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Embodiment and Computational Creativity

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Abstract

We conjecture that creativity and the perception of creativity are, at least to some extent, shaped by embodiment. This makes embodiment highly relevant for computational creativity (CC) research, but existing research is scarce and the use of the concept highly ambiguous. We overcome this situation by means of a systematic review and a prescriptive analysis of publications at the International Conference on Computational Creativity. We adopt and extend an established typology of embodiment to resolve ambiguity through identifying and comparing different usages of the concept. We collect, contextualise and highlight opportunities and challenges in embracing embodiment in CC as a reference for research, and put forward important directions to further the embodied CC research programme.

Introduction

Most researchers agree that *creativity* and *intelligence* are closely intertwined (Kaufman and Plucker, 2011). Moreover, it is widely accepted that intelligence is conditioned on *embodiment* (Brooks, 1991; Clark, 1998); with the words of Pfeifer and Scheier, “intelligence cannot merely exist in the form of an abstract algorithm but requires a physical instantiation, a body” (Pfeifer and Scheier, 2001, p. 649). Without insisting on physicality, we conjecture that creativity, as a form of intelligent cognition, is also shaped by embodiment.

This makes embodiment highly relevant across the entire continuum of computational creativity (CC) research (Pérez y Pérez, 2018; Veale, Cardoso, and Pérez y Pérez, 2019), from engineering artificial systems that can be considered autonomously creative (Colton, 2008; Colton and Wiggins, 2012), to understanding creativity in living beings through computational modelling and simulation (Boden, 2003). Here, some of the most striking questions are if reproducing human-like creativity by computational means is at all possible without also reproducing human embodiment (Guckelsberger, Salge, and Colton, 2017; Valverde-Pérez and Negrete-Yankelevich, 2018), and how changes to a system’s embodiment affect its potential creativity.

Unlike psychologists, whose human subjects share similar embodiments, CC researchers can go beyond investigating the effect of embodiment on *creativity per se* and explore how people’s *perception of creativity* (Colton, 2008;

Colton, Pease, and Saunders, 2018) as exhibited by an artificial system is affected by their own and the system’s embodiment. If such an effect existed, embodiment would have to be considered an integral factor in the evaluation of CC (Jordanous, 2012) to facilitate fairer comparisons between computational systems and with human creativity. Moreover, using this knowledge, researchers could tune a system’s embodiment to improve the perception of its creativity, and, vice versa, how it perceives the creativity of others.

Given these potential ramifications, it is surprising and alarming that “embodiment” seems to have received little attention in CC research. One potential reason for the apparent void is that the very concept is highly ambiguous (Ziemke, 2003). Theories of embodied cognition – from minimal accounts that “rule out anatomy and bodily movement as important” (Gallagher, 2011), to radical approaches that understand cognition as inextricably bound to bodily processes – conceptualise embodiment differently. Moreover, embodied cognition is closely associated with other, popular extracranial and extra-bodily theories of cognition, in particular theories of enactive, embedded and extended cognition. Due to their proximity and interdependence, they are frequently grouped together into the complex of “4E cognition”.

Crucially though, there appears to be very little awareness of this ambiguity and complexity within CC research. At present, it is perfectly imaginable that two researchers excitedly referred to the “embodiment” of their respective system without noticing that they are talking about entirely different things. We consider this a major problem, given that the various types of embodiment likely have radically different effects on (the perception of) creativity. We argue that the advancement of the field through concerted investigations requires the use of common definitions of embodiment.

The first goal of this paper is to counteract this ambiguity and provide a rich overview of what some authors have already coined “embodied computational creativity (CC)” (Saunders and Gemeinboeck, 2014; Guckelsberger, Salge, and Colton, 2017; Colton, Pease, and Saunders, 2018) research. Based on a systematic review of related work at the International Conference on Computational Creativity (ICCC) as the prime and domain-agnostic venue of CC research, we answer the following research questions:

RQ1: What types of embodiment have been embraced in CC research, and how has the usage evolved over time?

RQ2: Why did CC researchers embrace these embodiment types in their work, and what challenges did they face?

RQ3: What does CC research reveal about the relationship of embodiment and (the perception of) creativity?

To counteract ambiguity in the usage of the embodiment concept, we extend and apply a well established typology of embodiment informed by cognitive science to assess the specific types addressed in each relevant contribution. By making transparent which types of embodiment have been embraced, and by highlighting our challenges in assessing them, we want to provide a frame of reference for researchers to adequately and unambiguously address questions of embodiment in their work. Our insights moreover allow us to provide recommendations for an embodied CC research programme – the second goal of this paper.

