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Wildly Oscillating Molecules: Technological mediation of the atomic force microscope

ABSTRACT

The human sensory experience of submolecular phenomena is only possible through complex technological mediations that include not just magnifications, but also manipulations of time and translations from one sense to another. In my creative moving image project Wildly Oscillating Molecules, *I develop strategies for using an atomic force microscope (AFM) as a cinematographic instrument, specifically using its tactile mechanisms to generate video. Using the AFM over four years to generate experimental moving image installations, I examine my physical and psychological experiences of this nanoscientific instrumentation. Although referred to by the philosopher of technology Don Ihde, the AFM's style of technological mediation has not been subjectively explored. Working to engage with an infinitesimal scale, the AFM has a unique style of spatial and temporal mediation that can be manipulated through the post-production and exhibition practices of the moving image.* Wildly Oscillating Molecules *provides insight into how the AFM influences human spatial and temporal perception of nanoscale phenomena and provides a new framework with which to analyse nanoscientific imaging practices. Understanding the nuances of technological mediation encourages science artists working with submolecular phenomena to adopt, evolve or transform properties of technological mediation when presenting their work to an audience.*

KEYWORDS

nanoart
art science
moving image
technological mediation
submolecular perception
tactile microscopy

1. Phenomenology refers generally to our subjective experience of the world whereas *post*phenomenology refers to the state of incorporating technology into our phenomenological schemas, as is commonplace today in everyday use of phones and computers. Simply put, postphenomenology is the philosophy of technological mediation.

2. A camera-stabilization system mounted directly on the camera operator's body.

INTRODUCTION

Working with the atomic force microscope (AFM), I have been keenly aware of the lack of bodily connection to the nanoscale samples and have sought to use my creative work to physically connect to nanoscale phenomena in some way. Compared with my previous work with microscopy and cinematography, where I had a sense of real-time feedback through the technology that I was using, the lack of connected, sensorial mediation jarred in my creative interactions with the AFM. If only the technology would 'get out of the way', the phenomena might be available to the human sensory system in real time. This is an intrinsically human drive – we humans want to use our sense organs and experience to understand the world around us (Ihde 1998). The submolecular physical scale means that we must use complex mechanical and algorithmic technologies to enable interactions with nanoscale phenomena. The visualization technologies that we use are distancing technologies, in that they physically and temporally fall between humans and nanoscale phenomena. However, they also bring us perceptually in contact with those phenomena by creating an observable experience, when without technology humans would be unable to perceive them at all.

Theories of technological embodiment show how different technologies mediate our experience of the world and how we embody those technologies into our perceptual experience with varying degrees of transparency. I draw on concepts of technological mediation and technological embodiment from postphenomenologists Don Ihde, Helena De Preester and Robert Rosenberger, to frame the nature of the relationship between nanoscale phenomena and human users of the AFM.[1] Through working directly with the AFM, I identified three characteristics of the instrumental system that influenced my phenomenological experience of the nanoscale, and subsequently have informed the creation of the moving image works in the *Wildly Oscillating Molecules* project: first, the body in space – the real-scale relationship between the user and the AFM, second, the interpretive and translational nature of the AFM and third, temporal mediation and the absence of real-time feedback.

TECHNOLOGICAL MEDIATION AND TECHNOLOGICAL EMBODIMENT

Our experience of technology takes a multitude of forms, and technological embodiment describes one particularly close, transparent form of interaction with technology. One way of framing this experience is to think of technology physically or cognitively extending humans (Brey 2000; Lawson 2010; McLuhan 2013; Rothenberg 1993). For example, as a cinematographer I feel 'as one with' the camera both, phenomenologically and physically. The camera is an extension of the perceptual act of sight and of the cinematographer's body as they move through space together – this spatial aspect being most pronounced in handheld cinematography and Steadicam operation.[2] In this case, the camera is encountered as an extension and the operator embodies it.

Ihde provides a detailed account of technological embodiment that will help to interrogate the nature of the relationship between an AFM operator and nanoscale phenomena. In this section I explore four of Ihde's concepts that have informed my thinking and shifted the way in which I relate to the AFM as a creative instrument in my moving image practice. Ihde's concept of 'embodied technology' reflects my previous experience of human-microscope assemblages and camera operation, 'analogue mediation' and 'translation mediation' distinguish the AFM from light microscopes and 'hermeneutic mediation' most accurately describes the interpretive and translational nature of AFM mediation.

