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Tangible Interfaces for Interactive Evolutionary Computation

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Abstract

Interactive evolutionary computation (IEC) is a powerful human-machine optimisation procedure for evolving solutions to complex design problems. In this paper we introduce the novel concept of Tangible Interactive Evolutionary Computation (TIEC), leveraging the benefits of tangible user interfaces to enhance the IEC process and experience to alleviate user fatigue. An example TIEC system is presented and used to evolve biomorph images, with a recreation of the canonical IEC application: The Blind Watchmaker program. An expanded version of the system is also used to design visual states for an atomic visualisation platform called danceroom Spectroscopy, that allows participants to explore quantum phenomena through movement and dance. Initial findings from an informal observational test are presented along with the results from a pilot study to evaluate the potential for TIEC.

Author Keywords

Tangible User Interface; Interactive Evolutionary Computation; Aesthetic Evolution

ACM Classification Keywords

H.1.2 [Models and Principles]: User/Machine Systems—Human factors; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Input devices and strategies (e.g., mouse, touchscreen), Prototyping

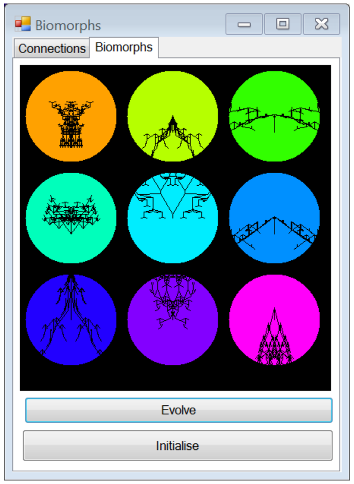


Figure 1: The Blind Watchmaker program for evolving Biomorphs.

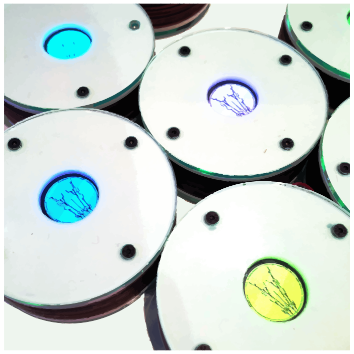


Figure 2: PETRI tangibles for guiding evolutionary algorithms.

Introduction

Interactive Evolutionary Computation (IEC) is a long established and powerful method for generating solutions to complex design problems. By elegantly marrying computational optimisation with instinctive human enquiry, IEC has been successfully applied across multiple disciplines to produce higher-quality solutions more rapidly than when humans and machines work independently [20, 5, 23]. However, IEC places a considerable burden on users who can quickly become fatigued. Several efforts have been made to address these problems [18, 12, 11] but, to our knowledge, there have been relatively few attempts to explore alternative interfaces to IEC for enhancing the user-experience. In particular, we propose that the use of Tangible User Interfaces (TUIs), provides a number of benefits over the standard practice of using Graphical User Interfaces (GUIs):

1. By engaging multiple sensory modalities the TUI offers a low barrier to entry and promotes prolonged interaction with reduced fatigue.
2. The use of tangibles enables a wide range of spatial organisational benefits, allowing complex modes of operation to be achieved in an improvisatory manner.
3. The distributed nature of the TUI increases the potential for co-located and collaborative interaction.

Interactive Evolutionary Computation (IEC)

IEC is an Evolutionary Computation-based design method that operates under the supervision of a human user [6]. It offers a generalised optimisation procedure that is appropriate for scenarios where a formalised objective may not be specified and design candidates must be assessed by a human evaluator. The process has gained substantial uptake in applications emphasising aesthetics, which generally require a human to guide the process towards subjectively pleasing regions of the object space [2]. Consequently, IEC has gained notoriety within arts and design disciplines; however, it has also been used to solve engineering and science problems [21].

A widely acknowledged drawback of IEC is the length of time that operators are required to invest in the evaluation of candidate solutions. This bottleneck of user intervention necessarily places constraints on the number of individuals that a user can reasonably be expected to evaluate before experiencing fatigue [8, 19]. Several solutions to this problem have been suggested, including novel methods for collaborative interaction [23, 13] to leverage the efforts of multiple users. Another approach is to train a surrogate model with users' subjective responses to enable partial automation of the evaluation process [11, 10]. However, along with Breukelaar et al [1], we consider the IEC user interface to be an important factor that enables the selection and optimisation of high-quality solutions.

