The Question of the Emergence of Dance in Human Evolution

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Abstract

The role of this thesis will be to build a conceptual-empirical model of the emergence of dance in human evolution and to test it through computational modelling. The question we will be aiming to answer is to what extent can dance be considered to have contributed to the development of human fitness and culture. If we define fitness as a measure of the probability of a new generation, dance can only be considered a positive contribution to fitness if it can be shown to have any *developmental* effects on behaviour in general. There is nothing in dance that directly provides any more access to resources, protection from disease or from predators. However, dance is significant as a motor-cognitive, as a social phenomenon, as a universal feature of human cultures and as a self-justifying activity that depends on types of mimesis; a fundament of culture in general. We will argue for the need to resist reductionism when addressing the question of dance, that the answers to its evolutionary significance lie in the fact that it is an activity where so many domains of variation overlap. Dance has all the attributes of a cultural activity; convention, mediation and internally constrained, while having all the attributes of a spontaneous, emergent activity. It is necessary therefore to dedicate more efforts to developing unified conceptual frameworks and to modify future research with this goal in mind. If we remain confined to individual fields, an entire class of questions of this nature will remain forever out of reach. Part of the paper will be dedicated to mathematical and computational models of evolution. We will show how mathematics can contribute to the building of a common framework and how computational simulations can generate complementary data to answer questions that by their very nature deal with very limited data sets.

Contents

Author Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

1 Introduction: The question of dance

The question of the emergence of dance in human evolution is often equated with the question of adaptation: How could dance increase the reproductive fitness of the individual, of the group or of the species [49] [138]? Does dance increase social bonding within a group, and therefore its performance more generally [145]? While these types of questions are certainly relevant to the problem of the emergence of dance in human evolution, the question of adaptation limits the inquiry to the scale of an individual or the scale of a group. Dance is not only an individual or group phenomenon: it is also a cultural activity which, by definition, transcends any single individual, group or generation. Culture can be broadly defined as a body of information (conventions, technologies, techniques, rituals, religions, institutions...) that is mediated, or transmitted, over generations via non-genetic means [180]. As a phenomenon, it is not reducible to a single generation: it is the product of a lineage. Any attempt at answering the question of the emergence of dance needs to account for this.

Dance is sometimes dismissed as *'merely a recreational activity'* by those who oppose the idea that dance has an adaptive benefit [145]. Indeed, the ubiquity of dance in human cultures [138][86] should not be considered an indication that dance is adaptive: it is only an indication that humans have a universal taste for dance [56][121]. However, the idea that a trait can be either functional or a 'mere recreational activity' is misleading for at least two reasons: First, play is by definition an activity, or a set of activities, that is recreational on the local timescale [37]; it is nevertheless critical to the neurological and social development of almost all social animals including humans [124] [64]. The developmental process that occurs through play is critical to the functioning not only of the individual, but of the social group and the culture as well [122]. Second, according to the work of Andreas Wagner, a trait that is 'neutral' on the local timescale (that is it does not contribute to an increase or decrease in reproductive fitness) is not neutral on the ultimate timescale if it contributes to the evolvability of the species [174]. Indeed, as will be seen in this thesis, new complex traits are more likely to be combinations of existing ones than they are to emerge from scratch [101]. This means that, at least in principle, a recreational activity can be critical to the development and preservation of key cognitive, social and cultural traits that contribute to the overall evolvability and robustness of the culture.

The aim of this thesis is to contextualise the question of the emergence of dance within the broader set of research questions on cultural evolution, with a particular focus on the origins of culture. We will argue that 'playful' activities should be expected to be fundamental to many aspects of human culture which rely heavily on conventions (language for example). It will be shown that the emergence of human culture depends on a certain level of mimesis or imitation [65] [101], on social-demographics and mediation [70] [46], on endogenously defined physical forms (a prerequisite for symbolic representation), perception and value hierarchies [53] [59] [43][111], and on repetitive rehearsal of complex movements [38][42]. It will be shown that dancing, as an activity, has a part to play in all these foundational attributes.

This thesis will be composed of four chapters: The aim of the first will be to introduce the various concepts and schools of thought that are necessary for approaching the question of dance from the perspective of cultural evolution. The second chapter will build on this introduction by reviewing the relevant literature concerning the origins of culture, including the cognitive, social-demographic and the various interpretations of the archaeological data. The aim of the second chapter will be to identify where dance would fit into the various models and explanations that have been proposed.

The aim of the third will be to develop a unified conceptual framework of culture in general, and the significance of dance within it. The function of this framework will be to provide a solid conceptual grounding for potential computational models. The fourth and final chapter will be a review of a minimal computational model of the unique properties of cultural evolution, namely the effects of imitation and social demographics on evolutionary trajectories. This will be concluded with a discussion on possible areas of development on this question.

1.1 Dance: The Necessity of Interdisciplinary Research

In this thesis, dance will be defined as a capacity to synchronise movements with an external auditory rhythm and with other participants [96]. The question of the emergence of dance in human evolution is interdisciplinary. It is significant on the social level in being an activity through which multiple individuals can bond [46]. It is significant on the developmental level, as dance has been shown to be extremely effective in the development of general motor-control functionality at all stages of life; in children, adults and elderly [20] [103] [140]. Furthermore, it is a behaviour that is extremely rare in nature [17] [96], it is almost completely absent in other species with very few animals even having the capacity to synchronise movement to an external auditory rhythm (these being dolphins, sea-lions, seals, some song birds and humans; notably no other primate relative seems to have this capacity) [146] [127].

Dance is a highly significant activity from the perspective of culture and cultural evolution. Hoppit and Laland define culture as "group-typical behaviour patterns that are shared by members of a group, that rely on *socially learned and transmitted* behaviour" [82], where social learning is defined as "learning that is *facilitated* by the observation or interaction with, another individual (or product of another individual)" [82], and social transmission is defined as occurring when the prior acquisition of behavioural trait by an individual, when performed or in through another behaviour associated to the trait, has a positive causal influence on the rate at which another individual acquires that trait [82]. Boyd and Richerson define culture as "information capable of affecting individuals' behaviour that they acquire from other members of their species through teaching, imitation, and other forms of social transmission [13], where information is used as a broad term encompassing many forms of behavioural patterns (from skills and techniques to rituals and values)[13]. Here we shall be defining culture as patterns of behaviour or information that can me mediated (transmitted) through social interactions, intra and/or intergenerationally. Dance is significant in being an activity that can exist both as a cultural activity (a behavioural pattern that is transmitted via social interaction) but also as an instinctive capacity independent of any culture [103]. It is an activity that can exist both within and without a cultural context.

This distinguishes it from cultural activities that can only exist within a cultural context and depend on the existence of preexisting cultural information. Language for example, has no existence outside of a cultural context and could not emerge without preexisting forms of culture; language depend on more fundamental standardised social interactions, more fundamental pattens of behaviour that would have had to be cultural [42] [97]. This shall be discussed in depth in section 2.8.2. Complex technologies such as silicon chips, or lunar modules depend on the generations' worth of knowledge and expertise; they are culturally dependent technologies [32]. In the case of dance however, it is possible for it to emerge in the absence of any preexisting culture; in the terminology of Magnus Enquist, in its spontaneous form, dance is a *cultural seed*: a cultural trait that does not depend on any existing culture[54]. Dance can exist as both a spontaneous, undirected, emergent behaviour [142] [103] *and* as a cultural dance which depends on preexisting dance being mediated. Dance is a behaviour which can exist in both a pre-cultural and a cultural context.

The question of the emergence of culture is, by definition, intimately linked to both the emergence of cultural seeds and the development of social learning and transmission. To explain the origins of culture, we must be able to explain how information began to be mediated between generations, as an emergent phenomenon of an uncultured group. The mechanisms by which culture is mediated between generations are themselves shaped by culture. Forms of transmission such as with written instruction [82] are themselves the product of culture and so presuppose more fundamental mechanisms by which behavioural patterns can be mediated. Hoppit and Laland distinguish between eleven types of social learning processes [82]:

1. *Stimulus enhancement*: occurs when the action or product of a demonstrator exposes an *observer* to a stimulus which has a causal effect on the behaviour of that observer at a future time.

2. *Local enhancement*: occurs when the presence of a demonstrator at a particular location where learning can take place increases the probability with which an observer is likely to visit that location.

3. *Observational conditioning*: is when the observation of a demonstrator exposes the observer to a certain stimuli, and that stimuli leads to a change in behaviour at a later time.

4. *Response facilitation* occurs if the presence of a demonstrator animal performing an act (often resulting in reward) increases the probability of an animal that sees it doing the same.

5. *Social enhancement of food preference*: this occurs when a demonstrator's diet increases the likelihood with which an observer is likely to consume that diet.

6. *Social facilitation*: occurs when the mere presence of a demonstrator affects the observer's behaviour.

7. *Contextual imitation*: occurs when, directly through observing a demonstrator perform an action in a specific context, an observer becomes more likely to perform that action in the same context.

8. *Production imitation*: which occurs after observing a demonstrator performing an action, a combination of actions or a sequence of actions that were not previously within the observer's behavioural repertoire,

9. *Emulation*: occurs when after observing a demonstrator interacting with certain objects, the observer is more likely to try and perform any actions to try and get the same result.

10. *Opportunity providing*: occurs when the products of the behaviour of the demonstrator provide the observer with an opportunity to engage in operant learning that would otherwise be unlikely to arise — for example by providing an easier, less dangerous or more accessible version of the task.

11. *Inadvertent coaching*: occurs when the response of a demonstrator to the behaviour of the observer inadvertently acts to encourage or discourage that behaviour.

All forms of social learning involve some causal relation between a 'demonstrator', which exhibits a certain behaviour, and an 'observer', who acquires the trait after being exposed to a stimulus called the learning phase. When an individual learns a new behavioural trait after exposure to a stimulus and there is no causal dependence between the stimulus and another member of the species then this is known as environmental learning. With these distinctions made, we can define two broad categories of social learning. The first being *facilitators* where the demonstrator has a positive effect on the probability that the observer will be exposed or acquire a trait from being exposed to some external, environmental stimulus. These include social facilitation, local enhancement, observational conditioning, response facilitation etc.. Then there are the *imitative* or mimetic types of social learning, where the principal stimulus *is* the demonstrator. These do not require (although they may include) any relationship to an external, environmental stimuli. It is with this latter category of social learning which we shall be mainly concern with in this thesis because any formalised dance depends on it [103], as indeed do many fundamental human cultural traits including language amongst other endogenously defined cultural activities. [65] [186] [38].

1.1.1 An introduction to Culture and Cultural evolution

It is helpful in this present introduction to regard biological evolution and cultural evolution as two examples of a more general process of intergenerational mediation of information. In biological evolution information is mediated via genetics, through sexual and asexual reproduction, while in cultural evolution, information is mediated via non-genetic means such as imitation or physical artefacts [97]. This information can be, but is not necessarily, adaptive. Following the framework of C.G.Williams; a distinction must be made between two domains of selection. There is the domain of information, which is referred to as the *codial* domain; and there is the domain of material, which is the physical manifestation of a pattern in the physical domain [121]. (These are sometimes referred to as the domain of replicators and interactors) [30]. There is a distinction made between a pattern and the physical manifestation of the pattern: "Information can exist only as a material pattern, but the same information can be recorded by a variety of patterns in many different kinds of material. A message is always coded in some medium, but the medium is really not the message" [121].

In the case of biological evolution, the material domain would be the DNA molecules and the codial domain the genetic sequence. What is being replicated is a specific *sequence* or pattern which takes the physical form of DNA molecules. It is the sequence, or the pattern that is being replicated; it is not the physical molecules themselves that are being duplicated. In the case of culture the material domain would be any physical medium that is patterned in space and time which can be replicated onto another physical medium we use to transfer information from one individual to another. For example a written piece of literature, or instructions for fabricating tools, or indeed a physical demonstration from a teacher, would belong to material domain, while the codial domain would be the information that is replicated in these various mediums. The physical manifestation of the information is not equivalent to the information itself. Information depends on a medium that can be patterned in order to exist, but it is not the pattern. Following this reasoning; to explain the emergence of culture it is necessary to explain not only the emergence of specific cultural information, but also the emergence of the medium that supports it.

This distinction between the message and the material pattern is important to bear in mind when dealing with cultural phenomena; explanations can quickly become convoluted without it. In this light, we find that the single term ‘dance’ is used to refer to a spectrum of qualitatively different behaviour both cultural and non-cultural domains [60] [33]. We refer to the spontaneous movement to music of infants and babies in their high chairs as dance, and we use the same term to refer to highly coordinated choreographies and dance rituals [103]. However, the former is a spontaneous behaviour that is independent of any cultural information, the latter cases depend on cultural information. There are also differences in types of cultural dance. A dance that is dependent on cultural information does not necessarily need to convey any specific information beyond the sequence itself. However, it can also function as a form of representation or dramatisation, in which there is information mediated through the dance which is not reducible to the dance.

Whilst all dance involves the coordination of movement to an audible rhythm in the physical world, there are categorical differences between those that are purely the product of a spontaneous activity, and those that are the product of some form of transmission of information. The two cases are distinct in terms of their relationships to the codial domain: the latter being dependent on some preexisting information, (which is not transmitted chemically), while the former does not.

1.1.2 Exaptation and Time-scale: the False Dichotomy between Adaptation and Invention

In general, evolutionary theories of dance and music can be separated into adaptionist (the behaviours provided a selective advantage to the group) and non-adaptionist categories. Was musical ability an invention which emerged on existing brain functions, or was the ability for music and dance adaptive, that is that it provided a selective advantage for humans and so was directly selected for by nature? The first position is often referred to as the cheese-cake model [131]; an analogy first coined by Stephan Pinker who argued that the physiological and neurological receptors for music evolved independently from the existence of music just as the receptors that appreciate the taste of cheese-cake emerged independently of the existence of cheese-cake [21]. Both positions hold the premise that, bar a few specific exceptions, music and dance ability is present in almost all individuals and cultures, and did emerge in humans. The disagreement lies in whether music and dance emerged because it is (or was) a *universal human need* or a *universal human taste*? This supposed dichotomy is undermined by Patrick E. Savage.

Savage emphasises that the debate on whether music and dance was an invention or an adaptation has outlived its utility for advancing the research into their origins[145]. These are not distinct evolutionary questions: there is the evolution of music (as a cultural and social phenomenon) and there is the evolution of musicality (the biological capacity to do music). Whether dance and music was an adaptation upon its emergence is too narrow a question. Dance is an individual and a group behaviour; but it is also a cultural phenomenon that exists across generations. Determining its adaptive qualities therefore cannot be reduced only to the level of an individual and a group timescale, but that of a cultural lineage as well. The current function of a trait need not be the same as its original function, and its functionality need not be a product of natural selection [7]. Functionality can be an *emergent* property of a trait and an environment, occurring after the trait emerged as a product of selected or drift. Heredity is a multifaceted process that occurs as a combination of DNA and intergenerational social transmission, reducing the question of dance to a dichotomy is nonsensical [7]. When dealing with complex behaviour, i.e. one that depends on multiple faculties, the likelihood that all of these were selected for a single capacity becomes vanishing small [93]. Complex human behaviour can never be divorced from the social/environmental context in which it emerged, nor from the effect it may have had on existing behaviours and on those yet to exist.

The term exaptation was first introduced by Stephen Jay Gould in 1982, in response to the apparent confusion in the biological community about the timescale over which natural selection occurs [68]. Exaptation refers to "features that now enhance fitness but were not built by natural selection for their current role". Adaptation refers to features that enhance fitness in response to immediate pressure from the environment; the feature in particular underwent selection at the time of its appearance *for* its ability to perform the function it currently serves. Examples of exaptations have been postulated at every level of biology from viral infection [87] and bacterial conjugation [69], to the level of human cognition [3].

Being an invention is not an indication of being less significant than an 'adaptation' with respect to the evolutionary trajectory of a species. An example of this is the domestication of fire. Although the domestication of fire was an invention, the introduction of cooked food altered the selection of the human genome [182]. Cooked food was an invention but had drastic consequences on our biology, behaviour and culture. Cooked food lead to modification of all levels of our metabolic system, our teeth and our brains and also had drastic social implications in terms of organisation and division of labour. Cooking is an invention but it says nothing of its significance in human evolution. Patel argues that although music is likely to have emerged as an invention, its consequences were so profound that it set off a biological feedback loop that selected for specific traits[128].

An extensive amount of time and resources are currently dedicated to finding a biological grounding for the capacity for music. That is, there is a search for genetic material that would be involved in musical ability *only* [81]. If this is found, it would be considered strong evidence that musical ability was genetically selected and must therefore be adaptive behaviour [133]. Although the discovery of such material would indeed be strong evidence in favour of the adaptive position, genes do not provide information on the context under which they were selected, nor the consequences of their emergence. Furthermore, if no such genetic material is found, this would not be evidence against the adaptive contribution of dance; neurological capacities generally fulfil multiple behavioural needs and new behavioural capacities emerge on existing ones [3]. These new behaviours can very well be considered adaptive even if they do not have a single, exclusive dedicated piece of genetic material or brain function. Traits that do not contribute to a local increase in fitness may nevertheless increase the evolvability of the species (the potential to evolve and adapt to variations in extrinsic conditions)[174].

1.2 The Role of Mathematical Modelling in Cultural Evolution Research

Evolutionary research, by its nature, is severely limited by the amounts of real world data it can draw from; most of what has been produced by evolution leaves no trace. Evolution generally takes place over extremely long timescales and over generations. Biologists resort to experimenting with fast reproducing cells or organisms and particular fossil records. Cultural evolutionary research is restricted to well conserved cultural artefacts. Intergenerational experimentation involving slow reproducing and long living organisms such as humans is extremely difficult, if not impossible. However, mathematical modelling can offer an alternative to this. Through mathematical modelling there is the possibility of testing the general assumptions of postulated rules and boundary conditions that govern an evolutionary system [153]. Mathematical models provide the possibility to simulate an evolutionary system over time scales that are not feasible to study through experiments. Being a phenomenon that takes place over extremely large time scales, the study of evolution will forever be constrained to a limited set of hard data sets: the fossils, geological data and cultural artefacts that are preserved. In mathematical modelling, it is possible to create representations of propositions from researcher in different fields. There are risks involved in this method. When constructing models it is easy to design them to produce the results that are expected and make them mere pictorial tautologies. To counter this, it is imperative to motivate assumptions as firmly as possible in real world data and to be certain not to mistake mathematical models for hard data sets. Mathematical models are, and will remain, a tool for research and a topic of research in its own right.

The ability to ground the assumptions of a model in many different fields can be tremendously powerful. Phenomena that get researched in different fields are often described under different conceptual frameworks and this severely hinders the amount of interdisciplinary work that can be done. There are cases where it is necessary to use terms which are specific to a certain field, however, often this needlessly hinders interdisciplinary research. One should not underestimate the impact of conceptual tools on research and academia. As Robert L. Trivers writes in the foreword to the 40th anniversary edition of Richard Dawkin's *Selfish Gene*, "this landmark book was revolutionary not because it presented any new evidence, but showed the existing evidence in a new light", which has shaped the direction of future research [30]. Independently of the merits and flaws of Dawkin's theory, his work has shaped and focused the discussion of future research, which has been tremendously fruitful. This a remarkable achievement [**?**]. In mathematical modelling there is the potential better to synchronise our conceptual frameworks across different disciplines. The role of mathematical models will never be a substitute for other forms of evolutionary research and data but will be a powerful complementary methodology. Research topics in general transcend fields. Any tool, therefore, that offers the possibility of integrating fields under a single framework, and thereby transcends them should be held with great interest and invested in.

