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Aesthetic Selection and the Stochastic Basis of Art, Design and Interactive Evolutionary Computation

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ABSTRACT
We present data demonstrating that the application of interactive evolution and related techniques has been growing since the early 1990s. Much research has honed the technique for specific applications. In this paper, we explicitly consider the interaction between chance and human creative tendencies as exercised by manual selection during interactive evolutionary computation. Since stochastic processes have interacted with dynamical human and technological processes for creative design throughout the history of art, we survey a few pertinent examples as we tackle interactive evolutionary computing specifically. In this context, chance governs the crossover and mutation of genes and therefore ultimately decides which forms will be displayed to a user for consideration. We derive some simple suggestions as to how chance's role may be extended in interactive evolution, demonstrate these in practice, and discuss how such randomness benefits human creativity.

Categories and Subject Descriptors
I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search–*Heuristic Methods*. J.5 [**Arts and Humanities**]: –*Architecture, Fine arts, Performing arts (e.g., dance, music)* J.6 [**Computer-aided Engineering**]: –*Computer-aided design (CAD)*

General Terms
Algorithms, Human Factors

Keywords
Generative art; computer art; artificial life art; interactive evolution; randomness

1. INTRODUCTION
Judging purely by the amount of literature published in the area, a coarse but still helpful point of reference, interest in interactive evolution has risen steadily since 1990 (Fig. 1). Compared to "evolutionary computation", a search term that returns 13,200 hits for 2012, this remains a niche technique. However, it is one that is especially relevant for design processes where human intuition, aesthetic preferences, or our other "solution recognising" capabilities are necessary. Since in these cases the explicit fitness functions required for standard evolutionary computation are elusive [48].

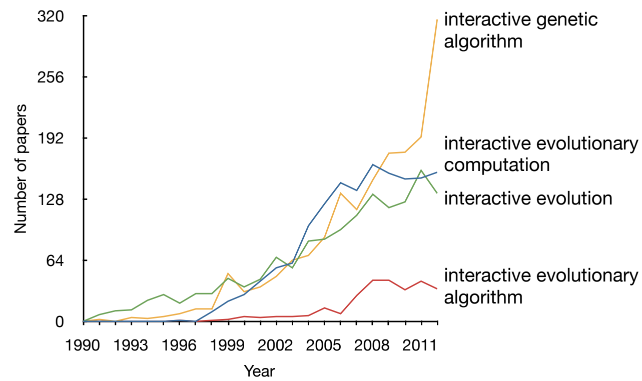


Figure 1. The number of papers published annually with the search terms listed.[1] Single data points in 1990, 94 and 96 were removed as they did not refer to relevant papers. Other data points are un-cleaned. The searches are not mutually exclusive; some papers contain multiple search terms.

Surveys on the detail of interactive evolutionary computation for creative applications are provided elsewhere [7, 43, 48]. Many papers on the technique either specifically target, or at least mention in passing, problems with the basic algorithm. Sometimes they offer concrete solutions as to how they may be overcome [31]. These are interesting here, not for the details of each, but for their relevance to two general principles of creative activity discussed shortly. Of particular interest in existing literature are improvements to basic interactive evolutionary computation (IEC) techniques that also encompass explicit fitness functions [35, 36, 51], ways to ensure that the trajectory of the software through design space matches the demonstrated preferences of the designer-artist, or that a likely path to a satisfactory design solution is followed [1, 27, 31]. These same problems have been addressed repeatedly ever since early implementations of the idea were coded specifically as creative tools (e.g. [49, pp. 84-87]). To some extent, the need for a solution to these difficulties can be linked back to the algorithm's inherent dependence on

[1] Google Scholar (accessed 18 December 2012). Terms were "double-quoted" for each search.

randomness – IEC is a "stochastic design process" tempered by phases of (less stochastic) human selection. The stochastic element is both its greatest strength, and, in some cases, its users' greatest frustration. As we shall show, a similar dependence on stochastic processes plays a significant role in many creative activities, not just those employing IEC for their realisation. Even in these contexts randomness is both a curse and a blessing. We will explore below how some (traditional and electronic) artists have allowed the benefits to flourish, while minimising the drawbacks.

