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Chance and Complexity: Stochastic and Generative Processes in Art and Creativity

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ABSTRACT
This paper examines the recurrence of stochastic processes as mechanisms to drive and enhance human creativity throughout the history of art. From prehistory up until the present day, random events, and technologically instantiated generative processes have operated in concert, extending the scope for the production of aesthetic objects of all kinds. In the last half-century of computational art, chance has played alongside generative computer programs – a trend that looks set to continue. A range of works is explored here, highlighting the interaction between chance and dynamic processes to generate complex representations, virtual spaces and aesthetic artefacts. With this approach, the paper argues, chance and dynamics have the potential to continue as dominant creative forces into the future of art.

Categories and Subject Descriptors
J.5 [**Arts and Humanities**]: *–Fine arts, Architecture, Media Arts, Sound and Music computing*

General Terms
Algorithms, Human Factors

Keywords
Generative art, computer art, artificial life, biological simulation, stochastic software, random numbers

1. INTRODUCTION
The earliest aesthetic artefact we have found, the *Makapansgat* pebble, was created by chance [47]. It is an attractive shade of red/ochre, weighs 260 grams, and has an uncanny resemblance to a human face. About 3 million years ago, the pebble was collected by *Australopithecus*, probably due to its colour and remarkable natural form. Although isolated in time from other similar objects, the pebble suggests it is a fundamental trait of our kind to see familiar forms, especially faces, in random data – in clouds (*Hamlet*, iii:2:265-275), tree branches [24], on the Moon [49], even in the pattern burnt onto our morning toast.[1] Such aesthetic objects emerge from two of the most universal "forces" – stochastic and generative processes – nature is full of examples [5]. Luck provides the initial conditions, and then with a physical, chemical, biological or technological process as its ally, it has the potential to generate forms that (due to our evolutionary and cultural histories) we find "appealing".

When harnessed, chance and dynamics provide an approach to art making with the potential to generate spatio-temporal "timbre" rivaling the complexity of nature.[2] Such complexity is a personal goal that is shared by some (e.g. see [45]), however chance and dynamics are not the only possible means of achieving it. The purpose of this paper is to discuss specifically how far we have come with the approach, especially in "Generative art" [30], and to explore where we might still take it. It has recently been proposed that randomness is a key element of Generative Art [39, question 6]. I will show that many generative pieces are based around a fusion of stochastic and generative dynamics and explore the contribution they make to the final work.

There are many specific proposals for enhancing human creativity with software. (See [41] for a collection of recent perspectives.) Shneiderman adopts a particularly broad view, addressing a designer's engagement with their community and their tools [57]. His report begins by categorising previous theories of creativity and constructing an approach to user interface design that supports them. This paper is broader still. It isn't concerned with any single theory or particular style of creativity. It is however intended to subtly shift our perspective to consider chance as an ally, even in software for creative activities. The synonyms chance, luck, randomness and stochastic processes are not touted as features of packaged software; they usually indicate bugs! But if luck enters design appropriately, creativity can sneak in too. In fact, it has been said that creativity *is* a stochastic process [58]. This paper discusses how luck has infiltrated art so far, and how this may be furthered.

[1] *Pareidolia* is the identification of familiar forms in random data.

[2] Here I adopt a very loose definition of art including any vaguely aesthetic object, decorative or purely functional, symbolic or non-symbolic etc. With it, I adopt a loose concept of creativity that is nevertheless specific to the manufacture of any novel artefact but especially those that fall under the loose definition of art adopted here. Detailed discussions of creativity are given elsewhere [10, 26].

Before examining specific works, we describe a scale of creative thought ranging from basic human abilities up to highly specialised and probably, in evolutionary terms, more recently acquired skills (§2). We then discuss how chance affects human discovery (§3). Next the paper examines how artists have welcomed chance into their human and technological processes (§4). We provide some concrete proposals to apply these ideas in off-the-shelf software for art and creative applications (§5), and conclude the paper with a discussion (§6).

