38Hz., 7.5 Minutes

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In this paper I recount a series of experiences with the anomalous behavior of a vibrating steel plate and reflect upon what it suggests about my understanding of materials. I hesitate to call these experiences "experiments" as they aspire to and achieve little of the control that scientific experiments require. In addition, I do not begin with a hypothesis and collect evidence. I do not intend to add to a collective body of knowledge, but rather, to wear away at what I "know" in order to become more open to potential and possibility. So, I do not approach this activity as either a scientist seeking to uncover the nature of things or as an artist seeking to produce or express anything of significance to the culture, but as a designer whose interest is less in achieving the pragmatic or instrumental than finding the epistemic implications of the work.

Listening to the Inaudible

This project grew out of interest in sensory substitution, and speculations that it may be possible to use these same principles to open the human sensorium to additional phenomena such as magnetic fields by means of prosthetic interfaces (Krueger 2007). The attempt to build such devices is grounded in the frameworks developed as alternatives to the information-based cognitivist or computationalist perspectives that have dominated studies of cognition and perception (Krueger 2006). Variously referred to as skill-based, enactive, or embodied, some theories of cognition acknowledge the active role of the agent in the activity of perception and the active role of the environment in cognition.

While the devices in my earlier work involved magnetic fields, my interest is wider than one specific class of sensors; my effort is to gain a better understanding of both the abilities and limitations of perception.

In order to explore the subaural phenomenon of infrasound, I began to build a very large-scale subwoofer by attaching a voice coil-type tactile transducer to a variety of materials in a range of sizes and geometries and driving them through a distribution of frequencies. This 'build and test' approach was used because there is very little information available about building speakers that cannot be heard. The range of human hearing is typically considered to be 20 to 20,000 cycles per second; why would you build an inaudible speaker? There would seem to be limited commercial value.

This supposes that the perceivable is limited to the range given. But my experiences have shown me that this is far from the case. The infrasonic is not silent, but rather the frequencies below the range of hearing are simply perceivable by some (perhaps several) other means; the qualitative difference between those that can be heard and those that cannot is subtle. Evelyn Glennie, often considered one of the best solo percussionists in the world, is deaf, but shows no inability in perceiving the playing of the musicians that accompany her.

All of my efforts to build a monster subwoofer were failures, although the modes of failure varied. Hot-rolled mill-finished steel plate suspended in a testing rig produced a wide range of frequencies, many of which were in the audible range, complicating and obscuring those that were not. The steel was a completely inappropriate substrate for producing infrasound, but it sure sounded interesting.

The work in infrasound took another direction, towards building tuned chambers as Helmholtz resonators driven by a subwoofer. This was a much more successful approach and resulted in the practice of working in a room within the selected frequency for extended periods of time. Many claims have

been made about the effects of infrasound from their development as military weapons to the (probably false) alleged ability of certain frequencies to induce a loss of bowel control. The periods of extended listening were an attempt to become aware of some of the physiological, cognitive or emotional effects of infrasound that may not be initially apparent.

This manner of working was influenced to a large extent by my experience of the work of La Monte Young and Marian Zazeela as installed at the Dream House in New York. [1] Young's sound installation, *The Base 9:7:4 Symmetry in Prime Time When Centered above and below The Lowest Term Primes in The Range 288 to 224 with The Addition of 279 and 261 in Which The Half of The Symmetric Division Mapped above and Including 288 Consists of The Powers of 2 Multiplied by The Primes within The Ranges of 144 to 128, 72 to 64 and 36 to 32 Which Are Symmetrical to Those Primes in Lowest Terms in The Half of The Symmetric Division Mapped below and Including 224 within The Ranges 126 to 112, 63 to 56 and 31.5 to 28 with The Addition of 119,* is a single, albeit extremely complex, tone that has been played continuously for almost twenty years. I have experienced this work on numerous occasions in sessions that have lasted up to four and a half hours. I have written about this experience in a paper called "This is Not Entertainment: Experiencing the Dream House" (Krueger 2008). In addition, I have learned a great deal from my colleague Pauline Oliveros and her practice of *Deep Listening*. [2] I had on several occasions attempted to audit her course on Deep Listening, but my administrative duties kept me from regular attendance. Still, I experienced enough to come away with a deep respect for this composer's practice and to understand that the focused and sustained attention directed to sound could open possibilities I had not imagined. My experiences with extended listening did not always remain acute and focused but varied from the intense and directed to benign neglect and complete boredom.