Two aspects of general creative activity will be of assistance in allowing us to place IEC in the broad context of randomness in art: first, a simple scale of the difficulty of different creative activities (sect. 2) [38]; and second, a set of entry points for chance into creative work (sect. 3) [4]. These have been discussed in detail, and in the context of art, elsewhere [22]. Here we briefly recount them, while investigating their specific relevance to IEC.

The IEC technique is particularly entwined with random events at the level of crossover and mutation of genotypes, but also through the initiation of a random population, and throughout the dialogue with a user whose whims may lead them on a winding path. This is why it will be helpful to examine how chance fits within creative practice generally. Any understanding will inform our perspective of how IEC fits within the scope of stochastic art and design processes.

While some of the observations and suggestions regarding IEC discussed here may be applied broadly, this paper focuses on visually guided interactive evolution, even if the inspiration comes from diverse domains. Some of the paper's remarks will require reconsideration before application to other domains, especially those with long-term temporal elements such as music-composition, dance or cinema. A simple software application for designing (visual, fictional) animated microorganisms is presented as an example of the application of some of the ideas. Others are illustrated by reference to existing artworks.

2. VISUAL ART BEGAN BY CHANCE

Readers familiar with the utility of IEC must be aware of the degree to which chance plays a role in the application of the technique to the design process. In its basic form as implemented by Richard Dawkins [17], the approach requires users only to aesthetically evaluate a series of images generated by random mutation of a previously selected figure, and to click the one they prefer. The creative input required for this process has long been called into question [19], it is much more like pigeon breeding than it is like art making.[2] However, it is worth noting that just such "aesthetic selection" may be a fundamental hominid "artistic" thought, at least in the visual domain.

Amongst the earliest aesthetic artefacts we have uncovered are: the *Makapansgat pebble* (a face-shaped river stone, collected by *Australopithecus* about 3 million years ago [40]); the *Venus of Tan-Tan*, a stone figurine crudely fashioned by *H. heidelbergensis* from a rock with an originally coarse humanoid form (Morocco, c. 300k-500k years BP [6]); and the *Venus of Berekhat Ram* which was also fashioned by enhancing the natural shape of a rock (Golan Heights, c. 250k-280k years BP [13, 37]). These three objects were all "aesthetically selected" by our ancestors. The latter two were then modified slightly to increase their likeness to humanoid form. Collections of fossils, interesting stones, bones and shells were also selected by Neanderthals [47].

Aesthetic selection continued into the Palaeolithic period when the Chauvet and Lascaux caves in southern France were spectacularly decorated (c. 30k and c. 15k BP respectively) [2]. Here aesthetic selection concerned rock features and blemishes with the potential to be used as design elements in large-scale paintings. For example, nodules formed the basis of eyes; a depression was used as a face; ridges were included as an animal's spine, head and legs. Why this was important to the painters may never be known. But, so interested were the artists in the possibilities of blemishes, that sometimes their inclusion meant that animals were not depicted in natural poses [34, 37].

The existence of such early artworks based on chance natural forms suggests it is a fundamental trait of hominids to seek familiar patterns in random data. Notably, even non-artists see these in complex noisy structures, including clouds (*Hamlet*, iii:2:265-275), tree branches [21], and on the surface of the Moon [41]. Morriss-Kay suggests that this behaviour forms a part of a scale of increasing hominid capability to visualise 3D forms in the "mind's eye" [38]. The four stages of this creative activity can be set out explicitly 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 (e.g. the *Makapansgat pebble*). (A-ii) refers to the crude enhancement of human or animal-like natural forms (e.g. the Venus figures). The Palaeolithic embellishment of barely suggestive cave surface irregularities is activity of type (A-iii). Lastly, artists working from a blank canvas or wall, on smooth sand, cut tree bark or from a rectilinear stone block can create new forms from their "mind's eye" (A-iv). Leaving aside the evidence for an evolutionary or cultural trajectory,[3] this sequence doesn't press modern intuition or experience regarding the order of difficulty of creative tasks very far. This latter point, more than its archaeological significance, makes the proposal relevant here.

Anecdotally, stages (A-i) to (A-iv) are of increasing difficulty. 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, drawing a simple face or other well-rehearsed scribble within an existing shape, or from an earlier random line. A few of us can copy a pleasing image and can reproduce it on a blank page. But how many of us can conceive a novel image in our mind's eye and illustrate it? This is a rare skill.

