Joseph La Delfa [1,2]
joseph@bitcraze.io

Rachael Garrett [2]
rachaelg@kth.se

Airi Lampinen [3]
airi@dsv.su.se

Kristina Höök [2]
khook@kth.se

[[[Bitcraze[1]] Malmö][[KTH Royal Institute of Technology[2]][Stockholm University[3]] Stockholm] Sweden]

Exploring the Umwelt as a Design Metaphor for Human-drone Interaction

Abstract

How To Train Your Drone is a novel human-drone interaction that demonstrates the generative potential of a design metaphor: the umwelt. We describe the concept of the umwelt and detail how we applied it to inform our soma design process, creating an interactive space where somatic understandings between human and drone could emerge. The system was deployed for a month into a shared household. We describe how three people explored and shaped the umwelts of their drones, leading to unique and intimate human-drone couplings. We discuss the compatibility of the umwelt to soma design practice and identify future avenues for research inspired by artificial life and evolutionary robotics. As our contribution, we illustrate how the umwelt as a design metaphor, can open up a generative new design space for human-drone interaction.

Author Keywords

Soma design, drones, the umwelt, design metaphor

CSS Concepts

Human-centered computing ~ Interaction design ~ Empirical studies in interaction design

Introduction

Moving with a drone can be a captivating experience. A drone can easily grab my attention, yet the quality of that hold is distinct from a screen where my body 'goes missing' and my eyes are 'held captive'. Instead, my body feels alive and present, as if every part of me is playing a crucial role in keeping the drone in the air. The sensors on my body enable the drone to respond to my movements, which in turn, increases my own sensitivity of the drone.

It's like carrying a hot cup of tea with a book under my arm, any sudden movement from any part of my body disturbs the tea and vice versa - reflection by Joseph, the first author.

Designing with a drone can be a challenging experience. Their technical requirements restrain many design possibilities, tightly coupling the design of drones to their flight performance. Their radially symmetrical bodies make their movements difficult to interpret consistently [7,18]. When these factors are taken together, moving and designing with a drone can be a very fluid experience. Changes in both human and drone bodies manifest in the interaction, altering the experience moment-to-moment [27]. Further, when different human bodies start interacting with different drones, trying to design for a consistent and generalized experience starts to make little sense [40].

In light of this, we explore drones, less as a technology to be 'finished' by the designer, and more as an agent to evolve alongside an individual. To do this, we present the design process and deployment of *How To Train Your Drone* (HTTYD), a research product [32] created using a soma design approach [24]. In soma design, a designer's first-person experiences are used to drive the design process [24]. In so doing, attention is directed to their felt experience, and reflection on these sensations is intended to enrich interaction designs and the quality of experiences they offer [41].

Here, we incorporate the umwelt into our soma design process. The concept of the umwelt posits that every organism in the animal kingdom experiences reality in radically different ways because of how their bodies sense and act on the world. This assertion 'isolates' each species to a degree, rendering their respective lived experiences mutually inaccessible [43]. This conception encourages humans to accumulatively build channels of understanding across different umwelts and felt experiences [45]. Whilst we do not consider a drone to experience an umwelt like any living creature or organism, we, as designers, are inspired by the umwelt as a generative design metaphor [6]. We relinquish the assumption that a drone needs to understand or communicate to us in an immediately understandable manner [22] or fit into a coarsely categorized anthropomorphic or zoomorphic form [14]. Instead, we focus on creative ways to imagine channels across different umwelts.

This work both joins and responds to calls for more generative and fluid metaphors in human-robot interaction (HRI) [6]. It is also related to a push for leveraging how a robot senses and acts, in order to inform how it communicates [4,37]. We conclude this pictorial with practical suggestions that borrow from the fields of artificial life and evolutionary robotics, to identify future design spaces where the umwelt metaphor might be applied, working towards human-drone and -robot interactions that embrace their underlying hardware.

DIS '24, July 1–5, 2024, IT University of Copenhagen, Denmark

ACM ISBN 979-8-4007-0583-0/24/07…
https://doi.org/10.1145/3643834.3660737

''Swimming, feeding, and breathing are carried out by the same rhythmic contraction of the muscles on the edge of the umbrella. To ensure continuity of this motion, eight bell-shaped organs are located on the periphery of the umbrella, whose clappers strike a nerve end at each beat. The stimulus thus produced elicits the next umbrella-beat. In this way the medusa gives herself her own effector cue, and this releases the same receptor cue, which again elicits the same effector cue ad infinitum. In the medusa's world, the same bell signal rings all the time, and dominates the rhythm of life. All other stimuli are cut off.'' Jakob von Uexküll [43]

Background

Soma design aims to create applications *"where the interactions subtly turn users' attention inwards, towards their own body, enriching their sensitivity, enjoyment and appreciation"* [24]. The intention is to make space for reflection and melioration (self-improvement, in whatever way one deems best). This is a practice that is essential to a life well lived, according to the philosophy of somaesthetics, which considers *"the [soma] as a locus of sensory-aesthetic appreciation and creative self-fashioning"* [39]. In other words, somaesthetics asks us (regardless of our roles as "designers" or "users") to engage with our bodily felt experience, the 'raw sensory data' that our bodies produce, to cultivate rich and meaningful experiences through our senses [24].

Another foundational perspective of soma design is the primacy of movement [38], which draws from (amongst other works) evolutionary biology to consider movement at the core of our existence. From a single-celled organism to the complex multicellular human, *"our bodies, their morphology, and their potential movements are the foundation of all human meaning-making processes. It is in this movement that language is grounded"* [24]. This resonates well with the concept of the umwelt. Biologist Jakob von Üexkull, likens an organism's umwelt to that of a house.

"Each house has a number of windows, which open onto a garden: a light window, a sound window, an olfactory window, a taste window, and a great number of tactile windows. Depending on the manner in which these windows are built, the garden changes as it is seen from the house. By no means does it appear as a section of a larger world. Rather, it is the only world that belongs to the house — its [umwelt]. The garden that appears to our eye is fundamentally different from that which presents itself to the inhabitants of the house." [45]

The sea urchin for example, has only three windows in its house, needing only pressure, light and chemical senses to navigate its corner of the ecosystem [43]. It retreats when a shadow is cast over it, however, it does not possess a human (i.e. spatial) sense of darkness. Instead, von Uexküll reasons that a better analogy would be *"a wad of cotton passing lightly over its photosensitive skin"* [43]. Von Üexkull wrote extensively about these 'unknowable sensory worlds' [5,43], and espoused a sense of inquiry into how the world might present to organisms with radically different morphologies to our own.

Before we detail the design process of HTTYD, from the perspective of the first author, Joseph, we invite you to indulge in such an exercise while reflecting on the jellyfish above; a creature acutely isolated from an outside world perceived through one sole "window". Next, we will describe how Joseph came to realise the design potential of the jellyfish's 'numb yet nascent existence' – a starting point for how a technology's metaphorical umwelt could be expanded and shaped with a human. This process of shaping would, in turn, be guided by their own sensory-aesthetic appreciation.

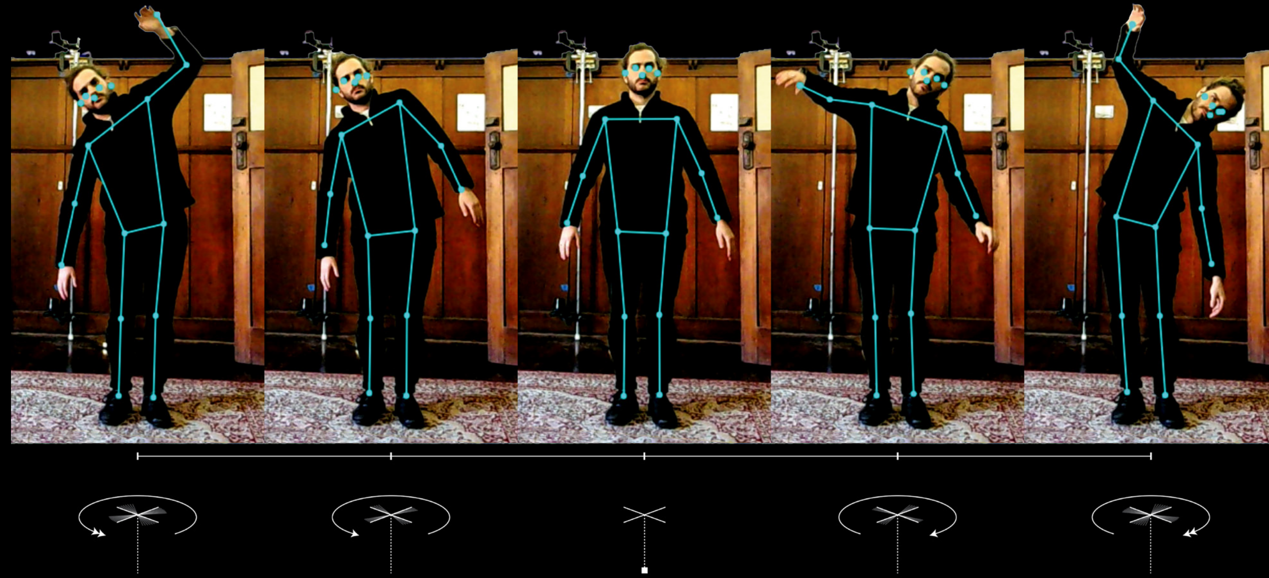
Design methods and process

The generative potential of the umwelt as a design metaphor was revealed through a research through design process [36,46], blending soma design and product design engineering methods (previously employed in [28].) This meant that strategies from soma design such as body storming [31] and estrangement [30] were used alongside a process of assessing the suitability of various hardware and material configurations for a given design concept.