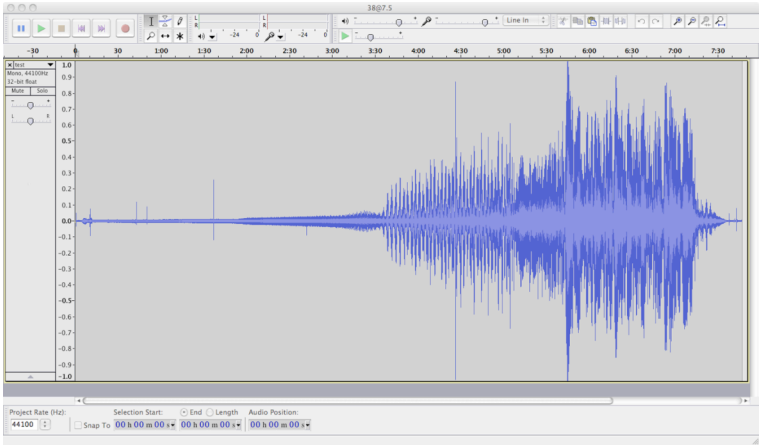
This strategy of extended listening was also used in the work with steel plates that I was undertaking simultaneously. I applied a selected frequency at constant amplitude to the plates for runs lasting up to nine hours. In contrast to the uniformity and predictability of the Helmholtz resonators, strange and

unexpected things happened to the plates. I had a simple steel plate with simple perturbations and from it I expected a simple result. I was educated about vibrational modes using illustrations of the classic Chladni patterns [3] and expected vibration to be coherent, predictable, and beautiful. This was not to be.

The physical setup for this work consisted of a stand made of two fiberboard open boxes separated by slotted steel angle posts. The steel plate was suspended from the upper box by a variety of methods, typically a chain of steel hooks running from an eyebolt in the upper box to a drilled hole in the plate. Neoprene tie-down straps such as those that hold tarpaulins in place on trailers, bent threaded rods, or recently, much more elaborate offset and counterbalanced methods have also been employed. The signal is supplied by a frequency generator, amplifier and associated power supply located in an adjacent shelving unit.

Phases

The first novel behavior I noticed was the development of a sequence of distinct and increasingly energetic phases proceeding from a barely audible hum to the convulsive shaking of sound-effects thunder. The plate contains a broad spectrum of frequencies that cancel and reinforce in complex ways. My sense was that there was a capacitance for frequencies within the plate, some kind of storage mechanism that would build up enough energy in a certain frequency to shift the plate into the new vibrational mode. In the sound file *38hz, 7.5 minutes* these transitions can be heard at 1:50, 3:35, 5:08, and 5:43 and can be visually identified on the amplitude plot in illustration 1.



The first phase is the quietest, with a gradual increase in amplitude; the tone is steady and at this point one is tempted to say that little is happening. That begins to shift in the next phase when the amplitude generally increases and there is a distinct pulsing, although the amplitude decreases and the pluses stretch just before the third phase begins. The third proceeds in a series of crescendo hums that last about three seconds. They are initially distinct and cohesive but begin to fracture into sets of shorter pulses. These shorter pulses cohere into a driving rhythmic structure in the fourth phase that erupts in the fifth into energetic and chaotic activity.

If I examine the first phase, in which little appears to happen, I can detect an increase in a higher frequency just before the phase ends. I can hear this by listening in close succession to two segments separated in the original recording by several seconds (this can be heard in sound file ComparisonA.mp3). It may be that the expression of this frequency gives some clue as to the state of the plate as it shifts towards or into another phase. Other changes can be found through a similar process of inspection or comparison, but for me, this additional examination has yielded only a more fine-grained level of description. This descriptive activity can be continued, perhaps infinitely, but there is no implication of causality in any of the shifts that I have observed. I had what I thought was a very simple condition—a suspended steel plate perturbed by a simple and stable frequency at constant amplitude—but the results varied greatly. The apparent organization or structure of its behavior at a variety of scales surprised me.

Anti-sound

I have a rather limited budget for my research activity and have obtained equipment from online auctions, yard sales, and discount houses. From time-to-time some of the equipment that I've used has stopped functioning; these things happen. When the sound of a vibrating plate that I'd listened to for a long time suddenly stopped, I assumed that I'd "burned-up" yet another amplifier and went over to turn off the apparatus. But I was surprised to discover first that the equipment continued to function, and then to see that the plate continued to move, but now emitted (almost) silence instead. The plate produced its own anti-sound, perhaps.