In many design programs 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).

[2] "Art" and "creativity" are used very loosely in this paper. Art here refers to any design created using IEC – a coarse, inclusive application of the term! Detailed discussions of creativity are given elsewhere [8, 23].

[3] An earlier and thorough discussion of the evidence for the origins of art has been offered by Bednarik that includes its own proposal for the development of iconic 3D sculpture [5].

IEC however, harnesses the early stages of the sequence (A-i & ii), by firstly presenting users with a range of images from which to choose one or more, and secondly by allowing these to be fused together to increase the likeness of the initial random forms to the desired outcome, whether or not this is held in the mind's eye in advance.

Since chance plays a dominant role in deciding what will be displayed to an IEC user, and what will be generated from the selections they make, it is worthwhile to consider how chance enters creative processes generally. This is the subject of the next section.

3. KINDS OF CHANCE[4]

The real world is much less controlled than the virtual space. In general, I believe this is a missed opportunity for computer artists. IEC is one instance however, where chance is deliberately and usefully allowed to enter. In order to understand how this entry assists human creativity, here is (my paraphrasing 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) Personalised action - chance favours those with idiosyncratic interests and behaviours.

Chance (B-i) can enter seemingly from nowhere to take a project in a new direction. This is equivalent to finding a fully formed face-shaped *Makapansgat pebble* as you sit by a riverbank, when you weren't actually looking for a face.

Chance (B-ii) comes into play when you actively pass many pebbles, perhaps by walking along the riverbank. The more you see, the greater the chance an interesting pebble will appear, even if you weren't specifically looking for one.

Chance (B-iii) requires a particularly prepared state-of-mind; you need to be able to form connections between subtle hints that others might not even recognise as offering any service. For instance, some aspect of a (metaphoric) "pebble" might remind you of a problem you encountered before and let you, and possibly only you, see how it might be relevant in understanding a situation. You must be open to subtle chance suggestions and able to discern the specific aspects of the pebbles relevant to the many ideas you are engaged with.

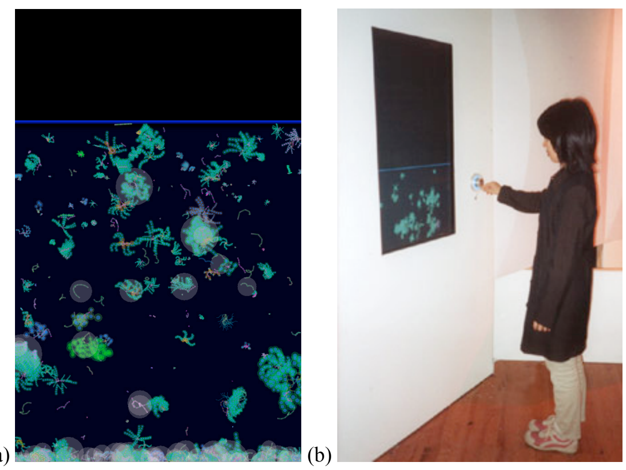
Chance (B-iv) requires not just a wander along a riverbank, but a rockclimb in the mountains and a work trip to a quarry. Not only must you be busy, you must have a diverse range of interests that allow you to draw on unusual and seemingly disconnected behaviours to facilitate the combination of findings from different sources into novel ideas. Due to your idiosyncrasies, the combinations you are capable of generating will be as unique as your personality.

[4] In addition to the "kinds of chance" discussed here, there are also many probability *distributions* that describe the likelihood with which particular random events occur. For instance, the Gaussian distribution forms a symmetrical bell-shaped curve around a mean. Events drawn from this distribution are more likely to be close to the mean than distant from it. By contrast, events drawn from a continuous Uniform distribution will be spread evenly across its range as they have equal probability. An exploration of probability distributions is beyond the scope of this paper. The curious reader should consult texts on statistics.

4. CHANCE IN ART AND IEC

The creative activities and chance entry points we have listed have been examined generally for their relevance to a range of artistic practices elsewhere [22]. Here we summarise a selection of these artworks to understand stochastic art generally, with the aim of placing IEC in context. As we will argue by example, some applications of chance to traditional art suggest general principles that have the potential to simply enhance IEC. A few have been explored in existing software, some not. We shall highlight these as we go, illustrating some basic applications by reference to an earlier artificial life artwork by the author, *Meniscus* (2003) [20].

