Designing Improvisational Interfaces

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Abstract

This paper examines the possibilities for creative interaction with computers, in particular modes of interaction based on improvisation and spontaneous creative discovery. We consider research findings from studies in psychology that investigate how humans improvise together to see what could be useful in helping us to design systems that provide new kinds of interactive opportunities. We draw on our personal experiences both as computer scientists working across art and music, and as practicing artists and musicians, to examine what artists and musicians would want in any system designed to support creative interaction with a computer. We bring together these different findings to propose a series of working principles which form a basis for designing systems that facilitate collaboration and improvisation with computers in creative domains.

Introduction

We are interested in designing systems that provide individuals and groups with opportunities for new kinds of collaborative creative experiences with machines. There is the potential to design new experiences and interaction scenarios which can increase the scope and depth of an individual's artistic practice and enhance creative development. In order to do this, we want to fully realise the potential concept of the machine as a *creative collaborator*. We differentiate this approach from the view of computers as "smart tools" or "productivity enhancers", or approaches that seek to create machines as lone systems capable of autonomous, independent creative activity.

In order to design such systems, and to understand the range of potential scenarios, our principle design approach is one which centre stages the contemporary needs of artists in their own practice. In doing so, we believe it is possible to design new kinds of interactions and outcomes by imbuing the machine with the agency of a creative collaborator. Through this approach we aim to bring new experiences to a wide range of people; encouraging greater levels of creative activity and engagement in general. If we can build systems with the right sense of agency and autonomy, then we can provide new opportunities for learning through collaboration, new opportunities for performances involving human-machine interaction, and new opportunities for individual artistic discovery and expanded creative cultures.

To appreciate the machine as a collaborator, it has to be perceived as having a degree of *creative agency* (Bown and McCormack 2009), being an active contributor to the unfolding creative process rather than simply responding automatically as a tool. The degree of proactive, autonomous creative agency facilitates experiences closer to "collaboration" than with software tools having a fixed reactive functionality. A high-level of creative agency should enable us to interact with the computer in natural and intuitive ways, just as we might if collaborating with other human artists: jamming and improvising, listening and responding in artistically meaningful ways. In this sense our approach is a humanist one that sees technology's role as nurturing, supporting and expanding human creative activity, rather than mimicking or replacing it (d'Inverno and McCormack 2015). We emphasise the *human experience* (Dewey 1934), rather than the system per se.

Undoubtedly, designing these systems is a challenging task. A key reason that makes the design challenging is that whilst artists are always exploring new ways of working, they like to explore things in their own way, and rarely like the idea of giving over agency in the creative process to a machine or being forced into constrained interactions that are dictated by the hardware or software design. It's our experience that when a machine has its own agency, the artist using the machine for the first time (rather then the software engineer who built it) is typically frustrated rather then excited. Nonetheless, a number of existing projects illustrate the enormous potential embodied in this approach, provided we are guided by the needs of artists rather then the needs of the engineer in demonstrating a new system design.

As a starting point for this endeavour, we will focus on *improvisational interaction*. We want to build interactive computer systems that intelligently interact and perform with artists in real time; systems that adapt to – and learn about – a person's style, dexterity and proficiency in general. Good improvisational interaction requires people and computers working together seamlessly in an on-going dialogue where, as this dialogue progresses, it grows in nuance and virtuosity, even as the human artist's capacity and insight expand. In this style of interaction the emphasis is on play and experimentation rather than formal composition, but this doesn't preclude the development or progression of substantive creative ideas and works. Successful improvisational exchange between person and machine requires a free and natural interaction, unmediated by unnecessary layers of technology. Hence the problem is one of both successful physical interface design for a given context (how one interacts when improvising) and the substance of that interaction (the creative agency of the system you are interacting with). Any solution will necessarily involve a high degree of co-dependency between interaction, intention and agency.

