THE (TROUBLED) SONICITY OF THE COMPUTATIONAL

THROUGH
SITES OF CROSSTALKING

by

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ABSTRACT

The PhD project revolves around a sonic portfolio I composed–in the sense of put together–in retrospect. The portfolio contains electromagnetic traces of a split involvement with some of the relations and non-relations between (abstractive) computational processes and (lived) experiences.

The computational prefixes practices that relate to computers, their material foundations, and the logistics they produce. In engineering, the physical phenomenon of *crosstalking* refers to the mutual interference of separate yet neighbouring wires. The techno-poetical practice engages with computational crosstalking in a literal and tangible way; it traces electromagnetic *sonicity* as induced by computational activity over time. With this, I approach the sonic through computational logic(s), phenomena and habits. The artistic research, on the other hand, understands computational situations beyond their functional workings as propagating into and interfering with all sorts of environments, not only the technical ones. I draw on the notion of mutual influence (coupling) yet not merging (decoupled) to apply it twofold beyond its original meaning: first, as a vehicle to bring abstract, observable and experienced manifestations of the computational in relation, and second, as an informal and applicable proposal for *inversing* contemporary computational practices.

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I am grateful towards
all I cross paths with regularly
all offering a place to come back to
and
all the
encounters
in everyday life

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The total duration is 90:15

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1 INTRODUCTION

The accompanying body of sonic work consists of provoked and traced, streamed and collected electromagnetic emissions of computational activity. The single tracks are excerpts from improvisations with a self-built environment for playing with–and from within–the electrosmog of personal devices or from long-term observations of technical infrastructures. The portfolio chronicles the slow process of coming closer to performing and composing through repeated sonic work–much less by intention. The practice-based artistic research was initially devised as applied media theory, which reached a speculative, nevertheless practical proposal. I distil insights from a reluctant techno-poetical practice in experimental music composition for building individual and collective techno-intuition[1] applicable from within the asymmetries, inequities, and harms attendant on present-day technology in the Global North. The chapters head towards *inversing* the computational as part of existing engagements to overcome technology-centred development.

The endeavour traverses arts and engineering by example to engage with the lack of societal and political framing. Instead of filling or bridging gaps, such as those between the computational/societal, sonic/computational, theory/practice, or exemplary/general, the approaches may stay parallel and fragmented. Likewise, computational conditions may be described as too dispersed and too monolithic by civil and theoretical attempts to overcome the thus-far unbroken resilience of digital technologies as *infrastructures of abstractions* against critique or regulation going beyond superficial or partial fixes. The recent proposal by the EU to regulate AI(s), for example, is the first attempt to dampen risks imposed by digital

1 I draw on Yolande Harris (2011) to combine navigating through technology and intuitive navigation.

technologies on a larger scale. While further reaching than any other so far, digital rights organisations report multiple shortcomings. It fails, for example, to account for the high risk of discrimination of migrating people. Computing *otherwise,* on the contrary, strives not to relativise negative societal consequences or trade out one justice for another.

Initiated by multiple practices I pursued during the PhD, I reflect upon the capacities and limitations of sonically abstract*ing otherwise*. Despite, and due to, the previously mentioned manifold blanks, I derive conceptual and tangible vehicles from my own and related work to approach what leaks, interferes or pours over separate yet neighbouring domains. I aim to put interference into practice: between art and engineering, sonic and written form, reflection and doing. The proposed vehicles are primarily intended to support a daily practice–or habit–while engaging with computational conditions of some sort, not as theory. They have particular meanings in specific settings and stay bendable across various backgrounds, providing colloquial and temporary common ground. Thinking along the lines of abstraction versus experience within the digital and the sonic, for example, might be such a vehicle for discussing a particular situation from different perspectives. The thesis is occupied with Beatrice Fazi's finding that the digital is built upon a *non*-relation between abstraction and experience. The proposed terms bring their own histories and stem from very different circumstances. Instead of focusing on the terms too strongly, I am interested in what is or might be happening between seemingly decoupled spaces and the coproduction of *extra* experience, understanding, or knowledge. I propose practices for investing computational scenarios with only fragmented access available to conceptualise gaps between technical and social worlds and to reconsider the images and self-images of computing cultures, for example, by continuously rethinking notions such as the virtual and the actual, or the necessary and the contingent.

I hope to provide pleasurable listening to the traces from a split engagement. With the reflections, the intention is to enlarge the available space for existing non-extractivist thought and vision. In order to turn the computational *inside-out*, with this thesis, I employ concepts and concerns as expressed by new materialist informatics[2] and sonic cyberfeminism[3]. I hope to contribute in a practical/poetical way by querying the execution of computational sites, understood with Eric Snodgrass, in both a technical and a sociopolitical sense. These inquiries are necessary where computational conditions and consequences are decoupled. The commentary at hand spans a context around computational *sonicity*, which, without explicit and collective framing, remains a remote and otherworldly place.

1.1.1 Purpose

The core purpose of the sonic portfolio, together with the thesis, is to frame ongoing practices that work in diverging directions, entangling with technology from inside *and* from outside simultaneously. By 'inside', I refer to any environment, idea, person or entity required for the operation of the devices and infrastructures that are considered part of what are known as digital technologies. Likewise, by 'outside', I refer to any environment, idea, person, or other entity that *cannot* be fully captured by the internal boundaries and logics of computing. This distinction only makes sense with respect to the *inside* of digital technologies. The *outsides*

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2 Klumbytė, G. and Draude, C. (2022) 'Prospects for a New Materialist Informatics: Introduction to a Special Issue', *Matter: Journal of New Materialist Research*, 3(1). Available at: https://doi.org/10.1344/jnmr.v3i1.38955.

3 Goh, A. and Thompson, M. (2021) 'Sonic Cyberfeminisms: Introduction', *Feminist Review*, 127(1), pp. 1–12. Available at: https://doi.org/10.1177/0141778920967624.

with which this thesis is concerned escape the formal, abstract, and discrete. I am situated within two realms: initially in applied computer science and shifting gradually towards computational and sonic arts. Notwithstanding this and the computational being at the core, the aim is to consistently move away from technical and aesthetic aspects and towards an *extra* occurring beyond the boundaries of *insides* and *outsides* as defined by a computational setting, scenario, or situation. The PhD project is artistic practice within technological fields and aims at attending to these boundaries defined by computational thought and practice. It is motivated, though, metaphorically speaking, by the 'noise' that 'returns in the circuit as the unpatterned information lying beside and not within dialectical autopoiesis' (Parisi and Ferreira da Silva 2021). Hence, the *inside*/*outside* captures how the computational is conceptualised and implemented, and the *extra* refers to what is not captured by this distinction.

The intention is to not dissolve the computational and the sonic into a hybrid to acknowledge their very different places in societies with regard to their different socioeconomic impacts. A hybrid, according to Lisa Nakamura and Donna Haraway, is 'a comforting category in many ways because it seems that everyone can get in on it on a sort of equal basis' and hybridisation 'tends to be […] a means of walking away from contradiction'.[4] Overall, I maintain in place the incompatibilities between, for example, the computational and the sonic, or between practice and reflection. My interest is in the ambiguous as well as concrete *extra* understanding or experience that is co-produced yet not always made public while working on deliverable outcomes, such as a live performance, installation, piece of software, or text.

4 Haraway, in an interview with Nakamura (2003): 'And I think that if anything characterizes what I believe over this whole period of time it's that you can't walk away from a contradiction. We need somehow to be accountable to all of them even though we know we can't.'

Chapter 4 makes space for what was *not* part of the shareable artistic or technical work: for being too incidental, encounters without a perceivable outcome, personal experience, out of format, or not sufficiently condensed; no verbally expressible intention, no straightforward causal relationship between an activity and its presentable outcome, too much or too little detail, or too much or too little aesthetics (for an imagined or real audience).

The sonic works and the written commentary settle on crossings (or entanglements or transitions) between engineering and non-engineering ways of being with technologies. The co-existence is the core theme and applied method: I gather related projects, recall encounters which I initiated or responded to, distil commonalities between practices, and probe poetic readings or processing of computational situations. The poetic stands for switching between formal and informal, abstract and discrete engagement with computational scenarios. The framed yet spontaneous practice accompanies the two central threads: a close inspection of computational conditions and, conversely, doing sonic work through a computational lens. The project is a balancing act: staying with computational logic(s) and habits in some ways and countering them in others. The intrinsic variability, as expressed, for example, by avoiding singular definitions of terms and collecting multiple ones to approach a temporary and local meaning, walks a thin line and may become elusive if the particular purpose slips away and the meaning becomes arbitrary. The same is true for the personal account of anecdotes in the middle chapters. I collect and juxtapose hands-on, or ‘low’-level, encounters and large-scale or ‘high-level’ embedding to arrive at an intuition towards computational situations and conditions based on specific experience and understanding. The last chapter proposes starting points for *inversing* the computational with the support of informal practices.

1.1.2 Outline

The portfolio of sonic works emerged from traced, improvised, streamed, and composed recordings and pieces captured from the electromagnetic fields of digital devices and infrastructures, shortened to *electromagnetics* in the following. There are 20 tracks in total, 90 minutes duration, extracted from performance and recording practices spanning multiple years. The chapter on related frameworks contextualises the portfolio. It introduces selected key concepts from composition, media theory, sonic, and computational arts, proposes a series of preliminary figurative vehicles for understanding and utilising gaps, and positions my activities across composing and critical computing. The chapters W*orks* and P*rocedures* chronicle selected aspects of their making, highlighting patterns and dynamics in the pathways that depart from a computational scenario and arrive at a sonic outcome. The iterative, responsive, and context-based activity of such sonic practice shall display the overall motivation and illustrate the proposed approach, as detailed in Chapters 1 and 2, by way of their 'encoding' into sonic work (Impett 2021b, 132), not so much by way of the sonic results. The subsequent Chapter 5 moves from a sonic to a mixed-media format. As in Chapters 3 and 4, the computational situation is no longer a discrete and accessible site but the technical documentation of an exemplary European research and innovation project on technologies for border control, *iBorderCtrl*. Various technical, conceptual, conversational and political threads are *decomposed* into fragments and interweaved again in an informal publishing format, a blog post, to prepare for the unstructured yet framed collaborations I envision in Chapter 6.

1.1.3 Portfolio

I record the electromagnetic emissions of computer processes as if they were acoustic. I either run the processes myself on a personal computer in an environment I built for improvising with and from within the electrosmog of digital devices or capture processes from an existing infrastructure such as a scientific underwater observatory or a computing centre. The portfolio involves recorded emissions, known as electrosmog and surrounding personal devices or computer centres of varying size. The changing electromagnetic fields correlate with the computer processes running on a particular system, or rather, being executed there. The portfolio comprises untreated recordings, mixes, and composed pieces that audify exemplary computational scenarios. The sonic works are ordered first by type, from more on the computational side to more on the sonic side. Chapters 3 and 4 detail how they lean towards one or the other. Next, they are ordered by the computational source: from personal devices to supercomputing centres or by production mode – solo or duo improvisation, rehearsal, concert, or release. Some tracks are raw electromagnetic field recordings, unprocessed and unedited, while others are collages from multiple recordings, synchronous in time or captured during different moments. Some are extracted from long-term collections of electromagnetics that range from one day up to numerous years.

1.1.4 Commentary

The written commentary contextualises the portfolio from multiple perspectives. The content and structure of the thesis are formed and guided by the same intentions as the practice itself, namely approaching the computational from somewhere else, in an iterative procedure and in response to circumstances. As a practice- and artistic-based PhD project, the commentary to the portfolio is brief, and this is not a theoretically grounded work. The theme is on *crosstalking* practices, theories and realms in an applied manner that the commentary illustrates. The references are not comprehensive and shall bind the threads together and support the ‘pouring over’ from one domain to the other.

1.1.5 Practice

Chapters 1, 2, 5 and 6 frame the artistic practice by giving a broader computational context. I respond to internal and external dynamics between involved people and environments and react to specific circumstances. In this way, I do not aim to create sonic art per se. This is not to say that the artistic activity was without thought or care or patience, merely that doing art was not the primary motivation or first thought. Nevertheless, part of the portfolio would not stand out formally at a contemporary music festival. The pieces sound like, and are, composed pieces in the sense that this was the first thought while producing them, such as when mixing a track from live recordings. Without an invitation by a label to release, however, I would not have initiated the production. If listening to the sonic outcome is appreciated without its context (the computational), one realm (the practices with and from within the computational) is subsumed by the other (the sonic practices). This does not make a difference to a listening audience. However, in this thesis, instead of analysing the aesthetic outcome of bringing computational material and sonic procedures together, the poles remain. I intend to adhere to these categories because they play out in technology-driven societies and to keep sociopolitical consequences of the computational in focus. I highlight individual experiences and reflections occurring before one realm disappears within the other.

1.1.6 Embedding

Regardless of formal training and years of software engineering, I wondered where and why software is executing *for real*; the meaning of *real* varies over time and context. I followed 'down' the abstraction ladder: from 'higher' programming languages to machine languages, to the current of power each machine instruction generates, to the physical emissions radiated by flowing current, such as electromagnetic fields or temperature. This seems to be the 'opposite' of *realness* if it should include the societies affected by computing. Nevertheless, the dispersed radiations of cyberspace might mirror large-scale *infrastructures of abstraction*: local and yet not, pervasive and yet elusive, tangible and yet not. The figure of emitting technologies expands the notion of computing, and I trialled different variations of non-computational, literal, and personal habits with and on computing. Instead of positioning the PhD within artistic research and analysing or theorising how the areas of computing and art relate to each other, I juxtapose them in practice to derive a conceptual and tactical framing for working on the computational. Both approaches build on a certain openness regarding methodology and results and I am particularly interested in the potential of art to create a productive tension with computing (Britton, Klumbyte, and Draude 2019).[5]

1.1.7 Terminologies

The usage of terms serves a purpose specific to a context. I perform-compose by invitation, and the same is true for writing. I do not experience terminologies as fixed and maintain a certain discomfort with specialised jargon applicable within a particular group only. With the sonic works and written commentary, I am concerned with how to communicate on

5 Similar concerns on researching non-measurable knowledge and experience were expressed at a conference: 'Artistic research will eat itself' by artistic research institutions: http://sarconference2018.org (Accessed: 30 September 2022).

technologies in immediate ways that do not remove complexity and yet are familiar to those without a technical background, or at least are not closing the issue down as they provoke an association–perhaps an unintentional *extra*. I am more interested in the different understandings of a term and how to navigate within a state of merging and diverging terminologies. In saying this, I contradict the previous argument regarding the need to avoid hybridisation in the case of vocabulary. A fluid exchange of meaning might become problematic within a setting that does not expect it. I invite a generous reading of technical and conceptual terms in this commentary that assumes multiple interpretations and misunderstandings. I build on the habitual sense(s) that become more differentiated with usage and time if needed. Thus, the main aim is to provide a common ground between various backgrounds. To give one example, I use the terms *abstraction* and *experience* colloquially and do not specifically derive from, or position against, existing writing on (human) understanding or experience. Throughout the different chapters, the concepts of abstraction and experience appear in various manners that do not fit a theoretical discourse yet with the theme.

2 FRAMEWORKS

This chapter brings together works from the arts, engineering and theory. The projects iterate between specific examples and scholarly, artistic, and other attempts to work on *gaps* or *borders* marked by a computational scenario. The imprecise notions of gaps and scenarios integrate a range of occurrences: deliberate or unintentional, experienced or imagined, explicit or implicit. The examples come from computational and sonic domains and consider coupling and simultaneous decoupling in some ways. This chapter further outlines the differences between abstractive methods in conventional computing studies and figurative vehicles for abstract*ing*. Subsequent invocations of the vehicles gradually animate the containers rather than define them. Similarly, the foremost physical phenomenon of crosstalk develops iteratively by repeated use and practice instead of analytically; crosstalking refers to the non-explicit and mutual influences of decoupled yet entangled parties and is applied throughout the chapter.

2.1 Patterns of trouble

As an introductory example, the *Imperialist Competitive Algorithm (ICA)* developed within the specialised field of evolutionary computing in 2007 illustrates how race- and class-based dominations form *patterns of trouble* and manifest in computational abstraction (Illustration 1). The categorically incompatible entities of empire and colony derive from one variable, the cost of labour, and the roles in the computational scenario may reverse when the price of labour changes. Formally, the unidirectional steps and binary yes-or-no decisions seem self-explanatory. At the same time, the diagram leaves scope for decision-making to the single implementations of the abstract chart into program code.

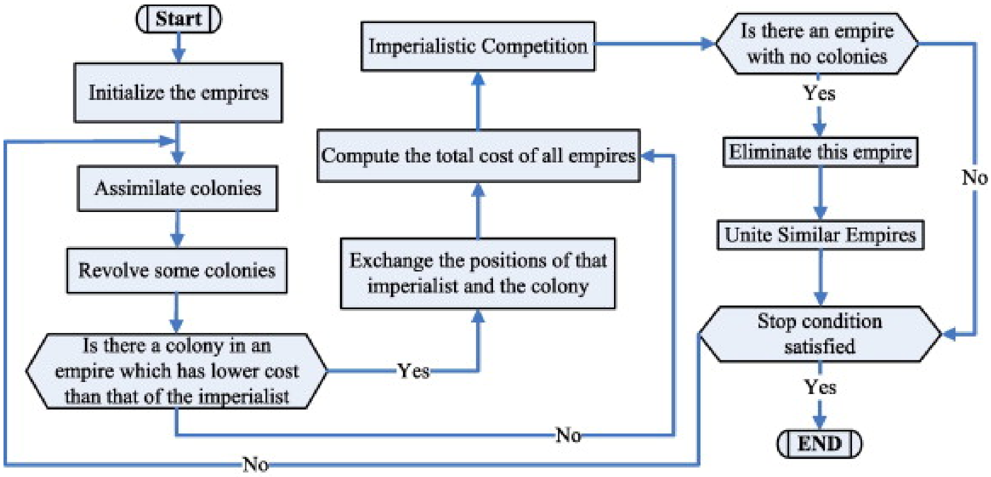

Illustration 1: Flowchart of the 'Imperialist Competitive Algorithm' (ICA)[6]

By looking at the chart, the first steps, 'Initialize the empires' and 'Assimilate colonies', are unspecified; it remains unclear if decisions are taken and how they would determine the subsequent, recursive algorithmic proceeding. The inconsiderate abstraction caused minimal discussion in engineering circles, although the flowchart demonstrates complicity with the violence of colonial empires. The seemingly unconscious weight of historical and contemporary geopolitical realities is accompanied by a simultaneous, seemingly intentional void of the same. In a subsequent publication, one of the originators pointed out their origins in a former colony to invalidate critique by placing it in the past. The textual description of the pseudocode explains that during the initialisation of the states, the roles of empire and colony are distributed randomly, thus shifting the metaphor even more from reality into theory or a game scenario. In 2016, two years after the ICA algorithm was entered into Wikipedia, one editor requested the deletion of the article due to being 'metaheuristic cruft'. The request

6 'Imperialist competitive algorithm' (2023) Wikipedia. Available at: https://en.wikipedia.org/w/index.php?title=Imperialist_competitive_algorithm&oldid=1152384009 (Accessed: 9 July 2023).

was rejected for the formal reason that this was no officially accepted reason for deletion. Thus, no ‘policy- or -guideline-based rationale’ had been provided, which would, in turn, question the ‘notability’ of the editor. As no other person voted for deletion and the ICA algorithm was cited throughout thousands of scientific articles already, it was decided to keep it. Otherwise, it was argued, one person would speak ‘on behalf of a whole community of researchers’ and ‘removal of it [would] make Wikipedia a worse data source’.[7] A couple of months later, another Wikipedia editor proposed in vein to remove at least one part from the article. The pseudocode would be ‘inaccurate and inappropriate’ and, secondly, be ‘poisoning’. Pseudocode, or ‘boilerplate’ text, is another abstraction of the algorithm in verbal form, which is intended to be readable by humans instead of being formally executable by machines. For example, the ‘elimination’ step is described as ‘Eliminate the powerless empires. Weak empires lose their power gradually and they will finally be eliminated’.[8] The algorithm remains part of the canon of optimisation algorithms in evolutionary computing and has been further developed by specialised variants.

Addressing issues enhanced or caused by technologies, numerous initiatives are working on more legitimate ones across activist, academic, and artistic zones–on a surprisingly small scale when considering the planetary impact and in comparison with other movements. Black Lives Matter or the climate change movement act internationally and are tackled more broadly. A similarly outspoken and politically driven moment for technology-related questions of justice has yet to become visible besides punctual resistance, such as against face

7 The–compared with the deletion request–wordy rejection is archived at ‘Wikipedia:Articles for Deletion/Imperialist Competitive Algorithm’. 2022. In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Wikipedia:Articles_for_deletion/Imperialist_competitive_algorithm&oldid=1077966739.

8 The article’s history lists both quoted revisions; one is from 21 July 2016, and the other from 6 September 2016: ‘Imperialist Competitive Algorithm: Revision History - Wikipedia’. n.d. Accessed 9 July 2023. https://en.wikipedia.org/w/index.php?title=Imperialist_competitive_algorithm&action=history.

recognition in public spaces and in real-time, leaving other applications in place. Focus- or state-oriented organisations deal with net-political topics and open technology activities; they lack the scope of supporters, although billions of people use digital devices and infrastructures or are affected by them indirectly. However, not even the large volume of users has led to a far-reaching and industrial shift to fair(er) electronics and computing. The two notable regulations affecting populations broadly within the EU are the unpopular General Data Protection Regulation and the welcomed standardised USB-C charging port for electronic devices coming by the end of 2024.[9][10] The eventually implemented outcome of the EU AI Act is open up to now.

The computer scientist Donald Knuth remarked in 1989 that '[e]ven when the machine's instructions are known, there will be problems' (Pritchard, Snodgrass, and Tyzlik-Carver 2018, 9). In this regard, he was concerned about unforeseen technical issues. Almost a decade later, AI researcher Philipp E. Agre went considerably further and called for the integration of a thorough self-awareness and critique of technical practices and the impacts of technologies on society. However, his plea reached critical computing and humanities studies instead of the computer scientists he was targeting. After twenty years of critical research in the digital humanities, Agre has not participated in any public debates since 2010. Regardless of vast critical thought today, the philosophers and scholars Luciana Parisi and Denise Ferreira da Silva (2021) concluded that the two main contemporary critical views on technology, as well as techno-poetic attempts to counter oppressive technologies (the thesis of Master Algorithm

9 'General Data Protection Regulation (GDPR) Compliance Guidelines'. n.d. GDPR.Eu. Accessed 9 July 2023. https://gdpr.eu.

10 'Common Charger: Parliament Commits to Reducing Electronic Waste | News | European Parliament'. 2022. 4 May 2022. https://www.europarl.europa.eu/news/en/press-room/20220429IPR28224/common-charger-parliament-commits-to-reducing-electronic-waste.

and Computational Surveillance and the thesis of Platform Capitalism and Tools of Resistance, respectively), ‘operate within what Sylvia Winter calls Western cosmogony’ and that ‘this cosmology must include the myth of Prometheus, as the autopoietic creator and mythical origin of technology for the modern world’. This ‘myth […] ensures that the technology of fire evolves into the steam engine of the modern bioeconomic Man, telling the origin story of humanity as one of freedom from enslavement, from the obscurity of the unknown, and from Man’s own death’.

I argue for techno-poetic practices, less so for their aesthetic outcomes, to account for the perpetuating nature of the frameworks in which they operate and to attend to the equally limiting and enabling traits of any activity within them. In staying in the present concerning existing, probably harmful, real-world technological development, this approach differs from speculative visions of technologies that imagine profoundly different societies. Keeping the excoriating assessment of black feminist critique in sight as well as critical digital pedagogies (Malazita 2022), practices of computing *otherwise* support the individual and collective building of non-extractivist forms of computational knowledge and engagement. According to Parisi and da Silva (2021) ‘[b]lack feminist poethics’ offer the kind of ‘“incomputability” that breaks through the self-determining and self-referential logics of the’“techno-sociogenic instrumentalities”‘: ’Like an electronic circuit where noise ingresses the channel of a signal, each recursive feedback performs a duality, a sender-receiver pattern of recognition.’ It seems questionable whether existing computational frameworks can step out of their legacies and constitutions. Conversely, the *otherwise* of computing refers to accountable and situated computing, such as expressed by Klumbytė and Britton (2020), where abstraction becomes a process, an abstracting.[11]

The thesis builds upon insights by critical computing studies that '[t]echnologies cannot "fix" social or environmental issues if not tackled by societies first' (Dunbar-Hester 2020, 238) and '[t]echnology cannot stand in for implicit or abstract social goods because of how it is implicated in social relations and unequal power'. Official calls for democratic or socialist AIs veil its inherent impossibility and treat AIs' symptoms. Technological conditions appear, on a large scale, resilient to critiques and hesitant to recognise their inherent limitations.[12] Despite working on technicalities in the thesis, the trajectory is, further with Dunbar-Hester, to: 'engage in explicit political work and formal political intervention, not a pre-figurative politics of techno-utopianism in which social problems are solved by expanding our technical practitioner base'. This PhD project intends to support the political work of existing organisations by proposing unconventional formats to approach technological stances. Informal and artistic procedures, however, may 'unintentionally animate the flattened abstractions of system theory' (Haworth 2021) and require regular assessment to not shift towards the self-referential logic of the computational.

11 Klumbytė and Britton (2020, p. 27) invite readers to '[…] rethink abstraction beyond extraction and as a broader process of "trans*re*lation"—an invented term that combines and diffracts through one another the concepts of transing + translation + relationality. Such rethinking, we will argue, allows to highlight the residues and inheritances as well as the production of new meanings that emerge through the process of abstraction as trans*re*lation.'

12 Timnit Gebru, as one example, became more widely known as Google gave her notice after publishing critically on the company's practice and the digital technology sector in general. She later founded the independent DAIR institute: *DAIR (Distributed AI Research Institute)* (no date) *DAIR Institute*. Available at: https://dair-institute.org (Accessed: 9 July 2023).

2.2 Vehicles for: *beyond gaps and hybrids*

An example shall introduce core aspects of the practice the PhD project strives for. In this subsection, I recall and comment on preparing to write. Prior to writing the part on *crosstalking,* a few subchapters ahead, I searched for the term in my reference library with texts on and from computing and engineering from a poetic to a political perspective. From the 61 results yielded, I opened a journal article on the early works of Mendi + Keith Obadike's *Black.Net.Art Actions* from 2001 until 2003 (Driscoll 2017). They released a music album *Crosstalk,* containing the track *The Pink of Stealth* –originally *The Mauve Mix*– produced for a trilogy of media works for the web (home view) and exhibition (public view). Their sharp, intricate interventions responded to racial formations that lie at the core of networked technologies. The author of the paper, Megan Driscoll, summarises the public reception at that time: 'arts organizations were struggling to figure out how they related to this new field of internet-based art, leaving works like the Black.Net.Art Actions in a strange limbo between internet art groups that were unsure if this counted as net art, and arts organisations that were unsure if net art counted as art at all'. Driscoll's paper captures, contextualises, and links various cultural and technical aspects of the artist duo's work. Here, I quote two passages straight from the text; one from the concluding paragraph that draws a line from a broader cultural condition to technicalities, and the other from a footnote that does the same, but the other way around. Both exhibit the intention first to consider racial conditions and then technologies. Reading the two quotes in any order arrives at the same meaning despite a fragmented outline, without further explicit detail on the work or the historical conditions than is already stated.

‘The works demonstrate how the technical codes of the web can become a system of communication, subject to the process of encoding and decoding that gives all messages their meaning, and structures the boundaries of that signification. And in the process, they reveal how the ideologies embedded in the way that we talk about color are carried over both into the language we use to describe the web auctioning Blackness on the eBay, allowing only web-safe color(ed)s and the language that dictates what we see when we browse the web #FFFFFF (true white), #FFCCCC (pale pink).’	‘Hexadecimal color values are six-digit strings that represent colors in some computing applications, including the different types of code (HTML, CSS, etc.) that are used to build web pages. For example, #000000 tells your web browser to display black, whereas #FFFFFF tells your web browser to display white. The structure of the code itself is not arbitrary. It uses only 16 digits (0 9 and A F) and is built of three pairs of digits that each assign a certain intensity to a range of red, green, or blue, then combine to produce a specific color. Because they use the additive color process, hexadecimal colors follow the basic principles of light: #000000 is black because it’s a total absence of color, whereas #FFFFFF is white because it s a combination of all colors at full intensity. (You can explore how this works at http://www.w3schools.com/colors colors_hexadecimal.asp.) So for the computer, the reading of these codes is strictly objective. But *The Interaction of Coloreds* draws our attention to the interpretive layer that is introduced by the human reader of hexadecimal codes and the colors they produce, weighing down these seemingly neutral numeric codes with the social and cultural values that the colors carry in everyday language.’

Table 1: Two quotes from Driscoll’s article Color Coded (2017, 64)

The quotes outline entangled yet decoupled aspects: the colour coding scheme utilised by web pages, the colours displayed, and the cultural perception of these as they are brought together in the specific and poetic context of an artistic media action by Mendi and Keith Obadike. Each quote approaches multiple facets from different perspectives and conveys both detail (e.g. #FFFFFF, eBay) and abstract umbrellas (e.g. codes, auction). Detail and concept, in combination, as found in the quotes, prepare a multi-spectral view and an entry point into a computational (and networked) situation welcoming to persons with different backgrounds. Regardless of which details fade out while reading the quotes, the interleaved descriptions bind the scenario together and highlight other details that *are* in focus; the introduced scenario is neither complete nor incomplete. Taking two fragments out of an already mediated context, I try to uphold the core message of the artistic intervention and the paper. At this point, an additional step by the reading person is not necessary, yet might follow: tracing the artists online, reading the paper by Megan Driscoll, or listening to the *Crosstalk* album.

I had searched the term ‘crosstalk’ and followed up on one of the yielded results. Due to subtle circumstances in my ‘real life’ situation, I switched back and forth from Driscoll’s article to the archived web art; I did a sequence of steps, one following the other in immediate reaction and realised the series of events suited to illustrate the intentions in this thesis. Foremost, the Obadike’s actions effectively *inverse* current-day technologies by adding historical and cultural framing. Unspecific computational entities, the details, are brought into relation with broader cultural landscapes; they correlate in more or less concealed ways, resulting from computational logic that abstracts lived experience and cultural meaning away. On a very different plane, I intended to highlight multiple gaps, or polarities, from the events: society and technology, online and offline, out-of-scope art and art, hexadecimal numbers and the physics of light, for example. I engaged with the findings in textual, visual and desktop-related somatic activity, with the prospect of listening to the album. Other reading persons might think of other relations within the cited quotes stemming from their different backgrounds and favourite modalities. From the writing in the reference library mentioning *crosstalk*, I choose the art actions of the Obadikes as they conceive of computing code in conjunction with social codes, of social and technological networks as interdependent. Their works operate across multiple formats and weave various experiences together, including the sonic.[13]

13 Driscoll makes an effort to experience all: ‘The Obadikes work with sound, music, and poetry in addition to visual art, and frequently offer audio tracks as part of their media projects. However, these tracks are generally provided as separate downloads, rather than audio that runs automatically as you view the work. This unfortunately tends to make the sound components feel optional (or at least easy to miss), but they are worth the extra effort; adding the experience of listening to the experience of looking enhances the performative element of the Obadikes’ works.’ in (Driscoll 2017, 66).