Meniscus is a generative, evolutionary software artwork in which microorganism-like critters roam a column of water, finding mates according to their preferences and reproducing to maintain a dynamic virtual ecosystem (Fig. 2). The work incorporates basic IEC, usually for programmer use, to establish an initial population resembling real microorganisms.



(a) (b)

Figure 2. (a) The *Meniscus* virtual ecosystem. The horizontal line indicates the water level below which the creatures are constrained. (b) During exhibition, the water level is controlled via a wall-mounted dial. The water's agitation and depth impact on different species' health and reproductive success.

4.1 Permutations and combinations

Technology helps to explore permutations and combinations, regardless of an artist's idiosyncrasies (B-iv). For instance, wind-chimes such as the bronze *tintinnabulum* of ancient Rome (c. 1st C. CE), automatically generate a background of random time series from which a composer can extract sections as raw compositional material, even as they sit idly in the garden. This inter-play between determined pitches and indeterminate timing is mimicked by the interplay of predetermined visual features in indeterminate combinations within IEC. In some instances it is useful to present the user with random recombinations that are *not* the result of user-selected parents. This feature has been provided within *Meniscus'* IEC system by allowing the user to increase the population as desired, even massively, with randomly created phenotypes. In practice this has been found workable for this specific application. Interesting random arrivals are easily distinguished from those that are: (i) too similar to existing creatures to be worth investigating; (ii) too simple, static; or (iii) tiny or huge. Clearly this allows chance wider access to the process than it would have otherwise.

Since at least Ramon Llull's time (13th C CE) mechanical means for enumerating combinations of symbols have existed. In the missionary Catalan's *Ars Magna* (Great Art), Llull explained how to use symbol-inscribed discs and other diagrammatic devices to generate questions (Fig. 3 and [28, 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 ideas in *L'Harmonie Universelle* (1636) [33].

Figure 3. One of Llull's geometric mechanisms for computing permutations and combinations (*Ars Magna*, 1305 CE).

The practice of using combination and permutation of basic artistic elements with digital tools has roots in the computer art, cybernetic art and systems art that took early steps in the 1960s [42, 44, pp. 372-373; 386-387; 389, 45]. More recently, Paul Brown's *The Deluge* (1995) and *Sandlines* (2000) involve the rotation of patterned grid squares at regular intervals. By this means, Brown's works explore the permutations of the cells' orientations [9]. The combinatoric approach appears even outside computational art. Examples include Brion Gysin's *Junk Is No Good Baby* (1973) that simply enumerates combinations of the words in its title [52, p. 141]; and the "phasing" musical composition *Drumming* by Steve Reich (1970-71), that regularly shifts rhythms against one another over time.

IEC's recombination of selected parents to generate a new population of individuals is a scope-limited implementation of this process. I.e. the new population is a subset of possible recombined attributes of the parents with variation (sometimes) inversely proportional to the time over which the algorithm has been running. Something can be learned from Lull's devices, Gysin's piece and Reich's phasing: there may be circumstances when instead of chance dictating that a few individuals or a small subset be displayed during IEC, a more thorough enumeration of all possibilities be available for interactive exploration, even at a late stage in the process. Jared Tarbell's *Invader Fractal* (2003) explores this idea aesthetically (Fig. 4).[5] It generates images from the 32,768 bi-laterally symmetrical pixel arrays that make up the entire population, to create a fleet of "space invaders". Frequently in generative art, multiple "outputs" of a process are exhibited in some way like this, animated or interacted with, much as an artist displays several works to give a feeling for their output over some period (e.g. [24, 49, p. 31 (fig. 2.18)]).

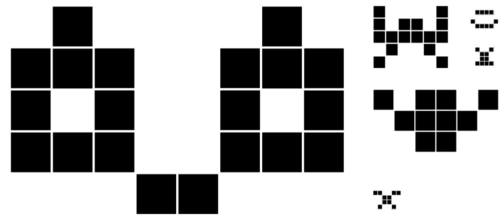


Figure 4. Illustrative "invaders" created by the author in the manner of the components of Tarbell's *Invader Fractal* (2003).

