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Constraints and Creativity in the Digital Arts

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In art, truth and reality begin when one no longer understands what one is doing or what one knows, and when there remains an energy that is all the stronger for being constrained, controlled and compressed.'

— Henri Matisse

1. Constraints and the Creative Process

When we refer to constraints in daily life we usually mean something that limits what we want to do or places boundaries around our choices. In the world of creative endeavour, the word has many interpretations. We think of constraints in creativity as both limiting and liberating. In our personal practice, they are used to impose boundaries upon the creative space we occupy and, at the same time, they enable us to grapple with inherent tensions between different demands, which, if successful, may lead to a new idea, direction or artefact. When we choose particular forms, materials and tools for our creative work, we are also choosing the kinds of constraints that will shape our process and its outcomes.

Creativity may be seen as a process of exercising free choice in the context of a range of existing constraints. Constraints may be both negative and positive influences on the creative activity or task: the negative may be externally imposed or the result of unexpected phenomena and the positive may be considered beneficial because they have either been self-imposed or have arisen from the intrinsic characteristics of the work itself. Constraints are restrictions that limit what the individual wishes to do but such restrictions may also be seen as having more a positive and indeed, necessary function by providing the creative person with a more manageable creative space. A totally free or unoccupied space in which to begin a creative work is both unimaginable and probably undesirable. It could be argued that by abandoning all existing constraints we make complete freedom of action possible. In reality, there are few situations where that occurs for we all bring some constraints to the creative process whether we choose to do so or not. The constraints may arise from situational limitations such as organisational rules, or our cognitive attributes of memory and perception. Constraints which impose fundamental limits on our ability to think, perceive and create, for example, mental blocks, are less amenable to change or control by the individual concerned than those that are self-imposed (Smith and Tindall 1997).

From this perspective, all creativity is a bounded activity. That the boundaries are extended or redrawn by someone's exceptional effort is what makes the process different and, ultimately, the outcome innovative. Constraints can be seen to work both ways in creativity. When you constrain thought, you automatically prevent ideas from being found outside of the defined territory. However, constraints also cause tension that can result in better ideas being found within the defined scope. The freedom in creativity is the ability to move between constraints or, to put it another way, the creative act is selecting the right path, from among all the possible paths defined by the constraints. By making an explicit statement of constraints, they can be critically examined and, if it seems right, be relaxed. In this way new paths are created.

2 Constraints in Design and Music

In the design process, constraints are included in the functional description of the artefact and the production processes used to manufacture it, including materials and dimensions. In engineering, where constraint-based approaches to supporting the design process are well established, it has been long recognised that constraints emerge during the process. There have been many studies into how designers carry out design activities including how they impose constraints that narrow down the number of solutions and help generate new concepts. They also change their goals and may tighten or relax or add constraints during the design process. Constraints are usually characterized as boundaries within which the object or artefact may be designed: for example, knowledge that a particular manufacturing process must be used to construct the product will impose constraints upon the design itself; in architecture, in designing an innovative building without worrying in advance how to construct it may, as in the case of the Sydney Opera House, provide significant challenges later for the structural engineers. In design education, students are

sometimes encouraged to ignore the problems that manufacturing considerations would impose whilst learning how to produce innovative visual effects, for example in vehicle styling.

Boden characterises constraints as a means of mapping "a territory of structural possibilities which can be explored and perhaps transformed to give another one". (Boden, 2004, p95). The way constraints within a particular genre are changed over time until an entirely new genre emerges is exemplified by the case of tonal music. Tonal music was developed over centuries by an exploration of the harmonic steps by which a melody could progress from one movement, phrase, chord or note to the next. There existed a structured space of chordal successions by which to modulate from one key to another and one would normally pass through successive neighbouring keys. By the end of the 19th century, composers had gradually abandoned tonal constraints: pathways between modulations had become progressively shorter and the notion of an approved chordal succession was increasingly problematic. Finally, Schoenberg took the step of dropping the final consonance indicating the end of a musical journey, and in doing so, create a new field governed by different rules in which conventions of modulation and consonance could not be expressed. He saw that the tonal conventions were not arbitrary but were intelligible, mutually coherent constraints - in effect, a 'coherent generative system' to use Boden's terminology. The development of a conceptual space such as tonal music is a rich and complex enterprise that took many centuries to map to the point where composers set it aside in favour of a new atonal space. However, to be understood as creative, atonal work has to be seen in relation to what preceded it and even after a century of existence, for some listeners, the mind map necessary to appreciate such work is yet to be drawn.

