What Quality? Performing Research on Movement and Computing

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ABSTRACT

This article investigates fundamental questions and methodological issues concerning research on movement and computing. Through a process of mapping of the various approaches and phases of research in this domain, it attempts to construct a coherent picture and overview of the research field. A series of questions arise that are discussed with the intent of anchoring and directing future research across different disciplines. In order to better apprehend the complexity of movement, gesture, action, and physical performance, and their role as topic of scientific, scholarly as well artistic research practices, an extension of the disciplinary and methodological framework is proposed. The juxtaposition of the diverse approaches and goals, and the extension of the research can indicate novel axes for generating techniques, methods, and ultimately knowledge. Based on this insight, a reflection on the potential of a wider cross-mediating research practice concludes this article.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **HCI theory, concepts and models**; • **Applied computing** → **Performing arts**; **Sound and music computing**;

KEYWORDS

Methodology; Domain Mapping; Research Approaches; Movement Quality

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INTRODUCTION

Human movement represents a complex field of study, in the way it is interwoven with body and mind, culture and society. Working with scientific and scholarly as well as artistic means in the field where movement, its capture, and technological interpretation is a central topic, inevitably leads to questions about methods, significations, and possible impacts produced by research in this domain.

By imagining how the investigation of human movement could be carried out to produce signifiant insights beyond the mechanical, physical, or even physiological aspects, the challenge of framing the research and circumscribing the topic becomes evident. Envisioning a type of research 'performance' implies altered aggregate states, between experience, systematic thinking, technological development, implementation, analysis, and interpretation. The act of stepping outside the established frame(s) and back inside, in a movement across 'doing', sketching, map-making, and subsequently capturing, analysing and systematising human movement, may enable a broader access to the question.

This article is informed by two perspectives: first that of a performing artist, whose principal tool is a technological instrument derived from scientific measurement tools (e.g., electronic music performance); second that of a researcher who is investigating embodiment and the agency of digital translations and real time applications of sensing technologies.[1]

The aim of this article is to create an overview over the diverse approaches collected in the short, yet rich history of movement-and-computing research and this conference. I am aware that my position is biased and inevitably informed by the practices and experiences originating from my specific and circumscribed field. Nevertheless, through the process of cartography and the ensuing reflections collected here, I intend to convey as complete a view as possible. How complete the map eventually becomes is restricted by the given space, and above all by my limited knowledge and the circumstantial encounters that have shaped my vision of this field.

RESEARCH CONTEXTS

Movement as a fundamental expressive aspect of performing arts, and combined with interaction through media and technology, represents a complex topic that is hard to apprehended from a single perspective. Research in the fields of dance, music, and theatre, on the one hand, is focused on distinct and clearly definable domains and topics. Each discipline brings with it a specific heritage, a specific set of problems and a set of methods and how to investigate the main issues in the field [29][39][60]. Scientific and scholarly research, on the other hand, is guided by the need to adhere to standards and criteria established by tradition and rigour [63][71]. When applying technological and mathematical models for either connecting or extracting information from movements, these perspectives begin to overlap.

[1] Due to the constrained space of this article, the actual application by the author of movement-and-computing as a research avenue as well as an artistic use-case can merely be referred to instead of explicitly shown. The following is an online journal publication exemplifying the cross-disciplinary practice in an artistic research context [75].

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In the context of movement-and-computing studies, the most frequent research approach seems to be based on specific use-cases [80] and the resolution of questions covering single elements within their set of constraints [13]. They usually cover a relatively narrow field; some are applied to a form of movement practice with artistic intent while others try to define generic templates, which would be applicable to a wider range of practices [27].

Paradigms and Approaches

Research about movement-and-computing occurs at the intersection of several disciplines and perspectives. They meet and are mixed in ways that are less the result of deliberate choices and conscious engagement and are more contingent on the background, schooling, and practice of each actor.

At least since the mid 20th century, philosophers of science, theorists, and science historians concur that no unified, coherent, and single practice of science exists, and rather that each domain and specialisation has developed their specific language, method, and discourse [56]. Thus even if an attempt is made here at categorising entire fields of investigation, it is still based on the premises that no single correct point of view exists [12].

The structures and relations presented in the following are thus one model among many possible ones and can only become useful if applied to concrete cases, something which I'll attempt to elucidate further on. The proposed maps and categorical subdivisions should therefore be considered as a performance and an operation across a heterogeneous field that is in continuous flux.

