AGENTIAL SCORES: EXPLORING EMERGENT, SELF-ORGANISING AND ENTANGLED MUSIC NOTATION

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ABSTRACT

Dynamic scores have gained popularity as an innovative intervention in musical performance, providing novelty for both performers and audiences. In this paper, we discuss agential scores and the implications of their emergent, self-organising, and entanglement affordances for musical performance ecologies. We approach this through practice-based research, introducing Tölvera, an artificial life software library for agential scores. We propose a typology of interaction scenarios for agential scores and investigate a subset of these, presenting the outcomes of early artistic encounters with Tölvera between two improvising guitarists. Reflecting on our experiences, we emphasise the unique challenges that emerge from engaging with scores as real-time agents, suggesting that agential scores promote fluidity of form in notation, which consequently prompts performers to identify with, mirror, and attune to them. Although scores have always possessed agency, we argue that a more explicit and practical focus on agency raises new questions and offers new possibilities for the intra-actions between human and non-human agents within musical ecologies.

1. INTRODUCTION

Musical scores serve as pivotal components within the musical cultures in which they are utilised, influencing the thoughts and actions of composers, performers, concert organisers, audiences, and music as a whole. This impact can be characterised in terms of material agency. Historically, the vigour of this agency has been limited by display and reproduction technologies, such as print media. However, computational multimedia scores are now truly coming to life through innovative mediums encompassing biology, artificial life simulation, and artificial intelligence. In the mediaeval era, music notation evolved into standards that represented principles in instrument making, musical training, and performance contexts. However, notation experienced significant diversification beginning in the twentieth century.

Under prescriptive notation, new developments and symbols have been added to the traditional Western notational system. These include graphic scores, enhanced tablatures, verbal notation [1], event scores [2], generative software and live coding [3], instruction pieces [4], realisation scores [5], soundpainting [6], S-notation for DJs [7], and animated notation [8]. Additionally, tangible [9] and haptic [10] scores, artificial life scores [11], and more have emerged.

Generative and dynamic scores have been extensively investigated, and the role of computational technologies is crucial in their implementation: computers enable us to achieve truly “dynamic media” [12] that were impossible with acoustic or purely analogue electronic technologies. These scores exhibit such diversity that their own becomes fluid and interchangeable with that of the composer, instrument or audience. Such systems span from being open to interpretation, where performers interpret as they wish, to more rigid systems where performers precisely execute what the system generates, for instance, by playing generated notes displayed in staff notation.

In our work involving dynamic and agential scores, we endeavour to utilise the emergent and self-organising properties of artificial life as a notational system for composition and performance. This is part of our wider effort to develop a library of technical components for composing musical systems, encompassing real-time MIDI models [13], feedback systems [14], sensors, actuators, and more, which we refer to as the *Organolib* [1] . The Organolib does not target a specific combination of composer, interpreter, instrument, and audience; instead, it aims to promote an ecological mindset regarding the distribution of agencies among technical elements and musical roles. Ultimately, we strive to facilitate the emergence of epiphenomenal structures that could be characterised as musical agency.

This paper presents our preliminary investigations into agential scores through artificial life. In contrast to the recent trends in artificial intelligence that favour machine learning approaches, both in industry and the arts, artificial life remains a relatively marginalised field, albeit one that may be experiencing a resurgence in interest. For us, artificial life serves as an almost literal Petri dish for practical exploration into musical agency [15], providing a diverse array of systems and species that inevitably engage with topics such as biology, evolution, ecology, philosophy, computation, and more.

[1] https://iil.is/research/organolib

2. BACKGROUND

2.1 Perspectives on Agency

The concept of agency frequently arises in the realm of new musical instrument design. These instruments are perceived to possess a certain degree of agency, influencing how we think, play, and behave within a specific performance ecology [16]. However, there is no general consensus on the meaning of agency, and various theoretical fields offer different perspectives.

In this context, we can contrast analytical philosophy, which views agency as a property of an intelligent being, typically the intentional action of an ethical human being [17], with theoretical biologists who regard agency as a characteristic of living organisms, as exemplified in the theory of autopoiesis [18]. Additionally, sociologists and philosophers of technology consider agency as a property of matter and objects [19], or of their intra-action [20].

Frauenberger refers to the convergence of these diverse viewpoints as "entanglement HCI" [21], asserting that "it is through non-human agency that we can create nuanced links between design intent, context of use, and people intra-acting with technology." In response to this notion, Nordmoen and McPherson describe a "decentring from human to more-than-human" approach in their practical explorations of interactive systems, acknowledging the "ecologies of different types of knowledge and raw materials" involved [22].

The autopoietic theory by Maturana and Varela [18] characterises living organisms not as physical entities, but rather as networks of processes [23]. Some have advocated for a "more embodied reformulation of autopoiesis" to address the perceived overly disembodied nature of the autopoietic theory's original formulation [24]. This argument for embodiment resonates with Sarah Kember's cyberfeminist critique of ALife, which challenges earlier conceptions of life as information [25].