As part of this paper we will examine a number of findings from the psychological literature on human creativity, where there has been a strong tradition of treating "creativity" as something distinct and tangible in the human mind that can be measured. Whilst we remain skeptical of this view (see (Still and d'Inverno 2016) for example), we do believe that there are studies in Psychology, when looking at "human creative activity", that can help better understand the processes involved when humans improvise: with each other, with other actors, and with tools, all of which are important considerations in designing software systems that support creativity. The literature on improvisation is quite expansive and detailed, with many long-term studies revealing interesting features and theories about what happens when humans take part in an improvisational activity. We believe it is worth exploring these findings to better understand how we approach the design of human-computer interaction in a collaborative, improvisational context.

In addition to the psychological literature, we also draw on our own experience as researchers who are also practicing artists and musicians. To date, many of the most successful systems within the field of *computational creativity* have been designed by people who are practicing artists, bringing the full depth of their artistic knowledge to the system's fundamental design, typically to further develop their artistic practice (e.g. (McCorduck 1990; Cope 1991) are two classic examples). In this paper we attempt to articulate some of this artistic knowledge and discuss it in a way that may be helpful for others designing systems as collaborators in a creative activity. In the final part of the paper, we draw together these ideas and propose a series of guidelines for designing systems that can be used in creative contexts where improvisation is key. Through this work we hope to inspire new insights into the design of systems that become collaborators with humans engaged in any creative activity.

Background

Mental states that best support a person's creative activity (known as "flow states") are most effectively attained when there is a good balance between creative challenges and the person's skills (Csikszentmihalyi 1997). Encouraging these states is increasingly a consideration in designing new kinds of creative computer systems, particularly now that touch, gestural, and body-based interaction with technology are increasingly popular. Coupled with software that can learn and adapt to individual users, these new technologies present an enormous opportunity to reimagine how people and computers might interact to achieve flow states.

As an individual's skills improve, the creative challenges must similarly grow in sophistication. Learning mastery in many creative professions – such as music, dance, performance, and fine art – is a difficult and time-consuming enterprise, requiring extensive personal dedication and perseverance. Typically it takes around 10 years or 10,000 hours of practice to become an expert in any domain (Gladwell 2008). Apart from a few gifted autodidacts, the reason the majority of creative professionals become competent in their field is that they had one-on-one tuition as a child. Without individual tuition it is hard to receive the support and feedback that motivates regular practice (Fig. 1). Consequently, many young people fascinated by the creative arts do not develop skills that would give them the satisfaction and the power to be truly resourceful and imaginative artists – rising to be originators, rather than ordinary consumers of the commercially infiltrated arts of our time.

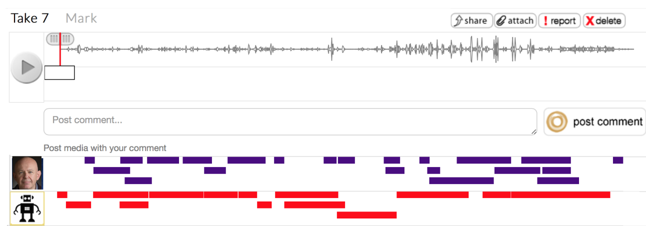

Figure 1: The system *Music Circle* from Goldsmiths allows human and automatic feedback on music performance. Understanding limitations of automatic feedback helps scope the potential of artificial systems to support improvisation.

Improvisational Interaction Design

As discussed, successful improvisation requires a free and natural interaction. Traditional hardware, such as the 2D screen and mouse, imposes constraints on the range of possible interactions, particularly for improvisation. Coupling new sensor technologies with a computer system that improvises with the artist as it learns and adapts to their individual style creates a powerful new creative learning and performing environment. Orthodox "creative software" (software deigned to support humans in creative contexts) is largely construed as a tool derived from the medium's pre-computational history. Software mimics paint brushes, photographic darkrooms, note pads, architect's drafting boards, recording studios and traditional instruments. Mass-production requires a standard interface and compliance to the constraints of the underlying machine architecture and operating system. Computers have an increasingly complex and significant influence on creative cultures, so mimicry of pre-computational tools in software seems limiting, particularly when computers offer many new possibilities that previous technologies are incapable of.

