Adaptation of an Autonomous Creative Evolutionary System for Real-World Design Application Based on Creative Cognition

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Abstract

This paper describes the conceptual and implementation shift from a creative research-based evolutionary system to a real-world evolutionary system for professional designers. The initial system, DarwinsGaze, is a Creative Genetic Programing system based on creative cognition theories. It generated artwork that 10,000's of viewers perceived as human-created art, during its successful run at peer-reviewed, solo shows at noted museums and art galleries. In an effort to improve the system for use with real-world designers, and with multi-person creativity in mind, we began working with a noted design firm exploring potential uses of our technology to support multi-variant creative design iteration. This second generation system, titled Evolver, provides designers with fast, unique creative options that expand beyond their habitual selections that can be inserted/extracted from the system process at any time for modular use at varying stages of the creative design process. We describe both systems and the design decisions to adapt our research system, whose goal was to incorporate creativity automatically within its algorithms, to our second generation system, which attempts to take elements of human creativity theories and populate them as tools back into the process. We report on our study with the design firm on the adapted system's effectiveness.

Introduction

Creativity is a complex set of cognitive process theorized to involve, among other elements, attention shifts between associative and analytical focus (Gabora, 2010), novel goals (Luo and Knoblich, 2007), and situated actions and difficult definitions of evaluation (Christoff et al, 2011). Computational creative systems strive to model a variety of creativity's aspects using computer algorithms from evolutionary 'small-step' modifications to intelligent autonomous composition and 'big-leap' innovation in an effort to better understand and replicate creative process (Boden, 2003). The focus by some researchers on replicating creativity in computational algorithms has been instrumental in learning more about human cognition (individual and collaborative) and how creative support tools might be used to enhance and augment human creative individuals and teams. All these aspects continue to evolve our perceptions of creativity and its role in computation in the current technology-saturated world.

Systems modeling creativity computationally have gained acceptance in the last two decades, situated mainly as artistic and research projects. Several researchers in computational creativity have addressed questions around such computational modeling by outlining different dimensions of creativity and proposing schema for evaluating a "level of creativity" of a given system, for example (Ritchie, 2007; Jennings, 2010; Colton, Pease and Charnley, 2011). While there is ongoing research and scholarly discourse about how a system is realized, how the results are generated, selected and adjusted and how the process and product are evaluated, there is less research about direct applications of creative cognitive support systems in real-world situations. Now that more autonomous, generative creative systems have been developed, we are re-evaluating the role of the human collaborator(s) when designing a creative system for real-world applications in an iterative creative design process environment (Shneiderman, 2007).

We explore creativity from theories of cognition that attempt to understand attentional shifts between associative and analytical focus. The existence of two stages of the creative process is consistent with the widely held view that there are two distinct forms of thought (Dartnell, 1993; Neisser, 1963; Piaget, 1926; Rips, 2001; Sloman, 1996). It has been proposed that creativity involves the ability to vary the degree of conceptual fluidity in response to the demands of any given phase of the creative process (Gabora, 2000; 2002a; 2002b; 2005). This dimension of variability in focus is referred to as contextual focus. Focused attention produces analytic thought, which is conducive to manipulating symbolic primitives and deducing laws of cause and effect, while defocused attention produces fluid or associative thought which is conducive to analogy and unearthing relationships of correlation. Thus, creativity is not just a matter of eliminating rules but of assimilating and then breaking free of them where warranted.

This paper focuses first on the implementation and applicability of contextual focus through our research system, DarwinsGaze, developed to use an automatic fitness function. Second, we present our effort to adapt this successful but specific research system for more general use with real-world designers, and with multi-person creativity in mind. We worked with a noted design firm to examine potential uses of our technology for supporting multi-variant creative design iteration. Our analysis of their process combined with our knowledge of the cognitive aspects of creativity (gleaned from our early research), were used to completely rewrite the DarwinsGaze system to an interactive creativity support tool within a production pipeline. This 2nd generation system, Evolver, provides designers with fast, unique options that expand beyond their habitual selections that can be inserted and extracted from the system process at any time for modular use at varying stages of the creative design process. The changes focused firstly on usability needs, but became more important when we saw opportunities for affecting the shifts between contextual and analytical focus of the designer through the Evolver system. This process required evaluating the real-world iterative process of designers and testing various prototypes with designers from the firm Farmboy Fine Arts (FBFA) to see how they engaged with interactive creativity support. Lastly we evaluated with a user study the effectiveness of this conversion process and how non-technical designers appreciated and used this Creative Evolutionary System. We hope that our experience and evaluation can be a guide for other researchers to adapt creative research systems to more robust and user centric real world production tools.