A significant property of dance is that it bridges the spectrum between an activity that can serve as a material medium through which the codial domain of cultural information can exist, and also as a spontaneous, non-cultural activity that is not contingent on the codial domain. This may also has repercussions for the development of imitation and mimesis, which is at the foundation of culture more generally [96]. One of the aims of this thesis will be to describe this transition mathematically and to represent it in a computational model.

1.2.1 Higher dimensional spaces

Chapter 4 will propose and present a minimal computational model for cultural evolution. The computational model will be a modification of models from systems biology (namely evolution in high dimensional spaces) that will contain the particular aspects of cultural evolution. Evolutionary systems biology models a biological system, such as a cell, in terms of a parameter space with each parameter defining a dimension of the space. Within the parameter space, there is a viable subspace: for certain values of a parameter the system is function, for other values the system is defective. Such models can help describe the evolution of biological systems in terms of trajectories through this high dimensional parameter space.

To introduce the idea of evolutionary systems as high dimensional space we consider the following example: There are around 5000 chemical reactions that are known to take place in the various metabolisms of each organism on earth [174]. Each organism can perform some of these reactions but none can perform all. The set of reactions that an organism can perform describes its metabolic genotype. This metabolic phenotype can be represented by a binary string in a 5000 dimensional space where a 1 in position n would indicate that metabolic reaction R_n is present and a 0 in position m would indicate that reaction R_m is absent in the organism's metabolic phenotype.

Reaction number	Metabolic phenotype
R_1	1
R_2	0
R_3	1
$\vdots$	$\vdots$
R_{2500}	1
R_{2501}	0
$\vdots$	$\vdots$
R_{4998}	1
R_{4999}	1
R_{5000}	0

Table 1: Metabolic phenotype

Since a metabolism is essential to all life forms all life forms have a 'metabolic genotype' which can be represented by a 5000-dimensional binary string. Furthermore, it is possible to represent the evolution of a given genotype to another by changing a 1 to a 0 when it loses a metabolic function, and changing 0 to a 1 when it gains a metabolic function. The evolution of a metabolic genotype is represented by a trajectory in this high dimensional space.

In a similar way, culture can be represented by such a high dimensional space. If we consider for now the technological capacity of a population, the *'technological genotype'* of that population can be represented by a binary string in the space of all possible technologies. Just as a metabolic reaction is performing a certain function: providing a specific output for a certain input; we represent each technological capacity as the ability of producing a certain output for a certain input (where the capacity is acquired via learning, social or otherwise). Such a space may ultimately be infinite, but the technological capacity of every human culture at any time is finite. We represent every technological culture by a binary string in an n-dimensional space where n is the number of all technologies.

Technological space	Technological phenotype
T_1	1
T_2	0
T_3	1
$\vdots$	$\vdots$
T_i	0
T_j	1
$\vdots$	$\vdots$
T_n	0

Table 2: Technological phenotype

The technological genotype has a particularity with respect to the metabolic phenotype in that certain technological traits are dependent on preexisting ones. For example, if trait T_k represents steel sword making, this presupposes a host of other technologies such as mining, mastery of fire, manufacturing of hammers etc.; if T_j represents net making, this presupposes the presence of rope making and the capacity to make knots. In Tazmania, the loss of the capacity to make bone needles led to the loss of warm clothing, as skins could no longer be sewn together [70]. Certain technological traits depend on the preexistence of others. However, there are broader cultural capacities implied within the capacity to manufacture certain technologies; while tool use has been observed in other animals such as chimpanzees, capuchin monkeys, dolphins and the New Caledonian crow [173], none of these animals have the cognitive or cultural capacities to manufacture highly complex technologies.

If culture is defined as forms of information that is transferred across generations, then complex technology is part of culture. Culture can be described as a set of distinct traits which, like technology, has interdependencies with other traits: for example, social groups can emerge only if its members are capable of sustaining social relations and this is only possible if there is play during their developmental years [124][8]. Therefore, the capacity to sustain complex social groups is contingent on the presence of play in infant development. Likewise, traits that depend on complex motor-control such as spear throwing or speech are in turn dependent on the capacity to rehearse movements accurately in order to refine the neurological connection; such traits require the capacity to rehearse which means abstracting a movement from an immediate goal; so far the rehearsal of movements has not been observed in any other primate [39][42].

This very basic model which describes human cultures in terms of points in the space of all possible culture is undoubtedly highly simplistic. For example, it does not capture the specific variations between traits of the same category. However, at this highly abstract level it will be possible to observe some of the direct consequences of mediation of traits between individuals.

Although unlike genetic evolution which has an empiric genotype-phenotype map, where the encoded genome is in fact encoded in the physical space; in the case of the ‘cultural phenotype’ the code is implicit. This follows from Williams’ distinction between the codial and physical domains; because there is a recognisable physical cultural pattern that repeats itself in individuals and over generations, this model implicitly models the codial domain which is the code that corresponds to the cultural traits in question. Cultural traits have properties which are distinct from genetic traits: the evolution of cultural traits depends on both external and internal constraints. The external constraints which are satisfied are generally regarded as *functional* qualities of culture, such as the ability to prepare foods which are toxic unless a proper procedure is followed. [23]. While the internally constrained characteristics of culture, such as the differences between different tea ceremonies in Japan, India, Morocco or England are considered conventional and perfectly ambiguous from the point of view of external constraints and therefore neutral variations from the point of view of natural selection. However, as we have seen, certain internal constraints that are neutral in their specificity with respect to nature can lead to the emergence of functionality. For example the capacity to learn new sounds and distinguish them by internal convergence is a prerequisite to language [110]. Although there is bias as to which facial expressions or movements humans and even other apes react to, such as those that communicate fear or danger [136], there is a degree of ambiguity to the specific physical form, but no ambiguity to the function of the expressions.

1.3 Robustness of Culture

This capacity for being able to evolve across neutral trajectories from the point of view of natural selection on a local timescale is not neutral on the ultimate timescale. A remarkable quality of human beings is the capacity for thriving in almost every environment on earth. Humans are *robust* with respect to ecological variation. Something is robust if it remains functional under extensive variation, and it is fragile if a little variation causes it to become defective. To use Andreas Wagner's analogy of human communication and computer programs; written language is robust [174]:

"N smll stp fr mn, n gtn lp fr mn knd"

remains understandable to a human being. The meaning can be conveyed despite significant alteration. However, a single misplaced semi-colon can render an entire computer program defective. A computer program is fragile. In biology, robustness of a genetic code can be tested by "genetic knockout" experiments whereby a single gene is removed from a DNA molecule and the functionality of the single celled organism is tested. What was found is that in the vast majority of cases the genes were superfluous; that is removing the gene had no effect on the functionality and the reproductive success of the organism [174]. This should be surprising as genetic material is costly to make, therefore any organism that has a large amount of superfluous genes is using resources unnecessarily and therefore nature should select against these. However, it is precisely the presence of this 'superfluous' genetic material that makes these robust.

The bacterium *Eschericha Coli* can survive on dozens of different food sources thanks to a metabolism that has over 1000 different chemical reactions. If its preferred food source glucose is not available, an *E.Coli* is able to switch to a secondary source such as ethanol. In comparison, the bacterium *Buhnera aphidicola* has a metabolic system of only 263 chemical reactions and can only survive in a very specific environment, namely within the cells of aphids. Outside of this environment, its survival prospects are very low [174]. The very genes that are not functional in most cases in the case of *E.Coli* are what make the bacterium robust in the face of environmental variation. Indeed most of *E.Coli's* genetic material can be removed and the bacterium will remain functional. However, 90% of the Buhnera bacterium is necessary to its survival.

Like *E.Coli*, humans are able to survive and thrive in almost every environment on earth and are able to adapt to rapid environmental changes. However, this is only possible with culture. As the ill fated Burke and Wills were to find out during their exploration of Australia in 1860, cultural information is critical to survival in new environments. When the exploration party ran out of provisions they were forced to find local sources of food. The staple for the local Aborigine populations was *nardoo*, a type of aquatic fern. Without a specific preparation the fern is poisonous. Nardoo contains thiaminase, an enzyme that breaks down thiamine. The explorers failed to acquire the local cultural knowledge of preparation and subsequently died of thiamine deficiency [23]. Humans can survive in the Australian desert, and they can survive in the Siberian wilderness, Alaska, the jungles of the Amazon and central Africa; humans are robust with respect to ecological variation, but this robustness is contingent on their capacity for culture.

The capacity for culture is multifaceted. It depends on intrinsic relationships between individuals over generations, and therefore a locally perceived benefit to interaction with others in the group. One of the aims of the thesis is to develop the ideas of Wagner who describes the space of all possible genotypes as a high-dimensional space. As the space increases in the number of dimensions, so too does the probability that there is a viable evolutionary solution in close proximity to any position in the cube.

> *Neutral change provides the browsers of nature's libraries with a safe path to innovation through treacherous territory of meaningless texts. Once-neutral can turn into essential parts of innovations [...]. And once they do natural selection can preserve them. [...] After neutral changes have paved the way to an innovation, selection preserves those neutral changes that contributed to the innovation. [174]*

In other words, the evolvability of a species is only possible if there are neutral variations to move from one point in the space of possibility to another. As was seen in the introduction, genetic material that does not perform a local function (and should therefore be considered an inefficiency from the perspective of natural selection), is precisely what allows the evolvability of the genome, and therefore is 'functional' on the ultimate timescale. In theory it is possible that as things become more complex, there are more functional solutions.

Behaviours such as language occupy very specific regions in the hyper-cube of possible behaviours. Presumably the path towards it is also available to the other animals, but what constrained the path towards it? Culture is not a uniquely genetic process, if all of culture were to disappear over night, humans would still have the genetic capacity for culture, but there would be no language, no technology, no songs or formalised dances: what would be the activities available to us that would move humans through the hypercube incrementally to the space that we have fully developed culture again?

Arthur Koestler illustrates the question that needs to be addressed in the parable of the two watchmakers Bios and Mekhos:

> *The watches they made consisted of about one thousand parts each, however, the two rivals used different methods to assemble them. Mekhos assembled his watches bit by bit – rather like making a mosaic floor out of small coloured tiles. Bios, on the other hand, had designed a method by which he would first assemble the parts into subassemblies of about ten parts each, each of these could be held as independent units. He would then assemble ten of these subassemblies into a higher order subassembly (consisting therefore of around a hundred parts each) and finally combine those to make the watch. If Mekhos was interrupted for any reason, and put down his partially assembled watch, it would break down into its individual parts. When Bios was interrupted, the partially assembled watch would only break down into subassemblies, or a particular subassembly into its comparatively little number of parts. [...] Complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not. The resulting complex forms of the former case will be hierarchic. We have only to turn the argument around to explain the observed predominance of hierarchies among the complex forms; hierarchies are the ones that have the time to evolve.[93]*

Culture is highly complex, and although it is not a mechanical structure like a watch, it would have had to emerge progressively in a hierarchical manner and with every incremental cultural subsystem being able to sustain itself through time. However, in evolutionary theory we do not presume that there is a watchmaker assembling these subsystems [93]; they would need to assemble themselves according to their own local and internal operations, without foresight of the overarching structure that can emerge as all the parts are in place.

From this perspective, the question of whether dance is adaptive or not becomes secondary. For complex culture to have emerged there would have to had been many stable ‘subassemblies’ in place prior to its emergence. Whether this subassembly is made stable because it is has been heavily selected for by natural selection, or that it is stable because it is a self-justifying activity that individuals are compelled to engage in, does not matter from the perspective of the higher order assembly. Provided that the organism as a whole is viable from the point of view of natural selection and that the subsystem can facilitate the emergence of a higher order system, this would be sufficient for a ‘merely self justified activity’ to be significant but only in a counterfactual way. In the case of dance the question would be: to what extent does dance, or any of its cognitive sub-components, contribute to other forms of cultural behaviour? At what level in the cultural hierarchy does dance belong: is it a foundational subassembly? Or a higher order cultural behaviour? Does it catalyse the formation of other forms of culture?

Is Dance Functional? The fact that dance is ubiquitous in the human species is not evidence that it is an adaptation; a point that Williams makes about cultural traits in general: “There is no more reason to expect a cultural practice transmitted between churchgoers to increase churchgoers’ fitness than there is to expect a similarly transmitted flu virus to increase fitness. When the rates of transmission of infectious elements are rapid relative to turnover rates in host populations, the fitness of the transmitted information is largely decoupled from that of the host.”[121]. In order to justify whether dance is indeed adaptive it is necessary to examine what dance is in more detail and specifically in the context of the emergence of culture in general.

In a review, Bernhard Fink presents some of the functionalities of dance [138]. First, dance could have functioned in courtship performance as more competent male dancers are perceived more attractive than less competent dancers [176]. [103] (There is no evidence however that this increase in attractiveness translates into a significant increase in reproduction rates). Second, dance could have developed for ritualistic purposes. Rituals are essential for the redirection of aggression within a society, which in turn is essential for maintaining the viability of a social group [102] [148][65]. In the case of humans who are wholly dependent on the functionality of the group outside of which there is no survival or reproduction [44], an activity that reduces the risk of group disintegration would increase the fitness of the species. (This does not necessarily translate to an individual increase in fitness; although a ritual may increase the fitness of the group, this may come at the expense of an individual in the case of a human sacrifice or expulsion [65]). Third, dance could have an effect on social cohesion more generally [49]. There is evidence that moving in a synchronised manner increases the production of endorphins associated with pleasure and prosocial behaviour [48]. Group dance could also act as an unfakeable demonstration of coalition strength [19].

In order for information to be edited by selection, it must be able to undergo selection at a higher rate than the rate of competing processes such as mutation and drift[121]. This supposes therefore that if information is to be acted upon by natural selection there must be either a very high rate of selection or the rate of mutation and drift must be low [101]. If cultural traits are to undergo any natural selection, they need to encode information reliably otherwise cultural drift will dominate the evolutionary dynamic. This a precondition for natural selection to have any editing effect on the evolution of any information pool. There are at the very least two levels of selection operating in parallel; there is selection for the information, but only when there is sufficient accuracy of information preservation. There is variation not only in the information but in the material medium in which it is embodied. Since all information depends on a material medium to exist in the physical world, it follows that the material medium must precede any cultural information. Only once there is a medium and mediatory mechanism, then a feedback loop can emerge and select for the mediums that are best for preserving cultural information. But again there must first be an initial medium.

One of the particularities of culture, is that the mediums that are used to convey cultural information are themselves defined by cultural conventions. Languages for example depend on culturally determined rules, or codification, and therefore presuppose the existence of culture [42]. Dance exists as both a cultural activity that follows a culturally transmitted rules and conventions, but it also exists as a non-cultural, spontaneous and instinctive activity [103]. In this sense dance can be argued to be more fundamental as it does not require preexisting culture. Dance is significant from a sociological perspective. It is almost a universal feature of human societies at all points in history [138]; even in contemporary societies which have discontinued many of their rituals, dance remains prominent [103]. Dance is a social activity for both the participants and the spectators, and can engage collective attention independently of culture [103][85], which is a prerequisite for shared intentionality [167].

However, the extent to which dance can be regarded as a catalyst for other cultural behaviours to emerge needs to be evaluated empirically; a point made by Ian Cross about the music and language:

> *They may be different manifestations of the same underlying capacities; or they may be the same suite of communicative capacities co-opted for different ends in different situations. They may have evolved separately or conjointly, or they may have merged or split over the course of human evolution. They or their subcomponents may be present in the repertoire of other species, or they may be unique to humans. Only by synthesizing evidence from the whole range of human sciences, in the context of investigations that are alert to cross-cultural differences in the conceptualization and implementation of communicative skills and the features shared with other species, can we achieve a degree of defensible clarity in our understanding.[84]*

1.4 Concluding remarks

In this section, we presented culture as existing in two distinct domains; existing both as information in a codial domain and as material patterns in the physical world. Culture is not simply abstract information, it is *embodied*, and this premise has real consequences for the way we interpret the evidence. From this perspective, dance occupies a unique position: it can exist as a material phenomenon, as a material phenomenon that embodies codial information about itself and then as a medium for information beyond its own sequencing. With this in mind, the second chapter will review the literature of cultural evolution. The third section will develop existing conceptual models which will allow us to represent the emergence of cultural evolution in general and the emergence of dance in particular. This will be followed by an introductory computational model which will abstract some of the premises of the conceptual model. The final section will be a discussion some of the implications of this thesis and what future research would be worth investing in.

2 Review of the Literature

The aim of this chapter is to make a critical review of the literature on cultural evolution. Unfortunately, it is not possible to infer the emergence of dance in human evolution directly as it leaves no material traces. The capacity to dance does not have an observable effect on physical anatomy, or any other physical markers. It is necessary therefore, to use an indirect approach. There are material markers which would have required culture to produce. These can therefore be used as a proxy for the presence of culture in prehistory. By combining these with additional observations from cognitive sciences it is possible to build a general hypothesis for culture, and from there proceed deductively to a theory of the emergence of dancing.

The first section will argue why it is necessary to employ multivariate analysis when dealing with the question of dance. This will be followed with a critical review of the archaeological record and the various conflicting theories of culture that are based on it. We will also look at evidence for gene-culture coevolution and the cultural-niche hypothesis, which shall both be presented later in the chapter. Both hypotheses hold the premise that culture must be explained within the context of the environment, genetics and social group. This will be followed with a review of the cognitive literature, its relation to evolution and individual development.

As was mentioned in the introduction, dance refers to a spectrum of behaviour that spans both the cultural and the pre-cultural domains. It functionality is not singular. It cannot be reduced to simply a social-bonding mechanism, courtship display, a functionless pleasure system riding on the neurological reward mechanisms selected for other purposes, or any other single property. Looking from the point of view of selection, dance is relevant on at least three levels: natural, cultural and sexual selection.

2.1 Multiple levels of variation

The significance of the emergence of dance in human evolution can only be understood in terms of its place in the evolution of culture in general. Dance is an activity that does not directly provide more resources, offspring or protection from predators and so cannot be argued to be a ‘freestanding‘, fitness enhancing behaviour, from the point of view of natural selection in that it does not offer a local fitness benefit to those that partake in it (the question of sexual selection will be addressed later). However, as forementioned, cultural traits do not exist in isolation and can, in principle, affect the emergence of others (either positively or negatively) [54]. Dance is a cultural activity, it is found in all human cultures, it has a profound effect on both cognition and social-group demographics. If there is an argument that dance has a positive effect on the fitness of individuals and a group, it has to be via its effect on factors that favour the emergence of locally adaptive traits.

Our capacity for culture depends on and sustains specific social-group demographics and cognition. These factors mutually constrain each other: the social-group demographics change the requirements on cognition and different sets of cognitive faculties will influence the social-group demographics [47]. The social-group is a major influence of the type of experience an individual will have, and therefore the cognition and behaviour it can acquire through experience. There is a strong dependency between cognition and demographics, however; they remain distinct levels of variation.

Variation at one level will not automatically translate to variation at another. Different social-group demographics can exist for a given set of cognitive faculties and vice-versa. The cognitive faculties of an individual human are dependant on the combination of genetic inheritance *and* experience. For a given genetic make-up, the experience of an individual can vary drastically [117]. Cognition and genetics therefore occupy distinct, although related, levels of variation.

There are certain rules that must be considered when undertaking multilevel research:

1. First, one cannot generalise findings across levels of analysis. Findings at one level of analysis do not automatically translate to others. Correlations at the population level do not generally translate to the individual level [90]. For example, archaeologists may find a strong correlation between the quality of tool making and the global health of a population. However, an individual who makes very poor quality tools may still have good health; he may still have access to good tools made by other members of the population, or simply the extra resources that the better quality tools provide. The correlation between tool quality and health does not translate to the individual level [119]. Similarly, an individual level correlation does not automatically translate to the population level. A study by Michael Muehlenbein found a strong correlation between the levels of testosterone of male chimpanzees and their social status within the population [112]. However a population with a high average level of testosterone in its males would not necessarily perform better than a population with lower average testosterone. Correlations at the individual level may be greater, smaller, neutral or even reversed at the population level [119]. And since high testosterone levels are linked to increased metabolic rates and immunosuppression [116], the latter case is a distinct possibility.