Yet the complexity of modern digital tools often prohibits an exhaustive exploration of all their functional possibilities. Users are typically biased and unwilling to explore, or question the software's fundamental assumptions. As a result they tend to stick with paradigms whose success is modest but at least proven. *They adapt to the software rather than it adapting to them.* Software design and development is largely an engineering discipline, not an artistic one. Mathematical and engineering conventions frequently dominate the conceptual basis of software design, forcing users to conceptualise their process according to the embedded conventions, limiting the development of creative ideas that can be naturally supported through the software's use.

Computer Improvisation

Computer improvisation involves the simultaneous creation and performance of sonic, visual, physical, or linguistic elements. It may be a considered creative means in itself, or part of a wider process in developing a creative work or idea. Early research, pioneered by Fry (1980), and by Lewis (1999), whose *Voyager* system could accompany its human designer at a professional musical level – was generally constrained to low-level creative tasks or specific artistic genres. A breakthrough came with *The Continuator*, an interactive music system based on variable-length Markov models developed by Pachet (Pachet 2002a). This system could learn and creatively respond interactively to any human musical input, from children with no musical training to jazz virtuosos (2002b). The Continuator builds and refines Markov representations in real-time as the person plays musical phrases into the system. If the player pauses momentarily the system responds with its own phrase, based on accumulated knowledge of the player's previous phrases, but biased toward the most recent. This simple interaction creates, over time, an increasingly complex musical dialogue.

Developing this work further, Pachet and colleagues introduced the concept of "reflexive interactions": human/machine interactions with a system that attempts to imitate a player's style. The *Reflexive Looper* is a progression of the concept of musical looping, where a learning system allows you to play with past virtual copies of yourself (Pachet et al. 2013) (Fig. 2). The looper can take on different instantiations of a guitarist (for example) playing a bass line, a chord line, and a solo, with each of these instantiations responding to live playing from the performer. The system shares the performer's goal of trying to create great music, and it achieves this by aiming at the best "ensemble" sound possible. The creative activity of musicians is challenged and stimulated by playing with responsive copies of themselves, leading to impressive musical creations that would not have been possible for a musician playing alone.

This system was an important advance in designing systems for improvisational interaction. It enabled "virtual copies" of a musician to be made, allowing them to improvise with themselves.[1] The system's success stems from it's ability to evoke genuine musical agency that was often interpreted as autonomous when the machine would "lead". Because the system knows the tempo, feel and chord sequence it provides the human player with a strong degree of confidence and certainty. The system could also take part in collaborative improvisation by first understanding what the "live" version was doing, such as playing a bass line, the harmonic chords, or a lead solo line. The looper would then "fill in the gaps", responding to what was happening live by trying to use the most musically appropriate segments of what had been played previously. As the performance develops, the representation of you as a performer develops, allowing the system to make increasingly varied and nuanced decisions about what to play while performing. This dialogue challenges and stimulates the live performer to push themselves further, creating yet more ideas that are then added to the growing data base for instantiating musical copies.

[1] https://www.youtube.com/watch?v=VVgXX1XkzNQ

Figure 2: The reflexive looper from Sony CSL. This system provides a clear sense of musical agency for the performer.

Another popular general model for improvisational interaction between artists and machines has been the "live algorithms" framework (Blackwell, Bown, and Young 2012). A live algorithm is an autonomous machine that interacts with artists in an improvised setting. It consists of an input module which "listens" to incoming features, an output module that "plays", and internal modules for analysis, synthesis and patterning that are updated in real-time in response to features extracted by the analysis module and by internal evaluation. The nature and implementation of these modules were deliberately left open, leading to numerous implementations, bespoke to a particular style or researcher. This framework and its successors have predominantly been applied to live music performance.