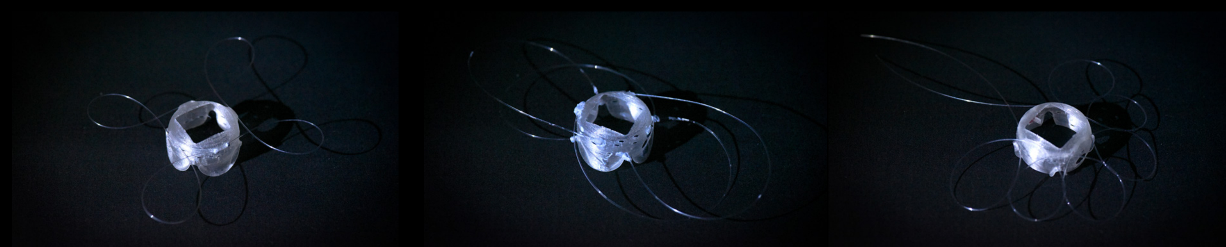
Meaningful Couplings: Joseph's initial intention was to create a rich and complex control mapping between human and drone movements (e.g., [27]). This was explored by using pose estimation [33]. For example, by tracking one's average center of gravity, then using that data to spin the drone clockwise or counter-clockwise (see top right). This affected the felt experience of flying as it destabilized the drone. His assumption was that, through layering many such couplings on top of each other in the interaction, a meliorative somatic experience would emerge. However, he realized that any couplings he designed still encoded a way of moving that *only he* thought was meaningful. Joseph moved away from this design strategy, wanting to give the *individual's* lived experience primacy in the meaning-making process.

Shaping the drones: Drawing on Joseph's fascination with the *otherness* of sea creatures [19,20], he moved towards jellyfish as their radially symmetric bodies mapped well onto the drone's. He settled on a physical design concept based loosely on the multistage life of a jellyfish (see bottom left). While charging, the drones emulate the *polyp* stage of the organism's life cycle - attaching to a hard surface and growing like a plant, but slightly more animate. While flying, they emulate the *medusa* stage - venturing out into the sea, like an animal, but not quite as responsive [20].

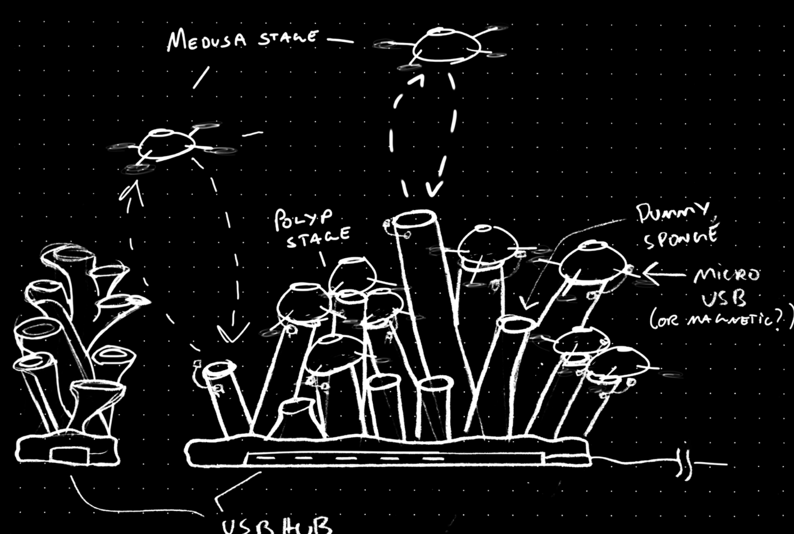
A number of prototypes were made to explore how the propeller guards could be "styled" by hand (see middle). This idea changed how the drone flew in a way that was out of Joseph's control (unlike the pose estimation approach). However, this lead to many spectacular failures, and so this approach was abandoned. But the notion of shaping the drone's form to change how it acted left an impression that would later catalyse an embrace of the umwelt metahor.

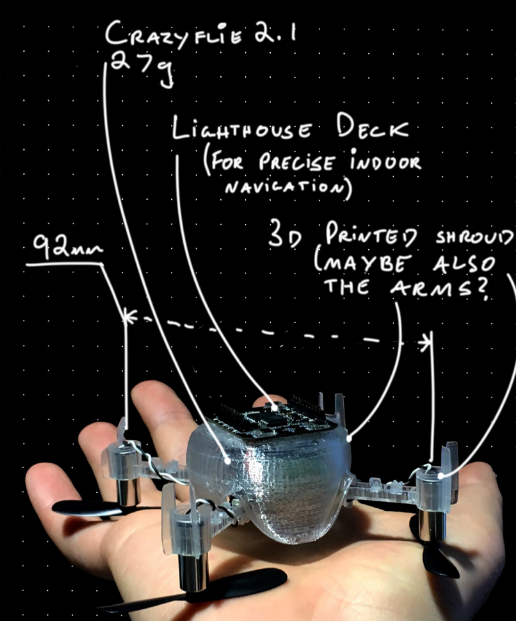


Drone reaches max CCW spin | Drone spins counter-clockwise | Drone does not spin | Drone spins clockwise | Drone reaches max CW spin



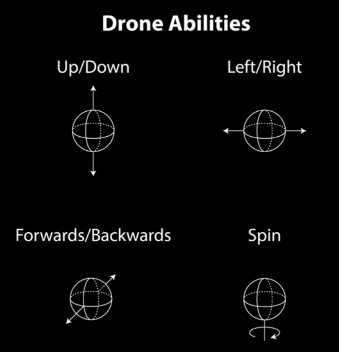
Shrunken propeller guards | Expanded propeller guards | Lopsided propeller guards



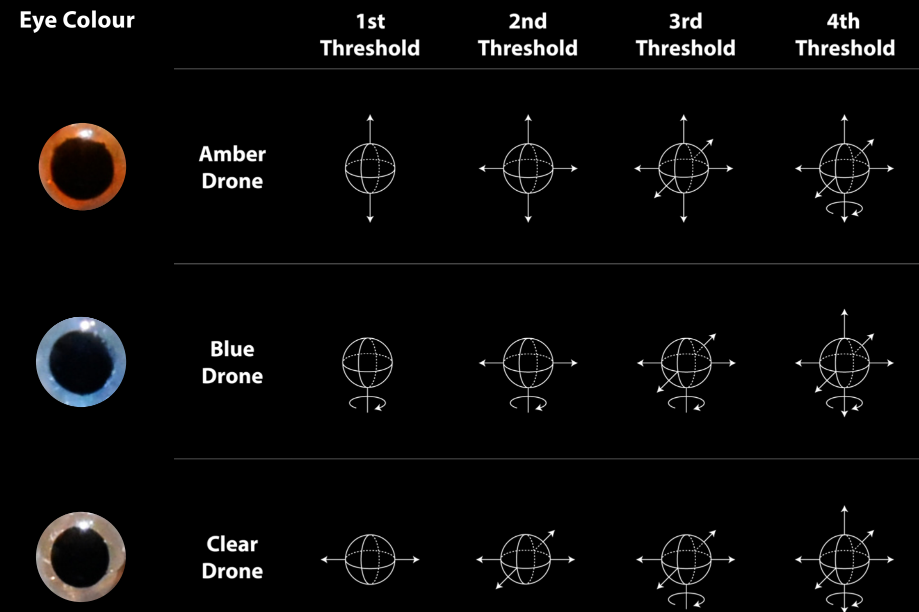


Embracing the umwelt metaphor: A breakthrough came as Joseph watched his infant daughter rolling on the floor, grabbing and tasting her feet. Whilst attending neonatal lessons, he learned that babies - through sensing and acting - learn about their body parts and how to use them. In doing so, they learn different skills at different times. He saw the opportunity for a system that could grow with the individual and cumulatively change with them in divergent ways.

His first attempt at this new direction was a re-arranged version of the pose estimation concept (see right). Whereby different drone abilities were denoted by eye colour. However, the problem of who should define the coupling between the human movement and the drone movement remained. Shaping the drone to change how it could *act* (as demonstrated by the shape changing propeller guards) seemed to be the answer, but doing this *physically* was not feasible. He realized that if the drones were going to act differently to one another, then they would need to evolve different ways of *sensing*. This could be done *virtually*.



