Five C's for Human–Computer Co-Creativity — An Update on Classical Creativity Perspectives

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Abstract

This paper presents a domain independent framework for discussing human–computer co-creativity. It expands on Rhodes' (1961) four perspectives on creativity and their later adaptations to socio-cultural views of creativity and computational creativity. The new framework allows the attribution of creativity not only to individual creators but to a *collective* of creators, recognising the importance of meta-level communication to the creative *collaboration*, and the variety of creative *contributions* that emerge during a co-creative process. It also elaborates on the different *communities* and *contexts* surrounding co-creative collaboration and thus facilitates the analysis, evaluation and study of human–computer co-creativity by allowing researchers to describe and situate their work in the field.

Introduction

Human–computer co-creativity is a sub-field of computational creativity, which considers collaborative creativity between at least one human and at least one computational agent. This collaborative activity has been defined as mutually influential contributions (Davis, 2013), mixing of human and computational initiatives (Yannakakis, Liapis, and Alexopoulos, 2014) and the sharing of creative responsibility (Kantosalo et al., 2014).

In recent years we have seen many relevant practical contributions to human–computer co-creativity emerge in various domains, including e.g. visual arts (Davis et al., 2014), poetry (Kantosalo et al., 2014), game content generation (Yannakakis, Liapis, and Alexopoulos, 2014), and music (Bown, 2018). However, apart from a few models intended for describing human–computer co-creativity as a process (see e.g. Davis et al., 2015; Kantosalo and Toivonen, 2016; Hoffmann, 2016), the fundamental, domain independent factors characterising human–computer co-creativity have received little attention.

Meanwhile, human creativity researchers (Rhodes, 1961; Glăveanu, 2013) and computational creativity researchers (Jordanous, 2016; Lamb, Brown, and Clarke, 2018; Corneli, 2016) have suggested that to gain a thorough view of creativity it should be viewed from multiple perspectives. Process is just one of these perspectives, which usually include also the creative individual, their creative products and the societal (Rhodes, 1961; Glăveanu, 2013; Jordanous, 2016) and material (Glăveanu, 2013) context surrounding the creative activity. An earlier attempt to use some of these perspectives to analyse human–computer co-creativity was made by Kantosalo (2019) in her thesis. However these traditional perspectives have been designed for individual creativity, and despite loosely incorporating the ideas of social creativity (Glăveanu, 2013), or the possibility of computational or human creative individuals and their interactions (Jordanous, 2016), they are insufficient for examining human–computer co-creativity, which may deal with varying numbers of participants, complex processes mixing human and computational initiative, and a myriad of contributions that take place before arriving at a final product.

In this position paper we first examine Rhodes' (1961) original 4'Ps of creativity framework, Glăveanu's (2013) elaborations and Jordanous' (2016) translation of it for the field of computational creativity. We then present our new framework for human–computer co-creativity, which describes human–computer co-creativity as the interactions within a human–computer *collective*, the collective's *collaboration* process and creative *contributions* to a *community*, all situated within a rich *context*. We then move on to describing communications within the framework and finally proceed to discuss how the framework could be used for describing current systems and the design and evaluation of future co-creative systems.

Classical Perspectives on Creativity

As the interest in creativity as a psychological phenomenon surged in the 1950's (see e.g. Plucker, 2001), defining creativity itself became a topical task. Rhodes (1961) participated in this discussion suggesting that instead of a single uniform definition for creativity different definitions of creativity together offered four interwoven perspectives on creativity: the person, the process, the product and the press.

Rhodes' framework has remained relevant over time acting as a way for researchers to position their own research within the field of creativity (Glăveanu, 2013). The framework has also been popular within computational creativity (see e.g. Corneli, 2016; Jordanous, 2016; Lamb, Brown, and Clarke, 2018) and an early attempt to use it for describing human–computer co-creativity was made by Kantosalo (2019). In this section we first examine Rhodes' original framework, then visit Glăveanu's (2013) extension of it and finally describe how the framework has been used in computational creativity research.

Rhodes' Four Perspectives on Creativity

Rhodes' (1961) four perspectives are based on 40 definitions of creativity and 16 definitions of imagination. His analysis concluded that creativity is typically used to describe only a part of a multifaceted phenomenon, which includes aspects of the creative *person*, the creative *process*, the creative *product* and the person's relations to their environment, the *press*. Together the perspectives are known as the 4 P's.

To Rhodes (1961) the *person* perspective considers properties of the creative individual and their relation with creativity. He focuses on identifying creative persons and considers the effects of their physical and mental abilities on creativity.

The *process* perspective in Rhodes' (1961) original formulation examines the mental processes of idea creation. Rhodes focuses on identifying the stages of creative processes, and what motivates the process. In addition he is interested in how the creative process can be taught and how does it differ from problem solving.