2.2 Exploring Agency through Boundary Objects

In the realm of musical instrument theory, agency is characterised as a relational concept [26]. Although sociologist Latour finds it reasonable to attribute agency to a specific door-locking mechanism [27] (thing-agency), such a notion may not be appealing to a biologist (bio-agency). As we engage with intelligent instruments, we are not only confident in our recognition of agency within the technologies we create but also actively investigating the boundaries surrounding the term. This is not a straightforward task, particularly as the concept of agency is rapidly evolving within the context of contemporary AI advancements.

In this regard, we perceive our agential scoring system, delineated in the subsequent section, as a boundary object [28] for examining agency from a multitude of diverse perspectives. Stapleton and Davis [29] discuss agency as distributed and relational, occurring in the interaction between the performer and the instrument. We concur with this ontology; however, in our work with artificial life and machine learning, it is also intriguing to investigate how we and the users of our instruments engage with these terms when projecting our ideas onto the dynamic behaviour of our systems [14]. Our research programme does not aim to rigidly define these terms from the outset; instead, we endeavour to observe how they are applied in the context of use by composers, performers, and audience members.

3. AGENTIAL SCORES

Taking into account the perspectives reviewed in Section 2.1, we propose an approach to musical notation that we call agential scores. Initially, we have been considering an agential score as one that responds to environmental inputs, possesses goals or directions, seeks equilibrium or development based on these objectives, and maintains a self-identical unity that endures over time. In our work involving artificial life as components of dynamic scores and musical instruments, we explore emergent behaviours that arise only when individual parts interact within a larger system. Although attributing goal-seeking characteristics may appear anthropomorphic, recent biological theories have challenged the notion of restricting such terms exclusively to humans [31]. In this spirit, we prefer to maintain openness regarding defining this space.

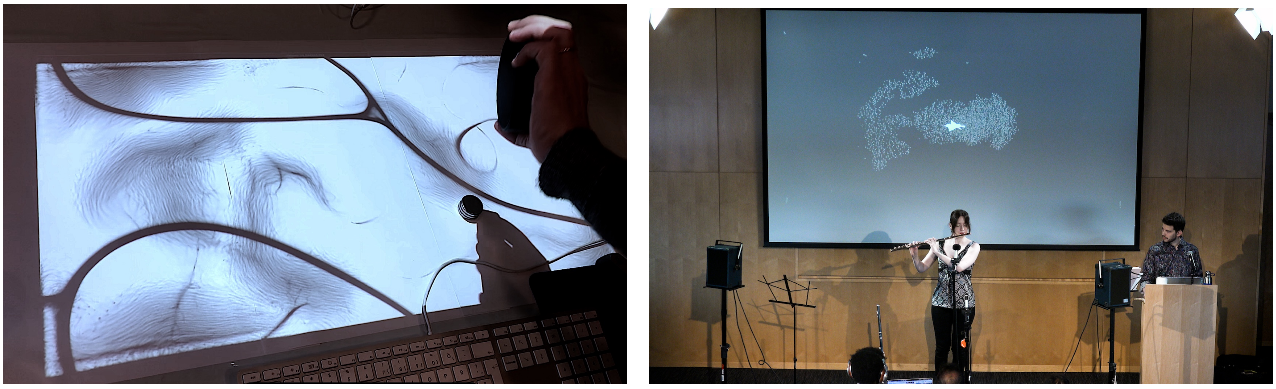
In this section we start from the bottom-up, by describing the agency of raw notational inscriptions, and then move to the top-down, by describing the entanglements [21] between scores, instruments, composers and performers. Then we turn to describing what emerges out of these entanglements in terms of assemblages [32] and intra-action [20].

3.1 Agency of Points and Lines

The historical significance of points and lines can be traced back to the earliest known human writing systems [33], and primitive geometries have been found to possess consistent interpretations across cultures and geographies [34]. Similarly, points and lines are also deemed to be prevalent elements in numerous forms of music notation throughout history [35].

In static, dynamic, and computational musical scores, points and lines exhibit distinct agencies, akin to their differences in paintings, animations, and real-time computer graphics. The painter Kandinsky ascribed concealed human attributes to points, characterising them as "the highest degree of restraint which, nevertheless, speaks." [36] Another artist, Paul Klee, illustrated in his pedagogical sketchbook, "An active line on a walk, moving freely, without goal. A walk for a walk's sake. The mobility agent is a point, shifting its position forward." [37] Although paintings remain static, our eyes move in relation to them, and both Kandinsky and Klee imbue their stationary media with a sense of motion. Conversely, animated points and lines exhibit actual movement. Pioneer Norman McLaren's concept of "pure" cinema emphasised "little or no reliance on factors other than motion", favouring the expressive potential of basic forms over cinematography [38].

Nonetheless, once drawn or rendered, the motion of points and lines in animation remains fixed in time. In this context, we can differentiate between a temporally fixed dynamic score and a procedural dynamic score, where the



(a) *FerroNeural* (2023) featuring gestural control of a Tölvera scene via handheld magnetic disc controllers [30]. Authors: Nicola Privato and Jack Armitage.