2. Second, the individual performance ratings of the parts cannot be evaluated independently of the whole. For example; an orchestra constituted of highly talented musicians may nonetheless perform badly together [177]. There will no doubt be a relationship between orchestral and individual performance, but the evaluation of an individual's ability cannot be taken in isolation from the orchestra. The desired characteristics of the individual is a function of all the other members of the orchestra, the genre of music played by the orchestra, the audience... A human being is heavily dependent on the performance of the population for its survival. Hunting big game, for example, is only possible by working in a team. The ability of a population to hunt big game no doubt depends upon the physical prowess of individuals, but only if they are able to work as a coordinated, integrated unit and perform at the team level. The archaeological and ethnographic record of Paleolithic and contemporary hunter gatherer societies show that division of labour is crucial to the evolutionary success of the population [156]. Tasks such as hunting, foraging, sewing, cooking are distributed across the population. Although the distribution is often done according to sex and age, there is a high degree of permeability to this:

   > *"The axiomatic 'division of subsistence labour' in recent foraging peoples holds that men tend to hunt large animals, and women and children tend to focus more of their efforts on gathering plants, capturing smaller animals or both. Ethnographic accounts also teach us that the boundaries between these broad economic roles are highly permeable, and that there are many individual departures from the general pattern. It is clear from some ethnographic studies, for example, that women possess the knowledge and skills needed for hunting large game, and that boys without mothers may learn to sew weatherproof clothing in regions where it is needed" [156]*

The performance of the individual can only be gauged in tandem with that of the group. If follows that the evolutionary fitness of humans can only be evaluated by considering it in a group context. Both need to be accounted for in evolutionary explanations of human behaviour. Favourable strategies of how to prosper in an environment do not depend simply on the interactions of individuals with an environment; they depend on the behaviour of a group within an environment and the behaviour of the individuals in that context. There are multiple levels of variation to consider.

One cannot infer across levels of analysis; correlations at one level do not translate immediately to the other. Unfortunately, this fact is often overlooked in evolutionary fields. Too often researchers will commit the fallacy of inferring across levels of analysis. Richard Boyd argues that the 'evolutionary' prefix has allowed a 'methodological anaesthesia' in the field of evolutionary psychology, in particular moral psychology [11]. Evolutionary theory has been used to justify contentious un-scientific claims in the field, and unwarranted bias to nativist and modular theories. These assumptions are beginning to be exposed as psychological evidence is being examined (eg: neural reuse hypothesis [3]). The theory of evolution is one of biology's most successful theories, and undoubtedly has profound relevance for other fields such as psychology, neuroscience, anthropology and others. Evolutionary theory is so powerful due to the far reaching implications in different fields, but one needs to keep track of the assumptions that are made whether they are warranted by the evidence or not.

Evolutionary theories of human behaviour are fundamentally limited in the data from which they are able to draw. It is not feasible to isolate a population of humans over any meaningful evolutionary time. Evolutionary theories of human behaviour have to resort to making predictions which can be tested against the limited record we have available [155]. Caution is of paramount importance when looking at dance from an evolutionary context. An evolutionary explanation requires a synthesis of many different fields which although may all bare the same prefix: 'evolutionary' may not necessarily be comparable or compatible. The remainder of this chapter will examine the general evolutionary questions and theories in different fields and discuss whether they are compatible or not.

2.2 The Archaeological Record

In archaeology, culture is defined as accumulated information that has continuity from one generation to the next [31]: special techniques and technology, knowledge of natural environment, social conventions. New information can enter the culture, innovations can displace existing information; but a culture must have a form of continuity from generation to generation.

The archaeological record is the first source of hard evidence for the emergence of human culture. It is however extremely limited, the record is open to many different interpretations, and any specific claims difficult to defend on the basis of the record alone. It can provide a valuable understanding of how social demographics are a crucial component of cultural evolution, and there is enough evidence to suppose that the emergence of culture was a gradual, generative process. In archaeology, cumulative culture is inferred by markers of behaviour that depend on the transfer of accumulated information capital from one generation to the next [155]. At what point humans became capable of accumulating information is one of the most pertinent questions in archaeology. Answering this relies on our ability to interpret the archaeological record; unfortunately this is the source of much debate [107].

This section will critically review the archaeological record, discuss the points of contention regarding the dating of the findings, as well as the limitations of the record itself.

2.2.1 Markers of Cumulative Culture

Markers of cumulative culture are any material artefacts which would have required an accumulation of information to produce, and therefore from which we can infer the presence of cumulative culture. Examples of technological markers are stone technologies; blades, microliths, backing; use of materials such as bones and antlers; and more advanced technologies such as bow and arrows or throwing spears. Microliths are perhaps the most popular markers because they are found in many parts of the world (Africa, Asia, Australia) and at various periods in history [75].

Other markers could be: jewellery, beads, ornaments and use of pigment; mortuary practice such as burying the dead, possibly with objects and ornaments; advanced forms of hunting such as hunting large game; the ability to survive harsher, variable environments; and advanced control of fire.

The limitations of the record Although we can infer the presence of cumulative information by the presence of markers, the absence of markers does not indicate an absence of cumulated information. As is pointed out by Peter Hiscock and Sue O'Connor [74] [76]; old markers will be less well preserved than more recent ones. Therefore, the further back in time we go, we should expect a decrease in markers, simply because they have not survived to this day. The increase in markers we find over time does not necessarily indicate a gradual accumulation of culture, but rather an inherent bias of the record. Hiscock and O'Connor further argue that we cannot infer congitive capacity from technological markers alone. Even if it were the case that ancient groups did not make tools that depended on cumulated information, this would not indicate that they were behaviourally or cognitively primitive. Older groups may have had fewer incentives to innovate if they lived in an environment that did not require it. This does not mean that they were not cognitively capable of producing them, it could just indicate an absence of necessity. The social structures may have, nevertheless, been complex [107]. Accurately deducing the place and time of the emergence of cumulative culture is made more difficult by these biases in the record, and any explanation needs to take these limitations into account.

One of the predominant hypothesis for the emergence of culture is the 'Cultural revolution hypothesis'. It suggests that the sudden explosion of cultural markers in the archaeological record, around 50-40 kya, is evidence that culture must have spontaneously emerged around the same time. This model is severely criticised; it is accused of ignoring the time bias described above. The time bias is also linked to a second, geographical, bias. The explosion of markers around 50-40 kya coincides with mass migration from Africa to Europe. Europe has been more heavily excavated than any other continent in the world and therefore the discovery of more markers from this time could simply be a reflection of new migrations to that area, rather than the emergence of technology in our species. Proponents of the cultural revolution hypothesis have been accused of failing to acknowledge the richness of the African archaeological record; many of the markers found in the European record were present in African Middle Stone age tens of thousands of years prior to the supposed cultural revolution [107]. Finally, the increase in number of markers could be an indication of increased population size rather than the emergence of any new cognitive attributes. An increase in population size would increase the demand for more tools and therefore lead to the more markers without directly implying new technological capacity (although an increasing population is in itself significant from the point of view of social evolution). This highlights another limitation of the record: that it is very difficult, if not impossible, to infer the origins of a new marker. When a new marker first emerges, it is by definition singular; the material record however naturally is dominated by markers that are numerous and easy to find. New technologies only become part of the record once they are established and a common feature of a group's tool kit.

2.3 Breakthrough hypotheses

Dance as a cultural activity does not leave any clearly identifiable markers in the archaeological record; as a result, the question of the emergence of dance needs to be approached indirectly in the light of current theories of culture more generally. This section is intended as an overview of the various models of culture that exist, which can then serve as a starting point for the question of dance. Hypotheses for the emergence of cultural evolution can be separated into two broad categories: *break-through models* and *incremental models* [155]. Break-through models argue that the human capacity for culture emerged suddenly, brought about when a certain set of initial conditions were right. The main candidates for causing the breakthrough are: genetic mutations, leading to the development of cognition capable of sustaining culture; the emergence of symbolic thought and language (either caused by genetic mutations, a new social environments that would select for language, or both); population size explosion leading to new selection pressures for culture.

2.3.1 Evidence against break-through models

Break-though models are struggling to hold up to archaeological evidence. They have been undermined by a lack of evidence for a sudden switch in behaviour or social demographics, at one point in time [107]. Instead there appears to have been a "flickering" period between 100-200 kya. ""Various signs of cognitive sophistication eg: expanded trade networks, bow and arrow technology, jewellery and ornaments, appear and then disappear in different regions of Africa" [72]" Paul Mellars and Chis Stringer [77] [109]argue that cultural evolution was driven by genetic mutation around 50-40 kya. However, Kyle Brown and colleagues have pushed back the emergence of microlithic technology to at least 71 kya in South-Africa [16]. Brown shows that there were at least six steps for making these microliths: gathering wood fuel; heat treating the stone; preparing the stone core; producing the bladelets; and trimming the bladelets into their final shape [144]. Mounting the blades as spear or possibly arrow heads, would have required additional steps. The making of these tools were likely to have taken place over extended periods of time, (weeks or months) and would have been interrupted by other necessary tasks. Advanced capabilities for planning and imagination would be required for making these tools: a representation of the tool would need to be held in memory, as would a representation of incremental steps. This technology is therefore a suitable proxy for the presence of advanced cognitive abilities long before the 50-40 kya suggested in the breakthrough models. Of course this could simply push back the cultural revolution to a much earlier time. However, the fluctuating pattern of microliths in the record seem to suggest that the technology was lost and re-emerged several times in history [16].This would seem to suggest that culture therefore could not be reduced to quick genetic changes, sudden emergence of language, or any other critical event. It is likely to depend on a conglomeration of factors which combined over time.

That some have a patchy record could be due to the fact that only a small area of Africa has been excavated; they claim that the absence of evidence for cumulative culture is not evidence of its absence, and that patches in the record will be filled in with time [144]. This claim however is unfalsifiable, and so the burden of proof should remain firmly with the proponents of this theory. Until proven otherwise, the fluctuations (which persist throughout time) will remain a major flaw in the break-through models.

There are several other crucial pieces of evidence against the genetic mutation hypothesis [36].

1. There is extensive evidence of cultural behaviour in other human lineages. Neanderthal and Denisovian cultures in Europe and Asia show signs of tool use, mortuary practices and symbolic mediated behaviour [10][63]. If the emergence of culture was dependent on a key series of genetic mutations, one would have to explain how the capacity for culture emerged in non Homo sapiens. Indeed this suggests that the genes required for early culture are very ancient and would have had time to coevolve with culture.

2. There are multiple examples of cultural traits being lost in different populations. For example, there is evidence that over an 8,000 year isolation from the continental mainland, the societies of Tasmania lost a variety of valuable skills and technologies; including bone-tools, cold-weather clothing, hafted tools, nets, fishing spears, barbed spears, spear-throwers, boomerangs and even the domestication of fire [70]. Another example is the correlation between the size and connectivity of a population, and the complexity of their tool kits [92]. These would indicate that a distributed mechanism within the population is necessary in addition to any individual genetically determined cognitive capacities. Both of these examples suggest that variations in population demographics, which are highly variable in time, were fundamental to the emergence of culture.

Perhaps the most unsatisfactory aspect of the break-through models, beyond not fitting well with the archaeological record, is that they demand the presence of very specific initial conditions. There is a lack of a mechanism which would explain how these initial conditions arose in the first place. The hypotheses are not generative, but needle in the haystack proposals with little explanatory power.

2.4 Generative models of culture

The evidence suggests that both culture, and the capacity for culture, emerged incrementally over extended periods of time. This has motivated several *generative models* of culture, which explain the emergence of culture as a multivariate generative process. For example, because culture apparently began at least 71 kya, genes and culture would have had time to coevolve and mutually constrain each other, which has motivated what is known as the gene-culture coevolution hypothesis [13]. A second example is the complementary hypothesis of cultural niche construction [95], which suggests that the individual cognitive potential for culture is insufficient for culture; there must also be the right cultural environment for culture to exist. This sets additional conditions of possibility for culture. Culture does not depend only on the genetic substrate, but also on the social-demographics and the environment. The conditions of possibility are distributed over many different factors.

The generative models, by definition, depend on the relations among multiple factors. Consequently, because the archaeological record is limited to markers that have survived through millennia, a generative model must depend on other cognitive and socio-demographic factors. Such models are often criticised for not being strictly falsifiable in the Popperian sense. However, these models can have great epistemological value, but they require first the proposition of a mechanism before it can be open to further empirical corroboration [4]. In this section we will review a few examples of these.

2.4.1 The Interdependence of Cultural Traits

To understand the emergence of dance as a cultural as a cultural activity, we need to understand the consequences of interdependence of cultural traits; given that ethnographies show a strong relation between dance and other cultural activities such as ritual [27]. In his model, Magnus Enquiste lays out the mathematical framework for modelling cumulative culture. The model aims to capture: the evolution and diversity of culture, the dependencies of cultural traits to one another, as well as their tendency to appear and disappear [54]. There are two key properties of the model: (i) a cultural trait can be lost once acquired; (ii) and all the cultural traits in a population relate to one another in that they increase or decrease the probability with which a trait can be gained or lost. A trait can either increase or decrease the probability with which another is discovered or lost. A trait that is used frequently is less likely to be lost than one that isn't. For example, a population living near the sea may develop technologies and techniques for fishing, and pass the knowledge and artefacts across generations. If, for whatever reason, the population moves in-land, fishing knowledge would become obsolete. It will therefore be used less frequently and is more likely to be lost from the population. Some cultural traits depend on the presence of others in order to be acquired. For example, cooking could only come after the domestication of fire. These traits therefore depend on the pre-existence of other traits. Therefore, the full body of culture depends on a special class of cultural traits that can emerge when there are no previous traits in the population present: we refer to these as *cultural seeds.*

Central to Enquist's argument is the notion that different traits can either facilitate or inhibit the emergence of future traits. Several traits could mutually facilitate one another. Mutual facilitators make it more likely that similar sets of traits will eventually appear in different cultures; it increases the number of avenues by which a trait can enter a population. Similarly, traits could mutually inhibit one another; the presence of one trait in the population reduces the probability of the other being acquired, or may even exclude it as a possibility. Mutual inhibitors increase differences among cultures. Different cultures may acquire different incompatible traits at different times and therefore never converge thereafter because their current cultural repertoire prohibits it. Only by losing one of the mutual inhibitors could they converge again. Given the relationship between traits, the model suggests that:

1. Although some cultural traits may provide little or no evolutionary benefit in isolation, they could be a prerequisite to other, fitness enhancing traits. The greater the net number of traits in the population, the greater the space of future traits with a non-zero probability of emerging.

2. Therefore, having a mechanism to keep the total number of traits in the population high, even low fitness enhancing traits, would increase the potential for acquiring high fitness traits in the future.

This leads to the question: What early cultural activities would most greatly facilitate the emergence of adaptive cultural traits? A group that engages in a *facilitating* activity would be more likely to develop culture than those that do not. Given that dance engages many cognitive capacities that are relevant to other cultural capacities, such as the imitation of conventionally defined movements, the question of whether dance could be such a facilitating activity is appropriate. Consequently, the focus of the study of dance from an evolutionary perspective would be to try and identify the effect that dance has or doesn't have on the emergence of other cultural traits.

2.4.2 Social-demographics and Cultural Capital

As a cultural trait, dance depends on social transmission and social learning, which is in turn heavily dependent on social demographics. Understanding the effect of social demographics on the transmission of other forms of culture, such as technologies, is relevant to understanding dance as a cultural activity more generally; especially when considering the possible socialising affects of dance [51][103]. Joseph Henrich presents a model of cumulative culture that aims to explain why certain groups lose vast amounts of adaptive cultural information when they become isolated, and uses the example of Tasmania, whose societies were isolated from mainland Australia for over 10,000 years. At the time of the first European contact with Tasmania, the population had not only far simpler tool kits compared to the societies of mainland Australia (200 km to the North), they also had far simpler tool kits compared to their own ancestors. In total, the entire Tasmanian tool-kit consisted of around 24 basic item, compared to the mainland Australians who processed almost the entire Tasmanian tool-kit, plus hundreds of more specialised tools, such as bowls, barbed spears and canoes. Perhaps more striking is the comparison to their own ancestors. Since the separation from the mainland, there was a substantial loss of adaptive technologies. There is evidence of fish being a significant part of the diet between 8000 and 5000 years ago, only for fishing to disappear completely from then onward. It is similar story for cold-weather clothing which disappeared also. Considering that Tasmania had a cool maritime climate only a few hundred kilometres north of an extended Antarctica, the clothing would certainly have been beneficial.

$$\Delta\bar{z} = -\alpha + \beta(\epsilon + ln(N)). \tag{1}$$

"Cultural learning becomes cumulatively adaptive when the effect of having a larger set of models from which to pick the most skilled exceeds the losses from imperfect copying." [70] The main point emphasised in his model is that cumulative adaptive cultural evolution is "the joint product of our evolved cognitive abilities and sociodemographic factors."[70].

There have been counter arguments to this model, arguing that the reason for the loss of technology in Tasmania may be due to the varying selective pressures rather than a failing of cultural transmission. However, loss of technology is not isolated to the case of Tasmania. Indeed a pertinent observation was made by William Rivers as early as 1912 in "The disappearance of the useful arts" [70] [141]. Rivers observed that certain oceanic populations had lost technologies such as the canoes that they would have required to get to the island in the first place. Their disappearance could not be attributed either to economic reasons (i.e. loss of raw materials), nor to any replacement technologies, as these were not present. Although it is difficult to draw any precise conclusions from Rivers' data, it does suggest that loss of technology is not isolated to the case of Tasmania.

Comparing this data to that of better connected groups in similar habitats seems to suggest that connectedness is a crucial factor. In Terra de Fuego, which shares a very similar climate to Tasmania, the better connected populations living there did not lose technology [70]. Michelle Kline and Robert Boyd have shown a correlation between connectedness and the size of a population and the technological complexity of their tool kit in island populations across Oceania [92]. It was found that bigger and better connected groups had more complex and better performing technologies in their cultural repertoire. All the populations in the study lived in similar habitats, and there was no evidence of any variability in cognition between groups.

This evidence suggests that social-group demographics are important for to the emergence of adaptive cultural information and cumulative culture. The evidence suggests that *before* cumulative culture can emerge and be maintained, a certain sociodemographic threshold must be breached. The benefit of technology is not sufficient of a condition to be selected; the ability for the group to connect and reliably mediate information is more fundamental to its existence.

Stereley (in press) argues that cultural evolution did not take place to the same extent in other descendants of Homo Heidelbergensis because, although they possessed the genetic starter kit, their group sizes were too small and were weakly connected. In these conditions, adaptive innovations are more apt to be lost. Novel innovations have fewer potential students so they are more likely to be lost soon after they emerge. Fewer copies also means fewer variations are generated and so selection would be slower. Fewer connected groups also means that there are fewer models to learn. The collective intelligence hypothesis suggests that around 250 kya humans started to live in larger and better connected foraging bands, meaning that cultural evolution could finally begin to get off the ground; flickering initially before taking off (citations pending).

2.4.3 Further models of Culture as Adaptive Information Capital

Both cultural and biological evolution share a number of key properties, namely: variation, inheritance and selection. However there are also fundamental differences among them:

1. In genetic evolution only the offspring are able to acquire certain genes, in the case of cultural evolution the ‘offspring’ are in fact students.
2. Genetic information is acquired only once but cultural information can be acquired, lost and reacquired many times in an individual’s or population’s lifetime [157]
3. Culture regulates its own evolution through regulatory traits. A regulatory cultural trait is one which changes an individual’s disposition to future cultural traits “Culture creates it’s own rules” [1].