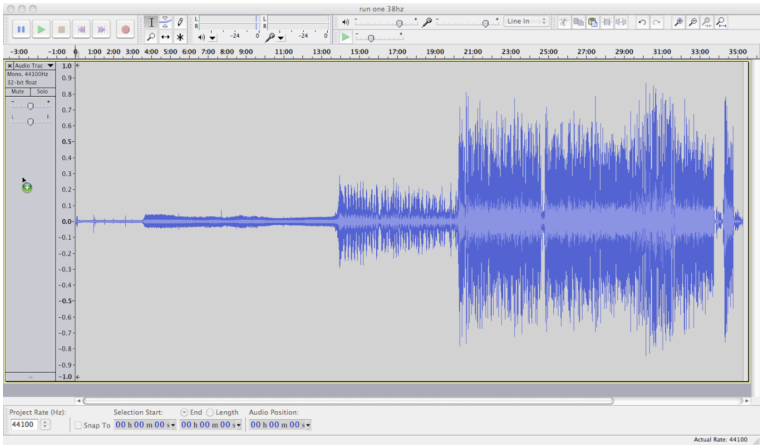
An example of this can be found between times 24:36 and 24:49 on the file *38hz, 35 minutes* (dropout.mp3). While certainly surprising the first time it occurred, it was not a rare event. Similar episodic reductions in volume can be found on the same sound file between 16:01 and 16:07 and from 20:34 to 20:37. It seems odd in retrospect that while I had become accustomed to the idea that a variety of

different sounds could result from a simple input to a suspended plate, I hadn't considered that "no sound" could be one of the options. Typically, the sound returned spontaneously after several seconds.

Residual Effects

One evening, I had listened to a long sequence of phases that culminated in one that was loud, chaotic and apparently long-lived. I thought it less interesting than the sequence that preceded it. These had been varied with a fascinating polyrhythm. I decided to make a recording of the sequence produced by that particular frequency and amplitude combination before moving on to explore the behaviors at others. I turned off the apparatus, damped the plate and the support frame, and after configuring the microphones and software, I began again. But the behavior of the plate did not begin again. Instead, it continued from its most recent phase: loud, chaotic and apparently stable. It was as if it 'remembered' in what state it had been and picked up about where it left off.

On the recording *38hz, 35 minutes*, I demonstrate this at time 33:43 (damping and return.mp3). There is a short startup phase that lasts about three seconds, then another ten seconds of chaotic behavior before settling into to a structure that is remarkably similar to what was evident before damping the plate.



There is some residue. Perhaps this is akin to what Rupert Sheldrake, the heterodox biochemist, called morphic resonance (Sheldrake 1988). Some may consider it a form of memory physically instantiated within the material, at least seemingly for a time. Personally, I prefer to avoid the term memory because of the cultural baggage it carries; it is difficult to know if this will be helpful. [4] However, the presence of this residual disposition makes me wonder if there is any initial start that I can consider to be an "uncontaminated" origin. If the plate is vibrating at a certain frequency and another is introduced, the two frequencies interact and through reinforcement and cancellation produce a whole new range of effects. I have had the sense that when the plate is hanging quietly and I turn on the amplifier and frequency generator that I am starting anew. But if the plate has been vibrating vigorously and recently, as in the example above, this is clearly not the case. When I begin again with a new frequency, are the results that I obtain due to the frequency and time that I used on the plate the day before? Perhaps my activities over the course of several years with this plate have long-term residual effects. I assume that the steel plate is the same as when I first started, but the residual effect calls this assumption into question. Is this residual effect restricted to the domain of steel plates vibrating in basement workshops, or is it of wider applicability? In other domains, I am completely comfortable with the properties of steel retaining effects from its history: the blade of a knife can be tempered and the edge hardened in the course of its making; a shape memory alloy's shape can be recorded and erased with temperature; distorting a metal may cause work hardening and accompanying brittleness. Perhaps there is never starting anew, no tabula rasa. We are always entirely enmeshed in residual effects. There may only be residual effects.