The DarwinsGaze System

The DarwinsGaze system (DiPaola and Gabora, 2007) is a Creative Evolutionary System (CES) (Bentley and Corne, 2002) (see Figure 1) based on a variant of Genetic Programming (GP). Unlike typical Genetic Programming systems this system favors exploration over optimization, finding innovative or novel solutions over a preconceived notion of a specific optimal solution. It uses an automatic fitness function (albeit one specific to portrait painting) allowing it to function without human intervention between being launched and obtaining the final, often unanticipated and pleasing set of results; in this specific and limited sense we refer to DarwinsGaze as "autonomous". The inspiration for this work is to directly explore to what extent computer algorithms can be creative on their own (Gabora and DiPaola, 2012). Related work has begun to use creative evolutionary systems with automatic fitness functions in design and music (Bentley and Corne, 2002), as well as building of a creative invention machine (Koza, 2003). A contribution of the DarwinsGaze work is to model, in software, newly theorized aspects of human creativity, especially in terms of fluid contextual focus (see Figure 2).

DarwinsGaze capitalizes on recent developments in GP by employing a form of GP called Cartesian Genetic Programming (CGP) (Miller and Thomson, 2000; Walker and Miller, 2005). CGP uses GP techniques (crossover, mutation, and survival), but differs in certain key respects. The

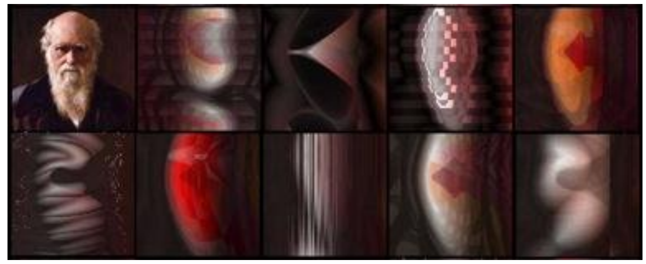

Figure 1. Source Darwin image with examples of evolved abstract portraits created using the DarwinsGaze autonomous creative system.

program is represented by a directed graph of indexed nodes. Each node has a number of inputs and a function that gives an output based on the inputs. The genotype is a list of integers determining the connectivity and functionality of the nodes, which can be mutated and mated to create new directed graphs.

CGP has several features that foster creativity including 1) its node based structure facilitates the creation of visual mapping modules, 2) its structure can represent complex computational input/output connectivity, thus accommodating our sophisticated tone and temperature-based color space model which enables designerly decision making, and most importantly 3) its component-based approach favors exploration over optimization by allowing different genotypes to map to the same phenotype. The last technique uses redundancy at the input, node, and functional levels, allowing the genotype to contain nodes that are not connected to the output nodes and so not expressed in the phenotype. Having different genotypes (recipes) map to the same phenotype (output) provides CGP with greater neutrality (Yu and Miller, 2005). Our work is based on Ashmore and Miller's (2004) CGP application to evolve visual algorithms for enhanced image complexity or circular objects in an image. Most of their efforts involve initializing a population and then letting the user take over. Our initial prototype was based upon their approach, but expanded it with a more sophisticated similarity and creativity function, and revised their system for a portrait painter process.

Since the advent of photography, portrait painting has not just been about accurate reproduction, but also about using modern painterly goals to achieve a creative representation of the sitter. We have created a fitness function that mainly rewards accurate representation, but given certain situations it also rewards visual painterly aesthetics using simple rules of art creation as well as a portrait knowledge space. Specifically, the painterly portion of our fitness function 1) weighs for face versus background composition, 2) uses tonal similarity over exact color similarity matched with a sophisticated artistic color space model which weighs for warm-cool color temperature relationships based analogous and complementary color harmony rules and 3) employs unequal dominate and subdominant tone and color rules and other artistic rules based on a portrait painter knowledge domain (DiPaola and Gabora, 2007) as illustrated in Figure 2. We mostly weight heavily towards resemblance, which gives us a structured system, but can under the influence of functional triggers allow for artistic creativity. The approach gives us novelty and innovation from within, or better said, responding to a structured system -- a trait of human creative individuals.