Rhodes (1961) uses the term *press* to describe the relationship between humans and their environment. According to him the influence of this press can take multiple forms: It can foster creativity during adolescence, or affect the mental processes of an individual during a creative process. He is interested in measuring both aspects of the environment as well as how a person reacts to them.

Finally Rhodes (1961) defines the creative *product* as an idea or concept produced in tangible form. He focuses on analysing and categorising ideas and differentiates between new concepts and innovations, which he considers as improvements to existing ideas. He considers products can also be categorised according to use, media of expression, utility or aesthetics.

These perspectives give a comprehensive overview of the creativity of individuals. However, although Rhodes (1961) admits that great inventions are not the work of a single mind, he does not describe creative collaborations or elaborate how collaboration is reflected in the different perspectives. The framework is therefore not ideal for describing co-creativity.

Glăveanu's Five Perspectives on Creativity

Glăveanu (2013) criticises Rhodes' (1961) 4P's framework for a focus on the individual and a lack of connections between the perspectives. After a short review of other extensions to the 4P's, he thoroughly updates the framework to better suit the modern focus of creativity research on social and cultural aspects of creativity.

Glăveanu's (2013) approach draws from embodied and distributed cognition, where mental processes do not only occur inside a person's brain, but are situated and distributed between the person and their environment. He is also inspired by "distributed creativity", an area of creativity research focused on the social factors related to creativity. Reflecting these theories he redefines Rhodes' (1961) perspectives as *actor*, *action*, *artifact*, *audience* and *affordances*.

Glăveanu's (2013) *actor* is a person, who exists in a wider social community. The actor perspective expands the person perspective to consider not only the individual traits of the creative person, but in what kind of roles and how the actor performs in their social context. The interactions between the actor and their social context are bi-directional: the actor can both affect and be affected by their context as they work within it or in coordination with their peers.

Glăveanu's (2013) *action* perspective attempts to capture both the psychological processes of creativity, as well as their external, behavioural manifestations. These actions are also situated in a context. The action perspective considers the creative process in a broad sense, incorporating both physical actions, such as painting a line, as well as the related perceptional processes.

Glăveanu's (2013) *artifact* is again a wider interpretation of the product perspective. Glăveanu considers products to be often seen as separate from the creative person and the process. His artifact is a rich object characterised by both contextual interpretations and meanings as well as its material properties, if it has any.

Glăveanu (2013) divides Rhodes' (1961) press perspective into two complementing perspectives: the social aspects of the press are represented by the *audience*, while the material aspects of the press are represented by the *affordances*. Glăveanu considers that during a creative act an actor is in interaction with multiple audiences involved in the emergence of the new artifacts. The affordances perspective then again considers the material constraints and supports of creative action.

While Glăveanu's (2013) framework gives more merit to the social interactions a creative person has with their environment and their audience during their creative process, his framework still does not consider collaborative creative activities within a group of artistic peers, limiting the applicability of the model to human–computer co-creativity.

Use of Perspectives in Computational Creativity Literature

Rhodes' (1961) original perspectives have also been used by computational creativity researchers: Jordanous (2016) has applied them to computational creativity and discussed their use in the evaluation of novelty and value. Her application of the framework has been used by Corneli (2016) to analyse design principles for creativity and by Kantosalo (2019) in an early attempt to describe different perspectives to human–computer co-creativity.

Jordanous (2016) considers the *producer* to be a more appropriate term for a creative computer. According to Jordanous, the producer has both physical and functional characteristics: The functional characteristics are described by the characteristics of the creative system, including for example its abilities to demonstrate skill, imagination and appreciation, while the physical characteristics are described by the embodiment of the system in hardware. Alternatively Jordanous proposes that the producer in computational creativity could also refer to the human collaborator in co-creative scenarios, or individuals involved in the development of the system.

According to Jordanous (2016), the *process* could consider specific algorithms employed by a system, or interactions between multiple systems, humans or the environment. For Jordanous the *product* in computational creativity is very similar to the product in Rhodes' (1961) original framework. She considers that producing good products has so far been one of the most successful areas of computational creativity research. Her interpretation of the *press* perspective considers mainly the area of social creativity research and bias against computational creativity.

Jordanous' (2016) re-formulation of Rhodes' (1961) framework already considers some aspects of co-creativity, allowing the producer role to be taken up by multiple creators at a time, and considering the interpretation of the creative process as interactions between different producers. However her work does not consider these aspects in detail and does not reflect upon what co-creativity means to the product and press perspectives.

Lamb et al. (2018) have written a review of computational creativity evaluation using Rhodes' (1961) original four perspectives. They selected to use the original 4P's and not Jordanous' (2016) adapted perspectives in order to comply with psychological literature. They do not therefore extend the original framework. However they note that for evaluation, the press perspective is an important construct for considering questions related to who is evaluating and the cultural context of evaluation affecting e.g. whether a product is perceived as P- or H-creative.