Types of Embodiment

Much research focuses on distinguishing theories of embodied cognition (e.g. Gallagher, 2011), but comparisons of the underlying and varying conceptualisations of embodiment are rare. To disambiguate different uses of the embodiment concept in CC, we adopt and extend the well-established typology by Ziemke (2003), who distinguishes six types of embodiment informed by research in cognitive science and robotics. We introduce three additions to this typology (one additional type, two additions to existing types) based on more recent insights, and highlight them in *italics* below.

structural coupling, characterising systems that can perturbate, and, vice versa, be perturbed by their surrounding environment (Varela, Rosch, and Thompson, 1991). Such perturbations facilitate a minimal interaction between the system and environment, in which each has the potential to affect the other’s state (Quick et al., 1999).

historical, characterising systems whose present state is the result of a history of structural couplings, developed through interactions with the environment over time (Varela, Rosch, and Thompson, 1991; Ziemke, 1999).

virtual, *characterising simulated systems embedded in and distinguished from a simulated environment. The virtual body can act on the environment and vice versa.*

physical, characterising systems with a physical body (Brooks, 1990; Pfeifer and Scheier, 2001) that can interact with the environment by being subjected to and by exercising physical force. Most prominently, robots are physically embodied (Pfeifer, Iida, and Bongard, 2005).

organismoid, characterising *virtually* or physically embodied systems with the same or a similar shape and sensorimotor equipment as living organisms, e.g. animals. We consider **humanoid** embodiment as approximations of the human body a subset of organismoid embodiment.

organismic, applying to living *and artificial* systems capable of organisational closure, i.e. of maintaining their organisation and surrounding boundary against internal and external perturbations by means of self-producing processes (Von Uexküll, 1920; Maturana and Varela, 1987). A prominent, minimal example is the living cell which, in

a self-referential process, maintains its organisation, including its membrane, against perturbations from the surrounding environment (Agmon, Gates, and Beer, 2016).

We briefly justify our additions. We have complemented *physical* with *virtual embodiment*, because AI researchers have successfully reproduced (super-)human cognitive abilities in virtual agents, embedded in e.g. high fidelity physics simulations (Lillicrap et al., 2015) or, often more coarse, videogame worlds (Mnih et al., 2015). Applying AI techniques to virtual agents in simulated worlds rather than to physically embodied systems allows for scalability, incremental development, and rapid iteration, amongst other advantages (Kiela et al., 2016). As a corollary, we have extended *organismoid* embodiment to *virtually embodied* systems, e.g. in the form of believable game characters with a human or animal-like appearance. We have finally extended *organismic embodiment* to artificial systems. Originally restricted to the biochemical domain, this type required the capacity for autopoiesis, i.e. self-production, to facilitate a radical form of autonomy. Varela overcomes this limitation by introducing the concept of organisational closure as “operational characterization of autonomy in general, living or otherwise” (Varela, 1979). Froese and Ziemke (2009) advocate that organisational closure can be realised by AI systems, and survey existing examples. We can thus consider organismic embodiment in artificial systems, which makes it relevant for CC research. Although organismic embodiment is arguably the least well-established type, we include it for its presence in existing CC theory (Saunders, 2012; Guckelsberger, Salge, and Colton, 2017), its potential future implications for CC, and its central role in related debates, e.g. on agency (Polani, Ikegami, and Biehl, 2016).

In our adaptation of Ziemke’s (2003) typology, we have dropped what e.g. Dautenhahn (1997) and Barsalou et al. (2003) refer to as social embodiment, because it denotes the use of different types of embodiment to facilitate social interaction (Ziemke, 2003), and is thus orthogonal to, and not at the same “atomic” level, as the other types. Metzinger (2014) has proposed a distinction between 1st, 2nd and 3rd order embodiment based on a system’s computational abilities, corresponding to (1) physical, reactive systems without explicit computation, (2) systems that explicitly represent themselves as embodied agents, and (3) systems that can consciously experience some of these body representations. We disregard this typology as (i) it is not derived from existing work on embodied cognition more generally and serve the specific purpose of grounding (artificial) consciousness as one aspect of cognition, and because (ii) it would only warrant little differentiation of existing work; most CC systems presently fall into a gap between the 1st and 2nd type.

Crucially, the extended typology is only loosely hierarchical. *Historically* as well as *physically* and *virtually* embodied systems are all *structurally coupled*. *Physically* and *virtually* embodied systems in turn can, but do not have to be *historically* embodied. *Organismoid* systems can be *virtually* or *physically* embodied, but we reserve *organismic* embodiment to *physically* embodied systems, as autonomy via organisational closure relies on physical forces that pose a real threat to a system’s organisation and boundary.

Review Method

To investigate how embodiment has been discussed in CC research, we performed a systematic literature review on the proceedings of the International Conference on Computational Creativity (ICCC), the prime venue for CC research, between its inception in 2010 and its latest edition in 2020. We expect our findings to be representative, as ICCC gathers a wide audience of CC researchers and practitioners, and welcomes contributions covering any creative domain, creative practice and aspect of creative cognition (Association for Computational Creativity, 2021). We constrained our review to paper candidates that explicitly mention the words “embodiment”, “embodied”, “disembodiment”, “disembodied”, “embody”, or “embodying”.

We acknowledge that our reliance on the explicit usage of the word may overlook a large amount of potentially relevant papers. This particularly concerns work on robotics, which often does not include explicit mentions of the embodiment of the investigated systems. Simply including the term “robotics” in our search however was impractical, as, for fairness, it would have required to also include any other type of system characterised by the remaining embodiment types. Given the inclusiveness of some types, the amount of potentially related papers would likely go beyond what could reasonably be reviewed in depth. Moreover, we believe that our present approach allows us to identify intentional and thus more informative discussions of the relationship between embodiment and (the perception of) creativity.

For our initial candidate paper selection, we divided the past ICCC proceedings into *pdf* files, each containing one paper, short paper, demo description, or other peer reviewed publication. We used a wildcard search in Adobe Acrobat reader with the phrase “*embod*” and the hyphenated version “*em-bod*”. In total we found 99 papers mentioning the word “embodiment”, “embodied”, “disembodiment”, “disembodied”, “embody”, or “embodying” explicitly, with a total of 491 matches to the search phrases.