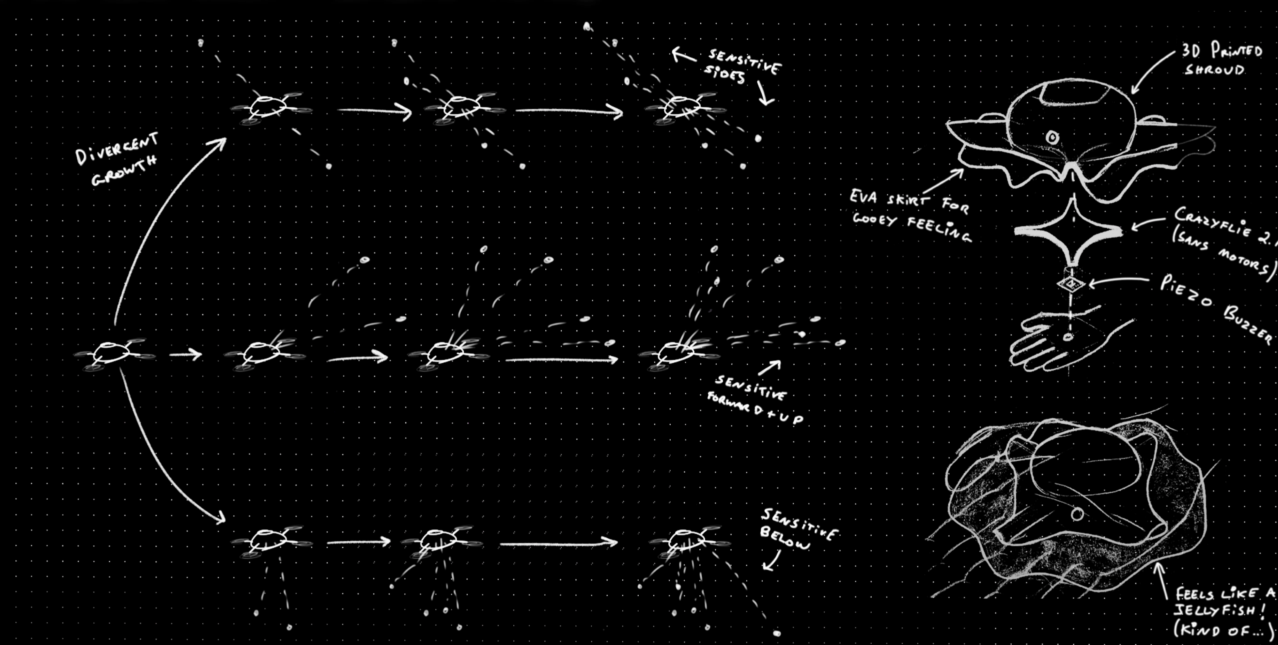
Movement Aspect	Threshold
Hands above head	> x sec
Knees Bent	> y sec
Average hand velocity	> a m/s
Average hand acceleration	> b m/s



''Babies start disconnected. They don't link what they see with what they do and what they feel. The connections are learned, slowly over many months. Ultimately, what unites the senses foremost is action. That is, the output - action - informs and integrates the input - sensation - through a feedback loop. Unifying the senses depends on acting: doing and seeing and feeling, sensing the feedback from the doing at the same time.'' Barbara Tversky [42]

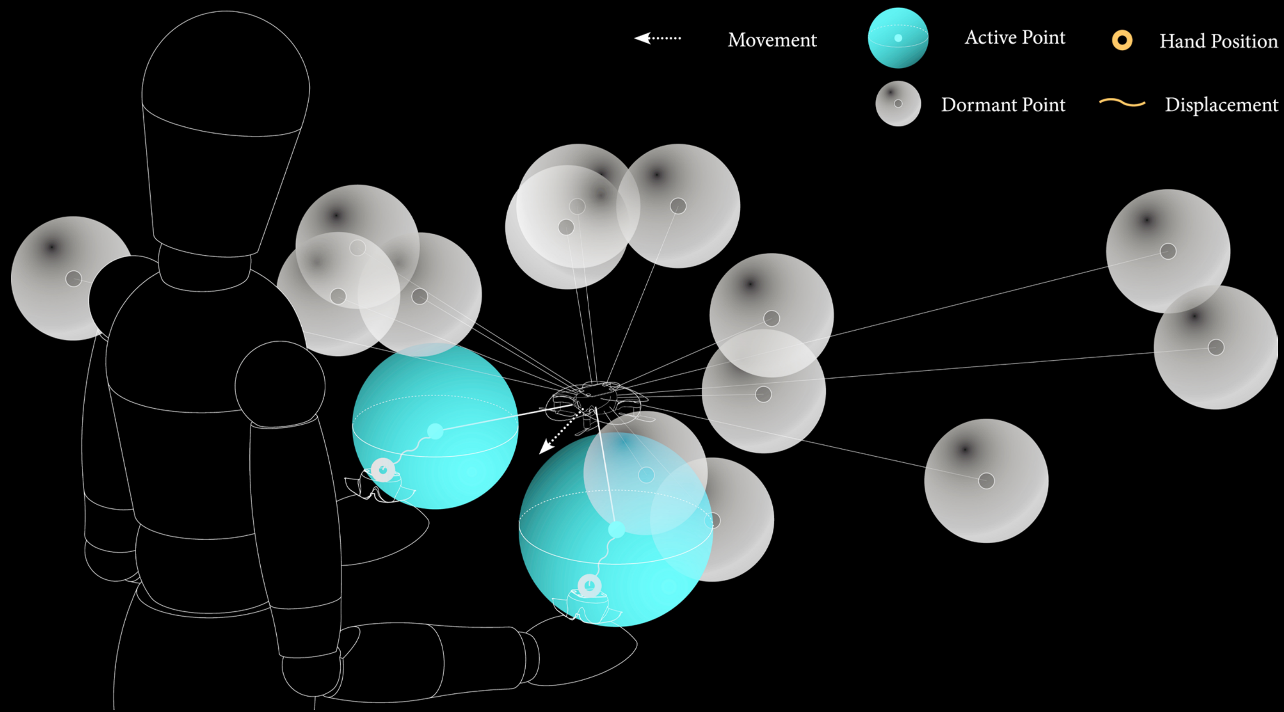
For the second attempt, each drone begins "life" like a jellyfish, in an umwelt of isolation with no windows to the outside world. Joseph designed hand-sensors using Crazyflie circuit boards (see far right) that would be integrated into a pair of finger-less gloves. These hand-sensors can be used to create virtual points around the drone. In other words, they record a virtual point in space that the drone remembers.

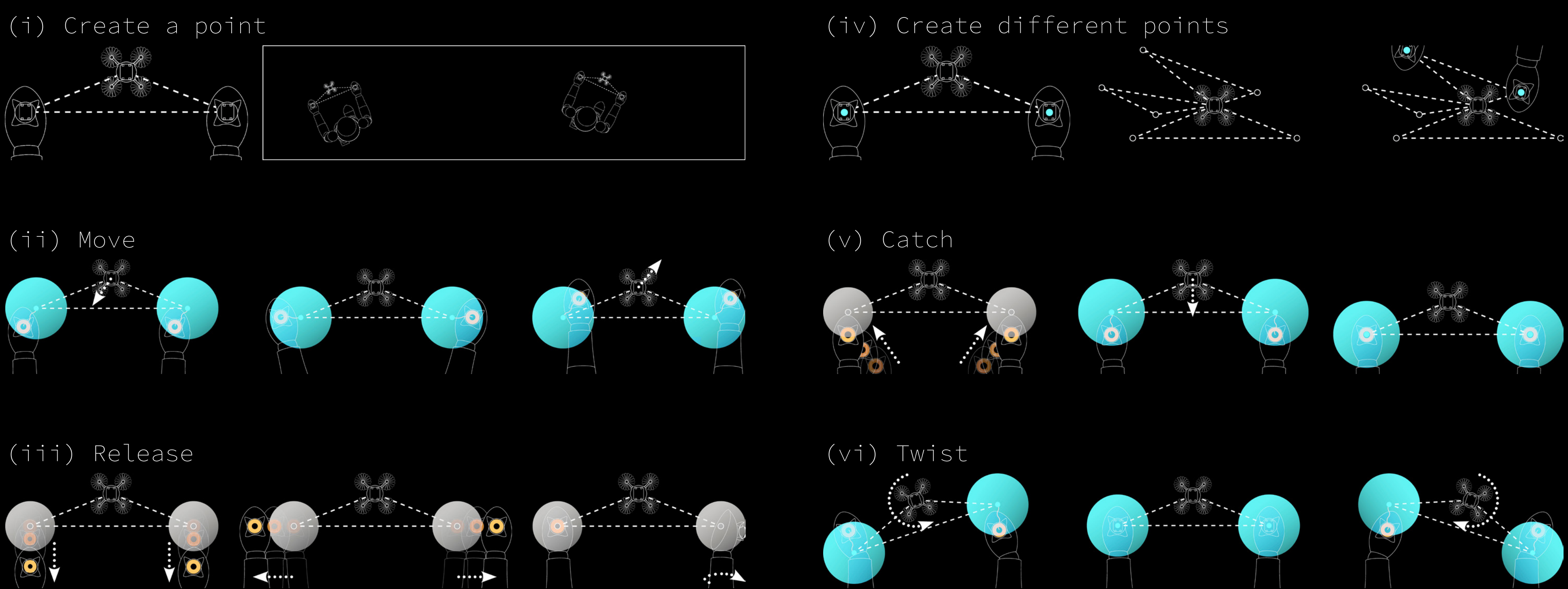
Metaphorically, these virtual points are tiny windows in the drone's umwelt, populating the space around the drone with tiny points that it can "sense" (see right). This means that one can use their hands to expand the drone's umwelt and, as its umwelt grows, the drone is gradually able to respond in more complex and nuanced ways. Yet, the drone has no sense of the human umwelt, just like the sea urchin has no spatial conception of light and dark. With the core concept in place, the basic interaction could be designed.



Shaping the drone's umwelt: One cannot move with the drone until there is first a point in its umwelt that it can "sense". First, one creates a point (i). This is done by holding the hand-sensors still until the drone spins around to face the person wearing them. After this point has been created, one can move the drone (ii). To move, one has to maintain the same-sized 'triangle' that was formed when that point was created - i.e., the relative distances between the hand-sensors and the drone needs to remain constant. Stretching this triangle too far will release the drone (iii). A certain amount of leeway is afforded by the blue bubble round the active points. One is free to create as many points as desired, anywhere in the flight environment (iv) or return to an old point by moving back into that position (v). One can also twist the drone by articulating the wrists (vi). A video demonstration of these actions can be found in the supplementary materials.

