Creative or Not? Birds and Ants Draw with Muscles

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Abstract. In this work, a novel approach of merging two swarm intelligence algorithms is considered – one mimicking the behaviour of ants foraging (Stochastic Diffusion Search [5]) and the other algorithm simulating the behaviour of birds flocking (Particle Swarm Optimisation [17]). This hybrid algorithm is assisted by a mechanism inspired from the behaviour of skeletal muscles activated by motor neurons. The operation of the swarm intelligence algorithms is first introduced via metaphor before the new hybrid algorithm is defined. Next, the novel behaviour of the hybrid algorithm is reflected through a cooperative attempt to make a drawing, followed by a discussion about creativity in general and the 'computational creativity' of the swarm.

1 Introduction

In recent years, studies of the behaviour of social insects (e.g. ants and bees) and social animals (e.g. birds and fish) have proposed several new metaheuristics for use in collective intelligence. This paper explores an artistic application of this collective intelligence, which emerges through the interaction of simple agents (representing the social insects/animals) in two nature-inspired algorithms, namely, Particle Swarm Optimisation (PSO) [17] and Stochastic Diffusion Search (SDS) [5]. Additionally, the mechanism of muscle activation is utilised to introduce the drawing with another layer of detail.

Natural examples of swarm intelligence that exhibit a form of social interaction are fish schooling, birds flocking, ant colonies in nesting and foraging, bacterial growth, animal herding, brood sorting etc.

The parable of the *blind men and the elephant* suggests how social interactions can lead to more intelligent behaviour. This famous tale, set in verse by John Godfrey Saxe [30] in the 19th century, characterises six blind men approaching an elephant. They end up having six different ideas about the elephant, as each person has experienced only one aspect of the elephant's body: wall (elephant's side), spear (tusk), snake (trunk), tree (knee), fan (ear) and rope (tail). The moral of the story is to show how people build their beliefs by drawing them from incomplete information, derived from incomplete knowledge about the world [18]. If the blind men had been communicating about what they were experiencing, they would have possibly come up with the conclusion that they were exploring the heterogeneous qualities that make up an elephant.

Following other works in the field of swarm painting (e.g. [22, 3, 33, 34] and ant colony paintings [14, 21]), this work, in addition to exhibiting the cooperation of birds and ants as a new way in making a drawing, benefits from the mechanism used in skeletal muscles.

In this paper, each of the swarm intelligence algorithms used are first explained (Sections 2 and 3), and an approach to their possible integration highlighted (Section 4). Subsequently the simplified mechanism of muscle activation is described (Section 5), followed by an explanation of how the new hybrid algorithm produces a drawing; a process initially inspired by an input sketch and the role that muscle activation mechanism plays (Section 6). In Section 7 the similar individualistic approach of the swarm and their importance in making a drawing is highlighted, followed by future research in the field.

Lastly, despite the novelty of this hybrid approach, it is not the intention of the authors to use the results outlined in the work to make either strong epistemological claims of computational creativity or strong aesthetic claims of style.

2 Birds: Particle Swarm Optimisation!

Particle Swarm Optimisation (PSO), first developed in 1995 by Kennedy and Eberhart [17, 12], is a population-based, optimization technique which came about as a result of an attempt to graphically simulate the choreography of fish schooling or birds flying (e.g. pigeons, starlings, and shorebirds) in coordinated flocks that show strong synchronisation in turning, initiation of flights and landing. Despite the fact that members of the swarm neither have knowledge about the global behaviour of the swarm nor a global information about the environment, the local interactions of the swarms triggers a complex collective behaviour, such as flocking, herding, schooling, exploration and foraging behaviour [27, 19, 4, 16].

A high-level description of PSO is presented in form of a social metaphor – Lost Child in Jungle [4] – demonstrating the procedures through which the communication exchange is facilitated between members of the swarm in its simplest possible form (for detailed, formal explanation and mathematical equations, see [17, 12]).

2.1 The Lost Child in Jungle

A group of villagers realise that a child is lost in a jungle nearby and set off to find the child. Each one of the villagers is given a mobile phone equipped with GPS that can be used to communicate with the head of the village. Each villager is also provided with a diary to record some data, as explained below:

> The villagers should log the location where they find the best information so far about the child in their diaries (Personal Best, *pbest* position) and inform the head of the village about it. Whenever they find something better that might lead to the location of the child (a location with a better fitness than their current *pbest*), they should provide the head of the village with the update.

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[4] Please note that this metaphor is presented here to give the reader an idea of how the algorithm works, without getting involved in detailed technical issues and mathematical equations.