It remains an open problem how to extend this and other frameworks beyond musical improvisation. As part of the research ambitions described in this paper, we therefore confront three important challenges: (i) how to extend existing frameworks to other creative tasks beyond musical improvisation, including activities such as sketching, arrangement, and composition; (ii) investigate how any generalised framework can play a significant role in improving learning and development of creative proficiency (such as playing a musical instrument, writing lyrics, sketching), particularly in children and younger adolescents; and (iii) how we can develop the most productive improvisational interactions between artists and machines in these expanded settings.

Learning from Improvising Musicians in Jazz

Arguably (at least in the eyes of the 2nd author) the greatest human-made improvisational interface is the piano, and the opportunity afforded for improvisation in jazz. In most situations jazz musicians will play from a set of standard musical repertoires which feature in various *real books* which are compendiums of jazz standards which consists of the tune and a chord sequence called leadsheets. Typically, the tune is played first, then members of the band *improvise* over the chord sequence - once through a "*chorus*)" - with soloists typically take a few choruses each[2], before the tune is then played again to a finish. The typical constants and variables are as follows:

1. Constants.
   (a) Feel. Do we play latin, swing or bossa?
   (b) Tempo. Up, down or rhubato?
   (c) Key. (Typically musicians stick to the same key. But going up a semitone or tone – *as long as everyone does it together* – is an old trick that often works well.)
   (d) The leadsheet of chords. (Everyone follows this. And if you get lost in the leadsheet never let anyone know!)
   (e) Structure of performance (tune, choruses, tune).
2. Variables.
   (a) Original choice of tune, feel, tempo and key.
   (b) Order of soloists. (Agreed in advance or just emerges.)
   (c) Introductions. (Do you go *straight in* to the song or do you have a rhubato introduction, signalling the speed through the playing?)
   (d) Chord alterations. (The chordal instruments such as piano and guitar are free to move away harmonically from what is written on the lead sheet.)
   (e) Choice of scale. (Good jazz musicians are able to move between different scales that fit over a particular chord in the chord sequence.)
   (f) Notes played. (Where improvisation can take place.)

So in a performance context you might say "Autumn Leaves. Gm. Swing. In 3. Bass solo first. Straight in. One ... , two... one, two, three, four ". In jazz improvisation there is a huge amount that is fixed which enables jazz music to happen without a huge amount of obvious interaction apparent to the audience. Visual signals include "I'm coming to the end of my solo can you go next?" and "follow me on this rall would you?", but there aren't many and so the unfolding interactions are very subtle and nuanced and almost completely contained within the music itself.

In free jazz on the other hand there are no constraints. The only constraint is that someone starts and that you have to finish; finishing being much harder than starting much of the time. But in this context – to improvise well – you have to be incredibly responsive. Visual and aural cues are coming in all the time and to work out how to respond, how to support, how to texture, how to subvert, how to challenge and so on requires an ongoing heightened awareness and sensitivity. This is often developed following many years of practice and experience. You make yourself open to any and all possibilities and you hope and expect your collaborators to be doing the same, and to sustain the intensity of music improvisation with others requires that interactions are entirely natural and intuitive.

There are many theories of what happens in improvisation but to do it well requires a deep and virtuosic understanding of how to play an instrument, an instinctive ability to navigate chord sequences, and a deeply-honed musical awareness and sensitivity to what is going on around you.

Figure 3: The Mark d'Inverno Quintet launching the album *Count on It* at London's leading venue: Pizza Express Soho. The guest sax Gilad Altzmon (centre stage) joined for several songs having never played with the quintet before.