ACROSS THE DIAGRAM

The diagrammatic process is performed here in order to obtain a better overview over research activities in the context of movement-and-computing (see Fig. 1). The diagram helps to see distributions and relationships between categories and can emphasise similarities between disparate elements. However, it also obscures specific positions because of its generalising intent and the choices made about what to include and what to exclude. Given its apparent fixity, a critical perspective should be maintained as to its construction and possible modulation, in particular when observed from a different point of view.

As a point of crystallisation, the diagram generates a field of significance to be explored. As a means of 'drawing through' or 'thinking through' the topic at hand, the "diagramma embodies a practice of figuring, defiguring, refiguring, and prefiguring" [52, 147]. As such, the processes of assembling and of navigating the diagram generate their value through the relationships they reveal and their inherent potential for experiencing new configurations: "The diagrammatic or abstract machine does not function to represent, even something real, but rather constructs a real that is yet to come, a new type of reality." [20, 142]

Model

As a starting point, it is interesting to note that research on movement-and-computing is carried out about existing phenomena but also from artificial models that are derived from them, but that do not necessarily represent them specifically [9]. The artificial models in question are those that attempt to structure movement analysis in a specific manner, for example by formalising Laban's Effort categories into algorithms for computing them [58], or that simulate movements based on avatars (body-models) [37] or other physical models [8]. Such models serve to reduce the complexity of the observed movement but also help to isolate and highlight aspects that are not measurable directly, such as inner forces and impulses.

Approach

Three conventional approaches can be distinguished (located at the the centre of the diagram):

The first is based on **data and measurement** and operates through quantifying and formalising aspects of movement. This implies the steps of *identifying*, capturing, *processing*, and finally *formalising* movement aspects [58]. The formalisation depends on the *discretisation* of movement into bits of data, so-called **key-frames** or chunks, with which to operate in time-series with formalised mathematical procedures.

The second approach is **descriptive** and takes the human experience and perception not just as object but also as a tool. Observation of performed movement is carried out either directly or on (video-)traces, in order to identify salient features and tag them with **key-words** [18]. Notation and *annotation* of traces of movement performance generate a new corpus of digital materials (objects) [18] that provide the basis for new methods in research, transmission, as well as practice. Explicited experience is collected in surveys, from which language and concepts are derived that are grounded in the concrete use-case.

The third approach provides a **mixed** set of methods, that derive their criteria from both quantitative and qualitative perspectives. Social sciences methods are used in combination with data-driven scientific approaches, in order to create a 'differential' interpretation. Data is generated both from measurements and from 'explicited' experience, then the two domains are cross-referenced and mathematical models applied. From this process are derived the **key-concepts** that are essential for cross-domain interpretation.

The fourth and more recent approach is synthetic and **combines** methods, sometimes with the express intent of research, sometimes for the purpose of generating a juxtaposition of forms. In addition, the artistic practices and processes of this approach become an integrated part in method-development and concept definition. The central process is the deployment of **key-elements** from the other approaches: using motion-capture on stage, for example, demands an adaptation of both the technology and the performance, the two systems' constraints have to be made compatible; or using the concept of phrase to identify units of movement that are not naturally seen as separate. The advantage of this approach is that in such an experimental setting the full adaptive loop between artistic intention, human movement, machinic response, and human perception can be constructed and controlled, and therefore the specific impact and significance of the human in the loop may come more clearly the foreground. This entire process range is described succinctly by Norman who asks us to be "creatively engaging with instruments [which] means striving to exceed the encoded possibilities of the object, the environment, and the nexus of live, physical and symbolic relations developed by the performer/s and witnesses." [67] I believe that it is by going beyond the elements, which form this nexus, that research can do justice to the complexity of human movement research, as I will discuss further on.

