Replicator-interactor in experimental cultural knowledge evolution

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Abstract. Cultural evolution may be studied at a 'macro' level, inspired from population dynamics, or at a 'micro' level, inspired from genetics. The replicator-interactor model generalises the genotype-phenotype distinction of genetic evolution. Here, we consider how it can be applied to cultural knowledge evolution experiments. In particular, we consider knowledge as replicator and the behaviour it induces as interactor. We show that this requires to address problems concerning transmission. We discuss the introduction of horizontal transmission within the replicator-interactor model and/or differential reproduction within cultural evolution experiments.

Keywords. evolution, cultural evolution, experimental knowledge evolution, replicator-interactor

1. Introduction: the replicator-interactor model

Natural selection has been uncovered in the zoological domain at a moment when genetics did not exists. Since then it has gained in depth, by better understanding of the mechanisms at stake, and in breadth, by its application to many other domains. We discuss this hereafter.

1.1. Evolution principles

Natural selection can be thought of as a control mechanism based on variation, selection and transmission 'operations' [1]. This can be implemented in computers as it had already been done for genetic programming.

One of the problem with this characterisation is that it does not tell what is affected by or what performs each operation. For instance, in life sciences, there are variations of the genotype which generate variations of the phenotype in an individual. Individuals are selected by the environment, which indirectly selects the genotype that will be transmitted to the next generation (of the population).

Towards the end of the 20th century, for thinking about the general principles of natural selection, biologists attempted to generalise Darwinism, i.e. to provide an abstract description of evolution mechanisms [2,3]. They introduced the replicator-interactor pattern as a generalisation of the genotype-phenotype articulation: the replicator generates

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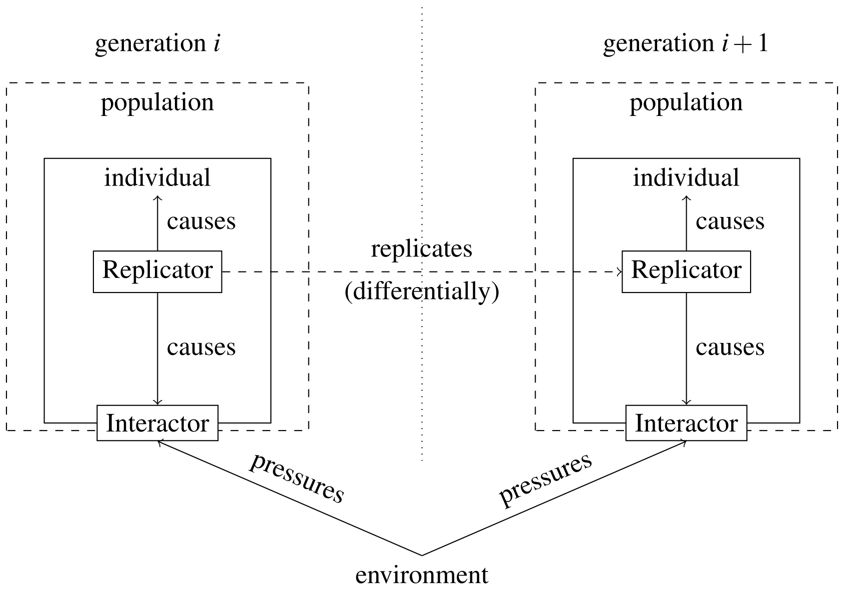

Figure 1. Replicator-interactor model (the environment is assumed frozen).

the interactor which, being in contact with the environment, receives the selective pressure and induces differential reproduction. Richard Dawkins [2] introduced the notions of replicators and vehicles, the latter term rendering precisely the idea of the selfish gene: that organisms are only vehicle for their genes. David Hull [4] found that term too passive and wanted to emphasise that it has to interact with the environment, so he renamed it interactor. Their 'definitions' are [5]:

Replicators Things that pass on their entire structure;

Interactors Traits that natural selection acts upon.