The Log in Appendix 2 shows the sequence of searching, reading, and looking up, along with the interacting events–browser behaviour and the changing state of the operating system. The brief procedural description chronologically captures circumstance, procedure, and turning points; it is an example of a *poetic reading* or *processing* and illustrates the artistic practice. Reading denotes an active and responsive process similar to the rather technical term processing. It is not about the steps I took nor their form; it is about a non-formal *and* formal, immediate, multi-threaded response within a directed openness to engage with *patterns of trouble* in computational scenarios, highlighting several details and juxtaposing them. I wrote quickly with little thought on an audience at first. The underlying idea was to locate fragments and process them in a loosely structured manner as part of a quick work-in-progress. I was not only reading a paper but also transforming it by extracting pieces and juxtaposing them with others. Thus, I do not propose any format, yet include an intentional experience–regardless of the scope–when dealing with technological abstraction. The putting-together as an actual step and experience, along with its framing, is a process of *abstracting*, a concept developed by Klumbyte and Britton to which I will return. The current subchapter results from the process captured by the Log and illustrates abstract concepts and their connections in the form of written thought and by doing. The log highlights additional aspects than the written paragraphs, namely the work process, bits of my background, and focus. It gives more hints as to how I arrived at the fragments and put them together. Because I assumed the log to be part of the commentary, I skipped some parts during the writing that I either did not want to share or would not know how to at that moment. Some of the un-shared parts kept me occupied; I included a few in side notes, wrote them down for a later occasion or simply kept a *sense* of the detail. I wrote the log quickly in a micro-performance without an audience, where the process is more significant than the outcome.

The choice I made to select from the findings and how I proceeded to integrate the findings was without prescribed intention and influenced by multiple momentary circumstances due to previous work and the current work environment. I presented *and* performed examples of practices on gaps through computational scenarios (the vicarious example of the Obadikes, Driscoll's theoretical account of it and my private practice of engaging with it). The two decoupled yet entangled media art histories recalled by Driscoll perpetuated in an event in 2018.[14] This PhD project does not provide an analytical account of the referenced works or my multi-modal activity. First and foremost, by repeatedly approaching the computational in other than only computational manners, the PhD project works towards collaborative study and research. The work by the Obadikes and Driscoll is one example I came across by chance while writing. However, it is not random; I am collecting exemplary and abstract accounts of societal impacts of digital technologies. Instead of theorising, the intention is to *do* theory: applying *c*onceptual thought to exemplary situations and, in turn, testing conceptual planes across multiple seemingly unrelated situations.

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14 The Obadikes refused a Giga Hertz Award by the German media art centre ZKM after a comment by a ZKM representative stating that for that year's award, they had to choose between quality and diversity (Villa, A. (2021) 'Sound Artists Decline German Art Award: "Pitting Quality Against Diversity Is Pernicious"', ARTnews.com, 29 November. Available at: https://www.artnews.com/art-news/news/zkm-giga-hertz-award-decline-1234611502 (Accessed: 26 June 2023)). The artists published a reaction on the reoccurring 'false binary' and concluded that the organisation is 'not quite ready to truly honor artists from the global community' (MendiandKeith Obadike (27 November 2021). Available at: https://www.facebook.com/permalink.php?story_fbid=pfbid02S4DRFyLw7iArx811GYPzZknPpM6nzfcLDiCDA4BgnNhTCoB2p4TfDTQb6ZAkUS5tl&id=1162860843 (Accessed: 26 June 2023)). The argument of needing to choose between seemingly objective quality and diversity demonstrates the pitfalls of the vague term of 'diversity' when used as a local fix of a broader issue within one place or one community without recognising global and interconnected issues as articulated by intersectional thought and without acknowledging the own structural dis/ability to act in it. Likewise, Dunbar-Hester provides a detailed account of the structural impossibilities of tackling diversity in open technology spaces (2020).

2.3 Concepts

2.3.1 Sonic

2.3.1.1 Audification

In *Energies in the arts*, D. Kahn (2019, 2) points out that ‘energies have neither been well understood nor the difficulty in doing so been fully appreciated’. With the help of the sonic, I assess several aspects of computational energies in terms of their ‘potential, presence and consequence’. Energies and their capacity for performing computational work lie at the core of this thesis. Moreover, according to Brian Larkin (2013), ‘[e]lectricity may be the most obvious substratum that allows the computer to operate’. The electromagnetic fields surrounding electrical cables and propagating into the environment are one physical derivative of flowing current; the fields change in direct correlation with the alternating current. As Larkin further remarks, ‘although electricity is the infrastructure of the computer, the computer is the infrastructure of electricity supply, as the entire transmission industry is regulated by computers’.

The energy flow, in the form of current or induced from electromagnetic fields, can be rendered audible simply by redirecting it to a speaker or other audio equipment. Treating a series of physical values as an audio stream is a subgenre of sonification known as audification (Hermann, Hunt, and Neuhoff 2011, chap. 12). I am concerned with audification as ‘emerging from a particular set of conditions’ and its ‘non-objectifying’, ‘relational’ and ‘non-binary’ characteristics (James, 2018). Before one snapshot of a flowing current (inside of a digital computer) is interpreted as a ‘0’ or a ‘1’, it still resides in the analogue and, as such, in proximity to the acoustic.[15] The pace-setting clocks of digital devices run much faster than what human hearing can distinguish. Nevertheless, I adhere to the audible range in all sonic works. The variety of sounds is sufficient to capture activity that is specific to a device's operations.[16] I call the results sonic to emphasise that I made them to be perceivable by human audiences, even in cases where this is not reasonably possible, such as archives of years of audio recordings. The term *sonic* is situated between the acoustic and the musical, and to further differentiate it, I propose measurement as a third cornerstone.

Although the audification of physical emissions, as I practise it, brings forward less noticed relations and experiences, it shall not reveal something specific in the same way other investments do, such as evidentiary realism in arts,[17] media archaeology, dreaming or leaking electronic product design[18], whistleblowing, or reverse engineering. Instead, I work on developing an 'extra-analytic' understanding and 'sense' of specific computational situations. Harun Farocki advised 'see[ing]' through the imagination when it is literally invisible (cited in Paglen 2015). In turn, the signal spaces of computation may become 'concrete aesthetic and

15 Wendy Chun on interference in computational electronics: 'At a fundamental level, cyberspace emerges through the erasure not only of hardware differences, but also disorderly hardware itself. In terms of hardware, the Internet does not exist—or, to be more precise, the difference the Internet makes cannot be recognized; at this level, machines influence each other through electromagnetic interference (in terms of EMI, a refrigerator and a computer are both communications devices), power (voltage*current) and resistance (voltage/current) are technical terms, and resistance is necessary for circuits to operate (as resistance goes to zero, current goes to infinity). Even at the cleaner level of logic gates, which erases circuit particularities, the difference the Internet makes makes no difference—a gate is a gate is a gate. Importantly, these other spaces do not completely dissolve but rather continually threaten 'pure order'. Because Puritan societies had to defend themselves against indigenous populations, their utopia was never effectively realized. Voltage differences are imprecise and continuous (von Neumann himself argued that computers are both analog and digital); alternating currents generate EMI, and thus the possibility of crosstalk; plugging boards into sockets causes potentially damaging voltage spikes.' (Chun 2006).

16 The lower end of the bandwidth captures a fraction of computing's emissions and is yet meaningful for cyperphysical security experimentation, for example ((Genkin, Shamir, and Tromer 2014); (Genkin, Pipman, and Tromer 2015); (Genkin et al. 2022)).

17 Showcased in exhibitions such as Evidentiary Realism: investigative, forensic and documentary art (2019). Berlin: NOME, and: Bazzichelli, T. (ed.) (2021) 'Art as Evidence', in Whistleblowing for Change: exposing systems of power and injustice. Bielefeld: transcript (Digitale Gesellschaft, 38).

18 Dunne, Anthony. 2008. *Hertzian Tales: Electronic Products, Aesthetic Experience, and Critical Design*. 1. MIT Press paperback ed. Cambridge, Mass. London: MIT Press.

semiotic vehicles for imagination oriented towards addresses' (Larkin, n.d.), enabling me to scrutinise coupled and decoupled aspects of the computational, an approach where other modes of cognition fall short. This is the default computational condition according to Shoshana Zuboff; she divides the double-fold realities of the computational into a primary 'text' as communicated by tech industries and politics versus the operative 'shadow text' (Zuboff 2019). Not at all comparable in scale and impact, the abstract nature of audified electromagnetic emissions is also prone to mystification. Although my work is not documentary, in cases where it portrays a specific situation, I provide further context to the acoustic-electromagnetic source by additional means. The expansive feature of current digital technologies is echoed through the audified signals.[19] To provoke and to hear the interfering and intercepting notions of computation may facilitate a personal as well as a generalisable experience. The 'quasi-uncovering' makes the abstractions involved more approachable in some parts and less approachable in others. Instead of evaluating deterministic, or for that matter, indeterministic features, the sonic works emphasise the relational within the causal computational relationships, where the term relational refers to all kinds of entanglements, not only the desired ones.

2.3.1.2 Sonic, sonicity and algorhythms

German media archaeology has introduced multiple neologisms to conceptualise sound-like phenomena that are neither necessarily sonic nor necessarily human. All invest in relationships between time and technology and extend theoretical media discourses by sonic

19 Listening to a system changing from one state to the other becomes part of a conceptual feedback loop when auditory features describe what energies are: if 'Sound vibration […] provided a basis for explaining the vibratory activity of energies in the external world, as well as nerve impulses in the body' and 'became a model for energy in general, which physicists described as vibratory, imperceptible and infinite' (Trower 2012, 37 and 39).

terminology to describe technical temporalities, ‘even if their engineering (such as coding or compression) does not always directly relate to cultures of listening and the audible’ (Ernst 2016, 7). *Sonicity* denotes the processual nature of signal events, whether these are analogue (continuous vibration) or digital (discrete impulse, rhythmic). It depicts sound that does not originate from a resonating body and has a ‘strict dependence on physical or technical embodiments’, yet ‘even vibrational events in optical physics can be identified in their processual sonicity’ (Ernst 2016, 24). Sonicity is not concerned with the phenomenology of sound, and the oscillatory events escape symbolic description. Rather, it centres on the ‘essential temporal nature’ of primarily inaudible ‘sonic tempor(e)alities’ by examining some of its scientifically grounded epistemologies, such as the frequency domain as the ‘mathematically reverse equivalent’ of oscillatory waves: the explicit tempor(e)alities in a technological, and by extension, cultural sense. Therein lies implicit knowledge that is transported by the implicit sonicity included in each mediated representation, whether sonified or visualised, and is studied by media archaeology.

Ernst (2016) briefly mentions a subclass of sonicity known as *sonics* (translated from ‘das Sonische’ in German). *Sonics* specialise exclusively in signals from ‘electro-technical and technomathematical’ processes (23), are embodied by electronics, and emphasise ‘the human-machine coupling of sonic media culture’. By focusing on the temporal relations derived from electricity’s ‘immediacy’ and deliberately removing the ‘human’, ‘history’, ‘space’ and ’the symbolic world of scriptural and printed information’ from the concept of *sonicity* (Ernst 2016, 33, 89), media archaeological studies remain somewhat disciplinary or philosophical.

Where Ernst invests in technologies and cultures of sound, Shintaro Miyazaki (2013) focuses specifically on algorithmic structures. *Algorhythms* refer to all (non-acoustic) oscillating phenomena, such as electromagnetic or thermal fluctuations. Most vibratory events first need to be transduced to visual, acoustic, or other forms of representation to be perceivable by the human senses. Miyazaki applied the term to understand spaces created by 'physical-real rhythms', especially high-frequent ones, in a double fold – as scientific signals and aesthetic and thus epistemic. For more than a decade, Miyazaki (2014) evolved the algorhythmic perspective to span a precise media archaeological tool, an aesthetic approach, and, recently, a theory-based call for communal practices to counter and alter contemporary capitalist technologies. Although Miyazaki attempts to merge materialism and immaterialism through Donna Haraway's cyborg and Karen Barad's model of diffraction and interference, there is a certain dualism kept alive in his propositions for 'encounter' and 'counter-algorhythmics'. The materialisation of algorithms remains 'dirty' and 'concrete', even though Miyazaki undertook meticulous and precise case studies. The argumentation seems caught in a discursive opposition to the pure idea or symbol, even if neglecting their existence. The abstract ideas of merging theory, aesthetics, and socio-politics seem conceptual, as does the call to create community and overcome large-scale technological structures (Miyazaki 2022).

Disregarding the obvious connection of my sonic work to the concept of algorhythms, in this thesis, I build on the notion of sonicity. Sonicity adequately captures that sonics mediate technical procedures taking place in time, meaning they come ahistorical. Everything beyond the procedural dynamic expressed in the sound is transported by non-sonic means such as the presentation itself and gestural, verbal, or textual supplements. Much of my artistic work addressed an unspecified audience outside engineering and music circles. Hereby, a foremost technical – algo, and second musical term – rhythm, hinder my endeavour, while *sonicity* sounds both familiar and unfamiliar and refers to agential and dispersing computational matter as well as the contained nature of the logic it carries out. The article *(Micro)Politics of Algorithmic Music* (Cox and Riis 2018) constructs a 'temporal' and 'tactical' bridge from the electronic arts to the political through, among others, the media archaeological perspective of Myazaki's algorhythms. The abstract argument is to expose the way algorithms operate as part of wider socio-technical assemblages, understand the dependency on algorithms and that non-human entities generate alternative forms of knowledge that are not easily perceptible by humans.

2.3.2 Computational

2.3.2.1 Computational scenarios

The rough conception of a computational scenario or situation used interchangeably derives from the *sites of execution* by Eric Snodgrass (2017), originally a technical term for running a piece of software. A site of execution is a set of bounded computationally-informed practices, the like-button of Facebook or the electromagnetic spectrum that 'hold[s] up the infrastructure of surveillance and control in migration politics', in terms of technical, cultural, material, and political affordances as they play out in their intra-actions.[20] Some of the computational situations covered throughout the PhD project, such as personal devices or computing centres, are site-specific. Yet, they become ubiquitous in an accumulated sense. Others again, such as technologies developed as part of European research on migration control addressed by Chapter 5, are currently in the making. Experimentation and prototyping of 'innovative'

20 Karen Barad reworks the interaction of separated parties to intra-actions of entangled entities: Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press. https://doi.org/10.1215/9780822388128.

technologies for the EU's borders such as that reported by Petra Molnar in *Technological Testing Grounds* are accompanied by little democratic oversight.[21][22] The computational scenarios covered in this thesis thus show varying degrees of visibility, accessibility and assessability.

2.3.2.2 Signal spaces of computing

The signalling spaces of digital(-analogue) devices are the–perhaps least–common ground between logic and logistics, near and remote environments, effective appearance and potential use. Electronic devices release heat while operating and light up LEDs; the single memory bits '0' and '1' *look* different and, in reverse, can be altered by a laser. These are examples that go beyond the most widely known and utilised electromagnetic radiation. The physical emissions of a digital system, referred to as entropy in physics, is energy 'that is unavailable for doing useful work' where 'ordered molecular motion' is the intended function of a system (Drake n.d.). The usefulness of the leakage, initially known as 'tempest', represented a security threat from its beginnings and has been tied to practices of eavesdropping and surveillance by state and non-state actors alike.[23] Public news refers to the electromagnetic as *electrosmog*: in *Digital Rubbish - a natural history of electronics*, Jennifer Gabrys coined it *e-waste*. Theories of digital materialism and media archaeology conclude that the embodiment of the digital takes place in the emissions, not the wiring. The concept of *transmateriality*[24]

21 The report is archived on Molnar's website: Molnar, P. (no date) *Published Works, Petra Molnar*. Available at: https://www.petramolnar.com/publishedworks (Accessed: 9 July 2023) or here: *Technological Testing Grounds: Border tech is experimenting with people's lives* (no date) *European Digital Rights (EDRi)*. Available at: https://edri.org/our-work/technological-testing-grounds-border-tech-is-experimenting-with-peoples-lives/ (Accessed: 9 July 2023).

22 Molnar announced a book *Artificial Borders* for 204 on AI, surveillance and border technological experimentation. Available at: https://www.petramolnar.com (Accessed: 26 June 2023).

23 For a short introduction to the origins of *Tempest* radiation and its re-application in software as *soft tempest* see: (Kuhn and Anderson 1998).

24 Mitchell Whitelaw defines transmateriality as 'view of media and computation as always and everywhere embodied, but constantly propagating or transducing patterns through specific material instantiations'

captures the transductive[25] and transversal qualities of technological devices and instrastructures. Among other considerations, Gabrys is concerned with the impalpable waste for registering ‘after-the-fact effects’ and examines how sensors and sensing practices ‘rework experiences’.[26] In turn, Manuel De Landa (2011) called the simulations of physical spaces in software *The storm in the computer*, virtual large-scale laboratories.[27] The figure of the storm twists the conception of the emissions as straightforward and unidirectional. Likewise, without explicit protection, the physical phenomena of crosstalking is a bi-, or omnidirectional interference through electrostatic or -magnetic charge, passed on either by air or direct contact. I bracket switching electric current and changing electromagnetic fields into *signals* and the structures enabling or prohibiting their flow as its *spaces*.

With the straightforward yet complex spaces, I probe aspects of the computational, paying attention to decoupled yet entangled perspectives. The emissions are not infrastructural itself; nevertheless, I suggest the emissions are a ‘semiotic and aesthetic vehicle’ akin to Larkin’s

(Whitelaw 2012, 223), and further a ‘useful concept, I’d argue, because among other things it can encompass this whole process without introducing ontological distinctions (or magical transformations) between one kind of thing and another - between data and matter. How does our view of computation change if we think of it all as ultimately the propagation of material patterns? This involves throwing all kinds of useful abstractions out the window, at least initially.’ and ‘Transmateriality is an attempt to ’ground’ the digital without losing sight of its (let’s say) generative capacities’.

25 Whitelaw expands on transduction between energy and matter: ‘The keyboard transduces motion into voltage; the screen transforms voltage into light; the hard drive mediates between voltage and electromagnetic fields. A printer takes in patterns of voltage and emits patterns of ink on a page. Strictly transduction only refers to transformations between different energy types; here I want to extend it to talk about all the propagating matter and energy within something like a computer, as well as those between that system and the rest of the world.’

26 In (Gabrys 2011, 255): ‘To date, with smart cities as well as the Internet of Things, some commentators note that it is not always clear what is being measured, what should even be taken into account, and how data might be made interoperable’. Further, ‘the problem of deciding which connectivities we really want as human beings on this planet’ and ‘rather than decide which connectivities are perred between already enumerated individuals, we might instead attend to the ways in which collectives are turned into measurable entities and individuals, which are further put into relation through infrastructures of measurement’.

27 Da Landa creates a materialist view on computer simulations of physical emergence by the example of a thunderstorm and its ‘possibility spaces’ that can be studied through simulations ‘as if it were a laboratory phenomenon’.

view on infrastructures as situated and contested spaces.[28] If sensors and sensing are 'bringing the world into the device', then the emissions are bringing the device back into the worlds.[29]

2.3.2.3 Virtual and actual

Technological developments complicate the couplings between the software on one side, considered *virtual*, and electronics on the other, supposedly *actual*. The hardware realises software through flows of physical signals. Two examples where the distinction does not hold are simulations of hardware in software and the Internet of Things. The latter disperses small-sized pieces of hardware across multiple locations and thereby binds software and hardware closer together; hardware resources are limited due to the size, and the programs running on them consider the limitations closely. Instead of two separated planes, a 'reciprocal materiality' carved out historically: '[i]t is not only that digital data are always inscribed in some material substrate (Kirschenbaum's "forensic" dimension of data); conversely, the materiality of the medium inscribes itself into the structure of digital data (its "formal" level)' (Heilmann 2015). Logic in the mathematical and causal sense can be found in all layers of abstraction, 'burnt' into the electronics or implemented in software. In this narrow sense, I use the term logics to refer to administrative means for defining and implementing virtual spaces. I use actual instead of physical to consider the effects and consequences of logic beyond their

28 In (Larkin 2013, 2): '[…] infrastructures also exist as forms separate from their purely technical functioning, and they need to be analyzed as concrete semiotic and aesthetic vehicles oriented to addressees. They emerge out of and store within them forms of desire and fantasy and can take on fetish-like aspects that sometimes can be wholly autonomous from their technical function. Focusing on the issue of form, or the poetics of infrastructure, allows us to understand how the political can be constituted through different means. It points to the sense of desire and possibility, what Benjamin (1999) would term the collective fantasy of society (De Boeck 2011, Humphrey 2005, Khan 2006, Larkin 2008, Mrazek 2002, Sneath et al. 2009). It also means being alive to the formal dimensions of infrastructures, understanding what sort of semiotic objects they are, and determining how they address and constitute subjects, as well as their technical operations.'

29 Hayles, N.K. (2007) 'Sensing', in D. Bell and B.M. Kennedy (eds) The cybercultures reader. 2nd ed. London ; New York: Routledge, pp. 562–573.

physical phenomena. The infinite number of states between the electrical ‘0’ and ‘1’ is among the initial motivations for introducing abstractions in the first place. The emissions interface the virtual and actual, sustaining the tension between coupling and decoupling simultaneously.

2.3.2.4 Operationality

The emissions are ‘organised’ by all involved entities, such as the operating system, hardware components, firmware, software processes, developers, users, environment, faulty conditions, and concurrent events. According to Salome Voegelin (2019), the emissions point to the ‘possibility of technology as an occurrence that is operational rather than functional’ and signifies what the instrumentalist view on technologies disregards. Geoff Cox (2015) similarly argues that performing sound by *live coding* ‘expose[s] the condition of possibility’ in times determined by computational processes. As such, it reflects and demonstrates not only contemporary conditions but also ‘modes of uncertainty in what otherwise would seem to be determinate computational processes’. Particularly noteworthy in the current practical and physical context, Matteo Pasquinelli roots the algorithmic emergence in material practices rather than abstract, mathematical ideas imposed upon concrete data. The thread of this argument is taken up by Beatrice Fazi (2018, 152): ‘Following the traditional empiricist precept, this physical reality is considered to be made up of records that are “loose and separate”‘, meaning through discrete and measurable points. Through her philosophical account of formal-axiomatic systems, Fazi cannot find any ‘intrinsic causation or internal regulation between the reality of computational abstraction and the reality of their empirical referent’, only association. Contingency lies at the core of the computational; customs and habits–built into its design–drive software application, implementation, and performance. The insight holds for all kinds of computing paradigms, which Fazi summarises as ’empiricist computing’: classical, unconventional, non-classical, and the so-called natural computing.[30]

2.3.2.5 Abstraction

The portfolio and the framing of this thesis move between two cornerstones. The first assumption is that a non-relation exists within computing between abstraction and experience (Fazi). The second is that abstraction can be thought of and performed differently as a process of abstract*ing* (Klumbyte and Britton, 2020). With fragmented knowledge at hand–the default position in contemporary digital conditions–there is a necessity to relate conceptually unrelated parts, which increases where first-hand experience is limited or impossible. The project aims to trial the philosophical assumptions about computational conditions in practice. Whilst computational abstractive processes and lived experiences entangle in manifold ways, they are also intrinsically and deliberately decoupled from each other. The portfolio and commentary pay attention to the intentionally contradictory condition of the computational as abstract and tangible.

Abstraction is one of the main principles of computation utilised for removing and condensing detail to manage complexity (Colburn and Shute 2007, p. 175). It highlights what is seen as relevant while neglecting or hiding what is not; as such, it functions to ‘protect systems from themselves’. As Klumbytė and Britton (2020) sum up, historically, it resembles one of the universal tools that were implicated in the exclusions of matter, corporeality, and particularities. Abstraction is thus a ‘method of extraction of presupposed essences, shared features, generalized procedures, and representations’. Further, it separates ideas from

30 The chapter *Computational Empiricism* discusses the computational forms in detail (Fazi 2018, p. 143).

temporal and spatial qualities and, together with formalisation and generalisation, yields universalism. By contrast, abstraction in the arts is ‘posited within a (false) binary’ with representation at the other end and faces similar issues regarding the exclusion of people ‘marked as non-artists’. Yet abstraction captures ‘enormous conceptual and technological creativity’. To harness the potential of abstraction, Klumbytė and Britton describe it as a process that can be held accountable, an *abstracting otherwise*. They further draw on Deleuze, who suggested that the opposite of abstraction would be *discretisation* rather than concretisation and can, therefore, deal with relations rather than ‘fixed essences’.

For artistic practices, Klumbytė and Britton (2020, 28) propose that ‘abstraction as a strategy or method of mixing, working with multiple people and non-human agencies and with rearranging histories, is a way to open up what abstraction might mean.’; they describe it as a process that *can* be held accountable, an abstracting otherwise. Compared to computational abstraction, thought is also abstract, yet not abstractive. Likewise, unorganised sound is abstract yet not abstractive. Where visual traits might be representable by another abstraction, like a pencil sketch might stand in for the characteristic traits of a painting (Veseley as cited in Impett, 2021, p. 122), a sonic experience would not be representable by another mediation or compressible without loosing some of its characteristics.

2.4 Phenomena

This chapter introduces three phenomena from engineering and computing that transcend the boundaries between system designs and their physical occurrences. The engineering of the phenomena aligns abstract concepts with material conditions by mapping *touchable* and *untouchable* entities of digital technologies. Conceiving the computational as *infrastructures* *of abstraction* (J. W. Malazita and Resetar 2019), the attribution of ‘0’ and ‘1’ to a discrete point of power current prepares ‘higher’ levels of abstraction. The current flow simultaneously radiates into its environment. In principle, the emissions correlate with the activity of each involved component, soft- and hardware, throughout all levels of abstraction. The abstraction levels of information and communication technologies thus remain in the electrical currents and emissions–the electrical and electromagnetic conflate in this thesis to the signal spaces of the computational. Besides expanding into its immediate environment, the opposite influence of environments on a system is integral when thinking through physical phenomena. Altering the physical environment provides entrance points into a system; changing the room temperature or ‘jamming’ a system with other electromagnetic fields might alter a system’s operations, possibly in a reproducible and intentional manner.

Engineering fields balance the often contradictory aims of ‘stability’, ‘security’, and ‘efficiency’ corresponding to technical, industrial, and political demands or current threats. The interfaces between physical and virtual worlds are prone to malicious abuse by various actors; the approaches, methodologies, and concerns complement or contradict narratives on the functionality and use of technologies. In the realm of security, attempts to either ‘exploit’ or ‘break’ a system or, on the contrary, ‘harden’ it against adversarial incentive may defy the ‘commonsense’ of the field if considered adequate, such as turning interference into the main design principle or using an FM radio as a remote control for a smartphone.

2.4.1 Crosstalking

The OED defines *crosstalking* as ‘unwanted transfer of signals from one circuit, channel, etc., to another’[31], a leaked charge between neighbouring signal lines or a ‘signal integrity issue’, infamously known as noise in engineering (Macha et al. 2017). Whilst it is one of the most basic physical conditions of engineering, it is also so ‘commonplace that it is removed from the engineering curricula’. In its origins, the effect is undesigned or uncontrolled and needs to be managed, for example, by shielding or keeping a physical distance. Depending on the individual resilience of the involved entities, the crosstalking effect may not be mutual or may vary in degree or type. Either way, the entities do not merge and keep their distance. Crosstalk is interference caused by induction that I propose as a–somewhat casual–figure for non-explicit and mutual influences of decoupled yet entangled parties. It denotes spaces between the virtual and the actual, between a system and its environments, and between single, functionally separated components of the same system.

In the process of shrinking hardware, the area disrupted by physical side effects became larger. The physical obstacles led to research such as *crosstalk computing* (Macha 2020) that instead builds upon and engineers the effects purposefully and claims to ‘be transformative for the semiconductor industry’ by ‘turn[ing] this unwanted coupling capacitance into a computing principle’, which seems unlikely given existing production sites. The point is not the practicality of the proposal but its working imaginaries, even though as a mere proof-of-concept. As a side note, the language of the research demonstrates and perpetuates market logic and *patterns of trouble* that go unnoticed to those working with it daily–crosstalk

31 “Crosstalk.” n.d. In *OED Online*. Oxford University Press. Accessed September 15, 2022. https://www-oed-com.bham-ezproxy.idm.oclc.org/view/Entry/44812?redirectedFrom=crosstalk#eid7853867.

circuits turn signal interference into a ‘deterministic, tunable, and controllable’ concept and ‘relax the aggressive transistor scaling requirements’.

The following additional examples of crosstalk each touch on multiple of this thesis’s topics: the sonic, the electronic and security or surveillance. *Crosstalking* refers to hearing someone else’s phone conversation or one side of a stereo audio recording leaking to another. The technique coined cross-device detection or tracking for commercial purposes aims to relate two personal devices, such as a TV and a smartphone, to one user. An ultrasonic audio beacon plays on the speaker of one device; it goes unnoticed for human-range hearing yet is detectable through the microphone of a second device in the same room. From the arts domain, Catherine MacLean exhibited the sound work *Cross-Talk* in the 1988 exhibition *As told to: structures for conversation* that transposed the everyday use of the term. As an audience walked through structures in the room, she recorded their conversations, redirected the sound waves, and played them back elsewhere in the room. The altered physical and temporal properties of their conversations caused ‘disorientation and heightened acoustic awareness’. (Lander and Lexier 1990, 157–60). In 2008, the media artist collective Mongrel designed a series of ‘Cross Talk’ case studies to understand communication systems between ‘humans and natural environments’ by sensing ‘intensities of nature’ understood as ‘Eco

Media' or 'free' media (Parikka and Ruskin 2011). Parikka later extrapolated their project to postulate [c]ross talking as a genuine artistic method in art and media.[32][33]

A cross-cultural analysis coined crosstalking described the 'communicative breakdown' occurring in encounters between individuals and members of an institution where the individual is unfamiliar with the appropriate institutional codes (Gumperz et al. 1979). They might be treated adversarially without understanding why and face potentially severe disadvantages. Such communicative breakdown would manifest computationally: upon implementing technology-based procedures, existing bias takes on new technological forms, as, for example, came to the public in the Netherlands after receivers of social welfare were wrongly accused of fraud on a big scale. Sanne Stevens localised an atmosphere of 'will to hunt' that preceded a simply biased technology. The administration had initially blamed faulty technological decisions.[34]

32 Parikka derives the art's potential to initiate a relation between incompatible dimensions, human and non-human, from media technologies' crosstalking: '[…] setting up relations across scales (such as media extending towards nature) can be seen at the core of such an understanding of art as creating new material dimensions of relationality. Instead of seeing it as metaphorics of bringing together two incompatible series through a linguistic act, it is a topological transduction of forces, where the art process is a catalyst of potentials. It is in this sense that I want to approach the Eco media project through its potential for "cross talk". Art and media ecology as cross talk remind us of the non-human roots of both art and media, and hence extend the work of experimentality as an exposition of potentialities to what we have usually thought of as "solids"- nature.' (Parikka and Ruskin 2011)

33 Loosely related to vibratory crosstalking are devices for vocalising the 'inner voice' by picking up nervous stimuli subcutaneously. LaBelle describes the voice as directed outwards and 'transverses', or unifies, all inner non-verbalised identities of a person (2014, 90). Conversely, the 'subvocal' or the 'unvoice' is a voice that goes inwards and '*ghosts* the spoken'. Similarly, the human senses register a fraction of the electromagnetic spectrum and rely on mediation primarily; the emissions have historically been perceived as an 'uncanny' place unless acquainted with daily habits such as radiating smartphones. Experimentation on the inner voice by NASA and the maker (DIY technology) industry, LaBelle foresees possible extensions of mobile networks and the 'future of modalities of communication' in general.

34 Presented at: 'PANEL: Centering social injustice, de-centering tech: The case of the Dutch child benefits scandal' (no date) *PrivacyCamp.eu*. Available at: https://www.privacycamp.eu/panel-centering-social-injustice-de-centering-tech-the-case-of-the-dutch-child-benefits-scandal/ (Accessed: 9 July 2023).