IEC GUIs typically present the population in a grid-based format. In this arrangement each individual is represented by a button that enables the auditioning, evaluation and selection of parents. If it is possible to express individuals pictorially on the button (see Figure 1), users may observe the entire population simultaneously. However, in applications where solutions represent time-based media (music or film), individuals must be auditioned sequentially. In this situation, users are required to memorise the grid location of favorable individuals, placing additional cognitive load on the user and thereby exacerbating the fatigue problem [21].

Tangible User Interfaces

TUIs are designed to give physical form to digital information, allowing virtual data to be represented physically and controlled through direct tangible manipulation [9]. Advantages of TUIs relevant in the development of TIECs include:

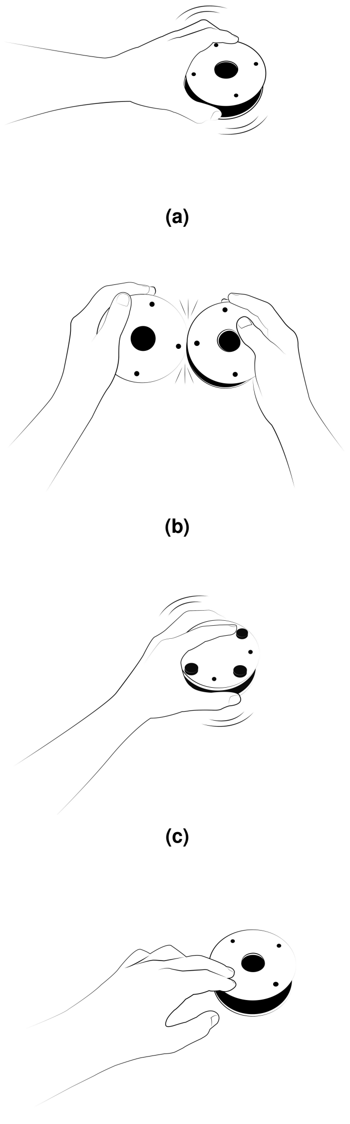


Figure 3: PETRI tangible puck interactions.

the ability to use previously learned bodily skills to interact; rich sensory feedback from manipulating physical objects; naturally multi-point interaction allowing multi-user operation; persistence, as the tangible objects remain in position and visible after interaction; and use of physical affordances to allow for extended use beyond the programmed applications.

In contrast to GUIs, which tend to offer a single interface through which all interaction is mediated, TUI's power comes from having a form specific to a particular task, allowing dedicated affordances analogous to real-world interactions. Hence, in developing a TIEC interface, consideration of context and application is necessary and it is unlikely that a single-form interface could be developed. However, interfaces such as Siftables [16], which offer a compromise between application specificity and generalisation, point towards a way of designing a 'universal TIEC' applicable to any problem.

PETRI - An Example TIEC

With the aim of exploring the potential of a tangible interface to IEC, we present an example system called PETRI, which draws inspiration from the biological origins of evolutionary computation. Each tangible is modelled on the form factor of a Petri dish (Figure 2), providing an easily recognisable and cross-cultural metaphor to help constrain affordances available to the user.

The PETRI Tangible Devices

Nine PETRI tangibles were made, each comprising a cylindrical enclosure ($\varnothing$ 100 mm h 36 mm) containing the necessary electronics to detect user manipulations and provide feedback. This includes, an inertial measurement unit for sensing motion, an OLED screen (27 mm $\times$ 27 mm) for visual feedback, and a vibration motor for haptic feedback. These components each connected internally to an x-OSC [14] interface device to provide wireless access to a host computer running the gesture analysis and IEC algorithms. Combined, these capabilities enable a network of PETRI tangibles to behave collectively as a single interface to the evolutionary process.

PETRI Interactions

As the PETRI system directly represents a population of individuals, users are able to identify favourable solutions as a physical object and invoke the evolutionary operators through their direct manipulation. The Petri dish metaphor combined with the sensing capabilities of the hardware led to an initial set of user manipulations or gestures which are ascribed to invoke evolutionary operators as described below and shown in Figure 3.

Shaking → Mutating To mutate an individual, users may shake the associated PETRI tangible (Figure 3a).

Colliding → Recombining Users may select two or more individuals for recombination by colliding their associated tangibles (Figure 3b). The individuals selected for recombination then produce offspring representing unique combinations of their parents genes.

Emptying → Resetting The disposal and reinitialisation of an unwanted individual may be achieved by turning the associated tangible upside down and shaking, mimicking an emptying gesture (Figure 3c).

Other Motions → Auditioning in circumstances where individuals must be auditioned sequentially, any other motion detected by a tangible would result in the associated individual being loaded for evaluation. In practice, this accommodated a range of observed manipulations including, grasping, tapping and nudging (Figure 3d).