In addition to these four concepts, Ihde has described an amplification-reduction pattern that occurs in all technological mediations. Every mediated amplification of phenomena is accompanied by a reduction of the senses (Ihde 2012). For example, looking through a microscope brings otherwise invisible cells into view, and yet the viewer is simultaneously blinkered to human-scale visual input. In these instances, we experience 'otherness through the machine, but that the experience through the machine transforms or stands in contrast to [our] ordinary experience in the "flesh"' (Ihde 1979: 9).

Sometime in 2016, I wrote of my experience working with confocal microscopes:

> A mirage of fluorescent colour swims into focus. I am in a dark, quiet, cold room staring down the barrel of a confocal microscope. This microscope fires lasers at biological samples that have been selectively stained with fluorescent molecules in order to visualise their cells and proteins. I am looking at a mouse retina that, when visualised with this type of microscope, appears coloured with bright green, blue, orange and pink. But under my gaze, the image begins to fade… the lasers are quickly dulling the fluorescent molecules.
>
> This is, and by design must be, an ephemeral viewing experience. On a good day, I will have had the time to shift from the microscope to the computer screen and capture some focussed images. On a bad day, I will glimpse the perfect image only to have it fade away in front of my eyes before I can capture it. Sometimes, the beauty of what I see down the microscope holds me there too long, considering the wonder of gazing upon a retina – looking through my eyes, my glasses and the microscope's optical lenses at the anatomical organ of sight. And in that moment what I sense, in my dark sensorium, blinkered and removed from the visual and aural stimuli that normally surround me, is a sensation of the surface of this tissue. On a computer screen this effect is reduced, but through the microscope, my eye touches the tissue in a way that elicits a profound visual-tactile experience.
>
> (personal diary, Rassell 2016)

After working with microscopes for five years, I began to notice these kinds of phenomenological shifts while I was using them. For me, light microscopes and confocal microscopes become partially transparent, and the focus of my visual perception is carried down through the microscope's objectives and lenses onto the samples themselves. I feel bound to the instrument in an act of perceptual collusion. Although this transparency, or embodiment of technology, is a matter of degrees, it is something that is desirable in the design of technology because it helps to retain our real-time, haptic, connected experience of the world. Heidegger, who used the hammer as a classic example of embodied technology, described the type of phenomenological shift that occurs as a technology becomes transparent. Simply, during the use of a hammer the focus of attention is at the point between the hammer and the nail – rather than at the point between the hand and the hammer. Merleau-Ponty similarly examined a blind man's cane:

> The blind man's tool has ceased to be an object for him, and is no longer perceived for itself: its point has become an area of sensitivity, extending

> the scope and active radius of touch, and providing a parallel to sight. In the exploration of things, the length of the stick does not enter expressly as a middle term: The blind man is rather aware of it through the position of objects through it. The position of things is immediately given *through the extent of the reach which carries him to it,* which comprises besides the arm's own reach the stick's range of action.
>
> (1962: 143, emphasis added)

Here Merleau-Ponty acknowledges the spatial extension of the human limb while also extending the boundary of the perceiving mind. Embodiment relations are bodily sensory, and they implicate how we interact with technologies and how these interactions transform our experience of the world, which occur *through* technology (de Preester 2011; Ihde 1991; Rosenberger and Verbeek 2015). Technology can become transparent in that it is not objectified 'but is taken into my experiencing of what is other in the World' (Ihde 1979: 8). In these cases the human and the instrument form a hybrid that in turn interacts with the world.

Analogue mediation and translation mediation are two forms of such hybrid mediation. Analogue mediation applies to technologies where human sense perception is directly connected to the stimuli while translation mediation requires a shift in the type of stimuli (Ihde 1979). Consider light reflected off the moon that is mediated through a telescope – this is an analogue visual experience because the stimuli (in this case, photons of light) travel directly from the moon to the eye. In contrast, translation mediation refers to processes that are indirect. For example, the Hubble telescope, which captures ultraviolet light, and the James Webb telescope, which captures infrared light, are translation-mediating technologies. They both capture light outside of the spectrum visible to the unaided human eye, and so a translation must occur to render the data visible. This translation is required in addition to the magnification of an analogue-mediating telescope.