2.4.2 Side-channels

A side-channel of a computing system refers to any source of information on the system's behaviour that is not part of its intended and documented functionality. Utilising side-channels therefore investigates a system through whatever is knowable or may be experienced in a particular setting by the persons involved and with the resources at hand, including information handed out deliberately by the makers of a system such as manuals and specifications, knowledge derived from the usage of a system, as well as information obtained by other means, from the *side*. In the case of physical side-channels, this could be observing the changing colour or speed of blinking LEDs, listening to the changing pace of a computer fan, or measuring skin resistance while touching a conductive part of a laptop casing. The sonic works documented in Chapters 3 and 4 conceptually derive from side-channels as researched by applied cryptanalysis experimentation, which Chapter 5 mentions in more detail.

2.4.3 Backdoors

The third phenomenon, backdoors, describes the possibility of covertly circumventing an intended access to a computational setting.[35] Instead of a physical annoyance such as crosstalk or a physical or logical side-effect such as a side-channel, it is either a deliberately manufactured entrance to the chip of a phone, computer, or router or a retrospectively discovered access via a system's security flaw.

35 'Backdoor (Computing)'. In *Wikipedia*, 9 July 2023. https://en.wikipedia.org/w/index.php?title=Backdoor_(computing)&oldid=1182982757.

2.4.4 On phenomena as vehicle

The pictorial ideas of crosstalking, side-channels, and backdoors precede the following chapters to hold them together. Beyond binding the computational, sonic, and written layers together, they exhibit links to computational principles and cultures, economies and politics. All of which are not part of this thesis in detail. Instead, the focus is on their literal, complex, omnidirectional, interdependent, interchangeable, simple to describe, challenging to measure, responsive, formal and non-formal traits. A family of terms is proposed not to tie to one concept, which might become a means to theorise instead of an applied yet analytic doing-thinking outside formal frames. The vehicles shall also not euphemise computational realities; they might seem spacious as metaphors, e.g. emanating into space instead of following a wire. More importantly, the figures describe ubiquitous and interwoven conditions with conflicting consequences while acknowledging partiality. The vehicles, put into practice, support the conceptualisation of computational conditions from across or a side. They shall encourage approaching the digital from non-computational perspectives and practices, as expressed by the examples in Chapter 5.2 and imagined further in Chapter 6.

2.5 Activities

So far, I derived concepts and phenomena by combining related work from the computational and the sonic. This subchapter situates my activities. The subchapter on performing-composing prepares the artistic work covered by Chapter 3 and the procedures covered by Chapter 4. A subchapter on technical-artistic hybrids brings examples of one realm appropriating the other, while the fourth marks how the concept of abstraction permeates existing computational cultures and the sociopolitical residues it creates.

2.5.1 Performing-composing

I build on Impett's definition of composition in its broadest sense as taking responsibility for a 'musical phenomenon' with 'some degree of boundedness and identity, regardless of how reproducible it might be or at what remove composers stand from a listener's experience', which includes sound artists and solo performers (2021b, 98). Impett states, 'On some level, at some point, they compose - they put together'. Furthermore, 'composition is not the sudden, unitary embodiment of an idea but a situated, distributed time-extensive activity'. Rather than considering the activity of composition as 'creative development per se', it is a process of 'producing and sharing knowledge'. At a later point, Impett (2021b, 120) recognises that this quest to 'specify and quantify its contribution to knowledge production' stems from academic contexts and addresses artistic production for 'research'. The notion of art as a genius's work has long been invalidated in scholarly environments, yet might have been somewhat replaced by the tension produced by a looming 'sense of responsibility to make a decision that is 'right' on some plane'; some apparent and consistent correlation between a process and the resulting work. The commentary aims at mapping the sonic works of the portfolio and the circumstances and procedures that yield them forth despite a hesitation to do artistic work (Chapter 4).

The portfolio's tracks are extracts of archives I gathered over ten years. Most initial auditory traces were not easy to listen to alone; they are either part of a broader project, document a live event, or were sketched hastily in response to a particular situation. Instead of analysing the technical or aesthetic aspects of the artistic productions or the single works, I contour the activity. Nevertheless, I worked in various artistic ways: I rehearsed and performed live, maintained continuous audio streaming from computing centres, and exhibited electromagnetic traces in sonic form as part of an artistic research project. One branch involved building, setting up, and maintaining a system to capture, stream, improvise, record, or diffuse electromagnetic emissions. Instead of technical or aesthetic analysis, I seek to frame, communicate, and hint towards what Rosenboom (2021, 57) described as ‘possible pathways from endogenous (private) experience to making exogenous (public) experiences’. Impett’s conception of performing-composing includes listening and imagining in anticipation or from memory. I propose to add the habit of provoking and tracing. The portfolio is a trace of the ‘cognitive synthesis’ during production in response to personal circumstances and not an individual or isolated process.

Ostensibly, noise might be a helpful grounding in the project. Not only because I perform under this label but also due to its critics as being ‘both obvious and evasive’ and ‘slipping’ between disciplines (Thompson 2017, 1–2), which resonates with critics of the computational. However, noise is already firmly constituted in music and engineering in diverse ways, so it might quickly become what Marie Thompson called a ‘floating signifier: it can be used to talk about anything’ and might unwittingly project similarities. Alternatively, it features polarities between noise and music, a temporary debate if ‘the new music is the once-was-noise’ (Thompson 2017, 139). While not going further, I depart from Marie Thompson’s view (as summarised by Sally Jane Norman in the preface) of ‘“noise” being essential to any medium or communicative act, relational and contextually affirmed’.

2.5.2 Sonic signal practice

Sensing the traces of computation is connotative for a diverse range of terms and practices: tracing, measuring, observing, eavesdropping, wiretapping, machine listening, and malicious listening. It is concerned with intelligibility, interpretation, recognition, listening machines, forensic evidence, and the *material witness*,[36] a term coined by Susan Schuppli.[37] Approaching computational signal spaces with sonic sensing is a technique that is also non-formal and uncompressed; a discrete access to a system's physical surplus through varying degrees of information and experience. Shintaro Myazaki's *Algorhythmic* media archaeology and Christina Kubisch' *Electrical Walks* are prominent examples of this.

I share the aim of *live coding*, making music by handling software code on stage, to 'bring code back into the frame of "material-discursive" practice' (Cox 2015).[38] Geoff Cox identifies *live coding* as a form of artistic research and a non-traditional form of coding that 'remain[s] attentive to the contradictions of what constitutes knowledge and meaning'. Ultimately, however, my procedures might resemble an expanded notion of Yolande Harris's physiologically sensing *techno-intuition*, a 'hybrid […] between navigation through technology and intuitive embodied navigation' (Harris and Dekker, 2009).[39] I propose techno-intuitive procedures for beyond-artistic use alike in Chapter 6.

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36 'The material witness — an entity (object or unit) whose physical properties or technical configuration records evidence of passing events to which it can bear witness. Whether these events register as a by-product of an unintentional encounter or as an expression of direct action, history and by extension politics is registered at these junctures of ontological intensity. Moreover, in disclosing these encoded events, the material witness makes "evident" the very conditions and practices that convert such eventful materials into matters of evidence.' (Schuppli, 2020).

37 An extended notion of eavesdropping: 'But eavesdropping isn't just about big data, surveillance and security. We all overhear. Listening itself is excessive. We cannot help but hear too much, more than we mean to. Eavesdropping, in this sense, is the condition – or the risk – of sociality per se, so that the question is not whether to eavesdrop, but the ethics and politics of doing so. This project pursues an expanded definition of eavesdropping therefore, one that includes contemporary mechanisms for listening-in but also activist practices of listening back, that is concerned with malicious listenings but also the responsibilities of the earwitness.' Parker, J.E.K. and Stern, J. (eds) (2019) *Eavesdropping: A Reader*. Wellington, New Zealand, Carlton, Australia, Melbourne, Australia: City Gallery Wellington; Melbourne Law School; Liquid Architecture.

38 For an overview of Live Coding, see Blackwell, A.F. et al. (2022) *Live Coding: A User's Manual*. Cambridge, MA, USA: MIT Press.

39 Harris creates instruments for sound and environment that are attuned to the persons playing the devices.

2.5.3 Technical-artistic hybrids

This project is not working towards technical-artistic hybrids in which both parties agree on collaboration and each party benefits in their own way or where one party silently appropriates the other. The former occurred when Google fell ‘in love with Bletchley Park’. Google prevented the sale of Alan Turing’s paper *On Computable Numbers,* a landmark paper in what became computing science and continued funding the Bletchley Park Trust. In the exhibition *The Art of Data - Making Sense of the World Together,* Google and Bletchley Park draw a future that seemed to have inevitably emerged from a past that was–as self-proclaimed–‘ahead of its time’, formed by all genders and sexual orientations on an equal footing. Numerous details in the Bletchley Park exhibition tell a different story regarding the everyday autonomy of the women working at the then-secret site during World War II and the reluctance to officially honour the legacy of Alan Turing or unveil the circumstance by which Turing was pathologised. The exhibition legitimates and celebrates secret intelligence work by charting it as not only a necessary endeavour but also one in the name of ‘beauty’. Likewise, located in the beginnings of the computational era, the conference *Recursions* and the accompanying journal *Music and Cybernetics in Historical Perspective* trace the historical entanglements of engineering and music. In this example, a collaboration was not announced a priori, and the mutual benefit simply *happened* by utilising the new possibilities in the case of electronic music or by ‘cybernetic imaginations’ gaining wide acceptance in society through their ‘extra-scientific meditation’; music being one example (Haworth 2021). The universal ambitions of cybernetic theory, explaining not only machines but humans and nature, ‘help[ed] naturalise the fluid exchanges between art and engineering contexts’ at that time.

2.5.4 Residues of abstraction

Despite the title, the book *Your Computer is on Fire* is not only a summary of computational troubles, but it also proposes starting points from which to act upon the devastating global states amplified by technology. In the résumé, Kavita Philips concludes that this is only made possible by linking the separated activisms and disciplines of social justice and technology. Philips finds technologists and humanists equally susceptible to either techno-utopian or technophobic responses (Mullaney et al. 2021, 365). No matter the profession, each takes their respective 'histories and contexts of the model of the humans and the world' as common sense and is misguided by 'simple, ahistoric distinctions'. To gain a more complex understanding across movements and disciplines, she urges readers to take into account the different languages, histories, and politics. Philips proposes these crucial points to not merely 'travel' disciplines, such as in the *mix and stir* technique; for example, teaching poetry to programmers superficially without a 'sense of how the skills of the other field might actually change their practice, call into question their authority, or shift the kinds of questions their field asks' (Mullaney et al. 2021, 368). Only by 'melding' the production processes of different disciplines can we avoid them being placed in 'separate bottles, with separate production histories'. Attempts to meld curricula in this sense are visible in a growing number of efforts to bring critical thought and artistic research to the curricula of academic computer science education. Although initiated by the institutions, publications report on the structural issues they encounter (e.g. Malazita 2019 and 2022).

I heed Donna Haraway's call to attend to current *troubles* literally and map it to technological conditions: *staying with* in the sense of a 'practice that participates in altering the parameters of a problem’.[40] Haraway rejects any hope for *techno-fixes*, that ‘technology will somehow come to the rescue’; instead, the question might be: ‘How can we unlearn and resist computational rationality that heralds optimisation, extraction and profit generation as the main goal?’[41]. In situations where both are necessary, that is a close reading of computational conditions and a process of ‘unlearning’ or changing the status quo, I propose artistic approaches beneficial. Haraway is not scapegoating tech; ‘it remains important to embrace situated technical projects and their people’. Along the same lines is the warning that by ignoring broader societal issues, the danger arises of simply rearranging (technicalities or the legal framework) to continue doing the same.[42] In 2021, a special issue of the Feminist Review summarised *sonic cyberfeminisms* as a conversation that scrutinises ‘conspicuous absences’ not only in techno-social relations to sound but also at the boundaries of its own constitutions and legacies (Goh and Thompson 2021). The lessons learnt from cyber-related activism reflect more general traits of computational cultures, as summarised in Asha Tamirisa’s contribution. Issues co-constituted across different social categories cannot be solved by singular means of empowerment, e.g. by acquiring technical skills, representation, or diversity to close gender or other gaps in technical environments.

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40 The more extended quote: [t]his approach should not be understood as an attempt to provide final solutions to an already known or pre-defined problem. Neither should it be understood as a method for problem finding - as if the problem is there to be discovered by some researcher or artist. Instead, it is an approach for ‘inventive problem making’ (Fraser 2012, Michael 2012), which refers to a ‘practice that participates in altering the parameters of a problem.’ (Ståhl, Lindström, and Snodgrass 2014).

41 From the ‘Call for Contributions: Otherwise Practices with/in Computing’ (2020), engines of difference, 18 September. Available at: https://enginesofdifference.org/2020/09/18/call-for-contributions-otherwise-practices-with-in-computing (Accessed: 17 September 2022).

42 Expressed, for example, during the *Privacy Camp* conference in 2021: Privacy Camp 22: 10th Anniversary edition (no date) PrivacyCamp.eu. Available at: https://privacycamp.eu (Accessed: 30 September 2022).

2.6 Towards sonic abstracting otherwise

Digital rights organisations continuously report disconcerting technical development; their regulations take a decade to implement and leave an array of loopholes.[43] It has long been established and thus comprehensively known that production and disposal severely impact and endanger humans and the environment. If technologies are forbidden in Western hemispheres or superseded by those which are more economical or better secured, they do not disappear but are used elsewhere. In the face of ongoing computational trouble, Malazita's question may be posed more broadly: how are computer science *and* practice producing a-political or anti-political subjects *and* scenarios? Malazita proposes two tactical frameworks to counter systemically losing lived experiences by abstracting them away: 'Scaffold *Everything* Politically' and 'Build Interdisciplinary Connections for Social Capital'. Tara McPherson's work linking the early development of the UNIX kernel to racial segregation, two remote analogues each 'co-constituting […] fragments from history', provides a poignant example of such coming together (McPherson 2012). Omitting these for large-scale technologies leaves *residues of abstraction*. Putting aside the microscopic scale in the face of planetary scale issues, attempts such as *abstracting otherwise* by Klumbyte and Britton, *Futuress*[44] and *The School for Poetic Computation*[45] are building collective capacity for dealing with the computational in non-extractivist ways. In this subchapter, I focus on the sonic; I gather exemplary works on the potential and pitfalls of sonic towards practices *otherwise*. Directed towards practice and social change, Salome Voegelin (2019, 157) used the expression 'quasi-sonic project' to describe new materialism as a form that draws on sonic

43 Organisations such as: *European Digital Rights (EDRi)* (no date). Available at: https://edri.org/ (Accessed: 9 July 2023).
44 Futuress (2023). Available at: https://futuress.org (Accessed: 3 July 2023).
45 School for Poetic Computation (no date). Available at: https://sfpc.study (Accessed: 3 July 2023).

understanding and extends to different contexts. I list several examples of what might be understood as quasi-sonic projects that reach out to social and political issues and are supportive of *sonic abstracting otherwise*.

2.6.1 Related work

In 1978, Pauline Oliveros (1984, 177), an early electronic music composer, contributed to a *Musical Creation and the Future* seminar. Tthe 'unhesitating' proposed title was *Software For People,* which later became the book title for a collection of unedited writing, including letters and funding applications. The talk outlined two poles of sonic attention, which Oliveros practised and taught for a lifetime: listening to environments with varying degrees of 'focal' and 'global' attention, induced internally by imagination or externally by an event. At that time, composing electronic music involved working with technical detail or 'low-level'; therefore, I assume Oliveros used the term software to express that listening is part of the 'human software' and could serve individually and collectively.[46] Sharon Stewart (2020) described Oliveros' 'listening to listening' movement as the performance of 'an irreversible hack of the musical score'.[47] Instead of composing music that sounds, the composing and the listening persons shall practice listening to their listening. In Oliveros' framing and Stewart's analysis, the computational and the sonic are entangled in straightforward and expansive ways, as imagination and practice face both outwards and inwards. As one of the multiple

46 Oliveros (1984, 190) comments on attention and listening: 'Good attentional flexibility is essential for participation in music no matter what one's role is. Along with the traditional focus on what to listen for in music, listeners could be trained to have greater awareness, through exercises which expose their processes and also teach them *how* to listen. Performers and composers of course could benefit in similar ways, thus greatly affecting the future of music.'

47 The extended quote: 'While she was certainly not the only musician busy with sonic explorations of the mind, sonic material, space, and time-Alvin Lucier and Bernhard Leitner immediately come to mind-through the scope and reach of her text scores, Oliveros performed an irreversible hack of the musical score. The score became, also, a vehicle for explorations of perception and self-reflective processes of sonic interaction with other humans and environmental actors.' (Stewart 2020, 245).

examples, Stewart recounts the artist's *sonic signatures* as a 'primary tool to abstract new territories within social/political structures as sociomusical acts'. In the analysis, Stewart links this to concepts of hacking and instituent practices. More than 40 years later, the artist, writer and theorist Brandon LaBelle constructs an equally generous and demanding purpose for the vision of *acoustic justice*, which is both an individual and collective attunement to the world and a conceptual framework.[48] Acoustics is understood as a 'material and social issue' rather than 'professional skill or science'. Similarly, the thesis attempts to shift the conception of cyberphysical phenomena. LaBelle includes the electroacoustic in the form of 'mediations of distributed sound and the technological apparatuses that enable sonic diffusion'. I am particularly interested in how LaBelle (2021, 31) apprehends 'acoustics less as a property and more as a performativity', which allows the 'everyday practices' of acoustics to be seen as a political question and introduces 'practices of composition embedded in struggles over recognition and justice'. LaBelle frames each investment into the acoustic politically, as in *sonic agency* or *sonic resistance*, which led to dismissive reviews in academic publications on the grounds that it was too far-fetched and imprecise.

48 From the first publication, *Towards Acoustic Justice*: 'By way of a focus on acoustics, along with sound and listening, which includes the articulations and reverberations of voice, the vibrational and resonant movements of social ecologies, and the cultural and symbolic productions and presentations of music, relationships emerge and are given traction. Following such perspectives, sound is emphasised as a deeply relational medium, one that enables social connection, processes of synchronisation and desynchronisation, attunement as well as interruption, and that moves across hearing and feeling, listening and touch; from the consonant to the dissonant, the harmonic to the cacophonous, sound provides a compelling framework for probing questions of relational experience as well as social equality.' (LaBelle 2020). Further detail is then provided on how acoustics as a concept turns into practice: 'I argue for acoustics as the basis for considering approaches toward social recognition and the making of collective worlds; acoustics as a path for reflecting upon the different forces at work in shaping the movements of people. In this context, acoustic justice is considered both on a micropolitical and macropolitical level, from the immediate ways in which questions of access, fairness, and ethical regard play out within street-level encounters, and further, to how acoustics participates on the level of law and governmentality, for instance in the courtroom or the classroom, by contributing to the rules of audibility and the norms that impact on how bodies are made to matter.'

2.6.2 Sonic pitfalls

Working with the sonic on other-than-sonic planes might fall into multiple traps, as summarised by Robin James. In *Philosophies or Phonographies?*, James (2018) unmasks Western attempts at using 'music or sound as a model of abstraction' as conceptually and politically flawed and trapped in opposition to the ocular and traditional philosophy more generally.[49] By contrast, the phonographic studies by Alexander Weheliye and Ashon Crawley's theory of *choreosonics* resemble 'undisciplined methods of abstraction' and 'exercises in performing and cultivating' without simply reducing phenomena to deterministic properties.[50] Sonic concepts carry 'a potent capacity to express and share understanding across somatic, psychological, mental and emotional dimensions'. Yet they also carry 'potential trouble if claims for interpretational or moral sovereignty is attached to it' or if they remain vague and without consequence.

2.6.3 Critical artistic practice on the computational

Responding to Agre's assessment that 'technology at present is covert philosophy; the point is to make it openly philosophical', Impett (2021a) draws on Agre's *critical technical practice* (CTP) to enjoin musicians and composers 'to provide a bilateral path between act and thought and public and expert discourse' and 'make music openly philosophical'. Notably, the title of

49 James (2019, 5) points out that 'The sonic episteme is dangerous, but thankfully it's not the only way to think with and through sound – i.e., to use sound to define concepts and other objects of knowledge, build theories, and abstract from sensory reality to human expressions. Sound, and even resonance, can be a productive model for theorizing if and only if it models intellectual and social practices that are designed to avoid and/or oppose the systemic relations of domination that classical liberalism and neoliberalism create.'

50 From the introduction: 'In order to come to grips with both sameness and difference in these iterations we need a theory of phonography – and of aesthetics in general – that blends sensation and perception and listens to the variety and intensity of their intermingling.' Weheliye, A.G. (2005) *Phonographies: grooves in sonic Afro-modernity*. Durham: Duke University Press. James concludes that 'instead of applying concepts from critical theory to musical works and practices, phonography analyzes both musical and literary texts for the kinds of abstractions that Afro-modern artists and aesthetics use to organize sounds.' (2018, 505).

Impett's article *Dissociation and Interference in Composers' Stories about Music* carries two of the themes central to this thesis: *dissociation* as a decoupled state and crosstalk as *interference*. In the following, I briefly outline the central connecting and diverging points of the three practices; Agre's CTP asks computer scientists to close gaps between technical and social realities, Impett's CTP invites musicians and composers to close discursive gaps by 'obligation' to an 'ethos', and I propose more unconventional practices to shortcut the understanding curve of people without computational backgrounds on particular, critical computational scenarios. All three concepts are concerned with 'relationships with formalisms in a technological milieu' and suggest more or less un-prescribed procedures to counter resulting, probably incomparable, gaps. Where Agre asks for self-awareness on implicit translations between formalisms of computing on one side and specific application domains on the other – the *borderlands*, Impett strives to highlight transduction processes between symbolic, theoretical, physical, and sonic modes. Agre locates gaps, or dissociation, as the result of leaving the intermediate *stages of abstraction* outside of the picture: 'routines, patterns of behaviour at all levels of time, detail, and awareness' which conceal underlying polarities such as 'mind vs world, mental activity vs perception, abstract ideals vs concrete things'. He proposes continuously applied meta-reflection; the developing person shall leave a detailed record in written form of all decisions made during the development process. Impett concludes that Agre's CTP is neither introspection nor autoethnographic; Agre would focus on the work itself, not the authoring person. Impett himself leaves the form of a CTP for sonic works open.

Whereas both CTPs call for self-reflection and assume self-transformative power, I propose informal practice on computational topics. This is not to exclude engineering expertise but to put social-political concern and perspective before technical or aesthetic considerations. At first sight, the *Log* in Appendix 2 resembles Agre's self-account of decisions. Yet, I do not propose an applicable methodology but bring an example of a pragmatic and informal approach or a personal practice. Agre's writing is illuminating as a *leak* of computational culture. It has much in common with composing, such as anticipation, imagination, narrative, taste, contingency, association, habits, and the encoding of motivation.

2.7 Concluding remarks

The necessity to explain or change oneself, the urgency, patience, and curiosity are not equally spread between computational and other disciplines. This thesis works towards more unconventional practices within a political framing of the computational in addition to existing critical work. I began this chapter with a spontaneous practical example of *crosstalk* between engineering and media art. I chose the work of the Obadikes as it oscillates between abstraction and experience on multiple planes and draws various histories of technology and media art together. Quick responses and immediate decision to interweave them with the writing process illustrate a personal way of processing related fragments, the aim being to share the process. The artistic procedures and works in the following two chapters display similar characteristics, bringing computational and sonic scenarios together. The sequence of activities demonstrated vehicles for conceptually and practically working with and from within gaps by putting fragments together in a layered and recursive way without merging them. The *Log* in Appendix 2 refers remotely to computational habits, such as the formatting and cross-links to a side-channel, the fan, or the active role of browsers. I invoked a family of interference phenomena from engineering to approach and engage with digital technologies and their environments in literal, conceptual, and imaginative ways–individually and collectively.

3 WORKS: POETICS OF COMPUTATIONAL SONICITY

Two branches of work underpin most tracks in the portfolio, except the two indicated as produced before the PhD. The first section in this chapter details the environment I developed for improvising with and from within the electrosmog of computational processes. After one concert, someone from the audience asked how to set up the *stress* environment to trial it and talk about it in a night radio show on art and hacking they hosted. For that occasion, I put together a how-to guide detailing the installation steps, which is in Appendix 3. The second section of this chapter covers sound streamings, installations, and archives, mainly conducted as part of the *Computersignale*[51] project. In each section, I unbundle technicities at first and fuse the separate components conceptually back together to propose multiple planes of crosstalking. For example, how scores, software, and hardware mutually influenced each other and how continuous sonic streams, walls, and archives cross paths.

3.1 Crosstalking scores

Appendix 4 shows a series of scribbled papers, each serving as a cheatsheet for one rehearsal before playing live. At the start of the PhD, I considered myself more on the computational side concerning artistic activity. I noted which software to 'operate' during a performance on a 'cheatsheet'–terms and habits situated within the ecology of technical tools. Each of the six columns of such a cheatsheet contains abbreviated versions of launching the Linux terminal tool *stress* with specific arguments. Over multiple years, I performed a couple of times yearly. With each public event and primarily due to the rehearsals in advance, the outcome gradually became more intentional concerning the sound. While transitioning to more on the sonic side,

51 The project's website is Rickli, H. (no date) Computersignale. Art and Biology in the Age of Digital Experimentation. Available at: https://computersignale.zhdk.ch (Accessed: 2 January 2023).

the cheatsheets became scores. The randomly chosen scores in Appendix 4 point towards the entangled, iterative rehearsal and scoring practice that developed from my sonic experience while *crosstalking* with Linux system calls–computational abstractions and operations registered by the listeners indirectly through the sonic outcome.

3.1.1 Sysadmin tool *stress* for improvisation with/in electrosmog

Since performing in public from 2008 onwards, I regularly switched computers, operating systems and software to trace. For each event, I tried new combinations thereof. From the range of sounds provoked, I presumed to elicit more diverse sonic outcomes by a more systematic approach: algorithmically controlling the system calls in ways that are not feasible manually, employing applications using the graphic card extensively or handling large data sets. Instead, I used thematically related software from security or system maintenance by hand. Also, the sound recording and processing could have been more sophisticated by using more than three pickups spread over the keyboard, treating the separate audio channels or specific frequency bands in realtime, or spatial diffusion. However, I neither applied engineering nor musicians' techniques. I installed, used and listened to minimal or specialised operating systems running fewer processes than a graphical operating system, thereby foregrounding the activity of single computer processes, yet sonically meagre. In 2018, I came across one specific combination of hardware and software: my own laptop, a small operating system used in system administration for testing the hardware of a computer, a particular boot medium, and the terminal tool *stress* to put a workload on specific hardware components, such as the memory (RAM). The resulting sonic textures were more elaborate and dynamic. In addition, the tool's arguments precise the processes, and multiple instances may run simultaneously. Until now, I have not been able to reproduce a similar variety with another combination of hardware and software. Running multiple commands in combination is crucial in this setup. Compared to encrypting or defragmenting a hard disk, the stress tool triggers more elaborate sounds from the electromagnetic emissions, and I began to think of the cheatsheets as scores. Performing the scores is still improvised; the sequence of calls is repeatable, yet not the sonic outcome.

3.1.1.1 Runtime

→ *portfolio tracks no. 03-06*;

3.1.1.1.1 Softwareness

Running processes are the virtual source of the portfolio, and the activity in the improvised pieces stems from the physical emissions while starting and stopping a software named *stress*. It is a small program used to check the performance and the 'health' of single hardware components of a computing device. Calling the tool requires specifying one or more hardware components to put a workload: the volatile memory (RAM), the processing unit (CPU), the input/output system (data busses or connections), or the disk storage. For each hardware component, one or more arguments determine how it is used, for example, by specifying the size of memory to occupy. The tool stress works without a graphical user interface; it is text-based and runs in a terminal.[52] The four supported components translate into four operating system calls. System calls are part of a Linux system on a 'lower' lever and remote from the person using it. On their way 'down the abstraction ladder', all programs eventually translate

52 The 12th screenshot on stresslinux' website shows an example: 'Stresslinux'. n.d. Accessed 2 January 2023. https://www.stresslinux.org.

into system calls. The *stress* tool is part of a micro–operating system explicitly assembled for it in 2009 named *stresslinux*. I had used other terminal-based distributions that did not efficiently isolate the sonic effects of the software I interacted with: the fewer the number of processes that operate simultaneously, the less the operating system switches to allocate and assign hardware components to each of them in turn. The switching occurs at high speeds that are not directly audible, yet the organisation of the processes and their current flow also change within the range of human hearing. The stresslinux operating system emanates, and thus sounds, different when booted from various media, such as a disk, a USB stick, or a CD ROM. Loading bits of the system into memory is organised differently in each case. Booting from CD ROM displays the most precise sonic structures; therefore, I adhere to this.

3.1.1.1.2 Hardwareness

While improvising, I pick up the electromagnetic fields of my main working laptop, a heavy desktop replacement. Its size and capacity might be one reason for the complexity and variation of the emissions and, thus, the sounds. While performing, I place the pickups directly on the keyboard. There are approximately three areas with well-distinguishable sonic characteristics. Although I know where the hardware components are located under the keyboard, I do not think about their location when making specific calls to the stress tool or while listening to the emissions. Instead of adopting an analytic or systematic approach, I focus on the actual sounds. The back side of the laptop radiates similarly, and occasionally, I begin with the laptop turned up by 90° degrees and standing on its two angled side edges. Because I cannot type in this position, I only move a pickup on the backside of the casing. Although this is a clear indication to the audience of the electromagnetic source and the sonic, I rarely use it because I do not practise gestures outside the scope of the regular usage of a computer. Instead, I search for *stress* configurations inducing varying emissions. Some regions I avoid for being too monotonous, such as the laptop’s fans.[53][54] I rarely use the constant, higher-pitched and sometimes spheric sounds from the disks. Each area exhibiting more detail has a centre point of a few millimetres, and moving pickups slightly may shift the ‘tone’ while the electromagnetic/sonic activity remains.

3.1.1.1.3 Sonic work

→ *portfolio tracks no. 16*

The sonority of the *stress* setup stems from the calling arguments, the combined calls and the starting/stopping of the calls. The *stresslinux* distribution has six parallel terminals–a terminal is functionally equivalent to a desktop of a graphical operating system–which are accessible via the upper row of Fn-keys. I use all six terminals to run up to six single stress calls in parallel and have established one habitude for convenience; I use the sixth terminal for the CPU. So far, I use one hardware component at a time per call. If I were searching for more sounds, there might be a difference between addressing two hardware components by one or two calls, even if they are functionally the same, yet the timing might differ. When using the memory, I typically give additional arguments like the memory size and whether the operating system shall release the memory right after a process comes to a halt. The number of processes needed to stress a particular part has a device-specific limit and crashes the stresslinux when exceeded; a reboot involuntarily becomes part of the performance. A specific

53 The acoustic noise of computer fans is also a side-channel in cyberphysical analyses.
54 A pickup placed right on top of a laptop’s speaker while playing speech or music will play the original speech or music back in low fidelity and distorted: it is picking up on the movement of the speaker’s coil, not the acoustic sound.

combination of calls does not always sound the same as it depends on the initial state of the operating system before launching the process and, therefore, is not consistently reproducible. The stresslinux system might ‘wear out’ over more than twenty minutes and become increasingly noisy. Some states, especially those that are evolving, are not easy to reproduce. I start and stop the stress tool more than a hundred times during a performance; often, a process runs for a short time only. The various areas of the motherboard sound different and give additional variety.