All created points move with the drone. Over time they form and extend the drone's metaphorical umwelt; a virtual manifestation of all the places in virtual space that the drone can "sense".





Designing subtle communications: Once the basic interaction was implemented, Joseph still had to decide how much, and what qualities of feedback and communication to embed into the drones. Designing some clear and consistent behavior patterns was necessary to provide interactional 'hooks', even whilst he strove to keep the over arching interaction ambiguous and resist implementing overly anthro- or zoomorphic responses [11,12]. He drew on the core soma design concept of *subtle guidance* [24], which seeks to avoid any overt communication that would draw attention away from the body.

Furthermore, the early release lighthouse positioning system was not yet able to reliably track the yaw of the hand sensors (i.e. "twist" on the previous page) or being turned upside down. This limited what could be communicated between human and drone. However, this resembled the often narrow bandwith between two species' umwelts. Which was a helpful perspective in the design process.

This left only two viable feedback modalities for the drone; the yaw of the drone (its ability to spin) and the piezoelectric buzzers on each hand. Variations in the drone's yaw were used to communicate that one is creating a point. The drone spins in place when it is not being moved. When the hands are held still, the spinning begins to slow down. When the spinning slows to a stop, the drone turns to face the person wearing the hand-sensors, indicating the point has been created.

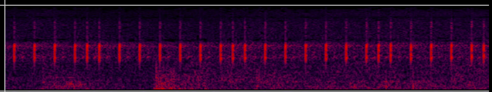
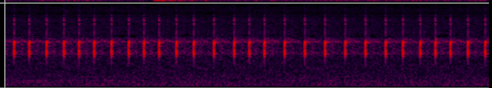
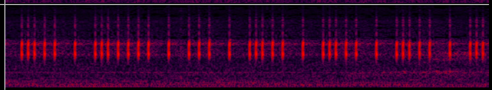
The buzzers are partially drowned out by the noise of propellers, so they play a subtler role in assisting in this communication. They emit a clicking sound (like a Geiger counter) when the drone is not being moved. This coalesces into a rising tone when the hands are held still and the spinning begins to slow down. Once a point is successfully created, the buzzers fall silent.

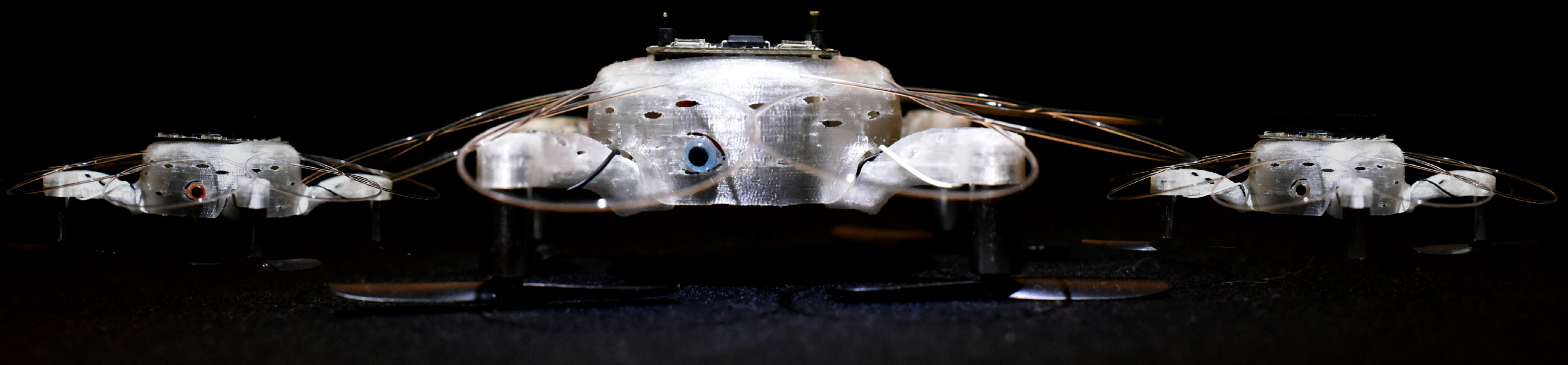
Phenotypes: To further encourage the emergence of divergent human-drone relationships, different "phenotypes" (i.e. observable characteristics) were designed into each drone.

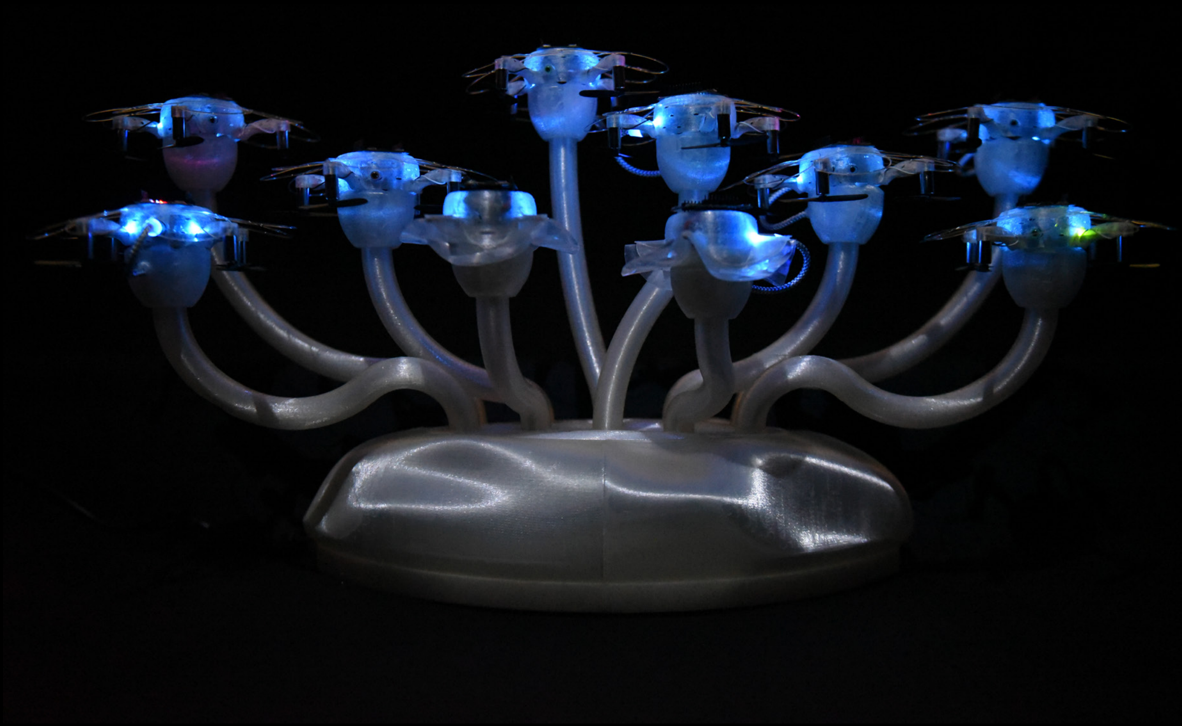
Each drone takes a different amount of time to "learn" a point, i.e., the amount of time the hands need to be held still to create a point. These "learn times" were set based on how long an individual could reliably hold their hands still, and how reliably the system could track a still hand (at that stage, the system was better at tracking the sensor when it was moving).

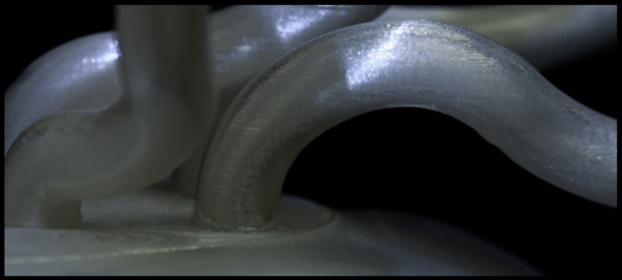
The diameter of the blue bubble around the active points varied between drones, affording more or less leeway when trying to move or catch the drone. The spin rate varies, which means that the act of training becomes more or less clear with different drones. Different launch heights also influences how one can approach the drone at the beginning of an interaction.

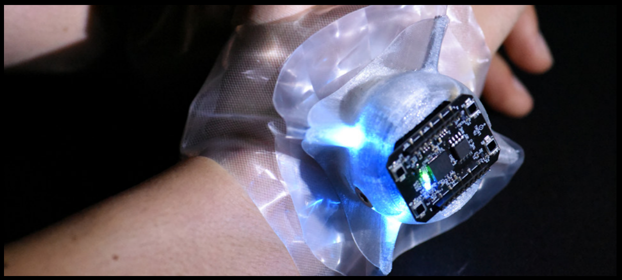
Finally, the buzzers on the hand-sensors clicked to a different cadence for each drone. These differences were achieved by leveraging the asynchronous rates that the drone's onboard data was sent to the laptop (via radio packets) and the rate that the laptop processed the drone's on board data.