The head of the village is responsible to contrast all the $pbest's$ he has received so far from all the villagers and pick the best one (Global Best, $gbest$ position). The resultant $gbest$ is communicated back to the villagers.

Each villager, on the other hand, should log the following three in his diary throughout the search:

- position
- speed (velocity) in walking
- $pbest$ position (which is also called $memory$)

Additionally, they should be able to access the $gbest$ position from the head of the village.

In the next step, when villagers decide about their next move from their current position, they need to consider their two bests ($pbest$ and $gbest$) and their current velocity.

Thus, while each villager does not neglect his personal findings, he has extra knowledge about its neighbourhood through $gbest$[5]; therefore, preserving a balance between exploration of the search space (e.g. jungle, in this case), and exploitation of potentially good areas around each villager's personal best.

In this example, villagers are analogous to particles in PSO, where optimisation is based on particles' individual experience ($pbest$) and their social interaction with the particle swarms (via $gbest$).

Algorithm 1 describes the metaphor chronologically.

At the convergence of the search process, villagers are most likely to congregate in the area of jungle where the child is most likely to be found; so hopefully, using this algorithm, the child is brought back to his family in the village.

Algorithm 1 The Lost Child in Jungle

```
Villagers spread in the jungle

While ( the child is not found )
    For all villagers
        Evaluate the fitness of the current location
            (how good the current location is
            to lead to the child)

        If (current location is better than pbest)
            pbest = current location
        If (pbest is better than gbest)
            gbest = pbest
        Villager decides about his next move
    End
End
```

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3 Ants: Stochastic Diffusion Search!

This section briefly introduces a multi-agent global search and optimisation algorithm called Stochastic Diffusion Search (SDS) [5], whose behaviour is based on simple interaction of agents.

SDS introduced a new probabilistic approach for solving best-fit pattern recognition and matching problems. SDS, as a multi-agent population-based global search and optimisation algorithm, is a distributed mode of computation utilising interaction between simple agents [11].

Unlike many nature inspired search algorithms, SDS has a strong mathematical framework, which describes the behaviour of the algorithm by investigating its resource allocation [24], convergence to global optimum [25], robustness and minimal convergence criteria [23] and linear time complexity [26]. A social metaphor, *the Mining*

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[5] The topology of the metaphor presented here is global neighbourhood.

Game [1], is used to describe the mechanism through which SDS allocates resources.

3.1 The Mining Game

This metaphor provides a simple high-level description of the behaviour of agents in SDS, where a mountain range is divided into hills and each hill is divided into regions:

A group of miners learn that there is gold to be found on the hills of a mountain range but have no information regarding its distribution. To maximize their collective wealth, the maximum number of miners should dig at the hill which has the richest seams of gold (this information is not available a-priori). In order to solve this problem, the miners decide to employ a simple Stochastic Diffusion Search.

- At the start of the mining process each miner is randomly allocated a hill to mine (his hill hypothesis, h).
- Every day each miner is allocated a randomly selected region, on the hill to mine.

At the end of each day, the probability that a miner is happy is proportional to the amount of gold he has found. Every evening, the miners congregate and each miner who is not happy selects another miner at random for communication. If the chosen miner is happy, he shares the location of his hill and thus both now maintain it as their hypothesis, h; if not, the unhappy miner selects a new hill hypothesis to mine at random.

As this process is structurally similar to SDS, miners will naturally self-organise to congregate over hill(s) of the mountain with high concentration of gold.

In the context of SDS, agents take the role of miners; active agents being 'happy miners', inactive agents being 'unhappy miners and the agent's hypothesis being the miner's 'hill-hypothesis'.

Algorithm 2 The Mining Game

```
Initialisation phase
Allocate each miner (agent) to a random
    hill (hypothesis) to pick a region randomly

While (all miners congregate over the highest
    concentration of gold)

    Test phase
        Each miner evaluates the amount of gold
            they have mined (hypotheses evaluation)
        Miners are classified into happy (active)
            and unhappy (inactive) groups

    Diffusion phase
        Unhappy miners consider a new hill by
            either communicating with another miner
            or, if the selected miner is also
            unhappy, there will be no information
            flow between the miners; instead the
            selecting miner must consider another
            hill (new hypothesis) at random
End
```
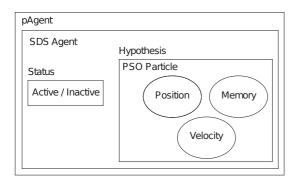
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4 Cooperation: Birds and Ants!