The AFM mediation style differs again from the simpler styles of analogue and translation mediation. It is a tool of translation, abstraction *and interpretation*, and these additional processes further distance the user from nanoscale phenomena. I operate a computer, which in turn operates the AFM. In addition, the AFM system does not *amplify* visual phenomena, but *translates* phenomena via tactile means to numerical data, which in turn are *interpreted* as visual phenomena. In science it is accepted that in some cases we must rely on mathematical analysis, implemented via algorithms, to convert data into micrographs. These are processes that are embedded in, and often difficult to disentangle from, the user interfaces of computational scientific imaging workflows. Within the process of translating tactile data to visual data, algorithmic interpretation determines how the visual material will be presented, and therefore, how the AFM mediates the human senses.

THE BODY IN SPACE

The cleanroom laboratory, a staple of nanoscientific research, is a physiologically challenging space. The environment, with its regulated pressure, temperature and humidity, can be likened to an airplane. Sophisticated air filtration systems minimize particulate matter using vertical airflow to keep the space clean – clean to the extent that there are under 100 particles of

Figure 1: RMIT Micro Nano Research Facility cleanroom, Andrea Rassell (left) with Natasha Mitchell (right). Melbourne, Australia. © Andrea Rassell 2018.

under 0.3 micrometres in size, i.e. 1/300th the width of a human hair, in a cubic metre. The air flows from the ceiling to the filtration system in the floor to collect particles from the body. Still, every object entering the lab, including the human body, needs to be modified so that the laboratory is not contaminated with microscopic debris. One skin cell, for example, could be the same size as a nanoscale sample and so could disrupt an experiment if they were numerous in the air, and were free to settle on laboratory surfaces.

Before even encountering any instrumentation, the process of entering the laboratory includes an alteration of my bodily state and a diminishing of my senses: touch dulled by rubber gloves; feet unsure in cumbersome boots; movements careful so as not to disturb things; and in the background the white noise of the air-filtration system reduces my capacity to hear. Everything seems delicate and I feel big, clumsy, constricted and hyperaware of my body. The laboratory environment thus transforms the human through the requirement for cumbersome personal protective equipment, and through a desiccated, low-particle environment. All restrictions, including mandated slow movements that reduce particle disruption, and minimal entries and exits, conspire in this transformation, so that people working within these cleanroom laboratories become hyperaware of the body and its actions.

In addition to these environmental restrictions, the human embodiment of technology is disconnected in the increasingly complex technological mediation pathways involving layers of instrumentation, hardware and

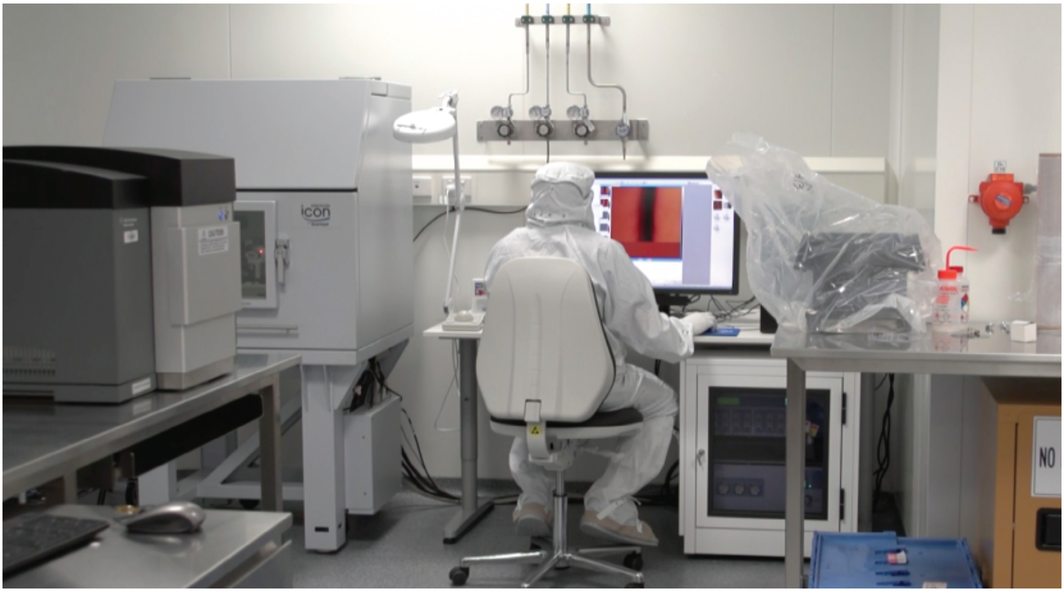

Figure 2: RMIT Micro Nano Research Facility cleanroom, AFM and user. Video still from Wildly Oscillating Molecules of Unanticipated Momentum*. © Andrea Rassell 2017.*

software. Optical microscopic techniques embody the technology. For example, light microscopes are direct extensions of the hands (through the knobs that control stage movement and coarse and fine focus), the eyes (through the two ocular eyepieces) and the body (which is curved over into an enfolding position over the microscope). However, the bodily position in relationship to much modern scientific imaging instrumentation is such that an instrument on one side of a room is connected to a computer – through which the instrument is operated – on the other (see Figure 2).