If we look at the evolution of culture as a probabilistic distribution, the weights for the emergence of a given trait depend on the existing distribution of traits in the population.

This argument is presented by Stefano Ghirlanda: that culture can introduce its own constraints on future evolutionary paths [62]. Ghirlanda’s model examined the self regulating effects of fashion cycles and conformity/anti-conformity dynamics. The simulations showed how the evolutionary paths were constrained by what came before.

Relevant to the question of dance is the capacity high fidelity imitation, that is the capacity to repeat a sequence of steps with a very high degree of accuracy. A model by Hannah Lewis and Kevin Laland [101] examines the interplay among four parameters of a trait: ρ_1 the probability that a trait is acquired by the group through invention, ρ_2 the probability that two traits in the group are combined to produce a new trait, ρ_3 the probability that a present trait is modified into a new trait, ρ_4 the probability that a trait is lost from the population. It was found that for $\rho_4 < 0.5$ cumulative culture was not sustained and that for $\rho_4 > 0.5$ it was almost inevitable. At $\rho_4 = 0$ cumulative culture was possible but somewhat limited. The models support Michael Tomasello’s argument that copying fidelity is crucial for cumulative culture to take place [168]. The model also showed that the trait was less likely to be lost in a larger population. Traits have to exist in a population long enough before it can be combined with others or developed; both copying fidelity and population size are crucial to this. There seems to be a correlation between the two factors. This is consistent with the evidence that humans are the only observed organisms to have extensively developed cumulative culture and also to have the largest social structures of any large animal. This model is relevant to the question of dance in human evolution because if copying fidelity is critical to the emergence of cumulative culture then we must suppose that humans had acquired the capacity for copying fidelity *before* any selectively advantageous, cumulative cultural behaviour that depend on this capacity could emerge. For this reason, I suggest that the capacity for high fidelity imitation could not have emerged by direct natural selection, because the cost of failure is so high. I suggest that high fidelity imitation would have had to develop under social environments where imitation is incentivised (or self-incentivised; i.e. fun), but inaccurate imitation does not lead to the activity dropping out of the culture altogether. I suggest that dance satisfies such conditions. The following section will examine the dependency between cognition and the social environment.

2.5 Cognition

Culture is information continually mediated across generations. This definition presupposes the *cognitive capacity* that can support a mechanism to mediate information and to maintain stable social groups across generations. This section will present how variation at the level of cognition occurs at the level of individuals, and from this derive its dependence on social factors. It is possible to infer a feedback loop whereby the social environment favours certain variations in cognition, and certain variations in cognition further sustain the social environment. The first subsection will review the neural reuse hypothesis which explains how variation in cognition is generated at the level of neural connectivity rather than variation of brain modules. This will be followed by an overview of how culture can exploit variation at this level to generate new cognitive functionality. We will review the cognitive gadget theory, the OPERA hypothesis, and will argue why cognitive exaptation should be expected as a natural consequence of having multiple levels of variation.

2.5.1 Neural reuse hypothesis

Neural reuse hypotheses are based on the observation that the functional organisation of the brain systematically reuses the same cognitive circuitry in different cognitive tasks. There are two prominent theories for how neural resources are deployed in the brain: *anatomic modularity* and *global wiring optimisation theory* [3].

Anatomic modularity suggests that brain regions are domain specific; individual areas of the brain are dedicated to specific tasks. Most anatomic modularity based theories use the definition of Jerry Fodor [58] [9]: that a module is a domain specific, innately specified, and informationally encapsulated system [120]. Anatomic modularity suggests that each area of the brain can be decomposed into independently functioning modules, each module being dedicated to a specific cognitive domain. Max Coltheart [120] suggests that the modularity of the brain is a fundamental assumption in neuropsychology, and that its success of neuropsychological treatment is evidence that this premise holds: that the brain is organised into anatomical modules. This inference is heavily criticised by Michael Anderson [3]. The inference is based on the observation that localised brain injuries can impede the ability to perform certain tasks in isolation; for example the cases of double-dissociation. Double-dissociation refers to instances where related tasks utilise independent brain regions. A patient can loose his ability to use syntax, which means he cannot formulate sentences, whilst retaining the capacity to *process* syntax and to comprehend a sentence. Similarly, a patient can loose the capacity for conceptual knowledge whilst retaining a capacity for syntax. A patient can retain the ability to place words in the correct syntactic form but the sentences would fail to refer to any conceptual understanding of the world. This evidence has repeatedly been used as evidence for the modularity of mind hypothesis. However, this inference has been strongly rejected by David Plaut and Guy Van Orden who argue that the modularity of mind hypotheses are based on overtly selected data to fit the models [132] [171]. They do not actually explain what is seen in general. A new hypothesis of cognitive structure is required to explain the functionality of the brain, both before and after traumatic brain injuries of all sorts; including, but not limited to, instances of double-dissociation.

Peter Carruthers probably presents the best attempt at salvaging any form of the modularity of mind hypothesis [22], by making some concessions to the reuse of certain parts of the brain for new functionality. However, Anderson believes that this small concession actually undermines the modular theory as a whole [3]. There is a logical fallacy in the argument: admission that certain parts of the modules can be reused whenever it is possible suggests that the modules are no longer fundamental building blocks. They can no longer be described as ‘modules’ in this sense. In addition to the empirical challenges to the modular hypotheses, there are theoretical challenges to some of its claims. Massive modularity was argued to be more efficient energetically, however: “Energetic constraints predict more compact or localized [brain systems], not necessarily fewer brain systems.” [3]. Massive modularity predicts energetically inefficient brains, which is not what is found in reality.

Optimal wiring hypothesis The hypothesis proposes that the wiring in the brain would tend to be optimised with respect to metabolic activity and the size and shape of the brain. Several examples for optimisation has been found in several neural circuits in cats, macaques and in the nervous system of Caenorhabditis elegans [24] [179]. An example of particular relevance, as stressed by Anderson [3], is the finding that the 57 Broadmann areas of the cat cortex are spatially arranged so to minimize total wiring length. Out of the 4×10^{76} potential layouts of the cat’s brain, it is close to optimal in terms of wiring length [24]. This finding heavily suggests the presence of a mechanism that minimises the possible search space. The space of potential arrangements is simply too vast to be optimised in evolutionary time without one.

Four predictions of global wiring optimisation and neural reuse [3] (i) Total wiring length is not the only relevant constraint; total brain mass is also important. Neural reuse would be a favourable strategy for keeping total brain mass low. (ii) Global optimisation predicts that sub-systems are likely to be sub-optimised. Optimisation of the whole predicts that the parts will in general be sub-optimal if their function is measured in isolation from that of the whole. (This is a result of an absolute trade-off, that emerges from traits relying on the same physical parameters. Statically, the optimisation of a specific trait with respect to some measurement tends to be distributed on a bell shaped curve. An optimised, or close to optimal, performance will lie at the tail ends of the distribution, and so would depend on a very specific arrangement. The probability that two different performance metrics would be equally optimised by the same configuration becomes increasingly small as the complexity of the physical substrate becomes large. This is due to the number of possible configurations increasing. There will therefore tend to be a trade-off between two traits that depend on the same physical substrate). (iii) The level of optimisation would not be distributed evenly across the brain. Some sub-systems are likely to be more optimised than others. (iv) Finally, the level of optimisation of the sub-system would likely correlate with its age. Neural reuse would predict the layout optimisation to be higher for older sub-systems than for newer ones because the system would have had more time in which to adjust to the new sub-system.

2.5.2 Cultural neural reuse

Variation in the neurocircuitry does not only need to be optimised with respect to wiring length, metabolic cost and brain mass; it must also be optimised with respect to function. The brain needs to be able to perform certain functions, otherwise the energetic efficiency would be redundant. This presents a new search problem. Unlike the physiological constraints, the functional constraints can fluctuate on much smaller time scales. Physiological constraints tend to be more stable, depending on chemical and physical processes. Functional constraints, however, depend on a higher order of variation which can vary with the environmental and sociocultural conditions.

Cultural neural reuse is a special instance of general neural reuse as defined by Anderson [3], in which existing neurocircuitry has been redeployed within the lifespan of an individual to perform new functions. [36]. D'Errico (2018) identifies four conditions that must be met in order to qualify as cultural neural reuse: (i)A brain area or region is to be reused for a cultural function (e.g., language, reading, numeracy, etc.) distinct from the one(s) it initially served (e.g., action recognition, object recognition, etc.), and for which it evolved. (ii) The reuse has to result in the formation or stabilisation of a new (functional or anatomical) network in the brain. (iii) The reuse must not be the direct outcome of heritable modifications in the genetic-developmental program that controls the formation of the species-specific brain gross functional anatomy and structural connectivity. (iv) The reuse is to be induced or triggered by the exposure to pervading cultural practices, involving teaching or other means of cultural transmission. "Cultural neural reuse refers to specific instances of neuro-plasticity. Neuroplasticity indicates the ability of the brain, and the central nervous system more generally, to modify physiological, functional, and/or structural features as a consequence of experience and practice," [36]

It follows from this definition that cultural neural reuse is deeply related to the sociocultural environment in which an individual lives. It also follows that any systematic emergence of cultural neural reuse would depend on the culture being able to sustain an optimal learning environment. Cultural neural reuse is selected by culture first and foremost. Even if a cognitive attribute can be argued to be an adaptive advantage with respect to nature, it does not follow that it is a natural adaptation. As was seen in the examples of the loss of 'useful arts' in isolated populations, natural selection is not strong enough a constraint to select for traits that depend on higher order mechanisms.

The hypothesis describes a feedback loop connecting culture, cognition and, by extension, sociodemographics. The argument up until now focused on how a combination of cognition and sociodemographics sustained culture. Now there is the added dimension of culture creating a feedback, changing the cognitive substrate that sustains it. The true significance of this will be developed later on. In the following section, however, we continue the review of the feedback of culture and cognition.

2.5.3 Cognitive gadgets

Examples of cultural neural reuse are not necessarily confined to higher order skills such as reading, writing, music or dance. Celia Heyes claims that key lower order cognitive mechanisms, such as selective social learning, imitation and theory of mind all show evidence to be *cognitive gadgets* rather than *cognitive instincts* [72]. The term cognitive gadget refers to cognitive mechanisms that are assimilated by cultural learning as opposed to instincts inherited through our genes.

Heyes suggests that strategies for social learning are themselves culturally transmitted. Imitation for example, is not, as has been claimed in the past, an instinctive capacity. New born infants do not imitate generally. Only in the case of tongue protrusion has a correlation been found, and given that newborn infants also protrude their tongues in reaction to other stimuli, it cannot be interpreted as imitation. Heyes suggests that imitation is learned through associative social learning; a child will learn from feedback from their parents and other accomplished imitators, when a baby frowns the mother frowns also and the baby will make the association that it is frowning. The feedback relationship between mother and child is crucial for child development. In an experiment by Dr Edward Tronick, mothers were asked to stare at their infant with a blank expressionless face for two minutes, which was enough time to induce a state of stress in the infant [169]. Although this is not direct evidence for imitation being a learned behaviour in particular, it shows a high level of dependence a child has on responses from a social environment.

A point of criticism to the cultural gadget theory is that proving that a particular skill such as imitation is affected by experience does not prove that it is the origin of it: "The course of a river can be changed, but that does not mean the original course of the river was carved out by canal diggers. Similarly, evidence that imitation can be changed by sensiormotor learning does not imply that the capacity to imitate normally develops through sensorimotor learning." [72]. Many animals are capable of associative learning, but very few can imitate, and none to the level of precision shown by humans. Imitation could not be explained by associative learning alone. Heyes argues that this is because other animals are not incentivised to imitate as much as humans; we reward imitation with social integration. This claim is yet to be supported with conclusive evidence, but a cross twin study by Fiona McEwan showed that identical twins showed no greater similarity for imitation than non identical twins [108][71]. This supports the claim that imitation is not dominated by genes.

Mindreading -the ability to infer the thoughts or intentions of others through external perception- is another proposed cultural gadget [73]. Similar to print reading, mindreading has a regulating and interpretive aspect; in being cognitively demanding and slow to develop. It is also characterised by neural specialisation, developmental disorders, and it shows evidence of cultural variation. Indeed, theory of mind is typically acquired at different ages in different cultures; Chinese children typically acquire theory of mind later than children in the US [143]. Mark Sabbagh suggests that this could be because Chinese children tend to have fewer siblings than those in the US and so have less exposure to other mental states. Mindreading is learned through a combination of observation and explicit instruction from 'expert mindreaders'. Cross-cultural differences show that the scaffolding process is crucial in the development of mindreading. Mindreading is a special skill required in teaching both from the point of view of the teacher and the pupil. This early scaffolding process could have a cumulative effect on the acquisition of other skills.

Fundamentally, the theory does not argue for any new relationship between cognition and culture: this is obviously the case in regards to higher order cognitive tasks such as language, music and dancing. Each culture has its own variation. The cultural gadget theory only stretches the effect of culture back much further to more fundamental cognitive tasks that were long presumed to be cognitive instincts inherited through our genes. Variations in cognition can occur at both the level of genes and culture. Selection does not care at which level the variation occurs, it only considers the cognitive variation exhibited and the speed with which that variation can be generated. There is thus a degree of continuity between the genetic cognitive starter kits and culturally facilitated cognition.

The evidence that culture impacts the development of fundamental cognitive faculties begs the question of what cultural activities were there at the beginning to set this process in motion. Cultural activities can in a sense be viewed as environments of their own, selecting for and refining certain cognitive attributes.

2.5.4 The OPERA hypothesis

OPERA stands for: Overlap, Precision, Emotion, Repetition, Attention [126]. Anri Patel measured the effect of musical training on the linguistic performance of dyslexic children. It was found that the children who received musical training improved their linguistic abilities far quicker than those without. Patel argues that the increase in performance is due to there being an *overlap* between the cognitive mechanisms used in musical and linguistic activities. However, the musical training held several crucial advantages over the linguistic training: (i) the auditory perception is used to a higher precision, (ii) the emotional aspect of the music meant the child was more engaged in the activity, therefore had a greater attention span and repeated it more often. Thus the cognitive mechanisms crucial for the linguistic performance were more efficiently trained in the musical training than in the linguistic training. However, linguistic performance still improved overall because the cognitive mechanisms used in linguistics were improved by being reinforced through musical activity.

The dyslexic group as a collective began with an under optimised linguistic ability and by engaging with music, increased the collective potential for language and therefore to communicate. This is an example of a certain cultural activity increasing the performance in another domain. It can be viewed as an example of both cognitive and cultural exaptation.

2.5.5 Exaptation: a fundamental principle of evolution

The term exaptation was first coined up by Sephen Jay Gould in 1982. Its purpose was to distinguish between the current functionality of a biological trait and its historical origin [68]. Its purpose was to undermine the misconception that adaptation had primacy for explaining biological traits [99]. Too often is adaptation conflated with the idea that it must therefore be the most important function. This inference is clearly false as there are multiple examples of fundamental biological traits which emerged as a by-product of its original functionality. “Calcified skeletal support might be a by-product of a mechanism to store calcium phosphate that evolved to compensate for seasonal fluctuations in oceanic phosphate availability, and the warning colours of aposematic organisms might originally have evolved in the context of sexual signalling.” [99] In spite of its clear relevance for biology, it has proven to be more successful in the realm of technology.

> *A classic example is microwave radiation, which was originally used in the radar magnetron to intercept and reflect off target objects, and was subsequently exapted as a means to heat food. [...] Visco-elastic polyurethane*

> *"memory" foam, which was invented as safety padding in aircraft, and microalgae-enriched food supplements, which derive from organic recycling agents designed for long space missions. [...] The Trinidadian steel drum was improvised from 55-gallon oil containers by carnival performers in the mid-twentieth century. [Robert Layton] observed that when the tractor replaced the horse and ox in French farms in the 1960s, discarded horseshoes were used as gate closures and hubs of wooden cartwheels were mounted horizontally to form the centre of a rotating stile. [99]*

The distinction between exaptation and adaptation is that: a trait is adaptive if it involves the emergence of a new *form* to perform the function, (where form is a new physical configuration); a trait is an exaptation if it uses an existing form for a new purpose.

This definition applies not only to biology and technology, but to cognition and motor-cognition. As was reviewed in the previous section, the same fundamental brain structure could be reused for new purposes. New cognitive traits can emerge as a consequence of exposure to a certain environment.

This should be expected as a natural consequence of natural selection and distinct multilevel variation. Selection only distinguishes between functional variations, and not between the specific mechanism that produced that variation. The specific mechanism that will end up generating the variation that is selected for will be the one that generates that variation the most quickly.

In the case of human cognition, variation can be generated at the level of the genetic information that codes for it, or the level of the substrate. And variation can be generated at the level of cognitive development. When the level of possible variation at the level of cognitive development is low, we should expect the majority of variation to occur at the level of the substrate; and therefore that selection will be tightly coupled with variation of the substrate. However, once enough variation can be generated at the level of brain development, then we expect the level that generates the better variation the most quickly to prevail. As the brain becomes increasingly complex, the number of possible wirings of the brain goes up also, and therefore so does the amount of possible variation that can be generated at that level without selecting for any new variation at the level of the substrate. What we regard as exaptation in the brain is a natural consequence of the brain anatomy reaching a certain level of complexity and therefore allowing variation in cognitive functions to occur independently of variation in the genetic substrate.

When the space of possible variation at a level of synthesis becomes large enough, then selection at that level becomes possible. Selection acts on variation which can take place at the level of a component or at the level of their synthesis. As the number of components in the set increases, the number of potential orderings and combinations increases. There is therefore an increase in the space of possible variations independent of any variation at the level of the component themselves. This would be analogous to varying the wiring of the brain through development rather than selecting for new variations in genes.

Through the lens of interaction and replication domains, this simple metaphor would describe two different forms of information from the replication domain: there is information about the components and there is information about the ordering of the components. There is no reason in principle that the information needs to be replicated through the same channels. Indeed, if Heyes' cognitive gadget theory is correct, they do not.

Cultural Exaptation The same notion of exaptation can be applied to cultural innovations. Cultural exaptation refers to the use of pre-existing cultural features for new functions [36].

A suitable example from physical technologies would be Artificial Memory Systems (AMSs) [36]; devices used for recording, storing, recovering and possibly transmitting information outside the body. They are early forms of notation. These usually take the form of marks on hard objects such as bone, antlers or stone. The techniques for manipulating these materials, as well as the cognitive apparatus required for processing the markings for what they were, needed to be in existence beforehand.

> *"The emergence of AMSs may be interpreted as a case of cultural exaptation in which materials, tools, and techniques developed for producing objects without any notational import have been co-opted for a new purpose, namely, the production of AMSs. At a more "cognitive" level, Upper Paleolithic AMSs emerge when personal ornaments, abstract engravings, and object coloring were already in place. This may suggest that also the cognitive ability to relate artificial objects or objects' features to some kind of "meaning" (self-identification, social status or belonging, ownership, etc.) was already developed and then exapted for producing AMSs."[36]*

Cultural exaptation not only applies the redeployment of technology but also of cognition. This suggests that the more traits there are in a population, the more potential exaptations or innovations can take place. Hypothetically, if there is a certain technological skill that is so specialised that no aspect of it can be reused towards other functions, then it would at worst contribute nothing to the potential for future innovation. If, on the other hand, there was an activity that involved a very large number of reusable traits, then the space of possible innovations increases drastically: it is a positive sum game (if we ignore for now the possibility of certain traits suppressing the emergence of others). Taking a very general view of human evolution; one of the qualities that makes humans remarkable is their ability not only to adapt, but to thrive in nearly any environment on earth. More generally than the inventions and use of technology, it is the continual ability to exapt that is qualitatively different from other species.