Improvisation in tonal jazz consists essentially of creating an (often singable) melodic line which is consistent with the underlying chord sequence (when there is one) utilising notes from these chords and their associated scale or scales to create motivic elements, often starting from elements based on the tune and developing the melodic line into a memorable melodic structure usually with a beginning, middle and end. Some commonly explored improvisational routes would typically be: 1. chordal improvisation – where we typically use notes on the current chord in a chord sequence in any order and run up and down the notes (arpeggiation); 2. scalic improvisation – where we typically run up and down parts of the scale or scales associated with a given chord, starting and stopping anywhere in the scale; 3. motivic improvisation – where we use notes from the associated scale to create an (often singable) musical phrase and then develop this motivic element using various techniques such displacement, rhythmic displacement, inversion, variation and recapitulation; 4. special devices – where we use particular devices with discretion to enhance a solo such as crushed notes, octaves, double octaves, multiple notes in the right hand, different variants of "locked hands" and "bluesyfication" to add interest to the solo.

Of these, motivic improvisation is often considered the most important – an approach strongly embedded in the courses *Learn to Play Jazz Piano Online* [3] by Ray d'Inverno, who has over 60 years as a jazz pianist and close to 50 years as a jazz educator (Fig. 4). The course covers a huge range of material to do with playing jazz piano, indicating that effective improvisation can only happen with a wide and deep range of concrete musical knowledge. Another way to appreciate improvisation is to provide some quotes from the greats that articulate what playing jazz and improvisation means to them, and perhaps sheds light on how we approach

[2] The story goes that Miles Davis once asked John Coltrane why his solos were so long. John Coltrane replied "I don't know how to stop." to which Miles responded with "Try taking the f****** horn out of your mouth."

[3] https://vimeo.com/99517780

Figure 4: Learn Jazz Piano Online by Ray d'Inverno. Jazz courses like this give a sense of the enormous scope of technical knowledge needed before improvisation can happen.

the issue of designing systems that are truely responsive to human improvisation.

> *I realised anytime I came home, the thing I was missing was the sights and sounds from this property. It's very lush, real winters, real summers. Everything changes all the time, you see struggle and that struggle to me is a parallel to the artistic struggle."*

Keith Jarrett, pianist.

> *When we're playing something in straight time, boy! When this thing locks, something else takes over and it's like you're not playing ... it's kind of floating! This level is reached on every track of Standards Live, effortless, as if it is the norm.*

Gary Peacock, bassist. Talking about playing with the "standards trio". (Fig. 5).

> *I love him because, as a pianist and drummer myself, I can identify with him, the concept of what to ignore, what to leave in, what to leave out – we intuitively understand that – that's why when we play together we never know what's going to happen, but we always get something happening that turns us on.*

Jack DeJohnette, drummer.

Figure 5: The Standards Trio: Keith Jarrett, Gary Peacock and Jack DeJohnette. Arguably the most accomplished jazz improvisation outfit ever because of a deep connection with the emotionality of the unfolding music and an almost telepathic awareness of each other.

As these quotes illustrate, improvisation embodies many of the complexities of being human. In encompasses learning, life experiences, expectation, virtuosity and skills that are typically developed over many years. When improvisation between players works they respond by articulating states of heightened awareness, well beyond the mechanical act of playing an instrument. Indeed, many aspects of the improvisational experience appear beyond conscious knowledge, or at least its verbal articulation. To give a concrete example, the Mark d'Inverno quintet had played many times together before including an intensive period recording a new album. However, with use of the lead sheet, they were able to invite a special guest – the virtuoso sax player Gilad Altzmon – to join them on a couple of the album's tracks without ever having rehearsed or playing together before (Fig. 3). This may seem "magical" to some audiences but relies on having a clear structure as defined by the lead sheet, a clear set of norms in terms of who is soloing and how the soloist leads the musical journey. However an empathy and awareness of what is unfolding in the improvisation from all musicians so that the band can interact successfully is also vital. In order for improvisation to be facilitated effectively, any computational system will need both the domain knowledge and an on-going sense of the activity other participants.