Technological embodiment relies upon a sensory continuity between human and instrument, and yet the human hand cannot touch the AFM. Any slight vibration, including from a hand resting on the instrument, would disrupt the action of the highly sensitive probe as it moves over the sample. Even though it is not directly connected to the human hand, the AFM is described as a tactile interface (Keysight Technology n.d.). The probe performs an action akin to the human finger tracing across a surface and can be imagined as a tactile sensory extension even if not directly attached to the body. The tactile sense, then, is the sensory proxy that the AFM uses to link human phenomenological experience to nanoscale phenomena.

More specifically, the connection between the AFM probe and the sample is electronic (or electro-tactile). The probe is repelled in response to physical forces created by the interaction of the electronics of the atoms that comprise the probe tip and the sample. While the probe-sample electro-tactile interaction acts as an analogy of the experience of texture between a finger and a macroscale object, it is not a complete model of the human tactile sensory system. However, using a sensory analogy, such as considering the AFM to have a superhuman resolution of touch, positions the AFM and its interactions with the nanoscale as an extension of my own sensory experience beyond the visual. This perspective has informed my creative decisions when creating moving image works, which have subsequently evolved to incorporate a multisensory approach, and to interrogate the relationship between scientific imaging technologies and the body.

The following moving image installations and screen-based experiments formed the exhibition *Wildly Oscillating Molecules*:

- *Wildly Oscillating Molecules of Unanticipated Momentum*, on loop, HD, stereo sound
- *Movement I (Nanomorphology)*, single-channel video, HD, 4.1 audio, 4:00 on loop
- *Movement II (Phosphorene)*, single-channel video, HD, 0:18 on loop
- *Movement III (Phosphorene)*, single-channel video, HD, 0:12 on loop
- *Movement IV (Morse Code)*, single-channel video, HD, 0:20 on loop

I developed a process of 'endurance microscopy' to capture multiple images across days to make abstract experimental videos that explored material and artificial samples. In *Movement I (Nanomorphology),* the movement seen is mainly dust and debris being dragged across layers of graphene. *Movement I (Nanomorphology)* was installed on a 4-centimetre screen embedded in the top of a custom built plinth, positioned in the middle of a 4.1 sound field, in a dark gallery. As such, it was designed to manipulate the viewer's body, so that the body enfolds over the screen, facing downward, and so denies gravity its normal influence on the body. Simultaneously, the gravitational force is replaced with immersive, pin-balling audio, surrounding the body in data and overwhelming the senses, in effect scaling the physical experience that the body undergoes from the real scale to somewhere much smaller.

In *Movement II (Phosphorene),* I captured the formation of nano-bubbles where the substance was degrading. In *Movement III (Phosphorene)*, I further

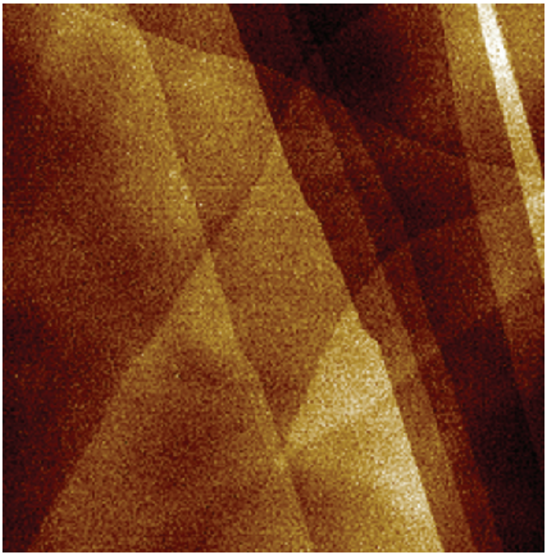

Figure 3: Graphene under the AFM. Video still from Movement I (Nanomorphology). *© Andrea Rassell 2018.*

