Towards Crowd-Controlled Evolutionary Design and Lamarckian Evolution of Shapes

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Abstract

In this paper we illuminate the role of the user in evolutionary design (ED), arguing for a user-driven and user-controlled approach to ED, including gaze-based, tag-based and crowd-controlled ED. We also demonstrate how reversible gene expression allows for Lamarckian evolution of shapes, increasing the potential for user-control. This is exemplified by a model that uses medial axis transform, skeletonization and chain-coding to provide for a reversible encoding of 2D raster graphics.

Keywords: *Interactive Evolutionary Design, Lamarckian Evolution, Morphology, Embryogeny, Reversible Gene Expression, Digital Shape Representation, Collaborative Design, Tagging*

1. Introduction

Current Systems for Morphological Design fall into two categories: source-based systems where the morphology is specified by a programming language [3,13] and target-based systems where the specification can be automatically generated according to a predefined target morphology, usually via evolutionary optimization [6]. But it is also possible to create Systems that combine both approaches, using a reversible mapping between source and target [9].

As we have pointed out, this is a great step for Evolutionary Design (ED), since it means that any object can be scanned in to be further optimized by artificial evolution [18]. It further implies that the designer can chose whether to operate on the target or the source, and opens up the possibility for Lamarckian evolution, where modifications to the target morphology are inherited by the source-DNA, which can be further evolved inside an interactive ED framework.

2. The User in Interactive Evolutionary Design

Interactive Evolutionary Design (iED) is Evolutionary Design [1] performed by humans, using Evolutionary Computation (EC) as a tool. (The term “interactive” is kept for historical reasons – in contrary to computation, design is a process which is interactive by definition).

Early research in interactive Evolutionary Computation (iEC) [21] regarded the human user as a necessary evil: if a fitness function could not be clearly defined, humans had to be employed to select the fittest individuals. Unfortunately humans are costly, slow, unreliable and subject to fatigue, so efforts have been taken, to reduce human interference to a minimum.

Although usability issues have been gaining more attention recently [15] , the focus in user-centered ED is still on using humans rather than on human users. A notable exception is Lund [12] who measured the level of user activity and control in an interface for font evolution, thus doing user experience research rather than usability research.

This change in perspective is important, since the problem of human fatigue may indeed be a result of under-demanding tasks: a system that provides adaptive task-complexity, or that gives control over task-complexity to the user, may be more effective in achieving good designs quickly while increasing user satisfaction at the same time. An example of increased user-control over task complexity is Kosorukoff's model of human-based Evolutionary Computation (hbEC), where operators for mutation and recombination are also delegated to humans [10].

The hbEC-approach is very useful in systems where application of genetic operators is non-trivial, or would mostly produce invalid results, as in the case of recombining entries in a dictionary. This kind of evolution is usually Lamarckian because humans operate on the phenotype (dictionary-text made from letters) from which the genotype (knowledge made from ideas) is reconstructed, before being subjected to further evolution.

3. Towards Crowd-Controlled Design

Rather than user-centric we suggest the terms user-driven and user-controlled, to account for the active role of the user. The term user-driven should be applied for systems where the user drives the system without overt intention, such as search-engines that assign page fitness by page-views. On the other hand, social bookmarking services where the user actively assigns fitness to a website would be considered user-controlled.

Several results from user-driven media research can be directly applied to Evolutionary Design: phenotypes can be assigned fitness values based on visual attention measured by an eye-tracking device. This approach has been used for image retrieval by Scherffig [17] and could serve as a basis for gaze-based Evolutionary Design (gbED).

While classic approaches to Evolutionary Design are restricted to a single user, distributed EC would provide the underpinnings for crowd-controlled ED (ccED) or multi-user-controlled ED, overcoming problems of human fatigue or incompetence. (The key difference between human based EC and crowd controlled ED being, that hbEC applies EC as a metaphor to the behavior of crowds, while ccED requires the actual implementation of EC algorithms inside a tool for designers)

Experiments by Kevan Davis have shown that clearly defined goals such as crowd-controlled evolution of a 400 pixel image towards a letter of the roman alphabet converge towards satisfying results [4]. While this experiment relied on distributing the selection task among users, other systems distribute the computationally expensive task of gene expression among the user's computers [5].