In ongoing research [2], an initial set of experiments aimed to investigate if the information diffusion mechanism deployed in SDS ("ants") on its own improves PSO ("birds") behaviour. Early results demonstrate the high potential of this integration.

In the hybrid algorithm, each PSO particle (villager in the Lost Child metaphor) has a current position, a memory (personal best position) and a velocity; each SDS agent (miner, in the Mining Game metaphor), on the other hand, has hypothesis (hill) and status (happy or unhappy).

In the experiment reported here, every PSO particle is an SDS agent too – together termed *pAgents*. In pAgent, SDS-style hypotheses are defined by the PSO particle positions, and an additional boolean variable (status) determines whether the pAgent is active or inactive (see Figure 1).

Figure 1. pAgent

The behaviour of the hybrid algorithm in its simplest form is presented in Algorithm 3.

Algorithm 3 Hybrid Algorithm

```
Initialise pAgents

While ( stopping condition is not met )
   For all pAgents
      Evaluate fitness value of each particle

      If ( evaluation counter MOD n == 0 )
         // START SDS
         // TEST PHASE
         for pAg = 1 to No−of−pAgents
            r_pAg = pick−random−pAgent()
            if ( pAg.pbestFitness() <=
                    r_pAg.pbestFitness() )
               pAg.setActivity (true)
            else
               pAg.setActivity (false)
            end if
         end for

         // DIFFUSION PHASE
         for ag = 1 to No_of_pAgents
            if ( pAg.activity() == false )
               r_pAg = pick−random−pAgent()
               if ( r_pAg.activity() == true )
                  pAg.setHypo( r_pAg.getHypo() )
               else
                  pAg.setHypo( randomHypo() )
               end if
            end if
         end for
      end if
      // END SDS

      If (current fitness is better than pbest)
         pbest = current fitness
      If (pbest is better than gbest)
         gbest = pbest
      Particle decides about its next move
   End
End
```

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5 The Simplified Mechanism of Muscle Activation

Motor neurons activate the skeletal muscle mainly through the neurotransmitter Acetylcholine (Ach) at the neuromuscular junction (NMJ). This junction is a synapse where the unmyelinated motor nerve terminals are separated from the postsynaptic membrane by a cleft that contains a basal lamina [28]. This cleft includes many proteins including acetylcholine esterase (AChE) which hydrolyse ACh. The postsynaptic membrane at the NMJ forms a series of deep folds. The acetylcholine receptors (AChRs) are found at the top one-third of these folds, whereas the voltage-gated sodium channels are anchored at the bottom of the folds [29, 15].

The nerve action potential from the motor neuron opens voltage-gated calcium channels that are located at the motor nerve terminal of the NMJ. The resulting influx of calcium leads to the release of acetylcholine (ACh) from the motor end of the junction into the synapse. Nearly 65% reaches the ACh receptors (AcHR) on the post-synaptic membrane. Binding of two ACh to each AChR leads to the opening of the AChR-associated ion channel, influx of cations (mainly sodium) and generation of an endplate potential (EPP) [31].

The EPP rapidly depolarises the postsynaptic membrane and, this depolarization should pass a certain threshold so that enough voltage-gated sodium channels are activated for the propagation of an action potential along the muscle fiber, once this happens the muscle contracts [10]. The extent to which the EPP exceeds that necessary threshold to initiate the action potential is usually called the safety factor for neuromuscular transmission [37]. The EPP is short-lived because the AChRs close spontaneously, ACh dissociates and escapes by diffusion or is hydrolysed by AChE.

In this paper, the effect of the activation of voltage-gated sodium channels on muscle contraction and the way motor neurons activate the skeletal muscle are used for an artistic purpose.

6 The Drawing Mechanism

In this section, first the drawing made with the hybrid swarm algorithm (PSO-SDS) is presented and then the influence of the muscle activation mechanism on the drawing is explored.