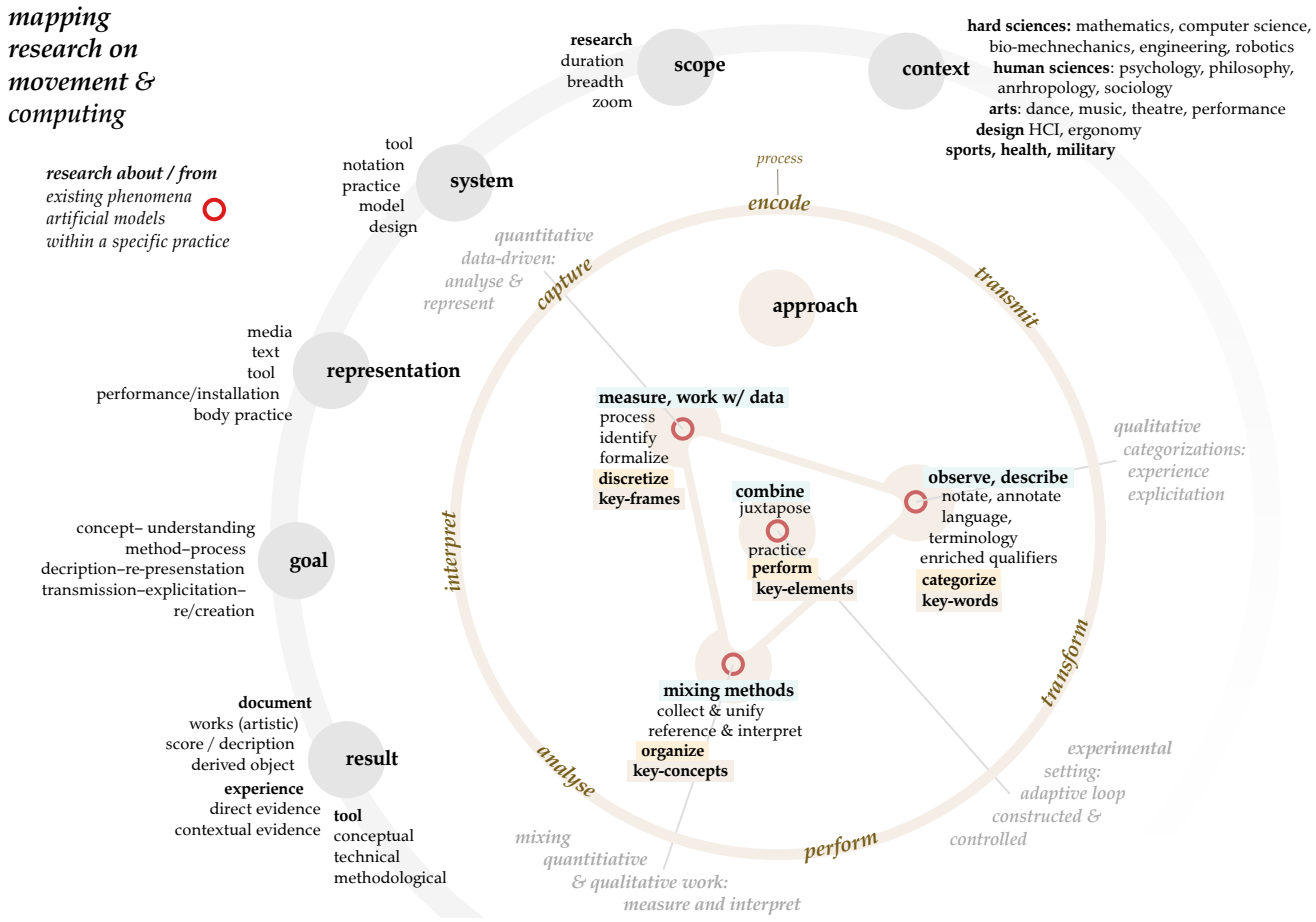

Figure 1: The diagram, in a single state.

Context

The research context and approach is a determining factor for research in general. In the following section the main research approaches from the movement-and-computing field are explored, providing the basis for inquiring into underlying issues.

The most powerful is the paradigm of deterministic and positivist control of the **Hard Sciences**. Here, the notion persists that given sufficiently detailed information and powerful tools, there is no limit to obtaining computable elements in relation to human behaviour, perception, and cognition. Engineering prowesses based on scientific and mathematical achievements and the rapid advances in technology provide sufficient new challenges and promise new and exciting solutions [38] to obscure the fact that the topic can only partially be apprehended by mathematical formalisation and deductive reasoning. Given the predominance of the academic and industrial context within which these research activities are carried out, a standardisation of thought models, research methods, and accepted scope is imposed by institutional validation processes [65][15]. Who can carry out this research and in what time-frame with what means is decided through a canon of scientific standards that represents and further cements the political as well as the economic power structures [30].