(b) *Motherbird* (2023) featuring interactive Tölvera murmuration simulation. Authors: Jessica Shand, Manuel Cherep and Jack Armitage. Photo: James Day, MIT Media Lab.

Figure 1: Photos from the development of the first two collaborative musical works that incorporate Tölvera.

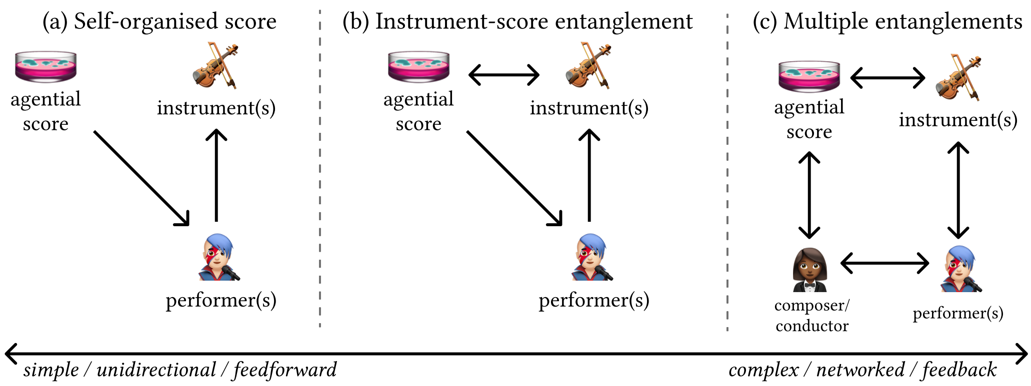


Figure 2: Three examples of entanglements [21] with agential scores, along a continuum of complexity. We investigate the phenomenology of self-organised scores (a, left) in Section 5. We are exploring instrument-score entanglements (b, middle) in the piece *FerroNeural* (Figure 1a), and multiple entanglements (c, right) in the piece *Motherbird* (Figure 1b).

latter is rendered in context, such as during live drawing or when utilising software. Specifically, with software, the preconception of motion is abstracted into the code. Self-organising swarms represent one artificial life approach for delegating notational dynamism in a manner that leads to the emergence of intriguing behaviour. Within this emergence, there exists the potential for points and lines with a fluid materiality, which reside "in the grey area of the continuum and have both the affordance of things and stuff" [39]. Self-organising systems advance the tradition of scores as points and lines, offering novel ways of experiencing fluid points and lines as notation.

3.2 A Typology of Entanglements with Agential Scores

Owing to the potential combinations of mappings between scores, instruments, and musicians, there is plenty to explore. Figure 2 depicts three examples of what we describe as entanglements with agential scores, following Frauenberger's description of entanglement human-computer interaction (HCI) [21]. In this way we suggest a typology of entanglements with agential scores based on identifying the network of relationships between "agents", as one way of decomposing the space of agential scores. There are many more possibilities that could potentially be described in this typological manner. We have found distinguishing types of entanglements can aid in the early stages of the agential score composition process, and when introducing agential scores to collaborators. There is also potential for such a typology to be developed further and used as an analysis tool, since it can also be used to describe performance ensembles and ecologies that do not necessarily make use of dynamic or computational media. We envision this might be useful as one of many "ad-hoc taxonomies" in a heterarchical organological interpretation [40].

3.3 Assemblages and Intra-action

We must also address the limitations of a purely typological approach to agential scores, which can only describe the elements of an entanglement and their relationships in simple terms, and not the emergent properties that arise from the interactions between them. Théberge proposes to consider musical instruments as assemblages, "components within a network" where the instrument maker's role is to "design relationships" rather than objects [32]. Barad