2. CHANCE-ASSISTED CREATIVITY

Ever since the *Makapansgat* pebble, chance is known to have participated in art. For instance, the *Venus of Tan-Tan* from Morocco (c. 300k-500k years BP) is a stone figurine small enough to hold in a hand. It appears this was crudely fashioned by *H. heidelbergensis* from a pebble that nature had created in the semblance of the human form [7]. Another figurine, the *Venus of Berekhat Ram* from the Golan Heights (c. 250k-280k years BP), was also fashioned by enhancing the natural shape of a rock [19, 38]. The caves at Chauvet (c. 30k BP) and Lascaux (c. 15k BP) in southern France were decorated by Palaeolithic artists [1]. They include spectacular drawings of animals and humans, created on and around natural irregularities in the surfaces on which they appear. Rock features and blemishes were sometimes the basis for Palaeolithic cave art, even in preference to depicting the subjects in natural poses [37, 38]. In places a nodule suggested an eye and ridges an animal's spine, head or legs. The Palaeolithic artists were strongly influenced by chance formations provided by nature, working to increase their likeness to imagined forms.

Morriss-Kay suggests that the path from collection, to enhancement of natural forms indicates a development or evolution of artistic ability relating to the production of three-dimensional artefacts [43]. Leaving aside the evidence for any neat evolutionary or cultural trajectory,[3] the four stages of this creative activity are useful to consider in the present context. I interpret them as follows.

(A-i) Recognition of a suggestive natural form;

(A-ii) Incremental manual improvement of a suggestive natural form to enhance its suggestion;

(A-iii) Significant manual improvement of a barely suggestive natural form to enhance its suggestion;

(A-iv) Creation of imagined forms in non-suggestive media.

Activity (A-i) is identified with early hominid collections of artefacts resembling faces and living creatures (e.g. the Makapansgat pebble, Neanderthals' collections of fossils). (A-ii) refers to the crude enhancement of human or animal-like natural forms when they are encountered (e.g. the Venus figures). The Palaeolithic artists' embellishment of barely suggestive cave surface irregularities constitutes activity of type (A-iii). Even today, some artists work from a blank canvas or wall, a smoothed bed of sand, cut tree bark or block of stone. On these they create new forms from representations fashioned initially "in the mind's eye" (A-iv). Although it is probably stretching things too far to interpret this as a pure progression, the hypothesis is seductive in the context of understanding chance and dynamics' role in the creation of complex aesthetic objects, if only because it doesn't press modern intuition or experience very far. This latter point, more than its archaeological significance, makes the proposal relevant here.

Anecdotal contemporary evidence for the thesis that stages (A-i) to (A-iv) are of increasing difficulty is at hand. We easily identify forms that please us – "I don't know much about art but I know what I like!" Secondly, most of us have doodled absentmindedly to create a simple face or other well-rehearsed scribble within an existing shape, or from an earlier random line. A few of us have learnt to copy a pleasing form and can reproduce it on a blank page. But how many of us can conceive and illustrate a truly novel form? This skill is rare enough that a living might be earned by doing it well.

In many programs for design the software engineers demand, subtly and overtly, a high degree of skill from their users at the most taxing task of the four in the list, mental image formation (A-iv). Below, we explain how the early stages of the sequence (A-i & ii), can be better harnessed, especially in software. First, some background on how to play the hand of chance is in order.

3. KINDS OF CHANCE

> *There is an ancient axiom in mountaineering that helps in planning an expedition. It goes like this: anything that can possibly go wrong, does.* [55, p.13].

For better or worse, chance reaches beyond the Alps to shape our world of pigment, modelling material, mechanism, light, physics, chemistry and biology. It underlies our universe at a fundamental level just as deeply as it impacts us every moment. For instance, suppose we stumble into a tree that resembles a withered old man. How might it have come about? First and foremost the existence of life, and that particular tree with it, springs from evolution, a creative, generative process with chance at its root and at every branch, twist and turn. Beyond that, the tree grew in response to a complex dynamic environment; the dynamic light we see on the tree must have happened to play on its complex lumpy surface in a particular way; our complex visual system happened to view the tree from a particular vantage point and at a particular stage in its developmental process. This is a richly layered web of chance and dynamics that is absent from most off-the-shelf software.

In conventional 3D modelling, shapes don't "grow". A lumpy surface texture only appears if we ask for it and isn't then derived from a complex dynamic environment. The light in the virtual workspace is simple and only tediously varied. The standard perspective view must be adjusted deliberately. Compare this to the process of painting a large physical canvas where the artist naturally moves around the work during creation, or to the process of sculpting a small clay object that shifts in the hand as it is moulded. In both cases materials are explored under many complex lighting conditions and perspectives.