In the **Human Sciences** the field of Psychology and Philosophy (of Mind) [33] have dealt with human perception, affordances [36], bodily self-perception [59], intentionality and agency [78]. The foundation for movement analysis was laid out by psychophysics (originating with Fechner in the 19th century [44]), whose methodological imperative informs until to today the neurosciences, cognitive sciences [50], and experimental psychology [73], as well as technological developments such as AI based on models of cognition that discretise states of information processing [46]. "The dominant paradigm ... has not grappled well with challenges .. [of the] knowledge ... that ordinal measures are not necessarily quantitative [64], and that psychometrics lacks valid units of measurement [51]" [11].

In the **Design** field, the question of interfacing human movement and action abilities with machines and algorithms is a perennial topic [25]. This is the basis for developing methods for object-use as well as the *process of design / the design of processes*. Attempting to solve questions about the appropriate tools and processes for movement analysis, the research about human-centred machine learning [38], in the context of the HCI-community, puts a focus on linking movement to design problems such as navigation a corpus of images or sounds, the engagement through free movement in virtual

reality, or the analysis and interpretation of complex movement patterns in artistic or task-oriented performance [47].

In the **Arts**, using a technological toolset as a means for extending expression is as old as the different disciplines themselves. However, the contemporary technological devices at our disposal produce a difference in kind. From the cyborg debate [43] to seeing augmented and virtual bodies on stage or in training [10], the technological transformation operated by computing and advanced algorithms is profound, not just in the practice but in the impact on aesthetics and culture. In addition, the function of computation as a documentation tool has contributed to extending and altering the traditional disciplines [53]. Technology also generates non-human actors on stage [41] and interactions with machines that distribute agency between all the actors [68]. Specific movement sensing technologies have engendered extended performing practices in dance [74] or music [88].

There are more domains where movement analysis has become inevitable. High performance movements such as in **athletics** and other **sports** [1], but also **health** applications such as rehabilitation through physiotherapy [23] rely increasingly on computation-based methods. Of course, the **military** applications should not be underestimated in this field, be it for robotics [14], exoskeleton developments [31], or performance analysis in simulations of all kinds.

Scope

The question about the scope of research is fundamentally linked with the approach, but also the context. The institutional context where it is carried out influences the **duration** of a research process, as well as the **breadth** of the question being addressed. Between a research project that covers the repertoire of a choreographer's entire career [81] and the project that describes a single implementation [3] there is considerable difference in time and human resource investment. In addition, different contexts demand a specific **zoom** or detail; between an engineering approach that attempts to resolve a single technical issue [86] and a human sciences approach that covers wide areas of culture and history [22] there exists a wide difference.

System

Looking at systems used for researching movement, a number of categories stand out. These cover systems for storing, thinking, or categorising research on movement include **notation** in scores and software. These provide solutions[2] through a **tools** approach. Systems are also **practices** such a somatic, choreographed, or improvised performance work [54] that include computation processes and technological elements. The next type are **model**-based approaches that use templates of movement, of bodies, or actually model artificial bodies [10]. These models also provide the foundation for machine learning methods that use supervised or unsupervised methods relying on ground-truth definitions (and thus models). Finally, movement analysis work is also based on a **design** paradigm that takes into account a wider field of application that deciphers, configures, or sequentialises elements of movement computing, such as gesture input, posture, or locomotion patterns.

[2]http://motionbank.org/en/event/pm2go-easy-use-video-annotation-tool

Representation

The objects with which to carry out research is often the representation of movement as opposed to the actual movement. This is related to the fact of repetition and repeatability and the need off-line processing of data. In some cases this is a basic problem, since capturing the relevant features of movement, such as their intention and goal oriented-ness, is not always possible [7]. The representations can occur in media, as text, in the form of a specific toolset, in the performance or the experience of an installation itself (residing in the tacit knowledge [69]) and indeed within a movement practice itself.

Goal

The goals of the processes carried on movement are diverse. The theoretical investigations seek to create concepts [66] that enable a better understanding of movement through technological methods. Not all of the processes aim at the creation of novel and explicit knowledge; the knowledge can be embedded in methods and processes. Furthering understanding depends to a large degree on description, technical as well as linguistic; this can then serve for (re-)presentation. Description in stabilised forms such a notation and an/notation [16] can serve the transmission of tacit movement knowledge, the explication of movement practice and technique, and ultimately the re/creation or re/mediation of in/direct performance.