Figure 1 illustrates this. Genes are replicators. They replicate to the offspring almost perfectly, modulo mutation or drift (variation). They are also the pattern for the whole organism. Among those traits expressed by genes, some are under the pressure of the environment (interactors). This means that the organisms will be more or less fit to the environment (healthy, in good shape to reproduce, eat, survive, mate, have offspring). Thus the selection operates indirectly on the capacity of replicators to replicate and thus been inherited. They do it differentially depending on the fitness of generated interactors.

The replicator-interactor pattern is a 'micro' level view of evolution.

Finally, from the discipline of epistemology, some created along these lines an evolutionary epistemology which seeks to apply generalised Darwinism to knowledge elaboration [6]. In this perspective, evolution is described as a way to gain knowledge. Like genetics, this approach aims at providing the operational details.

This model very nicely generalises natural selection. It is thus interesting to consider its application to cultural evolution.

1.2. Cultural evolution

In the 20th century, anthropologists [7,8] provided evidence of cultural evolution, so that it became an accepted discipline [9]. Culture, in this sense, is something shared by a particular population. It can take different forms: values, language, religion, know-how, clothes, etc. It is an 'artefact' that can be shared, transmitted and modified. It is subject to natural selection since populations with different cultures may experience different levels of fitness and thus different reproduction rates.

Cultural evolution has mostly been considered at a 'macro' level inspired from population biology: observing and modelling the evolution of knowledge of whole populations without figuring out the specific mechanisms implementing this cultural evolution.

In cultural evolution, cultural features are transmitted and selected by people. Variations, which may be voluntary or due to errors, are generated by these people. Evolution takes place while culture is selected and transmitted. There is apparently no distinction between phenotype and genotype (there is no reproduction, but transmission, of culture). The selection may not correspond to the death of individuals as individuals may adopt the culture of others...

The enterprise of abstracting from genetic evolution to cover cultural evolution is a worthy one. However, as discussed in [9]: "...] there is no clear equivalent to the genotype-phenotype (or replicator-interactor) distinction in culture. Loosely, we can speak of culturally acquired semantic information stored in brains as replicators and the expression of that information in behaviour or artifacts as their interactors." We consider in this paper the possibility of filling this gap and applying this approach to cultural evolution.

2. Experimental cultural knowledge evolution

Experimental cultural evolution is based on multi-agent simulation of cultural evolution. It thus adopts a 'micro'-level approach to cultural evolution by designing mechanisms through which cultural evolution may happen. It has been used to evolve abstract cultures [10] or natural language features [11].

Work has recently been developed for evolving alignments between ontologies. In this case, alignments and ontologies are part of agent knowledge. Cultural knowledge evolution can be used to repair alignments better than blind logical repair [12], to create alignments based on entity descriptions [13], to learn alignments from dialogues framed in interaction protocols [14,15], or to correct alignments until no error remains [16,17] and to start with no alignment [18]. Each study provides new insights and open directions.

Cultural knowledge evolution experiments involve knowledge-carrying agents interacting. This is usually described as playing a particular game which may aim at identifying an object of the environment or translating a statement. Given the outcome of the game, success or failure, the agents apply adaptation operators to their knowledge in order to improve its performance in the game. Experiments observe a large number of games among a population of agents and monitor the evolution of the success rate as well as other secondary measures. Measure of importance are usually that knowledge reaches a stable state or that it is 'correct' according to some definition of correctness.

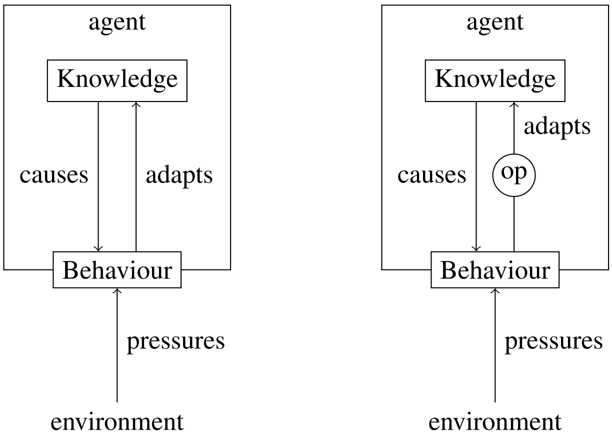

Figure 2. Knowledge as replicator; behaviour as interactor. On the right-hand side the operators used by agents for adapting knowledge are made explicit.