Chance *could* conceivably play a significant role at any stage during creative activities with software. But it is usually troublesome – random interruptions to the tedious and finicky process of virtual 3D animation for instance, would make the software frustrating to use. Wouldn't they? What if your virtual 3D model collapsed or sagged overnight while you slept? What if the lighting on your virtual 3D model changed over the course of

[3] An earlier and seemingly more thorough discussion of the evidence for the origins of art has been offered by Bednarik [6]. This concludes with a different proposal for the development of iconic 3D sculpture than Morriss-Kay's. However, the debate about the historical development of hominid art is tangential to the case for the utility of Morriss-Kay's proposal in the present context.

a day and varied with the seasons? Most 3D modellers would despair. A stop-motion animator working with clay might be equally annoyed, but would be less surprised at these circumstances. An artist engaged in Land Art would take such phenomena as part and parcel of their practice. The world is much less controlled than the virtual workspace. I believe this is a missed opportunity for computer artists. The real world provokes us with its inconveniences. The computer often obstructs us, but it seldom provokes. Sometimes it should! In order to understand why, here is a summary of American neurologist Austin's list of chance's entry points into biomedical research [3, p. 78, 4].

(B-i) An accident - blind luck;

(B-ii) General exploratory behavior - chance favours those in motion;

(B-iii) Sagacity - a prepared mind recognises something interesting when it finds it;

(B-iv) Personalized action - chance favours those with idiosyncratic interests and behaviours.

Chance can enter as a bolt from the blue to take a project in a new direction (B-i). This is equivalent to finding a fully formed face-shaped Makapansgat pebble on a riverbank. Or to spilling a bucket of paint and discovering it forms a lovely cloud on your painted blue sky (A-i). Alternatively, with a bit of work the spill can be shaped to become an aerial demon that wasn't originally considered (A-ii & iii)! In the physical world, this only happens when Murphy and his inevitable law turn a blind eye.[4] In off-the-shelf software, many chance events occur when accidentally clicking the wrong button, entering the wrong value in a text box, or exposing a software bug. The results are often catastrophic rather than incremental or interesting. For instance a model is completely lost, or the software freezes and the creative process is interrupted. There aren't currently many opportunities for chance (B-i) events to infiltrate conventional software processes in ways that have even the potential to be helpful.

It is possible to go about a project and passively wait for bolts from the blue, but chance favours the busy (B-ii). The more experiments made, the greater the opportunity for chance to intervene. In conventional 3D modelling software, this type of exploration occurs as a slider value is adjusted. I.e. on the way along a slider range something catchy appears. (B-ii) is also relevant as a user moves a light source around a 3D scene, but only if the display is rendered instantaneously with the changing conditions. If extended, such capabilities have some potential to provide chance with easy, well-controlled access to software-human interactions.

Point (B-iii) concerns the mental perspective of the creative person. For instance, had a pot of white accidentally spilled over a painted blue sky, an unreceptive designer would hurriedly clean it away, neglecting to reflect on what it might offer. A designer with an open approach might instead consider whether removal or adaptation is better under the circumstances. Software can play a role in this aspect of creativity only if the accidents that occur are consistently worth considering (*cf.* the remarks on point (B-i)). Otherwise, an open-minded designer will unlearn their receptivity.

People with idiosyncratic ways and disparate interests, can potentially devise novel ideas by making unusual connections (B-iv). Technology itself is excellent at exploring permutations and combinations in general, regardless of an artist's idiosyncrasies. For instance, wind chimes are aleatory devices that generate random time series. A composer can extract sections of these as raw compositional material.