We then reduced the candidate papers for our final, qualitative analysis in a two-stage process. We first excluded papers which mentioned these words only in the References section (7 papers), or as part of a general list of CC related topics (2 papers). We secondly excluded papers that used these keywords in a merely metaphorical way, such as suggesting that a specific algorithm or system “embodies” certain values (51 papers). This left us with a final pool of 40 papers for in-depth analysis. Figure 1 illustrates the overall usage of the term over the years, thus partly answering **RQ1**.

We assessed the embodiment of any system described in the remaining papers, either introduced there or through reference to other work, based on Ziemke’s (2003) extended typology. Since explicit definitions of embodiment were mostly absent, this usually required us to look at the specific characteristics of the system in question. To answer our research questions, we also gathered notes on:

- Which challenges did we encounter in assessing the embodiment described in the paper?
- Did we identify any embodiment types that were not yet present in our typology? (**RQ1**)

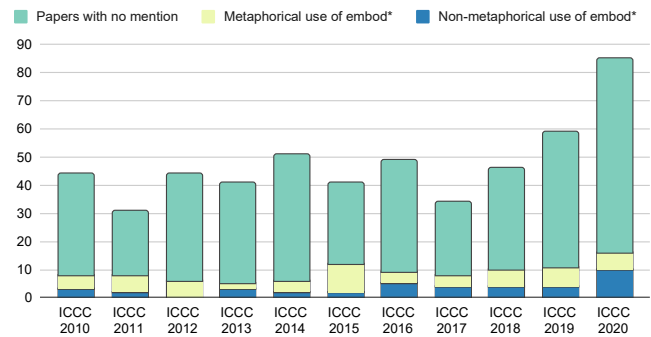


Figure 1: Absolute annual numbers of ICCC papers using words derived from ‘embodiment’ in a (non-)metaphorical way. On average, 7.1% of papers use the word ‘embodiment’ or its derivatives non-metaphorically, with the lowest proportion (0%) in 2012 and the highest (11.8%) in 2017 and 2020. Overall the term is used throughout the proceedings, but non-metaphorical usage has increased over the years.

- Why have the authors embraced this particular type of embodiment, and what challenges did they face? (**RQ2**)
- What did the paper express about the relationship between embodiment and creativity, or between embodiment and the perception of creativity? (**RQ3**)

Each of the remaining 40 papers was first assessed by one of the four researchers participating in the effort. We then discussed the challenges encountered, and cross-checked each paper with another colleague in the team. Any potential disagreements were resolved in dedicated discussions. Another four papers were removed during this step because the explicit mentions to embodiment were cursory. This reduced the final number of papers to 36.

The answers to the questions presented above were analysed by building an *affinity diagram*, a *qualitative* data analysis method used to group data into emergent categories (Rogers, Sharp, and Preece, 2011, p. 286). We first built individual affinity diagrams from the answers collected for each question by grouping similar items together and labelling them. We then merged categories between the different questions, yielding one large affinity diagram as a connected view of different aspects of embodiment in CC. We finally identified overarching themes within this structure.

Findings

We report our findings on the state-of-the-art of embodied CC in individual subsections. We first detail the types of embodiment identified in existing work, thus conclusively answering **RQ1**. We elaborate on our difficulties in this process later in the discussion section, where we go beyond the present findings and make recommendations for future research. Our review uncovered that existing insights on the relationship of embodiment and (the perception of) creativity are often tightly aligned with researchers’ motivations to embrace a certain type of embodiment in their work. In the second part of our findings, we consequently address **RQ2** and **RQ3** jointly through themes corresponding to *opportunities* and *challenges* for embodied CC. We distinguish each

