Phylogenetically Acquired Representations and Evolutionary Algorithms.

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Genetic Algorithms as artificial versions of artificial, and not natural selection

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First, we explain why Genetic Algorithms (GAs), inspired by the Modern Synthesis, do not accurately model biological evolution, being rather an artificial version of artificial, rather than natural selection. Being focused on optimisation, we propose two improvements of GAs, with the aim to successfully generate adapted, desired behaviour. The first one concerns phylogenetic grounding of meaning, a way to avoid the Symbol Grounding Problem. We give a definition of Phylogenetically Acquired Representations, based on a parallel between the notions of *representation* and of *adaptation*. In the second part of the paper, we propose a hybrid version of genetic algorithms, differently organizing the flow of genetic information by introducing inheritance of acquired traits and Horizontal Gene Transfer, a good tool for handle a cumulative directional process of artificial selection.

Evolutionary Computation (EC) refers to methods for designing autonomous agents (artificial systems like physical or simulated robots, software agents) inspired by biological evolution, as the Modern Synthesis (MS) understands it. One of those methods is Genetic Algorithms (GAs). EC and GAs use biological ideas for two main purposes: optimisation and modelling.

Optimisation, because the evolutionary process by natural selection is identified with seeking for optimum, for good or best "solution" to the problem of reproduction and/or of survival of autonomous agents. It is an instrumentalist, pragmatist goal of AI: efficacy in creating agents capable of successful operations relative to precise problems, in partially unknown environments without any intervention of the experimenter. AI uses artificial evolution because other methods are not successful (Harnad, 1990).

Modelling is the second and realist purpose underpinned by the hope that the better we know how reality works — given that reality works well — the more efficient our methods will be. The goal of AI, as those of other sciences, is to model and therefore to discover causal dependencies in evolutionary processes by natural selection. On the one hand, AI models and AI simulations are

crudely simplified with regards to the heterogeneity of the evolutionary realm; on the other hand, GAs isolate the external causes and internal effects, thus having the advantage of leaving the possibility of grasping causal relations open to empirical investigation. Of course, even if models and simulations help to discover the existence of such causal relations, it doesn't imply either that the causal mechanisms discovered this way give rise to processes identical to those that occur in nature, nor that they are the only factors that take part in those processes.

GAs are considered as a formal study of adaptation, an artificial version of natural selection (Goldberg, 1989). According to MS, adaptation is a "*mechanism thanks to which external cause is transformed into effect*"(Lewontin, 2003:118-120), an asymmetrical process where « *the environment brings about an organic change exactly in its own image* » (Godfrey-Smith, 1996:86), and where "*organisms adapt to theirs environments, never vice versa*" (Williams, 1992:484). In MS, the movement of natural selection is environmentally driven (the environment differentiates between two genotypes G_1 and G_2). GAs follows this externalist concept of the phylogenetic relation environment/organism and uses the traditional concept of adaptation in which populations move relative to stable *selective environments* (Brandon, 1990:45) defined by experimenter. The survival of the fittest among all genotypes in the population is computed as follows: the experimenter tests through the fitness function the abilities of the agent to solve the problem (s)he is interested in. Then, genotypes are selected probabilistically according to their fitness scores, and enter the mating pool, which engenders the next generation. Individuals are copied according to their so-called *function values* (in EC) or *fitness function* (in MS). Function is an intuitive notion of "some measure of profit, utility or goodness that we want to maximize" (Goldberg, 1989:10).

GAs do show the power of natural selection, as MS understands it. Nevertheless, according to the Extended Theory of Evolution (ETE, John Odling-Smee et al, 2003; Day et al, 2003), natural selection is not instantiated simply by an external factor: what constitutes selective factor is a resultant of both, environmental and organismic variables. In GAs the selective environment represents some externally fixed values, while in