Result

The outcomes or results of movement analysis and investigations take on different forms, depending on their objet, approach, method, goal, and context. Three main types can be distinguished: The first is the **document**, which can be in the form of a work (also artistic), fixed in a score, in a textual description, or in derived forms such as graphs, media etc. The second is the **tool**, either in conceptual, technical, or methodological form. The third is the **experience**, either as direct evidence of action, movement, and performance, or as an indirect and contextual evidence, the experience of watching, reflecting, or transforming a document or media trace of movement.

Process

Thinking about methodology and the actions carried out in research processes, the key processes described in the diagram can be seen as possible steps or waypoints in research (see Fig. 1, the process circle). Depending on the approach and the goal, varying sequences of activities may occur: 1) perform → capture → transmit; 2) capture → encode → analyse; 3) capture → encode → interpret → perform; 4) capture → interpret → transform → transmit; 5) analyse → encode → capture → transform; What is interesting to note with this perspective is that the most disparate of approaches share steps in their methods: while the first sequence characterises a technological arts performance, the second one describes an experimental psychophysics approach, the third and the fourth are appropriate for dance notation and transmission, and finally the fifth sequence could be a way of looking at machine-learning and re-mediation using media technology.

QUESTIONS

Using this tentative overview of the field of movement and computing, we can attempt to understand some underlying critical issues

of movement-and-computing. The interface between individual and world, movements and gestures, are defined by their intention, by their form, by their application, and by their wider context. Making things more difficult is the fact that not all of key elements of movement can be readily accessed, and those that are accessible require a variety of approaches.

What is it were are trying to discover, describe, and understand? Is movement the core element we need to be investigating? Does computing necessarily mean single domain, univocal formalisms? Is formalisation a necessary step in movement analysis? Is obtaining any kind of ground truth possible at all?

Why Compute?

We use technology in order to understand or alter our relationship with the body, movement, intention, and therefore meaning. However, this can only work in a state of suspended disbelief. In order to properly function with deeply entwined technological processes, we need to ignore the fact that the tool is limited in its effect and that, by extension, it limits our capabilities of moving, seeing, hearing, and feeling. So what does the addition of computation bring to human movement, its study, analysis, and application for example in artistic contexts?

Some of the fundamental functions of computers and their media-output consist in the abilities of the machine to mirror, store/replay, and inter-connect layers of information or data. It should not be forgotten, however, that the data only partially represents the measured phenomenon, and that this representation in discrete units has an agency and impact of its own, which is not identical with that of the moving body.

In the context of living movement of bodies, the storage/replay functionality is interesting because it offers the opportunity to experience our body in close temporal proximity with the movement, gesture, or action from an outside, mediated perspective [77]. The illusion of a 'real-time' response affords the engagement in an adaptive loop, where the organic and the constructed structures enter into an relationship of mutual influence. This extension of the relationship between movement and data, between memory inscribed in the body and that stored in an apparatus, alters the perspective and understanding of movement-and-computing. However, the difference between human and machine memory should not be neglected in this configuration: whereas human memories are inscribed in the body and mind and remain tied to experience and are ever-changing [6, p. 166][5], the status of data as stored memories changes according to its usage context [84].[3]

Applying mathematical models to organic movements resembles a process of dissection and can lead to deeper understanding of human capabilities, for example in bio-mechanical study of human (and non-human) motion and movement.[4] This is the direction taken by methods that quantify and attempt to understand mechanical movements, e.g., least-effort curves, economy of movement, ergonomics [24], as qualities that are perceivable or even beneficiary both for the mover and the viewer. This depends on the ability to read, measure, and capture human movement, which to some extent is always necessary when the task is to create, train, and optimise expertise. In this regard, simulation is one of the driving forces for the development of movement capture technologies, such as is used for example in cinema and computer-games.

What about non-human movement? A different field of study synthesises movements to make them look human, to provide a counterpart in mixed, yet artificial encounters. The field of robotics extends this to include non-humanoid shapes and processes.

In the artistic context the issue of computing movement seems to be rather about capturing the ephemeral, un-articulated, and non-identifiable elements of movement, in order to augment or extend the body's capabilities, the artistic language, or the social, ritual, and scenographic situation. The storage/replay capability, together with the capability of layering information provides another advantage of using computation in the arts: it complements, extends, and alters the mainly oral transmission of corporeal practice in performing arts (dance, music, theatre). The capabilities for modelling and formalising elements in algorithmic systems provide a tool for the creation of movements, choreographies, and instrumental gestures. Thus the technological apparatus becomes a tool for augmenting existing movement, which poses the question: in order to do what?