Authors	Year	Abbreviated Title	Concrete System(s)	Mult. Embodiments	Struct. Coupling	Embodiment Type					
						Historical	Virtual	Physical	Organismoid	Humanoid	Organismic
de Melo & Gratch	2010	Evolving Expression of Emotions	—	—	●	○	●	○	●	●	○
Saunders et al.	2010	Curious Whispers	✓	—	●	●	○	●	●	○	○
Kirsh	2011	Creative Cognition in Choreography	—	—	●	●	○	●	●	●	●
Gemeinboeck & Saunders	2013	Creative Machine Performance: Robotic Art	✓	—	●	●	○	●	●	○	○
Saunders, Chee & Gemeinboeck	2013	Evaluating Human-Robot Interaction	✓	—	●	●	○	●	●	○	○
Schubert & Mombaur	2013	Motion Dynamics in Abstract Painting	✓	—	●	●	○	●	○	○	○
Schorlemmer et al.	2014	COINVENT: Concept Invention Theory	—	—	○	○	○	○	○	○	○
Davis et al.	2014	Building Artistic Computer Colleagues	✓	—	●	○	○	●	○	○	○
Jacob & Magerko	2015	Interaction-based Authoring	✓	—	●	●	●	○	●	●	○
Takala	2015	Preconceptual Creativity	✓	—	●	●	○	○	○	○	○
Carlson et al.	2016	Cochoreo: Generative Choreography	✓	—	●	○	●	○	○	○	○
McCormack & d’Inverno	2016	Designing Improvisational Interfaces	✓	—	●	○	○	○	○	○	○
Crnkovic-Friis & Crnkovic-Friis	2016	Generative Choreography using Deep Learning	✓	—	○	○	○	○	○	○	○
Guckelsberger et al.	2016	Supportive and Antagonistic Behaviour	✓	✓	●	●	●	●	●	○	○
Brown	2016	Understanding Musical Practices	✓	—	●	○	○	○	○	○	○
Augello et al.	2017	Creative Robot Dance With Variational Encoder	✓	—	●	●	●	○	●	●	○
Fitzgerald, Goel & Thomaz	2017	Human-Robot Co-Creativity: Task Transfer	✓	—	●	●	○	●	●	●	○
Guckelsberger, Salge & Colton	2017	Non-Anthropocentric Intentional Creative Agency	✓	✓	●	●	○	●	●	●	●
Singh et al.	2017	Unified Classification and Generation Networks	✓	—	●	○	●	○	○	○	○
Colton, Pease & Saunders	2018	Issues of Authenticity in Creative Systems	✓	✓	●	●	○	●	●	○	○
Hedblom et al.	2018	Under the Super-Suit: Conceptual Blending	✓	—	○	○	○	○	○	○	○
Saunders & Gemeinboeck	2018	Performative Body Mapping for Robots	✓	✓	●	○	○	●	●	○	○
Wicke & Veale	2018	Interview With the Robot	✓	—	●	●	○	●	●	●	○
Jacob et al.	2019	Affordance-Based Generation of Object Variants	✓	—	○	○	●	○	○	○	○
Onate, Mendez & Gervas	2019	Elevator Conversations Based on Emotions	✓	—	○	○	○	○	○	○	○
Veale, Wicke & Mildner	2019	Duets Ex Machina: “Double Acts”	✓	✓	●	○	○	●	●	●	○
Loesel, Mirowski & Mathewson	2020	Do Digital Agents Do Dada?	✓	✓	●	○	●	●	●	●	●
Alexandre	2020	Creativity Explained by Cognitive Neuroscience	✓	—	●	●	○	●	●	●	●
Chen et al.	2020	Breaking the Imitation Barrier	✓	—	○	○	○	○	○	○	○
Ferguson et al.	2020	Automatic Similarity Detection in LEGO Ducks	✓	—	○	○	○	○	○	○	○
Kantosalo et al.	2020	Modalities, Styles and Strategies	—	—	●	○	○	●	○	○	○
Kantosalo & Takala	2020	Five C’s for Human–Computer Co-Creativity	✓	✓	●	○	○	●	○	○	○
LaViers & Vidrin	2020	Can a Robot Do a Trust Fall?	—	—	●	○	○	●	○	○	○
Savery, Zahray & Weinberg	2020	Shimon the Rapper: Robot Rap Battles	✓	—	●	●	○	●	●	○	○
Wallace et al.	2020	Movement Generation with Audio Features	✓	—	○	○	○	○	○	○	○
Wicke & Veale	2020	Show, Don’t (Just) Tell	✓	—	●	○	○	●	●	●	○

Table 1: Chronological overview of ICCC (2010-2020) papers mentioning the concept of embodiment explicitly and non-metaphorically. The circles ○, ●, and ● represent increasing degrees to which the described embodiment(s) match our types. Organismoid embodiment entails humanoid embodiment, but we also discriminate humanoid embodiment separately. For papers describing multiple embodied systems, e.g. a robot and a human, individual embodiment types were combined with a logic “or”. Papers introducing a “concrete system” have been marked; other papers consider theory or abstract systems.

theme as a paragraph heading, point out sub-themes in **bold**, and highlight which embodiment type it relies on in *italics*.

Embodiment Types

Table 1 provides an overview of our final paper selection, together with our assessment of the described embodiment. We found that *structural coupling* and *physical embodiment* are most common, each appearing in almost twenty papers. *Historical*, *virtual* and *organismoid* mentions appear quite equally, each in about ten papers. *Organismic embodiment* was only identified in four papers; Guckelsberger, Salge, and Colton (2017) discuss it with respect to machines, while the

other three instances relate to humans, which are organismically embodied by definition. Over the years, although there is considerable variation, the annual number of papers grows from 1.6 on average in the first half to 3.6 in the latter half of the decade, until there is a sudden peak of 10 in 2020. Mentions of different types follow a similar trend, except that *structural coupling* gives way to the more specific, *physical embodiment* in recent years. Out of the 36 papers, 23 present a concrete, embodied computational system, seven are at least partly theoretical or appealing to the embodiment of humans. In another seven papers, we were unable to identify one or multiple types of embodiment at

all, indicated by a row of empty circles in Table 1.

Our analysis highlights *virtual* and *physical embodiment* as strongest differentiators of existing work. It moreover identified a chasm between researchers poised to leverage *humanoid embodiment*, and those rejecting it for the benefits of other variations of *organismoid embodiment*.

Through our review, we identified one embodiment type that was not directly present in our extension of Ziemke's (2003) typology: Loesel, Mirowski, and Mathewson (2020) introduce "cyborg embodiment", which bridges between *virtual*, *organismoid (anthropomorphic)* and *physical embodiment*. It was demonstrated in their theatrical experiment "AI Improv", where a chatbot provides sentences to be articulated by a human actor, and receives new prompts to react to from a backstage operator who monitors the on-stage dialogue. The two people thus provide a split actuation and sensing interface to the artificial system, allowing for it to be embedded in the physical environment of the stage.