Returning for a moment to the model of Enquist for cumulative cultural innovation; the model presented the idea of a special class of cultural traits that did not depend on the preexistence of existing cultural traits, which were referred to as cultural seeds. In general however, cultural traits depended on the existence of others. The greater the number of traits therefore, the greater the space of possible cultural innovations [54]. There are, consequently, at least two questions that can be asked: what is it about human behaviour that keeps this potential for innovation high relative to the base rate of natural selection and mutations; and what 'cultural seeds' could set this process in motion.

2.6 Gene-culture coevolution

Given that culture has proven that it could be an adaptive advantage, it has been argued that genes facilitating the capacity for culture would be selected for [13] [97]. Provided that culture emerged gradually, one would predict that genes and culture would have coevolved: genes supporting the acquisition of more culture, and therefore more adaptive behaviour would be selected for. This hypothesis assumes that individuals capable of assimilating more cultural information would have greater reproductive success. However, whilst the argument is logically valid, there are very few empirical examples of specific genes relating immediately to culture. One of these being the distribution of adults capable of absorbing lactose in the world correlating with cultures that have a long history of consuming it [57]. The cultural trait of milk consumption would have selected for genes that allow lactose absorption.

Cumulative culture allows humans to adapt quickly to novel environments without requiring new genetic traits. Thus Cumulative culture takes selective pressure off genetic selection [161] [31] of new traits and instead, genetic traits that facilitate the acquisition and stabilisation of cultural traits would be selected for. Cumulative culture expands humans' behavioural repertoire and its potential for acquiring new ones. New adaptive solutions to environmental pressures can be reached through cultural innovation without new genetic traits being required. This is the basis of the gene-culture coevolution hypothesis [57] [105]. The debate of how cumulative culture emerged in human beings is sustained on multiple levels; the first being what proportion of its emergence is due to our genetic evolution. The long-standing argument that a quick succession of random mutations are responsible for triggering the emergence of Cumulative culture [77] is no longer viable; there is too much evidence in the archaeological record against it. The genetic mutation hypothesis suggests that key genetic mutations, responsible for encoding the neural circuitry used to support cumulative culture would emerge in a population and then be selected for as it is revealed to be an adaptive advantage. The gene-culture coevolution predicts a more gradual process in which the capacity for culture progressed gradually and adaptive cultural genes would be selected for at the same time as culture evolved.

General models of cultural evolution show that greater population sizes are crucial to the emergence of culture: by increasing the total number of models and students; increasing the potential for variation of traits and the potential for specialisation. Thus, genes that facilitate an increase in group size (increased capacity for socialisation) would be selected for within the frame of the gene-culture coevolution hypothesis.

2.7 Cultural niche-construction

Culture does not simply change the way a population interacts in the environment. A current generation will change the environment for future ones. Organisms do not just adapt to their environment, they also change them. They change them both physically and informationally [95]. Beaver dams, bee hives, ant hills, burrows, houses and farmland are all examples of niche construction. The organism changes its own environment in an adaptive way, a burrow for example providing protection from predators. The term cultural niche construction refers to adaptations that an organism makes so as to increase its capacity for culture. These could be modifications to the social structure or a group behaviour that increase the chance with which traits are transmitted to the following generation "in ways that scaffold the development of downstream generation of the skill and knowledge"[95]. Better variations of cultural niche construction will mean the following generation would have the potential for more adaptive behaviour, and therefore would be selected.

Kevin Laland gives five examples of cultural niche construction: (i) public broadcast, eg: through rituals, story telling, art, encoded information. (ii) Children learning technical skill or vocabulary (vocabulary cannot be learned without transmission). (iii) Division of informational labour. A human can only hold so much information in their head and is limited by how much they can pass on to others; dividing who holds what information increases the amount of adaptive information a population has access to. Elders, respected hunters, warriors, craftsmen, priests all will serve as a collective of guides for the following generation. (iv) Artefacts, technologies and techniques of generation N are available as templates and props to generation N+1 (v) children of generation N+1 can learn from multiple sources not just their parents [55]

Cultural-niche-construction models suggest that the existence of meta-cultural structure (structures that sustain the existence of others) are pivotal in the emergence of cumulative culture. Keeping cultural traits in the population from one generation to the next depends not only on the ability to perform the incremental steps for the trait itself, but also on the formation of a cultural environment that facilitates its transmission to the next generation. [95]

2.8 The emergence of dance in human evolution and cultural origins

Thus far this thesis has introduced the conditions that are required for the traits that initiate culture. The following will present what these conditions of necessity say about dance.

2.8.1 Dance as a cultural seed

A cultural seed, as defined in Enquist's mathematical framework [54], is a cultural trait that does not assume any pre-existing culture. Dance is a cultural seed in humans because it builds directly from human instincts and requires no pre-existing culture to emerge. A new born baby as young as a day old can differentiate between different rhythms. Istvan Winkler et al. have shown that a baby can detect the rhythmic difference between two sound bites [181]. If it is first played a sound bite with a certain beat, and then played a second tape with the same rhythm but with the pulse altered, the baby will perceive the anomaly. An electronic brain pattern associated with a mismatch between expectation and perception, called a mismatch negativity, will be measured [103]. Furthermore, babies are born with the ability to coordinate their movement to music; or the capacity for entrainment. A study by Marcel Zenter and Tuomas Eerola confirmed that babies naturally move in rhythm to music [184] This is an innate ability in developing children, who will spontaneously dance without any external social incentive or feedback [34].

There is a continuity between the instincts on which it is built and the cumulative cultural forms we see today. Dance, as a cultural activity, has evolved into an remarkable number of varieties. Different styles of dance are each examples of cumulative culture, with each generation building on what was transmitted to them [86]. In the hypothetical event that humans were to lose all their culture, the capacity for entrainment would remain, and dance would be able to re-emerge.

Whether dance can be argued to be a particularly significant cultural seed depends on the consequence of having such an activity within your cultural repertoire. As was iterated in the introduction, dance provides no immediate external benefit with respect to the environment. However, it could be beneficial if it satisfies either one or both of the following conditions:

1. It directly improves the internal functioning of the group which results in the group being better able to perform in face of the environment over all.
2. Having dance in your culture increases the probability of other fitness enhancing cultural traits which could not be acquired otherwise.

Group size and social bonding Given that group size plays a crucial role in the emergence of cumulative culture, any new activity, social mechanism or cognitive trait that would help keep the size of a group high should be accorded particular attention. Primate groups depend on social grooming to maintain group cohesion. Groups that do not dedicate enough time to maintaining social relationships (primarily through grooming) would tend to disintegrate [100]. There is a correlation between the cohesion of the group and the amount of time dedicated to social grooming. Unfortunately this imposes a fundamental constraint on the group sizes primates can maintain[48]. Grooming is generally a one-on-one activity, and requires a certain time investment for each grooming session. A larger group size means that more time must be dedicated to grooming at the expense of other necessary activities such as hunting, foraging, feeding and sleeping. The high time cost of grooming means that beyond a certain number, not enough grooming can take place between individuals and the group will disintegrate. Substituting grooming with a more time efficient bonding activity would be a significant step towards increasing group size and therefore creating an environment that favours the emergence of cumulative culture. Robin Dunbar suggest an extended grooming hypothesis: music, chanting (and dancing) would serve as a proxy for grooming [48]. Music, chanting and dancing, referred to a musiking [159] are known to provoke the release of endorphins in a similar fashion to grooming. Endorphins are known to be an essential chemical component to the bonding process. Musiking activities have a number of advantages over social grooming, the first being that it can involve more members and is therefore more time efficient than social grooming. Musiking is capable of bonding bigger numbers for a given amount of time.

Social groups are heavily dependent on the interpersonal relations of their constituent agents. The agents must be able to establish and maintain shared goals [50]. Ritual is another bonding mechanism used in human societies [138]. A correlation has been found between the number of initiation rituals an individual typically goes through and the harshness of the environment the group lives in. This is inconsistent with the hypothesis that groups that depend more on social cohesion for survival will invest more time in social bonding activities such as rituals. A group living in a harsher environment depends more heavily on the coordination of the group for survival [150]. One would therefore predict that a group that depends more on group cohesion would invest more time in activities that promote group cohesion.

A common view held in anthropology is that a ritualistic practice must be costly to the participants. One of the functions of a ritual is to display commitment to the group [149]. By incurring a visible personal cost, the individual demonstrates commitment and an alignment of interests. If there was no cost, the ritual would not represent a significant investment and therefore commitment could be faked. Although perhaps not costly in the sense of physical pain or mortal danger, a cultural dance can take a very long time to learn and thereby signals a significant time investment which cannot be faked. A traditional dance can be made to fulfil some of the cost condition of rituals, without resorting to physical cost, which could cost the group as a whole if there is serious injury. Having a lower cost ritual may have advantages. Being lower cost they can be performed more often, thus could serve to maintain a certain level of cohesion during extended periods without ritual.

Dance as a niche for cognitive gadgets Assuming that higher order cognition are more likely to be products of exaptations, traits that will increase the efficiency with which the space of possible cognitive exaptations can be explored would be an evolutionary advantage. Given that human cognition is incredibly complex, we can assume the search space for functional cognition to be extremely large. It has already been argued in this thesis that group size is likely to have been a critical factor for cumulative culture, and that this is significant from the point of view of cognition as well as technology. Increased population sizes mean more potential for variation in cultural traits and more potential for innovation in combining different cognitive traits. A larger population also means a bigger number of models and students, therefore a greater number of learning opportunities. And given that certain aspects of cognition are transmitted culturally, increased population size would increase the potential efficiency with which the space of cognitive exaptations are explored.

Increasing the potential for variation does not only depend on population size, it depends also on the activities engaged in. Different activities would present different opportunities for variation in cognitive faculties. The principle of selection assumes that some variations will outperform others. It follows that exploration of the variation space will have some cost attributed to it for there is the possibility that before a new variation which outperforms the existing one, far fewer performing variations would have to be trailed. Testing out a new variation of cognitive gadget in an activity such as hunting would have a large cost attributed to it: in the event that a less performant variation of cognition is utilised in a critical situation such as a hunt, the hunt would be less successful or even fail. The cost could be extremely high. Hunting would be an activity in which it would pay to stick to what works. It is an activity that is heavily constrained by natural selection, therefore one that has a low tolerance for underdeveloped variation. In an activity such as dance however, tolerance for variation is much higher. Less performant variations of cognitive gadgets would not represent the same immediate fitness penalty. Dance could therefore serve as an exploration function that can refine cognitive gadgets (such as imitation), even as an incubator for future, not yet performant cognitive gadgets. New combinations of neural circuitry can be tested and selected for.

It is highly likely that dance is itself a neural exaptation. The spacial awareness, spacial and temporal planning, and basic imitation, are likely to have been selected for much earlier than our capability for dance. But, because the activity is tolerant for variation at all orders, this means that once the exaptation has emerged in humans, more lower level traits are kept in the population increasing the potential for future exaptations. Dance collates these multiple, lower level, cognitive skills into a single activity. In terms of time efficiency this is an advantage because it means multiple sub-traits are used, and can be mediated to the succeeding generation as a single package. It also means that the space of combinations can begin to be explored, increasing the potential for further higher order functions to emerge.

It is a self sustaining cultural activity so it can insure some level of continuity between generations independently of environmental factors. In the mathematical framework of Enquist [54], dance is a trait that increases the probability of other traits emerging. First, by increasing the potential for variation of lower level traits. Second, by being a cultural seed engaging instincts into a cultural activity, thereby increasing the possibility for it to be used in future neurological exaptations. The potential for exaptations increases when more functional variation can be generated at the level of different syntheses. Increasing the number of possible syntheses from generation to generation would be valuable. And thirdly by facilitating more sociability, leading to greater group size and thus increase further the potential for variation and preservation of cultural traits.

There are overlaps between cognition used for lanuage and for music; however, a study that can explicitly link this to dance is yet to be done[126][125]. Language processing is known to have reused areas of the brain typically associated with fine motor control; an area that is used extensively in dance.

Laland's cultural-niche hypothesis poses a chicken and egg scenario: if culture depends on the cultural niche, what came first, the niche or the culture? If cumulative culture is dependent on the existence of a cultural niche and preexisting culture, what analogy can we make for the case of cultural seeds? How is the gap bridged from learned environmental and social information, to cultural information which depends on the preservation of internal constraints?

2.8.2 Bodily Mimesis and the Evolution of Human Culture

In this section, we will approach the question of the conditions of necessity for the emergence of human culture from the point of view of semiotics and *the bodily mimesis hypothesis*. Semiotician Jordan Zlatev argues that bodily mimesis - "the volitional use of the body as a representational device" - is a precondition for critical human characteristics such as imitation, pedagogy, intentional communication and representation, and furthermore, is a precondition for language itself [186]. The hypothesis is based on the observations that human culture rests on a capacity for intersubjectivity and representation that must have emerged before language because language itself is dependent on it. As argued by Merlin Donald: "Language is different from mimesis, but it has mimetic roots. It is a collective product *and must have evolved as a group adaptation*, in the context of mimetic expressive culture. Given the conventional, collective nature of language, it could not have emerged in any other way." [40]. That is, language is only functional in a group context; it must have evolved in a group context, and furthermore, one that is already capable of prelinguistic, expressive culture. He goes on:

> *"If languages are products of cognitive interaction in groups, this fact alone would demand a culture-first theory of language genesis. The evolutionary question then becomes: how would sophisticated and cognitively demanding interactive environments (complex cultures) have evolved in the first place? In such a scenario, our focus should shift to describing what adaptations to the hominid brain would be essential for consolidating the complex forms of culture that would trigger the spontaneous combustion of such exotic things as languages." [42].*

In an attempt to answer this question, Zlatev created a formalised model for the five stage mimesis hierarchy which takes place in child development[185]. First there must be a cross-modal mapping between sensory perception and proprioception, (for example between vision and kinaestesia). This is referred to as proto-mimesis which typically develops in babies between 0-9 months old. Second, proto-mimesis begins to be brought under conscious control, and is perceived externally to be a mapping to some other action, object or event (eg: repeating the action of an adult with a certain object). This is referred to as dyactic mimesis and develops between 9-14 months. It is not yet however used for functional purposes. This takes place in a third stage, in which the mapping (imitation) is not only *recognised* but *intentioned* to producing a result (eg: declarative pointing). This is referred to as Triadic mimesis and is learned after 14 months. The first three stages are categorised as the precursors of bodily mimesis; they are the three stages that are key to Zlatev's definition of bodily mimesis. The fourth and fifth stages are referred to as the post-mimetic level, and can be thought of as an expansion on the capacity for bodily mimesis. The forth stage is the beginnings of protolanguage, which can involve the use of words, but little mastery of syntax and grammar. The fifth and final stage is language [185].

While there is extensive evidence for the presence of proto-mimesis and some of dyadic mimesis in other primates, there seems to be a barrier at triadic mimesis. While there are some examples of great apes being able to use sign language, this was only possible after extensive training from humans. This suggests that rather than lacking any specific linguistic skill, it is the lack of bodily mimesis more generally that distinguishes humans from other great-apes. Zlatev goes on to cite the work of Krist Vaesen who documented the differences between humans and other apes relating to their capacity for tool fabrication and use. The differences included: inferior hand-eye coordination, differences in imitation, teaching, social reasoning, causal reasoning, function-based categorisation, and executive control (e.g. related to planning) [186][170]. Although no single cognitive trait could therefore be claimed to be *the* key factor that distinguishes us from other animals, bodily mimesis, in its fully developed form, encompasses all of these cognitive functions. This suggests that the capacity for bodily mimesis would include within it the prerequisites to language and cumulative culture in general.

The question is therefore: under what conditions would the capacity for bodily mimesis emerge and evolve? One of the key features of bodily mimesis is that it is determined by interaction with other agents with a relative freedom from external constraints. The domain where we see this most prominently in nature is play.

2.8.3 Rehearsal and Bodily Mimesis

Given the apparent barrier between dyadic mimesis and fully formed, intentionalised mimesis, this naturally poses the question of how this barrier was breached. The few examples of apes learning to use signs required years of training and positive reinforcement from the trainers [61]. In human children however, the initial stages of learning language occur spontaneously. This suggests that while the cognitive constraint may not lie in the potential to use or not to use signs, it lies in the potential to learn to use signs within a reasonable developmental time. Again, it is unlikely that the bridge between extremely crude sign use, requiring long time investments, to accurate language use, learned within reasonable developmental time could emerge without some constraint on the cognitive search space. Given that intentionalised mimesis only makes sense in a group setting, it follows that it must have emerged as a product of intentional collective interactions.

Bodily mimesis has been associated with its wider implications for the capacity of representation and tool making. However, it does not automatically follow that the origins of bodily mimesis developed there exclusively. To return to the problem of cultural-niches; the evidence that cultural transition depends on the existence of a cultural environment presents the question of how these emerged in the first place. To use the terminology of Jean-Pierre Dupuy, culture is "a program requiring the outputs of its execution in order to be executed" [53]. To explain the origins of culture, we cannot assume the preexistence of culture, and so it must have been initially generated in another way.

Here we can use the logical deduction of Merlin Donald on the origins of language:

> *"Language is different from mimesis, but it has mimetic roots. It is a collective product* and must have evolved as a group adaptation*, in the context of mimetic expressive culture. Given the conventional, collective nature of language, it could not have emerged in any other way." [39]*

(emphasis added) A similar argument can be made for culture in general, provided that it shares a conventional and collective nature. This begs the question: what kind of group behaviour would bridge the gulf between pre-mimetic and post mimetic interactions?

2.8.4 Play

Play-like behaviour is present in almost all social mammals [8], and is a crucial element of behavioural development in infants of all social species [124]; "there has been a unanimous conclusion that the development of social behavior is intimately related to the ontogeny of social play" [8]. Understanding the dynamic of social development is of critical importance to understand the behaviour of the species in general.

Play is an example of an activity that is not-functional on the local time scale (the time that it is being engaged in) compared to activities that are externally goal-oriented:

> *"Play is nonfunctional (but spontaneous and labile) when compared to goal-directed, survival-related behavior. It is autotelic (self-rewarding), generally social, composed of repeated exchanges of tensions and releases, related to exploration and the seeking of stimulation (i.e., an attraction to novelty and surprise), pleasurable, and metaphorical (as when, for example, a suitable toy becomes "prey"). [37]*

However on the medium to long timescale, it is indispensable. Studies of human children show that play is absolutely critical to a child's development. Children who are deprived of opportunities to play, including rough and tumble play and spontaneous, undirected play, struggle to develop social skills and emotional regulation [64]. Why this is the case is often misunderstood. The benefit of play is often broken down as a psychological and physiological phenomenon, in which the developing participants (generally children) learn to regulate their emotions: " Present evidence which suggests that play [...], contributes to learning by supporting children's development of metacognitive or self-regulatory skills, which are in turn crucial in the development of problem-solving and creativity [15]." This is the internal developmental story of play. But then there is also the external, consequential level of play, from which a cooperative social structure emerges. The better regulated, predictable behaviour and socialised behaviour of the participants actually leads to a stable social structure. It is not reducible to an internal developmental phenomenon, from it also emerges external, functional structures.

Although it is difficult to measure the direct, positive effects of play on social-order, the negative effect of play deprivation are well documented [18]. Clinical data of play deprivation unanimously show that moderate or severe play deprivation leads to a severe socialization deficit. " The histories of severe play deprivation revealed major deficits in social, bodily and emotional regulation that support the necessity of play experiences to learn and sustain cooperative empathetic social capacities" [18]. It follows that in the absence of a developmental activity, a social group cannot function because its constituent members cannot socialise. Consequently culture could not emerge either.

Developmental psychologist Jean Piaget, cited play as the environment in which a child develops the capacity to use symbolic representation; that through play a child gradually learns to distinguish between the symbol and that which it symbolises [14]. This is one of the defining aspects of intentionalised mimesis "mimesis also adds the capacity for referential signification. In miming one recognises for example, the difference between the miming act itself and the act that it mimics"[175].