ETE, the organism defines the referential within which the selective environment is measured. The only constant valid in all system of reference is the viability criterion (note that viability does not imply the externalist view of adaptation, as defined by MS). In ETE, there are two variables in the frame of reference of the selective environment and the change in the value of one (organism) drives the change in the value of the other (environment), and inversely. Selection in this context designates simultaneous and reciprocal causality. This is the reason why Evolutionary Computing, inspired from the Modern Synthesis of the Theory of Evolution, is not an artificial version of natural selection, as claimed (Goldberg, 1989:10), but rather an artificial version of artificial selection. Artificial selection differs from natural selection in that in the former, the organism evolves according to some externally defined function, while in the later one organism modifies itself the fitness (and its function) and the selective factor that it is supposed to adapt to. The organisms do not phylogenetically track an external factor, contrary to MS where natural selection is an asymmetrical process of one way (passive) adaptation of organism to an environmental, independent value. In ETE organisms evolve without direct reference to some external factor; population tends not to the optimum (in correspondence to an externally defined task) but to the value that is a resultant of environmental and organismic properties.

Therefore methods used in Artificial Intelligence do not model well the evolution by natural selection. GAs make use of an externally defined fitness function, but natural evolutionary processes are not engineering operations of adaptation according to externally fixed demands. Yet, this may be why ETE models wouldn't be of use for efficient evolving computer systems. After all, experimenters do not want to obtain any results, but results for a more or less specific task. Current ideas of evolutionary robotics, inspired from biological evolution, are used precisely in the field of function optimisation, for engineering purposes. GAs are an example of artificial selection and do show the power of natural selection, where the latter instantiates external factors, which experimenters judge important. Clearly, GAs are motivated by an optimisation purpose to improve the artificial selection of artificial, engineering-like evolution.

The goal of GAs is to successfully generate desired behaviour, adapted to an externally fixed demand. In the present paper we propose two improvements for GAs. The first part (§2) will concern a conceptual twist avoiding, in our opinion, the Symbol Grounding Problem by means of a phylogenetic grounding of meaning. The second part (§3) will concern two propositions of improvements of GAs through a different organisation of the flow of genetic information.

Phylogenetic grounding of meaning

One of the problem of AI is how the meaning of an external factor can be grounded, integrated, i.e. made intrinsic to the agent (Harnad, 1990). How can the experimenter make the agent understand the meaning of an external factor (symbol) s/he is interested in? Harnad's model of cognition is purely connectionist, top-down and symbolic, in the sprit of behaviourism, where names are connected to objects through invariant patterns in the sensory projections, learned through exposure and feedback. The meaning is supposed to be acquired via learning and is defined as a semantic correspondence with symbols. In this type of approach, the meaning of symbols emerges from the connection between the symbol system and the world (Fodor, 1994). Representational cognition is based on higher-order mental states and symbols (as Good Old Fashioned Artifcial Intelligence stated, Newell et al, 1976).

The AI definition of representation, as a direct mapping between internal symbols and external objects, has been undermined; nowadays learning is defined through interactions of the virtual individual with the world (Brooks, 1991). Therefore, behavioural responses join the rank of cognitive instances, though still only of those that are ontogenetically acquired[1]. The notions of learning and of adaptation are both localised at the ontogenetic level: learning mechanisms give the individual the ability of adapting to the environment and of elaborating behaviour in order to maintain itself in a viable state. Representations are learned

[1] Ontogenical acquisition is acquisition that takes place during the individual's life.

(never hard-wired) and of belief-type; they acquire their function (meaning) through the ontogenesis where individuals learn what a given fact indicates; e.g. birds learn (in ontogenesis) that the Monarch butterfly marks indicate inedibility which leads them to an avoidance behaviour. Representations must be the causes of behaviour; in this sense, reflex processes over which the individual has no control are not representational or cognitive states. This is linked with the question of agency: I have cause to do this or that, but it is not for this reason that I am doing it (representations must be both reasons and causes of actions, Dretske, 1999). The reason is the belief and the belief is acquired through ontogenetic experience.

The current AI concept of representation— as learning during ontogenetic interaction with environment (Brooks, 1991)— misses one important fact, namely that ontogenetic learning is only one among two modes of meaning acquisition. The first one is obviously ontogenetic learning, where the individual acquires the meaning of x during its individual life. The second one is phylogenetic, where the individual benefits from the knowledge about the meaning of x acquired during the phylogenetic adaptation of the species it belongs to. For many researchers, cognitive states cannot be ascribed to phylogenetically acquired properties. For them, evolutionary adaptation or phylogenetic learning is different from "true" learning where changes in the behaviour are individually acquired during the ontogeny of the cell (Kilian and Muller, 2001).