Kantosalo (2019) has used Jordanous' (2016) version of the framework to describe human–computer co-creativity. While her approach offers an interesting discussion of co-creativity in connection with traditional creativity research, the four perspectives alone do not offer an independent description of co-creativity, which is one of the goals of our new framework.

Five Perspectives for Human–Computer Co-Creativity

By reflecting on Rhodes' (1961) 4P's, Jordanous' (2016) adaptation of them and Glăveanu's (2013) 5A's we have derived the following descriptive definition for human–computer co-creativity:

> The creative human–computer *collective* consists of at least one human and one computational collaborator. The *collaboration* of the collective consists of individual and collaborative creative processes and interactions that support them. The collaboration results in an artefact or a product that represents the *contributions* of the collective. These contributions are communicated to and shared with a wider *community* of peers, audiences, and other social influences. The co-creative collaboration takes place in a *context* representing the environment of the creative act, including e.g. cultural artefacts and conventions, and more immediate factors such as material affordances and shared mental resources, such as the creative task.

Together the highlighted terms *collective*, *collaboration*, *contributions*, *community* and *context* form a new framework that is designed for discussing human–computer co-creativity from different perspectives. We elaborate on different parts of the framework below.

Collective

A *collective* is formed by the entities actively involved in the co-creative collaboration. In human–computer co-creativity a *collective* always consists of at least one human and one computational collaborator. Thus the collective perspective distinguishes co-creativity from individual creativity through the number of active creative individuals.

The term 'collective' was chosen to evoke parallels with an 'artist collective'; a group of artists interested in working together on a specific topic. In Rhodes' (1961) terms the human collaborator could be called a 'person', and in Jordanous' (2016) terms the computational collaborator a 'producer', while Glăveanu's (2013) neutral term 'actor' fits both. We prefer the word 'collaborator' for the individuals in the collective, as it has been used previously in human–computer co-creativity literature (see e.g. Guckelsberger et al., 2016; McCormack and d'Inverno, 2016).

The collective forms a single unit within human–computer co-creativity that allows for separating the actively participating artists from the surrounding community and context. The collaborators within the collective have a direct say in the internal working methods, goals and artistic processes of the collective, while the influence of the surrounding community and context on the collective's work is less direct and often filtered through the individual collaborators.

The interactions within the collective can be different from interactions with entities outside of the collective: Interactions within the collective are guided by the dynamics between the collaborators. These dynamics can consist of shared goals and history, or the preconceptions, assumptions and other mental models the collaborators have constructed about each other. Interactions with individuals outside the collective can be twofold: they can happen one-on-one between any individuals within and outside of the collective or the collective may also choose to interact as one entity with the rest of the community and the context. When interacting as a single unit, the collective may for example choose to present one single framing for its creative outputs.

The creativity of the human collaborator has been a strong focus of traditional creativity literature. Studies suggest that the individual creativity of the human collaborator is affected at least by task motivation, domain knowledge, and creative thinking skills (Amabile, 1988), while creative collaboration between humans is affected e.g. by how well the creative partners complement each other, interpersonal facility, gender and age (Abra, 1994). The relationship between individual creativity and collaboration is dynamic and collaboration can also change the individual (Amabile, 1988).

In human–computer co-creativity the human collaborator is often approached as a member of a user group (e.g. Davis et al., 2014; Kantosalo et al., 2014; Kantosalo,2019, p.13). Few studies have been conducted to examine how individual properties of the human collaborators affect co-creativity, but initial studies suggest that their user experiences are affected at least by their expertise (Clark et al., 2018).

As Jordanous' (2016) analysis shows, the producer perspective in computational creativity has also examined the methods and capabilities of computationally creative systems. Most of her examples focus on systems that are somewhat autonomously creative. Intentionality and limited self-awareness have also been suggested as qualities for computational collaborators (Davis et al., 2015), however co-creative systems may also be less autonomous than the original computational creativity methods they are based on (Kantosalo et al., 2014). Therefore autonomous systems may not offer a perfect comparison for current computational collaborators.

Reflecting the human collaborator, the computational collaborator may also have other properties, besides its creative capacity, which affect the work of the collective. These include, for example, what the computational collaborator is capable of communicating and how, as well as its representation, which can be either embodied or a software interface (Kantosalo, 2019, p.15).

Like Glăveanu (2013) suggests for his actor perspective, the collective perspective can also be used for analysing the roles of the human and the computational collaborator. So far several roles have been suggested for the computational collaborator in the collective. These include e.g. functional roles such as support, enhance and generator (Maher, 2012), behavioural roles, such as pleasing and provoking agents (Kantosalo and Toivonen, 2016) and older roles stemming from creativity support system literature (see e.g. Lubart, 2005; Nakakoji, 2006).