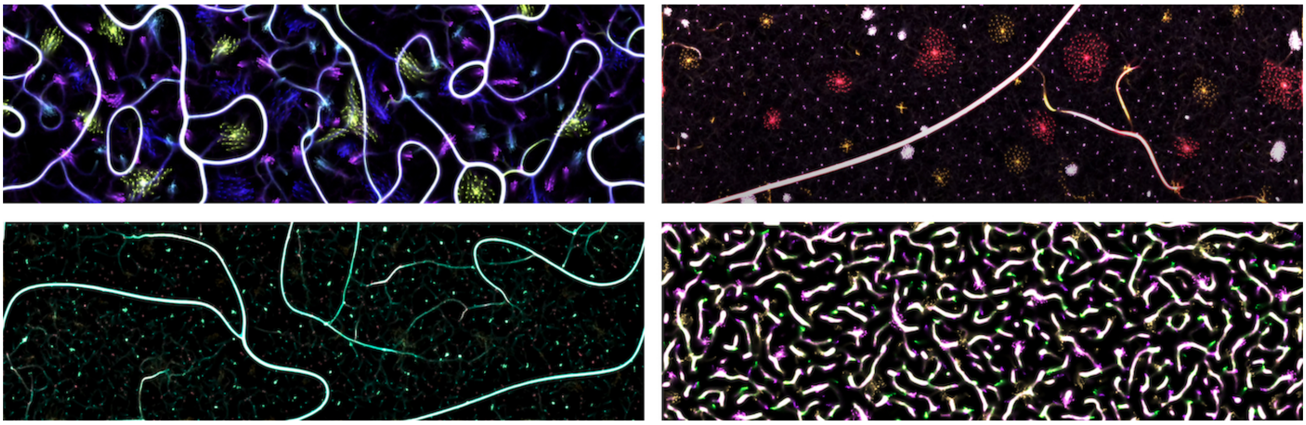


Figure 3: Examples of Tölvera combining Boids particles and Physarum pheromone trails, where the Boids particles also deposit pheromones to attract the Physarum. The variations arise from each species' behavioural parameters and the weighting of the mapping between them.

would describe working with musical scores from this perspective as a form of *intra-action*, "the mutual constitution of entangled agencies", which is contrasted with "the usual 'interaction', which assumes that there are separate individual agencies that precede their interaction". For Barad, "agencies are only distinct in relation to their mutual entanglement; they don't exist as individual elements". [20] Though emergent properties can be described in the reductive context of computer simulations, these are potentially much less determinable in the context of live musical performance. Detailed interpretations and reflections of these do exist in the context of highly entangled musical instruments [26, 29], but less appears to have been said about the role and agency of (particularly dynamic) scores in such entanglements. It is here that we perceive a research need that the framing of agential scores can potentially help to address, if it can be put into practice.

3.4 Agential Scores in Practice via Artificial Life

This work represents our first attempt to practically investigate agential scores, using artificial life, as many have done before although not with our specific aims and motivations in mind. Artificial life has been employed in both the sciences and the arts for various purposes. Christopher Langton, a founding advocate for the field, defines it as "life-as-it-could-be" [41]. Researchers within the field have elucidated and investigated how it can assist biologists and cognitive scientists in exploring the intricate issues of mind, agency, intelligence, and autopoiesis [18]. Although machine learning, particularly deep learning, has recently been the most publicised subdomain of artificial intelligence, there is now a growing interest in incorporating self-organising systems within these fields [42]. Additionally, machine learning is being utilised to train high-level goals in self-organising systems [43, 44]. In the arts, artificial life has been applied in the realm of computational creativity as systems capable of producing creative outcomes, such as in music or computer graphics [45]. In this context, artificial life is not perceived as a tool for solving problems but rather as an instrument that offers innovative, generative patterns and creative pathways [46].

4. TÖLVERA: A LIBRARY OF NUMBER BEINGS

Tölvera[2] is an open-source Python library for designing musical instruments and musical notations using artificial life[3]. Compared with existing tools like *NetLogo* and *Golly*, Tölvera is designed to use a modern and portable implementation, be more accessible and extensible to creative coders, and to be more easily integrated into musical instruments and notation systems. The name is an example of a *kenning*, a metaphorical compound expression found in Old Norse and Old English poetry. Tölvera combines the Icelandic words for computer (*tölvu*, derived from tala - number - and völva - prophetess or oracle) and being (*vera*). Our lab is situated in Iceland, and we have discovered that immersing ourselves in the local culture enhances our work and encourages public participation and collaboration [14]. We are also intentionally engaging with the agency of the Icelandic language itself, juxtaposing artificial life and musical scores with Icelandic folklore and mythology. Combining *number* with *being* also alludes to the discourse surrounding embodiment in artificial life, as discussed in Section 2. Listing 1 shows a simple Tölvera program that renders particles to a window.

```python
import taichi as ti
import tolvera as tol
def main(x=1920, y=1080, n=512, species=3):
    ti.init()
    particles = tol.Particles(x,y,n,species)
    pixels = tol.Pixels(x,y)
    def render():
        pixels.clear()
        particles(pixels)
    pixels.show(render)
```

Listing 1: Example of a Tölvera program that renders particles to a window.

[2] https://github.com/Intelligent-Instruments-Lab/iil-python-tools/tree/master/tolvera

[3] Please see the Tölvera YouTube playlist for demos and work-in-progress experiments https://www.youtube.com/playlist?list=PL8bdQleKUA1vNez5gw-pfQB21Q1-vHn3x.

4.1 Number Beings

Tölvera consists of a small number of simulations (vera, or beings) that are variously inspired by physics, biology, computation, or some mixture of these. Familiar examples include *Boids*, the classic flocking algorithm by Craig Reynolds. [47], and *Physarum*, a slime mould simulation popularised by artists such as Sage Jensen [4] . [48]. We are experimenting with adding many more vera such as *Lenia*, an artificial life continuous cellular automata (CCA) system discovered by Bert Chan, as a smooth generalisation of Conway's Game of Life. [49]. However, so far we have focused on the design of the library, so that it can be easily used by creative coders, and extended by other developers. Listing 2 shows a Tölvera program that renders multiple species of particles to a window.

```python
def render():
    pixels.diffuse()
    boids(particles)
    particles(pixels)
    physarum(particles)
    pixels.set(physarum.trail.px)
```

Listing 2: Example of a Tölvera render function that creates compound motion of particles by combining boids and physarum algorithms. In future this will be syntactically simplified via method chaining to e.g. `particles.boids(args).physarum(args)`.