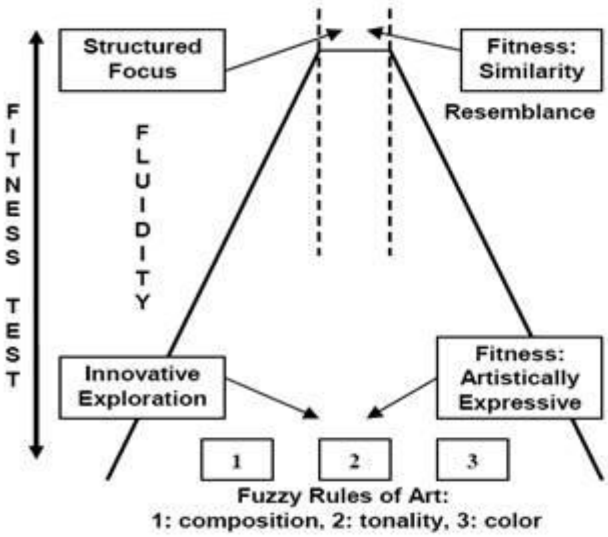

Figure 2. The DarwinsGaze fitness function mimics human creativity by moving between restrained focus (resemblance) to more unstructured associative focus (resemblance and more ambiguous art rules of composition, tonality and color theory).

Generated portrait programs in the beginning of the run will look less like the sitter but from an aesthetic point of view might be highly desirable, since the function set has been built with painterly rules. Specifically, the fitness function in the DarwinsGaze system calculates four scores (resemblance and the three painterly rules) separately and fluidly combines them in different ways to mimic human creativity by moving between restrained focus (resemblance) to more unstructured associative focus (3 rules of composition, tonality and color theory). In its default state the fitness function uses a ratio of 80% resemblance to 20% non-proportional scoring of our three painterly rules. Several functional triggers can alter this ratio in different ways. The system will also allow very high scoring of painterly rule individuals to be accepted into the next population. When a plateau or local minima is reached for a certain number of epochs, the fitness function ratio switches course where painterly rules are weighted higher than resemblance (on a sliding scale) and work in conjunction with redundancy at the input, node, and functional levels. Using this method, in the wider associative mode, high resemblance individuals are always part of the mix and when these individuals show a marked improvement in resemblance, a trigger is set to return to the more focused 80/20 resemblance ratio.

For CES used to create fine art paintings, the evaluation was based less on the process and more on the output. Could a closed process (that has no human intervention once the evolutionary process was started) produce artwork that was judged as creative using the methods by which real human artists are judged? Example pieces from the output over 30 days were framed and submitted to galleries as a related set of work. Care was taken by the author to select representational images of the evolved unsupervised process, however creative human bias obviously exists in the representational editing process. This is similar to how a curator chooses a subset of pieces from their artists, so it was deemed that is does not diminish the soft evaluation process.

The framed art work (darwinsgaze.com) was accepted and exhibited at six major galleries and museums including the TenderPixel Gallery in London, Emily Carr Galley in Vancouver, and Kings Art Centre at Cambridge University as well as the MIT Museum, and the High Museum in Atlanta, all either peer reviewed, juried or commissioned shows from institutions that typically only accept human art work. This gallery of abstract portraits of Darwin has been seen by tens of thousands of viewers who have commented with dated quotes in a gallery journal that they see the artwork as an aesthetic piece that ebbs and flows through creative ideas even though they were solely created by an evolutionary art computer program using contextual focus. Note that no attempt to create a formalized ‘creativity Turing Test’ was made. Most of the thousands of causal viewers assumed they were looking at human created art. The work was also selected for its aesthetic value to accompany an opinion piece in the journal Nature (Padian, 2008), and was given a strong critical review by the Harvard humanities critic, Browne (2009). While these are subjective measures, they are standards in the art world. The fact that the computer program produced novel creative artifacts, both as single art pieces and as a gallery collection of pieces with interrelated themes, is compelling evidence that the process passed a type of informal creativity Turing test.

The Shift from Autonomous Creative System to Creative Support Tool: the Evolver System

To move forward from the DarwinsGaze system we began looking to explore a real-world application of creativity in computation by leveraging concepts of contextual focus to integrate with collaborative process. The opportunity arose to work with FBFA, an international art consultancy firm that designs site-specific art collections for the luxury hotel and corporate sectors, to develop software that could complement and provoke their current iterative design processes. The focus on visual design for hotel decor was an interesting perspective that enabled us to consider what we had achieved with visual creative design in prior work, and how we could engage in the designer’s intuitive yet visual (and hence somewhat parameterized) creative process.