While it may be infeasible to display the vast population of possible offspring at each IEC generation, large arrays can still be scanned like pebbles on a riverbank if properly organised [50, pp. 170-175]. This might not be appropriate at every step of the way, but the user should at least have the choice, even after clicking through many evolutionary generations.

Sometimes, *Makapansgat pebbles* do turn up. In the context of IEC this is equivalent to finding that a member of the initial population is exactly what you needed – unlikely, if the solution space is truly vast! This is a creative activity of type (A-i). It isn't mentally taxing, but neither is it usually very helpful. Still, an IEC user can explore randomly generated starting populations *en masse*, or even explore previously evolved results and intermediaries that, for whatever reason, weren't suitable in other contexts (Fig. 5 and [15]). After all, chance favours those who examine many possibilities (B-ii). But IEC software can play a role in this aspect of creativity only if the chance forms that appear are consistently worth considering (B-i). Otherwise, a designer *will* quickly become frustrated.

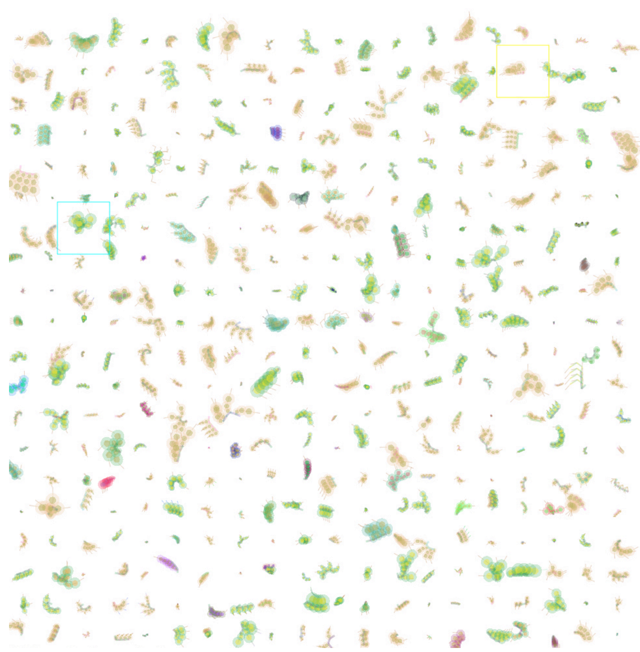


Figure 5. Meniscus' IEC system can operate on a large random or pre-saved population. In this case, it is easy to scan hundreds of animated miniatures for reproductive candidates. There is no need to limit the user to a handful.

So why, given the apparent unlikelihood, is it *unsurprising* that we have found face-shaped pebbles, clouds, trees and planet

[5] www.complexification.net/gallery/machines/invaderfractal/ (accessed 29 January 2013)

surface marks but simultaneously unsurprising that this happens seldom in initial IEC populations? An obvious reason is the sheer number of noisy natural forms we perceive and the immense diversity of perspectives and lighting conditions under which we see them. Such a variety is seldom present in IEC, many interactive programs treat more than 16 phenotypes as too taxing on the user. In many cases this concern is justified. But as noted above, there are some circumstances where it is appropriate to display hundreds, even thousands of possibilities to a user.

Another reason we are good at seeing forms, especially faces, in natural random data is that in nature we perceive rich *suggestions* of the forms our mind seeks. Sometimes the designs displayed by our IEC software are not suggestive. This limits our ability to imagine what they might *become* after evolution and instead guides us only to see them as poor design "solutions".

This tells us that in the early stages of IEC the phenotypes we see should be suggestive, not prescriptive. The *Blind Watchmaker* software's 2D stick-figures are suggestive in the required way [17]. *Meniscus*' patterns are similar. They are intricate and can be read in multiple ways. 3D models are more difficult to render ambiguously although computationally generated complexity, subtle surface variations and unusual lighting conditions can help provide multiple interpretations akin to those found in natural trees, rocks and clouds. If presented with many subtle suggestive figures during the early stages of IEC, a user's chances of finding a good starting point are maximised, even before evolution begins.