The poetic answer would be: in order to provide unseen or unheard experience by 'thickening' them, i.e., by adding layers of additional materials, significations, and expressions, and thus shifting the artistic practice into a territory that is less well charted.

What Quality?

> The problem with scientific discourse is that it slices up time and movement into isolated positions, the way a slide projector does [19]. Science eliminates qualitative features of experience. It ignores *duration*, the qualitative element of time, and *mobility*, the qualitative element of movement. [42, p.68, my emphasis]

The most intriguing and delicate term used in the discourse about movement and its capture and computation is the notion of **Quality**. Apart from being the counterpart of *quantity*, it is difficult to isolate and describe properly. Depending on movement practice and research focus, the dimension of quality varies wildly. Even so-called qualitative research, i.e., psychological or social science methods that extract experience information and then treat it with mathematical or linguistic models, cannot provide a clear definition and therefore a computable basis for qualities of movement, gesture, action, or any other corporeal expression.

Since Laban's [57] systematisation of living movements into effort,[5] we know that qualities of movement may be perceived as their 'inner aspects' and that at least they let us differentiate and identify movements with some semblance of intention and expressiveness. The categorisations implemented in his systematic analysis are aimed at being universal and are sufficiently general in order to be applied to many if not all movement descriptions, or so current applications suggest. When examining their scope and object, however, it is evident that these categories are mainly applied to free movement in space with the entire body, such as dance movement or whole body gesture. Furthermore, the categories mix source and destinations effects, that is, the perception of intention

[3] Thanks to Anne Dubos for making this distinction clear.

[4] This can perhaps be differentiated between the physical and unintentional vs. the intentional and expressive?

[5] "In order to discern the mechanics of motion within living movement ... it is useful to to give a name to the inner function originating such movement. The word used here for this purpose is *effort*. Every human movement is indissolubly linked with an effort, which is, indeed, its origin and inner aspect." [57, p.20]

[72], its manifested form within perception [33], and its affective and experiential impact [87].

Considering the least-effort paradigm for any optimised movement patterns [90], for example the performance quality of a given, choreographed movement sequence, as they are performed by high expertise performers, we can but wonder as to how much implicit bias the notion of movement quality contains in this standardised system.

Between the quantised, sampled frame-by-frame representation of a fluid movement and the perception of a fluid quality, both for the person executing the gesture and the person perceiving it in the other, there is a difference in kind of perception that can not readily be bridged, if at all.

Bergson speaks of indivisible qualities that are the expression of intention. Experience in his eyes is based on representative as well as affective sensations, the former being measurable whereas the latter is pure quality without reference to any external cause [42, p.58], and therefore "intensity is situated at the point where the two currents meet" [4, p.54]. Somatic practices and Somaesthetics [83] emphasise awareness of the body during movement; the quality is evaluated according to felt, not necessarily externally perceivable or measurable movement aspects. This poses the question of expertise, which is a large discussion in its own right [76].

Possible Hybrids?

'Mixed Method Research' represents an attempt at bridging between quantitative and qualitative research methodologies [49]. It connects the measurement-based formalisation and the descriptive, explication of subjective experiences, both of which are 'positivist' approaches based on the paradigm assuming that things are measurable and can be put into a formal mathematical, unequivocal representation or system. For example, in much of Music Psychology, the psychophysics approach is dominant: an experiment is devised to isolate clearly the relationships between a stimulus and a reaction through a the observation of behaviour. This is intended to construct a piecewise map of how the human psyche and cognitive apparatus function.

The tension between inductive and deductive approaches and the scope of research influence the positioning and production of the outcome across the range between formalised-technical [92] and descriptive-hermeneutical [32] approaches. The context of research furthermore biases or pre-defines the type of questions generated from the outset and the kind of outcomes produced at the closing of a research arc. This is a question of institutional demands, structure, and imposed quality criteria for research, as well as one of position and status of the individual researchers within the system.

Is there another way of doing research about the topics of embodiment and its perception in performing arts? Can research within a multiply defined field, which merges scientific, scholarly, and artistic approaches be fruitfully concentrated to address the big issues around body, movement, and cognition? Is an *experimental* as well as *experiential* approach possible, which spans from the direct, pre-linguistic, and non-coded experience and its making (in arts), all the way to the analytical methods, which leverage advanced computation techniques and capturing technologies in real-time? Can this approach produce a meaningful and unique perspective on movement research?