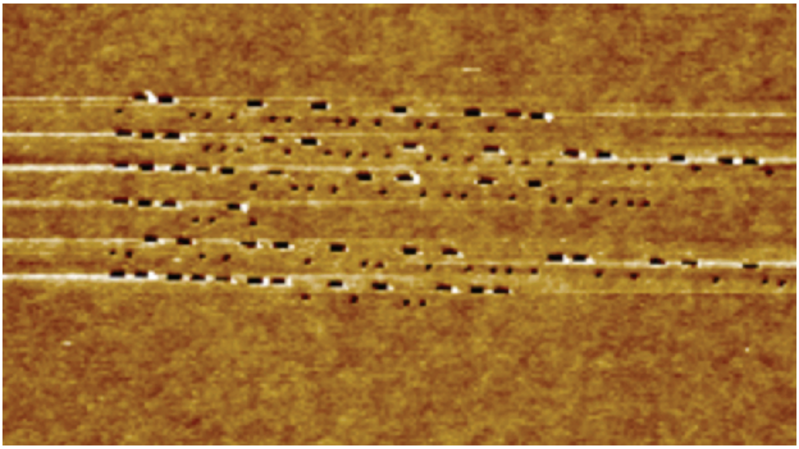

Figure 4: Artificially constructed crystals under the AFM. Video still from Movement IV (Morse Code)*. © Andrea Rassell 2018.*

experimented with using the AFM as a cinematographic instrument, panning and zooming across and into dynamic nanotopographies of Phosphorene. Cinematographic techniques are known for their ability to diminish space between the viewer and the subject on-screen. Cinematographers use formal qualities to this end, evoking a multisensory experience. Such qualities and techniques include grainy, unclear images; close-to-the-body camera positions and panning across the surface of objects; changes in focus; under- and over-exposure; densely textured images; and extreme close-ups. Jan Švankmajer, the godfather of Czech stop-motion animation, made films renowned for their tactile dimensions (Vasseleu 2009). He referred to the 'caressing camera', often using camera movements to replicate the movement of human touch. Endowing the AFM with the ability to create moving images, as opposed to still ones, and a moving camera, begins to reinstate the tactile, sensorial control of the cinematographer.

Movement IV (Morse Code) (see Figure 4) took a slightly different approach. For this work I created an artificial sample using thin layers of metal on a silicone substrate in a process called Electron Beam Lithography (EBL). In EBL, a focused beam of electrons is used to draw a pattern on an electron-sensitive surface called a resist. The pattern made in the resist, drawn at a resolution of under 10 nanometres, spells out *Wildly Oscillating Molecules of Unanticipated Momentum* in Morse Code. This experiment also utilized the movement technique that I developed, with the 'camera' moving across the sample in a manner reminiscent of a finger moving across the dots and dashes (Morse Code, like Braille, can be tactually identified). This work plays with the *movements* of a process of communication being translated across scales and from graphical to tactile to visual. Here, the generation of a tactile, multisensory experience is achieved by the movement of the instrument's mechanical 'finger' and the movement of the artificially created 'camera'.

In the *Movement* series *(Movement I–IV)* the AFM instrument itself is noticeably absent. However, in *Wildly Oscillating Molecules of Unanticipated Momentum* it is overtly present (see Figure 1). In this work, the instrument can be seen to be separate from the operator and the overlaid crosshairs are a reminder of the mediation that is at play (see Figure 3). In the *Wildly Oscillating Molecules* exhibition the AFM is therefore present with differing transparencies. At times its presence is apparent in the movements of the AFM mechanisms, or as shifting artefacts in the video as in *Movement I (Nanomorphology)*. At other times the AFM's presence is apparent because of the movements executed by the operator, as in the pans and zooms in *Movement III (Phosphorene)*. In *Wildly Oscillating Molecules of Unanticipated Momentum* the AFM appears dormant as the whole instrument sits alongside an operator interacting with the computer (see Figure 2). When the AFM is visible in its entireity like this, the instrument is at its most phenomenologically opaque. Concurrently, this is when its algorithmic and small-scale mechanistic processes are the least discernible in the moving image work.