In a more recent musical context, Kristian Walker sums up his own creative process in relation to the role of constraints and the need for structure:

> "Jazz relies heavily on soloing. Most jazz tunes have more bars dedicated to solos than anything else. But always there is the underlying rhythm and song structure that keeps the identity of the song intact. The solos are always framed around a melodic idea. Every time Duke Ellington and his orchestra played *C Jam Blues*, the experience was unique, but you always knew what song it was. Ben Webster would take that melody all over the countryside (sometimes into the next county) and back again, yet it was always familiar. The groove was intact.
>
> Most creative endeavors need that underlying groove for structure. I find I'm more creative in my work when I have limitations and boundaries. While this seems to be at odds with the idea that creativity is limitless exploration, it really isn't. Adding a wall or two to the beginning of the process provides direction and focus for the artist's energies.
>
> Many times the walls have to do with more "technical" restraints; the simple frame of a canvas or the complex 7-column grid of a brochure layout. I'm in the midst of a 20-page brochure. Each page has pretty much exactly the same elements (headline, main visual, body copy, pull-quote, company division ID). Because I've placed that 7-column grid underneath, each page is also a unique layout, with nothing repeated from spread to spread. I can riff around the design's melody and everyone still can recognize the song.
>
> Another advantage to placing boundaries in the creative process is that it provides a starting point for the brain. The blank, white page staring at you is much more daunting when there is no starting direction. Free Jazz (my least favorite) tries to build a song on nothing. The players just jam without any underlying musical structure at all, and it's hard on the ears to all but a few."

3. Constraints and the Digital Arts

In the digital arts, the creative process is fundamentally the same as in any other field of creative work. In any creative situation, some constraints are there because the artist chooses them; in others they are inherent to the context, the genre and the medium. The chosen genre is the basic creative conceptual space in which rules and conventions impose a set of boundary constraints within which the artist works. It is the choices made within this constrained space that create a distinctive individual style, which, if successful, is instantly recognisable as belonging to a particular person.

In selecting a particular medium, the artist chooses a set of constraints that are inherent to it. In the digital arts, the new technology brings with it special kinds of constraints that are both inherent to the nature of digital computers and are also facets of a medium that is less than one hundred years

old. The relative immaturity of the medium and its multi-faceted character are factors that have given rise to very different approaches to its use in the digital arts, from those who would "digitalise" existing forms to those who would change the very forms they work with. I will argue that the constraints inherent in digital media are being handled in very different ways that have implications for the future of digital art process and the technology support it demands. Some artists, often when new to digital technology, find that it restricts their creative work to a degree that is often frustrating and difficult to overcome, whilst others use the inherent constraints of the technology to pose challenges and opportunities for changing the very nature of the way they work and the final outcomes from that process. Significant challenges, do, however, imply changing the technology at a more fundamental level than is normally provided in commercially available software.

The digital elements in digital art may either be an inherent part of the work itself, or be tools that are used to make it, but are not part of that which is displayed or performed. In many cases, the digital forms part of the work, as in a screen based installation, as well as being used to write the program that generates the images or the music. In other cases, the work is developed using a software program but the final artefact is presented in another medium.

The distinction between the digital medium and the digital tool for some artists does not exist, so fundamental is the nature of digital technology to their work. This occurs both with early digital artists, whose move to digital predated the arrival of accessible software applications for image creation and manipulation, and the more recent generation of artists, whose technical skills are acquired as part of their education and for whom it is a natural part of their creative repertoire.