Collaboration

Collaboration within the collective considers the individual creative processes of the collaborators and how these are fitted together to form a collective creative process. It also includes meta-level interactions, such as agreeing on common goals, exchanging information and discussing working methods, which are typical also for non-creative human–computer collaboration (see e.g. Terveen, 1995). This new collaboration perspective is broader than the original process perspective. It implements both Glăveanu's (2013) ideas on mental and physical behaviours, as well as Jordanous' (2016) suggestion of adding interactions.

In human-human co-creativity, the organisation of creative work can take many forms. Abra (1994) has suggested four dichotomies for co-creativity between humans: *fixed vs. on-going*, *intimate vs. remote*, *horizontal vs. hierarchical*, and *homogeneous vs. heterogeneous*. Following Kantosalo (2019, p.16), we adopt these also for describing collaboration in human–computer co-creativity, however, we also add a fifth dichotomy, *human-initiative vs. computational-initiative* to further describe the collaboration dynamics between a human and a computational collaborator.

Abra's (1994) first dichotomy, *fixed vs. on-going* considers time: A collaborative process can have a fixed deadline or extend over a longer time. Human–computer co-creativity research has mostly focused on short term laboratory experiments, with the exception of a few long-term musical metacreativity collaborations (Kantosalo, 2019, p.16).

Abra's (1994) second dichotomy, *intimate vs. remote* considers co-located and remote collaboration. Collaboration with a non-embodied agent may resemble remote collaboration due to limited communication (Kantosalo, 2019, p.17).

Abra's (1994) third dichotomy, *horizontal vs. hierarchical* examines the organisation of the creative process. In horizontal collaboration the collaborators have equal decision making power, while in hierarchical collaboration dominance and power considerations are introduced into the collaboration. Many current co-creative systems introduce a hierarchical process, in which the human collaborators input is given priority over the computational collaborator's input (Kantosalo, 2019, p.17). A hierarchical relationship may even be the preference of the human collaborators (see e.g. d'Inverno and McCormack (2015)).

Abra's (1994) final dichotomy, *homogeneous vs. heterogeneous* considers the distribution of different tasks among the collaborators. In homogeneous collaboration both collaborators work on similar tasks, while in heterogeneous collaboration the tasks are different. This idea is also explored in human–computer co-creativity literature (see e.g. Yannakakis, Liapis, and Alexopoulos, 2014; Kantosalo and Toivonen, 2016).

We add to these a fifth dichotomy, specific to human–computer co-creativity, which expands on Abra's (1994) horizontal vs. hierarchical dichotomy: the *human-initiative vs. computational-initiative* dichotomy. This dichotomy characterises the dynamics of the human–computer co-creative collaboration through initiative. Initiative has been discussed extensively in human–computer co-creativity literature: Yannakakis, Liapis, and Alexopoulos (2014) define human–computer co-creativity through the mixed human and computational initiatives. Clark et al. (2018) argue that co-creative interaction can be described either as pulling (human initiated), pushing (computer initiated) or both. Karimi et al. (2018) consider that this spectrum from human-initiative to computer-initiative dominion affects a multitude of factors from frequency of communication to what is communicated.

In addition to the dichotomies described above, human–computer co-creative collaboration can also be described as a series of actions through which it proceeds. In such a series, the individual creative processes of the collaborators are often fitted together by following a specific form of interaction. Typical strategies include for example *turn taking*, in which the human and the computational collaborator take explicit turns in assuming an active role (see e.g. Winston and Magerko, 2017).

In essence the collaboration aspect adds to individual creativity the need to discuss common goals and context, and the organisation of work. The different dichotomies offer different options for arranging the collaboration, which in turn may or may not affect the individual processes of the collaborators. Nevertheless in a successful creative collaboration the collective benefits from the profound communication and sharing of contributions within the collective.

Contributions

A creative process usually results in a creative product. However, in the field of human–computer co-creativity the human and the computational collaborator typically exchange artefacts or parts of them already during the co-creative collaboration (see e.g. Davis et al., 2014; Kantosalo et al., 2014; Clark et al., 2018)). We think that these bits and pieces are vitally important in co-creativity as they form a part of the interaction and facilitate the collaboration in the collective. We call these complete and incomplete creative artifacts *contributions*. Like Rhodes' (1961) products and Glăveanu's (2013) artifacts, contributions can also be immaterial. We call physical contributions tangible contributions and immaterial contributions intangible contributions. Intangible contributions cover all meaningful inputs into the creative collaboration, such as the evaluations and feedback provided by the collaborators during the collaboration. If a distinction between contributions during the co-creative process and the end product is needed, we suggest the term 'final contribution' to describe the latter.