THE INTERPRETIVE, TRANSLATIONAL AFM

When we no longer directly 'use' an instrument, more complex forms of mediation take over. From nanoscale phenomena, to AFM probe, to electrical signal, to numerical data, to micrograph, the AFM system constructs a complex pathway of mediation. Ultimately, the instrumental processes of data translation create artefacts, such as micrographs, that must be interpreted. This interpretation harks back to Ihde's *Technics and Praxis* (1979), where he describes the process of hermeneutic mediation. This form of mediation occurs where there is no direct experience of the phenomena, and an act of interpretation is required to perceive it (Ihde 1979) – a user must therefore pay attention to the device itself and interpret its readouts (Rosenberger 2013). The AFM system detects phenomena using a non-optical, scanning technique and translates the resulting data into height data. This translation is part of an indirect, hermeneutic meditation that disrupts the notion of technological transparency. This characterization of transparency is important because it directly affects how sensible nanoscale phenomena are perceived to be.

Humans perceive technology with varying degrees of transparency (Ihde 2011). When the focus of attention is no longer between the body and the technology, but between the technology and the world with which it interacts, the technology becomes phenomenologically transparent, for example, with Merleau-Ponty's cane (de Preester 2011). However, with complex technologies such as those used in nanoscientific imaging, phenomenological experience of their use can fall on the opaque side of the transparent-opaque spectrum (Ihde 1979).

Within the AFM system, multiple transparency-opacities are at play. These traits are neither positive nor negative but rather are characteristics of technological mediation. The *macroscale* mechanical actions might be visible, but they are also phenomenologically transparent. These actions neither require my attention as an operator to function (aside from confirmation that the instrument is 'working'), nor for me to have feedback from the nanoscale phenomena. Conversely, the interaction at the probe tip level is invisible, and yet this does not automatically mean that the technology is phenomenologically transparent. In fact, the presentation of line-by-line scanning data makes me keenly aware of the pixel-by-pixel interaction of the probe with the sample, and the appearing micrograph alerts me towards issues that occur at the probe. In this way my phenomenological experience can momentarily be drawn down to the nanoscale. It becomes clear, from the fragmentary nature of the image being presented to the user line by line, that this phenomenological experience will shift depending on the user's focus – their *intended* focus of attention – in the process of imaging.

While the intended foci of a scientist and a moving image maker will necessarily be different, at some stage both will attend to the micrograph produced by the AFM, and this is a point of departure for the two practices. For a scientist, the micrograph is a complete entity, ready for analysis. For me, as a moving image-maker, it is complete as an 'image', and yet it is merely one unit in a sequence of videos. In either case, the micrograph acts as a separate mediating technology, which has a different form of mediating the nanoscale phenomena than that which is experienced through the AFM instrumentation. In the post-production stage, the mediation of the nanoscale phenomena becomes simpler. While working with the micrographs in media platforms, the AFM instrumentation is absent and therefore becomes transparent, and I begin to feel closer to the phenomena once these complex instrumental and algorithmic systems have been shed. The data, however, are the conduit that connects the scientific laboratory and the video-editing suite.

Five translational and experiential steps are involved in the creation of *Wildly Oscillating Molecules* data:

1. Data are collected by a tactile, electro-mechanical device (the AFM probe).
2. The data are translated into height values by the NanoScope software, and are presented as micrographs that use a colour gradient to depict height.
3. The data are mapped into audio, part of a sensory return where I attempt to make the data tactile again using NanoScope Analysis software, Adobe Audition for editing sound and Max MSP.
4. The micrographs are turned into a video sequence with Adobe Premiere Pro.
5. Lastly, the packets of data in the form of micrographs are experienced aurally, visually and texturally via audio-visual moving image works.

Through these steps, the numerical data dominate, existing as a tenuous phenomenological link, until the AFM system transforms them into micrographs, and I translate them into audio and video. The AFM system's inability to present a tactile experience of the data is itself an experiential disconnection; however, without the data, there would be no connection to the nanoscale phenomena whatsoever. Therefore, the AFM connects and disconnects, amplifies the experience of the nanoscale phenomena while it reduces the tactile experience of the instrument. As such, the recreation of a tactile experience in *Movement 1 (Nanomorphology)* is a sensory return, an amplification of the tactile in response to the AFM system's reduction of the tactile sense.