Manfred Mohr writes of the relationship between the algorithms he writes and the images that become exhibited artworks:

> "My algorithms have developed over the years and have always drawn on my aesthetic decisions and knowledge as an artist. My programs are continually updated through an interactive procedure between my abstract ideas and the creation of my algorithms.
>
> When I declare a program to be finished, all results of the program are accepted as equal aesthetic possibilities. The results are shown in a variety of ways but they are never altered and/or chosen for aesthetic reasons…Since there are infinite numbers of possibilities, I have to choose some of them to show as "still images". All instances however, are chosen with the intent of showing the greatest possible variety and are in most cases chosen randomly by the program itself" (Mohr, 2002)

In Mohr's creative process, the digital aspect is both medium and tool. For him, the defining of the constraints in algorithmic form completes the process in the sense that all resultant images are equally valid. He may go further by using another display medium and produce printed still images that show a range of different possibilities but there is no change to the original images that were generated by the algorithms.

A major difference between those who program their own generative systems and those who use software applications to generate their work is the degree to which the constraints have to be made explicit. In general, most would say that the effect of using digital tools is to demand a more precise specification of the form of the work. However, the act of programming goes deeper for it requires an explicit definition of the underlying structural constraints of the work.

4. Constraints and Structure

An important characteristic of digital technology is that to use it to its full, you have to be prepared to make explicit the implicit assumptions that are in your mind as you develop the work. It is the very need for explicitness that makes it both challenging and rewarding to many artists. In order to work digitally, the constraints have to be specified in such a way as to make the computer generate an outcome that is satisfying to the artist. But, more importantly, the process of specifying the constraints in digital form can be best understood as an integral part of the creative process. The choice of whether to program or to use a software application can be critical to how much the artist has control over the type and character of the constraints to be specified. There is no doubt that programming offers more flexibility and control in this respect. This view is not necessarily accepted in some artistic communities where programming may be seen as an instrumental part of the preparatory work, rather than part of the artistic process itself, and therefore, something that can be delegated to a person expert in programming who is not necessarily an artist. On this last

point, I would argue that in certain types of digital artwork, the delegation of the programming task in itself constitutes a diminution of control over the way the work is defined or characterised. In some types of work, being able to create the full scope of the work from its fundamental structure to its visual manifestation or performance, involves developing technological solutions that cannot be acquired as commercially available tools.

For artists working in the constructive, concrete and systems art traditions, in particular, the attraction to the digital is directly related to the computer's capacity to represent and 'execute' the underlying structure of the works.

> " The notion of *structure* implies something *recoverable*, in the sense that it is possible to look at an end result and determine the structures that generated it. It has a clear structure, and being clearly predictable, its structure is highly constrained." (Edmonds, 2002, p71).

If constraints (on elements of the work) such as colour, relationships between objects in the scene, sequences (in time-based work) and movement and location (in interactive work), are specified in a computer program, this can be used to understand their implications through to the visual appearance and in total, the true nature of the underlying structure. This necessitates an explicit definition of what those constraints are. These might be thought of as personal 'rules' that capture the significant elements that the artist chooses to focus upon.

> "I want to find not strict rules but to have my own rules in my work, and to find basic structures in things what I experience and what I see…I think that it is an inner necessity to find rules." Birgitte Weimer (in Edmonds, 2000).
>
> I invent rules which reflect my thinking and feelings." Manfred Mohr (in Edmonds, 2000)

In Edmonds' case, he describes the expression of constraints in this way:

> "Always, in the end, the selection of the colours and their juxtaposition is a matter of judgement that deeply affects the character, meaning or impact of the work. However, making those choices is often, even normally, made possible by the use of systems that limit the infinite possibilities and enable order to enter the creative process.
> ….
>
> When working on a piece, in whatever medium, my practice has been to select a line in a colour space and divide it up in perceptually equal intervals, the colour at each boundary point being included in the pallet for the work. Of-course, the line can be very short, giving a set of very close colours, or long including quite different hues, for example. It can also be curved or move only through levels of brightness. These methods lead up to and frame the final moment of selection. The choice is a matter of judgement that can only be made, in the end, by looking. This approach gives all the freedom I need. (Edmonds, 2005)