As Jordanous (2016) describes, computational creativity has been quite successful in delivering quality products in different fields. The contributions of co-creative collaborators also take multiple forms across various domains. In practise the contributions of the collaborators can be different in both quality and quantity (see e.g. Yannakakis, Liapis, and Alexopoulos, 2014), which is also true for human-human co-creativity (Abra, 1994).

Qualitatively different contributions in human–computer co-creativity could include for example the following:

- An inspiring artefact from the same or a different domain
- A suggestion for an artefact or part of it
- An evaluation of an artefact or part of it

In principle the contributions perspective could also be applied to non-creative collaboration. However, in co-creativity, we are usually interested in contributions that are themselves evaluated high by traditional computational creativity product evaluation measures, such as novelty, quality, typicality (Ritchie, 2007), or surprise (Grace and Maher, 2014). However, to gain best results for the overall collaboration, collaborators should not necessarily use universal standards for these metrics, but adjust their evaluations according to their collaborators instead (Grace et al., 2017).

While the evaluation of different contributions or final artefacts generated by the collective can utilise similar measures as the evaluation of the creative product in computational creativity, assessing or quantifying the contributions of different collaborators has proved more difficult. This is in part because the contributions of different collaborators may not manifest in a visible way in an end product (Kantosalo, Toivanen, and Toivonen, 2015).

Community

According to Jordanous' (2016) the press perspective in computational creativity is focused on the social aspects, including bias against computational creativity, however there are additional contextual factors that affect the design of co-creative systems (Kantosalo, 2019, p.19). Following Glăveanu's (2013) ideas we have divided Rhodes' (1961) press perspective into the social and material environment. In our framework the social environment is represented by the *community* perspective. This community may include additional artistic peers, audiences, critics, curators, collectors and other individuals and institutions outside the collective, who may also present biases towards the collective.

In Glăveanu's (2013) framework the audience may be interpreted to represent some aspects of co-creativity through its potential contributions to the creative work. We think it is more useful for co-creativity to separate the collaborative collective from individuals, who are interested in the contributions of the collective and may interact with the collective, while still remaining outside of it. There is also evidence to support that humans view the same co-creative systems differently when they are acting as an audience and when they are actively collaborating with the system (Bown, 2015b), suggesting this distinction is important in practise as well.

Context

Following Glăveanu's (2013) ideas the *context* in our framework represents the material surroundings of the work, while the social influencers of the environment are represented by the community. Following Csikszentmihalyi's (1988) influential idea about situating creative work in a creative domain, we have integrated also cultural aspects of the environment into the context. Our context thus includes the materials with which the collective interacts during co-creation, the previous influential works the collective may draw inspiration from, and the cultural norms and rules which may affect the collective and its work.

Our perspective encompasses Glăveanu's (2013) view of the material environment influencing or even participating in the creative work, an idea also shared by some computational creativity scholars, such as Bown (2015a). But it also incorporates two core concepts of computational creativity; the inspiring set and external knowledge bases (see e.g. Ventura, 2017; Ritchie, 2007). This implicates our context as a rich surrounding for the co-creative collective, which thus interacts and affects the work of the collective in many ways. As such, the context becomes an important perspective for designing co-creative experiences, similar to the design context in interaction design (Kantosalo, 2019, p.19).

Communication in the Framework

Together the *collective*, *collaboration*, *contributions*, *community* and *context* perspectives paint an interconnected picture of human–computer co-creativity. There are many connections between the different perspectives of the framework, which can be partly described through the complex communications that can occur before, during or after co-creation. While communication can be seen as a major part of collaboration, two other parts of the framework, contributions and context, have a special role in facilitating it. As depicted in Figure 1, contributions facilitate communication as a medium, and the context acts as a background for it.

Contributions have an important role as a communication medium within the framework. Different contributions can

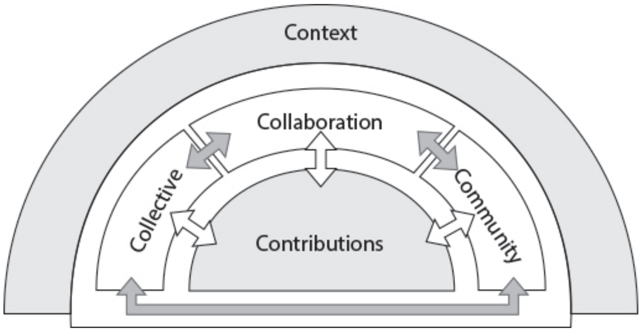

Figure 1: This figure highlights the role of contributions as a communication medium (white arrows). It also shows how context acts as a background for communication. Finally the grey arrows indicate meta-level communication considering multiple perspectives.

be used to establish common ground within the collective. The tangible contributions act as collective aids for embodied and distributed cognition, reflecting the theories that inspired Glăveanu (2013) to separate the material and social context from each other. The intangible contributions, such as evaluations also mediate and direct the communication within the collective during the collaboration and link different contributions to each other. Thus, following Ritchie's (2007) views on computational creativity evaluation, the different chains of contributions could also be used as 'evidence' of the creative behaviour of the collective.