3.1.1.2 Audification

Two to eight induction coils, called telephone pickups, capture the electromagnetic fields and connect to an eight-channel soundcard with pre-amplification. The soundcard has individual volume levels per channel and, therefore, per pickup. The sound card is attached to a dedicated laptop for slight denoising and recording. To avoid confusing the functional laptop of the soundcard with the one traced and heard, the soundcard and its laptop are stacked, and at the end of the table, the laptop screen is flipped backwards so that it lies horizontally. The font size of the terminals is increased for the audience to at least see the characters even if it might not be readable for everyone.[55] I created a Puredata patch to remove some of the static noise in realtime for the first performance at the Pixelache festival and still use the unmodified program. Due to the high amplification of the pickups, there is regularly a steady hum co-amplified from the electrical network in the space. Most of the time, plugging a DI-Box between the soundcard and the PA reduces it; otherwise, I play along with the hum.

55 The soundcard’s laptop may become part of the performance if I experience a crash on the computer that I trace and temporarily need an additional electromagnetic source while rebooting. I might place one or two pickups on the soundcard’s laptop and perform operations I know well. Sometimes, I include ASCII-based animations in the terminal; I move the window in a rhythmically aligned way or resize the graphical elements of the recording Puredata patch.

3.1.1.3 Cheatsheets as scores

→ *for a series of examples, see Appendix 4*

Typically, I work on one score over multiple concerts, which is not audible to an audience, as I have been told. I find variations of similar parts; one score might be more rhythmical or circle a certain tonal or atonal mood, integrating more or less harsh layers. Some concise melodic features or rhythms reoccur, but the actual sequence of sounds and the overall sonic dynamics differ. The sonic *feel* relates to exploring a particular stress invocation; for example, passing and varying the stride argument to write a ‘1’ to every X^{th} bit in the memory. Looking at the previous score, I have an approximate idea of the central theme of a score and almost no memory of how it developed while playing; the score is relatively remote to the playing. One score holds six columns, one for each terminal. I note the calls to start or stop from top to bottom chronologically: the hardware component and the arguments to pass. I do not have a consistent system for additional marks and use whatever is helpful at that moment to give extra information on the sounding. Three labels stayed consistent, indicating whether a stress call should start and stop quickly, whether combinations are evolving slowly, and to take care of loudness. I try not to change the score during the last two rehearsals. The day before the concert, I copy the score in multiple dry runs by pen and paper, without playing it, to memorise the process combinations. After multiple copies of the complete score on the day of the concert, I compress the notes with each iteration until I arrive at a condensed sketch of stress combinations.

3.1.1.4 Rehearsing

The rehearsals for a concert revolve around a series of stress combinations. Preparing, I turn to previous scores, the last one, or pick one randomly from dispersed staples of scores. Either I have a rough idea of the sound of a score and try to reproduce highlighted combinations, or I try arguments I have used sparingly so far. I might collect various calls or start from scratch. While rehearsing, I play for myself: trying combinations in a mode that is not just scanning for options but taking time to listen and trying minuscule variations. With each rehearsal, I work out and write down a new iteration of the score. Beginning with two pickups, I gradually increase to four or six. Before one concert, I conduct between ten and twenty rehearsals and sometimes one or two afterwards; if the performance differs from the preparations, I try the score again. I record all rehearsals as multi-channel with one channel per pickup.

3.1.1.5 Performing

→ portfolio track no. 17

I prefer playing at small venues and standing within the audience so that the hands on the keyboard and the screen are visible. It is unnecessary to read everything clearly; the font size is large enough to notice the change of commands on the terminal and get a sense of the correlation between pressing ‘enter’ to launch or interrupt a single *stress* invocation and the subsequent sound changes. Equally important, it becomes apparent that I am, in turn, reacting to the sound, which shows I am not merely controlling or using a system but activating and responding. Because I perform with one laptop so far, I try not to sit in front of the keyboard to distinguish my posture more from a regular placement in front of a computer. Although I keep the condensed version of the score in reach, under the keyboard or in sight, I hardly ever look at it while performing. I switch from following the score to playing from memory, recalling automatically instead of consciously and reacting to unforeseen events. If I am not fond of how it sounds while playing and do not know exactly how to continue, I may change the atmosphere gradually by running stress commands with a minor impact; sometimes, I audibly search for another combination. Alternatively, I shut the sound abruptly off, almost entirely down, by running *stress –cpu 4* in solo. This argument uses the hardware components in a way that, surprisingly, attenuates the strength of emissions and is almost silent for a while: the *–cpu* argument resolves to the Linux-internal system call *sqrt()* calculating the square root of a random number.

Even though performing with the stress environment is neither precise nor intuitive, I accept any invitation to play together. Independent of the actual stress calls, there is a general characteristic flatness of the sound, and I often cannot change the ambience in a timely and willful manner. The first occasion I played with others was for a live soundtrack to accompany the lo-fi science fiction movie *The Mechanical Man* from 1921, screening as part of a weekend of live music for early sci-fi movies. Jan-Kees van Kampen, Olsen Wolf and I assigned the electromagnetic noise of the laptops to the robot. The audience could not see the computer screens, so I only moved windows, did immediate user interactions on the graphical desktop, and focused on the timing to align with the robot's movements, often with a delay.[56]

56 L'uomo meccanico. Milano Film. Available at: https://www.imdb.com/title/tt0337377 (Accessed: 30 September 2022).

→ *portfolio track no. 13*

In 2018, the organiser of the Zarata festival invited Seijiro Muyarama, a percussionist and vocalist, and me to play as a duo. We agreed to play alongside each other instead of with each other. Muyarama refuses to talk before playing together to allow an un-wilful encounter, and the *stress* setup is not immediate and consistent enough to play it deliberately. We shared a soundcheck without further discussing it and decided on a time and loudness structure afterwards: 10 minutes less volume, 10 minutes more volume, and 10 minutes low volume again. Muyarama announced he would do percussion and would not be vocal. About halfway through, there was a moment when I heard a new sound and was convinced it must be coming from the laptop; I could not, however, relate it to any process. It turned out to be Muyarama's voice, and we heard back from the audience on multiple moments of uncertainty as to where precisely a sound originated.

3.1.2 Concluding remarks

Playing with the *stress* environment creates sonic abstraction as the direct sources, the computational processes, are not perceived in an immediate manner. Yet, the sonic is a physical representation of the processes and their environment. The audible structures in the sounds stem from multiple software entities that share limited resources–the hardware. The sonic activity expresses relations between the operating system, the stress tool, the hardware components, the electromagnetic emissions, me and the sound, the audience, and the speaker system in space. The person caring for the mixing desk makes an immense difference in dealing with the edgy and raw sound I leave almost as is. The sound check determines my perceived degree of freedom: switching between stress calls and arguments without precaution. The source of the sound is neither apparent nor unclear. The operationality of the system becomes plastic, almost haptic, through the sonic abstractions on a sonic and thus somatic level. The computational abstractions of the virtual processes *break down* upon *arriving* in the wires and radiate as sonic abstractions into the environment. One abstraction, the computational, is replaced with another, the sonic, to experience the sonority of the runtime environment. Nicolas Collins (2019) compared the sound of ‘softwareness’ and ‘hardwareness’ in electronic music-making and testified that the respective production processes are, even if subtly, recognisable in the sound. Although the hardware is considered ‘unique’ and appreciated for its ‘unruly tactileness’, Collins recalls Alvin Lucier’s dismissal of the application of hardware circuits in electronic music: ‘sound is three-dimensional, but electronic circuits are flat’. After one concert, an engineer for audio plugins among the audience reported that he heard, alongside my interactions, both sources of the sounds: the digital of the software and the analogue of the electromagnetic fields. The remark indicates hearing the entangled *computational sonicity* of the stress setup.

Labelling the artistic practice is not straightforward for me. I am no longer merely operating software on stage, and I acknowledge that I play noisy music. I enjoy rehearsing, yet I only do so with the prospect of an audience to play for. My reluctance stems from the sonic being the second thought; instead of a sonic idea and shaping the way it sounds, I adapt the aesthetic outcome to what is possible in certain circumstances. From rehearsing, I have expectations right before playing and might be unsatisfied with the result. I do not initiate sonic work without an incentive to share, though. On the other hand, I actively create circumstances to join other projects, play or publish via my network.

3.2 Crosstalking walls, streams, and archives

This section focuses on sound installations as part of two exhibitions by the *Computersignale* project. For more than ten years, the artistic research project has brought together various perspectives on the material, infrastructural foundations of exemplary scientific undertakings, where I am responsible for capturing and audifying their electrical footprints.[57]

3.2.1 Exhibition Walcheturm

→ *portfolio tracks no. 18*

The first exhibition took place in 2020 at *Walcheturm* in Zürich, a space for experimental arts located in the same city as the project.[58] It displayed a compressed panoramic version of 24 hours of recorded audio and video related to one of the scientific laboratories central to the project.[59]

3.2.1.1 Speakers via walls

The main objective for presenting the recorded sonic traces was to make 24 hours and 18 channels of dry audio recordings from infrastructural objects accessible to the public. The audio material consisted mainly of electromagnetic emissions and some acoustic or contact microphones. I aimed to use the exhibition room as an active infrastructure to redirect the sounds of the other remote infrastructure that the exhibit thematised. The second intention

57 The artistic research project's website: Rickli, H. (no date) *Computersignale. Art and Biology in the Age of Digital Experimentation*. Available at: https://computersignale.zhdk.ch (Accessed: 2 January 2023).

58 The exhibition's website is *Cichlid #3, Soundscape Texas « Kunstraum Walcheturm* (no date). Available at: https://www.walcheturm.ch/agenda/afrikanischer-buntbarsch-3-soundscape-texas (Accessed: 3 January 2023).

59 The online audio archive: Rickli, H. (2019) *Cichlid #3, Soundscape Texas*. Available at: https://computersignale.zhdk.ch/en/data/cichlid (Accessed: 26 September 2022).

was to avoid processing the audio recordings. Due to the large volume of the material, any treatment of the audio recordings was only punctually verifiable. Therefore, I used the type of speakers and their position in the room as filters to each audio channel. While not all acoustic details were audible, the overall acoustic conditions remained stable.

As an initial reduction of complexity, all acoustic recordings played in the first part of the space, right upon the entrance, and set an auditory atmosphere with explicit references to known acoustic environments: wind and mechanic sound emanating from metal structures. A wall of video screens displayed moving imagery from the eight locations and showed the source of the sounds. In front of the video wall, directional loudspeakers faced downwards from the ceiling. On some occasions, audio and video material synchronicity became apparent by, for example, simultaneously hearing and seeing a car passing by the gas and oil fracking station. The screens pointed to an ample space behind, separating it from the entrance area. Upon passing the wall, only electromagnetic and vibrational recordings played from multiple speakers, the visual clues from the screens no longer in sight. A projection on the wall gave descriptive notice of the source of the sound.

The subsequent simplification entailed diffusing only one location at a time; each site had been captured by one to three sensors. The recordings played on separate speakers spread in the semi-open room: four Genelecs, three directional speakers, and one subwoofer. Most recordings were too dense, sharp, or monotonous to be listened to alone. Without a 'right' volume, they quickly became too loud or too soft to hear the changing structures within clearly. The crucial part consisted of mapping single channels to the speakers to mediate the static nature of the infrastructural objects *and* their activity, balancing the dryness and giving an acoustic incentive to approach the speakers. The Genelecs covered a broader frequency range but were sharper than the directed speakers, effectively filtering out a significant portion of the signal. I pictured an audience outside of noise, music, and art scenes. How much of the activity in the recordings would still be audible? How listenable would it be perceived? The speakers' positioning mirrored the project's perspective on the material foundations of scientific endeavours in some way. The speakers aimed at infrastructural elements of the space itself instead of at the visiting people: either at a very short distance to the wall, still far enough for a person to pass in between, or one metre above head height and parallel to the ceiling instead of facing down, or positioned high and directed at the wall such that the direct sound from the speakers could not be perceived directly, merely its reflections–mediated by a wall. Pointing away from the visiting people neglected the audience, while counter-intuitive, the positioning filtered the sharpness out and made listening more engaging. There was a diffuse sound in the room from all speakers. Details in the sonic structures became audible by moving along walls, windows, and the room, especially at spots where reflections from multiple speakers would intersect.

3.2.1.2 Different points in time

Each location played for 2.5 minutes, and the six sites iterated with long crossfades of one minute–it took around ten minutes for each site to be included once. Duplicating a channel over more than one speaker did not improve the listening; the auditory space remained similar without bringing additional detail from the recordings. Playing two different timespans of the same location on each side of the room, though, e.g. one from 2:00 p.m. on the left and one from 2:30 p.m. on the right, increased the acoustic depth of the room significantly. Further activity in the sound added complexity without overburdening as the two recordings overlapped in the lower frequency bands, and the general characteristic was similar. In some recordings, the base tone shifted gradually over fifteen minutes, which became audible by layering multiple moments. The total duration of the loop covered 5 hours.

3.2.2 Exhibition German Maritime Museum

The more recent exhibition took place in 2022 in Bremerhaven, Germany, in the North Sea, in proximity to the second scientific lab the project worked on, an underwater observatory.[60][61][62] To invert the visual perspectives on the marine biologist's observatory and its ecological environment, I proposed to trace the electrical signals of the marine biologist's observatory as signifiers of the infrastructural activity and emissions. Since 2012, I have implemented and maintained embedded systems for continuous recording, uploading and archiving of five audio channels.

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60 The exhibition's website: *Listening to Data. How the environment gets into the computer*. Available at: https://www.dsm.museum/en/exhibition/exhibitions/hannes-rickli-listening-to-data-how-the-environment-gets-into-the-computer (Accessed: 26 September 2022).

61 The art project's approach to the observatory is introduced in Rickli, H. (2019) *Computersignale. RemOs1, Spitsbergen (since 2012)*. Available at: https://computersignale.zhdk.ch/en/data/remos1 (Accessed: 26 September 2022).

62 The audio archive is accessible on *Computer Signals Audio Archive* (no date). Available at: https://archiv.computersignale.zhdk.ch (Accessed: 9 July 2023). The audio corpus is migrating to a platform by the Alfred-Wegener-Institut to remain accessible after the artistic research project's lifetime: 'OPUS - The Open Portal to Underwater Soundscapes'. Available at: https://www.opus.aq (Accessed 9 July 2023).

3.2.2.1 Underwater observatory

→ portfolio tracks no. 07 and 08

The exhibition in the German Maritime Museum spanned the project's work on an underwater observatory, lasting more than ten years. It displayed the stereometric images made by the observatory alongside audio and video material. In the middle of the exhibition, in an almost sealed room showing live underwater webcams and the audio recordings of the previous day from Spitsbergen diffused over seven speakers: one hydrophone, the power consumption of the observatory, and two electromagnetic recordings. One of the pickups was close to a digital camera taking the pictures, and another one was placed in the middle of the casing that protected the cameras and all electronic components underwater. The hydrophone recordings played on four speakers in each corner of the room to recreate the observatory being immersed in water and the microphone's omnidirectionality. Three mechanically directed speakers were fixed on the ceiling in the centre of the room, facing straight downwards, and each played one type of sensor. The volumes were balanced according to the two states of waiting for 27 minutes and taking and uploading a stereometric picture for three minutes.

3.2.2.2 Computing centre

→ portfolio track no. 09

In May 2022, in advance of the exhibition, I set up four continuous audio streams from the computing centre archiving the underwater observatory's picture: one on top of virtualisation machines, one on fast storage, one on slow storage and network equipment, and one on the tape archive controller. The streamings will continue until the recording systems stop due to failure or the computing centre requires the occupied rack space. The collective π-node is hosting the streaming.[63] The streams refer to monitoring practices; they are potentially listened to by visitors on the website, and sometimes, a member of the collective schedules it for the night program. The four streams can be mixed via the volume levels per stream on the website or with the collaborative web mixer developed by the collective.

The streams played for two months during the exhibition in an empty space. Similar to the display in the Walcheturm, two speakers were fixed above head height and under the ceiling. The speakers lined up serially instead of facing each other to create an acoustic corridor parallel to the rounded wall. The sound propagated best close to the wall and between the two speakers. A person standing in between could hear the sound from the front and back, which is unusual compared with the more familiar stereo listening experience. The second speaker pointed to a small room adjacent to the bigger one and a window wall looking into the river delta in front of the museum. The speaker aimed at the window and, together with the walls, generated overlapping acoustic reflections. Additionally, there were a few spots in the room with more audible detail.

Each stream comprised a stereo mix of three or four electromagnetic pickups. Three of the four streams were layered and panned over the two speakers in the room according to the sound. The more pointed sounds diffused to the smaller room, and the more spheric ones to the larger space. The latter could be heard from outside as well. I made an approximate sound check and tried to memorise how each type of sound worked in the room. I had remote access to the mixer, and during the first two weeks, I made adjustments according to the current web

63 The broadcast's page on the π-node website is Radio AWI Rechenzentrum (no date). Available at: https://p-node.org/broadcasts/rz-awi (Accessed: 3 January 2023).

streams and out of memory. For the rest of the exhibition, two streams played with the same configuration, one spare in case the others either dropped out or became too harsh.

3.2.3 Concluding remarks

→ portfolio track no. 10

The second subchapter described making the continuous tracing of a scientific infrastructure's sonicity accessible online and in space. The presentations vary in how much of the original context of the recordings is conveyed to an audience, from barely any in the case of the web radio to a substantial amount in the exhibitions. The exhibition spaces were in local proximity to the parties of the projects, the recordings diffused without modification, and the speaker setup actively engaged the space as infrastructure—inviting subtle interaction by listening to the different acoustic reflections in the room. The speakers, the walls, and the infrastructure of the exhibition space influenced how the biologists' infrastructure presented and was perceived acoustically in the room.

Most recordings from the Computersignale project are accessible online.[64] The articulations of the scientific projects are of documentary-like aesthetics. Parts of the work processes are translated in detail to a broader audience, while the audio and image material of more than ten years is published fully and with little narration. The archive consists of energy-related captures that might only attract the interest of a niche audience. By contrast, the hydrophone recordings spawning several years of high-quality recordings in two locations also interest the biologists. The project initiated a series of calls to composers and sound artists, which, in

64 The audio archive of the *Computersignale* project is available at https://archiv.computersignale.zhdk.ch (Accessed: 3 January 2023).

theory, could also extend to a call for cyberphysical attack challenges occasionally conducted at cyber-security conferences. The live broadcasting of a security risk–by principle, the efforts to do so would not seem reasonable–into the exhibition space leaked one piece of information: a system administrator visiting the museum recognised the tape control in the live stream without having been told beforehand as he had worked in the tape archive for a couple of days in the past.

4 PROCEDURES: COMPOSING SONICITY THROUGH COMPUTATION

→ portfolio track no. 01

Assuming the power supply works, performing-composing with the electromagnetic radiation of digital matter is feasible once the power is switched on. Track no. 1 in the portfolio is a recording of an early mobile computer right after pressing the power button. The screen was broken, and it was unclear whether an operating system had actually launched. The electromagnetic fields and the power current typically contain audible differences from the device's activity. Both form part of the computational's sonicity and correlate with each other; the electromagnetic is accessible with less effort from outside the casing in a non-intrusive way. In *userland*[65], a personal device has various modes of doing nothing, such as idle, sleep, hibernate or aeroplane mode. Typically, the emissions will still reveal activity; processes are actively waiting, or the devices might be communicating.[66] The current chapter presents a series of computational scenarios within my reach, personal devices and infrastructures. I recorded their emissions and used them for sonic works, either for an audience or in collaborations. The recording setups are installed over longer periods of time and last from days to years; some involve live streaming. The formats are clear-cut and involve a degree of technical complexity due to the long duration of the project or its location. The subsequent chapter covers performative work, including improvising, live mixing of streams, or quick

65 Informal description: userland (no date). Available at: http://www.catb.org/jargon/html/U/userland.html (Accessed: 4 July 2023). The processes themselves are organised in *kernel space*: Kernel Space Definition (no date). Available at: http://www.linfo.org/kernel_space.html (Accessed: 4 July 2023).

66 The *introspection engine* developed by bunnie Huang and Edward Snowden is a physical shield designed to protect phones with sensitive content in such a case: Snowden, E. and Huang, Bunnie (2016) 'Against the law: countering lawful abuses of digital surveillance', PubPub [Preprint]. Available at: https://doi.org/10.21428/12268.

mixing from the extensive archives. The applied procedures are simple, and the technical setups stripped to the bare essentials.

4.1 Cyberinstruments

Listening to the electromagnetic fields of computing has two historical roots. In the 30s, Clara Rockmore introduced the first etheric music instrument, the theremin, to a classical music audience. The theremin is played without contact by moving hands in between two antennas; the *cyber-instrument* drew attention to the link between the sound and its technological source while simultaneously subverting the ability to understand (Emily Dolan and Thomas Patteson cited in Latham, 2021, p. 566). Compared with radio, it was not that the source was hidden; instead, 'no logical source seemed to exist'. In the mid-40s and beginning 50s of early computing, single machinic operations could be distinguished from each other by listening to the clicking sounds of vacuum tubes, later then indirectly by attaching speakers to wires or by receiving the electromagnetic fields with AM radio (Miyazaki, 2012; Miyazaki, 2013). The physical matter became congruent with informational patterns.[67] In *Handmade Electronic Music*, Nicolas overviews related techniques for musicians and artists (Collins and Lonergan, 2020, Chapter 6 *Circuit Sniffing – Eavesdropping on Hidden Magnetic Music*). Jennifer Gottschalk introduces musicians working with *Finding hidden Sounds* in her Book on *Experimental Music since 1970* (Gottschalk, 2016, p. 64). Lastly, the Chapter *Sonic Archaeologies* by Shannon Mattern is a starting point for media-related experimentation (Bull, 2019, p. 222).

67 On a side note, it was documented in the 18th century that electricity can be *heard*–an acoustic side-channel of electric current.

In the following, I outline my own cyberinstruments for the cybernetic mundane, as coined by Eric Drott. I use off-the-shelf induction coils (Monacor AC-71[68]) called *telephone adapters*, which I was introduced to by the local electronic store *Pusterla*[69] in Zürich in 2004 and have not replaced since.[70] The frequency range of a telephone adapter covers the frequency range of human hearing. It is a passive device and picks up the surrounding field only if placed on top of digital devices or in close proximity. Its low sensitivity is helpful if only a specific kind of radiation needs to be captured, rather than picking up on a variety of emissions as done by Christina Kubisch in the *Electrical Walks*.[71] I prefer not to change the characteristics of the pickup in order to keep a reference to earlier recordings. In *Stereo Bugscope*, the Japanese musician Haco used similar coils in a binaural setup on computing devices in 2004.[72]

4.2 Reluctant techno-poetics

I coin the sonic work *reluctant* because the intention to capture is motivated by the correlating computational activity and its context, not how it sounds. The works are snapshots of a procedure, and their outcome is influenced by the spaces, the involved people, and the available time. Without an invitation to perform, I would not rehearse, for example. Similarly,

68 AC-71/3,5MM (no date). Available at: https://www.monacor.com/AC-71_3,5MM (Accessed: 1 January 2023).

69 The shop was the main supplier for Zürich-based media artists: Home (no date) Pusterla Elektronik AG. Available at: http://pusterla.ch (Accessed: 4 July 2023). The website of the Department for New Media, where I was then, does not exist anymore: Department for New Media ZHDK Zürich - Monoskop (no date). Available at: https://monoskop.org/Department_for_New_Media_ZHDK_Z%C3%BCrich (Accessed: 4 July 2023).

70 The original use in the early 50s was for eavesdropping on telephone conversations by holding the pickup next to a telephone's speaker.

71 Kubisch recalls the emissions of a computer being picked up by her induction coils for environmental radiation (Tara Rodgers, 2016, p. 122): 'I always heard the basic sounds of electricity when using the induction headphones. But since the middle of the '90s there were more and more places which had other sounds like small rhythms, pulsations, and strange signals. I remember this particularly for an installation in San Sebastian in 1999, where I heard some mysterious signals coming into my own sound transmission. I found out that behind the wall where my work was installed was a computer office. I decided to include these sounds and tried to know more and more about magnetic fields created by digital technologies.'

72 Haco (no date) *stereo bugscope 1*. Available at: https://hacohaco.net/soundart/stereo_bugscope_1_e.html (Accessed: 9 July 2023).

I listen to the archives either upon an invitation to present, set up a stream, release a track, or do maintenance work on the recording system. Before positioning the pickups, I trace characteristic operations with the induction coil first; afterwards, I make adjustments only as long as it still captures the distinctive electromagnetic activity. I reduce aesthetic choices to a minimum so that the material is often usable in combination with other recordings only. I output a mono channel when playing live and avoid optimisation except for occasional minor audio processing, like applying narrowband notch filters on sharp sinusoidal tones in long-term setups. I certainly have aesthetic preferences and make aesthetic choices. I take decisions ad-hoc without deriving rules or techniques, though, and I am not working intentionally towards a personal style or technique. None of the made or omitted choices is driven by principle. Conversely, if I have more time for positioning the pickups or setting up an installation, I take the time available for listening and adjustments.

In summary, I foreground continuous practice and repetition with a readiness to respond to encounters with persons, real-life environments, software, and hardware while setting up, operating, tracing, and listening. The reluctance I describe also manifests in the hesitation to present either process or result through fixed formats.

4.3 Response in progress

Bringing abstract, observable and experienced manifestations of the computational together is at the core of the sonic portfolio. The following sections describe such contact points as particular to specific computationally driven scenarios and processes yet give weight to their embedding into social configurations, existing or evolving. Each of the involved entities, from processes to real-life spaces and persons, are highlighted as responses to the other. Foremost technical terms such as processes and threads traverse their intended boundary, like the processing unit, an operating system or a network.

4.3.1 Scenarios

Before performing live, I rendered the *runtime environment* of computer processes audible in two installations. The runtime is a technical concept for the life cycle of a computer process, from its launching to its halt. The runtime environment is the time-space frame in which an operating system organises the resources to run computer processes. In 2006, I was handed out six discarded desktops. A computer process would place a workload on each of the computers by reading different texts and translating the single characters to start and stop the equivalent processes on the other ones connected by a local network. Induction coils were placed on top of the memory modules and outputted the raw electromagnetic fields through consumer speakers placed within the open desktop casings. The audience walked through the desktops uplifted to head height and could hear the memory activity of each computer, manifested as the acoustic projection of the six runtime environments in the exhibition space. The emissions rendered the two principal states of a process audible – running or not. Other variations resulting from the single characters of the inputted text remained less clear. Nevertheless, on hearing the activity of the computer processes, Peter Trachsel[73], a Swiss performance artist, noted that it would make him *understand* what computers were actually doing. In March 2007, Trachsel invited me to display the six desktops in the Swiss mountains inside of an open pavilion constructed on the top of a hill that he would guard for two

73 Available at: https://petertrachsel.info (Accessed: 2 January 2023).

weeks.[74] The vocalist Kornelia Bruggmann[75] participated in the opening and responded vocally to the memory modules' noise.

Sometime later, Trachsel invited me to work and exhibit for five years on the first floor of a former school from 1860 close to the hill. I set up a permanent installation of a dozen laptops I collected from neighbouring villages and wrote a program in assembler, a type of computer language close to the design of hardware components, thus lacking 'higher-level' abstraction.[76] When the computers powered on, they launched the bootloader program instead of loading a regular operating system. The program displayed the codename 'DEADBEEF' for corrupt memory in hexadecimal numbers and initiated its reboot. On each laptop or desktop, an induction coil traced the emissions and an analogue, over-sized mixer from the 70s amplified and played them back into the room. Peter Trachsel and I were given the mixer for our project by a musician he befriended. A visiting person could start the installation by plugging the power supply that initiated the cycling boot sequences. The electromagnetic sounds captured from the computers' motherboards varied in structure, activity and duration. A magazine publicly displayed in the room contained the printed program, along with quotes and reflections on the generativity of software and software art. The permanent installation was open for multiple years, and I organised a yearly public event on software and music where I would perform. On one occasion, the networked live-coding band *Powerbooks Unplugged* came as guests for a concert outdoors.[77] A local IT company from the valley

74 *Sei Personaggi Part 2*. Available at: https://sei-personaggi-part2.ch/photosluzein.html (Accessed: 1 October 2022).
75 Available at: https://korneliabruggmann.ch (Accessed: 2 January 2023).
76 The announcement of the opening is archived on the project's blog: Ein Museum in Bewegung (no date). Available at: http://www.museumpraettigau.ch (Accessed: 26 September 2022) and listed in the posts of the village 'Luzein' and the month, March 2010.
77 See video documentation: Ein Museum in Bewegung71 (2012). Available at: https://www.youtube.com/watch?v=9T1qf40G54g (Accessed: 26 September 2022).

sponsored the travels: *Calanda Comp - mehr wie es wird schon gehen*, which translates as 'more than it will work somehow'. Before we closed the space, we announced in the local newspaper that I could be invited to perform 'chamber music' with personal computers at the owners' homes. One person responded, and we recorded multiple tracks where the person used their own laptop and programs from daily work while moving the pickups over the keyboard. The Z*eromoon* label published one of these tracks online.[78]

4.3.1.1 Multi-threading

I continued to collect hardware from IT departments to which I had access, friends, and computer shops I happened to come across. When I turned towards performing live, I used laptops instead of desktops and travelled with up to five, often old and unwieldy, laptops. Playing software in front of an audience, I followed a kind of choreography from the software operations that I worked off or *operated* in parallel on the multiple laptops, picking up different spots from the motherboards and amplifying them through a PA system in concert settings. A sequence of actions comprised, for example, boot the first laptop and then defragment the disk while simultaneously encrypting the files on the drive. If feasible, I stood in the audience instead of on stage and turned around at an angle to put focus on my hands on the keyboards. In addition to the audible emissions on the speaker system and the movements between the laptops and on the keyboards, I projected the laptop's screens to follow the software choreography when supported by the historical or minimal operating systems I used.

I organised workshops, or jams, to play the electromagnetic emissions of devices and try different operating systems and tools. In the first part, the participants listened while trying

78 It's the 5th track of the zeromoon release *Tripping through runtime*. Available at: https://zeromoon.bandcamp.com/album/tripping-through-runtime (Accessed: 2 January 2023).

different software, sitting around the same table but with individual pickup and one headphone per person. During the second part, we used a speaker per person or a shared PA system to play with each other. During both parts, I recorded each pickup as a separate channel. Another collective daily routine took place while setting up the exhibition *Ministry of Hacking* at the *esc* media art laboratory in Graz, Austria; we were listening to the boot sequence of the personal computers in the mornings.

4.3.1.2 In the centres of computing (culture)

The first continuous recording setup in a server space was hosted by *mur.at*, a close collaborator of the *esc* and an independent provider of infrastructure for cultural workers and a facilitator of net art. The recordings were visualised and published online. We imagined a *side-channel radio* where the program would derive from the setup, maintenance, and troubleshooting work of the system administrators. We invited a cyber-physical specialist for a conversation on broadcasting a security risk, and I performed for the public at the launch of the server radio. I created electromagnetic recordings in both institutions to which I had access: the *Birmingham for Academic Research (BEAR)* and the computational infrastructure of the art university. The latter event was organised by the *Computersignale* project for the public day of artistic research. I played the emissions of our project’s infrastructure–the hard drives storing the media we gathered from the two researchers’ labs–via two speakers in the art school’s computing centre.

Thus far, the introduced scenarios captured the dynamics of software processes on hardware at fixed locations. I hosted another streaming event during one of the larger tech conferences in Europe, the self-organised *Chaos Communication Congress,* at the end of each year. I participated in its 36th iteration in 2019 in Leipzig, Germany, and installed a live web radio channel over four days. An openly accessible mixer invited passers-by to plug in a live or generative source. We hosted discussions, and I prepared a ‘fallback’ audio source that would go live whenever nothing else happened: pickups were placed on two laptops, one that followed the security advice on the wiki of the congress to protect devices from hacking co-visitors and another one that did not and thus would be a ‘honeypot’ for intrusive activity, which could potentially be heard in the audio streaming. The presumably safer laptop was from before 2008, which marks the year that ‘hardware backdoors’ were reported–undocumented methods provided by manufacturers to bypass standard user authentication or encryption.