In the effort to evaluate a CES within a Visual Design domain, we explored the use and adaptation of “Evolver”. Evolver is a computational creative tool modified from the DarwinsGaze project structure. Evolver was created as a result of in-depth research and observations to support a specific design process at FBFA by automating some of the design tasks and restructuring the contextual search space. It provides a platform for brainstorming by generating various versions of original artwork provided by designers, through specific features such as controlling the color scheme or marrying different artworks together. It also offers some production capabilities by automating repeating tasks such as cropping for mass quantities of artworks traditionally performed by designers in programs such as Adobe Photoshop. Evolver incorporates a user-friendly GUI (see Figure 3) paired with a flexible internal image representation format for ease of use by the designer. The designer provides the seed material and selects preferred results while the system generates a population of artwork candidates, cross breeds and mutates the candidates under user control to generate new design products. The designer may select and extract any resulting candidate piece at any stage of the process for use in other areas or as generative fodder to later projects. System parameters of Evolver include shapes, colors, layers, patterns, symmetries and canvas dimensions.

Developing the Evolver System to Fit the Needs and Process of a Design Firm

FBFA takes design briefs from the hotel interior designers, and based on their extensive photo and graphic design database as source, designs specific art and design objects in a multitude of material (although typically wall hanging) often in unique sizes, shapes and multiples to specifically work with the hotel’s (typically their large lobby and restaurants) needs. They do this by incorporating a number of designers who using digital systems like Adobe Illustrator significantly rework a source design to refit the space, shape and material specifics.

We began by demonstrating to them an interactive version of our DarwinsGaze system, which was mocked up on the darwinsgaze.com website, called ‘Evolve It’ to show what a potentially fully-interactive new system would look like. The designer’s process to create a successful prototype for the client was a multi-step, iterative and somewhat inefficient process which relied on the designer’s ‘feel’ of the problem context, the potential solution contexts and their intuitive exploration and selection process. In this particular situation designers would discuss a project with a client, then go to physical boxes or their digital database containing immense amounts of image material, find seed material that fits the feeling of the multiple contexts and then manipulate them to better fit the design problem in Adobe Illustrator. The designer’s manipulation adjusts size, scale, shape, multiples and color in layers by hand. This process is highly labor-heavy and we felt it was most receptive to computational support because the designer had already defined the contextual focus for this problem through their own interpretation of the available options, constraints and aesthetic preference (which had already been confirmed by the client engaging with this company).

While the designers were reluctant to give up control of their intuitive, creative knowledge, they readily engaged with the Evolver system once they saw how CESs could support the restructuring of the designer’s contextual space while also reducing the labor-intensive prior process. This shift freed up the designer’s ability to creatively engage with the problem at hand. We strove to make the new systems flexible to different creative processes and paths that different designers might have.

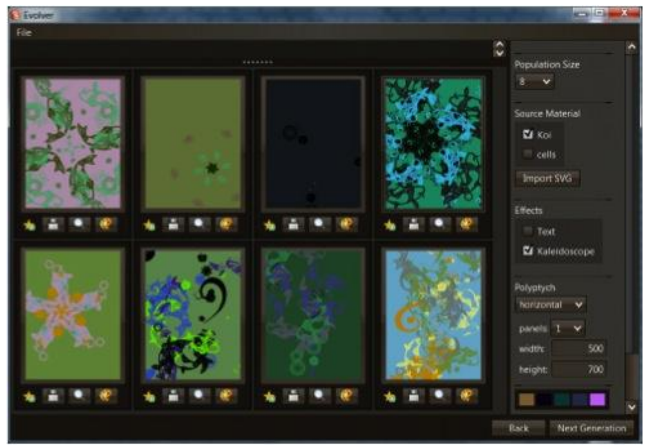

Figure 3. The Evolver Interface

Evolver’s cognitive aspect provides designers with a platform to externalize and visualize their ideas. Artwork generated through Evolver can be used for different purposes in different phases of the design process, from conceptual design through to presentation. During the early phase of conceptual design, free-hand, non-rigid sketching techniques have an important role in the formation of creative ideas as designers externalize their ideas and interact with them spatially and visually (Suwa, Gero and Purcell, 1998). Evolver supports flexibility of ideas in this phase by enabling designers to easily produce an extensive range of alternatives. The ambiguous nature of the multiple generations produced supports the uncertain and fuzzy nature of conceptual design as they discover, frame out early ideas and brainstorm. The alternatives produced relieve cognitive load from the designer by separating them from the manual task of manipulating the design parameters, but do not separate them so far from the process that they cannot use their psychomotor and affective design knowledge.