To be able to distinguish an act in isolation from the function of the act is highly non-trivial, and is absolutely essential to the capacity for representation and rehearsals of movement. Part of the reason why humans are so coordinated, both at the level of individuals and groups, is that we rehearse actions. This is not seen in other primates:

> *Even after having being taught how to break stones to create a cutting tool, bonobos do not try to improve their technique. Similarly, although gibbons*

> *may throw stones as projectiles in regional fights over territory, they never think to practice or refine their technique. [41].*

It would seem that rather than there being a clear distinction in basic motor-cognition required to perform the action, the differences lie at the level of the metacognition required to rehearse an action. In this light, the role of mimesis takes even further significance.

Only human children have been found to do what is misleadingly called "over imitation". That is that only human children will reproduce with high fidelity a full action sequence when some of the movements are non functional to the task, whereas a chimpanzee will perform only the functional steps to achieve the goal (e.g. removing food from a box with a stick)[83]. Whilst objectively being an inefficient way of completing a task, it is also the basis for human children to learn skills where the pay-off of the skill is not locally perceived. There is a distinction made between the action and the function of the action.

Play is a generative activity in which participants can test variations of behaviour within a context of lower penalty for non-viable variations in behaviour, in comparison to a 'real-life' context in which penalties can be far greater. In this sense it shares key properties with practice and rehearsal. The penalty for failure in practice will be less than failure in the real activity.

This applies to the level of the individual, but again, it extrapolates to the level of the group. If a new variation of group behaviour were to emerge, it would be less costly for it to emerge in an environment where failure is not as severely penalised. In a sense, social information has entered the system, and a social ordering is made possible through play. This is not yet fully formed culture, but as we can see from the evidence of antisocial and dysfunctional behaviour in adults who have been deprived of play [29], individual development through play is a precondition for culture.

I suggest that dance plays a similar developmental function. Before fully developed culture could emerge, there needed to be activities which could develop cognition to a higher order of precision and refinement. As posited by Donald; language, and culture in general, depends on a hierarchy of complex skills. Complex skills need an activity in which to develop the required refinement to perform. "Of course, the possibility must be entertained that language came first, and was the precondition for complex culture. However, that hypothesis has a fatal flaw: languages are complex skill-hierarchies in themselves, and must be learned. Therefore the cognitive apparatus for refining skill must have existed in some form before languages could emerge from group interactions. There is a causal chain argument at the core of this argument: refined skill, involving the systematic practice and rehearsal of an action toward improving its outcome, is a requirement for lexical invention." [42]

A generative theory of culture requires the presence of developmental activities which can scaffold the development of cognitive and social structures. The emergence of culture depends on primordial cultural niches which will repeatedly redevelop and refine fundamental cognitive skills and apparatus so that future, higher order functions can emerge. The initial developmental activities are those that are not locally constrained by positive or negative pay-off from the environment, thereby lowering the cost of development. The most general of these is play; but this thesis proposes that dance also works in this way. As a cultural seed, dance does not require preexisting culture. As an activity, dance acts as a environment in which cultural mediation can begin to emerge without immediate cost from the environment. Dance can fulfil a certain socialising role, but on the long time scale, it is the technological and technical benefit that comes from a better capacity for mimesis, developing fine control of movement, being able to distinguish between a representation and that which is being represented, that pays off in the environment.

2.9 Review

The aim of this chapter was to approach the question of dance from the question of the origins of culture in general. So far I have argued that the evidence suggests that the emergence of culture required an extended developmental stage, both at the level of individuals and the level of groups. I have also suggested that dance, as a special instance of play, would have played a key role in that developmental stage. Dance can provide the environment in which cultural mediation can emerge without incurring an immediate environmental penalty if it were under developed. Play only makes sense in the context of an environment in which functionality matters. Dance is not proposed to be *the* single originator of culture, but rather a complementary developmental environment for bodily mimesis and rehearsal.

The following chapter will use these concepts and ideas to build a general framework for a generative theory of dance and culture. This framework will then be used to motivate a number of computational models which can test the claims made so far.

3 A Unified Conceptual Framework

The aim of this chapter is to lay out the a unified conceptual framework for the emergence and evolution of culture. From the existing state of culture we can derive some of its conditions of possibility (conditions that ar requisites for the emergence of an entity [158]) and from these form a hypothesis for how these conditions of possibility were satisfied. The first subsection will address the conditions of possibility for symbolic communication and language to emerge. Such means of communication depend on physical forms that are constrained and defined endogenously, i.e. they depend upon a process of codification of physical forms. How such a process of codification could take place prior to any complex symbolic representational system is the question we try to address by looking at play, and dance in particular, as examples of activities in which physical forms can be defined according to endogenously defined rules. The second subsection will look at the consequences of mediation of information within a population on the overall fitness of the population and the individuals within it. The third subsection will look at some of the conditions of possibility that need to be satisfied regarding intra-group conflict and competition. Darwinian selection selects for entities that are able to replicate more successfully than its competition. The forth subsection will address the question of dance from the perspective of the conditions of possibility that we know to have been satisfied prior to and during the emergence of complex culture.

Darwin's *The Origin of Species* revolutionised the natural sciences by unifying all life under a single, gradualistic mechanism. From the perspective of natural selection, the differences between humanity and the rest of the natural order, are not one of kind but of degree. There is overwhelming evidence in support of physical continuity between humanity and the rest of nature; both at the level of physiology and brain structure. Given that the behavioural evolution of animals occurred in parallel with their physical evolution, it would seem that Darwin's theory would, in principle, favour a continuity theory of human culture. However, the evidence suggests that there are both elements of continuity and discontinuity between humans and the rest of the natural order; unique characteristics such as language and cumulative culture are both differences of kind and degree. This is the primary challenge for any post-Darwinian account of human origins: "[A] post-Darwinian account must somehow combine the gradualism of Darwinian evolution with the essentialism of the pre-Darwinians, stressing both the continuity and the discontinuity of humanity with the rest of the natural order. [164]". Although the continuity of physical anatomy, genetics, brain chemistry, functions and structures, hormones and other physical characteristics are not in question, there are nevertheless unique behavioural qualities of humans which cannot be explained by a purely gradualistic picture. Traits such as language, religion, genocides, cumulative technology, music and dance, do not have analogues in any other species. The task of this chapter is to build a synthesis of both the gradualistic and exceptional characteristics of the human species.

All sciences depend on some form of determinism (consistent, universal property of the phenomenon in question) [53]; it follows that at the centre of any theory of homonization there should be some form of determinism proper to humans. Humans exhibit a huge variety of behaviours and are able to thrive in very different habitats. However, humans always depend on a group and culture: regardless of the environmental context, there is always a group and a culture outside of which there is no survival or reproduction. To borrow a concept from the archaeologist Ian Hodder "The determinative factor in human action is neither material nor ideal. What is determinative *is the entanglement itself*, the totality of the links which hold and produce individual events, things, humans." [78] (emphasis added). Although in this case Hodder is speaking specifically in reference to human's dependence on technology, the argument holds for culture more generally because it is what makes such technology possible to begin with. If humans are dependent on something, they are also dependent on their conditions of possibility. Technologies depend on humans to produce them, but with time, humans become dependent on the technologies for their own survival. Entanglement does not only exist between humans and technology; there is entanglement within technology itself: technologies, that depend on the existence of preexisting technologies (cumulative technological culture). And there is an entangled relationship between humans: humans depend on the behaviour of other humans. Two entities are entangled if they mutually depend on each other's existence for their own existence. The determinism that is proper to man is its entanglement with culture [44]. There is an entangled dependence between culture and humans: culture depends on the specific behaviours of humans, and human survival depends on a form of culture.

In this light; is it reasonable to expect natural selection, happening at the level of the individual, to explain the evolution of human characteristics on its own? A famous example of the limitation of natural selection as an overarching explanatory mechanism is language. One of the challenges of evolutionary theory is that language is "overly complex" for the local, ecological constraints it looks to satisfy. From the point of view of evolutionary biology, nature should select for traits that are fit for local purposes and not for overly adaptive traits [97]. This suggests that the origins of language, although it clearly gives an advantage from the point of view of natural selection, can not be explained by natural selection alone; a point made by David Premack:

> *Human language is an embarrassment for evolutionary theory because it is vastly more powerful than one can account for in terms of selective fitness. A semantic language with simple mapping rules, of a kind one might suppose that the chimpanzee would have, appears to confer all the advantages one normally associates with discussions of mastodon hunting or the like...syntactic classes, structure-dependent rules, recursion and the rest, are overly powerful devices, absurdly so.[135] , pp. 281–282.*

If ecological necessity cannot explain the emergence of language, its local necessity must be an attribute of the social-group. The question then becomes: what properties of the social group would be necessary for there to be the emergence of language? A human is dependent on a cultural niche; without knowledge, technologies, a developmental environment, stable social relations, a human is not expected to survive and reproduce. Therefore, the selection of a human supposes not only an individual phenotype, but also a conglomeration of other entangled factors, simultaneously extrinsic and dependent on it. Any evolutionary explanation of man needs to account for this: "Humans get caught in a double bind, depending on things that depend on humans [79] "; if the very survival of the individual is firmly entangled with a group and a culture, and the survival of the culture cannot be reduced to evolution by natural selection at the level of an individual (because it is, by definition, a collective and inter-generational phenomenon), it follows that natural selection is insufficient to explain the evolution of humans. The group and the culture is more than a difference of kind, which can simply be regarded as an extension of the external environment and habitat that the individual occupies. Unlike the environment, the culture does not exist in the absence of the organisms that support it.

In evolutionary theory, there are two fundamental classes of questions. There are *'why'* questions such as: why did humans become increasingly dependent on culture? Why are humans so dependent on each other and the heritable cultural capital? These are sometimes called ‘ultimate questions’ dealing with the ultimate pay-off, the ultimate result of the emergence of culture. Then there are *‘how’* questions such as: how can culture possibly function? How are the behaviours of distinct individuals causally connected in a way that can be recognised as culture? These are sometimes referred to as the ‘proximate questions’ of evolution, and look into the causal mechanisms that underpin what we see [6]. It is on the latter class of questions that this chapter will focus. Why culture would emerge is comparatively easy to answer: among other things, culture reduces human vulnerability to variable environmental factors, culture has allowed humans to thrive in vastly different climates; technology, which is supported by culture, has made a relatively innocuous organism into the most ruthless predator in nature. How culture could emerge is a more difficult question. If, like David Barash, we were to subscribe to the mainstream view of biology that attributes “the adaptive behaviour to adaptive benefit *experienced* by individuals, with group outcomes being largely (if not exclusively) the sum effect of such behaviours” [6] (emphasis added) then the quality of any explanation of culture is contingent to the explanation of how the perception of the individuals, at the local level, correlates with the ultimate payoff at the group and cultural levels. Here “*experienced* by individuals” could be replaced by “perceived” or “sensed” by individuals. Every individual exhibits a certain behavioural dynamic, that dynamic is dependent on how it perceives and learns in the sociocultural environment and the culture is dependent on the aggregate of such behaviours. Culture by definition transcends any given individual, in fact it transcends any given generation or society. It is the product of generations and is mediated through generations. For this to occur, it is necessary for the culture to have a causal effect on the perception of its individuals. In this chapter we will build on the ideas of Giuseppe Fornari and David Hoffman whose works suggest that for there to be individuals whose local perception will correlate with the required dynamics of the culture, there must be a mediatory quality of culture. Culture is an example of an autopoetic system: a structure that not only self organises from its components, but also creates the components required for its own propagation in time. Culture relies upon its capacity to mediate among individuals and so having a causal effect on the perceptual system. How are humans causally related in a way that information can be continually mediated over generations? Indeed all animals living in social groups depend on each other and are causally related. However, they are not connected in a way that would allow cumulative culture to form.

3.1 An Autopoetic Theory of Culture

An autopoetic system is one that forms a structure from its own internal dynamics *and* the formation of its own elements[**?**][163][104]. Autopoesis is a distinct concept to self-organisation. Self-organising systems form structures from its own internal operations. Whereas an autopoetic system also produces its own components; there is an additional temporal element to it [104]. Life forms are an example of an autopoetic system: they are not only a self-organised structure, but they are productive: they produce their own components for growth, repair and reproduction. Culture can also be regarded as an autopoetic system. It is not only a self organised system, in which its internal operations produce structure; it also maintains itself in time by facilitating the cultural development of the following generation. An autopoetic system is a stable structure that is generated by the internal dynamics of the system while converging subsequent dynamics to those that produced it. A cultural niche is sustained by the dynamics of its constituent individuals, while constraining the dynamics of the individuals in a way that sustains its own existence. To repeat Dupuy’s terminology: culture is “a program requiring the outputs of its execution in order to be executed" [53].

If culture is a self-propagating system in which its own output is necessary for its own existence, to explain its origins it is necessary and sufficient to explain how the initial conditions necessary to sustain the self-propagating system could emerge in the absence of their own output. In other words, it is necessary to derive what the foundational mechanisms of culture are and to explain how these could come about in the absence of fully developed culture.

According to Rene Girard's theory of culture, mimesis, the capacity to imitate movements and intentions, is the foundation of distinctively human forms culture [65]. In Mimetic Theory, mimesis simultaneously makes culture possible and *necessary*: it is the capacity that allows almost all distinctively human behaviours such as language, complex tool use and symbolic representation; while it simultaneously increases the risk of intra- and inter-group rivalry and therefore violence [65]. Culture thus transitions from merely a *possibility* to a necessity in order to contain and prevent the potentially destructive forms of violence that are mediated through mimesis [44]. From this theory follows that once a threshold of mimesis is breached that culture will emerge. There is no reason *a priori* to expect there to be a single causal factor that would provoke such a transition, in fact because culture is a highly multifaceted and broad term, simultaneously referring to the capacity of cumulative technologies, rituals, symbolic representation, forms of social organisation and languages, the opposite should be expected. Despite this, it will be possible to build a hypothesis for the role of dance in the development of mimesis and culture more generally.

3.1.1 Mimesis and the Conditions of Possibility for Referential Systems

The observation that humans are fundamentally imitative was made as early as 335BC by Aristotle: "Imitation is natural to man from childhood, [...] he is the most imitative creature in the world, and learns at first by imitation"[5]. Humans do not only imitate one another's actions, they also imitate each other's desires, otherwise called acquisitive mimesis [65]. So fundamental is mimesis to the acquisition of distinctly human behaviour, it is not reductionist to say that the difference in degree in this capacity marks a discontinuity with other animals because it is a condition of possibility for cumulative culture [164]. Cumulative cultural traits are traits that would be impossible to acquire within a single generation, let alone a single lifetime; it is the capacity to *'Stand on the shoulders of giants'* (*Isaac Newton*). If an entangled dependence on cumulative culture is a determined characteristic of man, so too are its conditions of possibility. Mimesis is fundamentally relational: it is by definition a causal relationship between a minimum of two individuals. As a result, mimesis cannot be reduced to the individual *capacity* for mimesis; it is a social and an irreducibly relational phenomenon. It follows that mimesis cannot simply be viewed through the lens of individual Darwinian selection, when the fitness of this characteristic automatically depends on another. The value of mimesis is only as great as the value of the behaviour that is being reproduced.

The question of culture is a question of relation and mediation between individuals. Today we depend primarily on languages to communicate, however, a condition of possibility for language is the existence of an interrelated group which already shares common points of reference

> *to understand or use a symbol appropriately in context you must first understand what it represents, and this referential understanding is inherently non symbolic. For instance, to understand why it is amusing to name a reclusive hound dog "Raskolnikov", one must know something of Dostoevsky's novel,*

> *something of the brooding, asocial intelligence of hound dogs, and something of the style of contemporary humour [39].*

For there to be mediation through the use of symbols there must first have been a complex culture, a point made here by Merlin Donald:

> *Of course, the possibility must be entertained that language came first, and was the precondition for complex culture. However, that hypothesis has a fatal flaw: languages are complex skill-hierarchies in themselves, and must be learned. Therefore the cognitive apparatus for refining skill must have existed in some form before languages could emerge from group interactions. There is a causal chain argument at the core of this argument: refined skill, involving the systematic practice and rehearsal of an action toward improving its outcome, is a requirement for lexical invention. Humans have a remarkable capacity for acquiring, rehearsing, and refining hundreds of skills, and arranging them in complex automatized hierarchies; language is just one example of such a hierarchy. I have argued that a general capacity for refining skill was fundamental because a capacity for refining skill is a logical precondition for the evolution of languages: any morphophonology, and any lexicon, whether oral, manual, or multimodal, consists of a complex set of conventionalized and automatized skills (Donald, 1998b). Thus the evolution of a capacity for refining complex skill-hierarchies is a prior consideration in any theory of language evolution. A parsimonious theory should try to account for both features, that is, for both refined skill and language, in that order. [...] Language is, in this sense, not a feature of the brain per se. It is a cognitive epiphenomenon, a socially constructed (Searle, 1969) cultural over-write imposed on a brain which is essentially primate in its design. Language thus has its origin in a distributed cognitive system, while it is performed by a local cognitive system, that is, the brain of an individual. It is the child of an interactive cultural imagination, that is, of groups of brains in collision. Its original interactive logic is primarily mimetic in the Aristotelian sense, that is, it follows an analogue, embodied logic, based on a greatly expanded capacity for procedural learning and mimetic expression. [42]*

Language and symbolic representation are cultural products and their existence reveals something about the cultural conditions that must have preceded them. As argued by Donald, refined skills, the capacity for rehearsing an action for improving its outcome, conventionalising complex skills, is a logical precondition to any form of language. The goal here is not to focus on the specific characteristics of language, but rather to derive what was had to be present in the early stages of culture for it to have emerged. Symbolic representation is not a purely cognitive phenomenon; symbols are fundamentally physical entities that are defined endogenously by the group: they are conventions. A movement intended for representation is defined differently from a movement that is used for a functional purpose. For example, the movements that are made in the making of a tool are constrained by the physical requirements of making a tool (it must be sharp, the material must be struck in a way that it doesn't break it); it is constrained by characteristics extrinsic to the individual or group that is performing the movements. There are physical constraints. In representation however, the movements are internally constrained. There are three key requirements for the emergence of symbolic representation [38]:

1. A referential system can only function if that which is referenced is known by the receptor of the symbol. Therefore there is the need for a non symbolic common experience so that the symbols can function as a referential system.
2. Symbols are fundamentally endogenously determined physical entities. Be it a gesture, a pattern incised on a stone, a mime; a referential system needs to be physically manifested; a symbol is a physical form. Therefore, the broadcasters of the representation and the receptors must be able to produce and perceive distinct physical forms defined internally.
3. There must be a mechanism by which symbols are generated endogenously to a group. Symbolic representations are not individual cognitive capacities; they are collectively defined physical entities.

For all these reasons, collective social activities, in which movements or other motor controlled sequences are conventional or constrained endogenously, are a logical precondition to the emergence of symbolic representation or language. The specificity of conventions must have been generated by self reinforcing dynamics, as we do not presuppose any external defining constraints. Today a child uses symbols that have been previously defined by the culture, at the level of the individual they are extrinsic to it. However, in the origins of culture, the original defining of symbolic forms must have been an emergent consequence of a collective activity. Furthermore, the acquisition and the mastery of symbolic use and language is a highly refined skill; it requires children many years and much repetition to acquire it. It would be presumptuous therefore to suppose that the origins of symbolic representation, as specific physical forms, produced by specific motor-controlled sequences, be it a movement of the limbs, hands, face or vocal cords, required extensive repetition and refinement of the motor skills *before* they could become functional. These activities would need to be repeated and refined over time; the motor skills required for producing a physical form need to be refined before they are functional; they are by definition constrained by conventions and so must be constrained in the context of the group. Such an activity would have energy and time costs and so would need to be adaptive at the macro-level (the level of the group). However, the specific conventions within the activity must have independence from external incentives or payoffs otherwise they would not be internally determined.