Space

It was about the same time as I was discovering these strange behaviors that I noticed another. While not all frequencies result in interesting behavior, I had also learned that some just take a long time to develop. I may be entertained or I may be bored. It's not easy to predict when a shift in behavior is about to occur. The plate hangs in the middle of the room and next to it sits a massive steel

welder's table where I often work while the plate vibrates in the background. Frequently after a long passage of identical behavior, I noticed that the sound of the plate would change exactly when I was about to leave the room. Furthermore, if I returned to the worktable, it would return to its old routine. Convinced that its behavior had stabilized once again, I would head for the door, and again the sound would shift just as I got to it. If I remained at the table, I noticed that this did not occur when others left the room and so, the explanation became clear. The small vestibule-like space formed by a shelving unit had unique acoustic properties and I was mistaking my change in position for a change in the plate.

My workspace in the basement of the Greene Building was once a classroom. I often use the space for seminars if the class size is small. It has windows spaced high in the walls looking out at ground level. It has steam heat and maple floors. Both my graduate students and seminar participants complained of a moldy smell from time to time; some said that it made them ill. At my request, the university's maintenance personnel came on several occasions with their sophisticated air quality sampling gear to check on the source of the complaints, but assured me that there was nothing amiss. Then one day the floors buckled severely due to the continued leaking in the steam pipes that ran below the floors. This required the complete removal of the contents of the room and the replacement of the floor with concrete. The moldy smell has disappeared. Gone too are many of the complex behaviors that I had recorded earlier.

It is far from certain what aspects or conditions of the prior configuration may have played a role. The lower fiberboard box on which the apparatus rested may have coupled to the wooden floor, creating below the floor a resonant chamber much like the body of a musical instrument. The scale of that chamber isn't known. The steam pipes run in a crawl space beneath the entire building and continue on to others; perhaps it was only the reflection of the sound from the floor back onto the plate that influenced the behavior, or the occupant's movements on the floor itself. Maybe the new effect is not due to what the floor did, but what the concrete does.

The change in behavior may not have had to do with the floor. I was traveling when the floor was replaced and could not supervise the removal of the contents of my workspace. A signal generator was damaged in the interim and while replaced with a similar device, the new one operates on transistors and the old on vacuum tubes. I may not have reassembled the set-up in quite the same way; I was not able to photograph the apparatus before it was taken apart. Perhaps the hanging mechanisms are not isolating, but couple in specific ways that in part determine the behavior of the system. There are as many explanations for the change as there are hypotheses about how the system might operate. But what can be learned from this sequence of events is not more detail about the operation of the system, but a new understanding of its scope. The system could not be circumscribed as closely as I had previously thought. It certainly is not a simple suspended plate with a simple perturbation. Its interest and its behavior come from its connectedness.

Regarding the Material

In *A Progress Note on Research into a Cybernetic Analogue of Fabric,* Stafford Beer, a cybernetician of management, reviewed an astonishing series of investigations into control mechanisms for highly dimensional complex systems (Beer 1994). He was doubtful that computational techniques could be crafted that would contain the requisite variety (Ashby 1958), so rather than designing a control system he attempted to take an existing self-organized system of high variety and constrain it. He worked on what he called "fungoid" or chemical systems inspired by Paskian colloidal cells (Pask 1961). He devised a game to be played by children to solve simultaneous linear equations as well as a physical network to be occupied by pigeons or rats, and he considered the activity of social insects. He experimented with fresh-water crustaceans by inducing them to ingest iron filings and then subjected them to environmental variables transduced into electromagnetic fields. He worked with populations of protozoa and eventually the ecology of a pond.

While Beer's work with these systems was typically not successful, his observations of his own experiences as an experimenter are of interest here. He notes:

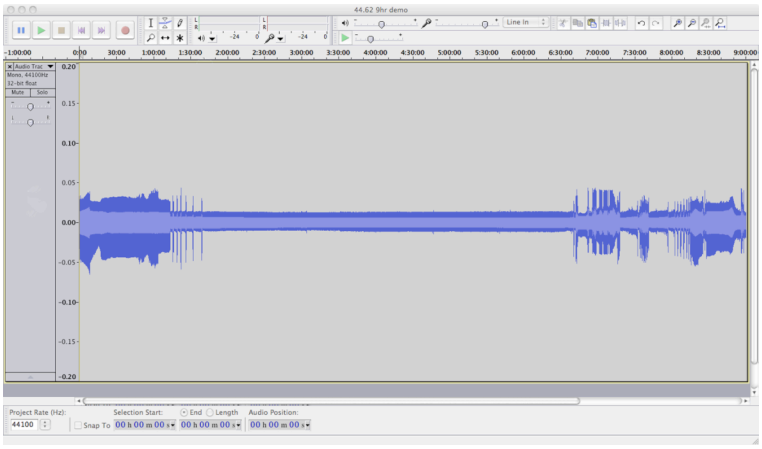
> Our scientific training, modified as it may be by years of experience in cybernetics, pushes us always towards attempts at analysis. I tell myself repeatedly that this thing is a black box in whose transfer functions I am not interested. Yet I repeatedly try to isolate experimental effects (…). I do not want to do this, but I do it. The reason is, of course, that although one can see experimental techniques for handling the total system and measuring its behavior, the results defy the kinds of interpretation at our disposal (Beer 1994: 31).