Opportunities of Embodied CC

Our analysis identified nine opportunities of embracing embodiment in CC. We can distinguish two sub-groups, based on how the themes relate to the concept of interaction. All types of embodiment distinguished in our typology assume at least a minimal form of interaction between an agent and its environment in the form of *structural coupling*. The first four themes concern how this embodiment-induced split provides opportunities for modelling a specific creative domain, outsourcing computation, letting creativity emerge and stimulating it. The remaining five themes operate on a stronger notion of interaction between agents, i.e. where the embodied agent's environment comprises interaction partners. In this group, embodiment is considered a means to model co-creativity, ground meaning, facilitate more natural interaction with people, support identification and empathy with the computational agent, and increase the CC system's creative intentionality and autonomy.

Domain Necessity *Any type of embodiment* presents the opportunity **to model creative processes that unfold between an agent and their environment**. Some creative domains may necessitate this split more than others in order to comprehensively model the creative processes within. Dance choreography represents a prime example (Augello et al., 2017; Carlson et al., 2016), but embodiment has also been embraced in e.g. music (Schorlemmer et al., 2014) and painting (Schubert and Mombaur, 2013; Singh et al., 2017) to model creative processes that rely on sensorimotor feedback between an agent and their surroundings.

Outsourcing Computation Embodied CC has adopted several premises of embodied AI more generally, notably the use of *physical embodiment* to **outsource computation into the physical world**. Saunders, Chee, and Gemeinboeck (2013) note that physical embodiment allows artificial agents "to take advantage of properties of the physical environment that would be difficult or impossible to simulate computationally" (paraphrasing Brooks, 1990; see also Gemeinboeck and Saunders, 2013). They thus relate to one

of the most prominently articulated benefits of embodied AI: the use of the world "as its own model" (Brooks, 1991).

Emergent Creativity While the outsourcing of computation seems a mere engineering benefit at first, it has major implications for the creativity that a *physically embodied* system can potentially exhibit. In particular, it allows to realise the very premise of systems theories of creativity (Csikszentmihalyi, 1988), the **emergence of creative behaviour through an agent's interaction with their environment**, including other agents: "embodiment provides opportunities for agents to experience the emergence of effects beyond the computational limits that they must work within" (Saunders, Chee, and Gemeinboeck, 2013). In the art installation *Zwischenräume*, the robots' creative agency "is not predetermined but evolves based on what happens in the environment they examine and manipulate" (Gemeinboeck and Saunders, 2013). This emergence benefits from a controller that is not pre-coded but sensitive to an agent's changing embodiment. Several authors (e.g. Saunders et al., 2010; Saunders, Chee, and Gemeinboeck, 2013; Guckelsberger et al., 2016; Guckelsberger, Salge, and Colton, 2017) highlight the use of computational intrinsic motivation to this end. A system with a suitable controller can leverage its embodiment to **expand its behavioural range beyond what can be anticipated by the system designer**, realising novelty as core criterion for creativity (Rhodes, 1961).

Stimulation of Creativity As a specific case of emergent creative behaviour, several researchers argue that **constraints imposed through embodiment can stimulate creativity**. Drawing on Pickering (2005), Saunders et al. highlight that the "world offers opportunities, as well as presenting constraints: human creativity has evolved to exploit the former and overcome the latter, and in doing both, the structure of creative processes emerge" (Saunders et al., 2010). Guckelsberger et al. (2016) argue in an artistic context, drawing on different embodied CC systems and a thought-experiment on the *physically embodied* robot society *Curious Whispers* (Saunders et al., 2010), that overcoming embodiment-related constraints in an environment can necessitate and – given a suitable agent controller – yield creativity. Takala (2015) demonstrates this on a simulated robotic arm capable of inventing new and useful movements when encountering obstacles. This also highlights that creative action is possible without creative reasoning, a distinction which is later picked up by Fitzgerald, Goel, and Thomaz (2017). By utilising *virtual embodiment*, Takala demonstrates that the effect of embodiment constraints on creativity can be investigated without physical embodiment. However, the use of physical embodiment can better alleviate doubts about the emergent behaviour being truly novel, and not engineered a priori into a simulated environment.

Co-Creativity Many of the analysed papers express a focus on stronger forms of interaction between agents. Two particular modes of interaction are given by human-machine and machine-machine co-creativity (Saunders and Bown, 2015; Kantosalo and Toivonen, 2016). This focus can be explained with the observation that **embodiment is a prereq-**

uisite for co-creativity. Guckelsberger et al. (2016) highlight that “co-creative and social creativity systems are only meaningful if each agent has a different perspective on a shared world, allowing them to complement each other, and for creativity to emerge from their interaction”. The necessary separation of agent and environment is crucially facilitated by *any type of embodiment*. This allows for the attribution of embodiment to a given system, based on the systemic nature of the system alone. The next three themes represent additional lenses on human-machine co-creativity.