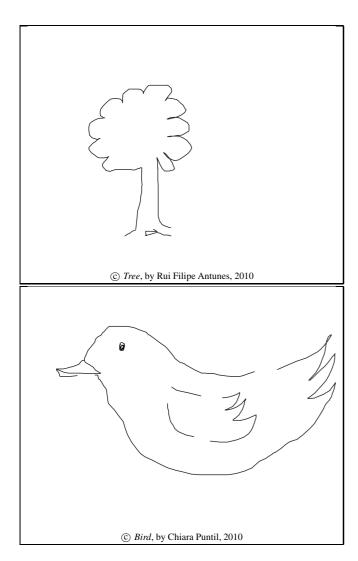### 6.1 Birds and Ants Set off to Draw

Once the swarm (birds and ants) are presented with a sketch (see Figure 2), they use it as inspiration and begin making a drawing based on the sketch, but utilising their own 'style'.
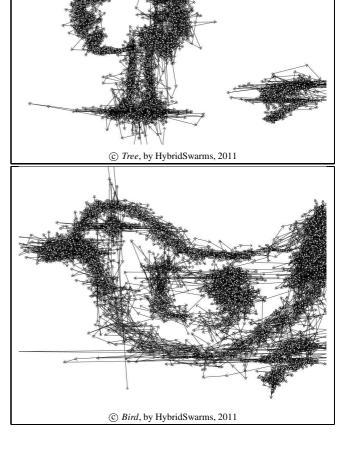
The goal of "birds" (PSO algorithm) is to trace the lines (series of points) in the sketch, and "ants" (SDS algorithm) help the birds in this process as explained in Section 4. The trace of the birds and the footprints of the ants stay on the canvas, creating a drawing inspired by the initial sketch, followed by a signature of the swarm at the corner of the canvas (see Figure 3).

6.2 How Muscle Contraction Shapes the Drawing

The simplified mechanism of muscle contraction is used in the drawing to reflect the relation between the time spent for drawing each part (e.g. each line) and the form (spikes' diameter) of the disks representing the contracted muscles, which are visible around each member of the swarm.

Here, in drawing, the concept of duration (for drawing a line), is reversely analogous to the idea of the activation of voltage-gated sodium channels in the mechanism of muscle contraction, which –

Figure 2. Sketches Provided to the Swarm

© *Tree*, by Rui Filipe Antunes, 2010

© *Bird*, by Chiara Puntil, 2010

Figure 3. The Drawings of the Hybrid Swarms

© *Tree*, by HybridSwarms, 2011
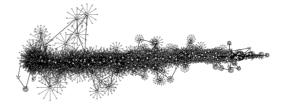

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for this artistic purpose – indicates, the shorter the time, the higher the activation voltage-gated sodium channels, which in turn leads to a bigger contraction (or shock) in each member of the swarm.

When a line is drawn faster than the other in a drawing, the spikes formed around each member of the swarm (while drawing that line), is bigger (more spread on the canvas), but when a line is drawn slower (i.e. the pressure is higher), it will have smaller, more intense (concentrated on the canvas) disk around the member of the swarm. See Figure 4.

Having the concept of contraction or 'shock' derived from muscle activation, Figure 5 shows the sketches drawn by the swarm, using birds, ants and the mechanism of muscle contraction.
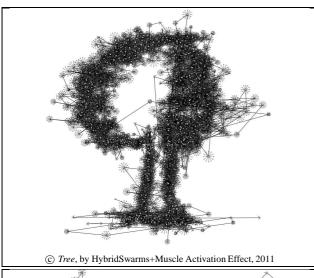
Although even if the hybrid swarm mechanism (of birds, ants and muscle) processes the same sketch several times it will not make two identical drawings; furthermore the outputs it produces are not merely randomised versions of the input. This can be demonstrated qualitatively by comparing the output of the hybrid swarm system with a simple randomised tracing algorithm (e.g. contrast Figures 6 with Figure 7). The reason why the hybrid swarm drawings are different from using random lines and spikes (shocked muscles) following the lines of a sketch, is that the underlying algorithms and mecha-
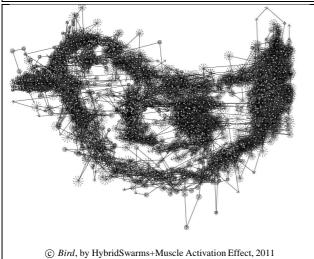
Figure 4. Muscle Contraction (shock) on Drawing

nism [used to coordinate the concentrations at any particular point on the canvas] employ proven swarm intelligence techniques; a method which is better (more 'loyal' to the original sketch) than a simple randomisation, but which still has enough 'freedom' to ensure originality in the resulting drawing (i.e. the swarm mechanisms ensure high-level fidelity to the input without making an exact low-level copy of the sketch). Thus, despite the fact that the swarm are constrained by the rules they follow (see Sections 2 and 3), the stochastic parts of the algorithms allow them to demonstrate a "regulated difference" rather than a simple "random difference".