4.3.2 A scenario’s processes

→ *portfolio track no. 15*

4.3.2.1 Thematic selection

Performing live, I selected themed software and operating systems from (1) cyberphysical security, (2) software to test hardware, (3) minimal systems, (4) historical systems, (4) daily system administration and maintenance tools, as well as (5) ‘gimmick’ software such as animated ASCII art in the terminal that demonstrated the relationship between the running software and the audible sound. Depending on the context of the performance, I choose software or operating systems meaningful to an audience, such as a virus scanner or Microsoft’s operating system ‘Windows 95’. I frequently employed a micro–operating system on a floppy called ‘Tinfoil Hat Linux’, a private initiative ‘from and for paranoid people’ that ‘talks’ to its users continuously while interacting with it on the terminal. It includes a ‘paranoia’ mode that, clearly audible, morse-codes a random encryption key via the LEDs on a keyboard to ‘stir up’ the electromagnetic emission of the real encryption key and avoid being intercepted by a ‘helicopter’ from above.[79]

Traced software and audience were linked closest at my farewell from software engineering in a hearing aid company; I had co-worked on measuring the acoustic conditions in front of the eardrum as part of fitting a hearing aid to a person. During the performance, I picked up solely on the fitting software itself and the graphical workflow that steered the measurement device for an audience of more than 40 engineers who were developing the fitting software daily, some for up to twenty years. One responded by saying they ’felt addressed personally by the sounds’: writing the software code behind the graphical user interface made them feel responsible for the sounds, including the underlying electromagnetic emissions.

4.3.2.2 Explicit initiation

Similar to the installation of the looping bootloaders in the Swiss mountains, the preceding installation *Harddisko*[80], zoomed in on a similar moment after the power was switched on but focused on a different type of hardware component. Sixteen hard drives were switched on and off automatically every 60 to 180 seconds. After powering a disk, software that is ‘burned’, meaning stored, on the disk’s chip by the manufacturer, called the firmware, runs and initiates

79 The Tinfoil Hat readme document reads as follows: ‘If at all possible, disconnect all external cables, including the power & mouse. Turn off nearby radios, including cell phones and microwaves. Put yourself and the computer in a well-grounded opaque copper cube.’ The project’s website: The Shmoo Group. Available at: http://tinfoilhat.shmoo.com (Accessed: 30 September 2022) and a description of it can be found here: Paranoid II - The Revenge of TinFoil Hat (2002). Available at: https://web.archive.org/web/20021204010949/http://www.evilmutant.com/stuff/tinfoil (Accessed: 30 September 2022).

80 Vuksic, V. (no date) Harddisko. Available at: https://harddisko.ch (Accessed: 2 January 2023).

the first steps to address the hardware: test procedures check whether the drive functions as intended and whether, for example, the reading head moves correctly over the aluminium disk. The routines run by the firmware differ from model to model and the current state of the disks. A pickup placed on the motor controller of a reading arm captured and amplified the electromagnetic emissions of the controllers' software steering the motor. A mixer amplified the signals and played the partly repetitive and partly irregular noises and tone patterns over two speakers.

4.4 Sonic abstractions

After hearing a performance lecture by Shintaro Myazaki on algorhythms and listening to the electrical signal world of 'our' algorithms, the following question came from the audience: 'how would you hear if you were to listen to this extensively'? I had already been listening for more than ten years, yet I did not respond. I thought about how my listening, or my hearing, has changed. Would I 'know' more about my personal infrastructure? I did not know more in the sense that I had much more information at hand than would have been the case had I not listened to the electromagnetics of my devices. More meaningful than learning to hear differently was the deliberate shift of focus away from affordances and the workings of information technologies that occupied me doing engineering work. Accordingly, technicalities should be as simple and as unmediated as possible. The practice of rehearsing for a performance took on this role for me.

4.4.1 Rehearsing –within opposing poles

→ portfolio track no. 11 and 12

Since 2009 at the Pixelache Festival, I have been rehearsing to improvise with software processes and their electromagnetic emissions. The setup remained the same during the different periods of performing, yet the running processes changed. In the beginning, I chose software related to users' and system administrators' daily activities to listen to the changes in electromagnetic fields they produced. I 'operated through it', and gradually, this shifted to 'playing' a thematic selection of software with a more 'musical' sense until I arrived at the most 'musically' precise and deliberate environment, or instrument, for and with electromagnetic emissions. Without a formal background in music, I have no explicit musical intention and my conception of 'music' and 'musical' is blurry.

4.4.2 Mixing –as coming together

→ portfolio track no. 18

4.4.2.1 Mono or more channels

For playing or recording, I use two or three pickups, occasionally more, and do not derive the placement from technical knowledge, even if it is informed. A single pickup represents one fragment in space at a particular time. Multiple pickups make it more apparent that the captured traces are just one possible choice and capture the activity of multiple hardware components. Hence, the resulting sonic structures are more layered and show a more extensive range of sonic activity over time. During live performances, I downmix three to six pickups to one mono channel for the PA. Rather than spatialising through separate channels and speakers, I focus on the activity of the processes alone. I map pickups to specific regions of the motherboard when playing live or to speakers in installations. A new dimension, such as spatialisation, would keep me occupied with learning a new skill and, I am concerned, shift the focus away from the processes' activity. Each pickup is a separate audio channel to regulate the volume independently while playing and afterwards during mixing.

4.4.2.2 One or more streams

For long-term streaming, two or three pickups are downmixed before recording or streaming. Mixing the signals attenuates the risk of reverse engineering a signal and was a security requirement by one of the computing centres to give permission to trace and publish electromagnetic radiation of their servers. The sonic outcome of mixing multiple and unattended pickups is not well predictable, meaning less monotonous, which might be more engaging or, on the contrary, too dense. I had set up four streams from different locations in the computing centre for redundancy and also to be able to mix them later on. The streams show separately on the π-node platform and may be individually balanced.

4.4.3 From rehearsals and archives

This section describes pieces of shorter duration and composed from various recordings. The first mix was to document a workshop on the electromagnetic emissions of personal devices, and the participants' channels simply played simultaneously without any adjustment, also not the volume. Each participant had headphones and could not hear the others and nevertheless, it sounded like an intentional and shared performance. While I had given notice in advance to record, we paid no attention to it during the workshop hours.

Mixing multiple recordings into one track, I try different groupings by either time, location or project without pre-listening to the single recordings: for example, all (mono) pickup recordings of the rehearsals of one specific score, 24 hours of one day in an archive, the same hour of one pickup during multiple days, or all endings of rehearsals from a particular period. I start by overlaying the individually recorded audio channels. If normalising, levelling, and selecting seem insufficient, I add or reduce the number of recordings or move single portions in time. If I cannot avoid it, I add fading single channels in or out.

4.4.4 (A)Synchronously

→ *portfolio track no. 14*

During a residency at the *l'Atelier Expérimental* in Clans (FR) in 2021, I shared a workspace with Aurélie Derouin. She constructed a copper skeleton to wear during a (silent) dance art performance. After using the same type of conduction coil for more than ten years, I tested one different radio-capturing sensor. The *EtherSoma* covers a broad frequency range and includes multiple coils and antennas.[81] Besides tracing the near-field of computing devices, it actively sonifies electromagnetic radiation outdoors. The *EtherSoma* is sensitive to higher frequencies than are perceptible by human ears and transposes them to under 20 kHz. Contact points on the casing extend the electric antenna by the own body and are processed by non-linear regulators–just plugging a recording device into it instead of headphones alters the

81 Ether – SOMA LABORATORY (no date). Available at: https://somasynths.com/ether (Accessed: 2 January 2023).

results of the circuit. It is designed to be susceptible to influence and deliberately positions itself between a measurement device and a musical instrument. The built-in musical abstractions of the active device were unusual for me, and I tried different ways of interfering in the tracing, sometimes to find a source or a pattern–sometimes I tried ‘playing’ it by regularly tapping on the contact points, consciously moving the device and turning the controls. Spontaneously, Aurélie Derouin and I did a half-hour-long exploration using her skeleton as an antenna. We switched between placing and moving the device across the skeleton and changing the settings of the EtherSoma: we semi-explored and semi-played for each other.

With the collective web mixer of the pi-box–a custom streaming box of π-node–multiple people may simultaneously plug any number of inputs (files, soundcard, streams) into any number of outputs (files, soundcard, streams, FM). In 2020, I invited the π-node collective for a 12-hour night of electromagnetic sounds from computing centres: to start, I prepared more than ten live streams from the computer centre I was streaming at that time and playlists from previous ones to choose from. It was the first shared usage of the web interface, and we decided to take a turn every half hour to not over-burden the user interface with more than one person changing the settings. Over 12 hours, we balanced all the different sources into one, sometimes re-routing one of the single streams for local processing and feeding it back as an additional stream. After six hours, in the middle of the night and before the involved persons went to sleep, 15 different and partially already dense sources were balanced to make each audible within the noise floor. Layering all sources had not been an explicitly stated goal; no one turned any stream off and made subtle adjustments until each newly added stream would contribute to the mix. The streaming continued during the night, and later, we found that one person had changed the mix slightly early in the morning again, and one other person had registered the change while listening to the stream, without knowing in advance that someone was active.

On another occasion, I stepped out of the induction coil habits as part of a group installation by π-node, a series of exhibits where, in each iteration, between ten to fifteen persons take part.[82] It is a reenactment of the kinetic and pneumatic installation 'Der Lauf der Dinge' by Fischli&Weiss in 'signal'-form. An audio signal travels serially from one transduction to another and traverses different media, such as wire, water, antenna, stone, modem protocols and speech-to-text. Each participant contributes one module, ordered approximately by the degree of narrowing speech legibility and introducing sonic artefacts. The transmitted sound narrates the path of the signal from a first-person perspective. Gesturing towards a cyberphysical experiment based on covert data transmission over LEDs that I was reading at that time (more in Chapter 5.2), the module I included to the parkour of the signal was a wireless transmission between an LED that received its power from the audio signal, fluctuated in correlation with the content of the audio signal, and was captured one centimetre further away by a light emitter, to finally, feed into the next module.

4.4.5 Tracing electromagnetic fields

Positioning the pickups on hardware components is approximate for multiple reasons. The pickups are directional, which in most cases does not make a significant difference around the casings of personal devices; the interference within server racks is more substantial, however. In some cases, the emissions might seem static for a larger area, which could change at a later

82 The latest iteration: Radio Fischli Weiss IV. Available at: https://p-node.org/works/artworks/radio-fischli-weiss-4 (Accessed: 30 September 2022).

point in time depending on the running processes and the states of the hardware. Because the components placed on the motherboard of a laptop are smaller in size and closer together, one millimetre might make an audible difference and using it during a live performance would be less precise. The accessibility of the infrastructure might be limited in time, and environmental noise from air ventilation might impede hearing through headphones.

The underwater observatory was the most straightforward placement of the pickups in terms of what they should relate to. The aim was to identify two state changes of the observatory: the waiting state and taking a picture-pair every half hour. Testing was only possible in the lab, and we would not know in advance if and how the observatory's power source underwater influenced the current flows and the electromagnetic fields. The installation was set up to record for multiple years, and there was no access possible after it was shipped and installed. The pickup to capture the area in the middle of the box could not be attached to anything; it had to 'stand' at an angle slightly different from 90°. Otherwise, a constant high pitch would, over time, cover up other emissions. During the transport of the observatory, the mount came loose, and it took a few attempts from the biologists to reconstruct the position from pictures. The observatory is moving daily, so it might change its location again.

4.5 Concluding remarks

The artistic procedures introduced in this chapter engage with crosstalking in and surrounding the computational; techniques and aesthetics are not the primary concern. Fazi describes a computational process in execution as 'concrete and concrescent'; '[S]omething in computation remains unknown, and ultimately, beyond representation'; 'a decisive element of the actual procedures of computation […] does not belong to life, the living, or the lived, but to computation itself' and further asserts that 'although it is beyond representation, it is still within logos'. Fazi's statements link the formal-axiomatic foundation of the computational to its operational levels, which is consistent from both a philosophical and engineering perspective. Fazi refuses to 'perceive computation as static and finite' as 'formal-axiomatic systems are exposed to their own indeterminacy, even before any empirically or existentially attempt to access them'. Read from *outside* of the computational, Fazi's computational philosophy seems to fall into the same trap she warns about. When abstract laws become more fundamental to reality than phenomena, based on 'transcending' qualities, then this is a form of 'computational idealism', which Parisi/da Silva call self-referential and self-deterministic. Above all, Fazi reverses the self-image and societal image of computing logic and culture: beginning with its mathematical roots in Gödel's incompleteness and Turing's incomputability, she asks to think about computational and human abstraction–and their consequence–simultaneously to address and precise their differences, which debates and theory on artificial intelligence do not make explicit enough.[83] From a different angle and with different modalities, the artistic procedures aim at a similar trajectory; approaching coupled (intertwined) and decoupled (incommensurable) computationally related dynamics at the same time. The geeky and implicit sonic outfits of the described sonic works remain, to a large extent, *inside* the computational realm unless the making itself is individually

83 Language as media is the precondition for translating between computational and human abstraction; Fazi takes distance though to historical accounts of incommensurability between human and computational (2012, 68): 'So, for instance, we say that a computing machine 'sees', 'listens' or 'thinks', just as we say that an aeroplane 'flies' despite our awareness that an aircraft and a bird take flight in profoundly different ways. In this respect, however, the challenge for both the philosophical and sociocultural studies of computational automation is to find or found the epistemological means to theorise, as well as possible, the incommensurable orders of intelligibility and sensibility that automated computational agents produce. Inevitably, the notion of incommensurability to be developed must transcend that proposed in the history of the philosophy of science: the long-term goal is not to apply Kuhn's or Feyerabend's respective understandings of the incommensurable to computational media and computational culture but to develop a radical version of the concept to address the specificities of human and algorithmic modes of abstraction.'

experienced and contextualised, such as during the workshops to experience the own device's sonicity.

Working with technology that is used daily, directly as with phones or indirectly as with computational infrastructures, I am interested in what Eric Drott (20121) called the *cybernetic mundane*: 'activities, discourses, and projects that so thoroughly internalized and normalized the cybernetic ethos that it eludes notice'. On the one hand, electromagnetic emissions are closely linked to surveillance practices and cybercrime and impacts on environments and health. Conversely, the sonic works can be listened to without their context. While the literal titles draw a clear link to the computational material, they also downplay their complexities, such as *Harddisko* or *Tripping through runtime*. And yet, musical material can address relations alongside their ignorable non-relations as it is 'never quite reflective and never quite independent' (Denver cited in Impett, 2021). Computational sonicity might remain in the computational if mediated through sound alone. By tracing signal spaces and reading technical documentation in detail, I find (remote) similarities with Adrian Mackenzie's 'auto-archaeological' account, which is not ethnographic but has an 'ethnographic situation'. In *Machine Learners*, Mackenzie is expanding the process of theorising (on code and coding) by weaving in his private coding practice when writing about it and thus mingling both the research subject and the process of researching the subject. Along similar lines, I 'emulate' methods from engineering as an 'experiment in *in-situ* hybridisation' that documents itself in sonic works.[84]

84 Mackenzie (2017, 9): 'I emulate the apparatus of science and engineering publication as an experiment in *in-situ* hybridization. Social science and humanities researchers, even when they are observant participants in their field sites, rarely experience a coincidence between their own writing practices and that of the participants in the research site they study. The object of study in this book, however, is a knowledge practice that documents itself in code, equations, diagrams, and statements circulated in articles, books, and various online formats (biogs, wikis, software repositories). It is also possible for a social researcher to adopt some of these conventions, even if they sometimes take us to the limits of coherence, and of easily

5 DECOMPOSING: (A)POLITICS OF COMPUTATIONAL SONICITY

This chapter links indirectly, yet substantially, to the procedures of the sonic practice outlined in the previous chapters. From a personal perspective, I approached the computational through the sonic. The intention was neither to gain specialised knowledge nor to perform geeky art. Simultaneously and without a public, I undertook close readings of technical documents typically perceived in specialist circles and pursued the investigations outside a defined frame. Code-switching between artistic and engineering surroundings influenced me to focus on the engineering's making of *outsides.* Alongside the crossings between the *insides* and *outsides* of computational scenarios, I sought what Impett summarised as 'narrative, taste, or contingency' that technical work presents as shorn off. Instead of giving results, I aimed for poetic readings or poetic processing. I introduced a way of working to propose extra-disciplinary procedures for the personal acquisition and experience of technical documentation, mine and the public, that, in some ways, is out of direct reach. This chapter covers the artistic reading and processing of two exemplary, very different kinds of technical experimentation: cyberphysical security and border technology. My interest lies in imaginaries and urgencies expressed through technical documents and how political aspects and dimensions are interwoven or left aside, which is not part of the thesis. The two examples are cases of adopting technological scenarios as one's own by artistic practices: informal, abstracting yet not abstractive, partly reflective, partly intuitive, responding and initiating procedures. The last chapter proposes such an appropriation for non-artistic contexts alike; a self-chosen form of experience when studying technicalities in detail is not possible.

understandable expression.'

5.1 Poetic reading and processing

The first reading focused on cyberphysical experimentation in engineering laboratories that simulate and implement malicious attacks through physical phenomena, first known as Tempest[85] radiation. Rather than considering apparent ties to military and vicious abuses, state- and non-state-based, I scrutinised more subtle conceptual takeaways from less spectacular experiments. Rather than focusing on single events reported in public or debates in security circles, I was concerned with the mundane practices of cyberphysical research as represented in academic publications. I assembled papers by interest: electromagnetic and power analysis as these relate literally to my artistic practice, 'discovered' side channels as being part of the physical spectrum embedding the digital, consumer rather than high-end equipment due to their potential applicability, and, finally, experiments targeting broader contexts than encryption keys, such as extracting a password when logging in to online banking through a browser. Instead of progressing technologies, the experiments render visible additional use, which I term extra functionality. They create new connections, local-to-local and local-to-remote, which form extra channels for transmission. A local event might not be accessible from nearby, but it may be potentially accessible from a remote location. The juxtaposition of security threats and their countermeasures, along with drawbacks in performance or cost, might enter the architecture of next-generation computation. In summary, the signal spaces of an experiment render other affordances than intended 'useful' technologies.

85 A brief historical and cultural introduction is 'Tempest (codename)' (2023) *Wikipedia*. Available at: https://en.wikipedia.org/w/index.php?title=Tempest_(codename)&oldid=1161972739#cite_note-USAF140107011-1 (Accessed: 9 July 2023).

The second reading focused on EU-funded research on cyberphysical experimentation at state borders. The reach and impact starkly contrast with the engineering experiments, the seemingly otherworldly academic undertakings designed to indirectly understand and steer computational systems via its side channels, sidestepping regular functionality and usage. Although research on technology for borders consumes much larger public subsidies, specific technologies gather rare moments of publicity only.[86] The public image draws on innovation; the details are unknown to a large extent, but the outcomes of this research will have a significant impact beyond Europe. Looking at the sparse technical documentation that is publicly available, the focus was on how the language in the documents steers the argumentation towards the need for these technologies. I searched for technical solutions involving physical emissions.[87] Here, the first paragraphs bluntly argue for the necessity of 'hidden human detector[s]', abbreviated to HHD, and effectively abstracting the 'target objects' away. The persons in question are the primary motivation for pursuing the research while simultaneously blanked out through the textual 'project deliverables', a concise example of how computer science projects produce (a)political or (anti)political situations.[88]

86 Research into an optical lie detector is one of the few examples that has attracted media attention: *Smart lie-detection system to tighten EU's busy borders | Research and Innovation*. Available at: https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/smart-lie-detection-system-tighten-eus-busy-borders (Accessed: 26 September 2022). It is also exceptional that a member of parliament, Patrick Breyer, filed a transparency complaint against it: 'Press briefing: Transparency complaint against secret EU surveillance research "iBorderCtrl"' (2021) Patrick Breyer, 15 December. Available at: https://www.patrick-breyer.de/en/press-briefing-transparency-complaint-against-secret-eu-surveillance-research-iborderctrl (Accessed: 26 September 2022).

87 One of the documents provided by the iBorderCtrl project: 7 D3 1 Data Collection Devices Specifications Redacted - DocumentCloud. Available at: https://www.documentcloud.org/documents/5634636-7-D3-1-Data-Collection-Devices-Specifications (Accessed: 30 September 2022).

88 The article references a reverse-engineered document on the communication strategy of the project, which anticipates the project's need to manipulate public opinion and change existing legislation: 'Big brother, video lie detector: EU research funds are misused to lobby for legislative changes' (2021) Patrick Breyer, 27 April. Available at: https://www.patrick-breyer.de/en/big-brother-video-lie-detector-eu-research-funds-are-misused-to-lobby-for-legislative-changes (Accessed: 30 September 2022).

5.2 Sample reading: experiments on cyberphysical security

Typically, an experiment on cyberphysical security aims to retrieve a secret encryption key. In addition to the hidden and sensitive state (the key), there is a visible or shared state (the physical emissions). Side-channel information is a list of observations from the visible part (measurement of the varying physical emissions, e.g. electromagnetic fields) from which a system's current state can be derived stochastically to guess which data are being processed at a particular moment. The measurement contains remnants of the hidden state the experiments aim to extract. From hundreds of cyberphysical experiments, I scanned most of them roughly to categorise the experiments by side-channels and goals and read selected ones thoroughly. Within a *Master by Research* program in an engineering department, I probed methodologies and tools from applied and physical cryptanalysis. I conducted the first step of a machine learning process manually, analysing features extracted from the power and electromagnetic traces of the underwater observatory to distinguish the observatory's states, idle and non-idle, from each other. The intention was to punctually experience the contact zones drawn by engineering between the material and the immaterial of digital technologies. The analytical understanding did not enable the experience I refer to, nor were the results utilisable in engineering. Instead, a particular understanding came with the possibility of bringing perspective and questions instead of learning the given ones. Whereas Agre talked about the 'borderlands' between people developing technologies and people using them, this project looks at the 'borderlands' between abstract concepts and particular implementations and how, from a particular standpoint, they are entangled *and* decoupled. It is concerned with the simultaneous remoteness and contact of engineering and non-engineering worlds in tangible physical ways in this chapter–which refers to the separation that can only be maintained from a strictly engineering view.

5.2.1 Physical side-channel analysis

The physical phenomena of computation form part of the side-channels and are not required for the primary function of a system. The thermal, acoustical, optical, mechanical, or electric leakages are intrinsic and can be re-purposed deliberately by manufacturers or maliciously by others. Applied cryptanalysis is the primary field in which they are examined and is situated between engineering and computer science.[89] Notably, the 'analysis' of a (target) system is interchangeably called an 'attack'. The baseline argument for 'breaking' a system via its physical appearance is that there are cases where retrieving information by hacking in through software is barely possible, for example, when data are strongly encrypted. In some cases, it might be easier to derive the secret key just before or after the encryption process through its unintended leakages. A system is entered through 'flaws' in its implementation and in real-time while its processes are in operation. Here, the focus is on physical side channels, while the field of applied cryptanalysis also considers logical side channels, such as timing behaviour; it could be instructive to know that a process takes more or less time to finish depending on its input. The experimental setups resemble micro-temporal viewpoints from purely engineering standpoints and are conducted by hackers and scientists alike. They derive from unintentional entanglements between a device and its local environment: extracting information from, e.g. the actual electric current from a device (a passive reading of actual power consumption), or energy is inflicted upon a system, in its simplest form as temperature,

89 For an introduction to physical side channels: Standaert, François-Xavier. 'Introduction to Side-Channel Attacks', 27–42. Springer, Boston, MA, 2010. https://doi.org/10.1007/978-0-387-71829-3_2.

to change and steer its proceedings (an active attack). Several side channels were discovered during the last three decades. Statistics and machine learning simplify or improve the extraction while the required equipment becomes less expensive and easier to use. The vulnerabilities of smaller devices like RFID and smartcards were researched first. Subsequently, the experiments targeted more complex systems, such as microcontrollers and processors, and expanded towards non-cryptographic areas like browsers and mobile devices.

The 'imperfect' implementation of a logical design as an electronic device is 'exploited' as a concrete entity in a specific environment and not approached as an abstract conception alone. Mechanisms and interdependencies unmentioned in official documentation are potentially applicable for debugging or monitoring, as well as are potentially misused by cyber-criminals, legal authorities, and marketing departments. The experiments or assembled scenarios render a technological device intelligible via exemplary local appearances and shed specific light on its operation rather than its functionality.

5.2.2 Conceptual takeaways

5.2.2.1 Virtual-actual crossings

Other disciplines are concerned with virtual-actual crossings: human-computer interaction (HCI), sensors and robotics, the emulation of hardware with software, and many more. By contrast, cyberphysical security does not work on technical solutions and displays accidental, incidental, and contingent aspects of technological methods in a specific implementation, which are discrete instances of abstract design. Unusual for a field of the 'hard' sciences, security-targeted setups are often based on admittedly heuristic approaches and experimentation by intuition; the arrangements disclose ‘soft’ imaginary-driven development in the way seemingly unrelated entities come together, yet the experimentation is operative and ‘works’ at least as a proof-of-concept. They embody an astonishing double-fold approach to technology, specifically, plotting threat scenarios and merging disparate practices in undogmatic manners. The engineering efforts regarding the subtle, analogue, physical phenomena of digital devices are remarkable in their conjoint approach to the logical and the physical domain: this pragmatic yet unconstrained approach to the energetic exhausts of (micro-) computation favours implementation over a concept and interference over separation. The experiments consider not only the ‘targeted’ system but also the sum of its logical and physical environments, both the known and the yet unknown. The life cycles of security vulnerabilities may be short and limited to one experimental setup or linger for years before they are disclosed. In addition to connecting software with hardware and analogue with digital, other crossings occur in cyberphysical experimentation. Different side-channels often correlate with each other, which could be termed physical-physical crossings: putting the workload on a system increases the temperature, makes noise, and increases the flow of current, which changes the surrounding electromagnetic fields. Functionally unrelated components exhibit crosstalking, such as the two electronic boards integrated into mobile phones, one for the operating system and one for mobile, Bluetooth, WLAN, or GPS communication. The emissions connect a device and its environments in ways other than the marketed features of the device, such as deriving the access code to a phone from the oily residues of fingers on touch screens or recording a spoken conversation in a room by repurposing the vibration of gyroscope sensors in a phone used for rotating the screen display. A system is part of a plurality of environments: the room in which it is located, the person using it, other people in the room, the electric grid, the 'low-level' software environments, the 'high-level' software environments, or the various radio networks with which it can be connected.

5.2.2.2 Extra functionality

Speaking with Snodgrass, the cyberphysical setups contain discursive elements such as information, program code, and maths, and non-discursive ones like entropy, noise, and material; the experiments are grounded in both the intended functionality of the system and the unintended, or 'discovered', ones. With more experiments successfully utilising a side-channel emission in a particular way, this becomes a functionality in the sense that it can be relied upon in subsequent experiments. The extra functionality the setups afford is simultaneously *real* and *unreal* in a technological sense; it is only quasi-operable or applicable. Harnessing unintended entrances to a system like side-channels or backdoors requires numerous preconditions to be met and typically remains unreliable edge cases. Nevertheless, there is extra space available, potentially as well as factually.

5.2.2.3 Extra transmission

One category of cyberphysical experiments constructs covert channels for communication between devices, most notably air-gapped devices. For example, two computers in the same room do not share a network and sometimes are even plugged into separate power networks within a building. If they are close enough, however, the temperature may transmit (digital) information by deliberately putting a workload on one computer, which increases the temperature around the system, while a temperature sensor on the other computer notices changes in the temperature and interprets it as a ‘0’ or ‘1’, according to a predefined threshold. Alternatively, the electromagnetic emissions of memory, data busses, processors, or video display cables could be used instead, or the sounds emitted by the moving parts of a ventilating fan. Here, the side channels provide extra transmission instead of extra functionality.

5.2.2.4 Dialectic of measures and countermeasures

Friedrich Kittler stated that technical media do not arise from human needs; they follow each other in a ‘rhythm of escalating strategic answers’.[90] On a minuscule level, this mechanism is illustrated by countermeasures to potential security threats spiralling. Each countermeasure has drawbacks, such as resource consumption, cost or speed, and whether and how to implement it is not a plain technical decision. These non-functional developments arise out of a need to stabilise a system but go unnoticed by those using it, provided they are not affected directly by exploitation. Countermeasures to attacks are non-functional yet frequently implemented parts of a system that receive less attention beyond specialists. Proposals to counter the ‘vulnerability’ of systems, as found in the experiments, are to shut off the operation that is leaking, or a leaking component if it is unrelated to the function, mask (e.g. by deliberately including randomised activity), hide (e.g. by changing a design), or isolate the process, and actively cancel the leaking or shielding. Countermeasures may slow down a system, make it more expensive, increase resource consumption if redundant operations or components are implemented, or merely make an attack more difficult while not prohibiting it.

90 Cited in: Diduck, R.A. and Born, G. (2018) *Mad skills: MIDI and music technology in the twentieth century*. London: Repeater Books.

5.3 Sample processing: experiments on border control

Political and commercial ambitions, as well as ethical concerns of research and development on technology for migration control, contrast the side-channel experimentation in every aspect. The EU-funded projects are multi-disciplinary and traverse not only European countries but also economic, political, administrative and juridical divisions; these joint ventures are emphasised in the self-promotion of the projects. Here, I was also looking for virtual-physical and virtual-actual crossings, as evident in the minimal technical documentation that is publicly available and how engineering habits determine the proceedings. Although little is known about the internals, the experimentation was undertaken in plain sight of a democratic arena and not in a closed laboratory.

In late 2020, the platform *engines of difference* called for contributions to a blog series on *otherwise practices with/in computing*: 'How can we unlearn and resist computational rationality that heralds optimisation, extraction and profit generation as the main goal?'.[91] A quote by Pauline Alexis Gumbs on 'stopping to think to know' introduced the call addressing research and (artistic) practice. The book *M Archive: after the end of the world* (Gumbs 2018) comprises the middle part of a poetic and political trilogy on oppressive technologies and visions of an existence without. I was reading the 'lab notebooks of the last experiments' as antidote to the technical documents on border control technologies.

91 'Call for Contributions: Otherwise Practices with/in Computing' (2020) *engines of difference*, 18 September. Available at: https://enginesofdifference.org/2020/09/18/call-for-contributions-otherwise-practices-with-in-computing (Accessed: 26 September 2022).

5.3.1 Blog post for 'Otherwise Practices with/in Computing'

I responded to the call with a blog post that was neither an academic paper nor an artistic contribution. It resulted from an artistic workflow designed to open up the procedure for a joint investigation. Without a conceptual idea of the resulting format, I used it as a tool to process, join, and share items from the archive of technological experimentation. I imagined the post as a repeatable and adaptable procedure with other technical documents, political poetry or writing. Through the narration of an asynchronous discussion, I interlaced and juxtaposed a series of quotes from diverse sources aligned through themes of entanglement and decoupling, gaps, and blanked-out content or relations. Rather than describing them, the relations unfolded through writing, similar to a conversation. I chose two technological experiments, one cyberphysical experiment and one EU research project, and fragments by Gumps in juxtaposition. Fragments from the various threads interweaved through literal or implicit association: conceptual takeaways from cyberphysical setups, technological development motivated by more or less concealed political motivation, and poetic or other technologies for analysis. At that time, I was also reading the work of Donna Haraway for another perspective on dismantling and staying with technologies. To frame not only the post but the new series of readings in general, I compiled key terms in a manner akin to an academic paper from quotes in cybersecurity experimentation: *cutting-edge surveillance*, *unverifiable tech*, *high-risk laboratory,* and *ad-hoc-tech that leads to risky security*. The subtitle *A rehearsal in staying with painful technologies and a response-in-progress* linked not only to my rehearsals with electromagnetic pollution but to the necessity of collectively dealing with the unwanted side-effects of technology by the societies that produce them. Haraway's call to face contemporary 'troubles' and find new modes of coexistence is echoed in the title and the reference list. By *response-in-progress*, I referred to responding to technological experimentation.