The context provides a background for communication in the framework. It can constrain or support communication within or in between the different perspectives. The context can be interpreted in two ways; as the idealised objective context describing the real world accurately, and to the individual subjective context that are incomplete interpretations of the ideal context. The ideal context includes all societal norms and material affordances which constrain and support the work of the collective. It can also act as a bank of inspiration, including well respected masterworks from different fields. As such it has similar properties to Csikszentmihalyi's (1988) domain, which can also connect artists to each other via contributions.

In order to be able to work effectively in a context, the individuals in the collective (and community), need to negotiate and share their subjective interpretations of the contexts with each other. This may include for example negotiating different time constraints or the use of materials. Through this negotiation the collective may form a more accurate view of the objective context. This may allow the individuals in the collective to gain access to materials they would not have been able to use alone.

Negotiating a shared understanding of the context is a meta-level task, and like other meta-level communications, it is best viewed through multiple perspectives at a time. In addition to viewing how the collective communicates about collaboration, the meta-level perspective can be used for example to view how members of the collective may gradually change as a result of the collaboration (Abra, 1994; Terveen, 1995), or how the collective could be influenced by the community and its aesthetic through commission of works. Viewing these communications on the meta-level through various perspectives can also be utilised to give the collective meta-creative capabilities for reflecting and controlling its own work (see Linkola et al., 2017).

Discussion

There are several ways in which the framework could be used in practise. These include the description and comparison of human–computer co-creative systems, analysing and planning evaluations, as well as planning new research.

The framework allows for describing and comparing systems on different levels of detail, identifying different aspects important for co-creativity: The collective perspective allows us to recognise and differentiate different co-creative systems by the number and properties of participants. For example the collective of the Drawing Apprentice system (Davis et al., 2015) includes one human and one computational collaborator, while the collective of the Curious Whispers system (Saunders et al., 2010) consists of three computational collaborators and one human. This perspective can also be used to examine different aspects of the collaborators: the computational collaborators in Curious Whispers are embodied, while the Drawing Apprentice is a software based collaborator. It can also be used to analyse the relationships between collaborators in different settings.

Through the collaboration perspective we can investigate questions related to the organisation of work within the collective. For example Clark et al. (2018) compare two different ways to arrange work with linguistically creative computational collaborators, one in which human collaborators are limited to work on one sentence at a time, only receiving input from the computational colleague after returning their contribution, and another with which human collaborators can request further contributions from the computational collaborator at will.

Through the contributions we can attempt to estimate what happened during the collaboration or discuss the authorship of the final contributions (see e.g. Kantosalo, Toivanen, and Toivonen, 2015). The context and community perspectives also allow us to identify different domains of work.

Karimi et al. (2018) argue that who evaluates and what to evaluate are important questions for co-creativity evaluation. This view is echoed by Lamb, Brown, and Clarke (2018) for computational creativity. Jordanous (2016) argues that computational creativity evaluation should consider multiple perspectives. Following her approach, we recommend using the different perspectives for discussing what to evaluate. But we also consider they can be used to discuss who conducts the evaluation.

For what to evaluate Karimi et al. (2018) suggest four targets; the outcomes of the collaboration, the creative process, the creativity of the user, or the interactions between the user and the system. These correspond to the contributions, collaboration, and collective perspectives in the framework, which considers the interactions as part of both the collective and contribution perspectives. However, as Lamb, Brown, and Clarke (2018) suggest the community perspective allows also for assessing the bias in evaluation. The context perspective then again allows for assessing the effects of material surroundings to co-creativity, following Bown's (2015a) ideas about the role of materials.

For discussing who evaluates creativity in co-creativity, Karimi et al. suggest three potential evaluators: "the AI, the user and a third party" (Karimi et al., 2018, p. 105). These correspond to the computational and the human collaborator and the community perspective in our framework. Similarly Agres, Forth, and Wiggins (2016) have considered internal and external evaluation of musical metacreation, reflecting a distinction between evaluations done within the collective to improve its work and evaluations received from the community. The added benefit of our framework is that it makes it possible to discuss the relationship different potential evaluators have to each other and the evaluated perspective.

The framework could also help researchers to design their systems and allow them to define how different parts of their system interact with each other. This can be used to select interesting research questions. For example, researchers might deliberately examine different ways of organising collaboration keeping the collective, contributions, community and context perspectives equal.