The overall goal of this work is to understand how simple agents may evolve their knowledge and if it provides them benefits.

Like in cultural evolution, knowledge transmission does not necessarily happen through reproductive inheritance. On the contrary agents may transmit knowledge by cooperating or by directly exchanging it.

3. Knowledge as replicator

Cultural knowledge evolution, and the associated experimental designs, may be related to the replicator-interactor approach. This would provide yet another field covered by generalised evolution. As we will see, this also raises interesting questions.

The replicator-interactor approach may directly be applied to knowledge. Knowledge generates individual behaviour, which is subject to selective pressure from the environement and thus spreads differentially. Here, the alignments cause the way agents are playing the game and agents select them based on the game outcome. Knowledge evolution can indeed be implemented as a mechanism which makes knowledge evolve seamlessly while it is used.

Figure 2 (left-hand side) casts the current practice of experimental knowledge evolution within the replicator-interactor model.

So far, the replicator is not replicated from generation to generation through reproduction, but between contemporary agents through horizontal transmission. Transmission is part of the behaviour of agents. There are two types of horizontal transmission (see Figure 3):

- Implicit transmission occurs through game playing by agents adapting their knowledge. It could be, for instance, imitation, but should rather be considered as a general form of learning-by-doing.

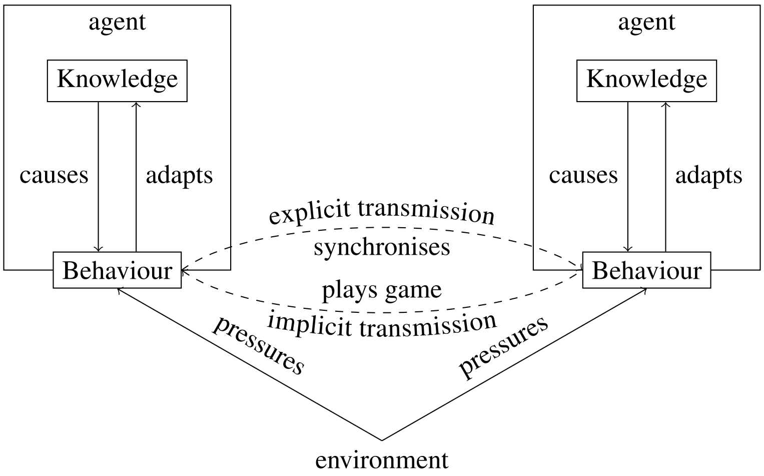

Figure 3. Explicit and implicit horizontal knowledge transmission.

- Explicit transmission occurs when agents of the same population can exchange their knowledge. We call it synchronisation but it can be considered as similar to what Luc Steels calls alignment [11]. This rather resemble learning-by-being-told.

These transmission modes, performed in the experimental games, indirectly apply selective pressure from the environment.

This is quite satisfying: knowledge is the replicator, although so far, it does not replicate much. But it indeed causes the behaviour of the agent which receives pressure from the environment (or the other agents through the games they play). This pressure leads the agent itself to adapt (through operators) directly its knowledge.

This model, however convincing, does not stick closely to the initial replicator-interactor model. We stress below various differences and issues that it raises, evaluate their impact and discuss extensions. These differences go along the following lines:

1. Knowledge does not create the agent,
2. The agent controls the process,
3. There is no population,
4. There is no reproduction, nor generation so far.

As often, these issues are interrelated, but we address them separately.

4. What exactly is the replicator?

One apparent difference between knowledge and genes is that knowledge does not really create the individual, but only participates to its behaviour. However, in biology, genes do not control everything: reproduction depends on maternal or environmental characteristics, genes cannot easily get rid of the ‘universality of the genetic code’. This is the main topic of evolutionary developmental biology and the notion of evolvability has been inspired from evolutionary computation [19]. Genes are only an ingredient for creating an individual and on this ground, the idea that the replicator causes the interactor should be revised as being only a partial cause of it.

In case of human cultural evolution, this is of course co-evolution of knowledge and genome that has to be taken into account as the full replicator. Knowledge participates to fitness; genotype contributes to its evolution.