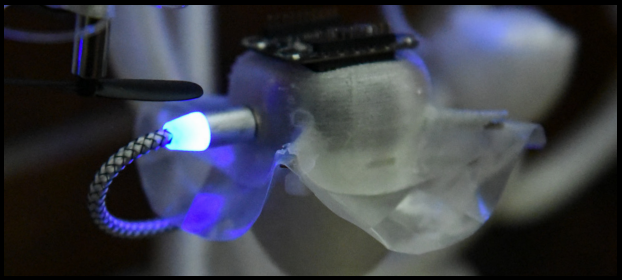
Eye color	Learn time	Bubble size	Spin rate	Launch height	Cadence
Amber	*9 sec*	*180 mm ⌀*	*50 deg/sec*	*900 mm*	
Blue	*10 sec*	*240 mm ⌀*	*60 deg/sec*	*1000 mm*	
Clear	*12 sec*	*180 mm ⌀*	*80 deg/sec*	*1200 mm*	







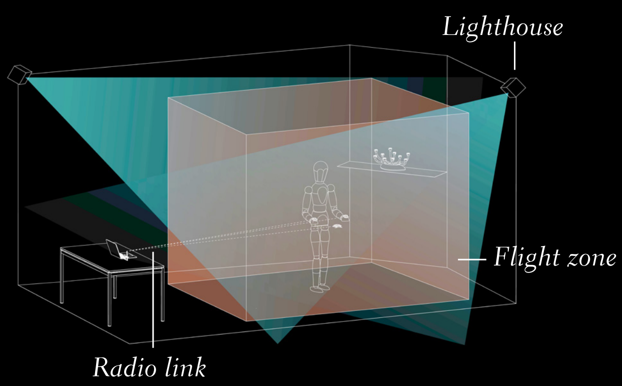




Presenting a research product

HTTYD was designed as a research product; a prototype that appears more like a consumer product in an everyday setting [32]. When exploring ambiguity in design, research products are useful because they present as something that operates "as intended". As opposed to a more rough-looking prototype in a lab setting, where ambiguous behavior may be disregarded as the result of a prototype unfinished [32]. They have previously been used to probe the blurred relationships between designer, user and object in the home [21, 44].

The system consisted of six drones (two of each phenotype), two hand-sensors, three sets of gloves, and a charging station with magnetic quick access ports. Care was taken to ensure that the drones could be used with minimal fuss. A laptop with a basic user interface and a calibrated lighthouse positioning system was included. Additional safety features such as a battery health check, bounded flight zones, and automatic low-battery landing were also implemented. The code repository for the system can be found at [16,17].



Deployment

Over a period of a month, three people, Justin (left), Nora (middle) and Tom (right) had the opportunity to explore how to train their drones from the comfort of their own home. The system was set up in a 10-bedroom shared household, in a lounge room that facilitated the flight environment. None of the researchers resided at the property. Coincidently, the house used to be a maternity ward, a fitting backdrop for the three of them to raise their drones from infancy.

All three participated in a pre-interview and were shown the basic operation of the system (i.e the operations depicted on page 5). Each of the housemates were assigned a different drone and told to explore whatever they felt like doing with it.

In total, we collected 9 hours of interview data, 5.5 hours of video footage. We analysed this data using a reflexive thematic analysis [9] and constructed stories of how they each co-shaped the metaphorical umwelt of their drones. More details about the study and analysis are available in [29]. Key moments from the footage and an animated render of each drone's umwelt can be found in the supplementary materials.

Justin, Nora, and Tom (pseudonyms) reviewed their stories and confirmed their experiences were represented accurately. They also agreed to have their photographs included in research publications. The study received ethics approval from the Royal Melbourne Institute of Technology, Australia (RMIT).









Justin and the amber umwelt

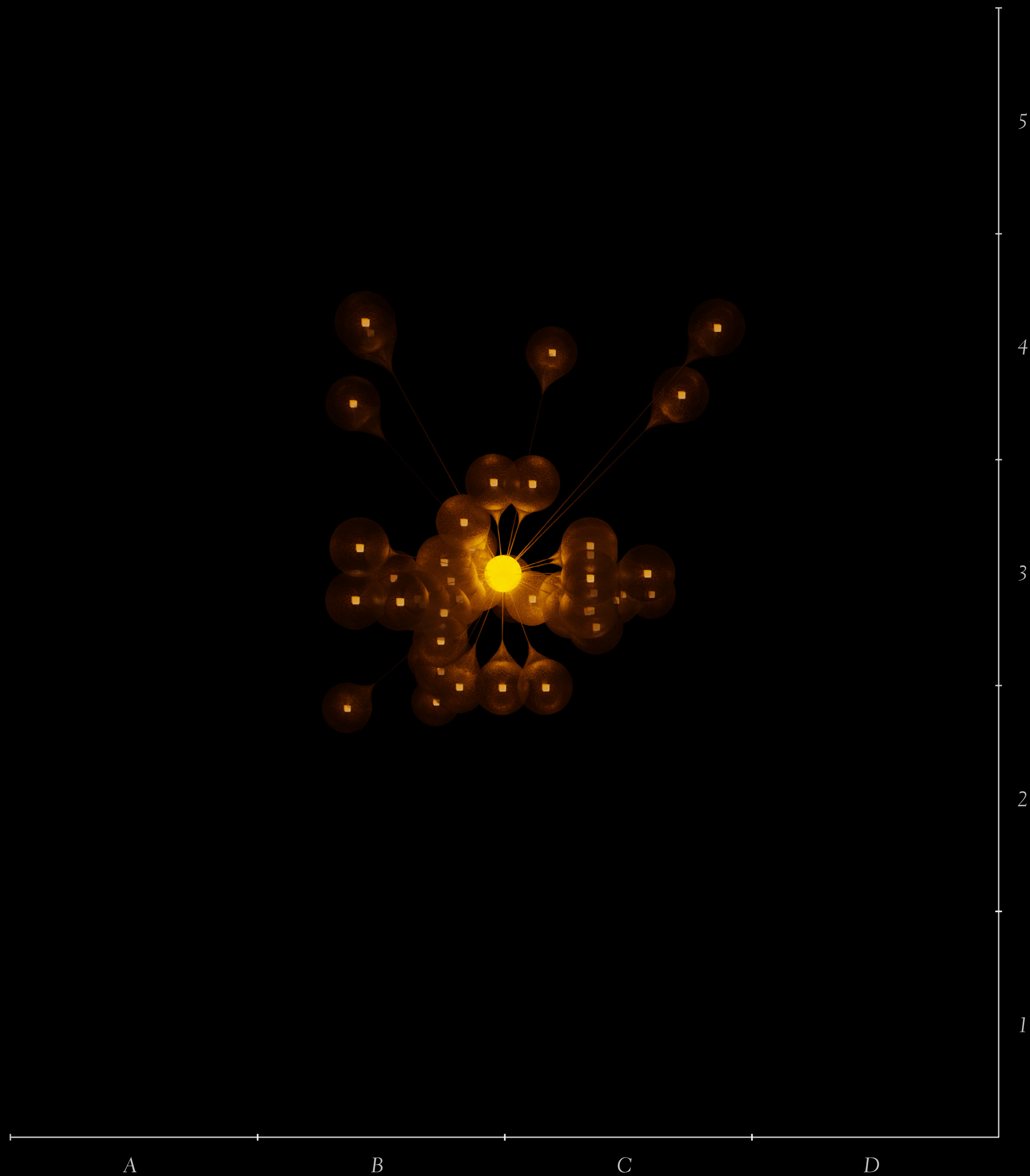
Justin is a maverick with relentless positive energy. He works as a bio-mechanical engineer and, beyond work, leads a busy life filled with many interests, including record collecting, ice hockey, and working on the restoration of his small wooden sailboat. Justin was given the amber drone. The amber drone is the most difficult of the three to move, due to the smallest amount of leeway around each point. This afforded a *brittle* quality to the interaction.

The first time Justin launched his drone, he immediately stretched his hands out in front of him and successfully created a position that held the drone in between his hands at about waist height. However, he could not take a single step in any direction before the drone abruptly broke contact, returning to spinning in place as his hands moved away from the active points. He often moved so quickly that he even bumped into the drone itself.

"I found that, when moving to the side, it's quite difficult. It's quite easy to move up and down because the drone doesn't get in the way, but when moving laterally...you're going to bump your hand into it."

Justin came to move his body in a highly coordinated manner. He began to appreciate that, to be able to move with the drone, he needed to coordinate his whole body to support the lateral movement of his hands. To move left, for example, rather than moving from the shoulders or the hips, Justin would cast a pointed left foot out to the side while placing his weight on a firmly planted right foot. He would then slowly shift his weight onto his left foot, keeping his arms still, as his torso and the drone, glided to the left together.

Conversely, Justins movements also shaped the drone. Looking at the points that Justin created from the pictured side view, we see that the amber drone has dense formations of points either side of it in sections B3 and C3 from Justin's numerous attempts to move it side-to-side. In the event that his lateral movements were too abrupt, these dense formations allowed him to quickly break out of one point and move into another. Once he mastered that, new formations started to spring much further from the drone in sections B4 and C4 as he began to explore new mvements.