Finally, by combining different perspectives we may begin to analyse the complex societal role of co-creativity. This includes how the contributions of the collective may break or change societal norms (Shneiderman, 2000), or how a collective may use its contributions to harm a community, e.g. by creating fake news (see Bown and Brown (2018)).

Conclusions

We have presented a new framework for viewing human–computer co-creativity from five perspectives named the *collective*, the *collaboration*, the *contribution*, the *community* and the *context*. The suggested perspectives have been inspired by Rhodes' (1961), Glăveanu (2013) and Jordanous (2016). To incorporate different aspects of co-creativity the new perspectives are more extensive than the perspectives suggested in prior frameworks.

The first three perspectives, collective, collaboration and contribution can be used to distinguish co-creativity from individual creativity by the number of participants, through the identification of integrated creative processes and metaprocesses related to organising creative work in a group, and by acknowledging contributions to the creative artefact that can include partial artefacts or useful evaluations and feedback. The collective and context perspectives offer a way to situate co-creativity in a wider socio-cultural and physical setting, while offering a way to analyse the effect that individuals and materials outside the collective may have on co-creativity.

Acknowledgments

This research has been funded by the Academy of Finland (decision #311090, Digital Aura). We thank Prof. Hannu Toivonen for useful discussions on Rhodes' 4P's and Henkka Hyppönen for making us aware of Glăveanu's 5A's.

References

Abra, J. 1994. Collaboration in creative work: An initiative for investigation. *Creativity Research Journal* 7(1):1–20.

Agres, K.; Forth, J.; and Wiggins, G. A. 2016. Evaluation of musical creativity and musical metacreation systems. *Computers in Entertainment (CIE)* 14(3):1–33.

Amabile, T. M. 1988. A model of creativity and innovation in organizations. *Research in organizational behavior* 10(1):123–167.

Bown, O., and Brown, A. R. 2018. Interaction design for metacreative systems. In *New Directions in Third Wave Human-Computer Interaction: Volume 1-Technologies*. Springer. 67–87.

Bown, O. 2015a. Attributing creative agency: Are we doing it right? In *Proceedings of the Sixth International Conference on Computational Creativity, Park City, Utah*, 17–22.

Bown, O. 2015b. Player responses to a live algorithm: Conceptualising computational creativity without recourse to human comparisons? In *Proceedings of the Sixth International Conference on Computational Creativity, Park City, Utah*, 126–133.

Bown, O. 2018. Performer interaction and expectation with live algorithms: experiences with zamyatin. *Digital Creativity* 29(1):37–50.

Clark, E.; Ross, A. S.; Tan, C.; Ji, Y.; and Smith, N. A. 2018. Creative writing with a machine in the loop: Case studies on slogans and stories. In *23rd International Conference on Intelligent User Interfaces, Tokyo, Japan*, 329–340. ACM.

Corneli, J. 2016. An institutional approach to computational social creativity. In *Proceedings of the Seventh International Conference on Computational Creativity, UPMC, Paris, France*, 131–138.

Csikszentmihalyi, M. 1988. Society, culture, and person: A systems view of creativity. In *R. J. Sternberg (Ed.), The nature of creativity: Contemporary psychological perspectives*. Cambridge University Press. 325–339.

Davis, N. M.; Popova, Y.; Sysoev, I.; Hsiao, C.; Zhang, D.; and Magerko, B. 2014. Building artistic computer colleagues with an enactive model of creativity. In *Proceedings of the Fifth International Conference on Computational Creativity, Ljubljana, Slovenia*, 38–45.

Davis, N.; Hsiao, C.-P.; Popova, Y.; and Magerko, B. 2015. An enactive model of creativity for computational collaboration and co-creation. In Zagalo, N., and Branco, P., eds., *Creativity in the Digital Age*. Springer. 109–133.

Davis, N. 2013. Human-computer co-creativity: Blending human and computational creativity. In *Doctoral Consortium of the Ninth AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment*, 9–12. AAAI.

d'Inverno, M., and McCormack, J. 2015. Heroic versus collaborative AI for the arts. In *Proceedings of the Twenty-Fourth International Joint Conference on Artificial Intelligence, IJCAI 2015, Buenos Aires, Argentina*, 2138–2444.

Glăveanu, V. P. 2013. Rewriting the language of creativity: The five a's framework. *Review of General Psychology* 17(1):69–81.

Grace, K., and Maher, M. L. 2014. What to expect when you're expecting: The role of unexpectedness in computationally evaluating creativity. In *Proceedings of the Fifth International Conference on Computational Creativity, Ljubljana, Slovenia*, 120–128.