Nevertheless, if learning means a modification of the internal states of an organism (or parameters in a virtual individual) during its interaction with the environment, learning does take place during individual experience *and* during species experience. What's more, learning mechanisms enabling ontogenetical adaptation of individuals to the environment and behaviour maintaining them in a viable state, already seat in their innate cognition, i.e. are based on phylogenetically acquired structures carried by *genetic open programs* (Mayr, 1974).

It is an old and plausible idea (developed by Platon[2]; Descartes[3]; Leibniz; Kant[4]; Lorenz[5]; Chomsky, 1975), that there is

[2] Platon's (Socrates') methods of revealing by questioning (a slave boy), in the *Meno*.

nothing in the representation, which does not come from the sensory, individual experience, except the senses, the cognitive apparatus itself[6]. The evidence and the measure for phylogenetically acquired and (partially) innate components of cognitive and representational states would be the following: if we take sensory experience as the input and behavioural response of the individual as the output, we will see that the output contains more information than provided by the individual, sensory experience of external stimulus. We subtract the stimulus from the output; we thus obtain the contribution brought by innate knowledge. It brings out the fact that representation contains an innate component, and pinpoints the existence of an innate cognitive endowment of the organism. If representations are underpinned by innate components in such a way that the latter are indispensable for those representations, the innate components also must be considered as part of the representation.

Obviously, many innate cognitive and representational states are not fully manifested at birth, and the presence of some external, triggering, factor is needed for these ideas to become

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[3] "*And man who rightly observes the limitations of the senses, and what precisely it is that can penetrate through this medium to our faculty of thinking must needs admit that no ideas of things, in the shape in which we envisage them by thought, are presented to us by senses. So much so that in our ideas there is nothing which was not innate in the mind, or faculty of thinking*". Quoted in Chomsky, 1975.

[4] "(…) *what is borrowed solely from experience is, as we say, known only a posteriori, or empirically. Now we find, what is especially noteworthy, that even into our experience there enter modes of knowledge which must have their origin a priori, and which perhaps serve only to give coherence to our sense-representations. For if we eliminate from our experience everything which belongs to the senses, there still remain certain original concepts and certain judgments derived from them, which must have arisen completely a priori, independently of experience, inasmuch as they enable us to say, or at least lead us to believe that we can say, in regard to the objects which appear to the senses, more than mere experience would teach – giving to assertions true universality and strict necessity, such as mere empirical knowledge cannot supply*". (Kant, 1781:A2)

[5] "(…) *the blueprint contained in the genome requires innumerable environmental factors in order to be realised in the phenogeny of structures and functions. During his individual growth, the male stickleback may need water of sufficient oxygen content, copepods for food, light, detailed pictures on his retina and millions of other conditions in order to enable him, as an adult, to respond selectively to the red belly of rival. Whatever wonders phenogeny can perform, however, it cannot extract from these factors information which simply is not contained in them, namely, the information that a rival is red underneath*". (Lorenz 1966:37)

[6] Paraphrase de Leibniz: *Nihil est in intellectu, quod non fuerit in sensu, excipe: nisi ipse intellectus.*

available (Ariew, 1996; Lorenz, 1966). Thus, the representation of the world is built not only from learned components, but depends also on the innate ones. Evolving organisms benefit from the combination of phylogenetic and ontogenetic learning. It raises a few points against the exclusivity of intentional conceptions: why do we attribute representational status to ontogenetically acquired features but refuse it to hard-wired ones? There is a striking parallel between the notions of *representation* and of *adaptation*, that will lead us to the notion of Phylogenetically Acquired Representations (PAR):

Representation	**Adaptation**
An (a set of) internal state(s) of the a	A (a set of) hereditary (partly ca open genetic program) property agent
that holds a relation of reference	that results from a causal phyl relation
toward certain objects in the externa	toward an external factor.
The representation of the object, as in the mind, does not entirely deri sensory, individual experience object.	The contribution of the sensory, in experience of this factor is not s for the trait-adaptation to develop.