Since at least Ramon Llull's time (13th C CE) mechanical means for enumerating combinations of symbols have existed.[5] In the missionary Catalan's *Ars Magna* (Great Art), Llull explained how to use symbol-inscribed discs and other diagrammatic devices to generate questions [31, chapt. 1]. Llullian combinatorics has played a niche role in art since at least the 17th century. At this time French theologian and mathematician Marin Mersenne adopted Llull's ideas to music theory, expounding his interpretation in *L'Harmonie Universelle* (1636) [35]. The idea of art making by combination and permutation of basic elements gained popularity in the 20th century. Brion Gysin's *Junk Is No Good Baby* (1973) for example, is a printed poem that simply enumerates combinations of the words in its title [64, p. 141].[6] The "phasing" musical composition *Drumming* by Steve Reich (1970-71) shifts performed rhythms against one another over time to generate new patterns from their superposition.

I am not proposing that Morriss-Kay's scale of creative activity or Austin's list of chance's entry points in research is groundbreaking in the context of art. Yet together these intuitions can help to understand how some artists and some existing artworks generate complexity. We discuss this next. Having examined the lists we will bear in mind that even trained artists adept at creative activities of type (A-iv), are good at (A-i, ii & iii). So the focus of the following section is on how these people lean on chance to influence their artistic processes.

4. CHANCE AND PROCESS

Chance elements provided the initial inspiration for the creators of the ancient Venus figures and for some Palaeolithic cave artists. The dynamics of their processes then shaped the aesthetic achievements. Contemporary artists have continued to apply this basic approach, but have also explicitly and mathematically explored randomness, often extending its reach into their creative processes (e.g. [11, 17, 42]).

4.1 Painting

The abstract expressionist "action paintings" by Jackson Pollock (e.g. *Blue Poles / Number 11* (1952)) provide a particularly clear example of the extended approach to chance's inclusion in a primeval art. Chance is facilitated by deliberate reduction in the artist's control over the pigment. Pollock's process involves dripping and pouring paint onto surfaces. Through experimentation, the artist learnt how to guide chance in desirable ways, engaging with (B-i, ii & iv). Once a single drip hit Pollock's canvas, he began to engage with creative activities (A-i, ii & iii). Each chance form suggests further movements. He then modified the chance outcomes by deliberate scratching and dragging with sticks, trowel and knives. Pollock explained, "It is

[4] Murphy's Law was quoted at the start of this section.

[5] Llull was reputedly inspired by the Arab *zairja* used for astrology.

[6] Gysin had rediscovered the Dada "cut up" method suggested in the 1920s by Tristan Tzara who created poetry by randomly drawing words from a hat. This technique found favour with the Surrealists as a means to explore the subconscious. It was also adopted by Beat writer William S. Burroughs in his texts, and considered as a technique for splicing cinema film and audio tape [15].

only after a sort of ‘get acquainted’ period that I see what I have been about”. The chance and dynamics of his process gives a painting “a life of its own” [18, p. 548]. This general approach is relevant in any medium. Hence, while a new form may appear in the mind’s eye of an experienced artist (A-iv), once the process of implementing it begins, activities (A-i, ii & iii) guide the creative process, possibly away from the original idea into one suggested by the combination of chance and dynamics. This is relevant even to the fundamental art of pigment application.

4.2 Music Composition

Chance has informally generated music since the bronze *tintinnabulum*, wind chimes of ancient Rome (c. 1st C. CE). Lately its role has been explicitly considered, for instance in 18th century “dice games” where the numbers rolled determine which musical phrases or pitches occur in a sequence [33]. Twentieth century composition by chance includes John Cage’s application of techniques for divination from the *I-Ching* (Book of Changes), an ancient Chinese text. Cage’s aim was to renounce control over the detail of his work [46, pp. 60-62]. Twentieth century Greek composer, architect and engineer Iannis Xenakis also showed significant interest in stochastic composition and music synthesis techniques. For instance he used burning charcoal as a sound source and explored computer-based random processes to assemble the components of several of his pieces [32]. In wind chimes and the works of Cage and Xennakis, chances (B-i & ii) arguably play dominant roles. The pieces are deliberately set up to allow this. In the former case, the deliberate choice of chime pitches and locations precedes the chance action of the wind. In the latter works the situation is reversed. Chance establishes initial conditions that are shaped by deliberate choices and processes enacted by the artists.

Steve Reich is another twentieth century composer who has deliberately allowed chance to build complexity. His *Pendulum Music* (1968/1974) is performed by suspending several microphones by their cords from the ceiling in front of amplifiers to which they are connected. The microphones are set swinging, generating feedback as they pass in front of the amplifiers sitting on the floor. Eventually everything comes to rest producing a wall of noise. Reich’s piece varies in detail between performances. The microphones will be released from different heights, at different times, will commence with different accelerations and swing from different lengths of cord.