In summary, improvisation in modern jazz is making up your own tune which fits with the chord sequence, where a tune consists of musical phrases that are often "singable". The limitation of this definition is the use of the word "musical". We can often recognise non-musical improvising (sometimes called "noodling"), where all the notes in use are correct in that they fit the chords and scales, but they do not add up to anything "musically meaningful". Again, "musically meaningful" is hard to define, although those with a suitably trained ear can mostly agree when it happens. It has something to do with a musical phrase or line having a "shape" or a "structure", with components identifiable as a beginning, middle and end. Since music takes place in time it is also about how it occurs in relationship to what has come before and what happens afterwards. Perhaps to help with these abstract definitions it is best to listen to the greats of the modern jazz world such as Charlie Parker, Miles Davis, John Coltrane and Michael Brecker and pianists Bill Evans and Keith Jarrett. The musical tradition of jazz can be thought of as a quest, a journey or race where the torch is handed on from one generation to the next, thereby retaining the best of the old but frequently searching for the new.

Learning from Artists

The concept of art and what activities it encompasses has undergone regular revisions in Western culture, particularly in the last 200 or so years. One important shift in emphasis in the process of art-making has been from *problem-solving* to *problem-finding*. In problem-solving the creative emphasis is on how to achieve outcomes – "how do I represent this?", for example. Problem-solving relies on developing mastery and skills over a working lifetime, hence when, as a society, we value problem-solving in artistic creative activity, the importance of a person's creative work tends to increase with their age and experience. An individual's creative peak comes late in their career, in contrast to popular notions that people reach a creative peak at a young age or in the early or middle of their professional careers.

> Artists like Cezanne explored a single "problem" for their entire career, and they gradually got better at it; that's why Cezanne's later paintings are worth more. (Sawyer 2011, p. 302)

In contrast, problem-finding shifts the emphasis to the *process of making art* as an exploration, rather than a finished product. Changes in our conception of what constitutes the creative value of an artwork in twentieth century art favoured the problem-finding approach. For example, a major study by Galenson showed the art world increasingly favoured problem-finding artists as art developed in the nineteenth and twentieth centuries (Galenson 2009). Similarly, Csikszentmihalyi found that contemporary problem-finding artists had more successful careers. This shift from problem-solving to problem-finding also brings changes in what we consider "good creativity" in an artwork and when we typically view an artist to be at their creative peak.

Such shifts seem culturally determined. As we discuss below, Western, individualistic cultures emphasise value in originality – problem finding – as a point of differentiation, whereas other, less-individualist cultures place value in the faithfulness of a representation or idiom. Current graduating art shows often appear to display acute diversity, typically with some "standout" works being perceived as far more creative than others. But historically this isn't the case. Looking back at graduating art shows over decades reveals a homogeny and sameness that is bound with the particular point in time the works were developed, again suggesting that our idea of creative value shifts with time and culture. These observations point to the hypothesis that many factors in our judgement of creative activity and creative value are culturally determined. As time and culture changes, so does the *creative value* assigned to any artefacts produced. As complex computer technology is increasingly pervasive in our culture, we would naturally expect this change to influence how our creative judgment is formed and the value we ascribe to creative activities.

From a more personal perspective, improvisational creative activity in a visual arts practice often involves a nuanced feedback between action and result. The artist is constantly evaluating a work as it emerges, often trying many different ideas or approaches before finally arriving at a fruitful idea. The form and application of this evaluation is quite different than one would get from an audience or reviewer, for example. Sketchbooks – either literal or metaphorical – that allow easy and rapid expression of ideas, anytime, anywhere, support this developmental process. The metaphor of a sketchbook has been successfully applied in the area of creative coding, for example, however as previously discussed physical metaphors translated to software may limit creative expression.

This is precisely the same as music composition or play writing for that matter: there is one part of you creates something, then another part of you that assesses and edits. Wearing two very different hats in the creative process is often difficult for the lone creative, illustrating the potential value of an artificial collaborator that can take on specific and changing roles in human/machine collaboration.