Figure 4: danceroom Spectroscopy © Interactive Scientific.

To acknowledge and confirm the above manipulations, haptic feedback is triggered for each tangible whenever mutation, recombination or replacement are invoked.

Applications

Two application examples were developed to enable comparison between graphical and tangible interfaces to IEC. First, PETRI was connected to control a recreation of Dawkins' Blind Watchmaker program: the canonical IEC example for evolving creature like images called *biomorphs* [4]. Second, the interface was adapted to control a system called danceroom Spectroscopy, an immersive and interactive atomic simulation allowing participants to explore quantum phenomena through movement and dance [17, 7].

Biomorphs

A biomorph is a simple computer generated image comprising an arrangement of intersecting vertices which are encoded as a simple set of branching rules. When a conventional GUI is employed, the human operator is presented with a grid of nine random biomorph images, each representing expressions of their respective genes (or *phenotypes*). Based upon subjective evaluation, one or more of the nine images are chosen from which progeny are created to produce the subsequent generation of biomorphs. Repetition of this process enables the user to converge the biomorph form on images reminiscent of trees, insects and other organisms. With the tangible interface, each individual is represented by a single PETRI puck and its respective biomorph image is displayed on its screen, see Figure 2.

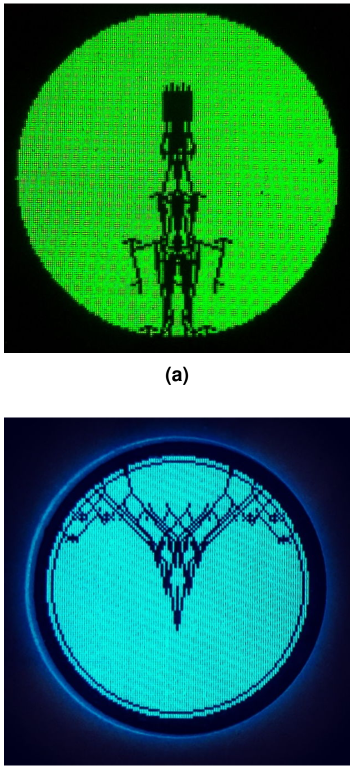
Discussion The system was initially trialed in an informal, open testing session in which six participants with no prior experience of the Blind Watchmaker program were observed evolving biomorphs using both the GUI (Figure 1) and TUI (Figure 2). After a brief explanation and demonstration, participants took turns to use both interfaces and salient observations were noted. In general, participants were more attracted to the TUI, almost always choosing to use this interface first. TUI sessions lasted longer and engaged the entire group more than the GUI sessions, with participants often showing tangibles to others within the group. However, generations proceeded more rapidly in the GUI session, presumably because individuals could be observed more easily and operators were quicker to invoke by mouse click.

Danceroom Spectroscopy

Having tested a basic version of the system to evolve biomorphs, we reconfigured the PETRI system to evolve a more sophisticated real-world design application. Specifically, the aesthetics and dynamics of an interactive atomic simulation engine called danceroom Spectroscopy (dS) [7], a large-scale sci-art framework enabling participants to interact with a simulated and immersive nanoworld, see Figure 4.

The settings of the atomic simulation are normally controlled by manually configuring hundreds of parameters that require users to possess expert knowledge of physics, graphics and interactive technology. However, the project has recently made use of IEC with a conventional grid-based GUI to enable the rapid design and configuration of parameters by non-experts [3]. This IEC system was modified such that the PETRI TUI could be used in place of the existing GUI.

As is it not possible to render the atomic simulation on the OLED screens of each tangible, the dS supercomputer runs alongside the PETRI system, displaying the visual *state* of each individual when its associated tangible is moved (Figure 3d) and thus selected for auditioning. The screen on the tangible glows red when its state is being expressed



(a)

(b)

Figure 5: Biomorphs produced by participant 8 by (a) GUI and (b) TUI.

by the dS simulation so that the currently loaded tangible may be identified. When new offspring are created, their associated tangibles are set to glow green indicating that they have not yet been evaluated by the user.

Discussion The dS application was explored within the same open testing session as the biomorphs described earlier. Users were invited to again design a visualisation state with the PETRI interface and the existing GUI. In this application, users tended to work much more collaboratively than the previous application, working towards a visualisation state representing the consensus of the group rather than any one individual. Consequently, participants frequently swapped over, picking up from where other participants left off with some users interacting with the simulation while others interacted with the IEC interface. It was also observed that users repeatedly struggled to locate their prefered individuals when operating the GUI, looking to the group to verify where favorable individuals were located. However, this was less of a problem with the TUI as participants tended to locate preferred individuals in an ad hoc mating area on the work surface.