Evolver is structured to support the shift between contextual and analytical focus by restructuring the contextual space users are working in. Users can choose to relinquish a degree of control while broadening their focus, gaining the ability to be inspired or provoked by novel generations from the system. On the other hand, it is possible to guide successive evolutions in a more deliberate, analytical way and the ability of Evolver to import/export individuals to/from a precisely editable format (SVG - Adobe Illustrator) allows tightly focused design directions to be pursued. At later stages in the design process, artwork generated through Evolver can be used as mockups for clients and prototyping, and also as a communication tool in uses such as presentation at the very end of design process. The work produced by Evolver can be incorporated directly into the tool-chain leading to a finished piece.

Evolver Genetic Encoding: Moving to a More "Linear" Scheme

One of the most far-reaching design decisions involved in the construction of an evolutionary system is the specification of the genetic encoding. A particular choice of encoding delineates the space of possible images and dramatically influences the manner in which images can change during the course of evolution. The genotype induces a metric on the space of potential images: certain choices of representation will cause certain styles or images to be genetically related and others to be genetically distant. The related images will appear with much more probability, even if the distant images are technically possible to represent in the encoding system. For this reason, it is important that the genotype causes images that are aesthetically similar to be genetically related. Relevant aspects of the aesthetic merit of a work can then be successfully selected for and combined throughout the course of the evolutionary run. This property is referred to as gene linkage (Harik et al, 2006). We identified this property as especially important to an interactive creativity support tool, for designers who are used to exerting a high degree of creative control over their output and in a scenario where a certain sense of "high quality design" is to be maintained.

A genetic encoding can either be low level, representing extremely basic atomic elements such as pixels and color values, or high level, representing more complex structures such as shapes and patterns. A common low level encoding is to represent images as the composition of elemental mathematical functions (Bentley and Corne 2002). Though it is technically possible that any image can be conceivably represented as a composition of such functions, this encoding typically results in recognizable geometric patterns that readily signal the algorithmic nature of the process. A higher level encoding can be seen in shape grammars that represent not individual pixels but aggregates of primitive shapes (Machado et al, 2010). This approach can theoretically produce a much narrower range of images, but the images that are produced do not demonstrate the same highly-mathematical nature of lower-level encodings. Compared to the CGP genetic structure of DarwinsGaze, Evolver uses a list-based, tree-structure encoding that draws some inspiration from CGP but operates on higher-level components in order to maximize the property of gene linkage and user interpretability.

We viewed this new genetic representation as broadly "linear" in the sense that the genotype could be decomposed into elements and recombined, leading to a corresponding effect in the phenotype of recombining visually identifiable elements. The genetic representation is based on a collection of "design elements" (DEs), which are objects that denote particular aspects of the image. For example, a major component of our image representation is that of a symbol: a shape that can be duplicated and positioned on the canvas according to a position, rotation, and scaling parameter. DEs are defined in terms of atomic values and composite collections. The DE for a symbol, for example, is represented as a tuple consisting of two floats representing the x and y coordinates of the shape, a float representing the rotation, a float representing the scale, and an enumerable variable representing the particular shape graphic of the symbol. An image is then described by a list of these symbols. The genetic operations of mutation and crossover are derived from the structure of the DE definitions. Mutation is defined for the atomic values as a perturbation of the current value. Crossover is defined for the collection structures. The genotype is "strongly typed" so only genes of the same type can cross over. (For example, "position" may cross over with "position" of another other stamp's record, "color" may cross over with "color"; however "position" will never cross over with "color".) Figure 4 shows an example of Evolver system output.

Evolver User Interface: Optimizing Creative Support

To make the power of this flexible encoding system available to designers, we constructed an automatic import tool that analyzed existing images and parsed their structure into DEs that formed initial seed populations for the interactive evolution. This approach served to bootstrap the evolutionary search with images that are known to demonstrate artistic merit. Source artwork is converted to the SVG vector image format, which is a tree-based description of the shapes and curves that comprise a vector based image. The hierarchical grouping of art elements in the original work is preserved in the SVG format, and is used in determining which pieces are isolated to form symbol DEs. We also make use of heuristics that take into account the size of various potential groupings art elements and any commonly duplicated patterns to identify candidates for extraction.

The interactive evolution proceeds from a seed population constructed from these original parsed image elements. The user interface, by default, depicts a population of 8 pieces of generated art. These individuals can be selected from, to become the parents of the next generation, as is typical in interactive evolution. An added feature, which proved useful, was the ability to bookmark individuals, which placed them in a different collection that was separated from the evolutionary run. This collection of bookmarked individuals allowed users to store any interesting images discovered during the run while proceeding to guide the evolution in a different direction.