It should be easy to rummage through a collection of suggestive objects and select one for close consideration or inclusion in an initial IEC population. 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 starting points for projects include scrapbooks, workshop part bins, craft boxes and trunks of fabric offcuts. Arguably, an idiosyncratic collection is desirable (B-iv). In software, an infinite number of virtual forms should be available. These should be loosely but consistently ordered and interactively re-orderable to enhance the likelihood of chance being helpful (B-i), without frustrating any preconceived ideas (A-iv), and while allowing a user to gain familiarity with their collection over time.

4.2 Ambience

The "ambient" character of wind-chimes might be a useful aspect too. An IEC-like algorithm can act as a screen-saver (or, if it isn't too distracting, as a workspace background) that drifts randomly through genotype space, sometimes in the vicinity of previous explorations, sometimes in completely unexplored genotype regions. It is helpful then if a user can save a random form when something interesting happens to appear. The *Meniscus* software's original "ecosystemic" exhibition mode provides just such a feature (Fig. 2a). The work can be left running in the background and its species saved for interactive evolution at any moment. A backtrack feature and timeline could be included to ensure a missed opportunity to "save" can be retrieved.

4.3 Variable control

The abstract expressionist "action paintings" by Jackson Pollock (e.g. *Blue Poles* / *Number 11* (1952)) provide a clear example of the extended approach to chance's inclusion in traditional 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, trowels and knives.

IEC is similarly coarse in the level of control offered to the artist. Likewise, it can be enhanced by providing a range of control options. Just as Pollock sometimes picked up tools offering finer control than dripping buckets of pigment, an IEC user should have access to conventional modelling or bitmap image editing tools as appropriate at any stage in the evolutionary process. In practice, it is difficult (but not impossible) to manage this *during* evolution because as soon as a change is rendered to the phenotype a new genotype must be devised that produces the result via the IEC technique's developmental process. Dahlstedt suggests in a different context, a mechanism by which this may be possible using evolutionary computation with an explicit fitness function [16]. The idea is that a phenotype hops between two genotypic representations. The first genotype produces a phenotype that, in the context we are proposing here, is operated on by the user. After manual phenotypic editing that bypasses the genotype completely, this phenotype is (re-)converted into a new genotypic representation automatically by the software. It attempts to explicitly match the phenotypes it generates from a population of new genotypes to the phenotype produced by the manual human intervention. This automated reconversion into a genotype conveniently provides another point for chance to enter the creative process. However, in cases of practical interest, such as after bitmap image manipulation, the evolutionary reverse engineering of a target may be exceedingly difficult [18].

In practice, the most common tool available for fine-control over an individual is direct genotype editing. This circumvents the need for reconversion of a non-genotypically derived phenotype back into the encoding scheme. Even Dawkins' *Blind Watchmaker* allowed this by user entry of numbers into text boxes. Alternative interaction devices (e.g. mouse or touch-driven widgets) facilitate access to this facility.

4.4 IEC is an expedition

Pollock didn't always begin a work with a preconceived idea in his mind's eye (A-iv). He explained, "It is only after a sort of 'get acquainted' period that I see what I have been about". The chance element in his process gave each painting "a life of its own" [12, p. 548]. Activities (A-i, ii & iii) guided his creative process, possibly away from any original idea (if one ever existed) and into a region suggested by chance and his process. Anybody who has employed IEC to achieve even a slightly complex outcome must have seen how it allows chance to mould ideas in a similar way. In this case, the restrictions on the designs it produces are laid down by the software (is it for generating 3D model insects? 2D bitmap textures? furniture or architecture? etc.) rather than by the physical attributes of paint, its environment and manipulation.

Music composition processes explicitly guided by chance include 18th century "dice games" where the numbers rolled determine which musical phrases or pitches occur in a sequence [30]. More recently, 20th century composer John Cage applied techniques for divination from the *I-Ching* (Book of Changes), an ancient Chinese text. His aim was to renounce control over the detail of a work [39, pp. 60-62]. The "cut-up" technique of Brion Gysin alluded to earlier (sect. 4.1) has a similar effect on poetry. This harks back to the Dadaist and Surrealist methods, suggested originally in the 1920s by Tristan Tzara, of creating poetry by randomly assembling words drawn, in Tzara's procedure, from a hat. American Beat writer William S. Burroughs also explored the technique in text, and considered it for splicing cinema film and audio tape [10]. Twentieth century Greek composer, architect and engineer Iannis Xenakis also showed significant interest in stochastic procedures. He explored computer-based random processes to assemble the components of several of his musical compositions [29]. In these works chances (B-i & ii) arguably play dominant roles. IEC similarly allows these types of chance to intervene or even govern proceedings. As we have already noted, the initial population of the process is often randomly generated. Actually, it should be possible to introduce new random creatures at any stage. From here, an artist-led process can continue to be influenced by chance as parents are selected and randomly recombined or mutated to generate future components of a work.