It is worth remarking here that collaborative improvisation between human performers, or between machines and humans [29, 34], provides ample scope for the entry of chance. Significantly, improvisation also allows the full range of suggestive structures from (A-i) to (A-iii) to appear, as well as offering moments suitable for the entry of completely new ideas (A-iv) upon which musicians can build.

4.3 Sculpture

On a practical level, a contemporary sculptor working with physical materials engages with chance directly through their media in ways that have remained essentially untouched through archaeological history. However when mechanism, kinetics and other temporal aspects are introduced, chance and dynamics take on new importance.

The Islamic engineer and inventor al-Jazari, recorded many complex automata in his *Book of Knowledge of Ingenious Mechanical Devices* (1206 CE). Some of these machines, it has been argued, were deliberately “untoward” in their dynamical behavior, revealing the complexity and subtlety of God’s universe [44]. By contrast, many of the twentieth century “mobiles” of American artist Alexander Calder are elegant and controlled in their random movement [54]. In these works, Calder established the rules for artificial infinite universes from wire, mass, colour and form, to unfold under the quiet influence of air currents.

Between untowardness and random grace lie the kinetic sculptures of New Zealand born Len Lye. In particular his works made of large, flexible steel hoops and fine wires can be dramatic or contemplative. The resting forms of the steel in Lye’s works are forcefully disrupted, tripped or spun by motors into an expansive wobbly *Universe* (1976), the delicate mimicry of natural breezes moving across a meadow of *Grass* (1965), or the formality of a garden *Fountain* (1959).

All physical media act within the constraints of chance and natural law. But in art this is refined. Nature’s action is constrained or promoted by the will of the artist. From natural stochastic and generative processes a new creative process can be devised. The approach forms the backbone of Generative Art.

4.4 Generative Art

Generative artists employ autonomous processes as significant components in the production of their works, or even as the works themselves [30]. Arguably Cage, Reich, Calder and Lye are generative artists, although to my knowledge they haven’t ever referred to themselves in that light.[7] The participants in the *Scratch Orchestra*, a music and performance group from the late 1960s and early 70s, might equally be considered generative artists [16]. They wrote many poetic procedural specifications for performances, for instance, “Tear up different sounding paper into patterns, palm-trees and confetti” (*Ibid.* p. I), or more obtusely, “Make it rain, if it is raining already, make it stop” (*Ibid.* p. X). Many of their works engaged natural and human-driven dynamic processes with large degrees of randomness. Cornelius Cardew from the group is particularly well known for *Paragraph 7, The Great Learning* (1971). This is a randomly initialized, self-organising choral work where human singers recite or sing lines from a text according to simple rules. What each individual hears in their vicinity during the group performance influences what they sing within personal limits imposed by breath lengths, vocal range and on random whim.

A recent resurgence of interest in the generative paradigm has been encouraged by the availability of introductory guides, especially those based on programming and art (e.g. [48, 51]). The practice has roots in the digital art of the 1960s where the computer was exploited to run generative processes of combination and permutation, sometimes from random initial conditions [53, pp. 372-373; 386-387; 389]. The approach remains relevant: Jared Tarbell’s *Invader Fractal* (2003) illustrates 32,768 bi-laterally symmetrical pixel arrays to create an army of “space invaders”. In addition to enumeration, stochastic processes often participate in the production and dynamics of generative works [39], and can certainly assist us to understand the artists’ work after the fact [27]. Many software-based generative artists employ chance introduced through sequences of

[7] The *Cybernetic Serendipity* exhibition catalogue provides discussions and examples of many works from the 1960s that can be considered “generative” [52]. *Systems Art* of the period had similar concerns [56].

(pseudo) random numbers. These may establish initial conditions for dynamic processes and determine or influence the trajectory of their development.

The use of the *interactive evolutionary algorithm* provides a clear example of the utility of pseudo-randomness [8, 22, 59, 62, 63]. The algorithm mimics aspects of the natural evolutionary process to allow a user to interactively breed images, musical phrases, engineering constructions and 3D models for instance, by selecting parents from an initially random population, breeding them together repeatedly (an operation involving random crossover and random mutation of their digital "genes") until a desirable form is finally created.