Any real-time Taichi program can potentially be added or contributed to the Tölvera library, and though we do not prescribe a coding style, so far we follow Taichi's objective data-oriented programming paradigm by implementing each species or simulation as a data-oriented class. [5] As in other real-time creative computing contexts, each class aims to provide simple "process" functions that step the simulation forward and update behavioural parameters.

4.2 Mappings and Visualisations

One of the expressed aims of Tölvera is to commingle interfaces and instruments with artificial life. In this way, we envision that instruments provide input and output data streams to Tölvera, becoming its connection to physical reality. At the same time, Tölvera becomes integrated into the instrument for its performer. Listing 3 shows how to send and receive OSC messages from a Tölvera program.

Tölvera can by default run as a window on a regular computer screen. However, we have observed that projecting Tölvera onto horizontal surfaces (either from above or below) encourages intimate engagements, through tactile interventions such as hand-drawing notation, and improvised use of objects as notation (see Figures 1 and 4). Further, Tölvera could in future integrate computer vision to recognise these as inputs to the simulations, resulting in a commingling of physical and computational processes.

[4] https://cargocollective.com/sagejenson/physarum
[5] https://docs.taichi-lang.org/docs/odop

```python
p = tol.Particles(x,y,n,species)
# ...
osc_update = OSCUpdaters(osc, client="simple",
    receives={
        "/particles/set/pos": p.osc_set_pos,
        "/particles/set/vel": p.osc_set_vel
    }, receive_count=10,
    sends={
        "/particles/get/pos/all": p.osc_get_pos_all
    }, send_count=60
)
# ...
def render():
    osc_update()
    pixels.clear()
    particles(pixels)
```

Listing 3: Example of OSC messages being sent and received by the OSCUpdaters class in Tölvera. Counters are used to rate-limit how frequently received messages are processed and how frequently messages are sent. This allows OSC messages to be sent and received at a rate that is independent of the frame rate.

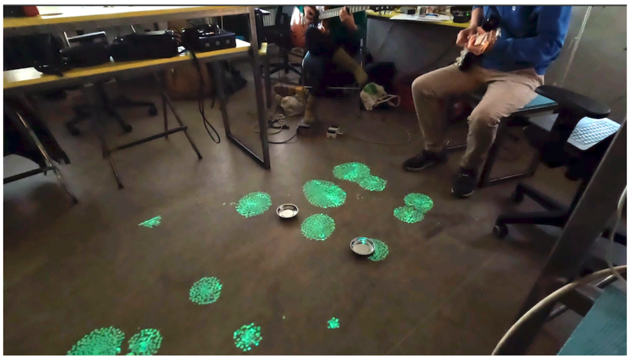
4.3 Implementation

Tölvera programs can be run in real-time on the CPU or GPU of a modern laptop, [6] and combined with other Python libraries enabling additional features such as machine learning. Tölvera is implemented in Taichi [7] , an imperative, parallel, domain specific language embedded in Python, for high-performance numerical computation. Taichi uses just-in-time (JIT) compiler frameworks such as LLVM, to offload compute-intensive code to native GPU or CPU instructions. We chose Taichi because it enables optimised graphics programming through a familiar high-level language, and because, being embedded in Python, it can interoperate with the rich tapestry of the machine learning ecosystem. Taichi programs can also be run on the GPU without any visual rendering, allowing the programs to be run "headless" in more resource-constrained contexts. They can be compiled to C/C++, and then to JavaScript via Emscripten, and also run in Unity, [8] enabling a wide variety of target contexts to be explored in future (see Section 6.4).

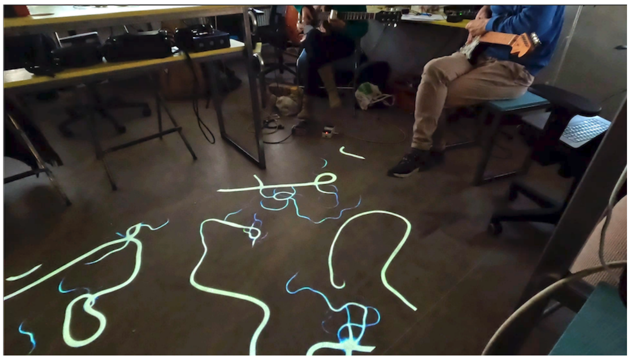
5. MUSICAL ENCOUNTERS WITH TÖLVERA

Tölvera is designed for instrumental and notational design, and we're researching how musicians and audiences interact with the concepts of intelligence, emergence, and agency. We've been conducting informal musical sessions, called *encounters*, with our research prototypes to inform design iterations and inspire future encounters. We present an ethnographic account of these encounters in this section, and offer an interpretation of the emerging themes in Section 6. Two professional guitarists participated in an

[6] Modern laptop with a GPU supporting backends such as OpenGL, CUDA, Vulkan and Metal: https://docs.taichi-lang.org/docs/hello_world.
[7] https://github.com/taichi-dev/taichi
[8] https://github.com/taichi-dev/Taichi-UnityExample



(a) Boids clustered into spheres, with players 'identifying' as metal bowls on the floor.