The sensory body, though, is reactivated in the viewing of *Movement 1 (Nanomorphology)* through two techniques. First, the presentation of the work within a gallery space encourages the body to move within the space in relation to the nanoscale phenomena. This is part of an inversion where the maker, normally a mobile agent when shooting video, is rendered static in front of the AFM system, whereas the viewer can attain mobile agency in front of the moving image as installation. Second, the spatiality and texture of the sound design are created for the viewer's body and their tactile perception. This audio-tactile sonic element is essential to the creation of a multisensory connection to the nanoscale, as it attempts to overwhelm the perception of the sense of gravity by replacing it instead with a sonic battery akin to

Brownian motion, the aforementioned major physical force of the nanoscale. These two strategies reactivate the body and its senses in a way that does not occur in the laboratory (where certain senses and movements are dulled).

Interpretations and translations are therefore key to the creative resolution of the work in *Wildly Oscillating Molecules* and to the AFM's style of mediation overall. Interpretation and translation make interaction with the nanoscale possible, while distancing and replacing a sensory experience of nanoscale phenomena. The act of translating, or data mapping, is something that I have extrapolated from the AFM system's strings of translations and transformations to create a multisensory embodiment of the nanoscale. The creative work then presents the amplification of the nanoscale phenomena, and in removing the material from the laboratory and shifting it into a gallery space, presents the least technologically clouded experience of nanoscale phenomena by the AFM.

TEMPORAL MEDIATION

Glaringly for an artist working with time-based media, several manifestations of time in my nanoart practice differ greatly from real-time, human-scale video recording. AFM micrographs are recorded incredibly slowly due to their scanning nature. The playback speed then has an abstracted relationship to real time because the videos cannot include all of what occurs across real time, but instead cover 24 hours in eight seconds, with each frame representing approximately five minutes. The videos of *Wildly Oscillating Molecules* compress time into a micro-film, that is, of a few seconds in length due to the difficulty in collecting frames for the films and depicting the guise of movement. Here, I examine my experience of time when producing moving images using the AFM and editing software to produce *Wildly Oscillating Molecules*.

The conscious experience of time in these works is important because as we engage with smaller scales, we encounter phenomena that move so rapidly that humans fail to perceive movement. These works ask a viewer to understand something seemingly ultra-fast as in reality ultra-slow in relation to the real-time phenomena. Moving image artworks, then, contribute to the development of cultural constructions of time. In my work, time is simulated via movement and duration, which are manipulated through speeds of recording, playback and editing.

A technology's level of transparency will alter based on whether it is experienced across time rather than with an immediate sense of real-time feedback. The AFM probe scans one spatial point at a time, before moving to the next location and gathering data for the next pixel. Each line of a sample is then scanned multiple times, meaning each pixel comprises multiple detections. More commonly, digital images are a collection of pixels captured all at once. The term capture itself denotes the simultaneous collection of all pixels in an image at once. AFM micrographs on the other hand are collected across time. Because of this, a real-time experience of nanoscale phenomena is impossible when using the AFM. Being a scanning technology as opposed to a capturing imaging technology, the AFM therefore has idiosyncrasies of temporal presentation that extend the users' interaction with nanoscale phenomena across an abstracted timescale, more so than a filmmaker shooting footage of the real scale.

The process of creating micrographs took a long time relative to the amount of footage being created. There is a temporal difference between the use of a short-range telescope, still camera and the AFM. Short-range telescopes remain a real-time experience, whereas still cameras create a sudden and comparatively complete arrest of time (Ihde 1998). In contrast to these technologies, the AFM transforms time very slowly (dragging across time as the probe drags across the sample), which warps it, making it an unusual entity to encounter for makers of the moving image accustomed to working with real-time video. Working in the lab for three days to create eight seconds of footage had an unusual phenomenological effect on me. Leaving the laboratory and stepping into the bustle of the city, I had the sense that everything had sped up, and that I was moving through a tar-like substance in comparison to other peoples' movements. This sensation recurred each day that I spent working with the AFM, using it to collect just one frame every five minutes, and lasted some hours afterward.

It seems that this phenomenological response occurs even though the temporal mediation of the scanned micrograph is largely imperceptible – the atoms and molecules being scanned are dynamically and rapidly shifting in space, subject to unfamiliar, sub-molecular forces. Even if modern instrumentation could provide an experimental real-time visualization of atomic or molecular motion, the human visual system is incapable of discerning movement at such high speeds. Dr Mike Kuiper, a computational research scientist and specialist in molecular interactions, suggests that at the seemingly ultrafast speeds at which molecules are depicted as interacting and moving, it would take years to watch one second of real-time activity unfold (2017, personal communication, 6 January). If a water molecule, for example, vibrates 102 trillion times in one second, and if it were played back at a perceivable limit of ten vibrations per second, it would take 347, 856 years to watch one second worth of movement (personal communication, Kuiper 30 July 2018). Therefore, within these micrographs time is presented, and from a moving image perspective *misrepresented*, because we moving image makers who work with real-time video understand one frame to be *of a moment*.