Pilot Study

An initial pilot study was performed to begin evaluating the efficacy of the tangible IEC interface when compared with the standard graphical interface. Nine participants with no prior experience of the system were set the task of evolving a biomorph creature design with both interfaces. The participants were individually sat at a desk on which a laptop showing the grid interface of a standard biomorph GUI was positioned, next to a 3×3 arrangement of the PETRI tangible interface.

Each user was asked to evolve a biomorph creature for both interface types with no time constraints, stopping voluntarily when satisfied with one of the designs. The first interface encountered was alternated for each participant in an attempt to control any effects that ordering might have on the results. Participants were provided with brief instructions on how to use each interface and at the end they were asked to comment on their experience with each interface and to answer a series of questions. The quantitative results are summarised in Table 1.

Participant no.	Time (s) (GUI/TUI)	Generations (GUI/TUI)	Preferred Creature	Preferred Interface
1	128/336	11/16	TUI	TUI
2	105/208	4/14	TUI	TUI
3	246/252	9/10	TUI	TUI
4	219/94	7/4	TUI	TUI
5	196/499	30/36	GUI	GUI
6	738/152	147/31	GUI	GUI
7	258/572	20/16	GUI	TUI
8	386/387	31/14	GUI	TUI
9	726/1346	80/23	TUI	TUI

Table 1: Results of the biomorph IEC GUI/TUI comparative pilot study

Discussion Figure 5 shows the biomorphs created by participant 8 during the study, with Figure 5a created using the GUI and 5b, the TUI. Seven out of ten participants were recorded to have engaged with the TUI for a longer period of time than with the GUI and the same proportion of participants stated that this was their preferred interface, suggesting that the TUI was the more engaging interface of the two. This result was also confirmed by the qualitative feedback gathered during the study, with all participants describing the interface as either ‘fun’ or ‘exciting’, even those that preferred the GUI overall. However, for all but one participant, the average amount of time spent evaluating the individuals at each generation was longer for the TUI than the GUI. One participant made the observation that “with the TUI you actually have to look, whereas with the GUI you just stare", referring to the greater effort required to evaluate biomorphs located on separate objects as opposed to a single screen. The participants raised a number of advantages relating to the ability to grasp and move the individuals of the TUI around. One notable observation was that the TUI enabled individuals to be taken aside and observed in isolation from the rest of the population; highlighting that individuals can only be observed amongst a neighbourhood of siblings with the grid-based GUI. One participant posited that the TUI encouraged 'better educated' choices and that their evaluation was consequently more rigorous. Participants also noted that the TUI more readily invited the recombination of individuals, although on average fewer parents were recombined at each generation with the TUI. Recombination with the TUI was stated to be easier to invoke with a single collision of objects rather than the multiple clicks of the GUI. A final observation made with the TUI was that the circular form factor meant that each individual could be evaluated from multiple orientations whereas the orientation of the individuals on the GUI was fixed.

Conclusion

In this paper we have presented a tangible interface for interactive evolutionary computation (TIEC) called PETRI that encourages engaged control of interactive evolutionary computation (IEC). We presented an informal observation study when the interface is used to evolve biomorphs with the Blind Watchmaker program and atomic aesthetics with danceroom Spectroscopy, comparing both applications with conventional grid-based GUIs. It was observed that the introduction of a tangible interface increased user engagement and also revealed a number of benefits including the ability to spatially organise individuals to form ad hoc mating pools. An initial pilot study was also presented to begin evaluating tangible interfaces for this application. These preliminary results indicated a universally positive reaction and engagement times were increased. However, due to the distributed nature of the TUI, evolutionary progress appeared to take longer. The pilot study presented so far was focussed only on the design of biomorphs. In future we intend to evaluate the danceroom Spectroscopy and other applications more rigorously. The TUI offers exciting potential for co-located and collaborative interaction, which will be easy to explore by simply modifying the replacement strategy of the IEC. Users would then be able to model more complex evolutionary processes by partitioning the tangibles into groups, evolving subpopulations independently (*speciation* [15]) and then reuniting members of these subpopulations at a later stage (*migration* [22]). Further information may also be derived directly from the manipulation of the tangibles. For example mutation severity may be derived from the magnitude of the shake gesture, providing users with fine-grained control over the degree to which offspring diverge from their parents.

We plan in future to conduct a number of experiments that will form the foundation of a new hands-on manner of evolutionary control, which to the authors knowledge is an entirely unexplored area ripe for study.

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