This configuration of topics contains disparate and contradictory levels of complexity in the domains of biology, cognition, psychology, physics, etc., but also about culture, discipline (artistic), practice contexts, and social significations. The use of technology can, but does not have to be, a factor in bringing to the foreground aspects along one of these lines. But perhaps technology is merely an element of practice to be chosen and then developed in order to clarify, to isolate, to juxtapose, to combine, and to connect elements of the configuration that would otherwise be less directly connected. Understanding minute movements in relation to music performance, for example, through the capture, measurement, and subsequent visualisation of kinematic data only became possible once motion capture technology became accurate and accessible enough to carry out this research [48].

To research means to ask questions within a specific frame, while continuously altering the frame and continuously looking to repose the questions differently in light of the evolving perspective and insights. This fluidity and indeterminacy poses the methodological problem and raises the fundamental question of how to constrain the field of operations [21]. The question is, wether this is a necessary step in order to reduce the research area to a manageable size? Is not rather uncertainty and the difficulties inherent to delimiting fields part of the honest attitude of (slow) research ? If reduction is pragmatically necessary, it shouldn't eliminate the *cross-contaminating* and *fertilising* aspects that only arise from a hybrid position: It should't be made simpler than necessary, to paraphrase a famous physicist.

A properly trans-disciplinary position of research about movement and its systematisation with or without technology is in need of a clear anchor to be able to extend beyond existing disciplines. What are such anchors and how do we integrate them into our methods and research plans? What institutional frames and conditions do we need in order to obtain the necessary space to work in this way? How do we circumvent the ever increasing pressure to conform to standardised methods and schemata [28] and carry out research in a slow enough manner to reach deeper insights than what is afforded by short project and study cycles [85].

Sampling or Blending?

> We come upon the two fundamental illusions of reflexive consciousness. The first consists in considering intensity as if it were a mathematical property of psychological states and not ... the special quality, the nuance specific to these diverse states. The second consists in replacing concrete reality, the dynamic process that consciousness perceives, by the material symbol of this process arrived at its term. [This would be] to wrongly suppose that the symbolic image by means of which one represented the performed operation has been drawn by this operation itself in the course of its progress, as if registered by some recording device. [4] translated by [42, footnote p.87].

Human thinking, that is, conscious, discursive, propositional thinking, is based on units of meaning, words, and sentences, and the concepts and notions attached, mobilised, enabled through and to them. The structure of language, and scientific language in particular, presupposes a static connection of signification to objects, ideas, concepts, and experiences, in order to be able to operate in a repeated, stable, and thus sense-accumulating manner. Since

the relationship between the elements in this system is standardised, it has the power to become carrier of information and enable communication across the inter-individual divide and across the timespans and spaces of and in between cultures [91]. All of these aspects apply to mathematics in an even more strict sense; computation as a concrete implementation of mathematical principles is an expression of this need to subdivide and standardise.

When we consider the analogical nature of being human – our body, our experience are in continuous exchange with the environment, with other humans, in social and cultural domains – a different type of organisation becomes evident. In it, layer upon layer of organic adaptation, energy signatures, phrases, or what Luria [61] (cited in [82]) calls the kinetic melody, and co-dependent processes of excitation and inhibition occur. These do not appear as separate and clearly delimited domains or processes, and this is where we encounter our fundamental dilemma: they are intertwined, mixed-up, co-dependant, and in continuous flux, changing their relations between themselves and to the outside, the environment. Our perception is focused on the environmental link: the affordances [35] of the situation are read, the intent of the other is interpreted [17], and the cultural codes are deciphered [34]. Cognition arises from the adaptive loop in which the organism evolves, grows, and learns [62][89].

Ripples of Duality?

From this perspective our movements and gestures seem like mere artefacts of our engagement with a much thicker, richer, and wider frame. Perhaps they are just ripples on the surface of our actions within and towards the world. They carry existential, factual, whimsical, or even poetical significance and signals from our intention into our environment. Effort, expressivity, or quality then become codes for a specific manner of execution, which is both effective in terms of ergonomic flow and efficient as carriers of affect and meaning.

The dilemma and paradox of movement–computation lies therefore in the necessity to think in terms of discretised units of meaning (and measurements) with regards to a fundamentally heterogeneous and indivisible aspect of human nature and culture. The sampling theorem and the standard procedure of science to discretise its object of study fail to account for the fact that human experience and its expressions can not be subdivided into equal parts to be subjected to rules and algorithms. It is true that sampling enables the creation of outlines of, for example, motions, and that time-series of equidistant key-frames enable to calculation of functions that can represent the measured phenomena in mathematical ways.

