraum). The panoptic construction of the machine maps the mechanical transactions on its surface to its display. Like an abstract string puppet play the machine projects its process to its own core. The decelerated neural network of *Rechnender Raum* (levers moving slowly between their poles) shows the in-between of a binary symbol manipulating machine. Norbert Wiener [Wiener, 1948, p. 158] called this in-between "time of nonreality".

The formal/algorithmic base for *Rechnender Raum* is a one-dimensional cellular automaton (rule 110, Wolfram) (Figs. 5 and 6) [Wolfram, 2002, p. 675]. The *Rechnender Raum* universe has a width of nine cells (connected at the edges) and three time steps that are also closed from bottom to top, forming a toroidal topography. Each cell consists of a network of logic gates (NOT, AND, OR) that computes an output by the inputs of its neighbours' cells. The communication in the cells and from cell to cell happens by strings. A pulled string is a logical 1 and a loose string is a logical 0. The results of a cell are delayed and amplified by a microcontroller equipped with a switch and a servomotor.

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