In conclusion, moving images create a way of depicting the physical environment of the nanoscale, and so amplify the experience of nanoscale phenomena. Concurrently, the temporal abstraction described reduces our access to dynamic, moving nanoscale phenomena. The nature of the AFM mediation is one of temporal and spatial shifts, where temporality is affected in multiple dimensions. This temporal-technological relationship in effect removes linearity from time, the way we 'normally' experience it, and 'normally' leverage it as moving image makers. Time is fractured and disrupted, both conceptually in our experience of the nanoscale phenomena and realistically in our experience of the moving image work. The real-time timeline is broken down from frame to frame and even from pixel to pixel.

CONCLUSION

There are three experiential shifts, or translations, that define AFM mediation: first, the spatial dislocation of the AFM, second, the interpretations and translations of data, and third, the temporal modification of nanoscale phenomena. These follow Ihde's model of the amplification-reduction pattern, which illustrates the accompaniment of every sensory amplification by some form of sensory reduction. Necessity dictates that the AFM be sequestered away from cumbersome human movements, and this phenomenologically disconnects the user from the AFM. Meanwhile, the data, which are translated by the hermeneutic design of the AFM, retain a connection between human and nanoscale phenomena. The nature of the temporal mediation of the AFM reduces the phenomenological access to nanoscale phenomena and puts the viewer and moving image maker in an abstracted and non-linear relationship with time.

Throughout the process of data collection and micrograph construction, a perceptual concertina is at play – one that simultaneously brings the user closer in contact with, and further away from, the phenomena of interest. The data and the ensuing visualization are amplifications of the nanoscale. Simultaneously, however, the tactile experience that the instrument has of the phenomena is replaced by a visual experience. When attending to a micrograph we are also effectively blinkering ourselves – shutting out the macro perceptions of the world as it is available to our senses. For every connection there is a disconnection; with every amplification, there is a reduction. However, instead of decoupling the human from the nanoscale phenomena, the mediation of the AFM embraces variable temporal and spatial relationships, leaving space for human agency and intentionality in relation to the phenomenological experience.

My creative process of making moving images is one where amplifications can be highlighted and reductions leveraged to construct an immersive phenomenological experience of the nanoscale. The manipulation of time within a moving image practice brings the viewer and nanoscale phenomena phenomenologically closer together. I propose that the shift from static to moving micrographs, textural audio and the use of installations in the presentation of the moving image comprise a multisensory strategy where human viewers can perceptually apprehend nanoscale phenomena.

Initially in my creative process, what I thought I was seeking was a sensorial connection to nanoscale phenomena enabled by scientific technology, and yet what I needed was to find agency as a maker. A heightened sense of agency eventuated through several techniques: reassigning freedom of movement to the body as it encounters nanoscale phenomena by choosing immersive viewing locations to show the work in; extrapolating the data manipulation beyond those opportunities within the AFM system through the design of a customized data-mapping pathway; and working within a media editing software timeline where I had temporal control over the data as audio-visual material. The evolution of the instrument's use of tactility into sonic textures in *Wildly Oscillating Molecules* demonstrates the extrapolation of the AFM's instrumental mediation into creative moving image works. In the experience of these artworks, these types of media techniques illustrate how the consideration of the technological mediation can inform the creation of a multisensorial experience of the nanoscale, drawing us ever closer to a world that we thought we would never sensorially experience.

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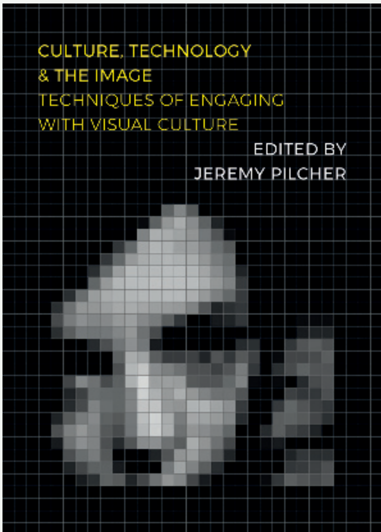

Culture, Technology and the Image

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