Grounding Meaning Another central premise of more radical theories of embodied cognition, bordering to enactivism (Varela, Thompson, and Rosch, 2017), is that *physical embodiment* can **overcome symbolic representations and ground meaning in sensorimotor interaction** (e.g. Dreyfus, 1992). Colton, Pease, and Saunders (2018) stress that this allows **re-representing** creative domains in action. As an example, they refer to the Marimba playing robot *Shimon* (Hoffman and Weinberg, 2010) which represents music as choreography of physical gestures. They also emphasise the grounding of machine “life experiences” as an important factor in **increasing the perception of authenticity in CC systems**. Related, Wicke, Veale and Mildner exploit robot gestures to provide the illusion of grounding computer-generated stories (Wicke and Veale, 2018, 2020; Veale, Wicke, and Mildner, 2019), thus leveraging embodiment to affect the perception of their robot’s creativity.

Natural Interaction Saunders et al. (2010) are first to stress that *physical embodiment* allows for CC systems to be **embedded in rich social and cultural environments**. This enables “computational agents to be creative in environments that humans can intuitively understand” (Saunders, Chee, and Gemeinboeck, 2013). Robotic art installations are highlighted as one means to “gain access to shared social spaces with other creative agents, e.g., audience members” (Gemeinboeck and Saunders, 2013). Existing research often stresses that situating CC systems in physical space **realises more natural interaction** by established means, and can **unleash new modes of interaction**. This is explained by *physical embodiment* **affording tight feedback loops** (Wicke and Veale, 2018) and **providing stronger cues** to the human interaction partners (Saunders, Chee, and Gemeinboeck, 2013). In some instances, this interaction is constrained to a few individuals, e.g. when situating a robot on stage to interact with musicians (Savery, Zahray, and Weinberg, 2020) or actors (Loesel, Mirowski, and Mathewson, 2020). In their art installation *Zwischenräume*, Gemeinboeck and Saunders in contrast open the interaction to a wider audience in an exhibition space, permitting “the development of significantly new modes of interaction” and “engaging a broad audience in the questions raised by models of artificial creative systems” (Gemeinboeck and Saunders, 2013). Within natural interaction spaces, *physical embodiment* can “improve the relationship between humans and AI, inspiring humans in new creative ways” (Savery, Zahray, and Weinberg, 2020), e.g. in partnering a human musician with *Shimon’s* reincarnation as rapper.

Identification & Empathy Within the overarching theme of agent interaction, researchers embraced *physical*, and in particular *organismoid* and *humanoid embodiment* to **facilitate and improve communication** and, consequently, **to afford identification, empathy and affect** between human and robot, or within a society of robots. Gemeinboeck and Saunders highlight embodied action in their installation *Zwischenräume* as a means for communication; it takes the form of robots creating noises with a hammer which members of an exhibition audience and other robots can perceive and react to. They moreover stress from an enactivist perspective that the robots’ actions provide “a window on the agents’ viewpoint” (Gemeinboeck and Saunders, 2013), thus possibly facilitating more introspection. Wicke and Veale refer to work outside CC to emphasise that, “when identification with the [story]teller is the goal, the physical presence of a moving body with a human shape makes all the difference” (Wicke and Veale, 2018), hence stressing the effect of *organismoid (humanoid) embodiment*. Moreover, they hypothesise that a “listener that can identify with the storyteller is better positioned to empathize with the story that the teller wants to convey, especially when that story is crafted from the life experiences of the listeners themselves”. This reliance on life experience resonates with Colton, Pease and Saunderson’s (2018) previously mentioned factors to improve the authenticity of CC systems.

Intentionality & Autonomy While *organismic embodiment* is rarely addressed in the literature and typically only through human embodiment (Kirsh, 2011; Alexandre, 2020; Loesel, Mirowski, and Mathewson, 2020), Guckelsberger et al. (2016) highlight that *organismic embodiment* realised in artificial systems might play a central role in future CC research. Their theoretical investigation sets out by considering non-artistic creativity in simple computational systems through the lens of autopoietic enactivism (Maturana and Varela, 1987) as adopted in the theory of enactive AI (Froese and Ziemke, 2009). The latter theory holds that machines with organismic embodiment can, similar to living beings, realise an intrinsic purpose by maintaining the precarious existence induced by this form of embodiment. It moreover claims that this intrinsic purpose can ground intentional agency. Guckelsberger et al. (2016) consider more specifically when organismic embodiment can ground **intentional creative agency**, realising genuine creative autonomy (Jennings, 2010). They argue that a machine grounds value and novelty in creative activity through the maintenance of their precarious identity, based on acts of self-production and adaptation against entropic forces. The claim that intentional creative agency is contingent on *organismic embodiment* allows for additional, radical statements. Guckelsberger et al. (2016) argue via Dreyfus (2007) that a CC system might have to accurately reproduce human *organismic embodiment* to **exhibit human-like creativity with intentional agency**. Moreover, they introduce the concept of “embodiment distance” to put forward hypotheses on the impact of *organismic embodiment* on the perception of creativity: “when we evaluate the creativity of non-human systems with intentional agency, we are likely to misjudge value

in their behaviour or artefacts, or hesitate to attribute any value at all, as our embodiment distance is too large” (Guckelsberger et al., 2016). This makes the mimicking of *organismoid*, and potentially, *humanoid embodiment* relevant. Colton, Pease, and Saunders (2018) extend the concept of embodiment distance to non-organismically embodied systems and discuss ways to overcome it to foster the perception of creativity and authenticity in CC systems.