Similarly, considering the exotic behavior exhibited by the vibration of the plate, it is tempting to make explanations. Models come to mind. When the plate shifts from one mode of response to another, I am reminded of the basins of attraction from the mathematics of chaos. Perhaps some shift at the molecular level accounts for the residual disposition effect, something akin to a change in temperature. Can a build-up and transfer of energy from the plate to the environment and back again be accounted for by the theory of coupled oscillators? Each of these might be investigated further; however, it might also be that the value of these behaviors lies not in the "finger" of physics, but what it is "pointing at" in epistemology.

If I frame the consideration of the plate in terms of an input to a physical system and its consequently surprising behavior, I look for explanations of the behavior within the realm of physics. But if I choose the frame differently, I consider the system to be a black box to which the input is frequency, amplitude and expectation and the output is surprise. Now in that case, I would look to the understanding that I bring to the situation and the understanding that I take away.

The activity of the plates opened up several insights for me. One is the way in which the system under observation extends spatially as noted above. Another is the way in which the temporal framing of an investigation circumscribes what

will be found. For example, I began recording the plate one morning, but was called away unexpectedly. This frequency/amplitude pair did not result in the phasing sequence that is seen in the other recordings noted here. It was recorded after the change of floor and its behavior is more typical of what occurs now. In this case, the activity was most vigorous at the beginning, but after a time the plate settled down into a steady hum. It is as if it takes a while for all parts of the plate to become organized to vibrate in unison, that the plate sheds its complex modes of vibration and falls into a behavioral basin of attraction. Sometimes this happens, and when it does, my experience has been that it doesn't change. If I had been in the room I would have turned it off long ago, but on that day I could not return for nine hours. What can be seen on the amplitude plot (9hr run.jpg) is that the plate gradually settles down to a steady state after 1:39:38. Nothing happens for five hours. Then, at 6:40:34 the behavior changes. In the sound file 9hr selections.mp3 I have recorded a short segment of the stable state in which the plates activity resided for about five hours. Appended to that is the transition from that state to the more active phase that follows and a portion of that more dynamic phase. [5]



This spontaneous action is not unique to vibrating plates. Richard Brown's Electrochemical Glass of 1998 is an experiment trapping between glass plates galvanically active metals within an electrolyte. Eight years after it was constructed a new and dramatic dendritic growth appeared over the course of several months (Glanville and Müller 2008: 30).

Things happen in their own time, and the temporal framing of our observations may preclude our experiencing them and thereby circumscribe our understanding. It may be that many things are not apprehended because there is too little cultural value placed on patience. Even with all my experiences with the plate, in fact because of them, I would have turned this recording off to look for more "interesting" things.

Another thing I learned has directly to do with "interesting" things. I liked the interesting and unexpected behavior and the way that it illuminated errors or inadequacies in my tacit understandings. I have come to appreciate the way in which these occurrences seemed to open up possibilities where before there had been standard answers. Perhaps this is simply extending Ranulph Glanville's notion of "generosity to the world at large", to what we take to be material substance. It may be that we are too concerned with conquering the chaos, with hammering it into the frameworks that we know as understanding. We can explain this. Or instead, we can listen to it; perhaps there's more it can say. The research that I undertake does not grow out of an intuition about the answer, but from an intuition that I can undertake activities in such a way as to raise questions. Perhaps this is what links it to design thinking. Design is more often involved in question than answer finding; perhaps for some, more concerned with listening than speaking.

But the repeated unexpectedness of the behavior of the plate suggests that there is something more fundamental at stake here. Much progress has been made on the task of reproducing sound accurately and many audio speakers work very well. Contemporary loudspeakers satisfy all but the most discerning. However, one has only to listen to an early recording played back on its original equipment to truly appreciate its original state of development. It is easy to forget that the quest for a faithful audio reproduction has been major challenge over the last century. Hence we mistakenly assume that the material is merely a docile reproducer of an audio signal.