PARs as adaptations. PARs are (a set of) features of the organism carried by open genetic programs that result from a causal phylogenetic relation with factors from the selective environment. The forms of PARs are thus not entirely determined by individual experience of the environmental factor.

PARs as representations. Phylogenetically acquired features have representational status, because adaptations (e.g. adaptative escape behaviour) corresponding to an environmental factor (e.g. snake), do not derive and cannot be fully explained, by the ontogenetically acquired experience of this factor. The ontogenetical exposure to snakes is not sufficient to acquire the escape behaviour that is triggered once the individual senses a snake. The reason for which individuals of species S fly snakes is not an ontogenetically acquired belief of these individuals, but

precisely a PAR, the meaning of a snake being acquired through the phylogenetic experience of S.

Natural selection is a process of discriminating sampling occurring when the individuals do not reproduce because their traits does not fit to their environment. The chance of individuals to contribute to the next generation depends on this fitness. In GAs natural selection designates a cause/effect relation, whereby the environment (as a fitness value fixed by experimenter) instantiates the cause and the organism instantiates the effect. This causal and externalist characteristic of natural selection guarantees that the main criterion of representation is fulfilled, namely the presence of the causal relation from object to representation. Thus, PAR is every feature that constitutes an adaptation, i.e. resulting from the discriminating process of natural selection. Since the latter can act only on what is heritable, and what is heritable is genetic, a structure that constitutes an adaptation must be (partially) innate[7]. There are three conditions for a feature F to be considered as representing x:

- F must enter the state S if x occurs, e.g. trigger escape behaviour in the presence of a sensory experience invoking a predator;

F must be an adaptation:

- the property of F to enter the state S if x must be the cause thanks to which F was retained in the discriminating process of natural selection
- F must be underpinned by the open genetic program (innate to some extent)

How then can the concept of phylogenetic acquisition of meaning and the definition of Phylogenetically Acquired Representations help to solve the Symbol Grounding Problem? How can the meaning of an external factor be grounded, integrated in the agent? Meaning is supposed to be acquired via the phylogenetic process of natural selection (species learning and not only ontogenetic learning) and designates an adaptive (and not ontogenetically semantic) correspondence with external factors. The meaning of those factors emerges from the selective relation between them and the genetic program of the species. Representational cognition is based not on higher-order mental states and symbols but on partly innate features underpinning

[7] Not every innate trait has to be an adaptation.

them. How then can the experimenter make the agent understand the meaning of an external factor s/he is interested in? We propose to take into account phylogenetic grounding, based on the assumption that the features-adaptations are rightfully representational ones and bear the meaning of the external factor according to which they evolved.

Hybrid Genetic Algorithms

In this part of the paper we will propose some ideas as to how to organise the flow of genetic information, rendering it more efficient in order to successfully generate the desired, adapted behaviour. To generate an evolutionary process, the three following requirements must be fulfilled. The first one is the *principle of variation*, i.e. the existence of polymorphism in morphologic, physiologic or behavioural traits within populations. At least some variants must be hereditary – *principle of heredity* – i.e. in the progeny's generation there must exist traits similar to those present in the parental generation. Without heredity, adaptive evolution is not possible (Dawkins, 1982), for only traits possessing genetic basis can be selected and passed from one generation to the next, and become an adaptation. Genes guaranty the possibility of transmission of selected variants. Finally, the *principle of selection*, is driven by fitness differences in the situation where some individuals, bearers of modified traits, leave more descendants than others. That is all we need to generate an evolutionary process of artificial selection. GAs not only fulfil all those three necessary conditions, but also take, what is more, some additional ones that have come with relatively recent discoveries integrated in the Modern Synthesis. In the case of the principles of variation, MS states that variation has two sources, mutation and recombination. When it comes to the principle of heredity, GAs' models are constructed according to the *Central Dogma* of molecular biology setting out that DNA causes the production of RNA that makes proteins and then cells. The reverse process doesn't occur: proteins or cells don't determine on their turn the nucleic acid. The fact that genotype affects phenotype and that phenotype does not affect genotype implies that acquired traits do

not affect an organism's genome and that only genome (and not what parents learned or acquired during their ontogenesis) is passed to the offspring. Genetic material is transferred to another organism that is a descendant, i.e. from parent to offspring, in an intragenerational way. This is called *vertical gene transfer* (VGT).