Challenges of Embodied CC

Our analysis exposed that many opportunities for embracing embodiment in CC have a flip-side, the impact of which is mediated by the respective embodiment type. The identified three challenges are easily overlooked, as they are often addressed separately from the corresponding opportunities.

Computational & Design Costs While affording a range of opportunities, such as more natural interaction, the stimulation of creativity, grounding, etc. – being embedded in our physical world also puts **high demands on [the] hardware, software and system engineering** (Saunders et al., 2010) of *physically embodied* agents. Fitzgerald, Goel, and Thomaz (2017) particularly lament the increased processing costs due to the high dimensionality of robot sensors and actuators. Gemeinboeck and Saunders summarise that “embodying creative agents and embedding them in our everyday or public environment is often messier and more ambiguous than purely computational simulation” (Gemeinboeck and Saunders, 2013). Especially when tempted by the opportunity to outsource computation into our physical environment, these costs must be carefully weighted.

Unpredictability Related, creative behaviour that emerges from the interaction of *any embodied* agent and their environment, especially if resulting from intrinsic motivation, is often **hard to predict** (Guckelsberger et al., 2016). This is more relevant in some application domains than others, with many artistic domains affording unique possibilities for playful experimentation. Across domains however, researchers must exercise particular caution when designing for interaction with people. Crucially, *virtual embodiment* comes with more well-defined interaction interfaces and affords more control in experiments that can be reset and afford stronger introspection.

False Expectations Several authors express hope that *organismoid*, in particular *humanoid embodiment* can facilitate stronger identification, empathy and affect (e.g. Wicke and Veale, 2018). Saunders and Gemeinboeck however warn that **humanoid robots can cause disappointment** as they “elicit human investment based on superficial and often false social cues” (Saunders and Gemeinboeck, 2018). Referencing studies of human-robot interaction (Dautenhahn, 2013), they particularly highlight the risk of shaping human expectations in a robot’s social capabilities based on appearance alone. As a workaround, they suggest focusing research efforts on non-anthropomorphic robots, and on generating embodied natural movement as means of identification, instead of a similar form or sensorimotor equipment.

Discussion of Embodiment Assessment

We faced several challenges in assessing the type of embodiment in the selected papers. We briefly elaborate on embodiment (i) classification challenges, (ii) biases, (iii) “under-” and (iv) “over-attributions”, and (v) typology limitations.

The classification (i) of embodiment was complicated by unspecific descriptions especially in theoretical papers. Moreover, some papers related to several systems at once, or exclusively addressed human rather than machine embodiment. Sometimes the lack of specifics did not allow us to gain insights into the use of embodiment in CC. Schorlemmer et al. (2014) for instance only appeal to embodied cognition in a side-note. Affected contributions are listed in Table 1 without an assessment of their embodiment type.

Biased views of embodiment (ii) were expressed when authors only explicitly recognised embodiment in humans, e.g. in the case of a virtual system affecting the embodiment of a human user, or when discussing the challenges of modelling human movement. An example of this can be seen in Schubert and Mombaur (2013), who attempt to capture the movement dynamics of human painters.

Some authors “under-attributed” (iii) embodiment in that they leveraged a specific embodiment without explicitly referring to its type or properties. We observed this particularly often for *organismoid embodiment*, e.g. in Saunders et al.’s (2010; 2013) description of the *Curious Whispers* robot society. Here, the robots’ bug-like, organismoid embodiment is not discussed explicitly, although it may have a specific effect on the perception by a human interaction partner.

Closely related, other authors “over-attributed” (iv) embodiment in that they explicitly appealed to a certain type of embodiment without fully implementing or discussing its required properties. For example de Melo and Gratch (2010) describe an experiment performed on “virtual humans”, but they are used as passive mannequins to shine light on. Given that a simulated environment to perturb and be perturbed is absent, we cannot even attest *structural coupling*. Again, this was particularly evident for *organismoid embodiment*.

Limitations of our typology (v) made it challenging to identify specific embodiment types, in particular *historical embodiment*: several systems presented memory or learning capabilities, but this learning did not necessarily happen during the systems’ lifetime. This launched a discussion amongst the authors on whether e.g. the existence of learning hardware is indicative of historical embodiment. We eventually agreed that historical embodiment is independent of a lifetime criterion or learning, and present if the system’s past structural coupling has an effect on its future coupling, e.g. when a past perception triggers a change in a virtual or physical sensor, e.g. affecting a camera’s angle, thus influencing future perceptions. *Organismoid embodiment* was also difficult to assess, as the proximity of a system in shape and sensorimotor equipment to living beings is a continuum. Given the focus of many systems on humanoid embodiment, it would have been helpful to consider it a separate type.

Some types of embodiment turned out to be worse at differentiating and distinguishing existing work and insights than others, but this does not necessarily disqualify them from future use. *Structural coupling* for instance is the most

inclusive type of embodiment and applied to almost all reviewed systems, in particular to any physical object; yet, it proved valuable for sanity-checking whether a simulated system can be considered embodied at all. *Organismic embodiment* in contrast was the most exclusive type. We think it should be included nonetheless, given that existing theoretical work (Guckelsberger, Salge, and Colton, 2017) assigns it a major role in future CC research, e.g. on creative autonomy. As for any other type, the current lack of differentiating power might indicate an under-appreciation in existing work, rather than a weakness of the type itself.