5.3.1.1 Explicit references and implicit activations

The bibliographic list comprised two parts. The technological experiments were referenced explicitly and in a regular manner. Instead of theorising Gumbs and Haraway, the intention was to activate a parallel reading to the technological experimentation implicitly yet foundationally. Throughout the blog post, reoccurring links were void placeholders for further discussion. I sought to regularly disrupt the technological recounts through more or less subtle connection points, similar to the background process of an operating system for ‘maintenance’. The links to Gumbs’s writing were repeatedly void of content to delimit a new plane of abstracting, yet were to be completed in another subsequent step and not by me alone. The post reached out to an audience already familiar with critical computing. It presented the process in an artistic rather than descriptive manner and proposed collaboration in place of conclusive findings.

5.3.1.2 Phone in idle mode

→ *portfolio track no. 02*

→ *portfolio track no. 19*

The four short electromagnetic audio recordings dispersed throughout the blog post were an explicit reference and response to the academic experiment and implicit activation of computing’s physical emissions. They can be listened to separately or simultaneously during or after reading the post. I recorded the emissions of the ‘smart feature’ phone I was using then, a hybrid between the ‘pre-smart’ and the ‘smart’ generation of mobile phones. The recording and the cited paper link to each other implicitly through the emissions as sites of interpretation, and both deal with understanding subtle noise in contrast to intentional information. I used a formal feature of the cyberphysical experiment and recorded its trace for 30 minutes while waiting in an idle state and without interaction. I cut the recording into three pieces of 10 minutes each and integrated them into the post. Several cyclic background processes of the phones’ operating system created a rhythm or a pace. The rhythm sounds lively at first but does not substantively change. If the person listening has patience, they might detect slight variations and short interruptions that interrupt the otherwise monotonous sonic trace. Overlaying a second part created a rhythm varying over time, and it would sound different each time it restarted. Overlaying the third part produced a dense and fast rhythm that required more attention or might be overburdening. At the end of the post, I included a recording where I logged on to the phone, the first user interaction interrupting the idle state. In the post, I only mentioned the formal connections to the paper and, by citing a related note from the publication, the cross-correlation of physical side-channels: the acoustic one applied in the post and the electromagnetic one I used in the recording.

5.4 Concluding remarks

I propose perspectives on technologies drawing from co-produced effects and interdependence as apparent within technological testing grounds. On more abstract planes, the emissions bind together the contained and the leaked, functionality and operationality, the secure and the insecure. The relations are straightforward and also complex in their manifestations, evading simple opposition between the poles. Looking through the lenses of cyberphysical experiments is one way to think about technological conditions in virtual and actual ways alike. It is a mediated, non-straightforward approach, yet pragmatic. Whilst cyberphysical experimentation is removed from any social and political concern, some of its perspectives and approaches might become useful for *inversing* computing science and practice.

There are direct, literal connection points between cyberphysical experimentation and the artistic practice with electromagnetic emissions. More influential, though, is the way the readings, alongside the sonic practice, shaped my conception and imagination of computable matter as ‘un-containable’ conditions. This is by no means a new discovery. Nevertheless, ‘enacting’ and repeating micro-gestures impacted me in different ways than formal education and work experience in engineering. I did not study the experiments to know them in an engineering sense but to gain a more profound understanding of the interdependencies of units or entities that have been ‘abstracted away’ from each other. The readings are not compliant with a discipline and resemble another thread of involvement in parallel to performing with the electromagnetic exhaust of digital devices. In combination, the performance practice and the readings shaped my experience of ‘low-level’ computing.

6 OUTLOOK: ON INVERSING THE COMPUTATIONAL

The term *inversing* serves as a placeholder for the intention to engage with the lack of computational otherwise(s) on broader scales and to pay attention to various *patterns of trouble* localised by (smaller scale) computational otherwise(s). It is neither unidirectional nor in opposition, yet details exemplary situations within deliberate political framing. It is applicable by any number of people–also one–who agree on which computational scenarios need to be understood and engaged with, the patterns of trouble in (or out of) focus, practised modalities, and shared habits. These parameters would be the first thought and priority. For the time being, *inversing* is a working title.[92] The proposal to inverse the computational draws on existing non-extractivist thought, projects and places that were cross-referenced throughout the commentary in various ways; it is a response that strives to put some of the conceptions into practice. The process of inversing relates to *transhackfeminist!*[93], Feminist Hardware[94], Feminist Server[95], Fullstack Feminism[96], the work by esc[97], constant[98] and varia[99], and the recent *Hackfest to Our Prostheses*[100]. Finding ways to rework existing computational landscapes, is motivated by research such as that conducted by Elisa Redmill at the Max-

92 *Inverting* would have been more straightforward in its usage, but it is an existing term in engineering and misleadingly suggests formalisable procedures.

93 transhackfeminist! (no date) 'THF!' Available at: https://transhackfeminist.noblogs.org (Accessed: 9 July 2023).

94 'festival – Mz* Baltazar's Lab' (no date). Available at: https://www.mzbaltazarslaboratory.org/category/festival (Accessed: 9 July 2023).

95 *feministserver | Etherpad constant* (no date). Available at: https://pad.constantvzw.org/p/feministserver (Accessed: 9 July 2023).

96 'Full Stack Feminism' (no date) *Full Stack Feminism* [Preprint]. Available at: https://fullstackfeminismdh.pubpub.org (Accessed: 9 July 2023).

97 *esc medien kunst labor | Initiiert und ermöglicht Kunstprojekte, sammelt, verarbeitet und veröffentlicht kulturelle Daten.* (no date). Available at: https://esc.mur.at (Accessed: 9 July 2023).

98 *Constant* (no date). Available at: https://constantvzw.org (Accessed 9 July 2023).

99 *Varia* (no date). Available at: https://varia.zone (Accessed: 9 July 2023).

100 goldjian (no date) 'A Nos Protheses ! | femhack'. Available at: https://femhack.noblogs.org/post/2023/05/19/a-nos-protheses (Accessed: 9 July 2023).

Plack-Institute[101] and the publications, the database and the fellowship of the Refugee Law Lab[102].

6.1 Unlearning

If engineering science is not a field of instrumentalist persons but rather a practice that produces non-political material systems (Malazita 2022, 11), then approaching the computational through sonic practice is a process of *unlearning* to inverse the customs and habits, framing and vision of computational realities.[103][104] Playing the portfolio to a friend, they commented that ‘technically you are composing, but not culturally’. The same might be true the other way around. I am undertaking technical work without being committed to a technical result or a field, but a political framing. The approaches outlined in the commentary

101 *Elissa M. Redmiles* (no date). Available at: https://elissaredmiles.com (Accessed: 9 July 2023).

102 ‘Refugee Law Lab - Refugee Law Lab’ (2020), 13 July. Available at: https://refugeelab.ca (Accessed: 9 July 2023).

103 James Malazita (2022) argues that ‘If we take seriously the epistemic infrastructures of STEM education, it would be wrong to think of students as instrumentalist persons who enter STEM in order to be filled with narrow technical expertise or of engineering instructors as conspiratorial antipolitical agents. Rather, the instrumentalist epistemic infrastructures of STEM education produce students and teachers who are technical practitioners: experts who through their mastery of the fundamentals of math and physics practice the production of “nonpolitical” material systems. Simultaneously, although engineering students generally understand that technology “in the world” has social dimensions, engineering’s epistemic infrastructures produce technology as an epistemic object – Technology as abstract and ideal, methodological and apolitical and define the boundaries of STEM’s knowledge domain as the exploration of that epistemic object of Technology’ and concludes ‘[i]t is thus imperative for humanists to learn that engineering students are not taught to build what we might understand as technological systems but rather are taught to practice apolitical Technology’.

104 Coming from an engineering background, I am *unlearning* due to the remoteness of the environments from places where digital technologies play out the most. In the final chapter of *Your computer is on fire*, Kavita Philips breaks it down to ‘how women in rural India, typists in China, phone users in Trinidad, and women programmers in Britain all have sophisticated understandings of the technologies in their context. They don’t need translators or knowledge brokers to dumb down the technical knowledge for them. The dumbing down of labor-relations theory into buzzwords like “innovation” and “skills training” has already brought them to economic cul-de-sacs’. She goes on to argue that ‘What they need is an egalitarian political context, a modern-day agora, in which to discuss, and contest, the unequal social relations that are being silently packaged within their technological devices. Skills will not set rural women free in the absence of a fuller explication of the economic pressures that force them into low-paid data-entry jobs. We understand why they are discouraged from play and creative computational activities only when we also see the history of why and how poor Global South workers are slotted into a global economy in which their low-level economic status has already been decided’ (Mullaney et al. 2021, 367).

are single occurrences of a gradual and iterative process of doing and thinking the computational through *non-standard ways of knowing* (Britton, Klumbyte, and Draude 2019, 314). I extracted the sonic portfolio and reflected upon the sonic practice *after* doing the actual sonic work. Describing this procedure by stating the outcome first, the portfolio and the reflection, is somewhat arduous and sketches a different pathway than I took. Britton et al. (2019, 314) elaborate further: ‘collective practicing between artistic research and computing asks that we take methodological openness seriously as a precondition for the possibility of results being transformative to both [sic] disciplines and shows that actual practicing is essential for such transformation. In other words, it asks that we do thinking as an open-ended material practice’. The *insides* of the computational do not have the intrinsic need or the means to be entirely open-ended; Malazita points out that history and sociology are not required for technologies to do their ‘work’ and may be disregarded. Parisi and da Silva (2021) find the universals ‘multiplicity, objectivity and duality [...] randomly – in a random book, a random page, a random paragraph’ of, in their case, contemporary (continental European) philosophy–and in my case by looking at random details of computational work.

6.2 Building techno-intuition

Tara McPherson brings together unrelated though co-constituent founding principles of computing and social conditions. They appear unrelated because it is hardly possible to prove a linear causality. Switching between digital humanities and race studies, McPherson (2012, 154) goes further and speculates that ‘the intense narrowing of our academic specialities over the past fifty years can actually be seen as an effect of or as complicit with the logics of modularity and the relational database’. She imagines critical scholars to ‘have at least a passing familiarity with code languages, operating systems, algorithmic thinking, and systems design'.[105] Due to complexity and fragmentation, even a passing familiarity is laborious. Facilitating this process, I envisage building techno-intuition to consciously and deliberately switch between technical and intuitive techniques in order to speed up understanding and share the research and the learning. Such techniques encompass repeated encounters with computational matters of any kind, switching between 'low'-level/hands-on activity and 'high-level' abstraction, poly-modal and non-linear procedures, putting abstract concepts and figures into practice, reading and processing computational scenarios through non-computational perspectives and habits. Dunbar-Hester describes building capacity in the face of global issues, while Britton, Klumbyte, and Draude (2019, 314) characterise shifting perspectives through cross-disciplinary work when it is not possible to answer the question: 'It sounds interesting. But what will [the collaboration] do?' because 'the outputs that artistic research produces operate on terms defined within their own situated contexts, making it rather difficult to answer the question "what will it do?" with pragmatic precision'.

105 This quote touches upon the core objectives of this PhD project (McPherson 2012, 154): 'In extending our critical methodologies, we must have at least a passing familiarity with code languages, operating systems, algorithmic thinking, and systems design. We need database literacies, algorithmic literacies, computational literacies, interface literacies. We need new hybrid practitioners: artist-theorists, programming humanists, activist-scholars; theoretical archivists, critical race coders. We need new forms of graduate and undergraduate education that hone both critical and digital literacies. We have to shake ourselves out of our small, field-based boxes so that we might take seriously the possibility that our own knowledge practices are normalized, modular, and black boxed in much the same way as the code we study in our work. That is, our very scholarly practices tend to undervalue broad contexts, meaningful relation, and promiscuous border crossing. While many of us identify as interdisciplinary, very few of us extend that border crossing very far (theorists tune out the technical; the technologists are impatient of the abstract; scholars of race mock the computational, seeing it as corrupt). […] Just as the relational database works by normalizing data- that is, by stripping it of meaningful, idiosyncratic context, creating a system of interchangeable equivalencies- our own scholarly practices tend to exist in relatively hermetically sealed boxes or nodes. Critical theory and poststructuralism have been powerful operating systems that have served us well; they were as hard to learn as the complex structures of C++, and we have dutifully learned them'.

6.3 Practical starting points

6.3.1 Inverse computational knowing

Instead of skills, *inversing* is a template for accessing and assessing a computational scenario, as required by the persons involved. Artistic practice might not be precise and prescribed; nevertheless, its principle situatedness, applicability, and efficiency render it useful with/in fragmented and multilayered sculptures of abstraction–emphasising the constructive, intentional and incremental nature of infrastructure. Applied in processes of abstracting, I propose to decompose (take apart) a computational scenario and compose (put together) a new plane of abstraction, for example, by reading the scarce, publicly available documentation of EU research and development projects on migration control technologies. The decomposing step could simply involve selectively reading the documents and highlighting details either of the content or their making. Such details could be integrated once again by either marking or commenting in the text, making paper notes, or any other method of processing the details quickly, ignoring everything that is too time- or attention-consuming at that moment.

Constructing a new plane of abstraction could involve reflecting available technical documentation of large-scale research and development of 'innovative' technologies for migration control and administration. The entanglement of narrative and technical detail might be discussed through, for example, the lens of *infrastructures of feelings* developed by cultural theorist Raymond Williams in the 60s and taken up by the prison abolitionist and scholar Ruth Wilson Gilmore, a perspective on the 'hard' substance of 'soft' feeling normalised at a particular time and society.[106][107] The intention is not to advance theory, but apply existing analytic thought with the experience and understanding available among the involved people. Reading or poetic processing of the material could be carried out using any number of iterative steps deemed necessary and shared in any way feasible and useful. For a collective situation, it might be necessary to explicitly tackle ‘naturally emerging hierarchies based on technical skill and reputational capital’ (Dunbar-Hester 2020, 51).[108] Finding ways to additionally *do* hands-on work that is related either to the scenario in focus or the persons involved might contribute to understanding it in ways other than acquiring factual knowledge. Similarly, for the practice of hacking, in *Hacker's Manifesto*, McKenzie talks about abstractions as either discovered or produced, material or immaterial. Each *hack* would ‘construct a plane upon which otherwise different and unrelated matters may be brought into many possible relations’ (McKenzie 2004).

106 Where Gilmore thinks about infrastructures of feeling in Black Radical Tradition (Gilmore 2022, chap. 20), the logic of technical documentation might be highlighted poignantly against its continuously affirmed feelings: ‘Raymond Williams argued more than fifty years ago that each age has its own “structure of feeling,” a narrative structure for understanding the dynamic material limits to the possibility of change. Paul Gilroy and many others have engaged Williams’s thinking and shown that ages and places necessarily have multiple structures of feeling, which are dialectical rather than merely contemporaneous. Williams went on to explain how we might best understand tradition as an accumulation of structures of feeling—that gather not by chance, nor through a natural process that would seem like a drift or tide, but rather by way of what he calls the “selection and re-selection of ancestors.” In this, Williams disavows the fixity of either culture or biology, discovering in perpetuation how even the least coherent aspects of human consciousness—feelings—have dynamically substantive shape.’

107 I am thankful for the invitation to a group reading of the chapter in: Gilmore, Ruth Wilson. 2022. *Abolition Geography: Essays towards Liberation*. Edited by Brenna Bhandar and Alberto Toscano. London, New York: Verso.

108 As Dunbar-Hester (2020) comments: ‘This has often resulted in naturally emerging hierarchies based on technical skill and reputational capital. Technical expertise is notoriously undemocratic and prone to hierarchy even when participants are committed to democratization, which they often are not, in part due to a historical legacy of engineering as an elite body of knowledge and practice. Technical projects may be especially difficult to run in a radically egalitarian manner, as some people are bound to be more expert than others: egalitarian politics may sit uneasily along unequally distributed expertise.’

6.3.2 Inverse computational curriculum

The singular activities together would form an inverse computational curriculum. The core focus is on future technologies for ‘innovation and containment’, as Ruha Benjamin coined them. Besides particular perspectives, such as those of Gilmore, more general tools might be helpful as a common ground, such as thinking along abstraction/experience, necessary/contingent, mundane/sublime, and virtual/actual as poles of gradual axes. Or to look at how conceptions of the human play out. Terms that mobilise across experience(s) and knowledge(s) might support such research in undefined spaces. Inversing would search for habits, customs, and associations at the core of the computational (in line with Fazi) and for narrative and taste (in line with Impett). These are examples of conceptual vehicles for abstracting new planes from existing computational scenarios through *otherwise* perspectives, which ask to take responsibility for technologies. This might require shifting from innovation to maintenance.

6.4 Conclusion

After attending an ethical panel at a closed conference on human genomes, Benjamin (2018) commented: ‘Our collective imaginations tend to shrink when confronted with entrenched inequality and injustice, when what we need is just as much investment and innovation in our social reality as we pour into transforming our material lives’. Technological fixes for social problems are ‘not only about solving, but also holding some things in place’. Reluctant techno-poetic/practical practice might help to stop holding certain things in place, and non-standard ways of navigating technological domains might support the inversing of future technologies.

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APPENDICES

Appendix 1: Portfolio of electromagnetic works (descriptions)

The total duration is 90:15

** pre Ph.D.*

→ full-length, stream, or archive is available online

on computing________________________

If not stated: direct recording of 1 or 2 electromagnetic pickups with no processing, no editing

Personal

Boot sequence

01:14 Laptop from the 90s with a broken screen (2008) * [No. 01]
Recorded as part of the long-term residency *Museum in Bewegung* 2008-2013 in the Swiss mountains by invitation of Peter Trachsel[109] // site-specific collection of laptops // first instantiation of the live-performance *Tripping through runtime*: listening to motherboards without running additional software programs.
→ Video: www.youtube.com/watch?v=p4gmqpyIrYw

Operating system

03:11 Phone in idle mode playable within a blog post (2021) [No. 02]
Recorded as part of the blog post *Staying with the tech trouble* // a smart feature phone waiting[110] // background activity of the operating system // overlay of two and then three different points in time simulating a person reading the blog post and playing the three tracks embedded at different positions of the text.
→ Blog post: www.enginesofdifference.org/2021/05/30/staying-with-the-tech-trouble

109 The artist's website: *Peter Trachsel und die Hasena*. Available at: https://petertrachsel.info (Accessed: 26 September 2022). For more on his work: Trachsel, P. *et al.* (2018) *Wir muten Ihnen alles zu - Peter Trachsel und die Hasena*. Zürich: Verlag Scheidegger & Spiess, the museum: *Ein Museum in Bewegung*. Available at: http://www.museumpraettigau.ch (Accessed: 26 September 2022) and the location: Switzerland, Graubünden, Luzein, Putz: https://de.wikipedia.org/wiki/Putz_GR.

110 A smart feature phone is a hybrid between an early generation and a 'smart' mobile phone.

Software-hardware processes

Demonstration of the system administration tool ‘stress’ using one hardware component at a time with varying arguments.[111]

00:50 Memory [No. 03]
Increasing the number of processes from 1 to 16.
Example call: ‘stress –vm 8’ where ‘vm’ stands for virtual memory

00:32 Memory writing ’1’s to every x^{th} bit [No. 04]
Four memory processes with increasing x (stride): 1, 2, 4, 8, 16, 32, 64, 128, 512, 1024.
Example call: ‘stress –vm 4 –vm-stride 16’.

00:12 Input/Output [No. 05]
Increasing the number of processes from 1 to 4.

00:11 Disk [No. 06]
Increasing the number of processes from 1 to 4.

Underwater observatory

01:02 Observatory taking one picture (since 2012) [No. 07]
Recorded as part of the project *Computersignale* by Hannes Rickli[112] // ongoing since 2012 // power current, electromagnetic fields near the camera and in the middle of the casing // the underwater observatory takes one stereometric picture every 30 minutes.
→ Archive https://archiv.computersignale.zhdk.ch

02:39 Observatory taking 48 pictures in one day [No. 08]
Overlay of 48 picture-taking events within one day.

111 User manual for the tool: https://linux.die.net/man/1/stress
112 Rickli, H. (2019) *Computersignale. RemOs1, Spitsbergen (since 2012)*. Available at: https://computersignale.zhdk.ch/en/data/remos1 (Accessed: 26 September 2022).

Computing centres

05:40 Computing centre handling the observatory's observations (since May 2022) [No. 09]
Recorded as part of permanent streaming from the scientific computing centre that processes all data related to the underwater observatory // ongoing since May 2022 // virtualisation machines, fast and slow storage, network, tape archive control // part of the exhibition *Listening to Data.*[113]
Mix of virtualisation machines and the tape archive control.
Overlay of two points in time per location.
→ Live streams (if up) and documentation: https://p-node.org/broadcasts/rz-awi

03:26 Another computing centre [No. 10]
Recorded as part of the project *Computer Signals* by Hannes Rickli.[114]
Mix of multiple pickups at different locations within the computing centre and at different points in time.
→ Archive: https://computersignale.zhdk.ch/en/data/cichlid/panorama

113 *Listening to Data. How the environment gets into the computer*. Available at: https://www.dsm.museum/en/exhibition/exhibitions/hannes-rickli-listening-to-data-how-the-environment-gets-into-the-computer (Accessed: 26 September 2022).
114 Rickli, H. (2019) *Cichlid #3*, *Soundscape Texas*. Available at: https://computersignale.zhdk.ch/en/data/cichlid (Accessed: 26 September 2022).

Rehearsing and performing

03:09 *Pixelache* (2009)* [No. 11]
Excerpt from the first performance using software processes at the Pixelache festival for electronic art[115] // room recording.
→ Video: https://vimeo.com/39271758

11:46 Rehearsals for *Leobener Logistik Sommer* (2021) [No. 12]
Rehearsal for a concert with the Radio Cyborg Transmitter by Reni Hofmüller at the Leobener Logistik Sommer.[116]
Overlay of two separate rehearsals

04:02 Concert with *Seijiro Murayama* (2018) [No. 13]
Excerpt from a concert at the Zarata fest 2018[117] // room recording.

04:41 Ad-hoc improvisation with *Aurélie Derouin* (2021) [No. 14]
Spontaneous improvisation with a copper skeleton as antenna during a 2-week-residency at the Atelier Expérimental[118] // first trials with wide-band radio frequencies and outdoor (without a computing device) // recorded with an EtherSoma.[119]
Excerpt from a 25-minute-long exploration without an audience.

14:30 Concert *l'Embobineuse* (2022) [No. 15]
Full-length concert at the l'Embobineuse venue as part of a work week with the π-node collective.[120]

04:02 Rehearsal for P*ushing Scores (excerpt)* [No. 16]
Rehearsal for an unreleased vinyl by DePlayer within the 'Pushing scores' project.[121]

03:43 Concert *Zaratan* (excerpt) [No. 17]
Excerpt from a concert at the artist-run space Zaratan.[122]

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115 https://www.pixelache.org/festivals/festival-2009
116 The sonification instrument by Reni Hofmüller can be viewed at https://esc.mur.at/en/projekt/radio-cyborgs-radio-cyborg-transmitter. The festival was organised by the *Independent Logistics Society* https://ils365.at under the theme of 'digital reality – was bleibt, was kommt, und wie können wir es am besten für uns nutzen?' (preparing themselves for a 'digital future' and asking what will remain of 'digital reality'), although there is no longer any trace of the festival on their website.
117 https://xedh.org/zaratafest2018
118 http://www.atelier-experimental.org
119 https://somasynths.com/ether
120 https://www.lembobineuse.biz
121 https://www.delayer.nl/pages/pushing-scores-project
122 https://zaratan.pt/en/event/233

Releases

05:04 Tape *Les Intérêts Spécifiques*: scientific fridge (release planned for 12/2023) [No. 18]
For a tape to be published by the label *Les Intérêts Spécifiques* // electromagnetic pickup, contact microphone, and acoustic microphone of a scientific fridge // overlay of two points in time.
Label (will include the release): https://specificinterest.bandcamp.com
→ Recordings: https://computersignale.zhdk.ch/de/data/cichlid/panorama? loc=refrigerator

14:49 Tape *Innernoise*: collage of fugitive sounds from rehearsals (2022) [No. 19]
Mixed for a tape published by the label *Innernoise* // selected from my archive of per-pickup recordings of rehearsals between 2016-2021.
→ Release: https://innernoise.bandcamp.com/album/electromagnetics

04:54 Observatory in the lab (2019) [No. 20]
Mixed for a radio streaming on p-node.org // test recordings (power and em) from the biologists' lab while installing the pickups in the observatory before everything was taken underwater.
Beginning of a 4-minute-long track: the condenser of the camera flash is loading multiple times.

Appendix 2: Log

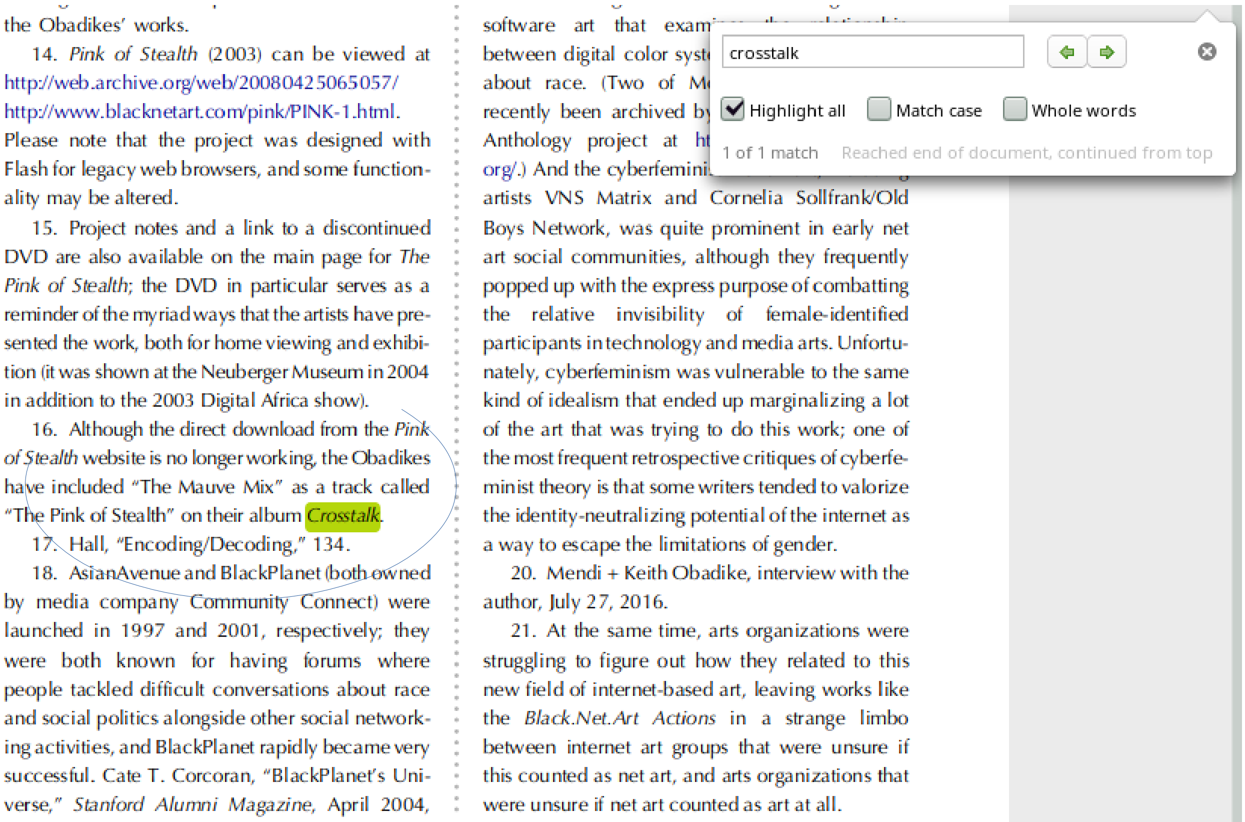
yesterday, before shutting down

> search the term *crosstalk* in my reference library's everything

<< 61 results

> pick Driscoll, M. (no date) 'Color Coded: Mendi + Keith Obadike's Black.Net.Art Actions and the Language of Computer Networks', p. 13.

> scroll to *crosstalk*



the Obadikes' works.

14. *Pink of Stealth* (2003) can be viewed at http://web.archive.org/web/20080425065057/ http://www.blacknetart.com/pink/PINK-1.html. Please note that the project was designed with Flash for legacy web browsers, and some functionality may be altered.

15. Project notes and a link to a discontinued DVD are also available on the main page for *The Pink of Stealth*; the DVD in particular serves as a reminder of the myriad ways that the artists have presented the work, both for home viewing and exhibition (it was shown at the Neuberger Museum in 2004 in addition to the 2003 Digital Africa show).

16. Although the direct download from the *Pink of Stealth* website is no longer working, the Obadikes have included "The Mauve Mix" as a track called "The Pink of Stealth" on their album *Crosstalk*.

17. Hall, "Encoding/Decoding," 134.

18. AsianAvenue and BlackPlanet (both owned by media company Community Connect) were launched in 1997 and 2001, respectively; they were both known for having forums where people tackled difficult conversations about race and social politics alongside other social networking activities, and BlackPlanet rapidly became very successful. Cate T. Corcoran, "BlackPlanet's Universe," *Stanford Alumni Magazine*, April 2004,

software art that exam[...]
between digital color syst[...]
about race. (Two of M[...]
recently been archived b[...]
Anthology project at ht[...]
org/.) And the cyberfemini[...]
artists VNS Matrix and Cornelia Sollfrank/Old Boys Network, was quite prominent in early net art social communities, although they frequently popped up with the express purpose of combatting the relative invisibility of female-identified participants in technology and media arts. Unfortunately, cyberfeminism was vulnerable to the same kind of idealism that ended up marginalizing a lot of the art that was trying to do this work; one of the most frequent retrospective critiques of cyberfeminist theory is that some writers tended to valorize the identity-neutralizing potential of the internet as a way to escape the limitations of gender.

20. Mendi + Keith Obadike, interview with the author, July 27, 2016.

21. At the same time, arts organizations were struggling to figure out how they related to this new field of internet-based art, leaving works like the *Black.Net.Art Actions* in a strange limbo between internet art groups that were unsure if this counted as net art, and arts organizations that were unsure if net art counted as art at all.

> launch http://web.archive.org/web/20080425065057/http://www.blacknetart.com/pink/PINK-1.html

went home

this morning

no network connection yet

<< fan begins

why –which program is running?

> switch through all open applications to turn them off one by one

open tab in browser still showing the archived PINK-1.html from yesterday

<< animated pink and white horizontal lines

make screenshots as quick as possible –for an animated GIF?

capture one static screenshot of the animation:

> press PrtSc

> enter OK for capturing the whole window

> enter SAVE

> still PINK?

> make another screenshot

web.archive.org is having trouble to find the site

STOP

include this situation to the appendix as an example for crosstalking between references and responses?

> begin writing this log

> connect to network

> refresh page

read the remark that the page was created with flash and for early browsers

how does the playback of flash actually work in the wayback machine?
is the original version accessible?