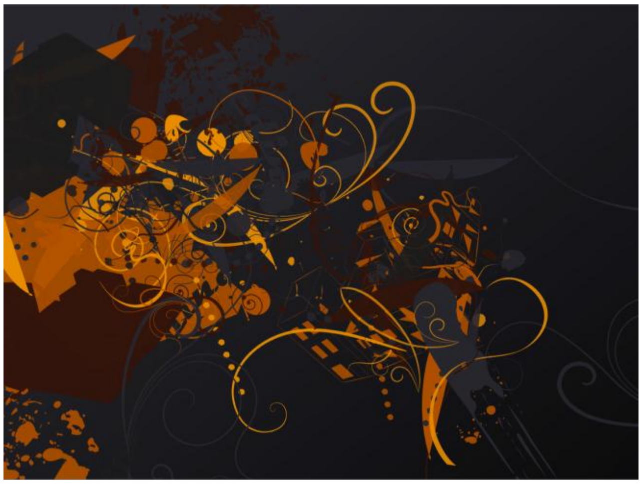

Figure 4. Example Evolver Output Image

Evaluating Designers' Usage and Opinions of the Evolver System

Some months after the end of the project, with Evolver still being used and available for real world production at FBFA, we invited a small group of FBFA and associated designers to our labs, now under controlled study conditions. There we conducted a 45 minute questionnaire-based qualitative study that took place in 2 phases: it began with a uniform re-introduction and re-demonstration of Evolver and its functionalities, followed by a short session where the designer had the opportunity to re-explore the tool and answer a series of nine structured interview questions that concentrate on the adaptation of Evolver within their current and future work practices. The specific questions in phase two were:

1. What is your first impression of 'Evolver'?
2. How and in which stage would you use this tool in your current practice?
3. How does this tool change your design process? Can you provide an existing scenario of your current practice and how you envision Evolver would change that?
4. Which features of this tool do you find most interesting? Why?
5. What features would you like to change and/or add in the future? Why?
6. How would you use this tool apart of your design thinking stage in your process?
7. How does it help with the conceptualization of ideas?
8. What do you think of the role of computational tools such as Evolver within the Visual Design domain?
9. Do you have any further comments/suggestions for the future of this research?

The full qualitative study discursive results are beyond the scope of this paper; however we have included an exemplary set of these results, based on direct quotes from the designers and our assessment of the dominant themes in designer responses. Our main takeaways from this study were:

1. Designers saw Evolver as a creative partner that could suggest alternatives outside of the normal human cognitive capacity:

> "[The] Human brain is sometimes limited, I find Evolver to have this unlimited capacity for creativity." (KK, Interview)
>
> "Evolver introduces me to design options I never thought of before, it enhances my design thinking and helps me to produce abstract out of the norm ideas." (LA, Interview)

2. Evolver also enhanced the human user's ability to enter a more intuitive or associative mode of thought by easing some of the effort in manually visualizing alternative design concepts:

> "Sketching stuff out on paper takes more energy and tweaking - Evolver allows me to visualize easier, have a dialogue and collaborate with the design space." (RW, Interview)

3. Evolver could be used flexibly at different stages of the design process to support different tasks and modes of thought, including both generation and communication of ideas

> "The best part about the Evolver is that you can stop it at any stage of generation, edit and feed it back to the engine, also it is mobile and you can take it to meetings with clients and easily communicate various ideas and establish a shared understanding. It provides a frame of reference- what is in your head now." (RW, Interview)

Comparison and Discussion

We compare the details of the decisions made to shift from the autonomous DarwinsGaze system to the interactive Evolver system and describe their importance (see Table 1). One of the first changes was to shift the genetic representation (or the 'gene' structure). The DarwinsGaze system has genes which work together in a tree structure, to evolve output as a bitmap of the whole piece. The Evolver System genes were more linear and 'predictably recombinable' in order to minimize contextual focus within the system while prioritizing a variety of potentially successful solutions. DarwinsGaze used automatic fitness function-based Cartesian Genetic Programing while Evolver shifted to a simpler and interactive Genetic Algorithm in order to engage the designer in the system and support their intuitive decision-making process. In DarwinsGaze there is no control over pieces, layers or options for interaction involvement. The Evolver system has many layers and elements and is built on the standards based vector language (SVG). Using a design-shelf structure the user has more subtle control including feature navigation, text, symmetry and rotation. The user can either import many small SVG files as seed material or import a single large file and the system will automatically separate and label the elements. With the user acting as the fitness function, the population size can be adjusted and desired results can be 'bookmarked' and set aside for manual iteration or can be reinserted into the Evolver system's gene pool. So for instance, work that they create traditionally can be used as partial seed material, used fully at the start, output at any time from the system as raw inspiration results to be reworked traditionally or used as a final result. A careful effort was made to iteratively develop the graphical user-interface based on feedback from the designers about how they think within a creative process, what metaphors they use, and which perspectives and skills they rely on based on their backgrounds and experience. Finally we integrated additional post-processing options to give added novelty if needed (outside of the Genetic Algorithm) with effects such as kaleidoscope and multiple panels.