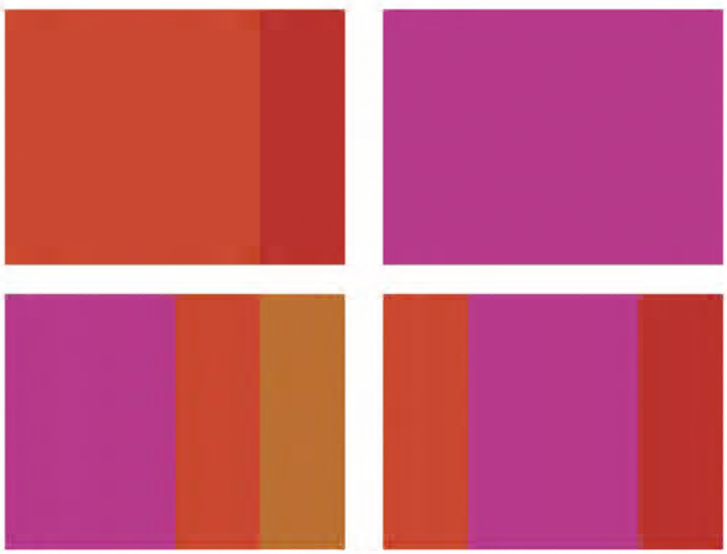

Figure 1: Ernest Edmonds. From Broadway 1,2,3,4. *Inkjet prints. Each 40 cm x 30 cm, 2004.*

By focusing on underlying structure, the need to define constraints explicitly is at the heart of the creative process. The process of making explicit the constraints that together make up the underlying structure of a work or series of works, is, in effect, a kind of boundary definition of a personal creative space: it is the capacity to make the space highly personalised that attracts many

artists to the problem of writing computer programs. Writing programs is only one way to express constraints, of course, but for those prepared to make the effort to learn the skills or, alternatively, to work with someone who has, it has some advantages over using a software application as the examples that follow in the following section demonstrate.

5. Making Opportunities of Digital Constraints

Artists who started going digital in the 1960s and 1970s had few options open to them other than to identify a suitable programming language and learn how to write programs themselves. *Harold Cohen*, already a successful painter, turned to digital work in the 1960s. His early digital work involved writing a computer program that generated abstract images in black and white. The program, called 'Aaron', was progressively modified over thirty years and now generates figurative images in colour. The role of technology in the process was two fold: first it was used by the artist to write the Aaron program in the Lisp language and second, it was used to drive a plotter, in the first instance, and later a colour painting machine. The painting machine was constructed from scratch. In this instance, the digital aspect operates at both the medium and tool level but it is the medium that is primary to the artist's creative process. The writing of the program involved making explicit constraints about composition, colour and figure definition and was continually evolved in response to his evaluation of the images produced (Cohen, 1995).

Since those days the opportunities open to artists to make digital works or to use digital tools to make works in other media are vast and the sheer size and diversity of the field is hard to keep track of. The survey by Wilson of artists working at the frontiers of emerging technologies was a brave attempt to be fairly comprehensive but nevertheless, missed important work then and, of course, much has happened since (Wilson, 2002). What follows attempts to give but a flavour of the types of digital work in art taking place today and how the need to extend or relax constraints inherent to the digital technology is being addressed through collaborative projects.

In June and July of 2002, a group of artists came together under the auspices of the COSTART research project to take part in a series of artist-in-residencies (COSTART). From the collaborative projects that took place new approaches to digital art emerged. A number of the artists were concerned with developing real-time interactive works and audience participation. Some projects examined the correspondences between sound and image whilst others concentrated on the interaction possibilities of sensor systems. Each project provided different challenges for both the technical requirements and the artistic intentions. The digital components of the works were essential to its character but what became obvious as the artists developed their individual projects was that there would be a significant effort needed to create new systems and, at the very least, modify existing ones.