(b) Players improvising in response to Physarum pheromone trails.

(c) Boids and Physarum combination, with Player A 'conducting' Player B's attention.

(d) Boids and Physarum combination, with Player B 'conducting' Player A's attention.

Figure 4: Video stills of four setups from the Tölvera improvisation session. Tölvera scenes were projected from above onto the floor. The two guitarists sat in chairs nearby.

informal session with Tölvera in an arts university studio lab space. The primary aim was to determine the extent to which basic configurations of Boids and Physarum particle systems could maintain engagement in an informal improvisation setting. The guitarists played their own instruments, and the Tölvera designer edited and randomised the Tölvera scenes in response to the musicians. The encounters lasted between three and seven minutes each.

5.1 Encounters Summaries

5.1.1 Encounter 1: Boids & Two Guitars

Figure 4a shows a video still from the first encounter between two guitarists and Boids. The Boids were divided into two species, referred to as Species 1 and Species 2. Player A focused on Species 1, which formed lengthy, sinuous streams, while Player B engaged with Species 2, which developed into small, swiftly agitated clusters. Player A alternated between playing phrases akin to those from earlier when Species 1 crossed their bowl and maintaining a steady rhythm of atonal chords for Species 2. Similarly, Player B played as before when Species 2 traversed their bowl and executed loud, heavy chord riffs when Species 1 emerged. The Boids species colours and parameters were randomised several times to generate variations. As more variations emerged, Player B asked, "how do I play this?" The music grew increasingly disjointed and chaotic as they attempted to adapt to new scenarios. The music ultimately ceased following a final randomisation, with both musicians pausing before Player B stated plainly, "I don't know," and they both shared a laugh.

5.1.2 Encounter 2: Physarum & Two Guitars

In the second encounter (Figure 4b), the players responded to the Physarum simulation this time. Player A played similar spacious slide guitar notes as before, while Player B utilised a pen to produce slide guitar sounds as well. Their sound was considerably quieter than in Encounter 1, possibly due to the increased amount of empty space in the scene and the reduced motion of the Physarum. Their flowing, sliding gestures appeared to correspond with the twisting, continuous pheromone trails. After a relatively calm encounter, the players concurred at the end that "this was fun".

5.1.3 Encounter 3: Boids, Physarum, Guitar & Conductor

Encounter 3 (Figure 4c) involved Boids and Physarum combined in a Tölvera scene. The Boids left an additional pheromone trail for the Physarum to follow, resulting in some interaction between them. Player A acted as a conductor by pointing a baton at the projection on the floor to direct Player B, who played guitar. The encounter began with randomisation of Tölvera parameters to find a preferred setting. Player A tracked a Physarum ring of pheromone trail that was slowly closing in on itself while Player B gradually increased their tempo, playing two semitones. As the ring exploded back out into the space, Player

A swept around with their baton before settling on tracing another more stable pheromone trail. Player B adapted their playing accordingly. Player A then followed various Boids clusters from different species, some of which were calmly floating and others that were more animated. Player B responded to each Boid cluster differently, adapting their previous musical ideas. The conducting and playing matched the progression of the Tölvera scene, becoming more dynamic than the previous encounters.

5.1.4 Encounter 4: Reversing Roles from Encounter 3

In the final encounter (Figure 4d), Player A and B switched roles from Encounter 3, with Player B becoming the 'conductor' and Player A returning to playing the guitar. They began by randomising Tölvera parameters to find an appealing scenario, with comments such as "Mmm hmm, this I like!", "It's good.", and "It's beautiful, no?". Player B started by tapping specific points and lifting their baton from the floor, causing Player A to inquire about when to play silence. Both players laughed and shrugged in response. Player B followed the trails of Physarum and collapsing rings, responding with spacious slide guitar phrases that mapped both ends of a trail to low and high pitches. During the performance, Player A accidentally knocked the projector mounting, causing both players to react with surprised laughter as the entire scene shook. Player B then traced a specific Boids cluster around the scene, which suddenly changed direction and darted off the edge of the screen. Both players laughed as Player B exclaimed and stepped back, saying, "I had started to sympathise [with that cluster]... Ah, it comes back this way, right?" upon realizing that the particles wrap around the edges of the scene.