DarwinsGaze System	Evolver System
Genes specific to image resemblance & art rules	Genes linear, strong typed, focus on existing parameters
Automatic CGP: complex FF / functional triggering	Interactive Genetic Algorithm: simple structured forms
Bitmap, evolve-as-a-whole	SVG, evolve as labeled layers
Operates autonomously, no import/export material	Ability to import/export labeled semantic material – HCI based
Research system with specific evolve towards the sitter images goals	Communicates at any point of process with trad. design tools supporting wide creative styles
Innovative / complex auto functional triggers : analytical to associative & back	Simpler user-interaction: population size, bookmarks to support human creative triggers
One system : full process of creativity, no external communication	Integrated system: built to work w/ other tools, processes; supports creativity as an adaptive human process
Informed by creativity theory and simulates it internally in complex ways	Informed by creativity theory but uses it to support a real world meta system w/humans

Table 1. Comparison Between DarwinsGaze and Evolver Systems

The study of Evolver in use also made apparent an attitude shift of visual designers towards CESs, which change their role from sole creators to editors and collaborators. The designers became more receptive of tools such as Evolver as they came to view them not as replacing designers or automating the creative process; but rather as promoting new ways of design thinking, assisting and taking designer's abilities to the next level by providing efficiency and encouraging more 'aha' moments. The visual designers in the study described Evolver as an "invisible teammate", who they could collaborate with at any stage of their design process. Evolver became a center of dialogue among designers and helped them communicate their mental models and understanding of design situations to clients and other stakeholders.

Conclusions

Many significant research CES systems exist that are both innovative and useful. However as the field matures, there will be an increasing need to make CESs production worthy and work within a creative industry environment such as a digital design firm. To support others in this effort for production-targeted transformation, in this paper we described the shift from an autonomous fitness function based creative system, DarwinsGaze, to an interactive fitness function based creative support system, Evolver, for real-world design collaboration. DarwinsGaze operates using a complex automatic fitness function to model contextual focus as well as other aspects of human creativity simulated internally. In shifting to the Evolver project we found that the contextual focus perspective remained relevant, but now re-situated to overlay the collaborative process between designer and system. Four design principles developed on this basis were: 1) support analytic focus by providing tools tailored to the designer's specific needs and aesthetic preferences, 2) support associative or intuitive focus by relieving the designer's cognitive capacity, enabling a quick and serendipitous workflow when desired, and offering a large variety of parameterized options to utilize, 3) support a triggering of focus-shift between the designer and the system through options to 'bookmark' and save interesting pieces for later, as well as to move creative material from and to the system while retaining the work's semantic structure and editability, and 4) support a joint 'train of thought' between system and user by structuring a genotype representation compatible with human visual/cognitive intuition.

We found that the shift to a real-world design scenario required attention to the collaboration and creative processes of the designers who value their experience-developed expertise. The system design had to act as both a support tool engaging some cognitive load of the process, and a flexible, interactive repository of potentially successful options. Future real-world design considerations can explore methods for adapting intelligent operations to the cognitive processes and constraints of necessary situations, taking into account the expertise of collaborators.

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References

Ashmore, L., and Miller, J. 2004. Evolutionary Art with Cartesian Genetic Programming. Technical Online Report. http://www.emoware.org/evolutionary_art.asp.

Bentley, P., and Corne, D. eds. 2002. Creative Evolutionary Systems, San Francisco, CA.: Morgan Kaufmann.

Boden, M. 2003. The Creative Mind. London: Abacus.

Brown, J. 2009. Looking at Darwin: portraits and the making of an icon. Isis. Sept, 100(3):542–70.

Dartnell, T. 1993. Artificial intelligence and creativity: An introduction. Artificial Intelligence and the Simulation of Intelligence Quarterly 85.

DiPaola, S. and Gabora, L. 2007. Incorporating characteristics of human creativity into an evolutionary art algorithm. In (D. Thierens, Ed.), Proc Genetic and Evol Computing Conf , 2442– 2449. July 7-11, Univ College London.