Figure 5. The Drawings of the Hybrid Swarms with Muscle Activation

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6.3 Regulated difference versus random difference

The drawings in Figure 6 (top and middle) show two outputs from the simple randomised algorithm when configured with limited 'artistic' freedom (i.e. there is a only small Gaussian random distance and direction from the lines of the original sketch); comparing the two drawings we note a lack of any significant difference between them. Furthermore, when more 'artistic freedom' is granted to the randomised algorithm (by further increasing the variance in the underlying Gaussian, which allows the technique to explore a wider areas of the canvas), the algorithm begins to deviate excessively from the original sketch. I.e. Excessive randomisation results in a poor - low fidelity - interpretation of the original sketch (Figure 6-bottom). In contrast although the agents in the hybrid 'bird, ant and muscle swarm' are free to access any part of the canvas they naturally maintain recognisable fidelity to the original input. Thus it can be seen that simply extending a basic swarm mechanism by giving it simply more randomised behaviour (giving it more 'artistic freedom') fails to demonstrate that more creative drawings would be produced.

Thus the 'controlled freedom' (or the *'tincture of madness'*) exhibited by the hybrid swarm algorithm (induced by the stochastic side

of the algorithms) is crucial to the resultant work[6] and is the reason why having the same sketch does not result in the system producing identical drawings[7].

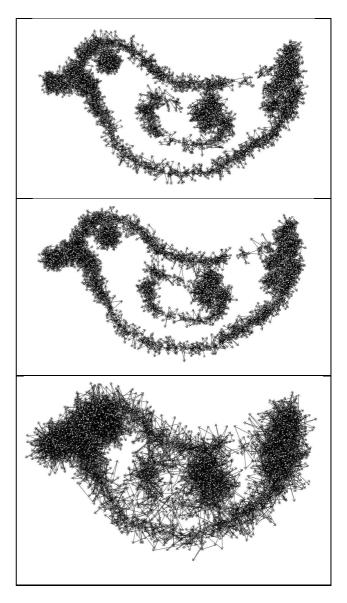**Figure 6.** The Drawings of the Swarms with Random Behaviour

Figure 7 shows a few drawings made by the hybrid swarm system, inspired by a single input sketch. Interestingly, and irrespective of whether the hybrid swarm is 'genuinely creative' or not, its individ-
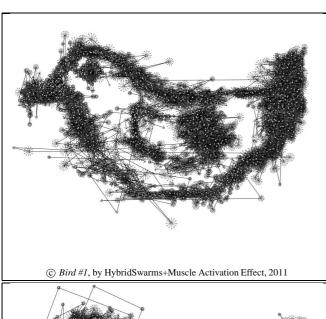
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[6] This freedom emerges, among other things, from the the stochasticity of SDS algorithm in picking agents for communication, as well as choosing agents to diffuse information (see Algorithm 2); and the tincture of madness in PSO algorithm is induced via its strategy of spreading villagers in the jungle as well as the stochastic elements in deciding the next move of each villager (see Algorithm 1).
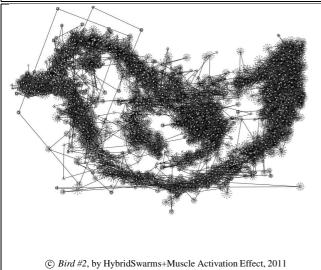
[7] Although the algorithms (PSO and SDS) and the mechanism (skeletal muscle activation) are biologically inspired we do not claim that the presented work is an accurate model of natural systems. Furthermore in designing the algorithm there was no explicit 'Hundertwasser-like' attempt - by which we mean stress on using curves instead of straight lines, as Hundertwasser considered straight lines not nature-like and 'godless' and tried not to use straight lines in his works - to bias the style of the system's drawings.

ualistic style is not totally dissimilar to those of the 'elephant artists' [36]):

"After I have handed the loaded paintbrush to [the elephants], they proceed to paint in their own distinctive style, with delicate strokes or broad ones, gently dabbing the bristles on the paper or with a sweeping flourish, vertical lines or arcs and loops, ponderously or rapidly and so on. No two artists have the same style."

Figure 7. Different Drawings of the Hybrid Swarms off a Single Sketch

© *Bird #1*, by HybridSwarms+Muscle Activation Effect, 2011

© *Bird #2*, by HybridSwarms+Muscle Activation Effect, 2011

7 Discussion on Creativity

In this section, the aim is to discuss whether the hybrid swarm algorithms can in some sense be 'computationally creative' in what they draw. In our discussion we emphasise the importance of: 'controlled freedom' (cf. unregulated randomness) and the combinatorial creativity of the hybrid swarm system and contrast it with examples of potential non-human assessment of aesthetic judgment and suggestions of creativity in natural distributed systems. In order to deflect the charge that computational systems cannot be sensitive to

emotion we subsequently briefly discuss recent work from Simon Colton. Finally, we complete the section with a demonstration of the provenance of the use of [real-world] swarm-systems in successful exhibited artworks (e.g. by Julie Freeman). Our modest conclusion is that 'controlled freedom' (pace unconstrained randomness) - as for example exhibited in the hybrid bird, ant and muscle algorithm presented herein - can be useful in generating interesting and intelligible drawing outputs.