Future versions of ccED could make use of a distributed gene pool with migration occurring along trust networks established by the users, thus allowing for niching and speciation, reflecting different group preferences, though still permitting for influx from other groups.
Nevertheless convergence effects can only be exploited when connected users breed their populations towards a common goal. But as soon as the users are in control, these goals may be contradictory even for different objects evolved by a single user. This problem can easily be overcome by the introduction of tagging, where users can either tag parts of the environment, complete individuals, or – in Lamarckian evolution – even parts of an individual, to link the fitness values with a user-defined goal, giving rise to tag-based ED (tbED).

Research on tagging has shown, that stable tag patterns emerge in collaborative tagging of rather stable objects (like websites) [7] but the co-evolution of tags and dynamically changing objects still requires further investigation.

4. Lamarckian Evolution of Shapes

Lamarckian evolution is concerned with the 'inheritance of acquired traits' as exemplified by the giraffe's neck story that is often attributed to Lamarck.When simply evolving DNA towards a target sequence, Lamarckian evolution converges faster than Darwinian evolution because it makes use of information acquired during ontogenesis [8]. But as soon as the phenotype is developed according to a more complex gene expression function, an inverse function is needed to reconstruct the genotype from the improved phenotype.

How much this reverse gene expression, which may also be termed 'phene compression' governs the evolution of multicellular organisms is still subject to debate: there are enzymes such as reverse transcriptase to encode ontogenetically acquired information back into so-called retrogenes. This mechanism may account for Lamarckian evolution of the human immune system, where the gene expression function is easily reversible. But since the assembly of proteins from DNA is generally considered an irreversible process, total phene compression cannot be observed in nature [20].

The prevalence of Darwinian evolution in nature, and its ease of implementation in the computer may be responsible for the fact that ED tools have mostly ignored the merits of Lamarckian evolution, although Lamarckian ED was realized to some degree in parametric design [14,18].
In Lamarckian ED the user is free to modify objects using standard design tools during the course of evolution, thus bridging the gap between user-driven constructive design and computer-driven evolutionary design.

5. Reversible Gene Expression

Gene expression functions can be classified, depending on whether they rely on deformation [18], folding [13] or growth [6].

Deformation-based gene expression makes use of geometric deformations similar to those first described by D'Arcy Thompson. They require a base-shape, the topology of which remains unchanged. For simply connected objects, algorithms for spherical parametrization can serve as phene compression functions, whereas objects of higher topological genus require a more general mapping scheme [19].

Folding-based gene expression basically folds a low dimensional object as to constitute an object of higher dimension. This low-dimensional object can even be provided by the DNA itself, as in the DNA-origami popularized by Rothemund [16]. Demaine published a phene compression algorithm, that can derive the folding instruction from the Hamilton-graph of a polygon in linear time.

Finally growth-based gene expression is only strictly reversible if no information is lost during morphogenesis. Shapes can be represented by weighted skeletons, that are derived from the medial axis transform popularized by Blum [2]. This constitutes a simple and straight-forward phene compression and was used in amorphous computing by Kondacs [9].

6. Phene Compression for Raster Graphics

We have developed a model for phene compression of uniform-colored 2D raster graphics which can be extended to three dimensions, building on the work of Leymarie [11]. Due to the limitations of discrete geometry, weighted skeletons either violate the minimum thickness principle, or the reversibility principle. We overcame this limitation by introducing a blow-up transformation, that effectively doubles the resolution, such that centers of growth always end up on a dedicated pixel.

The skeleton is traversed and compressed into the DNA, comprised of a chain-code of turtle-commands including a command for dropping growth hormone, whilst holes are encoded as negative shapes using anti-growth hormone. The sequence can be further compressed by a rewriting process that identifies frequently repeated sequences resulting in a compact hierarchical grammar similar to LZW-encoding.

7. Future Investigations

The Lamarckian evolution of shapes permits partial fitness assignment (or fitness tagging) where fitness-values are not assigned to an individual as a whole, but to selected parts of the phenotype. These fitness values can be propagated back to the genome during phene compression, so that selection really happens on a per gene basis, thus speeding up the evolution and leveling the field for truly user-controlled gaze-based and tag-based Evolutionary Design.

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