Nora and the clear umwelt

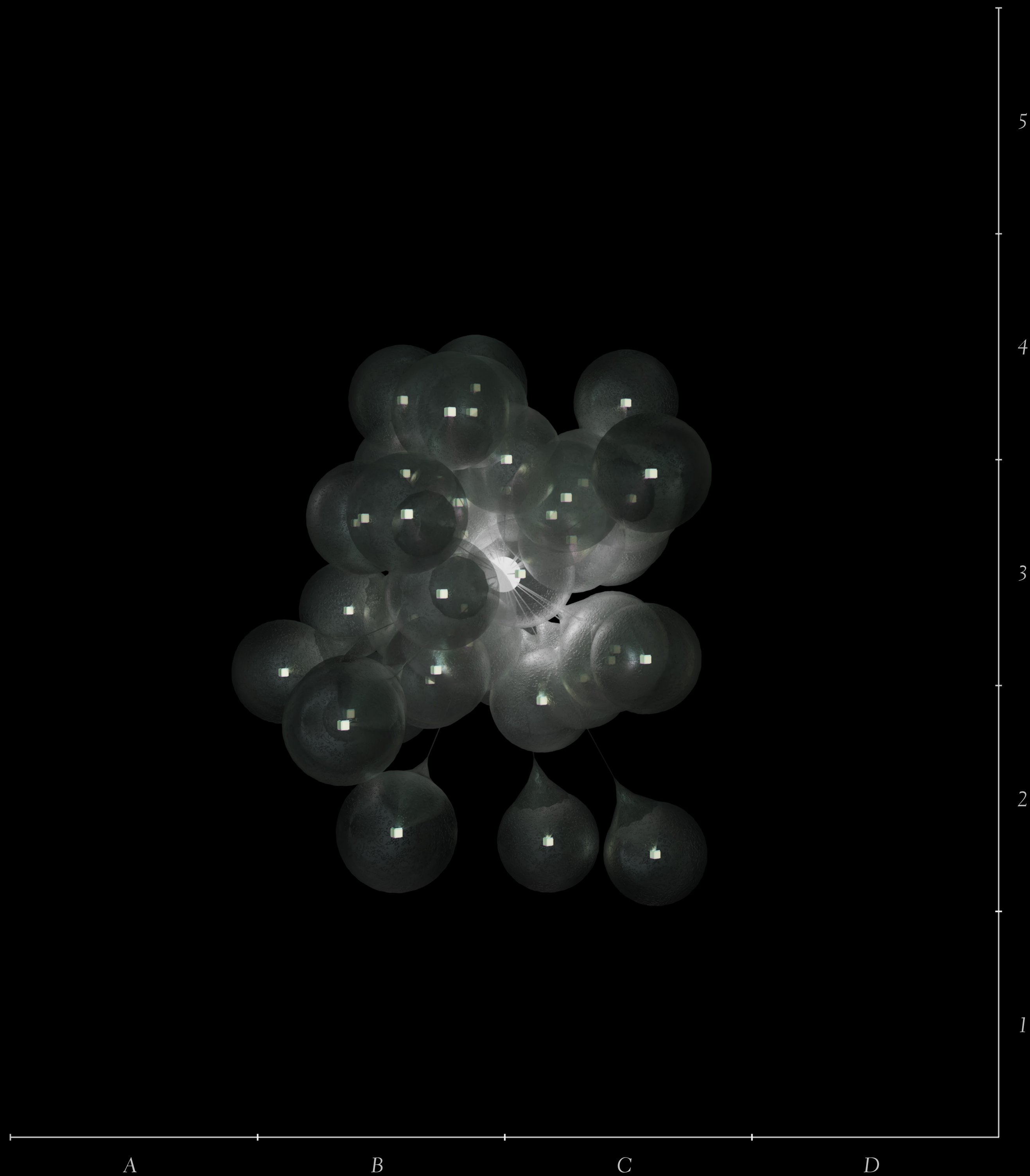
Nora is a vibrant, creative person with many different experiences from which to draw. Outside her job as a lead service designer, she regularly attends circus school and has previously practiced kung-fu and ballet. Nora was given the clear drone. The clear drone is the easiest to move, having the largest amount of leeway around each point. This afforded her drone a very *elastic* feel to its interaction.

Nora's drone first launched in front of her at chest height. She immediately placed her hands at head height and created a position. She then took a casual step sideways and the drone followed smoothly. She continued to move easily, back and forth across the room, taking big strides with a wide smile.

> *"For every session, I have approached it as having a fun time and just playing. I think in that context is good because you just have to respond to what is happening."*

Nora began to draw from her various creative practices to inspire her sessions with the drone. During one session, she stood with the drone held at chest height while the melody of Tchaikovsky's *Dance of the Sugar Plum Fairy* began to play. Nora lifted the drone high above her head and it broke free from her hands, spinning in place. Nora spun gracefully beneath the drone. When she reached up to retrieve the drone, she realized it was out of reach, and she leapt to retrieve it. Impressively, she did this in time with the music, bringing the drone down whilst smoothly dropping to her knees.

Looking at the points Nora created from a side view, we see that her drone has an evenly distributed capacity to sense her hands from any direction. But not to the fidelity that Justin's drone could. This is testament to how mobile she was with the drone from the outset. With her fluid and carefree style, she would plunge her hands into the central section of the cloud with no intention of catching any particular point. This meant that her drone was often darting around a lot to re-create previous triangles as her hands passed through many points in succession. Nora also had periods of purposeful movement with her drone and at greater distances. As shown by the points in sections B2 nd C2.



Tom and the blue umwelt

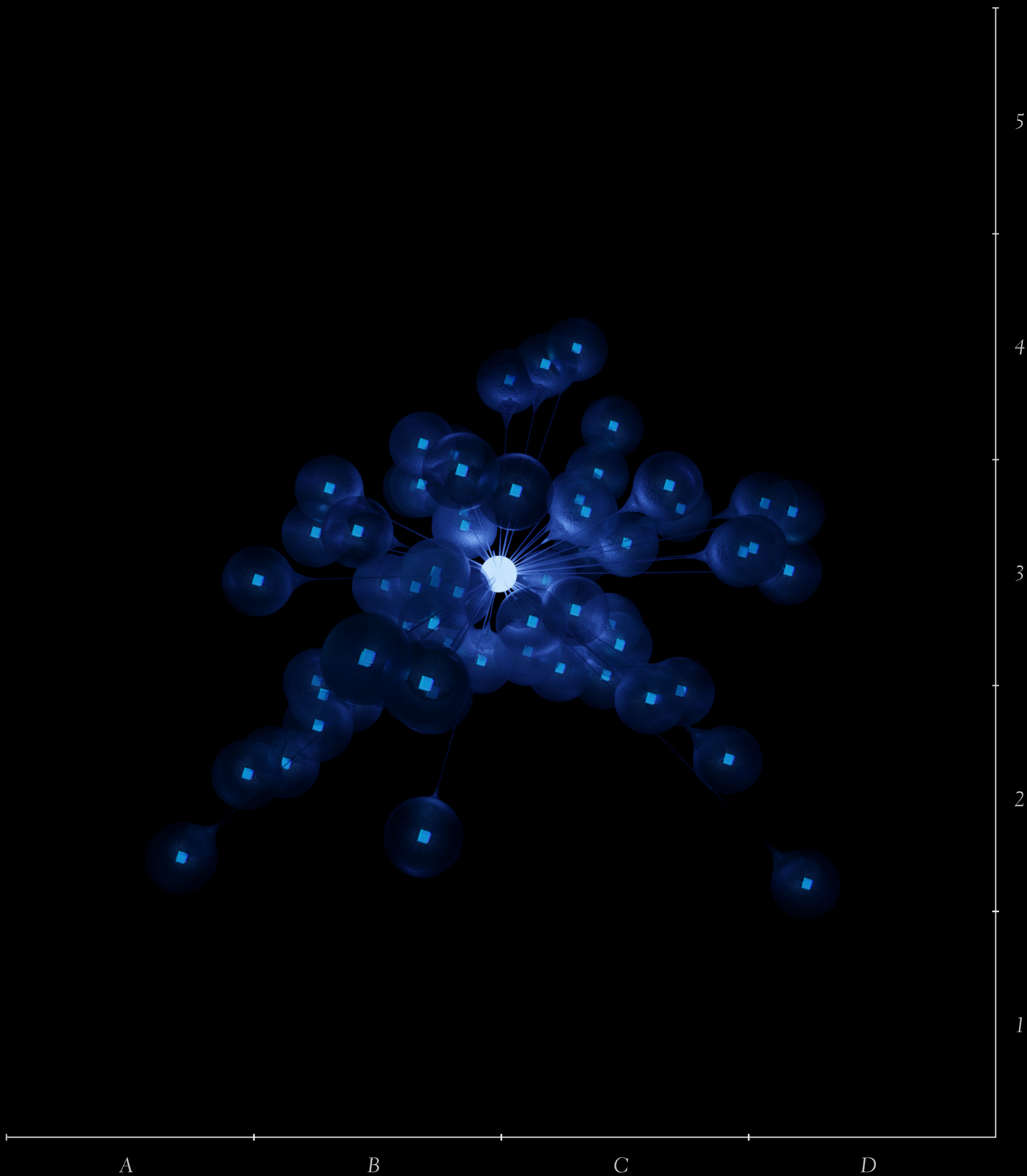
Tom loves to mess around but has a razor-sharp focus when learning or discussing something meaningful or of interest to him. He works as a machine learning engineer and enjoys going to the gym, practicing yoga, and playing board games. Tom was given the blue drone, which has an amount of leeway in between the amber and the clear drone.

During Tom's first session, the drone launched just below waist height. He moved his hands to either side of the drone and successfully created a position. Then, he immediately began to work on a plan. Tom later explained that he was attempting to lock the drone into positions that he was wanting to move through, linking them in a series of movements that he found fun and relaxing but also challenging. This meant that he was quite discerning about where he created points.

"If you just had points absolutely everywhere, that would be sort of boring to me, like free-form poetry. You have the whole world available to you, so, it is very hard to make a decision about which thing to use, as opposed to when you are constrained by the form and can be very creative in that form."