In agent simulation, this brings the question of what part of the agent software can evolve. In order for these to function, agents need to share a minimal common ground. There is latitude in choosing what is counted as knowledge/replicator in the agent:

- the agent ontologies and alignments (as we considered before),
- the adaptation operators and modality that they use to adapt these,
- the software on which it relies.

All of these may be refined in more precise layers, may be subject to evolution and may be modified to react to selective pressure.

This is illustrated by Figure 2: the adaptation operators may be part of the interactor (right-hand side), hence carried by knowledge and subject to selection, or they can be considered as part of the agent infrastructure (left-hand side), like the genetic code. Currently, it could be possible in the experimental cultural knowledge evolution setting to run experiments in which agents select their adaptation operators [18].

5. Who controls what?

Another important difference is that genes are not shown, though knowledge can be expressed. More strikingly, individuals can change their knowledge, not their genes (in principle). If this is the case, then replicators will be the direct object of selection, by their hosts, and they can be eliminated or altered without killing their hosts. Hence, the host behaviour depends on its culture, but the host may change its behaviour, by changing its culture. This indeed leads to faster cultural evolution, but does not seems to suit the replicator-interactor model.

In biological evolution, the environment selects the replicator (gene). In cultural evolution, it seems that the interactor is selecting the replicator, i.e. that people select their knowledge. This may seem contradictory.

Moreover, human agents may be in control of all steps:

variation they can change what they want, actually more by adaptation than by error, e.g. fashion;

transmission they can decide what to transmit in case of explicit concious transmission, in this sense this seems more Lamarkian;

selection they actively select their culture.

All are somewhat mixed in cultural evolution: The variation that occurred at transmission/replication time can now occur at any step, thought it may still occur during transmission (which is not inheritance). Moreover, the conscious variation occurring in cultural evolution is biased: it may be adaptation. Darwinian evolution requires reproductive selection because variation occurs during reproduction. It is difficult to claim that cultural evolution requires this kind of reproduction/transmission.

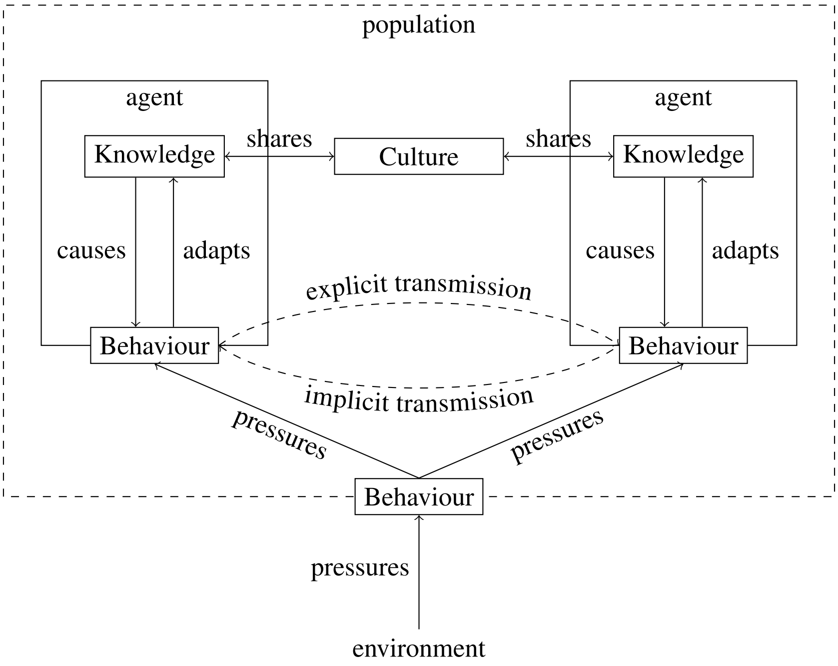

Figure 4. Culture as shared knowledge within a population.