4.5 Interacting elements

The participants in the *Scratch Orchestra*, a music and performance group from the late 1960s and early 70s, included Cornelius Cardew [11]. Their compositions often worked from natural and human-driven collaborations with large degrees of randomness. Cardew's *Paragraph 7, The Great Learning* (1971) is a randomly initialised, self-organising choral work where human singers recite or sing lines from a text according to prescribed 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.

Such between-human improvisations and interactions share features with the machine-human interactions of IEC. Collaborative improvisation between human performers, or between machines and humans [25, 32], 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 participants can build.

In addition to processes of human interaction, physical processes may also interact with artistic media to create complexity. This subject is worth recounting briefly here.

Tim Knowles has produced a number of *Tree Drawings* (2005-). 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. They impact heavily on the drawing a tree makes.

Erwin Driessens and Maria Verstappen's artwork[6] *Sandbox* (2009) employs chance and physical processes through the movement of grains of sand. They 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 (Fig. 6). 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.

[6] notnot.home.xs4all.nl (accessed 23 January 2013).

The interactions between active performers in Cardew's *Paragraph 7*, and between tree branches, sand grains and wax droplets with the air in Knowles, Driessens and Verstappen's works, highlights the role a temporally extended dynamic process outside the control of the artist can play in creative activity. These works are a kind of *Generative Art* [26]. In the context of IEC these process/media interactions suggest the possibility of introducing a developmental process that builds the phenotype from the genotype and is itself subject to chance intrusions and (software metaphors for) physical, chemical, biological or ecological processes with their own dynamics.

The *Meniscus* generative evolutionary ecosystem, its user interaction via the adjustable environmental control, and its IEC implementation, together fuse active agent-based interactions and aesthetic selection. Phenotypes could also (potentially) be subject to phases of explicit fitness-based evolution. Sommerer and Mignonneau's artwork *A-Volve* [46] was a pioneering work fusing interactive and ecosystemic interactions as it allowed the initial design of creatures for insertion into a virtual environment. As noted, *Meniscus* allows IEC to operate before free-running interaction of the creatures, or IEC may interrupt the ecosystem. In this way chance interactions within a constrained environment unfold outside the direct control of the designer, and can then be enhanced by the direct application of IEC.

Figure 6. Driessens and Verstappen, *Top-down Bottom-up*, Centraal Museum Utrecht, 2012 (Image © Driessens and Verstappen)

5. CONCLUSION

Chance is stamped out of a lot 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 realising 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. IEC provides a useful mechanism that allows users to harness basic creative abilities. If we treat it from the perspective that holds chance as paramount, a range of possibilities to increase its utility emerge. These are, to a very small extent, being realised outside of academic evolutionary computing and occasional electronic media art, in commercial software. For instance, *Genoform* allows for a similar procedure to be employed with off-the-shelf architectural and industrial design software.[7] Dahlstedt introduced the *Patch Mutator* to Clavia's Nord Modular G2 editor, allowing interactive evolution of audio patches for the synthesiser [14, 15].

Chance has played a significant role in our visual art and design ever since the origins of (pre-) human creative practice. Its implications for contemporary electronic media art are profound, especially in evolutionary computation and generative art, a field which, even by its incremental growth and niche popularity on the fringes of the fringes of art and design, highlights the utility of stochastic design. With this in mind, software offers us an opportunity to welcome chance into our creative processes or instantly banish it when it is inconvenient. However, as we have shown by examining both traditional and electronic arts practice in this article, if we permit the standard software engineer's elimination of its influence entirely we stand to lose a key resource and a natural creative ally.

6. ACKNOWLEDGMENTS

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