5.2 Post-Encounters Discussion

In a discussion, the researcher and author asked open-ended questions about encounters, leading to a conversation about potential Tölvera development. The players noticed the Boids clusters would occasionally suggest a musical representation, but were sometimes random. Player A talked about their film scoring practices and their awareness of "Mickey Mousing." They found this approach safe and comforting because it allowed for an easy association between the particles and musical gestures. However, they mentioned feeling lost when tracked clusters vanished and would sometimes intentionally try to lose their identity with a cluster. Player A also described experiencing various emotional states, such as feeling safe, lost, bored, and comforted. Player B commented that musicians are not predictable but follow certain expectations, while artificial life is less predictable.

The players compared their relationships to musical scores in classical and jazz contexts, respectively. Player A believed they adhered more strictly to rules in response to classical scores, while Player B felt jazz players had more freedom in interpretation. They both acknowledged that their experiences influenced their reactions to Tölvera scenes and appreciated the contrast in their musical responses. They discussed the limitations of guitar as an instrument, such as difficult fingerings and challenges with microtonality. Player A felt constrained by their instrument and thought a symphony orchestra was necessary to express diverse activity. Having two guitarists alleviated some pressure, but did not influence their reactions to specific encounters. Both players enjoyed playing and conducting, with the latter providing more freedom and the ability to anticipate the conductor's intentions. This suggests a shared attraction to similar types of activity and interpretations.

During a conduct by Player B, Player A wondered if a more formal, rule-based approach was anticipated, akin to their classical training. Player A suggested dynamically morphing or navigating between parameter states for future Tölvera development, instead of instantaneously randomizing all parameters. They often interpreted the distance between objects as pitch intervals and discussed the possibility of a visual demarcation of pitch space through a stave-like overlay. This stave could be microtonal or continuously graded, but it was uncertain whether it should indicate temporality. Player B proposed dividing the space into a grid of cells, each with different scoring instructions or mappings, and assigning players to specific cells. They also discussed explicitly representing players as particles or clusters and providing control over their range of motion and responses through mapping.

6. DISCUSSION

Despite the nascent state of Tölvera, we discovered that simple emergent patterns of Boids and Physarum particles facilitated diverse musical interpretations, evoked visceral emotional responses, and stimulated reflective discussions about the agency of musical scores and their influence on human and non-human interpreters. As discussed in Section 2, we are interested in agency from multiple perspectives, viewing our research systems as boundary objects [28] that can ignite pluralistic dialogue. In that spirit, we explore various themes of agency throughout the encounters to enrich our overall theme of agential scores.

6.1 Fluid Material Agency

The emergent patterns of the Boids and Physarum particles accentuate points and lines in the Tölvera scores. In accordance with the theories of material agency discussed earlier in Section 2, we suggest that real-time software-based dynamic scores alter the agency of points and lines, enabling them to convey the fluidity of these primitive forms through procedurally adaptive motion. This fluidity, experienced as emergent and self-organising music notation, subsequently restructures the musician's perceptive eye and interpretive mind, leading to a more spontaneous and dialogic negotiation of attention.

In the Tölvera scores, Boids are represented as points and Physarum as curved lines by default. As an open notational score, these fundamental forms raise questions about their musical interpretation. The guitarists improvised responses, with point sizes corresponding to volumes and line lengths to pitch ranges, among other mappings. However, certain species of Boids seemed to exhibit fluid-like behaviour, while Physarum trails could adopt more discrete appearances, such as rings, points, and grids. Individual Boids could merge into a cluster, which could then form larger clusters, containing internal oscillations of individual members. Similarly, Physarum rings could converge inwards to a single point before expanding outwards into tree-like structures or dissipating entirely. These morphological transformations between forms increased the demands on musicians' interpretation, requiring them to seamlessly combine rapid chains of diverse playing techniques and musical phrases, while adjusting their mappings in real-time.

The fluid materiality provided by artificial life consequently alters our perception of the agency of a point or line, acknowledging their inherent fluid potential. Barad contends that physical nature itself exhibits greater fluidity and queerness than ontological discreteness and causality, urging us to adopt a perspective of fluidity when observing the world [50]. How does our sense of self evolve when we associate with such fluid material in a symbolic musical relationship?

6.2 Mapping of Self Onto Agential Materials

The typology we described in Section 3.2 led us to describe this encounter as an entanglement between an agential score, two performers, and their instruments, with a simple unidirectional flow between them (Figure 2). However, we observed another kind of entanglement that was not explicitly described in the typology. It became apparent that the life-mimicking behaviour of the Tölvera scores prompted musicians to associate with specific aspects of the scores, even eliciting a subtle sympathetic response in Encounter 4. This projection of oneself onto the dynamic behaviour of the score was incidental and transient, as the life forms within the score continuously evolved, formed new configurations, and subsequently disintegrated.

Extrapolating from this, we envisage that only a slight perception of agency in a score is necessary to trigger human tendencies to identify, empathise, mirror, and attune. This process establishes an entanglement or mapping at a higher level than between notations and gestures and sounds, connecting human selves with agential materials. When unexpected behaviour from an agential material disrupts this mapping, visceral responses can be elicited ranging from surprise and excitement to disgust. Attunement to an agential score and its subversion presents a novel compositional device for musicians to explore and researchers to examine. In future work we seek to elaborate on these psychological and emotional aspects of experience with agential materials through an investigation into *agentology* [51].