Towards the end of the month Tom's sequence went something like this: starting with the drone at eye level and about arms length away, he would then pull the drone down and inwards towards his navel before pushing it down and up again from head height. Then he opens his arms outwards to full span while keeping the drone still in front of his chest before finally closing his arms inwards to return himself and the drone to the starting position. The sequence was constantly evolving however, as Tom searched for new ways to flow through the existing structures he built.

Looking at the points that Tom created, from a top down view, we see two points in the foreground of section B2 and B3 which he used to push the drone down. We also see a great arc of points that stretch across sections A2 to D2. The greatest distance between them marks his arm span. Late in the deployment, he stopped making new points and tried fitting his body to the drone in new ways. Tom's pre-meditated approach shaped his drone such that his hands had a path to follow, allowing him to flow from one position to the next.



Discussion

By the end of the month, Justin, Nora and Tom had all become highly proficient at moving with their individual drones. All three had divergently evolved with their drones and in turn, each umwelt took a unique shape. Nora's approach allowed the shape of her drone's umwelt to emerge from her instinctive and aesthetically-motivated activities. Tom took a pre-meditated approach to purposefully shape his drone's umwelt, only allowing for new points within an over arching structure. Justin was initially dominated by the constraints of his drones phenotype, but eventually came to terms with how he and the drone could move together.

The design process we have presented, and the stories of Justin, Nora and Tom demonstrate the generative potential of this design metaphor. Throughout the design process, Joseph sought an alternative approach to designing human-drone interactions, moving away from pre-determined human-to-drone relationships. The metaphor of the umwelt allowed him to take a step back and consider the conditions from which an intimate and unique human-drone interaction could emerge (i.e. arranging a "space" for the interaction, rather than the interaction itself). To some degree, HTTYD was a success in this regard. Justin, Nora and Tom were able to build three very different and intimately coupled relationships. Therefore, we see the umwelt as a viable response to Alves-Oliveira et al.'s call for more varied metaphors in HRI [6].

Justin, Nora and Tom sensitized themselves to the experience of their drone and in doing so, came to reflect on the ways in which they enjoyed moving - a cornerstone of somaesthetic appreciation [24]. Here, we note that they also seem to have learned to somatically understand their drones; machines with an extremely different morphology to our own. Höök [23] reflects on this relationship in her account of learning a new style of horseback riding. She highlights the differences between the human bipedal body and the equine quadruped body and how they manifest in movement. Through mutual bodily adaptation, they learn to ride together.

"There is a longer discussion to be held here about whether I can really be perceiving and acting in the horse's world, or if I am always restrained by my morphology, stuck in what is "available" to humans—or, vice versa, if the horse can be in my world."[ibid.]

We see a strong connection between Höök's account and learning to move with machines and machine-like [37] systems such as robots and drones. The metaphor of the umwelt asserts that we cannot be in the drone's 'world'. However, we can potentially somatically sensitize ourselves to how the drone senses 'our world' and how we are acting on the 'drone's world'. HTTYD asked Justin, Nora and Tom, not only to learn to move with a drone but also, to some degree, teach the drone how to move. To do so, they needed to contemplate the metaphorical umwelt of the technology, sensitize themselves to what the drones were sensing and how they were acting. Using the metaphor of umwelt to inform our design decisions, allowed us to design an interaction that helped facilitate the emergence of this somatic understanding.

> *''Nothing can sense everything, and nothing needs to. Indeed, that is why umwelten exist at all. It is also why the act of contemplating the umwelt of another creature is so deeply human and so utterly profound. Our senses filter what we need. We must choose to learn about the rest'' Ed Yong [37]*

Finally, it is important to highlight that the space in between the points is just important as the points themselves. Namely, the quote above from Ed Yong leads to a broader design space that values *what and how* a human or machine can sense over how much, how fast, or to what fidelity. We believe that the umwelt metaphor could support meaningingful and somaesthetically meliorative experiences between humans and machines with varying capabilities and limitations.

Future Work

We now turn briefly to other fields, namely evolutionary robotics [2] and artificial life [1]. Here researchers build both physical robots and virtual agents that must learn to sense and act [10]. A pseudo evolutionary process iteratively changes these capacities to fit a specific environment [34]. These robots often have drastically non-human forms that blend mechanical and biological design features [8,13]. In practice, the design of an agent is approached holistically [35] and - like somaesthetics - recognises the inseparability of body, mind and environment [28].

However, the roboticist's intuition and experience is still needed to bound an otherwise infinite solution space [13]. This approach is exemplified by the motto "understanding by building" [28] which denotes a hands on approach to exploring "life as it could be" [35]. This bears a striking resemblance to research through design which instead probes *design* as it could be [36]. A detailed breakdown of the epistemological and methodological parallels between these bodies of work can be found in Joseph's dissertation [26].

Given these paralells, we wonder what it would be like to move with these 'creatures', to evolve with them. We see potential value in adopting some of the design strategies from these fields to inform how we can design somatic or embodied interactions with machines. We align our future work to these questions and join calls to seriously consider the generative and aesthetic potential of robotic systems [4,25,29].

Conclusion

We have presented a research product – *How To Train Your Drone*. The system and design process were driven by the metaphor of the umwelt: that our participants could shape how each drone sensed the world and ways of acting on the world together would emerge. The system was deployed over the course of a month, where three people - Justin, Nora, and Tom - co-shaped their drone's umwelt. In doing so, they each became uniquely proficient in moving with their drone. We contribute the umwelt as a metaphor for designing meaningingful and somaesthetically meliorative experiences with drones, robots or other machine-like systems.

Acknowledgements

We would like to thank Justin, Nora, and Tom for participating in the study and congratulate Nora and Justin on their recent marriage! We also acknowledge those who helped in the technical implementation of the system including: Tim Fist, Nick Huppert, Kristoffer Richardsson, Tobias Antonsson, Sam Nolan, Michael Smith, Ben Koder, Robert Jarvis, and Stuart Lee. We also thank Catherine Fist who collected some additional interview data; Ian Peake who offered his lab space to develop this project during the pandemic; Enrico Khatchapuridze for modelling the drone umwelts. Finally we would like to thank Joseph's supervision team; Floyd Mueller and Leah Heiss for their invaluable input and feedback.

This research was conducted across; RMIT University, Melbourne, Australia; KTH Royal Institute of Technology, Stockholm, Sweden; and Stockholm University, Stockholm, Sweden.

This research is supported by; The Digital Futures Drone Arena, a Digital Futures Demonstrator Project at the Department of Computer and Systems Sciences at Stockholm University and The Connected Intelligence Unit at Research Institutes of Sweden (RISE); The Swedish foundation for Strategic Research (SSF) project CHI19-0034 Hardware for Energy Efficient Bodynets; and the Wallenberg AI, Autonomous Systems and Software Program – Humanity and Society (WASP-HS) through a Marianne and Marcus Wallenberg Foundation project MMW 2019.0228; The Wallenberg AI, Autonomous Systems and Software Program (WASP) funded by the Knut and Alice Wallenberg Foundation; The Australian Government Research Training Program (type RSS).

The title font is dronefly. The jellyfish image is from Nikolay Kovalenko.

References

[1] 2023. ALIFE ISAL 2023 Complete Proceedings. https://doi.org/10.1162/isal_a_00704 arXiv:https://direct.mit.edu/isal/proceedings-pdf/isal/35/1/2149218/isal_a_00704.pdf

[2] 2023. GECCO '23 Companion: Proceedings of the Companion Conference on Genetic and Evolutionary Computation (Lisbon, Portugal). Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3583133

[3] 2024. Home | Bitcraze. https://www.bitcraze.io/

[4] Naoko Abe. 2022. Beyond anthropomorphising robot motion and towards robot-specific motion: consideration of the potential of artist—dancers in research on robotic motion. Artificial Life and Robotics 27, 4 (01 Nov 2022), 777–785. https://doi.org/10.1007/s10015-022-00808-0

[5] Giorgio Agamben. 2004. The Open: Man and Animal. Stanford University Press, Stanford. 120 pages. http://www.sup.org/books/title/?id=5305

[6] Patrícia Alves-Oliveira, Maria Luce Lupetti, Michal Luria, Diana Löffler, Mafalda Gamboa, Lea Albaugh, Waki Kamino, Anastasia K. Ostrowski, David Puljiz, Pedro Reynolds-Cuéllar, Marcus Scheunemann, Michael Suguitan, and Dan Lockton. 2021. Collection of Metaphors for Human-Robot Interaction. In Proceedings of the 2021 ACM Designing Interactive Systems Conference (DIS '21). Association for Computing Machinery, New York, NY, USA, 1366–1379. https://doi.org/10.1145/3461778.3462060

[7] Harvey Bewley and Laurens Boer. 2018. Designing Blo-Nut: Design Principles, Choreography and Otherness in an Expressive Social Robot. In Proceedings of the 2018 Designing Interactive Systems Conference (Hong Kong, China) (DIS '18). Association for Computing Machinery, New York, NY, USA, 1069–1080. https://doi org/10.1145/3196709.3196817

[8] Josh Bongard, Victor Zykov, and Hod Lipson. 2006. Resilient Machines Through Continuous Self-Modeling. Science 314, 5802 (2006), 1118–1121. https://doi.org/10.1126/science.1133687 arXiv:https://www.science.org/doi/pdf/10.1126/science.1133687

[9] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. Qualitative Research in Psychology 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa arXiv:https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp063oa

[10] N. Bredeche, S. Doncieux, and J.-B. Mouret. 2019. Evolutionary Robotics Tutorial. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (Prague, Czech Republic) (GECCO '19). Association for Computing Machinery, New York, NY, USA, 431–460. https://doi.org/10.1145/3319619.3323391

[11] Jessica R Cauchard, Jane L E, Kevin Y Zhai, and James A Landay. 2015. Drone & me: an exploration into natural human-drone interaction. In Proceedings of the 2015 ACM international joint conference on pervasive and ubiquitous computing. 361–365.