39 snapshots of PINK-1.html between 23 Nov 2003 - 5 Dec 2022

a new window <pops up> in the background with the documentation on the *Pink of Stealth* project

> return to page

<< on top of the animated pink/white horizontal lines a javascript function has been printed out in the meantime

```
(function (d, w) {var x = d.getElementsByTagName('SCRIPT')\[0\];var f = function ()
{var s = d.createElement('SCRIPT');s.type = 'text/javascript;s'.async = true;s.src =
"//np.lexity.com/embed/YW/f5d6524f4707c6643c204fe73493975c?
id=12b05b69e4a8";x.parentNode.insertBefore(s, x);};w.attachEvent ?
w.attachEvent('onload',f) :w.addEventListener('load',f,false);}(document, window));
```

> switch to paper

> search the *Crosstalk* album

<< fan still making noise

<< another window <pops up>

> remove two entries from this log

> begin the writing on crosstalking

after writing the subchapter

Christina Kubisch was awarded the ZKM Giga Hertz the same year the Opadikes declined

what I see in the browser is just the background

after correcting the subchapter

> use > for my activity

> use << for either computer’s or Obadike’s web site’s activity

> work on readability, try not to change much

Appendix 3: Setup guide for the *stress* environment

The following how-to was written upon an individual request and is unmodified.

Preparing

Download the Linux distro *stress*

https://www.stresslinux.org → Downloads → latest ISO image is stresslinux_64bit_11.4.x86_64-0.7.106.iso.bz2

Create a bootable live system on CD or USB
https://www.stresslinux.org/sl/wiki/Documentation

→ it sounds different booting from a CD-ROM or USB stick or install it directly; on my laptop, booting from CD-ROM sounds best

Boot

→ on the boot screen, enlarge the video font size to a maximum of 800x600, so the audience can read the terminal

→ set the layout of your keyboard

→ you may enable or disable the internal sensors; for me, it doesn't make a difference in the sounds aka the electromagnetic radiation around the motherboard

Login

User: *stress* Password: *stress*

Six terminals

Once booted, you have six terminals → switch between them with the keys ALT + F1-F6

ALT + F1 for terminal 1, ALT + F2 for terminal 2...

Running the tool

On each of the six terminals, you can launch one instance of the *stress* tool.

Each *stress* instance can launch 1 to X processes.

Each process can use one or more components: memory (RAM), processor (CPU), input/output (IO) and disk (HDD).

RAM, CPU and IO accept additional parameters.

Overview
https://linux.die.net/man/1/stress

Source
https://github.com/resurrecting-open-source-projects/stress/blob/master/src/stress.c

→ the stress tool translates to four system calls: RAM to **malloc()/free()**, CPU to **sqrt()**, IO to **sync()**, HDD to **write()/unlink()**

Easier

If you are on a Linux, you can install *stress*, or the more recent, *stress-ng* directly
https://manpages.debian.org/bullseye/stress/stress.1.en.html
https://manpages.debian.org/jessie/stress-ng/stress-ng.1.en.html

→ this will sound more crowded because of the background processes of your system

More

Try other tools for testing and monitoring the stress distro

https://www.stresslinux.org/sl/wiki/Software

Or any other software on any other operating system, of course.

Extra: Tin foil hat floppy

Another distribution that works well for performing with the elctrosmog is the **Tin foil hat** Linux floppy.

Disappeared from the original site
http://tinfoilhat.shmoo.com

About
https://handwiki.org/wiki/Software:Tinfoil_Hat_Linux

Article
https://web.archive.org/web/20021204010949/http://www.evilmutant.com/stuff/tinfoil

Further info
https://web.archive.org/web/20020907012413/http://www.evilmutant.com/stuff/tinfoilpr0n

ISO
https://sourceforge.net/projects/tinhat

→ especially scrolling through the informative *Help* page and turning on the Tempest-scrambling *Paranoia mode* is interesting

Amplify

Plug an induction coil, e.g.

[https://www.monacor.com/products/components/cables-and-plug-in-connectors/adapters/ac-71-3-5mm/]

into a preamp and put the pickup on top of your motherboard

→ it’s ready!

Example calls

stress -m 4 –vm-stride 48 –vm-bytes 812m

stress -m 2 –vm-stride 8 –vm-keep

stress -d 1 –vm-bytes 1g

stress -i 1 –vm-bytes 1g

Appendix 4: Example scores

m4 keep m2 keep m2 last

[m2 1g hang1]

②

m4 keep m2 keep m1

m2 keep

m3 keep ← to switch to

c1 2

i1
i1 1k
i2 1m

d1
d1 1m

sts1 2. m2

hang1 sts.512 m1
m2

d1 1m

c1
i1

m1

m2 sts 64

m3 keep m1 keep

m2 str ll

[d1 1m]

fast i1 c1 2 3
last

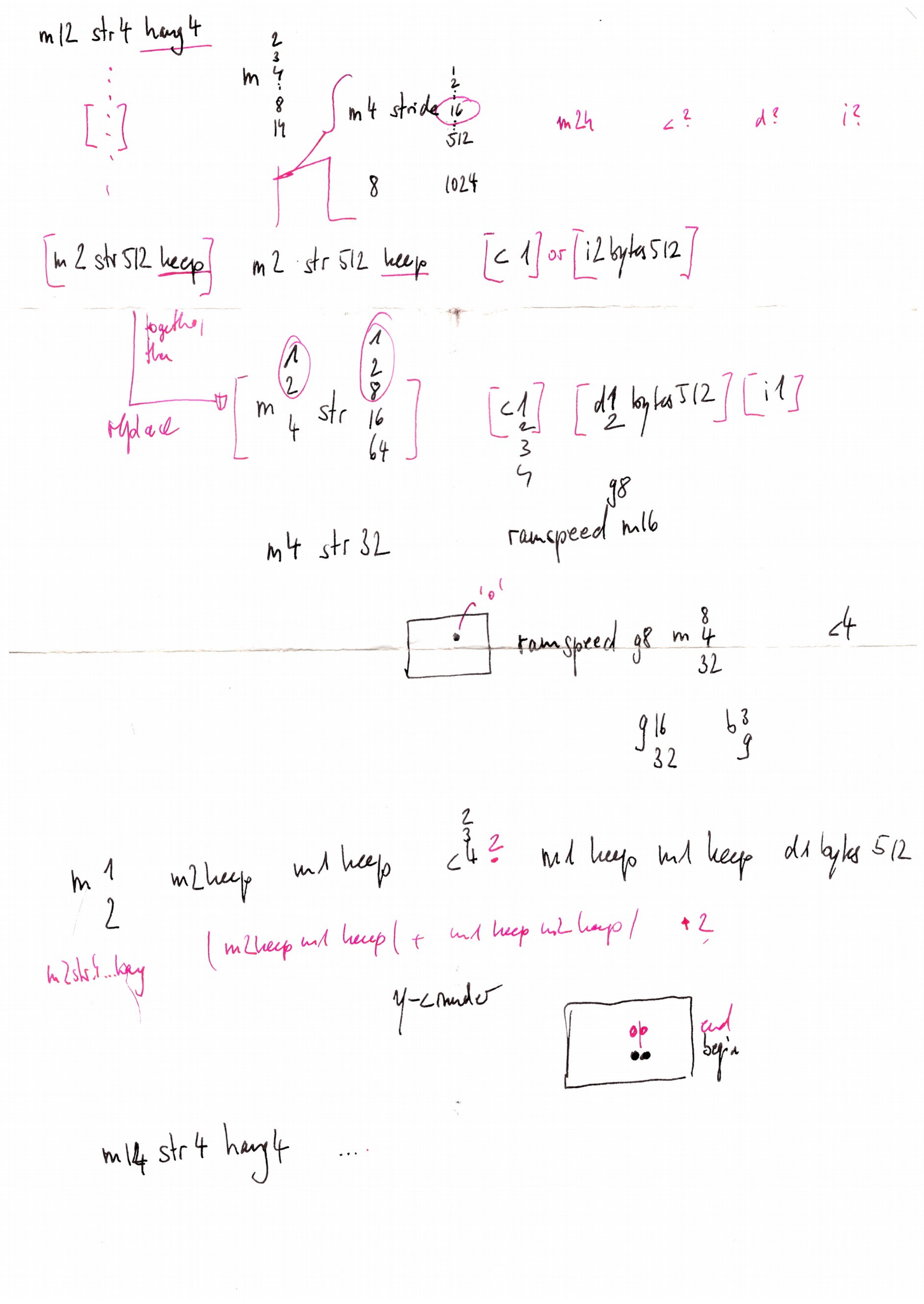
2.

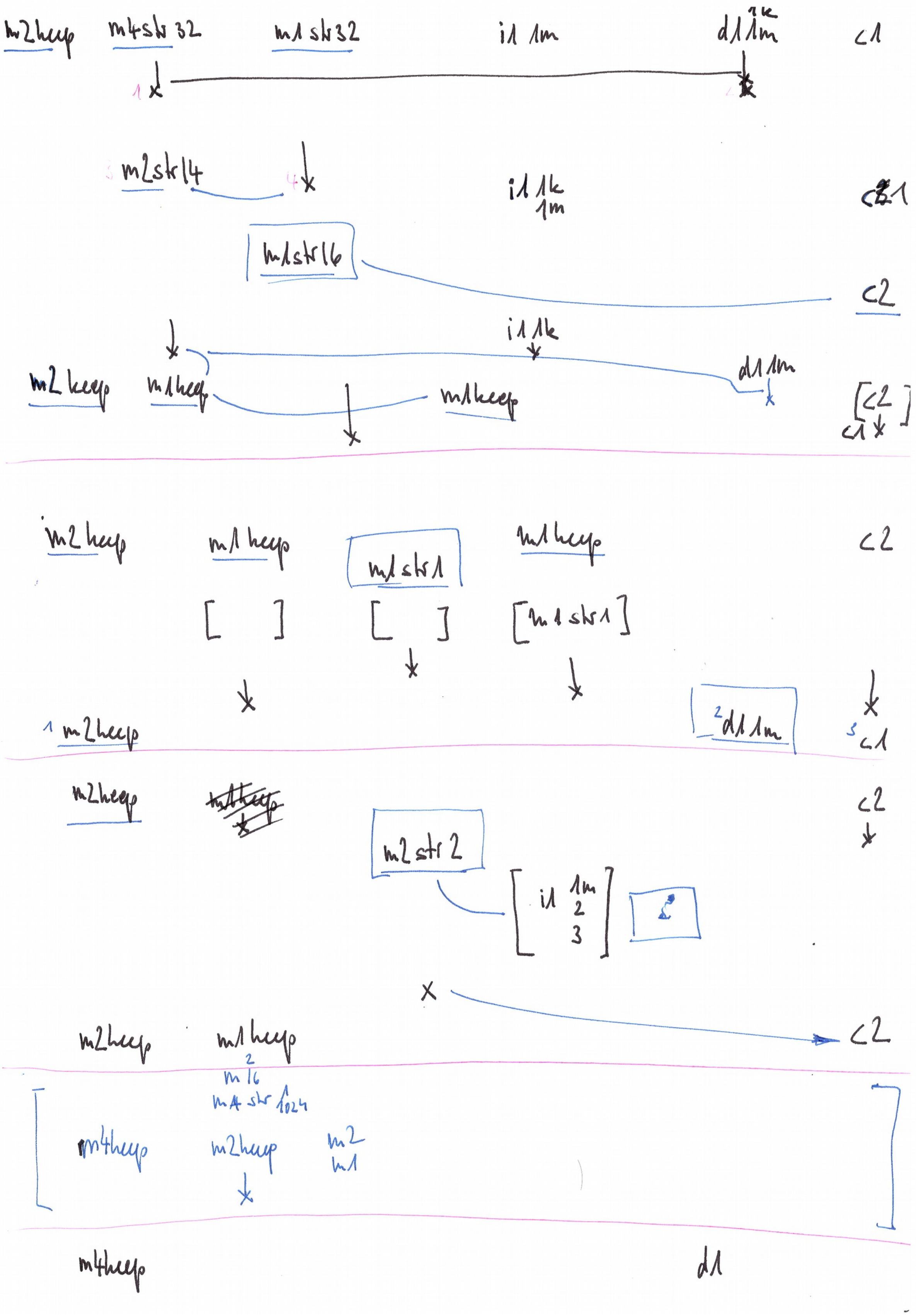
m4 m4 d1 1m
8 8
16 16

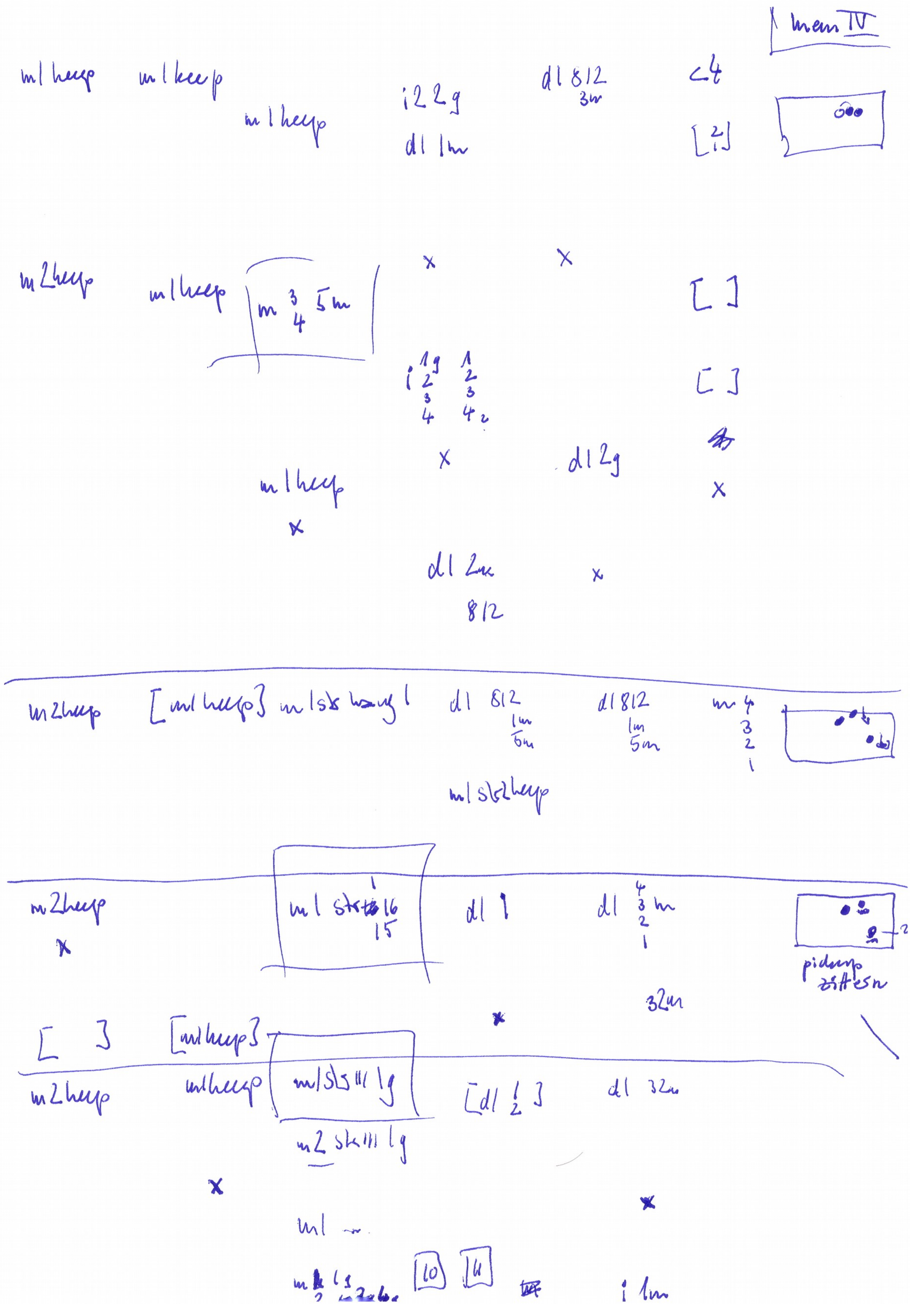
i1 1m

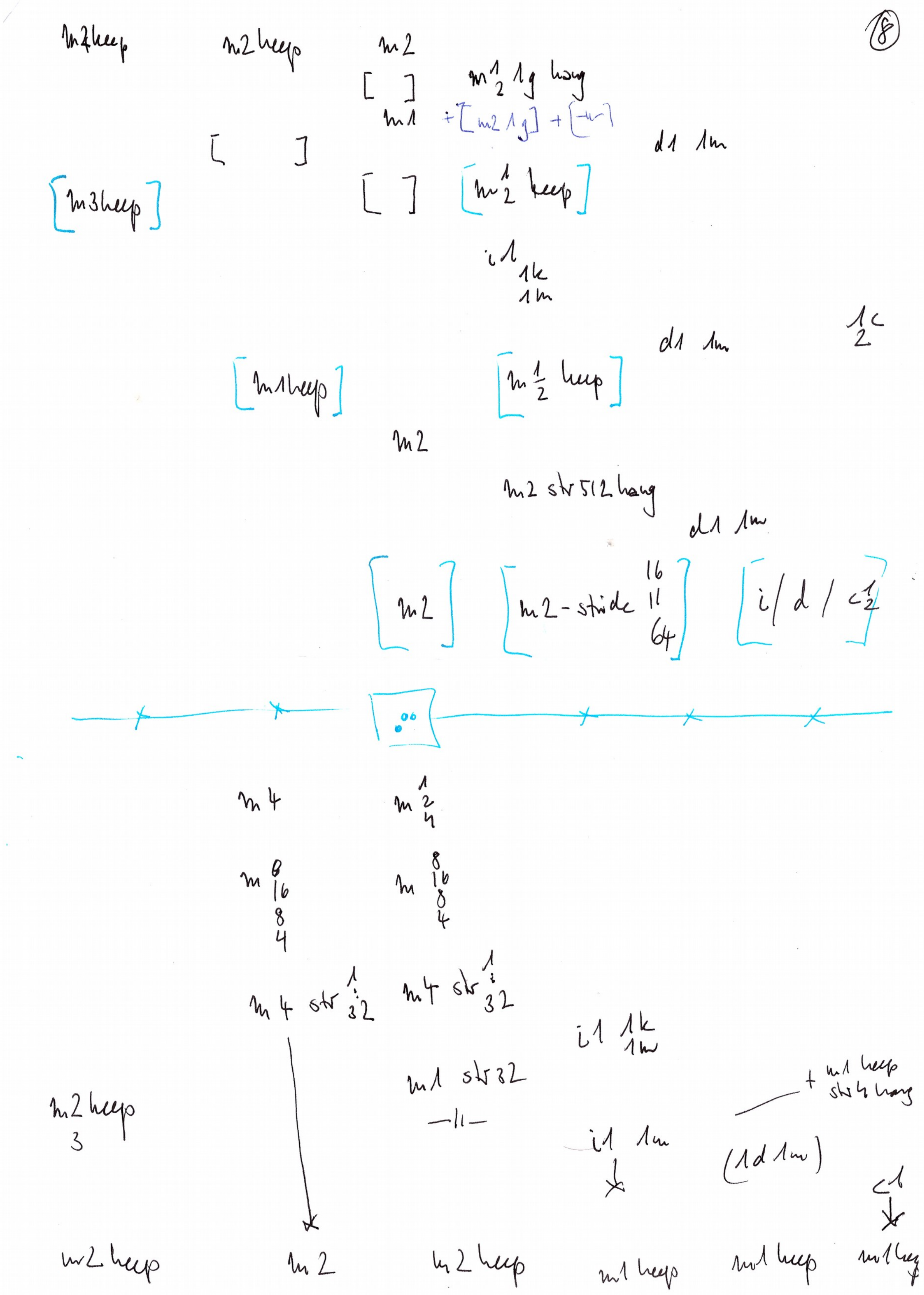
m4 sts 32 m4 sts 32 i1 1k d1 1m 2 2

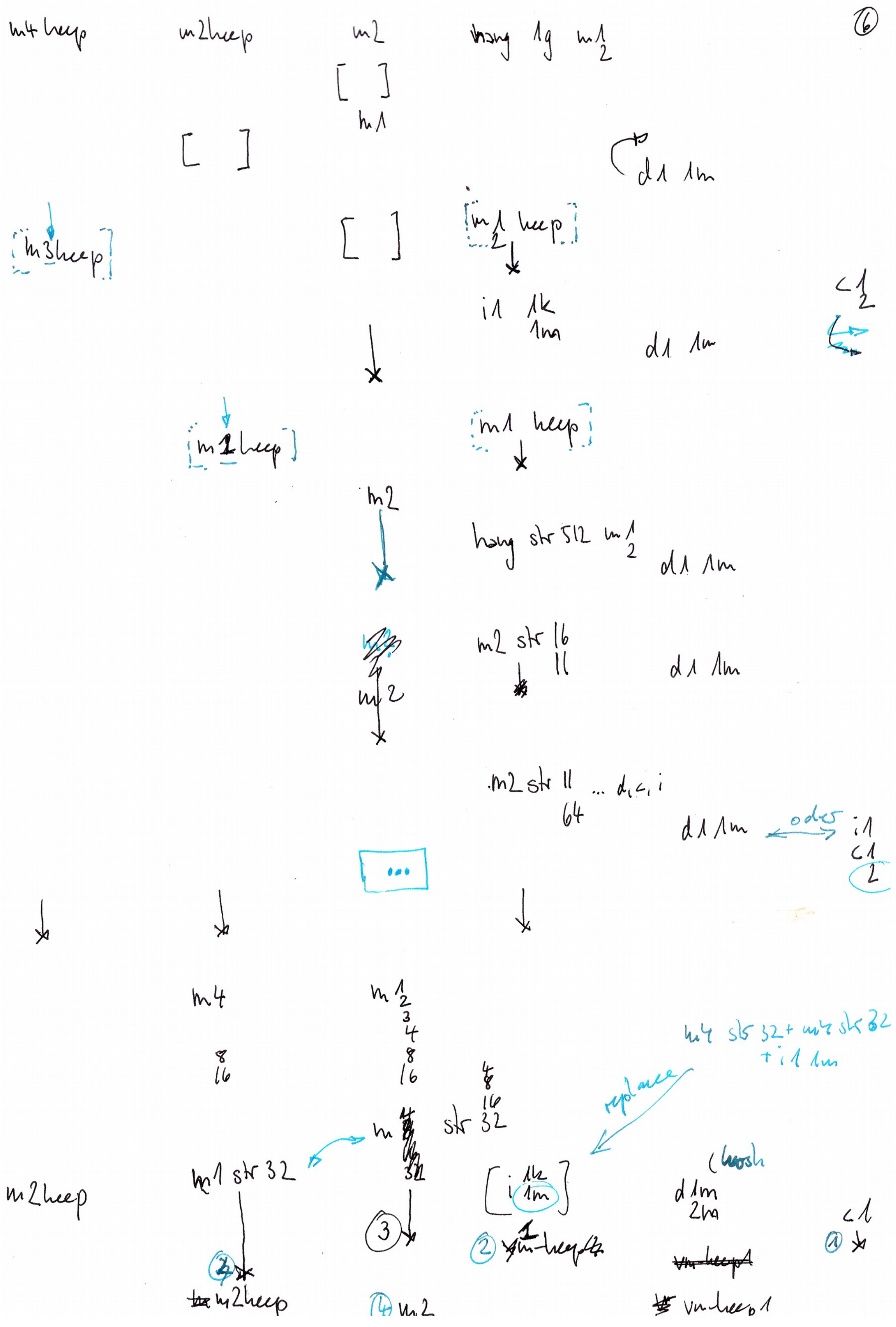
m1 keep m2 keep → m2
2
3
4
m3 keep

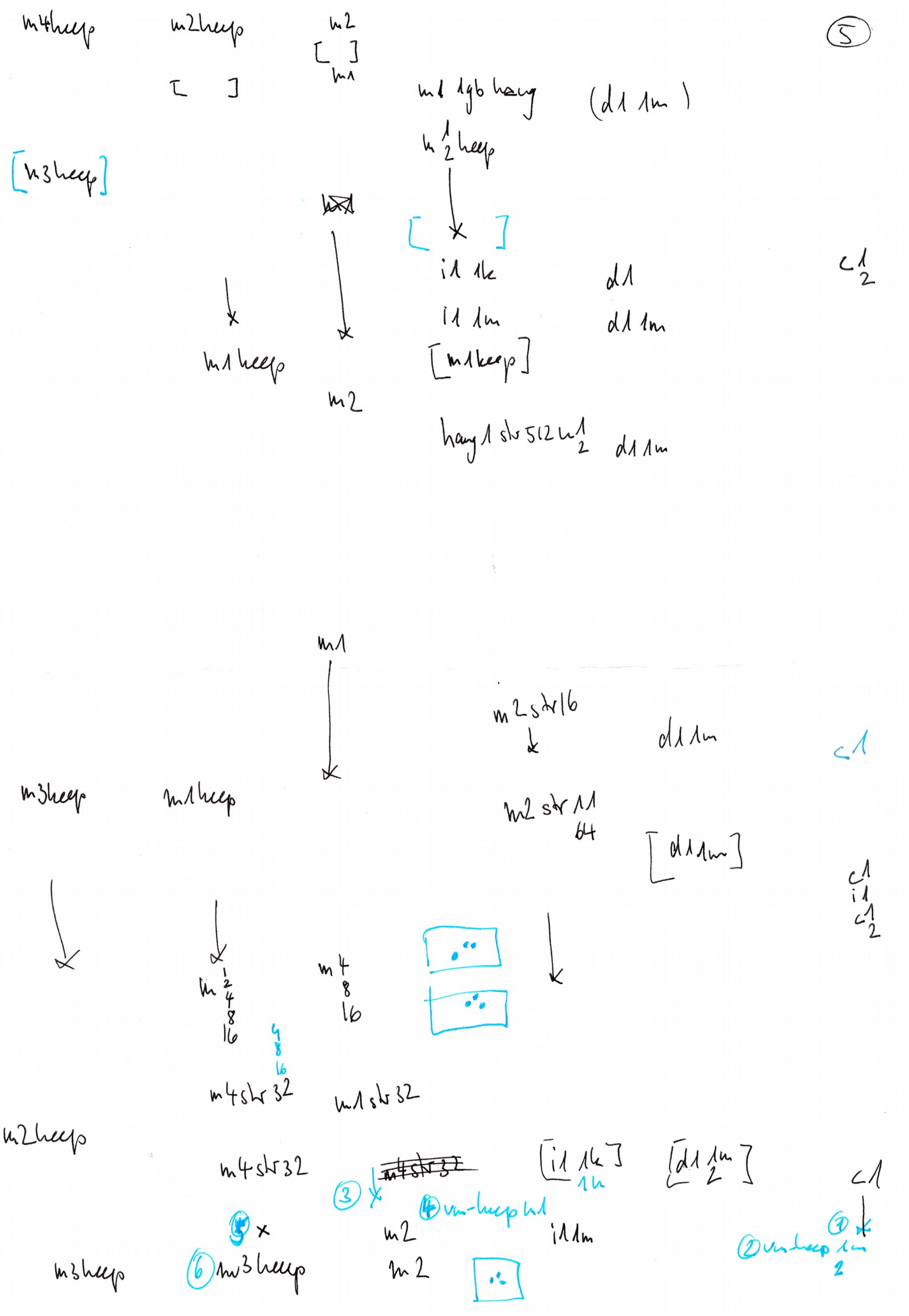

m12 str4 hang4
m4 stride
m24
8
1024
m2 str512 keep
m2 str512 keep
c1 or i2 bytes512
together, then
replace
m str 16 64
c1
d1 bytes512
i1
g8
ramspeed m16
m4 str32
ramspeed g8 m4 32
c4
g16 32
m1 2
m2keep
m1 keep
m1 keep m1 keep d1 bytes 512
m2keep m1 keep
m1 keep m2 keep
+2
y-counter
end
begin
m14 str4 hang4 ...