However, all those conditions are additional to the three ones necessary to generate an evolutionary process of artificial selection. Why are they accessory? Darwin developped his theory of natural selection (in 1859) without knowing exactly either the source of variation or the nature of inheritance. Before him, in 1809, Lamarck proposed his concept of evolution, where variation is somehow induced by the environment (variation is neither spontaneous nor random, as in MS), and the parental organisms transmit to their offspring the traits that they acquired in ontogenesis (contrary to the Central Dogma of MS). The mechanisms generating variation and responsible for inheritance were known much later. In 1866, Mendel gave the basis for the understanding of genetic recombination, and in 1904 Weismann showed that the germ line is segregated from the soma, thanks to the observation that the offsprings of mice with cut-off tails have normal tails. The conviction about the genome as a *one way transducing device* was reinforced after 1958 with the discoveries in molecular biology of Watson and Crick.

The goal of GAs is to successfully generate desired behaviour, adapted to an externally fixed demand. More realistic and complex genetic algorithms were conceived in order to obtain a precise result. Many evolutionarily inspired tricks were incorporated at different levels, like genetic transfer during cellular division (inversion, translocation, deletion, etc.), diploidy and sexual reproduction, coevolution (host-parasite, arm races), sexual selection, etc. MS inspired all those models. Nevertheless, VGT is a kind of frozen accident, far from being universal (its exceptions are e.g. retroviruses, retrotransposons, prions). "The non-inheritance of acquired characters is a contingent fact, usually but not always true, not a logical necessity" (Maynard-Smith, 2001). The same is valid for the source of variation. To generate an evolutionary, selective process, there must exist heritable variants and factor differentiating them, but the way of generating and making those variants inherited does not need to be exactly copied

from nature. It can be even simpler and maybe more efficient for engineering and optimisation purposes. We will now propose bipartite candidate theoretical solution, which we call Hybrid Genetic Algorithms (HGAs), for the current state of technology can provide experimental tools following this conceptual liberty.

Acquisition of acquired traits

In current models of GAs, acquired traits do not affect an organism's genome, which has some important implications. First, at least one generation is needed for the adaptative process to take place. Desirable combination (coming from intra-chromosomal or inter-chromosomal recombination) or an advantageous mutation can be simply lost and do not appear in the next generation. It is a drawback of the intragenerational mode of transmission that the (advantageous) variant traits must be generated de novo in each generation. The further implication of VGT is that what individuals learn during their lifetime is not genetically transmitted to the next generation. This is due to the fact that the ontogenetically acquired characteristics are not directly copied to the next generation, but the genes underpinning them. Consequently, the ontogenetic increase in performance relative to the fitness function is lost at the end of the individual life. AI can create evolutionary processes that function in a simpler manner and where the selective retention of adaptative traits, including those acquired during ontogenetic learning, is possible. In HGAs, it is not only genotype that would affects phenotype, but phenotype could also affect genotype. For example, in a robot controlled by an artificial neural network, genome would modify synaptic weights, as before, and additionally this change would directly drive a change in the genome. The adaptation would trigger an ontogenetic (and not phylogenetic) modification of the genome, a horizontal heritable trait acquisition. HGAs would take a Lamarckian orientation and acquired (learned) traits of an individual would affect its genome. The ontogenetic increase in performance according to the fitness function wouldn't be lost.

Thanks to inheritance of acquired features, an advantageous propriety that an individual acquires in the process of learning will be transmitted to the next generation. For instance, an individual in

a population P learns something about the object x, vitally related to all individuals of P. This knowledge allows this individual to progress (according to the fitness threshold established by the experimenter) and to gain further knowledge of x.