Outside of software, Tim Knowles has produced a number of *Tree Drawings* (2005–) that can be interpreted from our perspective. The artist attaches pens to the tips of tree branches, sitting them on fixed blank pages, and allowing the wind to shift the tree, dragging the markers with it as it moves. With respect to the artwork the development of suitable branches, their subtle variations and the wind conditions, are all stochastic processes that impact heavily on the drawing a tree makes.

Erwin Driessens and Maria Verstappen's artwork *Sandbox* (2009) employs chance and physical processes through the movement of grains of sand. The artists establish a miniature "desert" landscape inside a box and drive its formations indirectly by electric fan. Dunes form as they do in natural landscapes. In their work *Top-down Bottom-up* (2012) the Dutch artists set up machines to drip beeswax from the gallery ceiling. These generate massive stalagmites shaped by the chance movement of the molten wax through the air, its chance collision with the structure beneath it, its random path under gravity along the existing surface and the rate at which molten wax solidifies in the ambient conditions.

4.5 Virtual Ecosystems

Virtual ecosystems simulate organisms interacting with one another and have, excitingly I feel, found their way from science into electronic media art [9, 12, 20, 23, 25, 28, 36, 40, 50, 60, 61]. They are superb illustrations of the interaction between stochastic and generative processes in this domain.

Virtual habitats and environments are sometimes literal simulations of real spaces, but can also be abstract universes generated by computational rules. The common aspect of these systems is the establishment of feedback loops between low-level interactions (e.g. between inanimate building blocks or between organisms) and between collections of them (e.g. between molecules assembled from atoms or between communities and species). Because the feedback loops are multilevel, system dynamics have the potential to generate complex spectacles and opportunities for human-artwork interaction [23].

The creatures within many virtual ecosystems are controlled by processes coupled loosely to those shaping their inanimate habitat. For instance, creatures may have high-level behaviours specifying how they mate, avoid, chase, eat, compete or cooperate. These behaviours are "authorized" (or not) by the environment but are based in a different physics or chemistry to the rules governing inanimate activity. Hence, a creature's behavioural rules may instruct it to walk through an obstacle, but an independent physical rule may forbid this. In works of this type, analogies to processes from physics, chemistry, biology and ecology are common. Any may be deeply influenced by stochastic processes.

A creature's behaviours can be completely deterministic, based only on its internal state and local environmental conditions. However, random numbers sometimes parameterise creature decision-making. This helps prevent creatures getting stuck in infinite "loops" by ensuring that no two actions will ever be carried out identically or that no two situations will ever be perceived identically.

Virtual ecosystems can also be supported by a dynamic layer implementing artificial evolution (§4.4). For instance, Jon McCormack's *Eden* (2001) installation evolves a population of singing creatures restricted by the availability of food that grows in response to human movement [40]. The creatures' singing is intended to influence visitor behavior. Hence, the evolutionary process and the outside world are coupled.

In Dorin's *Meniscus* (2003) and *Pandemic* (2012), the outside world is a source of filtered noise.[8] Evolution is driven through a combination of a creature's genetically determined courtship behaviour and gallery visitor behavior. In both cases, a creature's mate preferences are genetically encoded. However, in *Meniscus* a creature's ability to *locate* mates varies by a spectator's explicit control over the water level in their environment. In *Pandemic*, the gallery visitors' clothing infects the virtual creatures of a similar colour, inhibiting their ability to accrue energy reserves for reproduction. In these two works the human input is essentially random with respect to the ecosystem processes, but it remains closely coupled to system dynamics.

Random numbers can also provide "meteorites" into virtual ecosystems, devastating populations or injecting new life. In short, just as with the dynamics of natural environments and species evolution, chance plays a major role in the unfolding of virtual ecosystems realised as electronic media art.

5. CHANCE, DYNAMICS AND OFF-THE-SHELF SOFTWARE

Chance is stamped out of software because it is often an irritating nuisance. But also because we presuppose that users are expert at forming images in their mind's eye and that therefore random events, even those with creative potential, would interfere with the process of realizing their vision. But even an expert is good at basic creative activities of type (A-i, ii & iii) and will be guided by chance as their manual or technologically supported artistic process unfolds. How can this conflict be addressed? As an example, we will suggest how to harness basic creative skills effectively in off-the-shelf 3D animation software, especially as they relate to the four entry points of chance.