6.3 Perceiving the Intra-Actants

Following Barad's agential realism and the concept of intra-action [20], we propose that each of our encounters generated a transient *intra-actant*, emerging from the assemblage of musicians, media, and materials, and possessing its own distinct agency. The qualities of each intra-actant were inextricably connected to each Tölvera score and the moment it took place in, and resist typological decomposition. What language and methods are appropriate for describing and comparing intra-actants, that evade the trap of a decompositional approach? Perhaps a new approach is needed that builds on astute methods like micro-phenomenonology [52, 53] to compare multiple experiences of the same moment, leading to a macro-phenomenonological account.

For inspiration, composers encountering agential scores for the first time might find it advantageous to examine the experiences of feedback instrumentalists [54]. These musicians have dedicated significant time to initially unruly complex musical systems and have developed aesthetics that are compatible with extended and augmented instrumental agencies. Agential instruments also present a natural pairing for agential scores.

6.4 Future Considerations

In this paper, we established a context for discourse on agential scores and recount early experimental artistic applications. We intentionally avoided providing a rigid definition or framework to allow for alternative perspectives and interpretations. Here we outline what will be our focus as we seek to develop the themes of this work further.

Our aim is to develop the Tölvera library through artistic and empirical encounters, generating insights surrounding agential scores and their design. The Tölvera library will expand in multiple directions, including incorporating more number beings, additional inputs, and a broader range of outputs. We also anticipate a vertical development towards goal-oriented and trainable behaviours and instrument mappings through integrating online machine learning processes.

We have yet to explore the roles of the composer and audience within the context of agential scores, and we envisage composers will eventually engage with agential scores through more accessible interfaces such as graphic design, drawing, and tangible or gestural interactions. In this scenario, a composer could create artificial life patterns and parameters using an assortment of familiar media, and subsequently instruct conductors and performers on interpreting these elements as notation (or even conduct and perform themselves).

With regard to audiences, their behaviour in large groups has been extensively modelled in the field of crowd simulation, providing a compelling entry point for integrating them with agential scores. Additionally, there is a growing research interest in enabling audience participation in music performances through networked, mobile, and gestural interfaces, which is highly relevant to this subject [55]. We consider Tölvera as an element in our Organolib system (see earlier footnote), and we anticipate that our community will discover increasingly diverse applications for it in combination with other elements.

As the system matures, we envisage designing encounters where more detailed accounts of intra-action can be captured, not only during performance but also during design and composition [56]. At the micro scale [57], this could involve comparing eye or gesture tracking data with particle data, and analysing their convergence and divergence across various score states. Based on our other studies, we are also interested to know how perception of symmetry and algorithmic pattern [58] affects projection or attribution of agency.

And qualitatively, micro-phenomenology can be used to capture the experience of the musicians and audience members. Such encounters would enable us to further develop linguistic and conceptual tools for the analysis and interpretation of the macro scale [59] agency of intra-actants.

7. CONCLUSION

In this paper, we introduced the concept of agential scores. An agential score is characterised by a self-identical unity that endures over time, responding to environmental inputs, possessing goals or directions, and striving for equilibrium or development in line with these objectives. We explored this idea by examining how points and lines gain fluid material agency through animation via dynamic computational materials and simulations. We compared a typological and decompositional approach to agential scores with a more holistic, macro-phenomenonological approach that situates agential scores as entangled with their material and social contexts. This broader context we described as an intra-actant, inspired by Barad's idea of intra-action, to emphasise the study and comparison of these high-level emergent entities.

We introduced Tölvera, an open-source software library written in Python and inspired by Icelandic kennings and mythology, for exploring agential scores in real-time through artificial life simulations. An initial musical encounter with Tölvera involving two improvising guitarists was conducted to ground the development process in empirical observation. Even at an early stage, Tölvera demonstrated that simple emergent patterns of Boids and Physarum particles facilitated diverse musical interpretations, elicited emotional reactions, and sparked thoughtful conversations about the agency of musical scores and their human and non-human interpreters.

Reflecting on our observations, we proposed that agential scores foreground a particular compositional mapping layer that mediates between musical selves and agential materials. We perceived this as having implications for ecological music perspectives. Lastly, we posed several challenging issues and questions that we anticipate will require addressing as more advanced agential scoring approaches emerge.

Acknowledgments

Thanks to Nicola Privato and Hafdís Bjarnadóttir for their participation in the encounter. Thanks to *Motherbird* collaborators Jessica Shand and Manuel Cherep. Thanks to Victor Shepardson for software development support, and Marco Donnarumma for testing and feedback. Thanks to the anonymous reviewers for their helpful comments.

This research is supported by the European Research Council (ERC) as part of the Intelligent Instruments project (INTENT), under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 101001848).

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