It can be argued at length whether agents perform selection on their own (free will) or this is fully determined by the environment in which they are. However, as already mentioned, the environment is the force behind selection although it is mediated through transmission and adaptation. One may argue that human agents are not in control of anything [20]: in fact they only respond to selective pressure and, ultimately, the environment is operating selection through the agent. A cultural trait may be selected out either by the organism, getting rid of the trait, or by the environment, by killing the individual. That the organism selects the trait may be interpreted as a simple answer to selective pressure. This double selection may be puzzling, but it is classical selection anyway.

It is also unclear what the object of selection is [21]: the replicator (Dawkins: gene), the individual or the population (Darwin: species)? Or it can be the interactors, if one remarks that selection does not necessarily reduce the set of individuals, but the distribution of traits. This is an anti-selfish gene statement. Already in biology, this chicken-and-egg problem occurs.

6. Population

So far we simply adopted the micro-standpoint of individual agents. It is interesting to introduce the population standpoint. We do not have to take a strong position about what makes a population. It is possible to assume that there exist populations of agents and that communication within these populations has something that they do not have across populations.

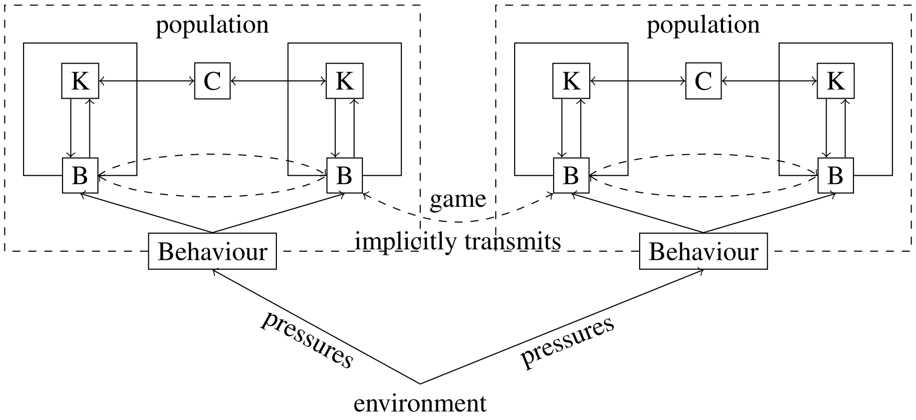

Figure 5. Implicit transmission across populations.

Just like species, populations are difficult to define. A species is not defined by sharing a precise set of genes (we do not have exactly the same), so interbreeding has been retained as a practical characterisation. In modern natural evolution, species are characterised by their pool of genes. Following the interactor-replicator model adapted to cultural knowledge experiments, this should be knowledge. This has already been considered as a simplifying definition [10].

It is arguable to define population by shared knowledge if knowledge can be trasmitted to other populaton without selection. However, defining a population as characterised by some shared knowledge has advantages. Maybe the capacity to live together is the definition of a population. With this capacity come that of sharing and exchanging ideas. This is also the occasion to give a more tangible definition of culture as the knowledge shared by a population. Therefore, we can adopt the following standpoint:

- the agents of the same population share some knowledge, that we can properly call (part of) culture;
- only agents of the same population directly explicitly transmit knowledge (synchronisation).

This is illustrated in Figure 4.

It is unclear if adaptation should be restricted to adapt private knowledge or if it could affect shared knowledge as well. In the former case, culture does not evolve; in the latter case, it is not easy to understand how a single individual can alter shared knowledge... we will have to invent it. If such individuals can alter shared knowledge, then it is clear that interacting with new populations, may alter population shared knowledge.

Now there is no obstacle that two populations, sharing the same environment, interact together. This happens, of course one individual with another, through implicit transmission, as in Figure 5.

Defining populations with respect to the knowledge they share opens the door to considering embedded subpopulations depending on the knowledge they share.

7. Generation

The notion of a generation is somewhat clear at the level of individuals, but unclear at the level of population. Often, it seems like a population would leave room to another population with its own characteristics.

Even in biology, individuals are generated one by one, or few by few, at least not one generation at once. Hence, the notion of generation is mainly abstract (at the population level). Moreover, individuals from several generations coexist in the same population. Exactly because of this, the former generation can transmit culture to the next. The important point is that, individuals cannot change genes, so they necessarily transmit them only to the next generation and only to their offspring. On the contrary, they can exchange and adopt knowledge. Hence, culture spreads horizontally; it replicates, but not from generation to generation.