[12] Jessica R. Cauchard, Kevin Y. Zhai, Marco Spadafora, and James A. Landay. 2016. Emotion encoding in Human-Drone Interaction. In 2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI). 263–270. https://doi.org/10.1109/HRI.2016.7451761 ISSN: 2167-2148.

[13] Francesco Corucci, Marcello Calisti, Helmut Hauser, and Cecilia Laschi. 2015. Novelty-Based Evolutionary Design of Morphing Underwater Robots. In Proceedings of the 2015 Annual Conference on Genetic and Evolutionary Computation (Madrid, Spain) (GECCO '15). Association for Computing Machinery, New York, NY, USA, 145–152. https://doi.org/10.1145/2739480.2754686

[14] Emily S. Cross and Richard Ramsey. 2021. Mind Meets Machine: Towards a Cognitive Science of Human–Machine Interactions. Trends in Cognitive Sciences 25, 3 (March 2021), 200–212. https://doi.org/10.1016/j.tics.2020.11.009

[15] Ian de Vere, Gavin Melles, and Ajay Kapoor. 2010. Product design engineering – a global education trend in multidisciplinary training for creative product design. European Journal of Engineering Education 35, 1 (2010), 33–43. https://doi.org/10.1080/03043790903312154 arXiv:https://doi.org/10.1080/03043790903312154

[16] Joseph La Delfa. 2024. crazyflie-clients-python. https://github.com/cafeciaojoe/crazyflie-clients-python/tree/HTTYD_crazyflie_pull

[17] Joseph La Delfa. 2024. crazyflie-firmware. https://github.com/cafeciaojoe/crazyflie-firmware/tree/User_Study_Hand_Pads

[18] Sara Eriksson, Åsa Unander-Scharin, Vincent Trichon, Carl Unander-Scharin, Hedvig Kjellström,

and Kristina Höök. 2019. Dancing with drones: Crafting novel artistic expressions through intercorporeality. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.1–12.

[19] P. Godfrey-Smith. 2016. Other Minds: The Octopus, the Sea, and the Deep Origins of Consciousness. Farrar, Straus and Giroux. https://books.google.se/books?id=SZ8sDAAAQBAJ

[20] P. Godfrey-Smith. 2020. Metazoa: Animal Life and the Birth of the Mind. Farrar, Straus and Giroux. https://books.google.se/books?id=yCLQDwAAQBAJ

[21] Sabrina Hauser, Ron Wakkary, William Odom, Peter-Paul Verbeek, Audrey Desjardins, Henry Lin, Matthew Dalton, Markus Schilling, and Gijs De Boer. 2018. Deployments of the table-non-table: A Reflection on the Relation Between Theory and Things in the Practice of Design Research. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. 1–13.

[22] V. Herdel, A. Kuzminykh, Y. Parmet, and J. R. Cauchard. 2022. Anthropomorphism and Affective Perception: Dimensions, Measurements, and Interdependencies in Aerial Robotics. IEEE Transactions on Affective Computing 01 (jan 2022), 1–12. https://doi.org/10.1109/TAFFC.2024.3349858

[23] Kristina Höök. 2010. Transferring Qualities from Horseback Riding to Design. In Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries (Reykjavik, Iceland) (NordiCHI '10). Association for Computing Machinery, New York, NY, USA, 226–235. https://doi.org/10.1145/1868914.1868943

[24] Kristina Höök. 2018. Designing with the body: somaesthetic interaction design. MIT Press, Cambridge, Massachusetts. https://mitpress.mit.edu/9780262038560/designing-with-the-body/

[25] Jonas Jørgensen. 2023. Towards a Soft Science of Soft Robots. A Call for a Place for Aesthetics in Soft Robotics Research. ACM Transactions on Human-Robot Interaction 12, 2 (March 2023), 15:1–15:11. https://doi.org/10.1145/3533681

[26] Joseph La Delfa. 2023. Cultivating Mechanical Sympathy: Making meaning with ambiguous machines. Ph. D. Dissertation. KTH Royal Institute of Technology.

[27] Joseph La Delfa, Mehmet Aydin Baytas, Emma Luke, Ben Koder, and Florian 'Floyd' Mueller. 2020. Designing Drone Chi: Unpacking the Thinking and Making of Somaesthetic Human-Drone Interaction. Association for Computing Machinery, New York, NY, USA, 575–586. https://doi.org/10.1145/3357236.3395589

[28] Joseph La Delfa, Mehmet Aydın Baytas, Rakesh Patibanda, Hazel Ngari, Rohit Ashok Khot, and Florian 'Floyd' Mueller. 2020. Drone Chi: Somaesthetic Human-Drone Interaction. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376786

[29] Joseph La Delfa, Rachael Garrett, Airi Lampinen, and Kristina Höök. 2024. Articulating Mechanical Sympathy for Somaesthetic Human–Machine Relations. In Proceedings of the 2024 ACM Conference on Designing Interactive Systems. 1–18. https://doi.org/10.1145/3643834.3661514

[30] Lian Loke and Toni Robertson. 2013. Moving and making strange: An embodied approach to movement-based interaction design. ACM Transactions on Computer-Human Interaction 20, 1 (March 2013), 1–25. https://doi.org/10.1145/2442106.2442113

[31] Elena Márquez Segura, Laia Turmo Vidal, and Asreen Rostami. 2016. Bodystorming for movement-based interaction design. Human Technology 12, 2 (Nov. 2016), 193–251. https://doi.org/10.17011/ht/urn.201611174655

[32] William Odom, Ron Wakkary, Youn-kyung Lim, Audrey Desjardins, Bart Hengeveld, and Richard Banks. 2016. From Research Prototype to Research Product. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (San Jose, California, USA) (CHI '16). Association for Computing Machinery, New York, NY, USA, 2549–2561. https://doi.org/10.1145/2858036.2858447

[33] Ian Peake, Joseph La Delfa, Ronal Bejarano, and Jan Olaf Blech. 2021. Simulation Components in Gazebo. In 2021 22nd IEEE International Conference on Industrial Technology (ICIT), Vol. 1. 1169–1175. https://doi.org/10.1109/ICIT46573.2021.9453594

[34] R. Pfeifer and J. Bongard. 2006. How the Body Shapes the Way We Think: A New View of Intelligence. MIT Press, Cambridge, Massachusetts.https://books.google.se/books?id=EHPMv9MfgWwC

[35] Rolf Pfeifer, Fumiya Iida, and Josh Bongard. 2005. New Robotics: Design Principles for Intelligent Systems. Artificial Life 11, 1-2 (Jan. 2005), 99–120. https://doi.org/10.1162/1064546053279017

[36] Johan Redström. 2017. Making design theory. MIT Press, Cambridge, Massachusetts.

[37] Eleanor Sandry. 2015. Re-evaluating the Form and Communication of Social Robots - The Benefits of Collaborating with Machinelike Robots. Int. J.Soc. Robotics 7, 3 (2015), 335–346. https://doi.org/10.1007/s12369-014-0278-3

[38] M. Sheets-Johnstone. 2011. The Primacy of Movement: Expanded second edition. John Benjamins Publishing Company. https://books.google.se/books?id=xZa85IJZH1IC

[39] Richard Shusterman. 2000. Pragmatist aesthetics: Living beauty, rethinking art. Rowman & Littlefield Publishers.

[40] Mousa Sondoqah, Fehmi Ben Abdesslem, Kristina Popova, Moira McGregor, Joseph La Delfa, Rachael Garrett, Airi Lampinen, Luca Mottola, and Kristina Höök. 2024. Shaping and Being Shaped by Drones: Programming in Perception-Action Loops. In Proceedings of the 2024 Conference on Designing Interactive Systems. 1–29. https://doi.org/10.1145/3643834.3661636

[41] Anna Ståhl, Martin Jonsson, Johanna Mercurio, Anna Karlsson, Kristina Höök, and Eva-Carin Banka Johnson. 2016. The Soma Mat and Breathing Light. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (San Jose, California, USA) (CHI EA '16). Association for Computing Machinery, New York, NY, USA, 305–308. https://doi.org/10.1145/2851581.2889464

[42] B. Tversky. 2019. Mind in Motion: How Action Shapes Thought. Basic Books. https://books.google.se/books?id=lv1wDwAAQBAJ

[43] J von Uexküll. 1992. A stroll through the worlds of animals and men: A picture book of invisible worlds. Semiotica 89, 4 (1992), 319–391.

[44] Ron Wakkary, Doenja Oogjes, Henry W. J. Lin, and Sabrina Hauser. 2018. Philosophers Living with the Tilting Bowl. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (Montreal QC, Canada) (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173668

[45] E. Yong. 2022. An Immense World: How Animal Senses Reveal the Hidden Realms Around Us. Random House Publishing Group. https://books.google.se/books?id=TLhPEAAAQBAJ

[46] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through Design as a Method for Interaction Design Research in HCI. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (San Jose, California, USA) (CHI '07). Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704