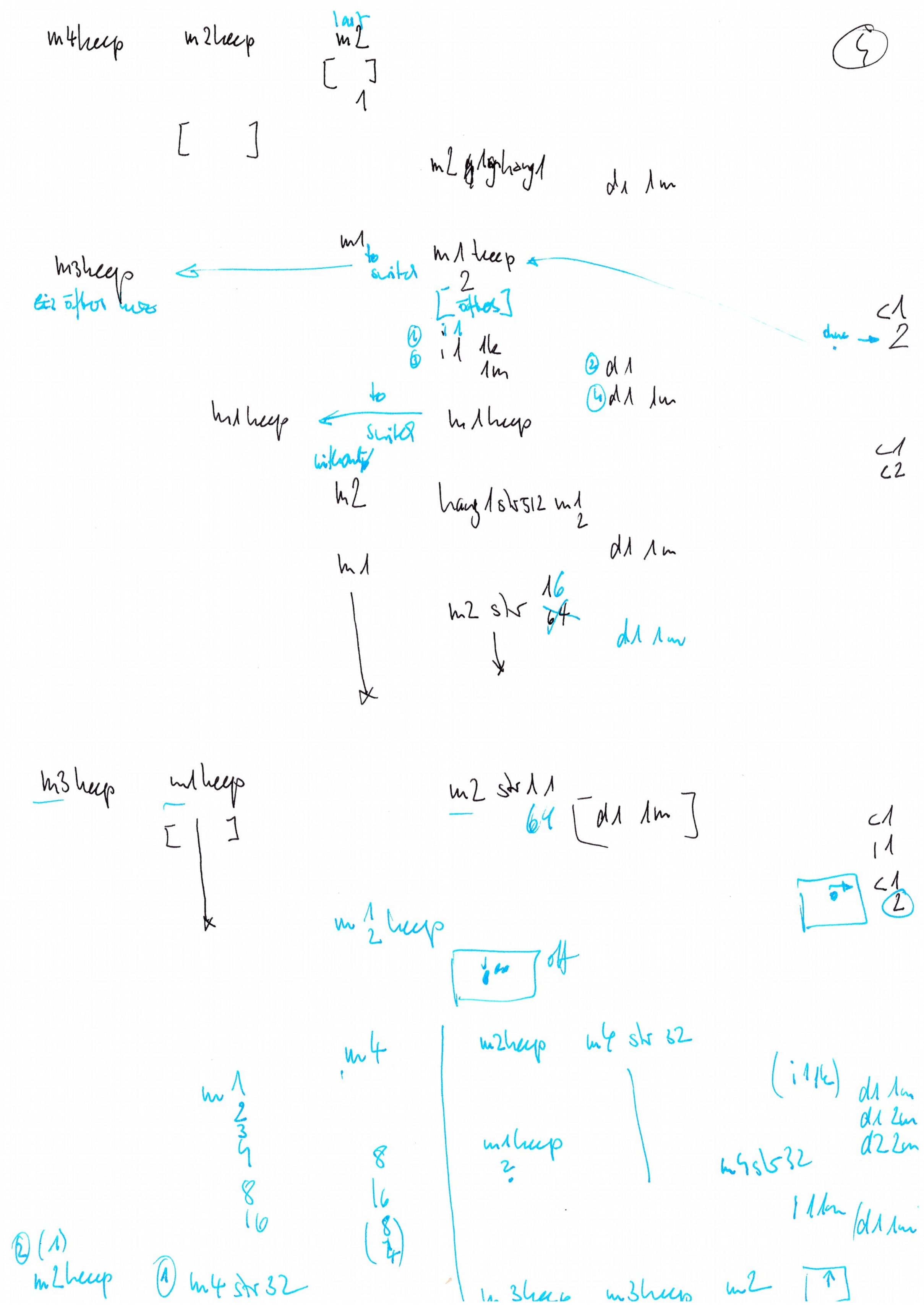

m2keep
m4str32
m1str32
i1 1m
d1 1m
c1
m2str14
i1 1k 1m
m1str16
c2
i1 1k
m2keep
m1keep
m1keep
d1 1m
c2
c1
m2keep
m1keep
m1str1
m1keep
c2
m1str1
m2keep
d1 1m
c1
m2keep
m2str2
c2
i1 1m 2 3
m2keep
m1keep
c2
m16
m4str 1024
m4keep
m2keep
m2
m1
m4keep
d1


mem IV
m1 keep
m1 keep
m1 keep
i2 2g
dl 812
3m
dl 1m
m2 keep
m1 keep
m 3 4 5m
dl 2g
m1 keep
dl 2m
812
m2 keep
[m1 keep]
m1 sls
m1 sls2 keep
dl 812
1m
5m
m2 keep
dl 32m
pidump
m2 keep
m1 keep
[m1 keep]
[dl 1 2]
dl 32m
m2 stk lg
i 1m


m2 keep
m2
m3 keep
d1 1m
i1
1k
1m
m1 keep
m2
d1 1m
m2
m2 - stride
m4
m4 str
i1 1k
1m
m1 str 32
m2 keep
3
i1 1m
(1d 1m)
m2 keep
m2
m2 keep
m1 keep
m1 keep


m4 keep
m2keep
m2
m3keep
m1 keep
i1 1k
d1 1m
m2 str 16
m2 str 11 ... d, c, i
d1 1m
oder
i1
c1
m4
m2keep
m1 str 32
str 32
replace
m2keep
m2


5
m4keep
m2keep
m2
m1
m1 1gb hang
(d1 1m)
[m3keep]
i1 1k
d1
i1 1m
d1 1m
[m1keep]
m1keep
m2
hang1 str 512 m1/2
d1 1m
m1
m2 str16
d1 1m
c1
m3keep
m1keep
m2 str 11 64
[d1 1m]
c1
i1
c1/2
m 4 8 16
m4 str 32
m1 str 32
m2keep
m4 str 32
[i1 1k]
[d1 1m/2]
c1
4 un-keep kd
i1 1m
2 unkeep 1m/2
m2
m3keep
6 m3keep
m2



m4keep
m2keep
m2
m1 keep
m3keep
m1keep
m2
m1
d1 1m
c1
c2
m2 str
m3 keep
m1keep
m2 str 1 1
64
m4
m2keep
m4 str 32
m1keep
m2keep
m4 str 32

m4 keep m2 keep m2 ③
1 (1)

(m1 keep)

m2 1g lang

m3 keep m2 keep m1
4

d

i 1m

m1

m2 <

m1 vm-lang1 str 512
2 1024

d2 1m ← and mit 1 x m3 keep

m3 keep m1 keep m2
~~3~~
1

d1 knwz

d1 1m i1 1m <1
lang 2

m2 str 64

[m3 keep + m1 keep]
[d1]m

m3 keep ? ~~m~~ m4 ~~m~~ 
② ①

d1 1m <4
2m

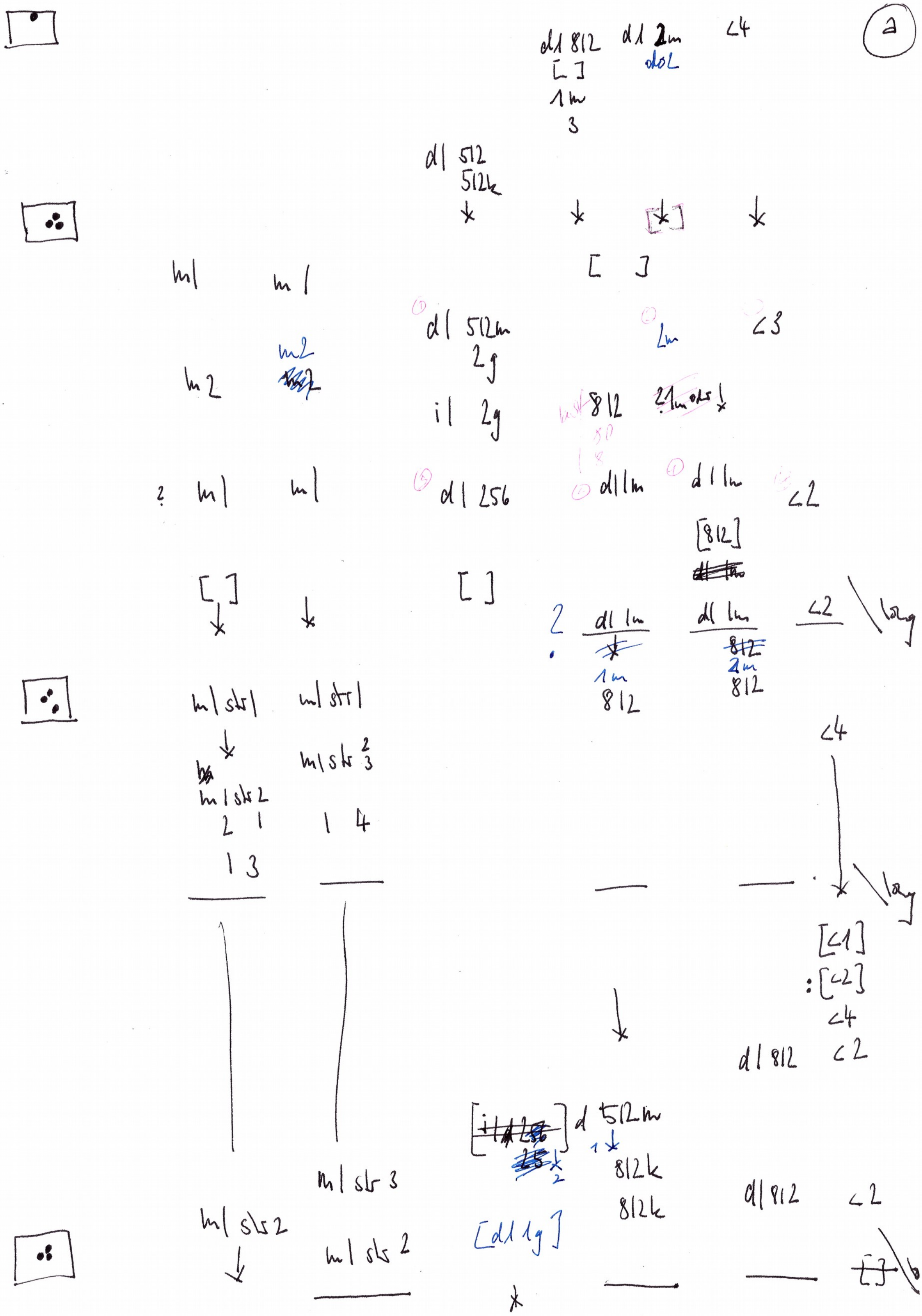
d1 k1

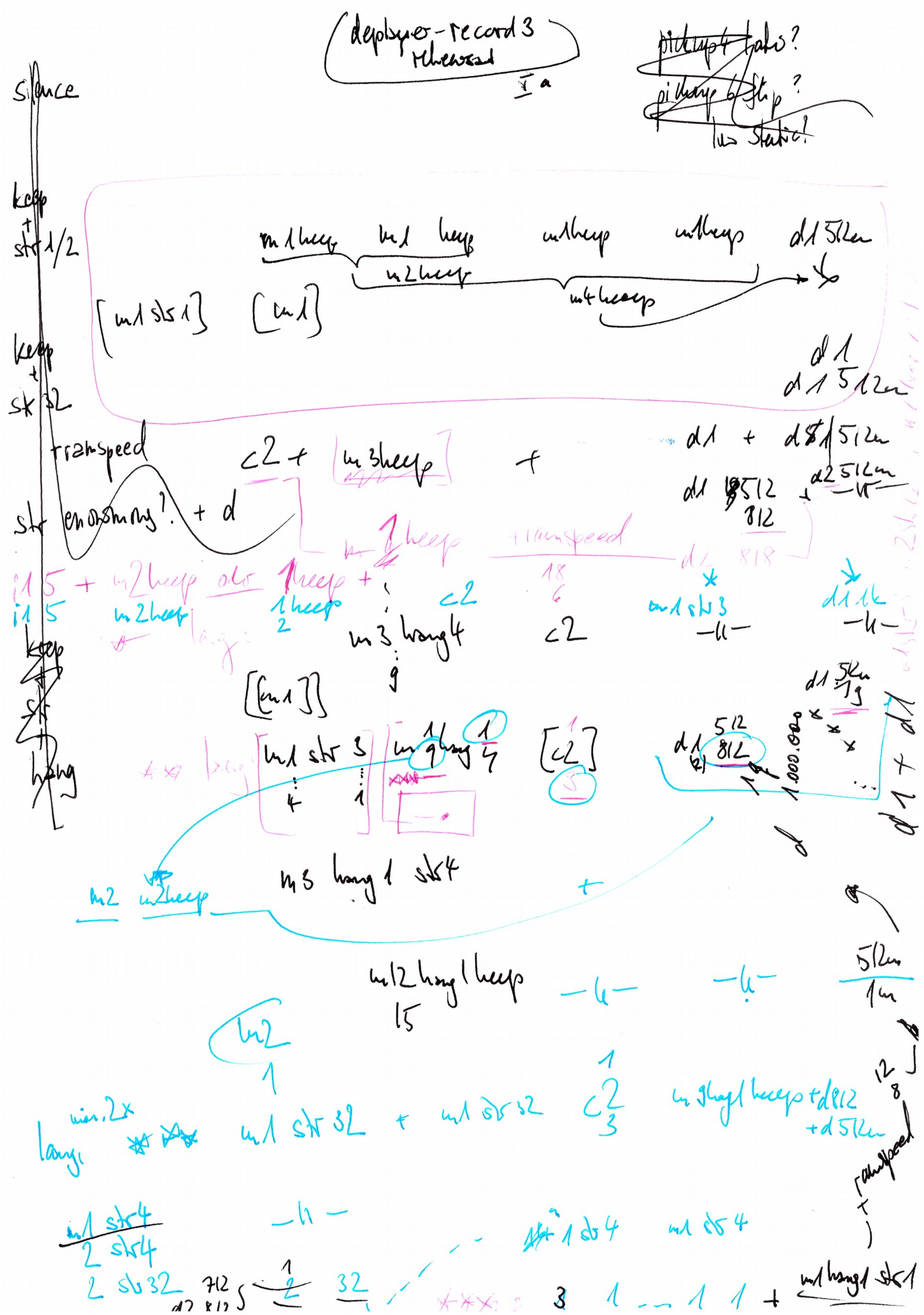
1 m4 d1 1m
m4 8
8 16 24
16

m4 str 32 m4 str 32 ② d2 2m ① i2 1k
2m

4 keep ③ [m1 keep]
2

m8 keep 





deployer-record 3
rehearsal
silence
keep
+
str 1/2
m1 keep
m2 keep
m4 keep
[m1 str 1]
[m1]
d1 512m
keep
+
str 32
transpeed
c2 +
m3 keep
+
str enormously? + d
d1 + d8 512m
m2 keep
1 keep
transpeed
i1 5
m3 hang 4
c2
[[m1]]
m1 str 3
c2
d1 812
1.000.000
m3 hang 1 str4
m2
m2 keep
m12 hang 1 keep
15
512m
1m
m2
m1 str 32
+
m1 str 32
d812
+d 512m
transpeed
m1 str4
2 str4
2 str 32
32
3
m1 hang 1 str 1

(I b)

m1 str 1 m1 str d1 6 6m

m 3 hang 3 str 3 m 3 hang 3 str 3 d1 6 2 m 1 <2

m 1 keep 2 3 <1 2 3 m 2 keep m1 str 4 m1 str 4 d1 6 6m d1 2

m1 keep m1 str 1 distance: i1 / d1 d1 12m 1512m

---

m1 2 3 hang 1 str 1 m 1 2 16 hang 1 m2 [m1 keep] d1 812 512 512m 312m

alone m 12 2 6 hang 1 str 1 9 4 keep [m2 keep <1] + [d1 1m 6]

m1 hang 1 str – 1 1 1 1 1 1 1 1 1 2 1 m 2 2 keep 3 2 m2 i 3 4 1 d1 1k 1 3 + 1 1m

long 12 10.000.000.000

m3 hang 3 str 3 m1 hang1 str1 m 2 3 2 keep m 1 2 3 m1 str 1 d2 10.000.000

---

m3 hang 3 str 3 –n– m2 keep m 1 2 str 1 2 m 1 2 str 1 2 <2

---

m2 keep d 1 2 888 888 8 + ~~m str hang~~. m3 keep hang 1 + str 2224

---

m2 m2 + m1 2 m1 keep m1 keep d2 8.888.888 i5 odo i 1 2 3 + i 1 2 3 d1

d1 12 ✶

---

m 6 2 hang 1 str 4 keep m2 hang 1 str 3 keep m2 keep m1 keep

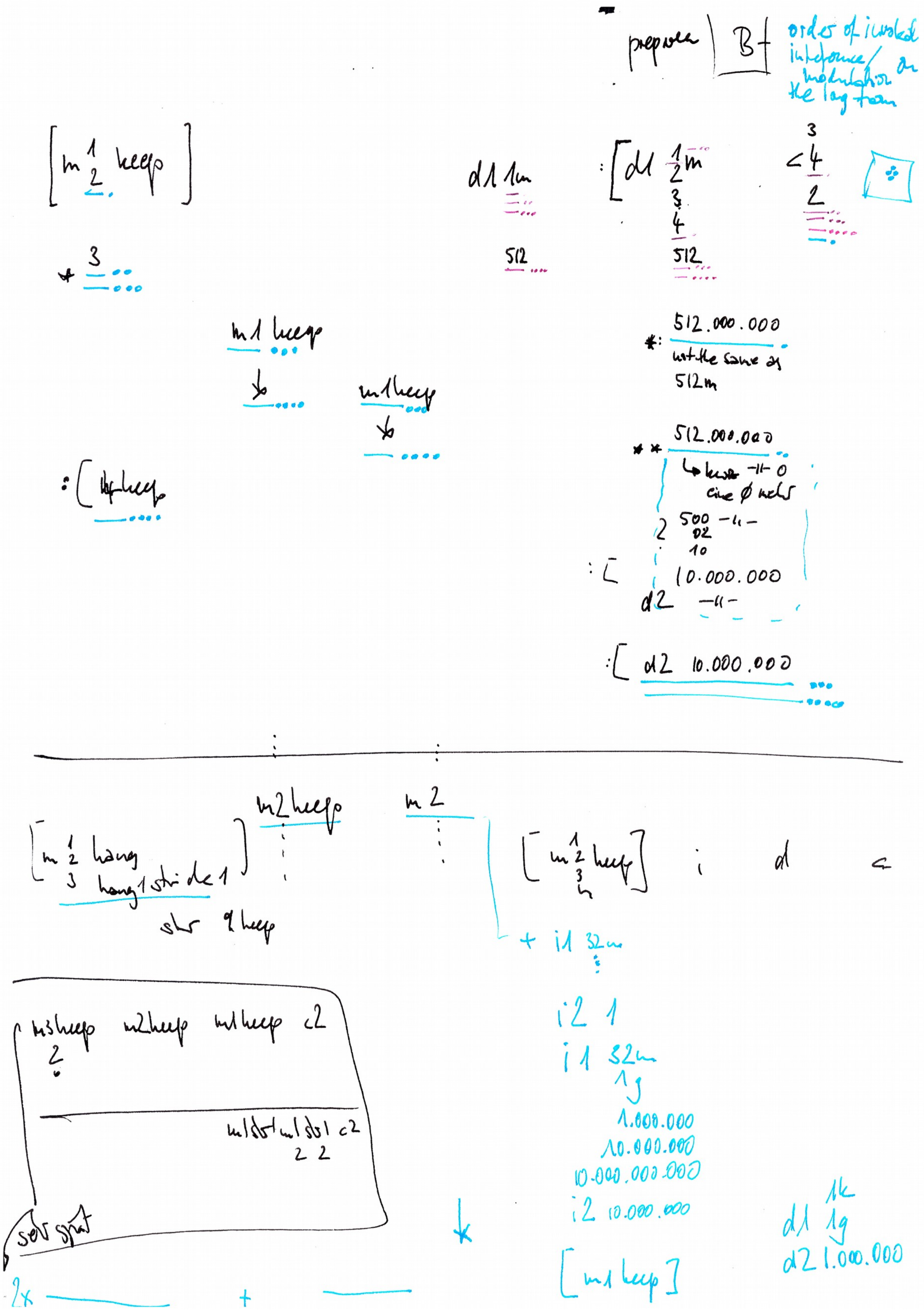
m1 keep m1 keep distance [[m2]]

m1 keep <2 1

m 2 4 <1 str

---

m7 hang 1 str 2224 keep m7 hang 1 str 223 keep m1 keep d1 88 m2 keep


prepare
order of invoked interference/modulation on the log term
m1 keep
d1 1m
512
512.000.000
not the same as 512m
10.000.000
d2 10.000.000
m2 keep
m2
m3 keep
m2 keep
m1 keep
c2
i2 1
i1 32m
1.000.000
10.000.000
10.000.000.000
i2 10.000.000
d1 1g
d2 1.000.000
m1 keep
2x
+

m3 hang3 str1   m2 hang1 str3 keep   m2 hang3   + dist 2m   <4

---

m2   m2 keep   [i1 2k 1m]   d1 812   d1 1g 5Rm

[ ]   [ ]   [m 1 2 2 str 1 2 2]   [<1 2 3]   high power interference

4

(deplayer–record3–rehearsal)   II a

m4 keep   m2 keep   m1 keep   d1 512m

m2 keep   m2 keep   m1 keep

[m1]   [m1 str1]   m1 keep   m1 keep   m1 keep   m1 keep   d1   d1

[m3 keep]   d1 812 / 715 / 512   d1 512m

m1 keep   rampspeed 1&6   m1 keep   d2 818   <2

i1 5   m2 keep

i1 5   m2 keep   m 1/2 keep   m1 str 3   d1 1k   <2

d1 812   d1 512m   <2

[m1]]   m3 hang 4 / 9:

[m1 hang1]   m 1/9 hang 1/4 / 3   [m 1/4 str 3/1]   –"–   –"–   1g   <1 2 3

2+d3 812   d1 512m

m2   m2 keep   m3 hang1 str4   d1 812   <3

m12 / 15 hang1 keep

m 2/1   :[m1 str 32   m9 hang1 keep / ~~m1 str 32~~   –"–   512m   <1 2 3

m1 str 32

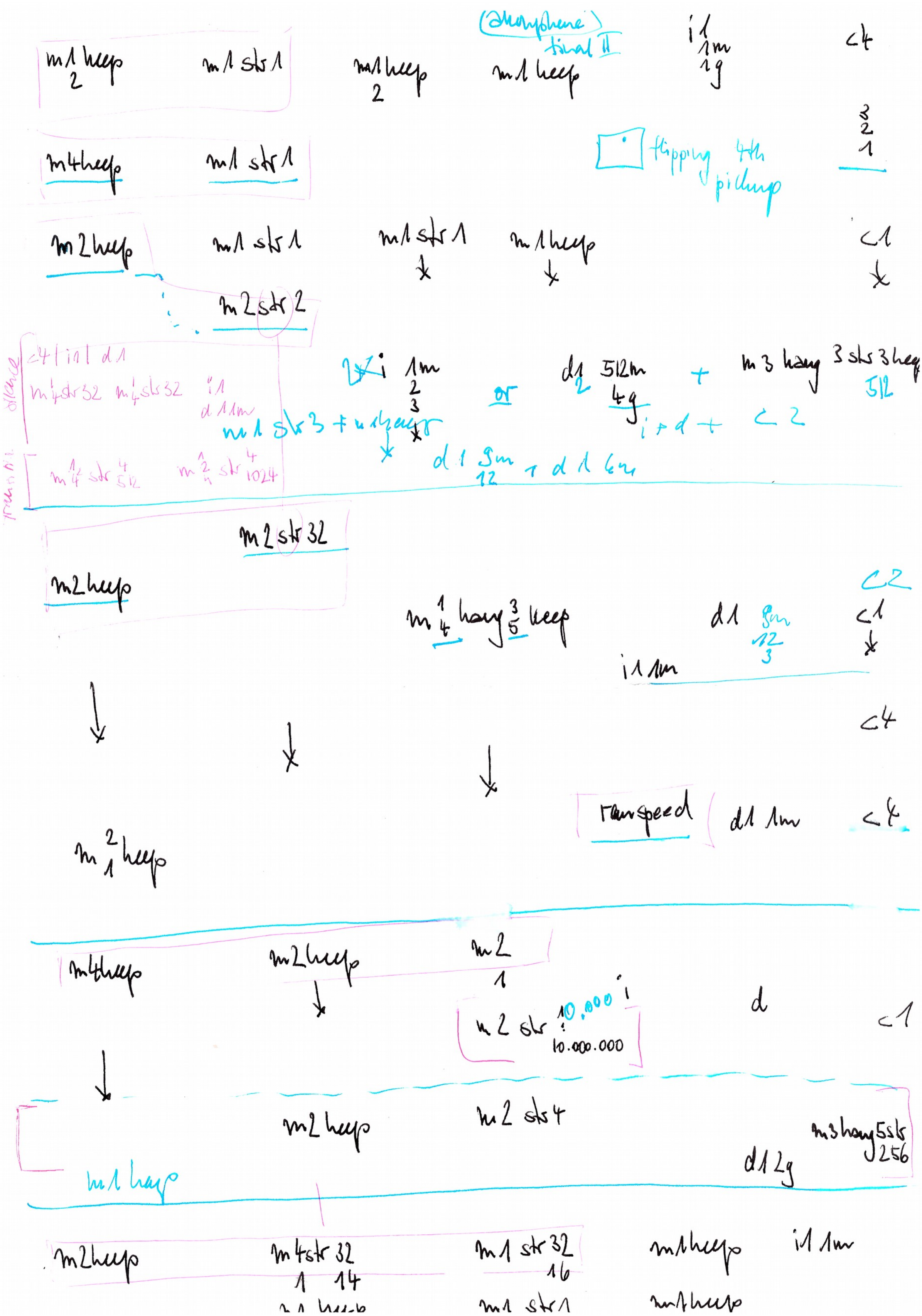
m1 str 4 –   m2 str 32   m1 hang1 str1 – – – –   712 / d2 812

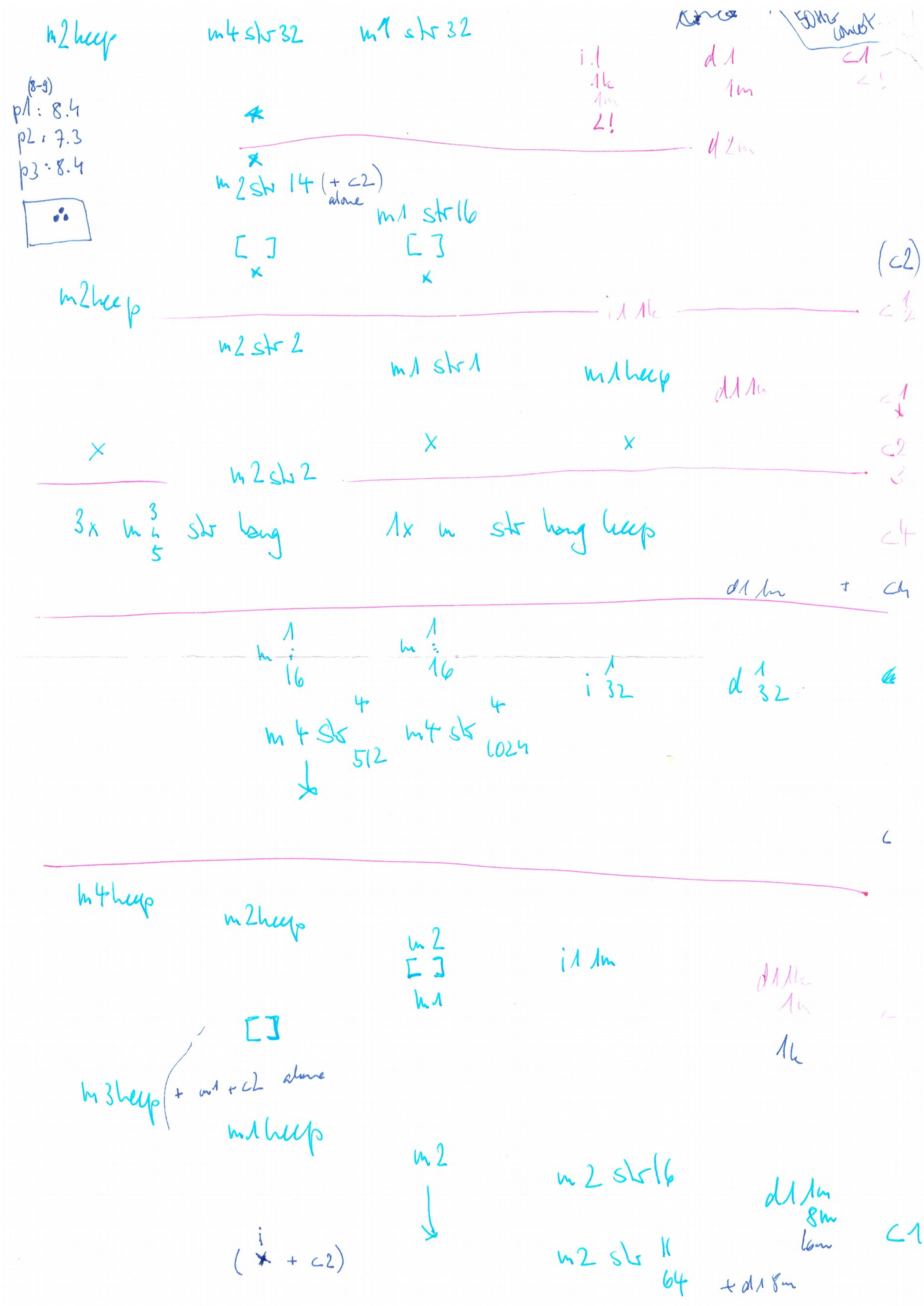
m3 str1   m1 str 1   –"– / 3   str 3   d1   d1 1

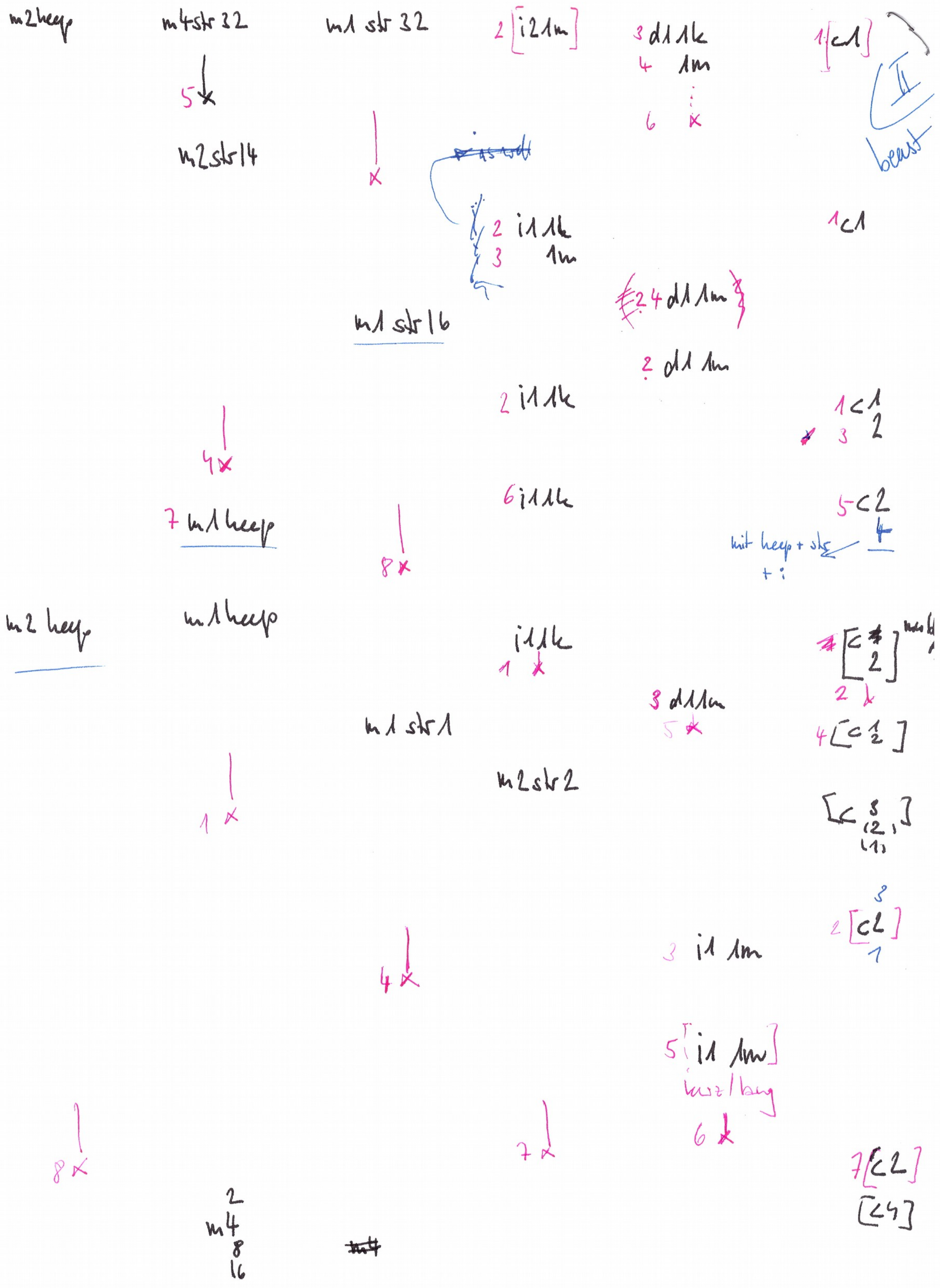
m1 str1   m2 str 4   m 9 hang 1 keep   30min aufnahme

m1 str 3   m2 str 4   m9 hang1 keep   d1   d1 1

m1 keep <2


m1 keep 2
m1 str 1
m1 keep 2
m1 keep
c4
m4 keep
m1 str 1
flipping 4th pickup
m2 keep
m1 str 1
m1 str 1
m1 keep
c1
m2 str 2
or
+
c2
m2 str 32
m2 keep
c2
c1
c4
transpeed
c4
m4 keep
m2 keep
m2
1
d
c1
10.000.000
m2 keep
m2 str 4
m3 hang 5 str 256
m1 hang
m2 keep
m4 str 32
m1 str 32
m1 keep


m2 heep
m4 str 32
m1 str 32
(8-9)
p1: 8.4
p2: 7.3
p3: 8.4
m 2 str 14 (+ c2) alone
m1 str16
(c2)
m2heep
m2 str 2
m1 str1
m1heep
3x m 3 4 5 str long
1x m str long heep
m 4 str 4 512
m4 str 4 1024
m4heep
m2heep
m2
m1
i1 1m
m3heep (+ m1 + c2 alone
m1heep
m2
m 2 str16
m2 str 16 64
d1 1m
8m
16m
c1
+ d1 8m
(* + c2)


m2heep
m4str32
m1 str 32
i21m
d11k
1m
c1
m2str4
i11k
1m
d11m
m1 str16
m1heep
mit heep + str
m2 heep
m1heep
m1 str1
m2str2
i1 1m
kurz/lang

m 2 3 4 … 8 14 | m4 stride 1 2 : 16 512 | m2 stride 512 keep

rhythmisch · 9 · 10.000 · sphärisch

1024
512 + [m2 stride 512 keep] + [i2 bytes 512] +c1

[m 2 4 str 2 8 16 64] [i1] [d1 b32 …]

schnell

m 4 8 16 stride 512 1024 hang m24 d1 bytes 32 2 512 i1 c 1 2 3 4

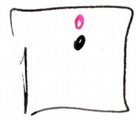
m 4 stride 1024 hang1 + [i 1 2 4 6 8] c 4

langsam

m4 stride 32 + schwierig: alle gleichzeitig + m1 keep + m1 3 keep + ramspeed -g8 -l3 -b3 mb

– 4 – + ramspeed

ruhig lebendig ramspeed



c4

m7 d1 bytes 512 + m1 keep + m1 2 : 2 keep + m1 keep

+ y-cruncher + c 2 3 4 : 2

m12 stride4 hang4