Grace, K.; Maher, M. L.; Mohseni, M.; and y Pérez, R. P. 2017. Encouraging p-creative behaviour with computational curiosity. In *Proceedings of the Eighth International Conference on Computational Creativity, Atlanta, Georgia*, 120–127.

Guckelsberger, C.; Salge, C.; Saunders, R.; and Colton, S. 2016. Supportive and antagonistic behaviour in distributed computational creativity via coupled empowerment maximisation. In *Proceedings of the Seventh International Conference on Computational Creativity, UPMC, Paris, France*, 9–16.

Hoffmann, O. 2016. On modeling human-computer co-creativity. In Kunifuji, S.; Papadopoulos, G. A.; Skulimowski, A. M.; and Kacprzyk , J., eds., *Knowledge, Information and Creativity Support Systems*, 37–48. Springer International Publishing.

Jordanous, A. 2016. Four pppperspectives on computational creativity in theory and in practice. *Connection Science* 28(2):194–216.

Kantosalo, A., and Toivonen, H. 2016. Modes for creative human-computer collaboration: Alternating and task-divided co-creativity. In *Proceedings of the Seventh International Conference on Computational Creativity, UPMC, Paris, France*, 77–84.

Kantosalo, A.; Toivanen, J. M.; Xiao, P.; and Toivonen, H. 2014. From isolation to involvement: Adapting machine creativity software to support human-computer co-creation. In *Proceedings of the Fifth International Conference on Computational Creativity, Ljubljana, Slovenia*, 1–7.

Kantosalo, A.; Toivanen, J. M.; and Toivonen, H. 2015. Interaction evaluation for human-computer co-creativity: A case study. In *Proceedings of the Sixth International Conference on Computational Creativity, Park City, Utah*, 276–283.

Kantosalo, A. 2019. Human-computer co-creativity—designing, evaluating and modelling computational collaborators for poetry writing. PhD Dissertation, University of Helsinki, Report A-2019-3.

Karimi, P.; Grace, K.; Maher, M. L.; and Davis, N. 2018. Evaluating creativity in computational co-creative systems. In *Proceedings of the Ninth International Conference on Computational Creativity, Salamanca, Spain*, 104–111.

Lamb, C.; Brown, D. G.; and Clarke, C. L. 2018. Evaluating computational creativity: An interdisciplinary tutorial. *ACM Computing Surveys (CSUR)* 51(2):1–34.

Linkola, S.; Kantosalo, A.; Männistö, T.; and Toivonen, H. 2017. Aspects of self-awareness: An anatomy of metacreative systems. In *Proceedings of the Eighth International Conference on Computational Creativity, Atlanta, Georgia*, 189–196.

Lubart, T. 2005. How can computers be partners in the creative process: classification and commentary on the special issue. *International Journal of Human-Computer Studies* 63(4-5):365–369.

Maher, M. L. 2012. Computational and collective creativity: Who's being creative? In *Proceedings of the Third International Conference on Computational Creativity, Dublin, Ireland*, 67–71.

McCormack, J., and d'Inverno, M. 2016. Designing improvisational interfaces. In *Proceedings of the Seventh International Conference on Computational Creativity, UPMC, Paris, France*, 98–106.

Nakakoji, K. 2006. Meanings of tools, support, and uses for creative design processes. In *International design research symposium*, volume 6, 156–165.

Plucker, J. A. 2001. Introduction to the special issue: Commemorating guilford's 1950 presidential address. *Creativity Research Journal* 13(3-4):247–247.

Rhodes, M. 1961. An analysis of creativity. *The Phi Delta Kappan* 42(7):305–310.

Ritchie, G. 2007. Some empirical criteria for attributing creativity to a computer program. *Minds and Machines* 17(1):67–99.

Saunders, R.; Gemeinboeck, P.; Lombard, A.; Bourke, D.; and Kocaballi, A. B. 2010. Curious whispers: An embodied artificial creative system. In *Proceedings of the First International Conference of Computational Creativity*, 100–109.

Shneiderman, B. 2000. Creating creativity: user interfaces for supporting innovation. *ACM Transactions on Computer-Human Interaction (TOCHI)* 7(1):114–138.

Terveen, L. G. 1995. Overview of human-computer collaboration. *Knowledge-Based Systems* 8(2-3):67–81.

Ventura, D. 2017. How to build a CC system. In *Proceedings of the Eighth International Conference on Computational Creativity, Atlanta, Georgia*, 253–260.

Winston, L., and Magerko, B. 2017. Turn-taking with improvisational co-creative agents. In *Proceedings of the Thirteenth AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment, Little Cottonwood Canyon, Utah*, 129–136.

Yannakakis, G. N.; Liapis, A.; and Alexopoulos, C. 2014. Mixed-initiative co-creativity. In *Proceedings of the 9th International Conference on the Foundations of Digital Games, FDG 2014*.