5.1 Start with something

Our ability to see patterns and extend them tells us to avoid presenting users with a completely blank slate. By providing suggestive marks or structures from which to begin, software allows a user to engage primitive and fundamental skills (A-i). From here the user can enhance existing forms (A-ii).

A menu with a few 3D geometric primitives or bland templates is standard in many modelling packages. This is useful, but the items lack inspiring suggestiveness and novelty. A lump of clay kneaded by hand, a knotted, twisted tree branch collected from the forest floor, or a suggestively eroded stone make better starting

[8] www.csse.monash.edu.au/~aland/films.html (accessed 12/12/12)

points. An infinite number of virtual shapes should be available. These should be loosely but consistently ordered – we want to enhance the likelihood of random chance (B-i), without frustrating any preconceived ideas (A-iv), and while allowing a user to gain familiarity with their collection over time.

It should be easy to rummage through the suggestive objects, select one for consideration, and throw it back in its original *and* modified forms to pursue other ideas. This maximises the ability of the user to stay in motion, increasing the likelihood of favourable chance events (B-ii). In the physical world inspiring collections for projects include scrapbooks, workshop part bins, craft boxes, trunks of fabric offcuts. Arguably, an idiosyncratic collection is desirable (B-iv).

5.2 Facilitate chance combinations

In the standard 3D modelling environment, a user only sees the current state of the forms being manipulated. They don't usually see a representation of the history of manipulations in their workspace or the alternatives they might consider. Previous "undone" forms are often lost from view completely. Contrast this with the production of a pencil sketch. New lines are progressively added to an outline. Some are reinforced, some are poorly erased, old lines are re-enhanced and new ones ignored – but during sketching many alternative lines are present simultaneously. This allows an illustrator to see combinations of old and new ideas, mentally travelling over parts of a line onto different lines to finish the stroke. The illustrator can enhance a newly perceived fortuitous combination of previous strokes for further consideration. Perhaps 3D software might work like this to facilitate (A-i & ii) and (B-i & ii), some 2D drawing software already does.

An additional helpful aspect of 2D lines is their ambiguity. Ambiguity facilitates creativity by allowing the mind to wander from one interpretation to another, hopefully finding surprising and suggestive connections between elements. Zoologist Richard Dawkins' *Blind Watchmaker* software for generating 2D stick-figures using interactive aesthetic evolution is lovely in this regard [21]. 3D models are more difficult to render ambiguously although subtle surface variations and unusual lighting conditions can help provide multiple interpretations much as natural formations (tree, rock and cloud structures) can be read in multiple ways.

Software might also present alternatives to the present state of a model by displaying the result of many different parameter combinations and permutations to a user, not just the current "selection". I.e. the user should be able to work simultaneously with a collection of models or traits. A colour-picker begins to achieve this. The user selects a colour part way along a range, the entire length of which is visualised, or from within a wheel showing an entire colour space. An analogous device could be reproduced for many parameters or conditions. For example, suppose a light source needs to be positioned in a 3D scene. As soon as the user selects the light source for positioning, the space of possible positions is automatically and randomly sampled. Sampling could be biased to occur often close to the current position, and less often with the source distant from its current position. The scene could then be rendered in miniature for each sampled light source position to show a range of effects with the source close by (B-ii), and a few options with the source in unusual positions in the hope that something interesting might turn up (B-i).

Adobe's bitmap editing software *Photoshop* visually displays the result of a range of possible image filters when a user opens a general menu.[9] It is probably best if these preview the state of the working image after application of each filter. Within a single filter's control the approach could also be adopted to simultaneously illustrate the impact of many parameter combinations – instead of offering a bank of sliders and expecting the user to fumble tediously through their combinations.