7.1 On Freedom and Art

For years, it has been argued that there is a relationship between art, creativity and freedom, among which is the famous German prose, by Ludwig Hevesi at the entrance of the Secession Building in Vienna:

"Der Zeit ihre Kunst

Der Kunst ihre Freiheit[8]"

Or a quote by Aristotle (384-322 BCE) [13], which emphasises on the link between creativity and freedom (here, having "a tincture of madness"):

"There was never a genius without a tincture of madness."

Boden, in [7], also argues that creativity has an ambiguous relationship with freedom. Among several definitions that have been given to creativity, around sixty of which (as stated by Taylor [32]) belong to combinational creativity, which is defined as *"the generation of unfamiliar combinations of familiar ideas"* [6]; a category that the presented work fits in. Considering the existence of many influencing factors in evaluating what is creative, raises questions about how humans evaluate artistic creativity. Galanter in [20] suggests that perhaps computational equivalent of a bird or an insect (e.g. in evaluating mate selection) is "all" that is required for computational aesthetic evaluation and furthermore states:

".. this provides some hope for those who would follow a psychological path to computational aesthetic evaluation, because creatures with simpler brains than man practice mate selection."

In this context Dorin and Korb [20] suggest that the tastes of the individual in male bowerbirds is visible when they gather collections of bones, glass, pebbles, shells, fruit, plastic and metal scraps from their environment, and arrange them to attract females [8]:

"They perform a mating dance within a specially prepared display court. The characteristics of an individual's dance or artefact display are specific to the species, but also to the capabilities and, apparently, the tastes of the individual."

However the underlying question - of whether 'mate selection behaviour in animals entails making a judgement analogous to aesthetic judgements in humans' - is perhaps (pace Nagel's famous discussion in Philosophical review (1974) of 'What it is like to be a bat?'), a question whose answer can never be known.

In contrast the role of education (or training) in recognising 'good' and 'bad', 'creative' and 'non-creative' has been more experimentally probed. A suggestive study investigating this topic by Watanabe [35], gathers a set of children's paintings which adult humans are asked to label 'good' or 'bad'. Pigeons are subsequently trained

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[8] To time its art, to art its freedom.

through operant conditioning to only peck at good paintings. After the training, when pigeons are exposed to a novel set of [judged] children's paintings, they show their ability in the correct classification of the paintings; emphasising the role of training in aesthetic judgement and opening the door to computational (machine learning) explorations in this area[9].

A further area relating swarm intelligence and creativity is that of social, distributed and extended systems. For example Bown in [20] argues that our creative capabilities are contingent on the objects and infrastructure available to us, which help us achieve individual goals, in two ways:

"One way to look at this is, as Clark does [9], in terms of the mind being extended to a distributed system with an embodied brain at the centre, and surrounded by various other tools, from digits to digital computers. Another way is to step away from the centrality of human brains altogether and consider social complexes as distributed systems involving more or less cognitive elements."

7.2 On the Emotional Sensitivity of Computer Artists

Can a computer program be sensitive to real emotion is directing its artistic output? Certainly Simon Colton's work at Imperial College suggests this may be so. Simon describes his 'Painting Fool' as follows, "Firstly, we used software developed by Maja Pantic, Michel Valstar and other members of the vision group at Imperial to take a video sequence of someone expressing an emotion (such as smiling, frowning, looking surprised, etc.). The software then: detected the emotion; determined where the features of the face were; and found the image in the video sequence where the emotion was being expressed the most. This information was then passed to the second piece of software in the combination, namely The Painting Fool, which proceeded to paint a portrait of the person in the video sequence. It based the portrait on the image provided from the emotional modeling software, and chose its art materials, colour palette and abstraction level according to the emotion being expressed. For instance, if it was told that the person was expressing happiness, it chose vibrant colours, and painted in simulated acrylic paints in a slapdash way. If, on the other hand, it was told that the person was sad, it chose to paint with pastels in muted colours." Such behaviour clearly suggests at least some sensitivity to [human] emotion is possible in computational systems.