Learning from Psychological Theories

In this section we look at psychological theories of human creativity and discuss how they might inform the design of improvisational systems that support a person in a creative task or act. In broad terms, there have been two major streams of thought about creativity and its locus of influence in human Psychology. These are often referred to as *individualist* and *sociocultural* theories of creativity. Individualist creativity has its origins in associationism theories of Psychology. As the name suggests, its focus is on the individual creative mind and views creativity as a distinct, but general human capability.

A major early goal of individualist research was to quantify and measure individual creativity or creative potential. The idea of being able to predict a person's creative potential was especially popular as an objective methodology to select "gifted" children for accelerated or enhanced learning programs. Over 100 measures of creative ability can be found in the psychological literature, but the most widely known are the *Divergent Thinking Tests* (Runco 1991). These tests typically ask participants to come up with as many unusual uses for common objects (e.g. bricks) as they can in a fixed time period. In this test, scoring is based on the total number of responses and the number of statistically unlikely responses.

While convenient to numerically score and rank a person's creative potential or ability, such tests have many problems (including methodological, design, and correspondence issues) and have been widely contested in the literature. Moreover, they are counterintuitive: individuals considered especially "creative", typically excel only in a specific domain and the psychological literature suggests that many aspect's of an individual's creative ability are highly domain specific (Hirschfeld and Gelman 1994; Kaufman and Baer 2004). Doing a short test to think of many different uses for bricks doesn't intuitively seem similar to the actuality of expressing oneself as a creative artist or musician.

Modern European cultures primarily associate individual creativity with novelty and originality, but other cultures focus more on how well an artist's work interprets an existing style or idiom. In such cultures, being new or different is not seen as creative or a positive trait. In highly individualist cultures, such as the US, emphasis is placed on individual creativity and ownership of originality. More than 2,000 patents worldwide are attributed to the American inventor, Thomas Edison, yet most of Edison's inventions were developed by large teams. These cultural differences suggest that the common concept of individual creativity, how it is assessed and evaluated, has significant determination and validation by the culture in which it arises.

It could be argued that the computational creativity community has sometimes favoured this individualist understanding of creativity, with one of its main goals being "to construct a program or computer capable of human-level creativity".[4] In contrast to individualist approaches, sociocultural creativity considers creativity as a product of social and physical interactions over time. It seeks to explain creative processes through interactions between groups, societies and cultures.

It is often seductive to think of creativity as residing exclusively in an individual, but we believe that any modern creative activity relies heavily on multiple social innovations and incremental discoveries. Contemporary creative artefacts – including skyscrapers, automobiles and computers – are created by multiple groups and organisations, who are distributed globally, connected using complex mechanisms and rely on numerous innovations developed previously. Music, cinema, dance and performance also rely on social creative activity; jazz ensembles and theatre performers innovate collectively and relay on group dynamics to drive the creative process (Sawyer 2003).

Creativity also occurs at a societal level. Systems of trade, complex organisational and distribution structures are not created by any single individual or group. They emerge through a complex interaction between many different individuals, groups, organisations, etc., which take place over decades or even centuries. Creative precincts and cities that have occurred throughout human history, from renaissance Florence to Silicon Valley, are complex creative ecosystems (McCormack 2012) that earn their creative currency from the interactions of many individuals, systems and events, not from any one super-creative individual working in isolation.

In the sociocultural view, creativity *emerges* through these interactions between people, objects and environments. It is incremental and builds on many small discoveries and often chance events. Increasingly, computers are a significant influence in the modern world's creative ecosystem. So any design of a system to support creativity must include the possibility of creativity being changed by that system itself.