5.3 Relinquish control

Software can simulate the complexity of real materials and tools, but this is unnecessarily limiting. A simulation can also extend the capabilities of real media. Better yet, new media with unique dynamic properties can be coded and explored. This is where the most exciting opportunities for computer-enhanced creativity lie. For instance, imagine materials that change colour when you squeeze or stretch them, that grow, bulge and warp when you light them, that decay or melt away as they move. There should be no limit to the coupling of parameters and controls in a modelling system.[10] Coupling should be under user control if desired, and it should be possible for a user to allow dynamical systems and constrained stochastic processes to take charge of parameter values as desired. In this way new modelling materials can be devised that will open unexplored doors for (virtual) sculpture.

The emergent complexity of virtual ecosystems (above) is illustrative of the behavior of dynamical systems in art [23]. Another approach yet to be widely explored is coupling a homeostat to model parameters such as shape, texture and temporal behaviour. A *homeostat* is a device that, through feedback loops within it and couplings to environmental variables, attempts to maintain internal parameters in a state of equilibrium. For instance, warm-blooded organisms are homeostatic with respect to their temperature and water content [2, chapt. 5]. To maintain these variables within viable physiological range the organisms sweat, shiver, consume sugars and water, shed fur or adjust clothing. The exact behavior will be governed by the changes in environmental temperature and humidity to which they are subjected. Such complex adaptive systems provide potential for generating unusual, pliable virtual artistic media with a "life of their own".

5.4 Collaborate, improvise

The interaction between a machine and human artist can be as useful in visual art as it is in music, especially with interfaces that allow the user to move freely (e.g. motion capture systems), but also with basic interaction devices. For instance, interactive aesthetic evolution is a process that offers the user procedurally generated options based on their preferences (§4.4). The software may be understood as a provocative assistant. An alternative approach is to allow a user to make gestures and have a generative system derive complex structure and pattern from these in a reversal of the usual situation where chance provides initial conditions and an artistic process works the chance occurrence into something satisfactory. Adrian Ward's *Signwave Auto-Illustrator* (2003),[11] a parody of Adobe's Illustrator vector-

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[9] Adobe *Photoshop* version CS5.

[10] Clavier's *Nord Modular synthesizer* might be taken as inspiration for the way it facilitates user-construction of digital musical instruments (www.clavia.se/ (accessed 15/1/13)).

[11] swai.signwave.co.uk/ (accessed 12/12/12).

graphics software, operates in this way. It appears that more control is given to the underlying generative procedures than to the user. While Ward intended this partly in jest and partly to call into question the notion of authorship of an image made using off-the-shelf software, in the context of the present discussion the idea is not at all ridiculous! If control could sometimes be returned to the user, human-machine collaborations of this type can be simultaneously useful and provocative.

5.5 Wresting back the reins

In offering alternatives to a user, an interface designer must avoid recreating the disruptive Microsoft *Clippy* paper clip, "I see you are trying to write a letter. Can I help you?" Suggestions must be unobtrusive. It must also be easy to turn them off when the form is sufficiently developed for the user to take complete control and guide a project to completion. When should the influx of randomness be halted? Who knows? Fortune may provide a project's perfect conclusion.

6. DISCUSSION AND CONCLUSION

The scope for connecting chance and generative processes to create complexity is as vast as nature itself. When we introduce computation and abstract symbol manipulation into the picture, arguably the scope increases by another order of magnitude. Of course not everyone will care. However, even the brief history of art and creative activity we have reviewed testifies to the fact that *many* do. Art provides the opportunity not just to explore our universe, but also to create new universes of experience and interpretation. Is there a more enticing way to further this practice than to extend nature's own techniques with our technology?

Explicit awareness of the interaction between stochastic and generative processes in nature facilitates us in making links to human creative capabilities and endeavours. From here the future of art looks exciting, complex and dynamic. At a personal level, I am still motivated to explore the original (later dejectedly reconsidered [14]) idea of American Systems Art theorist, Jack Burnham that,

> "The stabilized dynamic system will become not only a symbol of life but literally life in the artist's hands and the dominant medium of further aesthetic ventures. …As the Cybernetic Art of this generation grows more intelligent and sensitive, the Greek obsession with 'living' sculpture will take on an undreamed reality" [13].

Chance will always play a role in the dynamics of such systems. The complexity of a "living sculpture" would be a spectacular and thought-provoking achievement that must truly redefine our concepts of life and art, and the relationships between them.

7. ACKNOWLEDGMENTS

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