7.3 Fish: Real-World Swarm Art!

An example of the use of real-word swarms in computer art come from the artist, Julie Freeman[10]. In 2005 Julie completed a site installation 'Swarm Intelligence' art work at Tingrith Fisheries (a 4000 square meter lake bordering the Woburn Abbey Estate). For the artwork - The Lake - Julie implanted 16 fish (four each of four species) with electronic transducers that could be tracked in real time 24/7 by 6 audio transponders and their real-time movements used to develop electronic soundscape and concomitant computer generated images; different behaviours were initiated by fish schooling (swarming) and by individual forays through the lake. This work is very successful and has been extensively installed and exhibited internationally[11]. The success of this work by Freeman clearly demonstrates that there is at least one niche for the [real-world] swarm aesthetic in art.

8 Conclusion

In this paper, we make no strong claim about the 'computational creativity' of the work presented, neither do we try to tackle the infamous question on whether computers can be creative at all or generate creative art. This specific work described herein merely emphasises the importance of 'controlled freedom' in the production of 'drawings' by computer. The computational artist so described is the outcome of a novel marriage between two classical swarm intelligence algorithms (PSO and SDS)[12] and a simplified mechanism of muscle activation. In an ongoing research, the application of the new hybrid algorithm to make a 'swarmic' drawing 'as though through a human's gaze' is currently being investigated.

REFERENCES

[1] Mohammad Majid al-Rifaie and Mark Bishop, 'The mining game: a brief introduction to the stochastic diffusion search metaheuristic', *AISB Quarterly*, (2010).

[2] Mohammad Majid al-Rifaie, Mark Bishop, and Tim Blackwell, 'An investigation into the merger of stochastic diffusion search and particle swarm optimisation', *Genetic and Evolutionary Computation Conference (GECCO-2011)*, (July 2011).

[3] S. Aupetit, V. Bordeau, N. Monmarche, M. Slimane, and G. Venturini, 'Interactive evolution of ant paintings', in *Evolutionary Computation, 2003. CEC'03. The 2003 Congress on*, volume 2, pp. 1376–1383, (2004).

[4] O. Burchan Bayazit, Jyh-Ming Lien, and Nancy M. Amato, 'Roadmap-based flocking for complex environments', in *PG '02: Proceedings of the 10th Pacific Conference on Computer Graphics and Applications*, p. 104, Washington, DC, USA, (2002). IEEE Computer Society.

[5] J.M. Bishop, 'Stochastic searching networks', pp. 329–331, London, UK, (1989). Proc. 1st IEE Conf. on Artificial Neural Networks.

[6] M.A. Boden, 'Creativity in a nutshell', *Think*, 5(15), 83–96, (2007).

[7] M.A. Boden, *Creativity and Art: Three Roads to Surprise*, Oxford University Press, 2010.

[8] Gerald Borgia, 'Complex male display and female choice in the spotted bowerbird: specialized functions for different bower decorations', *Animal Behaviour*, 49, 1291–1301, (1995).

[9] A. Clark, *Natural-born cyborgs: Minds, technologies, and the future of human intelligence*, Oxford University Press, 2003.

[10] S. Cohen-Cory, 'The developing synapse: Construction and', *Science*, 1075510(770), 298, (2002).

[11] K. de Meyer, J. M. Bishop, and S. J. Nasuto, 'Stochastic diffusion: Using recruitment for search', *Evolvability and interaction: evolutionary substrates of communication, signalling, and perception in the dynamics of social complexity (ed. P. McOwan, K. Dautenhahn & CL Nehaniv) Technical Report*, 393, 60–65, (2003).

[12] R.C. Eberhart and J. Kennedy, 'A new optimizer using particle swarm theory', in *Proceedings of the sixth international symposium on micro machine and human science*, volume 43. New York, NY, USA: IEEE, (1995).

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[9] This also raises the question of the degree to which humans are trained (or 'biased') to distinguish good and/or creative work.

[10] Artist in Residence at the Microsystems & Nanotechnology Centre, Cranfield University and Associate Artist, Goldsmiths Digital Studios

[11] The work has also been shown in the Truman Brewery, London, UK; FILE, Sao Paulo, Brazil; FILE, Rio, Brazil; Arts Bioethics Network, Rijeka, Croatia; The National Centre for Contemporary Arts, Kaliningrad, Russia and in lastly in 2009 at MediaArtLab Center for Art and Culture, Moscow, Russia

[12] The scientific value of the new hybrid algorithm is currently being investigated via standard optimisation benchmarks [2].