Feist, G.J, 1999. The influence of personality on artistic and scientific creativity, in Handbook of Creativity, R.J. Sternberg, Ed. (Cambridge University Press, Cambridge, UK)

Gabora, L. 2000. Toward a theory of creative inklings. In (R. Ascott, Ed.) Art, Technology, and Consciousness, Intellect Press, Bristol, UK.

Gabora, L. 2002. The beer can theory of creativity, in (P. Bentley and D. Corne, Eds.) Creative Evolutionary Systems, 147-161. San Francisco, CA.: Morgan Kaufmann.

Gabora, L.2002. Cognitive mechanisms underlying the creative process. In (T. Hewett and T. Kavanagh, Eds.) Proceedings of the Fourth International Conference on Creativity and Cognition, Oct 13-16, UK, 126-133.

Gabora, L. 2005.Creative thought as a non-Darwinian evolutionary process. Journal of Creative Behavior, 39(4), 6587.

Gabora, L. 2010. Revenge of the "neurds": Characterizing creative thought in terms of the structure and dynamics of memory. Creativity Research Journal, 22(1), 1-13.

Gabora, L., and DiPaola, S. 2012. How did humans become so creative? Proceedings of the International Conference on Computational Creativity, 203-210. May 31 - June 1, Dublin, Ireland.

Harik, G. R., Lobo, F. G., and Sastry, K. 2006. Linkage Learning via Probabilistic Modeling in the Extended Compact Genetic Algorithm (ECGA). In D. M. Pelikan, K. Sastry, & D. E. CantúPaz (Eds.), Scalable Optimization via Probabilistic Modeling, 39–61. Springer Berlin Heidelberg.

Jennings, K. E. 2010. Developing creativity: Artificial barriers in artificial intelligence. Minds and Machines, 1– 13.

Koza, J R., Keane, M A., and Streeter, M J. 2003. Evolving inventions. Scientific American. February. 288(2) 52 – 59.

Lawson, B. 2006. How designers think: the design process demystified (4th Edition). Oxford: Elsevier.

Luo, J., and Knoblich, G. 2007. Studying insight with neuroscientific methods. Methods, 42, 77-86.

Machado, P., Nunes, H., & Romero, J. 2010. Graph-Based Evolution of Visual Languages. In C. D. Chio, A. Brabazon, G. A. D. Caro, M. Ebner, M. Farooq, A. Fink, N. Urquhart (Eds.), Applications of Evolutionary Computation, 271–280. Springer Berlin Heidelberg.

Miller, J. 2011. Cartesian Genetic Programming, Springer.

Miller, J., and Thomson, P. 2000. Cartesian Genetic Programming. Proceedings of the 3rd European Conference on Genetic Programming, 121-132. Edinburgh, UK.

Neisser, U. 1963. The multiplicity of thought. British Journal of Psychology, 54, 1-14.

Padian, K. 2008. Darwin's enduring legacy. Nature, 451(7179), 632–634.

Piaget, J. 1926. The Language and Thought of the Child. Routledge and Kegan Paul, London.

Pease, A. and Colton, S. 2011. On Impact and Evaluation in Computational Creativity: A Discussion of the Turing Test and an Alternative Proposal. In Proceedings of the AISB symposium on AI and Philosophy .

Rips, L. J. 2001. Necessity and natural categories. Psychological Bulletin, 127(6), 827-852.

Ritchie, G. 2007. Some empirical criteria for attributing creativity to a computer program. Minds and Machines 17.

Shneiderman, B. 2007. Creativity support tools: accelerating discovery and innovation. Commun. ACM, 50(12), 20–32.

Schön, D. 1988. Designing: Rules, Types, and Worlds. Design Studies, 9/3 181-4.

Sloman, S. 1996. The empirical case for two systems of reasoning. Psychol. Bull. 9(1), 3–22.

Suwa, M., Gero, J. S., and Purcell, T. 1998. The roles of sketches in early conceptual design processes. In Proceedings of Twentieth Annual Meeting of the Cognitive Science Society, 1043-1048.

Walker, J. and Miller, J. 2005. Improving the Evolvability of Digital Multipliers Using Embedded Cartesian Genetic Programming and Product Reduction. Evolvable Systems: From Biology to Hardware, 6th International Conference, ICES 2005, Proceedings, Sitges, Spain. Springer.

Yu, T., and Miller, J. 2001. Neutrality and the Evolvability of Boolean function landscape. Proceedings of the Fourth European Conference on Genetic Programming, 204-217. Berlin Springer-Verlag.