A tacit assumption that underlies the unexpectedness of the activity of the plate that has been found during these observations is the primacy of information and the assumed passivity of the material. In this, it recalls the assumption of substrate independence in both studies of artificial intelligence and artificial life. Tom Ray's *Tierra* is regarded by some to actually *be* a living system, instantiated in silicon rather than in organic compounds. Another example might be Doug Lenat's *CYC,* which attempted to ground an intelligent system by the brute force incorporation of "all" human knowledge. And unfortunately, much contemporary work within my own discipline of architecture is trapped in an understanding that retains a significant conceptual debt to the primacy of information over the material. This tradition is a long one in western culture, but one that is losing its vigor.

A second assumption is that of a linear causality, that is, that the signal will cause and control the behavior. It does not. A signal applied to the steel is not the driver of this activity. In fact, it was the response of the steel—inappropriate to the immediate task of infrasound, the "but it sure sounded interesting"—that began it all and that motivated the continuation of this work. So from another perspective, it is entirely valid to see the output as the causal agent, should one choose to do so. However, to substitute one causal vector for another is to entirely miss the point.

I often assign a chapter of Oyama's *Ontogeny of Information* to my students. "The ghosts in the ghost-in-the-machine machine" is valuable as an example of an argument critical not only of factual content and the philosophical frameworks used to determine and structure these facts, but of the similar oppositional structure that can be found across many theories of development. As a leading proponent of Developmental Systems Theory, Oyama is critical of descriptions that parcel responsibility for an organism's development to either genetics or environment or even to some combination of them. She ties an extremely wide range of theories together by showing a fundamental similarity within their assumptions about the nature of causality. Tied together in this way, a disparate group of theoretical positions can be seen not only to share this common

structure, but also thereby to share similar problems when matters of explanation confront them. Oyama is able to show that approaches that make use of this oppositional structure encounter similar impasses in accounting for the developmental sequence of organisms. In this case, a common shape or structure of the framework, rather than its explicit details, circumscribes its utility. Having understood this, it is possible to examine similar structures in other domains in this light and perhaps to find equivalent opportunities for a new understanding.

A significant portion of the unexpectedness of the activity of the plate detailed here is due to the way in which the set-up is framed. When I describe this physical configuration as a steel plate activated by an amplified signal I have already placed the material in a passive and neutral role and "information" in an active one. If conceptually I understand the system as a signal source, wires, a transducer and a sound-producing surface, I have recreated exactly the structure of the perceptual system models that I have rejected in my research on prosthetics. For example, the signal source can be considered equivalent to the eye, the wires to the optic nerve, the transducer to the visual cortex and the steel plate to the body, all contained within a workspace. The correspondence is striking; the structure of these models is identical and so is their assumptions and functioning. In one we find that the perceiving organism is a passive vessel within and through which the agency of information operates, and in the other, the material is expected to respond to the applied signal, to co-vary with it, but not to take an active role. This relationship between the body and the material is not due to similarities between bodies and materials – though there may be some. This relationship is entirely a function of the similar structures of the models used to describe the two situations and by the assumptions about the operation of agency within them. So then this is not an attempt to attribute biological properties to the material, but it is to point out that something akin to a developmental and dynamical systems perspectives could be more appropriate than a computationalist view in the effort to understand how material systems participate within the behaviors that were observed.

Notes

[1] I first encountered this amazing installation at the suggestion of and in the company of Ranulph Glanville who had been familiar with the work for a period of years. It's at 275 Church Street. You should go there.

[2] Additional information on Deep Listening as a practice can be obtained from the Deep Listening Institute (deeplistening.org).

[3] Ernst Chladni was an 18th century physicist, musician and musical instrument inventor who demonstrated the vibrational modes of horizontal plates. Sand on the surface of the plate collects in nodes as the plate reaches its resonant frequencies and the resulting patterns can be seen.

[4] It may indeed be that this phenomenon is like memory. Or, it may be that memory is like this phenomena. But, these are not necessarily equivalent statements.

[5] The files have been played back at triple speed. So it takes less time, and so it sounds "better". What is important here, however, not my preferences for the sound quality, but that there are differences across these phases. Perhaps also of interest is that no amount of description by a writer of my ability will make clear the changes as well as listening directly to them.

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