In order to advance their work using digital technology, each COSTART artist had to develop much tighter descriptions of the work he or she wished to realise in order to be able to develop a representation or mapping that could be made into digital form. Most often, the constraints of the technology were such that they were unable to achieve this alone: the presence of a technologist who was able to source tools and solutions was critical to how successful they could be. These were artists who were already working digitally for the most part, but given access to new forms and tools as well as expertise, were able to bring some of their dreams nearer to reality. Because of the collaborative context, the artists had to specify the nature of the work they envisaged to their technologist partners in order that they (the technologists) could provide appropriate advice and support. A major task for the technologists was to uncover the constraints of the technology and at the same time, provide the best kind of digital opportunities where they existed. Although the artists thought that by exploiting digital means they could extend the character of their work and do things not otherwise possible, they were not always aware of the limits of the technology. Inevitably this posed significant challenges for the technologists that sometimes gave rise to innovative solutions and sometimes unresolved problems.

The way in which digital constraints were changed in order to achieve artistic goals is exemplified in three examples from the COSTART project: the artists were Yasunao Tone, Gina Czarnecki and George Saxon all of whom collaborated with Mark Fell, a sound artist, who is also a skilled technologist. The works created in their residencies were shown at the Creativity and Cognition Exhibition in 2002. Descriptions of the projects, the artists and their collaborating technologists may be found in Candy and Edmonds, 2002a. The quotations cited below are taken from the same paper.

Yasunao Tone has pursued a totally new relationship between text and sound: *Molecular Music* is (1982-5) is his earliest experiment. His process for working with the conversion of calligraphic drawings into sound is very time-consuming involving as it does changing first Chinese characters into images and then the images into sound. As this inhibited the use of real-time interaction with his work, an instrument was developed that made it possible to do live performance in which, instead of having to transform the text into images with pictogram-like Chinese characters, the artist draws calligraphy on the board and transform any text into sound. The interaction device uses an electronic white board (Soft-Board) upon which the artist draws a series of strokes. The Soft-board sends information about pen colour, and pen position to software that is used to synthesize sound. Projected onto the soft board is a sequence of video images selected by the artist. As the artist draws, the video image advances frame by frame. When the pen is placed on the surface, the volume is switched on and when the pen is lifted the volume is silenced. Thus, sound is only heard when the pen is on the surface. Mark Fell comments on the process and the way in which the technology was used both for generation of ideas and delivery the outcomes as follows:

> I found the process of developing the work very difficult. This difficulty was not due to any technical limitation or problem that we could not overcome. Instead the difficulty (for me) was in making a system that fitted conceptually with Yasunao's approach to making his work. The problem was that I had to get away from a way of thinking about the problem of image-sound correspondence and interaction and to approach the problem from a new angle. …We could say that on a very basic level there was a changed relationship between the technology and the ideas that it enabled. A simplistic appraisal of this difference might suggest that the technology was used to generate ideas, not simply to communicate them. However, it is more accurate to say that the conditions that one might apply to the work were also applied to the making of the work."

This project led to the development of a novel interaction device that formed the basis of a new performance artwork by Tone (Edmonds et al, 2003). In effect, the limitations of the existing interaction device that could not meet the needs of this artist's particular sound and visual performances were overcome by changing the digital technology constraints.

Figure 2: Mark Fell and Max/MSP screenshot

Figure 3: Yasunao Tone in performance

Gina Czarnecki is deeply engaged in exploring the possibilities of audience interaction in a process modelled on biological evolution. Using images of people, the aim is to create real-time interaction between image sequences and sounds in order to generate new forms and sounds. The next generation of images is created by the audience selecting those images by means of interaction. The outcome is a work that challenges the audience to co-operate in selecting for breeding whilst embracing the question of willingness to participate in the possibilities highlighted. The preparation for the work involved many hours of discussion between the artist and her collaborator, Mark Fell. In his words:

> "Prior to the residency Gina had been developing a rough scheme for a video installation whereby people were able to select and evolve a virtual population. The work developed into a specification that described what it did, and how the participant would engage with it. However this description was developed bearing in mind some of the possibilities of available technologies, so during this process, technical, creative and

> ideological issues were being dealt with in parallel. Here there were some clear trade-offs; for example between what the systems could handle in real time, and image quality."