Group Improvisation

Sawyer (2011) lists ten key characteristics of group improvisation, generalising from a number of studies in free jazz improvisation, but also from many years of research in collaborative teams in business, industry, theatre, and so on – anywhere where group improvisation plays an important role. These characteristics can be summarised as follows:

- Provide a strong **match** between the group and the goal;
- Facilitate **close listening**, which can lead to unplanned responses to what has been said;
- Each person must **concentrate** and have complete focus on the task;
- Being in **control** – having the autonomy and authority to execute;
- **Blending egos** – each person's ideas build on the groups;
- **Equal participation** – everyone participates equally;
- **Familiarity** – tacit knowledge enables better communication;
- **Communication.** The group members are always in communication, always talking;
- **Keep it moving forward**. Each person builds on and elaborates the ideas generated by the others;
- **The potential for failure** - the potential for failure motivates peek performance.

These characteristics provide a pathway to developing computationally creative improvisational partners, designed to collaborate with humans artists. It is also interesting to compare these characteristics with our earlier explanation of specific examples in free jazz improvisation.

Towards a Theory of Human-computer Collaboration

The literature from psychology has explored how creativity occurs in individuals, groups and societies. To summarise our discussion thus far. The modern, sociocultural view sees creativity as an emergent process that arises through interactions, rather than the romantic idea of the lone, emancipated creative individual. Developing individual creativity takes many years of focused practice and dedication. Creative works develop mainly with small, incremental improvements, typically with many relatively small innovations rather than singular "eureka" moments of deep insight. Regular review, tweaking and feedback is generally what makes creative works great. Being especially creative in one area doesn't necessarily make make you very creative in others.

Moreover, popular understanding of what constitutes creativity and how we assign creative value varies according to time and culture. Most people are able to place a piece of music in the decade it was written, even if they have never heard the song before and it originated before they were born. When viewed historically, artworks from any specific period appear similar in style and influences, specific to the period of their creation, even if at the time there were large differences in their reception and perceived creativity.

These findings are important considerations for designing human-computer collaborative systems. As a starting point, below we present a set of guiding principles that we believe are necessary for building computationally creative improvisational systems. Our guiding principles are:

- creative activity is supported by social interaction, therefore we need a social infrastructure that supports both human and machine agency on an equal footing; (note that this not suggesting that the machine is necessarily creative in its own right. We leave that question for others, only that it brings creative agency or even creative autonomy to a specific creative context);
- proficiency takes many years of dedicated practice to develop mastery of a specific creative activity or discipline. The idea of "general creativity" doesn't correlate with the specificity observed in most creative domains; (as we touched upon playing jazz piano requires a huge amount of knowledge and practice, without this strong base effective group improvisation is simply not possible);

[4] http://computationalcreativity.net/home/about/computational-creativity/

- the challenges and responses must grow in proportion to each individual's development. Tasks that achieve a good balance between challenge and skills work best, so the computational system must change with each individual to support their creative development and virtuosity;
- people learn and flourish *into* their creative practice, they need support and encouragement but also critical feedback on how to improve; giving and receiving feedback on our developing practice is arguably a critical role for future systems (Fig. 1);
- in early development, free-play readily encourages creative exploration;
- interactive communication between active participants needs to be facilitated, often non-verbally.

Conclusions

Taken together with the characteristics of group improvisation, these guiding principles point to a way forward for designing collaborative machines with their own creative autonomy, that support improvisational development of artists. Clearly, we have only articulated basic principles, not described detailed designs for specific systems. Our research is not yet at this stage, but these principles – together with our understanding of the successful improvisational systems described earlier in the paper – form the basis for further investigations as we work towards developing computational systems that can significantly enhance and broaden both individual and group human creative activity.

We have looked at a number of findings from Psychology with regards to the concept of "improvisational creativity" in humans to see what we might learn as designers of systems interested in supporting and provoking the human creative. Additionally, we have described how improvisation flows in non-computational settings and drawn a set of broad guiding principles from this work. We hope that these insights will be helpful for the design of systems supporting human-computer improvisation (Yee-King and d'Inverno 2016).

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