Vertical transmission is however quite important in our societies, it is both a factor of knowledge preservation, transmission and selection. This can be added to experimental cultural evolution as described in Figure 6. Transmission from one generation to another may involve differential knowledge replication in a similar way as in genetic programming and eventually with the same alteration refinements.

8. Conclusion

Experimental agent-based simulation of cultural knowledge evolution may be considered from the replicator-interactor perspective. This provides a framework in which to raise questions, and eventually to answer them.

Although the simple 'knowledge as replicator-behaviour as interactor' model is intuitively appealing, it raises difficulties. We discussed them and refined the framework defining agents for simulation to address them. This is only one possible answer to such questions, but their implementation does not raise difficulties.

In fact, these problems are not specific to experimental cultural knowledge evolution: they have to be solved for accounting of cultural evolution at a 'micro' level. Most of these problems (1: culture does not create the individuals alone, 2: individuals control most of the selection process, and 4: culture is transmitted without reproduction) are already present in cultural evolution. Moreover, generations and populations are already biological abstractions. Hence, if the replicator-interactor model is a proper generalisation for evolution, these issues will have to be addressed.

We are currently testing this model with a replication of experiments in [17] across populations of agents which may after a given number of games either reproduce differentially or synchronise, i.e. exchange, their knowledge.

Of course, all this remains a simplifying model. The reality of cultural evolution is eminently more complex. However, this helps bridging the gap between generalised evolution and experimental cultural knowledge evolution, thus eventually cultural evolution.

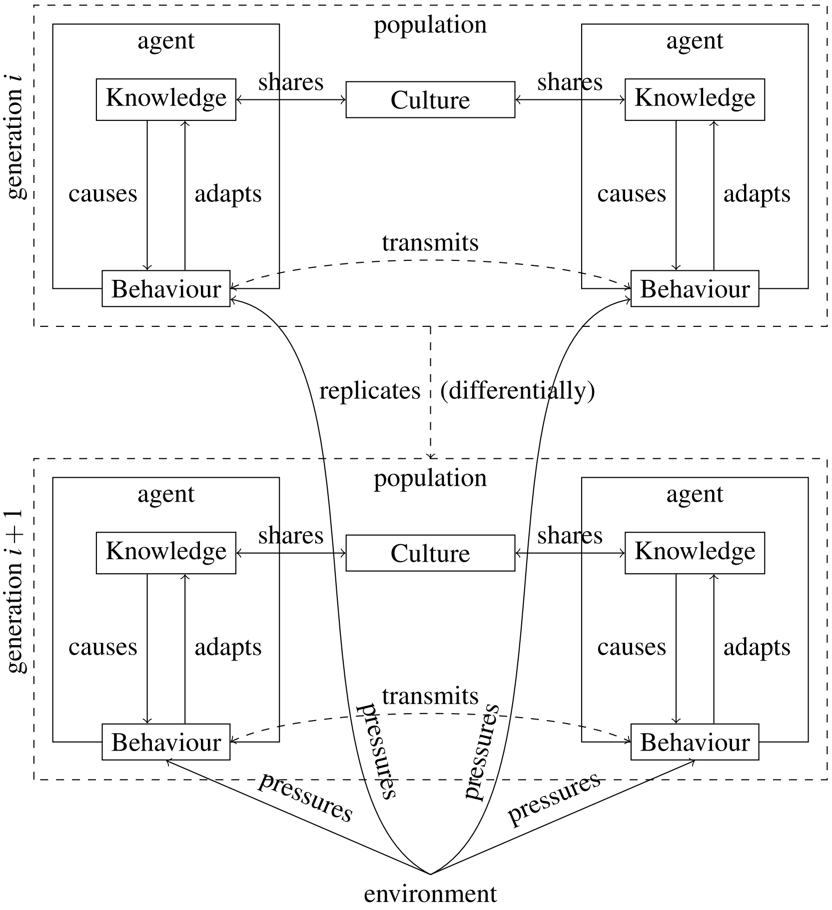

Figure 6. Generational (or vertical) knowledge transmission.

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