Directives for Embodied CC Research

Our analysis supports the hypothesis which motivated this systematic review in the first place: creativity in artificial systems, and how it is perceived, is affected by embodiment. If we assume this hypothesis, then furthering our insights into embodied CC will play a critical role in advancing the goals of CC more generally. However, existing research is highly fragmented and ambiguous, lacks generalising empirical results, and rarely trades-off the opportunities and challenges of a certain type of embodiment. We translate findings from our review on **RQ1**, **RQ3** and **RQ2** into three directives as pillars of a future embodied CC research agenda.

Clarify embodiment: Our review highlighted that many opportunities and challenges of embodied CC are exclusive to a specific type of embodiment. However, we experienced serious difficulties in assessing the specific type of embodiment embraced in existing work, as documented in the corresponding papers. In order to establish an efficient, unambiguous, verbal and written scientific discourse on embodied CC, we urge researchers to always clarify what specific embodiment they appeal to in a particular theoretical or applied project. To this end, adopting definitions from typologies as presented here may serve as a shortcut, foster comparison, and alleviate the “under-” or “over-attribution” of a certain embodiment. However, any typology can be contested and lacks detail; references to specific embodiment types should thus always be complemented with extensive descriptions.

To counteract the fragmentation of research output, we recommend to reference embodiment-related work extensively. This review, albeit non-exhaustive, might serve as a starting point to identify relevant work.

Conduct empirical studies: Our review moreover uncovered that no existing CC study produced generalising, empirical insights about the effect of embodiment on (i) an artificial system’s creativity, and (ii) how its creativity is perceived by others, including humans. Researchers either make assumptions on this relationship, or draw on existing empirical findings from other fields that may not easily translate to computational systems (e.g. Brown, 2016). We recommend to conduct qualitative and quantitative empirical studies on the impact of a specific embodiment, treated as independent variable, on (the perception of) creativity. Informed by our analysis of which embodiments differentiated existing work most, we recommend that initial empirical studies should investigate *virtual* and *physical*, or *hu-*

manoid and other variations of *organismoid embodiment*, as values of the independent variable.

In evaluating the perception of creativity (ii) as dependent variable, experimenters must eliminate or weight for creative ability (i). Vice versa, in evaluating creative ability (i), they must avoid bias by the perception of creativity (ii), e.g. by employing objective measures of creativity (Ritchie, 2007). When employing subjective measures, researchers should consider concepts introduced in the literature such as the *embodiment gap* (Guckelsberger, Salge, and Colton, 2017; Colton, Pease, and Saunders, 2018) between the system and its evaluator(s) as mediating variable.

Trade-off opportunities and challenges: We encourage researchers to eventually make use of these empirical insights for the design of systems that reliably leverage a certain embodiment as a means to an end, e.g. to accurately model creative processes that emerge from sensorimotor interaction in a specific domain. Crucially though, our review showed that most embodiment-related opportunities come with a challenging flip-side. In order to avoid an unfavourable trade-off, we recommend researchers to always inform their choice of a particular embodiment not only by its opportunities, but also by the corresponding challenges.

Conclusions and Future Work

Motivated by the potential impact of embodiment on creativity and its perception in artificial systems, we set out to map the present landscape of embodied computational creativity (CC), and offered directions for future research in this area. To this end, we conducted a systematic review of papers presented at the International Conference on Computational Creativity (ICCC) that explicitly discuss embodiment. To counteract ambiguity in the concept’s use, we adopted a well-established embodiment typology, and extended it based on the recent scientific debate. We found that most existing work can be differentiated by its focus on *virtual* vs. *physical*, and, more fine-granularly, on *humanoid* vs. *non-humanoid*, *organismoid embodiment*. Moreover, we showed that each type comes with its unique opportunities and challenges as flip-sides of the same coin. Overall, we identified nine opportunities, e.g. the outsourcing of computation or support for more natural interaction, and three challenges, e.g. unpredictability and the shaping of false expectations, from existing studies. We identified several shortcomings of existing work that likely hinder progress on embodied CC research, most prominently ambiguity in the use of the embodiment concept and a lack of dedicated empirical research. We leverage these insights in our final contribution: three directives to advance embodied CC research.

While we chose the scope of this study to provide a reasonably unbiased, big-picture view of embodied CC, future work should be dedicated to incorporating additional, relevant references. How to meaningfully constrain the scope is an open question, as relevant work can not only be found in CC books, but also related fields such as videogame AI, robotics, design and art. To allow for fairer and more direct, unambiguous comparisons, we moreover suggest to complement the present review methods with in-

terviews, in which researchers in embodied CC are asked directly to describe the embodiment in their concrete system or theory. We also deem it worthwhile to conduct a separate, deeper investigation of embodiment in co-creative systems and creative system societies, drawing on theories of embodied, embedded, extended and enactive social cognition (e.g. Barsalou et al., 2003; Dautenhahn, 1997; De Jaegher and Di Paolo, 2008), and on embodied interaction (e.g. Dourish, 2001) as well as embodied aesthetics research (e.g. Scarinzi, 2015). Together with these extensions, our review and the extended typology could eventually benefit a longitudinal analysis of embodied CC, identifying trends in the attitudes towards using specific embodiment types and their associated opportunities and challenges over time and across venues. We hope that this paper provides the necessary knowledge, inspiration, and guidance to drive future research on embodied computational creativity (CC).

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