The question is how to articulate these aspects of the manifold complex [45] represented the body, much less how to carry out systematic work on this indivisible entity through the use of technology? Clearly, there is a gain to be obtained from applying computation for example to sampled, key-framed captures of movement, be it as work on media, transformations in the way we perceive movement, or as methods for bringing to the surface otherwise hidden aspects and qualities of movement and gesture. How much this represents anything approaching human experience and affective meaning is another matter altogether.

Ever since Heisenberg formulated the uncertainty principle and Schroedinger put a cat in a box, we also know that phenomena in the physical world, albeit on an atomic level, do not exist and occur only in a *single* modality [70, pp. 243–247]. Quantum *entwinement* furthermore tells us that the classic laws of cause and effect, of energy conservation, and of reversibility of physical phenomena are not universal and that there are domains where we have to deal with a complex duality of states, an ambiguity that cannot be resolved with deterministic logic and argument [2].

Human behaviour and as a subset of this, movements and gestures, in particular in performing arts, should perhaps be considered to exhibit the wave/particle duality in a translated manner. Perhaps we can use the particle as model for the discretised movement, useful for describing and formalising, through the slices and still-frames needed to operate on clearly delimited and standardised units of measure. And *at the same time* we should consider human perception and its ability to apprehend a heterogeneous mass of stimuli present in human movement, gesture, as well as culturally bound behaviour, without the need to 'chunk' it [40]. This continuous flow of information then perhaps behaves more like the wave phenomenon, as an energy traversing a medium. Can these two fundamentally different ways of apprehending human, or living, movement be reconciled? How must a method for researching this domain be structured to do justice to the dual nature of inner and outer impact and significance?

INSIDE AND OUTSIDE UNIFIED

The paradox of movement analysis with computing tools can be considered a productive dilemma. If we accept the fact that human movement comprises action, gesture, and intention, as well as perception and resonance, that it stretches across numerous facets of our experience, and that *research as performance* with technology on this topic means implicating multiple disciplines and creating new methodologies, then perhaps a constructive approach is to create a larger frame for research, which productively combines, but also critically problematises, the different approaches that are implicated.

How can the scientific method necessary for working with technology and mathematical formalism, the scholarly reflection leading to theory and critical thinking, the mixed-method psychological experimentation aimed at understanding hidden aspects of human perception and behaviour, and the experience-based investigation come together and produce a meaningful outcome? How can hidden, inner processes [55], perceptions, and affects be combined with the outer manifestations of human intentions through movement, action, gesture, and performance? Why do artistic performance practices provide such a rich and singular field in which to study precisely the connection between inner and outer aspects of 'living' human movement? Can a methodological inquiry that originates from reflection about deciphering the cultural, cognitive, and psychological implications of an artistic practice be brought to a sufficiently differentiated level that a contribution to epistemological thinking can be attained? These and many other questions arise from this research perspective.

The theory of blended spaces may provide a guide here, as it postulates that: "The essence of the operation is to construct a partial match between two input mental spaces, to project selectively from those inputs into a novel 'blended' mental space, which then dynamically develops emergent structure" [26].

Unifying research about the inside perspective and the outside manifestation of bodily expressions, be it as movement, action, and gesture, or as intention, effort, and affective impact, could thus be a fruitful avenue for research. A non-dualistic, integrative approach could be aimed at uncovering both the primary experience of movement through its performance [55] and processes [79] as well as the epistemic gains that the perspective could afford. By operating at the intersection of these perspectives and by using methods that span across disciplines, the issue is to create a rich enough 'object' of research to do justice to its 'thickness' [34]. If the "remediations of [a] fleeting live movement [in order] to make it a reproducible artefact" [67] can tie the inner to the outer domain, what could a *cross-mediation* in repeated processes across methods and practices produce?

A circular, iterative approach across perspectives, ranging from the data-based quantitative method, the experience-based qualitative analysis, to investigations of experience has the potential to create an overarching, intersecting object, more appropriate to the study of the complexity of human expressive movement. Attempting to structure research processes along the lines sketched here may show us a way forward in movement-and-computing research. Keeping in mind the fundamental nature of movement as a lived experience, which enfolds all the complexity of human action and relation in a highly entwined manner, could inform all types of research, regardless of context, approach, or method.

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