Acquired DNA or Horizontal Gene Transfer (HGT)

Once we have at our disposition horizontal heritable trait acquisition we can enrich the method with horizontal gene acquisition. Suppose that the experimenter would like to spread among all individuals of the population ontogenetically gained feature and then encod it in the genome. In order to do it with GAs' methods, s/he must apply directional selection and wait a number of generations to see the desired effect universally fixed. However, there is a possibility to make the desired trait horizontally displaceable by introducing to the model the exchange of the genetic material within generation (interspecific recombination without creating new individuals). This genetic free swapping within population could be made by introducing Horizontal Gene Transfer (HGT), characteristic of the evolution of the cell before early, primitive cells differed in three primary lines of descent: bacteria, archea and eukaryotes (before Darwinian threshold, Ochman and all, 2000: 304). In HGT, substantial amounts of DNA are introduced (or deleted) from the chromosome. HGAs models would resemble a kind of mosaic or net, metaphors visualising the HGT exchange occurring at the roots of the tree of life. This would be a tool for the experimenter to improve the process of cumulative and directional selection.

In HGAs, population would be considered as a universal genetic pool, and HGT as a way of redistributing desired (non desired) traits. This would multiply the range of combinatorial heritable possibilities and increase the chance of obtaining the trait the experimenter is interested in. The content and the structure of genomes in the population, moulded by HGT, would probably display a wide degree of variants what would enable phylogenetic plasticity and increase the chance to obtain the desired characteristic[8].

[8] HTG explains why bacteria develop their incredible antibiotic resistance, their ability to adapt to the environments.

New traits would appear not only after point mutations or genetic recombination (intra-chromosomal — combination of parental and maternal genes— or inter-chromosomal — of chromosomes), but also to interspecific recombination[9], possible thanks to HGT. All desirable novelties (acquired during the ontogenetic learning, due to the point mutations, etc.) could be shared and henceforth evolve simultaneously. This would create an *unlimited system of heredity* (Maynard Smith and Szathamary, 1995), where a trait can vary into a great number of heritable states, as in the case of prokaryotes and bacteria or of languages and cultures. Of course, as in the vertical mode of acquisition, natural selection (i.e., the experimenter) is the arbiter of the adaptive value of traits.

Conclusions

In the first part of the paper, we explain the conceptual revolution made by the Extended Theory of Evolution (ETE, John Odling-Smee et al, 2003; Day et al, 2003). The latter points out that selective environment and fitness value, according to which organisms are supposed to evolve, are a resultant of two variables, environment *and* organism. Natural selection is not a simple externalist relation; the organisms do not only evolve in response to an external factor, but themselves partly define the fitness function. Thus, GAs are an instantiation of artificial selection, whose main purpose is optimisation, not realistic modelling.

We thus propose two improvements, conceptual and technical, in generating a desired, adapted behaviour. The first one (§2) concerns the phylogenetic grounding of meaning, a way to avoid the Symbol Grounding Problem. We explain the parallel between the notions of representation and of adaptation and elaborate the concept of Phylogenetically Acquired Representation. The meaning of an external factor can be grounded, integrated to the agent via the process of artificial selection; we take seriously the phylogenetic mode of acquisition,

[9] In the nature, DNA sequences are even transferred *among taxa*, being acquired from distantly related or non related organisms, e.g. Adzuki Bean Beetle's genome contains some sequences from the genome of Wolbachia, its parasit.

species learning, and consider feature-adaptations as legitimate representational ones, bearing the meaning of the external factor according to which they evolved.

In §3, we propose Hybrid Genetic Algorithms (HGAs), a melange of real and fictitious elements of evolutionary processes. We propose to incorporate to GAs horizontal heritable trait acquisition (inheritance of acquired traits) enriched by horizontal gene acquisition, a tool for the experimenter to handle the cumulative directional process of artificial selection. It introduces, in comparison to the Modern Synthesis, additional evolutionary mechanisms:

- new source of variation (Horizontal Gene Transfer, HGT, makes possible intraspecific recombination) and
- additional modes of inheritance, enabling the experimenter to easily conserve and spread or delete selected features (HGT) and ontogenetical modification of the genome (inheritance of acquired traits), contributing to the gain of the performance according to the fitness function.

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