By deriving some of the necessary preconditions of the emergence of language, we have defined an abstract group activity which would need to be social, endogenously specified, repetitive and rehearsed, engage and develop fine-motor skills, justify its energy and time costs, and have its own conditions of possibility met in a non linguistic context. Dance satisfies all of the above conditions and for this reason I propose that it was a precursor to the development of language.

This chapter has three main sections: The first will build on the arguments made above, namely; what conditions of possibility must have been satisfied prior to the emergence of language and symbolic representation, and how dance fulfils these. We will look into the importance of endogenous convergence towards standardised physical forms as a prerequisite for fully developed codified mediation. The second part will look at the consequences of mediation at the level of the group and at the level of individuals. The emergent culture depends on the aggregate of the behaviour of individuals and the behaviour of individuals depends on the emergent cultural structure; this section aims to explain how this relation is mediated through individuals. The third and final section will look at the relationship between natural selection and culture. As a consequence of entanglement, the culture must limit the extent to which natural selection occurs internally among members. In any population, it is necessary to contain the internal effects of natural selection within the population; excessive internal competition within a population can undermine the viability of a group and ultimately cost the individuals that depend on it [67]. This is true for all types of Darwinian populations, including humans. This will be followed by looking at the foundational role of mimesis in human societies and culture from the point of view of Girard's Mimetic Theory [65]. According to Mimetic Theory, mimesis, and acquisitive mimesis in particular, introduces a new type of endemic violence that cannot be contained by general animal social structures. Acquisitive mimesis multiplies the possibilities of rivalry within the group which threatens to disintegrate the group. Mimesis is the very capacity that allows human cultures to exist, however this does not prevent it from provoking new forms of violence which undermines general animal social structures, thereby introducing the necessity for distinctively human forms of culture that can contain this new, ever present, internal threat. Mimetic Theory is a generative theory of culture that begins from the premise of mimesis and the necessity to contain mimetic violence. The aim will be to complement this with a hypothesis of the developmental contribution of dancing to human's mimetic capacity in general. This will motivate a unified conceptual framework of human cultural origins which can be tested by computational simulations.

3.2 Play, Dance and Codification

In linguistics, codification is defined as the process of standardising the rules of a language. It is the process of selecting, developing and prescribing rules for proper language usage. Here we use a broader definition of codification: it is the process of standardising certain physical forms: sounds, movements and gestures or markings, that can be used in a referential context. The first stages of language acquisition in children is a process of convergence towards certain standardised sounds and/or gestures, as demonstrated by the process of vocal babbling in hearing infants, and *'gestural babbling'* in deaf infants [130]. Infants are capable of producing an array of different sounds and gestures before converging to the standardised set used in its native language. The infant is able to learn the standard code of its language from the surrounding adults and peers, i.e. models who have already acquired the language. However, in the question of the origins of codification, no preexisting standardised physical forms can be assumed. There are at least two levels of standardisation that must occur; the codial level and the represented level. The former is the domain of the physical patterns that must be standardised within the population. Be the pattern a specific sound, movement or marking; there must be a standardisation of a physical domain for there to be codification. The latter is the point argued by Donald in the introduction: there must be some common experience for there to be a possibility of representation [38]. The function of a representational medium is to refer to something outside itself: something non-symbolic [42]. It is on the level of the standardisation of the physical entities that this section will focus. The standardisation of sounds and gestures must have occurred endogenously.

For there to have been convergence towards a common set of physical forms (specific sound patterns, movements or markings) there must have been a causal relationship between individuals that would converge towards specific physical forms. These physical forms must be the direct product of human motor-control. If they were not, they could not be argued to follow internal rules but simply be a product of the external environment. Referencing is a human action, it follows that the process by which the referencing is mediated (here through abstract physical forms) must also be the product of human actions. Be the physical forms vocal (vocal chords are motor controlled), gestural or markings, the individuals must have fine motor-control to produce the standardised physical forms reliably.

3.2.1 Endogenous Fixed Points

An endogenous fixed point is an objective, distinguishable entity that is generated by the internal dynamics of a system. A set of standardised physical forms (standardised sounds, gestures or markings used in a language) can be viewed as endogenous fixed points. There is nothing external to the language which determines that a chair be called a chair or a stool a stool. The only condition that must be satisfied is that physical forms are standardised. The French language has different endogenous labels for chair and stool: *chaise* and *tabouret*. An endogenously defined fixed point is objective *as a fixed point* but its specificity is determined internally: it is arbitrary from the point of view of the external constraints on the form.

An endogenous fixed point is an example of what Dupuy calls 'complexity from noise', which is a self reinforcing stable state [52]. The dynamics converge to a stable point which is not determined by any external necessity, but by its own internal convergence "Chance here brings about a form of necessity that appears as such only retrospectively."[52]. This concept shares characteristics with a self-organising system; indeed a self-organising system is an endogenous fixed point, however not all endogenous fixed points are self-organising, although they must be the products of self-converging dynamics. The convergence towards the specific state is not determined by any external necessity, but from the internal, converging properties of the dynamics. The point of convergence is not determined, but the convergence itself is. An example of self-reinforcing dynamics is Polya's Urn model [52]. An urn contains two balls, one red and one white. For each round, one ball is selected at random; the colour is recorded and it is replaced in the urn with an additional ball of the same colour. With every iteration, the total number of balls in the urn increases by one. The ratio between the red balls and white balls, which begins at $1:1$, oscillates to begin with before converging to a fixed number. Despite the initial conditions being perfectly symmetrical, the ratio between the two colors that is converged to is not in general $1:1$. With every iteration the number of balls of the color recorded increases by one, thus increasing the likelihood that the same colour will be selected. What ratio the run will converge towards is not determined, however the fact that the system will converge to a fixed number is.

This is distinct from exogenous convergence or 'order from noise'. Here the dynamics of a system converge to a preexisting necessity which is independent of the specific dynamics. Examples of convergent evolution, such as the camera eye (emerging on at least eight separate occasions) [115], can be regarded as order from noise. A camera eye is constrained by the laws of optics which are consistent across nature and independent of the specific interactions of the organism. The properties of the eye converged to a point by a necessity external to the specific conditions that produced it.

A referential system, such as language, is a combination of the two types of fixed points. Referential systems have inherent value; there is a class of behaviours which can only emerge if information can be mediated efficiently by signs, for example complex planning, legal systems, myths, religions and story telling. However, embedded within a referential system are symbols, which are by definition, internally determined, conventional physical forms. These are products of complexity from noise. Given the variety of languages in existence, (or even the variety of accents within a language), the specific sounds and signs of a language are clearly endogenously determined. How do such endogenous fixed points emerge? Biological organisms that are able to generate endogenous fixed points are extremely rare in nature outside humans.

There have been some successes in teaching chimpanzees and gorillas (eg. Nim Chimpsky and Koko the gorilla) to use sign language [39], thus falsifying the theory that the ability to *use* a large vocabulary of signs is a uniquely human ability. The signs however, were taught by a human and so exogenous to the ape's genus [129][61]. Although the 'linguistic apes' were able to communicate intentions, no example of this has been observed in the wild or in the absence of human training, nor has any ape attempted to create a new sign with the trainer. It appears therefore that it is not the individual capacity for language that is unique, but the social capacity to create language. Humans are not only able to use signs; we are also able to generate them endogenously. The signs the apes used were by definition exogenous to their species.

Language is fundamentally a distributed phenomenon; it is not intrinsic to any individual and is only functional if more than one individual has the same language. The process of convergence to standard physical forms must also have been a social process: emerging from the interactions of individuals. Language depends upon standard physical forms, so that the original social capacity to converge to standard physical forms must have emerged in the absence of linguistic functionality. Only once language has emerged can there be a positive feedback-loop in which new symbols are generated for the purpose of being used in the language. It is not sufficient to have the individual capacity to learn how to use symbols with a certain grammatical structure if the group is unable to generate standardised physical forms endogenously. There must have been a 'cultural babbling phase' in which no standard forms yet existed. They must have been converged towards endogenously by mutually reinforcing dynamics. What causal relationship must there have been among individuals of the social group for such a convergence to occur?

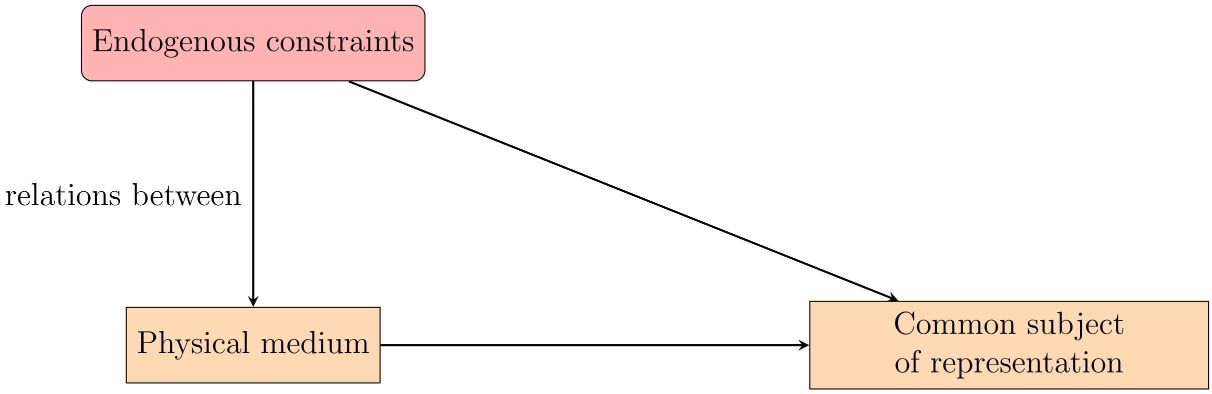
Before language, or any other standardised referential system could emerge, a process of codification (communication and physical form conventions) was necessary [147]. Humans must have been capable of converging to standardise physical forms, and have simultaneously developed the capacity to produce them (broadcaster) and perceive them (receptor). The question of codification presupposes that there was a development from comparatively ambiguous physical forms towards standardised, internally defined physical forms. For there to have been convergence, there must have been mimesis of motor-controlled human behaviour, in which certain physical forms produced by distinct individuals progressively become common to all through mutual imitation. For all of the above reasons, I propose that group activities, in which physical forms could emerge as the consequence of endogenous convergence, were a condition of possibility for codification and therefore for language. Such an activity would need to be engaging; standardisation and refinement require repetition and therefore the group must have a local incentive to participate in such an activity [38]. The incentive would need to be internally determined because codification need to be internally determined. For example the rehearsal of functional movements such as hunting techniques or specific techniques of tool making, while they would both involve mimesis and converging of movements to a common form, the movements would need to conform to external requirements; namely the physically optimal way of throwing a projectile or napping a certain stone. These movements are not internally defined, although they may be internally mediated. From the point of view of evolution, the activity would need to justify the cost in time and energy. From the point of view of optimising the emergence of standard physical forms, the activity would locally incentivise local convergence in the absence of any external incentives on the specific forms.

3.2.2 Triangulation

Representation is a triangular process. There is a broadcasting (the representation), a receptor (the receptor of the representation), and there is the object of representation (the object that is being represented). This triangulation has direct implications on the specific instances of representation with symbols; in this case there must be an object of representation that is common to the group; a physical medium that can be manipulated according to conventional, endogenously defined rules.

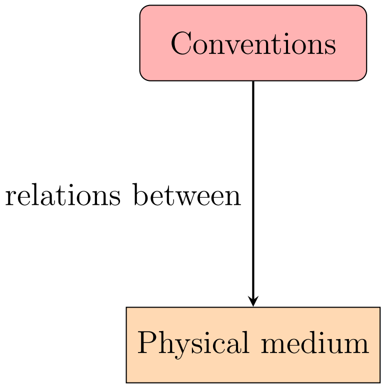
> *We are positing that everything that can actually be given – representation, nature, signification . . . is always . . . the imposition of an ensemblist organization on an initial stratum of the given which unceasingly lends itself to this. But we are also positing that it is never and can never be simply that – that it is always at the same time necessarily the institution of a magma of social imaginary significations [which] cannot be thought in terms of the identitary and ensemblist grid.*

(Original citation Castoriadis 1987: 344) [113] Here the ensemblist organization is an internal system of relations: standardised internal determination of the initial stratum. The initial stratum is a physical medium which can be determined by the internally generated rules. The physical medium must be able to be manipulated into distinct forms which can be recognised by an audience. The magma of social imagery is the set of common subjects of representation. Representation is fundamentally a mediatory phenomenon and so involves both a broadcasting and a reception of the representation, and that representation is a mapping of something external to it, otherwise it would fail to be a representation. Common subjects of representation are necessary for the same referential mapping to be shared, otherwise the system would be purely self referential and could not mediate any information beyond itself.



A system of representation functions by recreating a perceived external structure through a physical medium. Relations are recreated and interpreted as a map. It therefore requires the competence to perform deliberate actions so as to recreate a system of relations. The actions that constitute the representation need to be constrained inwardly so that its perceived defining characteristic is the structure to which it is referring and not the circumstances of the act of representation in question.

A puzzle for evolutionary theorists has been to identify why systems of representation emerged in humans and not other animals given that other animals are apparently capable of using signs and the obvious potentially selective benefits of so doing [153]. The most common attempts have been to suggest ways in which human social circumstances demand systems of representation. The precondition remains however, of how humans actually generate the conventional internal rules (the codification) necessary for representation. Dance can and does act as a medium of representation in many cultures. Stories and narratives can be communicated through dance (hunts, wars, natural disaster, etc.). However the representation is not necessary for the dance to exist. Indeed this is what we see in most forms of social dancing and the spontaneous sort of dancing we see in young children. Young children will spontaneously move to music for its own sake. In time, internally consistent relationships can emerge between moves, the music and the other participants. This is entirely independent of any intention to represent; it is self contained. The spontaneous dancing of infants is an example of how an inwardly generated system of relationships can be generated endogenously. The initial stratum here being the movements of the dancers.



We see the same thing occur with any developing form of dance. Jazz dance for example, evolved into many different forms from the late 1800s onwards. In night clubs and dance halls, various dances emerged progressively; internally consistent but independent of any external necessity. Dance is an example of how conventions emerge from an initial physical medium (here the movements of the dancers) which need not need to represent something external (although there are many examples of external representation occurring, it is however not necessary). This circumvents a hurdle for explaining how the capacity for representation could emerge in the absence of necessity for representation of something external.

The emergence of a representational system requires the simultaneous emergence of receptor and broadcaster. The broadcasting is an episodic event which is the manipulated physical medium which can be perceived; the receptor is that which perceives the episodic event and distinguishes it for what it is intended to be. These necessities define a search space of possible episodic events which conserve the function of mediation. That which is being represented must be distinguishable from the act of representation itself. This means that the medium of representation must emerge independently of that which is being represented. It must be free of the constraints present at the time of that which is being represented is subject to. When we lower the environmental constraints to a minimum, we rediscover the definition of play: an activity that is not directed towards any local, externally determined goal [172].

3.2.3 Satisfying the conditions of possibility of codification

Although all physical forms that can be codified (movements, sounds, markings...) are ultimately constrained by physical laws, and by the psychological and physiological capacities of individuals (by the possible range of sounds that can be produced or sensed, by the movements that can be performed), none of which are determined by the conventions of a group, within this range, codified physical forms are determined by convention. By definition, codification of physical forms are a form of convention; they are determined internally to a group. The question therefore is, how can the codifying of physical forms be generated in a group that does not previously have them?

I propose three conditions need to be satisfied for codification (convergence to a standard set of physical forms with their meaning) to emerge: (i) the activity would have to be social since conventions are by definition socially determined; (ii) the activity would have to be decoupled as much as possible from any external functionality, as to be maximally determined internally; (iii) the activity would need to be self-incentivised, or at least socially incentivised, since there are minimal external incentives.

Play was presented in the previous chapter as: a behaviour that is locally internally constrained (not for any external purpose other than the play itself: it is self-justified), but that nevertheless, performed an essential socialising function on the longer timescale. What I propose is that a specific type of play which had as a by-product, the convergence of participants to conventionally defined physical forms was necessary for codification to take place since natural selection has no foresight and can not select for codification in the absence of all the fitness enhancing activities that they make possible. Forms of play like rough and tumble play would already be too constrained: the movements in rough and tumble play are physically constrained by the necessity of one having to dominate the other. This form of play would have had to involve imitation, if not reciprocal imitation, which would produce convergence to standard physical forms. This activity would be a form of dance and musicality. In dance and music there is a local incentive for individuals to participate (music is entraining); dance can exist without standard physical forms, and convergence can occur within it. Such endogenous convergences are evident in group dance improvisations as well as specific forms such as contact improvisation [123] [134].

All movements, activities and productions of sound are ultimately externally constrained: the laws of physics and the physiology constrain the possible movements an individual can perform and the sounds that an individual can possibly produce or hear. However, within this domain of all possible movements, there are additional constraints that are proper to an activity. An activity that is *'functional'* has to satisfy additional constraints: story-telling, miming, playing with dolls, play-acting, painting, tool making and tool use, all have to perform a certain function. The movement of the actor or the story of the auditor must have a representational quality. In the case of tool-making the tool must be able to perform a function for which it is intended; if it is a projectile it must be able to be projected, if it is a net it must be made in a way that it does not break. There are additional external physical constraints on the activity to satisfy. In the most general definition of dance the external constraints are lowered to a minimum and the definition of the movements are determined internally to the group. In the case of playful, undirected dancing, the movements are defined internally by the collective of individuals. In the case of directed dance, although the movements are defined externally to the group acquiring the dance, they were nevertheless defined internally to the culture; they need not satisfy any additional external constraints, only those that are internally determined. All representational mediums rely on an internal determination of a physical form, however not all internal determination of a physical form needs to have a representational function. In dance and music there is an internal determination of a physical form that does not necessarily need to fulfil a representational function. In the first examples of dancing in children, the spontaneous entrainment has no representational quality. In dance, convergence to physical forms can emerge gradually without an immediate fitness penalty or the disengagement of participants. Dances can be repeated over time and over generations; refinement of motor-control and of the sequences themselves can occur over time, without the local incentives dropping to zero. Here we propose a table of the activities which were possibly present in pre-linguistic societies:

	painting	tool-making	story-telling	playing with dolls	play acting	dancing/music
referential	x		x	x	x	x
non-referential		x				x
locally-functional		x				
instinctive				x	x	x
endogenously constrained	x			x	x	x
exogenously constrained	x	x				
mediation-dependent			x			

A cultural dance (one that is mediated over generations) is only made possible if the dancers have a propensity to imitate a movement independently of external incentives. The incentive to repeat a certain movement must be attached to the movement itself and not the result of the movement. In the famous experiment between bonobos and human children where it was found that bonobos will only imitate the functional movements while children would also imitate the superfluous ones [25]; it would be a mistake to interpret this as a maladaptation of the children. Although the movements may not have been useful to the result of the task in hand and could therefore be interpreted as a 'locally' maladaptive, the inclination of children to imitate behaviours that have no perceivable local function is the very capacity that allows it to transcend the inherent limitations of its individual perceptions and to learn tasks that will only become functional in a later context.

One consequence of the ability to generate local constraints is that it becomes possible in principle for these to align with ultimate constraints on emergent properties of the population or generations. Local information that cannot possibly be meaningful locally because it is devoid of any feedback from the immediate environment can now have a medium through which value is made physical at the local level.