[13] A. Etzioni, A. Ben-Barak, S. Peron, and A. Durandy, 'Ataxia-telangiectasia in twins presenting as autosomal recessive hyper-immunoglobulin m syndrome', *IMAJ-RAMAT GAN-*, 9(5), 406, (2007).

[14] G. Greenfield, 'Evolutionary methods for ant colony paintings', *APPLICATIONS OF EVOLUTIONARY COMPUTING, PROCEEDINGS*, 3449, 478–487, (2005).

[15] M. D Henry and K. P Campbell, 'Dystroglycan: an extracellular matrix receptor linked to the cytoskeleton', *Current opinion in cell biology*, 8(5), 625631, (1996).

[16] Charles H. Janson, 'Experimental evidence for spatial memory in foraging wild capuchin monkeys,cebus apella', *Animal Behaviour*, 55, 1229–1243, (1998).

[17] J. Kennedy and R. C. Eberhart, 'Particle swarm optimization', in *Proceedings of the IEEE International Conference on Neural Networks*, volume IV, pp. 1942–1948, Piscataway, NJ, (1995). IEEE Service Center.

[18] James F. Kennedy, Russell C. Eberhart, and Yuhui Shi, *Swarm intelligence*, Morgan Kaufmann Publishers, San Francisco ; London, 2001.

[19] M.J. Mataric, *Interaction and Intelligent Behavior*, Ph.D. dissertation, Department of Electrical, Electronics and Computer Engineering, MIT, USA, 1994.

[20] Jon McCormack and Mark d'Inverno (eds), *Computers and Creativity*, Springer, Berlin, 2011.

[21] N. Monmarch, S. Aupetit, V. Bordeau, M. Slimane, and G Venturini, 'Interactive evolution of ant paintings', in *2003 Congress on Evolutionary Computation*, ed., B. McKay et al, volume 2, pp. 1376–1383. IEEE Press, (2003).

[22] L. Moura and V. Ramos, 'Swarm paintings–nonhuman art', *ARCHITOPIA book, art, architecture and science*, 5–24, (2007).

[23] D. R. Myatt, J. M. Bishop, and S. J. Nasuto, 'Minimum stable convergence criteria for stochastic diffusion search', *Electronics Letters*, 40(2), 112–113, (2004).

[24] S. J. Nasuto, *Resource Allocation Analysis of the Stochastic Diffusion Search*, Ph.D. dissertation, PhD Thesis, University of Reading, Reading, UK, 1999.

[25] S. J. Nasuto and J. M. Bishop, 'Convergence analysis of stochastic diffusion search', *Parallel Algorithms and Applications*, 14(2), (1999).

[26] S. J. Nasuto, J. M. Bishop, and S. Lauria, 'Time complexity of stochastic diffusion search', *Neural Computation*, NC98, (1998).

[27] Craig W. Reynolds, 'Flocks, herds, and schools: A distributed behavioral model', *Computer Graphics*, 21(4), 25–34, (1987).

[28] S. Rigoard, M. Wager, K. Buffenoir, S. Bauche, J. P. Giot, J. M. Maixent, and P. Rigoard, 'Major mechanisms involved in the synaptic transmission of the neuromuscular apparatus', *Neuro-Chirurgie*, 55, S22, (2009).

[29] J. R Sanes and J. W Lichtman, 'Induction, assembly, maturation and maintenance of a postsynaptic apparatus', *Nature Reviews Neuroscience*, 2(11), 791–805, (2001).

[30] John Godfrey. Saxe, D.A. Lathen, and B. Chief, 'The Blind Man and the Elephant', *The Poems of John Godfrey Saxe*, (1882).

[31] T. C S\dhof, 'The synaptic vesicle cycle', *Neuroscience*, 27(1), 509, (2004).

[32] C.W. Taylor, '4 Various approaches to and definitions of creativity', *The nature of creativity: Contemporary psychological perspectives*, 99, (1988).

[33] P. Urbano, 'Playing in the pheromone playground: Experiences in swarm painting', *Applications on Evolutionary Computing*, 527–532, (2005).

[34] P. Urbano, 'Consensual paintings', *Applications of Evolutionary Computing*, 622–632, (2006).

[35] Shigeru Watanabe, 'Pigeons can discriminate good and bad paintings by children', *Animal Cognition*, 13(1), (2009).

[36] Aum-Mon Weesatchanam, *Are Paintings by Elephants Really Art?*, The Elephant Art Gallery, 31 July 2006.

[37] S. J Wood et al., 'Safety factor at the neuromuscular junction', *Progress in neurobiology*, 64(4), 393–429, (2001).