The residency project developed into a dialogue between the artist and technologist in which the general scheme for the work was given much more precise definition: i.e. a specification that could be mapped to a technical representation in digital form. This process gave rise to a better understanding of the constraints which the artist was working with, not only for the technologist's purpose, but for the artist herself, whose grasp of their implications for the digital constraints developed in parallel with the artistic elements.

Figure 4: Gina Czarnecki: screenshot from 'Silvers Alter' in progress

George Saxon works with expanded notions of cinema to challenge conventional boundaries. He and Mark Fell decided to create a collaborative work that integrated live and pre-recorded material enabling real-time interaction. He proposed a number of explorations for the residency all concerned with interaction between the viewer and the work. The end result is a display of live camera input combined with recordings of earlier input so that people see themselves and others moving around the space by way of large video projections. Mark Fell describes how they used the technology in the gallery space to evolve the work together:

> "A major breakthrough came when George suggested that we set the system up in the gallery space and start to explore the space. Immediately things seemed to fall into place. We soon became aware that we had stumbled upon a rich vein of material and that there was a series of different combinations and variations that could be explored... The work was grown in the technology as much as the space. Within the five days allocated we created a display of live camera input combined with recordings of earlier input. The system takes a live video input from a camera that is fed into software which then cross fades at varying speeds between the recorded and live input. What is important is how the idea for the work came about. We did not start with a predefined idea, but, instead, used the computer to develop an idea and deal with the concepts we were interested in exploring. This approach is an important part of how the work was designed and constructed…. Initially we placed recorded imagery at either side, and live imagery in the centre. This was discarded but the split screen stayed because we liked it so much!

This project differs from the two previously referred to in that, whilst the digital constraints were well understood by both parties and need little technical development, the exploitation of them was not fully realised until one suggested trying out all the possibilities available to them in the environment where the final work would be installed. In effect, that shift in context led to a breakthrough in the creative process. By establishing the whole setup at the eventual point of delivery to the public, the exploratory, generative and evaluative stages of the creative process operated in a seamless and rapid manner. In terms of achieving a fully-fledged interactive

installation for public exhibition within a very short time scale, this was the most successful of the COSTART projects.

Figure 5: Water Feature Projections by George Saxon and Mark Fell

In order to carry out the kind of projects referred to above, much effort had to be expended in the defining, modification, implementation and evaluation of the digital components and this was only possible in collaboration with expert technologists. The point about such close collaboration is that it enabled a more imaginative approach to breaking the constraints imposed by the technology or a more informed way of finding an innovative route through them.

6. Overcoming Inherent Constraints in Digital Technology

For artists without the opportunities for support through collaboration of the COSTART kind, grappling with the bones of the technology is too onerous a burden to be undertaken, not least because it can divert the artistic purpose and process into distracting realms. This is why many prefer to work within the constraints of existing tools and make the best of the functions they offer. It is sometimes true that in overcoming the inherent constraints of a software tool, this can lead to new insights. Another approach is to look at the way technology is normally used and create work that evokes a completely unexpected and unfamiliar use of it. Some artists exploit and subvert the constraints of the Internet browser, for example, the work of Jon Thomson & Alison Craighead:

> "A lot of our on-line work looks at appropriating material that exists on-line and then reconfiguring it, manipulating it, and looking for resonance and meaning through these reconfigurations because we think that is very much about what the network is about" (Thompson from Interview by Charlotte Frost).

If, however, the work envisaged demands significant change to the existing technology, the opportunities to extend the functions of the technology or to make the inherent constraints more appropriate are limited. Fortunately, there is a growing research community with expertise in HCI (Human-Computer Interaction) and interaction design that is addressing the need for better creativity support tools. Some of these researchers draw directly upon the results of research into creativity in the search for ways of extending the capabilities of existing software applications whilst others specifically focus on artistic uses of digital tools. See, for example, Shneiderman, 2002 and Edmonds and Candy, 2005).

In selecting a particular software application, the artist inherits a set of constraints that are embedded and largely immutable: for example, in Photoshop or 3D Studio Max, the functional element of three dimensional views exists in one but not the other. Making changes to the basic constraints of these types of applications is not easy and few individuals would attempt to do it. However, by writing code, functional elements can be extended. Many applications do not support the experimentation and exploration process so essential to much creative work and it requires

programming effort to be able to overcome this constraint. For example, Terry and Mynatt's work on 'Side-Views' was explicitly designed to enable users to generate multiple versions of their sketches and work on them independently before committing to a final version. Side Views are tool-tips that provide the user with side-by-side comparisons, so that the most recent View remains visible when a new 'Side View' appears. Side Views make it possible to display previews of potential future states of the sketch in progress, you can understand the possible side-effects of making certain commands and can more easily choose among competing alternatives. (Terry and Mynatt, 2002). In effect, this approach provides a means to relax a constraint by delaying the moment of decision.

If choosing a pathway through the constraints of any given digital medium or tool is a critical challenge that the artist faces, then modifying an existing one or even introducing a new one could be seen to be at the heart of the creative process. It is sometimes argued that programming languages have attributes that make certain functions very much easier and that artists who wish to maintain full control over their work should learn to program or at least develop skills in that direction. As an example of a halfway house approach, using the pre-defined features of Macromind Director is a relatively easy process, but the scripting language, Lingo that goes with it requires more effort: that effort is rewarded with more opportunity to create your own constraints (MacroMedia).

The quest for programming languages that have representations based on artistic and creative criteria and are more accessible to artists, has given rise to Max/MSP, a visual programming language (cycling74). The origin of Max/MSP is in electronic music studios and the forms used are quite easy to understand for musicians. There are several communities of artists who are not necessarily expert programmers using Max/MSP. It turns out that artists working in visual interaction sometimes also find Max/MSP quite understandable without lengthy training (Edmonds et al, 2003). In the COSTART Project, it was used widely in particular, to facilitate the integration of sound and visual works (Candy and Edmonds, 2004). It provides the facility to integrate low-level system inputs with high-level visual programming tools so that a single software system can be used for the entire process. Max/MSP not only supports but also encourages different ways of approaching technology-based art. It conforms to the needs of the artistic community where different and contradictory strategies are often nurtured.

7. Conclusions

This paper has raised a number of issues about constraints in the creative process. It has suggested that bringing digital tools into the creative process leads to a more highly constrained creative space because of the inherent characteristics of the technology itself but that this in itself, can lead to new directions. In the digital arts, the computer's capacity to facilitate a more precise specification of the constraints which artists work with makes the technology an attractive medium to explore. For many, having the facility to specify their own artistic constraints implies using some form of programming techniques. This was the only option for the early pioneers: Harold Cohen had to discover how to program rules of composition, subject descriptions, colour representation etc. which involved knowing how to map a humanly perceived representation to a computational representation. Manfred Mohr's basic map is already geometric and therefore, on the face of it, more accessible to computational representation (Gomringer,1998). Edmonds works with a very tight set of constraints and his interest in underlying structure over visual form can be satisfied because of the capability offered by computer programming (Edmonds, 2005). The new generation of digital artists has more opportunity to work digitally but that very 'freedom' can pose problems of what to select and how to exploit it fully. As the COSTART artists demonstrated, in order to realise their projects, there were many aspects of the technology, beyond getting to grips with a particular software application that had to be addressed. Specifying personal artistic constraints often requires the full power and flexibility of a programming language: to do that collaboration with technologists may be essential.

The use of digital technology in the arts is in its infancy relative to the other media familiar and available to artists today. If we are to fully understand the both the degrees of freedom and types of constraint that apply as a result of using it in creative works, we need more experience, more practice and more research. To answer questions such as: what are the equivalents in digital technology of the overlapping conceptual spaces of 20th century music, there will need to be many more years of advances in the digital arts. We could take a first step by mapping the existing constraints of current digital technology that both enhance and impede both the creative process

and its outcomes as art forms for public exhibition. But that is another research programme in itself.

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