3.3 The Consequences of Mediation

A social organism is one whose individual fitness correlates with the fitness of its group. A cultural organism is a social organism whose fitness correlates with the culture of the group. This has consequences for the perceptual system of the organism. According to Donald's Hoffman's interface theory of perception, the function of a perceptual system is not to convey information about objective reality, but rather information that is relevant to the fitness of the organism [80]. In other words, the organism perceives its environment through a value hierarchy that is adapted to its needs. Hoffman has shown through evolutionary game theory that an organism whose perception is correlated with the fitness-landscape will out-compete an organism whose perception is correlated with objective reality [80]. An organism whose perceptual apparatus is correlated with its requirements (i.e. a perceptual system that is self-referential) would fare better than an organism whose perceptual apparatus is prioritising information about physical reality. In other words, nature will select for sensory perception that sees characteristics of reality that are relevant to its fitness rather than objective physical forms.

This has interesting consequences for social and cultural organisms whose fitness depends on the group and the culture. The interface theory would suggest that the perceptual system of a social animal would need to be adapted to the social environment and that the perceptual system of the cultural animal to be adapted to the cultural environment. This claim is supported by evidence that the more social primates have a greater variety of emotional expressions [94], thus making perceivable information that is relevant to the functioning of the social group. What analogy of this can be made for culture? If the fitness of an individual is dependent on a culture, according to the interface theory of perception, the perception of the cultural organism would depend on its culture.

3.3.1 The Endogenous Characteristic of Cultural Learning

At the level of the individual, all learning involves the acquisition of information through its senses [168], only the source of the information distinguishes between different types of learning. In individual learning, the behaviour is dependent on factors in the environment; there is no strong causal relationship to another individual in the group. Social learning is a special instance of individual learning that is influenced, to a greater or lesser extent, by information from the social group [168]. There is some causal relationship between individuals in a group. However, this includes instances of very minimal influence; for example exposing an individual to the environment within which it can learn. In this situation the social information is a facilitator and the learned behaviour could still be acquired in the absence of that information. This is insufficient for there to be culture; it must involve a form of learning in which the source of information is primarily another agent or the product of another agent, and not simply a facilitator. The first form of cultural learning is imitative learning, where an individual is able to internalise and reproduce a behaviour [13]. There are additional forms of cultural learning (such as instructed or collaborative learning [168]), but the commonality is that there is a direct causal relationship between the behaviour that was learned and one or several agents in the group.

On the conceptual level, the determining characteristic of cultural learning is the causal *mediatory* relationship between individuals. This is a condition of possibility for culture. A corollary to this is the possibility of conventions and other internally determined characteristics. Mediation has to pass through the physical domain. In a culture with fully developed representational capabilities, the physical events that constitute the representational structure are already internally determined and the following generation will converge towards the usage of these same fixed points. However, when dealing with the question of the origins of such systems, no such argument can be made, for the points towards which to converge are not yet determined. Since representational systems are by definition ordered and determined internally, they must be endogenously determined. There must have been a mechanism of convergence; self-reinforcing dynamics converging onto distinct points, similar to the argument made by Dupuy: “Far from expressing implicit order, they spring from the amplification of an initial fluctuation, and their appearance of pre-established harmony is a mere effect of unanimous polarization” [52] (where polarisation is used in the French sense meaning to converge to a point). For there to have been the emergence of conventional physical entities, there must have been the capacity for imitation and mimesis for there to be self reinforcement.

3.3.2 Bootstrapping culture

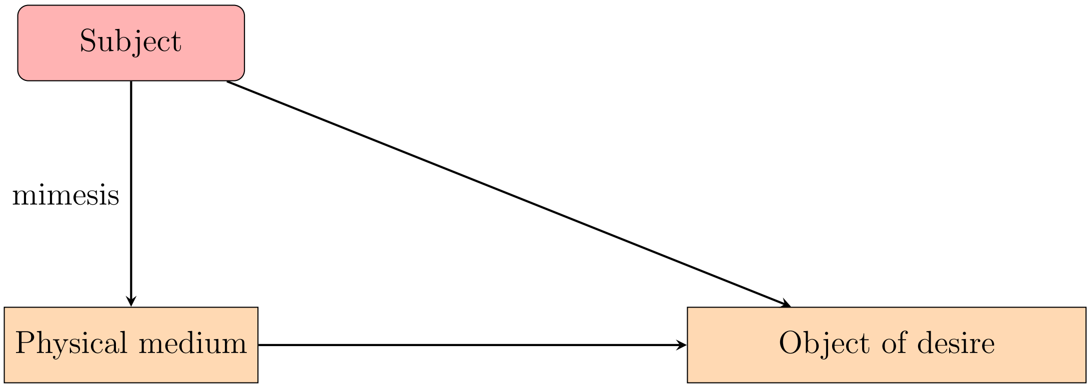
The preparedness to imitate in humans has been shown to contrast drastically from other apes in experiments. One such experiment[25]involved a demonstrator performing a sequence of movements to get an object out of a box with the help of a stick. Some movements were key to the operation (showing which hole the stick had to be pushed through) others were arbitrary (spinning the stick around his head before inserting it through the hole). Human children would attempt to imitate all the movements in the sequence whereas bonobos or chimpanzees would imitate only the functional ones; the moves that directly contributed to getting the object out of the box [25][162][166].

This is significant for two reasons: the first being that the child is able to perceive and reproduce a movement independently of ‘functional’ constraints. The arbitrary moves are not determined by the constraints of getting the object out of the box, but by the movements of the demonstrator (which is what is refered to as over imitation). This is an example of an endogenously constrained action where the specificity of the movement of the child is determined by the specific moves of the demonstrator. No environmental constraint determined the arbitrary moves, although it does constrain the functional ones that directly contribute to retracting the object from the box. Animals perceive reality not as an objective space, but through a value hierarchy that determines what in the environment is relevant and what is not [80]. It appears that the child’s perception is correlated with the successful imitation of the action rather than the outcome. The value structure is no longer confined to local experience of the individual in the environment but can be mediated through individuals.

This has implications for the types of behaviours that can emerge in humans compared to chimpanzees. It increases the potential for multi-stage functional tasks. Complex behaviours that involve long sequences of steps, such as composite tool making, depend on the subject being able to imitate in the absence of a local background incentive. Although a background incentive exists ultimately, it is absent at each incremental stage of the tool’s production. The incentive must be held internally. An individual may have the capacity to hold a representation of the tool in their mind, and therefore the incentive is made local. However, in the case of learning how to make the tool, the individuals who do not have the representation of the tool in their mind must be locally motivated to invest time and attention to its creation. In the absence of any local external incentives, the incentives must be internal to the group. It has been argued that humans have circumvented the absence of background incentives with positive reinforcement: the teacher or model rewards the pupil for imitating with social cues[72]. Social reward replaces the background incentive.

Imitation opens the possibility of *triangulation*: the incentive of the individual (actor, desirer) for an object or objective (may be physical, of non-physical) is mediated by a third party (a mediator). Such triangulation is desirable in the case of teaching a complex functional task, such as the example given above. It does, however, open the possibility for reciprocal mimesis where the mediator and the actor imitate one another reciprocally, thus desiring an object that may not have inherent value, but is desired by the other. (Such triangulation is what makes distinctively human phenomena such as fashion or money possible).

Imitation or mimesis introduces the possibility of mediating intention or desire. An individual will derive its desire for an object or an objective by mediation through a model. This is known as triangulation:



This capacity for mediation is a difference of kind from other animal societies.

Giuseppe Fornari’s Mediation theory proposes that in order to decouple our drivers from our instincts some form of representation is necessary, but it requires a medium of representation rooted in present experience [59]. Being bodies that are constrained in space and time, for a symbolic world to become accessible to such a being, it must be mediated through physical space. Human beings perceive and interact with objects and figures that possess not only material qualities but symbolic value as well. An additional layer of meaning is grafted onto physical objects and events but are irreducible to them. Meaning: “an emotional and cognitive relationship oriented towards and that goes beyond immediate and instinctually controlled aims” [59]. Fornari seeks to ground the emergence of symbolism in objective events that would have provoked its emergence.

Here Fornari refers to meaning as the perceived value of an object that does not depend exclusively on the qualities of the object itself but on other variables extrinsic to it. Similarly, for a symbolic event or action. Its symbolic qualities are not reducible to the physical characteristics of the event or action in question but depends on factors outside of these. For mediation to emerge, it is necessary for the agents to perceive the world with qualities extrinsic to its inherent characteristics.

> *The phenomenological characteristics of such object duality are not limited to the constitution of meaning, since its meaningfulness responds to two conditions: it coincides with an object, such that the symbolic is one with the process of meaning corresponding to an object, and of the object, assuming the meaning; it presents itself as a meaningful source - in other words, it establishes itself as a superior and original reality that bestows meaning. No spontaneous biological process could lead to a similar perception which introduces into the animal dimensional and element of transcendence, in the literal sense of something that goes beyond instinctual reality. This presupposes a factor, a force, that could have exercised such an influence on pre-humans. That could have exercised an influence on prehuman animals that would have compelled them to fracture their perspective and instinctually controlled behavioural horizon, and such a factor cannot but be radically traumatic and extraordinary creative. [59]*

The selection of this driver cannot be reduced to natural selection. This opens up the possibility for conflict between natural selection and this new selective force present in humans. There is no reason *a priori* why the selective force of drivers on the symbolic level would be in accord with that of natural selection. In fact, we would expect the opposite to be the case. If the values attributed to physical objects and events were isomorphic to those attributed to them through our instincts (biologically inhereted patterns of behaviours), then there would be no use for a symbolic dimension of value to emerge in the first place. The existence of this additional layer of value suggests that natural perception was insufficient. We expect therefore occasions of conflict between the two value spaces. The object becomes a source of meaning that transcends it. At best, its natural worth is embedded in its symbolic form, but its perception cannot escape the mediatory layer.

What force, constraint or traumatic event caused prehumans to fracture their perception from instinctually governed behaviour to one governed by an endogenously generated, mediated one? What caused the detachment from the instinctual sphere to a symbolic one? Fornari understands mediation in a double sense: that of the meaning of an object *and* that which makes such mediation possible [59]. That is, for mediation to be a possibility it requires additional value that is not reducible to the physical characteristics of the event or object *and* a perception of that value. One could describe this as the necessity of the simultaneous emergence of a broadcaster (the physical object/event) and a receptor (that which perceives the physical object/event with the additional symbolic value).

3.3.3 The need for cultural representation to perceive higher dimensions

The question of why it is necessary to have a representational system in the first place can be viewed through the lens of fitness landscapes in high dimensions. A fitness landscape is a conceptual model of an organism's evolutionary fitness [88]. For a cultural organism, the fitness landscape is entangled with its culture and therefore not correlated with only the present characteristics of the group or objects. Culture therefore requires an extra symbolic layer grafted onto the physical forms, because although its fitness depends on something that transcends objects, its perception depends on physical forms to mediate the information.

At the level of the group, the fittest path through the adaptive landscape is in a very high dimensional space and so imperceivable to the individual. Nor should we expect it to be possible to be selected in evolutionary time [89]. If we are to suppose that there is any species that could in theory discover adaptive behaviour at very high dimensions, it is necessary for it to have other means of making individual decisions than its own local perceptual system. Its perception, if correlated to its individual fitness, would not be able to make decisions that benefit it in the long run because the dimensionality is too high. However, if the individual is to acquire cultural behaviour that is mediated, it becomes more predictable, the variation in the fitness landscape for the group becomes less pronounced, and the group can operate in a higher dimensional space where the potential of finding a viable survival strategy becomes higher. The group is less dependent on the variability in the environment. Given that the fitness of humans depends on the emergent properties of the group and that there is no reason in principle why individual human perception would be able to perceive the emergent fitness landscape of the group locally, the question emerges of how modifying the local perception (the local fitness landscape) can be made to correlate with the emergent fitness of the group. How would a modification to the local perception of the group emerge?

3.4 Natural Selection, Entanglement and Niches

Although acquisitive mimesis makes possible the creation of new tools and techniques that are clearly beneficial from the point of view of individual selection, mimesis creates a dependency on a 'would-be rival' from the point of view of natural selection. The aim of this section is to understand both the effects and the limits of Darwinian selection, and its interdependence with mimesis. The question of human evolution has to address the question of natural selection. There are three core principles that are sufficient and necessary for evolution by natural selection to take place [67]:

1. Variation: there must be morphological, physiological or behavioural differences between members of a species.
2. Heritability: the variations must be in some part heritable, that is individuals will tend to share variations with their relations, more than with unrelated individuals
3. Differential of fitness: different variations have a different expected number of 'offspring'

These principles are very specific, and although they certainly explain the selection of large classes of variations within and among species, natural selection does explain all natural variations. This point was made by Charles Darwin himself, thirty-five years after the first edition of the *Origin of Species*, "I am convinced that natural selection has been the main but not the exclusive means of modification. This has been of no avail. Great is the power of steady misrepresentation" [28]. This was in response to the growing trend among biologists that natural selection could explain all the variations seen in nature, at the expense of other sources of variation such as drift (drift are the aggregate of chance variations over time). He goes on to say that "but the history of science shows that fortunately this power does not long endure" [28]. Unfortunately, Darwin may have been overly optimistic on this point: instead of being considered one factor among many, Darwinian evolution by natural selection continues to be regarded as the overarching paradigm of biology and has entered non-biological fields such as memetics and cultural evolution [30] [35]. The extent to which the three fundamental requirements of natural selection are satisfied in the context of culture is far from clear. Indeed, Paul Dumouchel claims that the role of culture is precisely to restrict natural selection within a population, to de-Darwinise human society and thereby reduce inter-group competition and violence [44]. The role of culture would be to restrict and prohibit certain forms of competition, i.e to restrict the role of natural selection in the group.

3.4.1 De-Darwinising Populations

Although the three principles are necessary for evolution by natural selection to take place, nature does not distinguish between the precise mechanism with which variation, heritability and selection takes place [67]. For example, variation can take place either at the level of genetics or of learned behaviour, provided that they both have heritability (in this case sexual reproduction and teaching). If the success in heritability differ, then natural selection can take place. Natural selection is not determined by a specific causal mechanism, but by the presence of a general causal connection between generations which satisfies the condition of heritability and differentiation, the specific causal connection is secondary. A Darwinian population is a population in which evolution by natural selection takes place between individuals in the group. Peter Godfrey-Smith defines a Darwinian population as "a collection of causally connected individual things" [67] in which variations in certain characteristics lead to a difference in the heritability of the characteristics. Whether natural selection occurs in a population is not a binary question of presence or absence, but one of degree. Godfrey-Smith defines five parameters:

1. Fidelity of heritability: if the level of fidelity is zero, then a trait is not causally related to the next generation. If it is one, then there is a perfect replication.

2. Variability: if there is no variability of an attribute within a population, then there can be no selection between differences. Any variation between generations would have to be attributed to drift (either genetic or phenotypic).

3. Competitive interactions: the reproductive success of one individual in the population should come at the expense of the success of another. If all members could reproduce indefinitely without constraining the reproduction of another, there would be no difference in outcome due to variations of traits and therefore no selection.

4. Intrinsic fitness difference: there must be differences in fitness linked to intrinsic characteristics of the individual. If fitness was solely attributable to extrinsic factors in the environment, independent of any variations in the individuals, then variations would not be adaptive. There would be evolution and natural selection, but no due to any of the characteristics of the individual.

5. Continuity: there must be continuity between the fitness of variations for there to be adaptation. If the fitness differences were very large or chaotic, then the fitness landscape would be impossible to navigate and adaptations would not occur. Random processes would dominate the evolution of the populations.

Natural selection can take a greater or lesser role within a population, depending on the strength of these parameters. Within this model it is possible to describe a de-Darwinising effect if at least one parameter is reduced. Indeed, if the fitness of an individual is correlated with the existence of a certain population structure, it is likely that local selection at the level of the individual will undermine the organisation of the population and therefore undermine the fitness of a set of characteristics on the ultimate timescale. Godfrey-Smith gives an important example of a situation in which de-Darwinisation is desirable in multicellular organisms. A multicellular organism can be regarded as a population of cells. And within this population, there are measures in place to protect it from natural selection occurring at the cellular level. Multicellular organisms would not exist if their constituent cells would overly compete with one another for resources and replication; this would destroy the organism. For example, if a cell were to overly replicate, this would cause a tumour and could be fatal to the organism. While selecting for better replicators is a consequence of natural selection at the local level, on the ultimate level of the organism, it is highly detrimental. It is for this reason that in a healthy organism, immune systems will destroy such cells [44].

For natural selection to occur at the level of the multicellular organism, natural selection at the cellular level needs to be restricted. Cells cannot be allowed to compete freely against each other in a way that is detrimental to the organism as a whole. Ultimately, the fitness of the cells is correlated with the fitness of the organism: if the organism dies, the cells die with it. In other words, the local incentives of the cells are not correlated with its ultimate incentives from the point of view of natural selection alone. It is therefore necessary for natural selection to occur at the level of a population to restrict local natural selection. Thus natural selection is not the only force in operation; there are internal dynamics to consider. “Natural selection is not a self regulating process. It simply moves forward, as the runaway growth of cancerous cells shows - the survival of the fittest has exhausted the resources of their environment.” [44]. Natural selection is not sufficient to explain the stability of populations: populations depend on some form of regulation. However, natural selection can, and does, select between different self-regulating systems. In the example of multicellular organisms, the regulation of Darwinian evolution at a lower level is a precondition for Darwinian evolution to occur at the higher levels.

The same logic can be applied to human populations. In Girard's theory, the critical role of culture is precisely as a regulatory system: in imposing and enforcing prohibitions, taboos and rituals, the culture regulates certain types of competition [65]. If natural selection at the level of the individual is regulated, then it is possible for selection at the level of the population to occur. In other words, one of the roles of culture is to correlate the local incentives of the individual with the ultimate incentives of the group. On the local level, it may make sense for a particular individual to gain an advantage, for example in acquiring more resources, or mates, in a way that the population fitness is lower as a result. There is an ever present threat of intra-group conflict which can lead to the total disintegration of the group. One of the primary roles of culture is to maintain mechanisms by which the threat of internal implosion is minimised.

When natural selection is restricted at the level of the individual, we expect the individuals to become increasingly dependent on the group. This is a result of a statistical trade off and drift. If we assume that there are few ways that an organism has a high fitness in an environment and many ways for it to have a low fitness, if variations between these are not selected for by nature, we expect individuals to become progressively more vulnerable outside the social-cultural niche, and will be therefore, at least in relative terms, more dependent on the group. Paul Dumouchel argues that this is the case for humans:

> *The niche of the human species is essentially social and cultural. Humans have managed to survive and prosper, more or less, in just about every natural environment on earth, but they are nowhere to be found outside of culture and society, living alone or in herds. [...] In this case, pressure for the cultural de-Darwinisation of human populations would be indistinguishable from the selection of fit individuals in the social niche of the human species. [44]*

Regardless of the habitat they occupy, humans are dependent on a social and cultural niche. Humans live almost exclusively in social niches outside of which there is no survival or reproduction. It is also the case that within all functional groups there is regulation on how individuals within the group can compete. This is tautological. If a group exists, there must be a mechanism to regulate intragroup conflict, so that the group on which every individual depends, does not disintegrate.

Dependence on the culture means a compromise must be reached between inner and external constraints.

Entanglement applies to other social species such as chimpanzees, gorillas, wolves and meerkats, these cases are primarily social rather than cultural entanglement. However, these social groups all have social structures, generally hierarchical, which contains intra-group violence by reducing the instances where conflict can occur [66].

3.4.2 Mimetic theory

Rather than decreasing the potential for violence, increased dependence on the group on its own can increase instances of violent conflict in the absence of cultural norms. In non-social animals, conflicts of interest do not generally result in destructive forms of violence (violence that inflicts physical damage) [45], simply because it is too costly to do so. For a non-social animal it is possible to walk away without a significant cost on fitness. In social groups however, disputes can not be so easily resolved as there is not the option of walking away: outside the group there is no survival. In social animal species, there are social hierarchies which, when these are not being challenged, minimise destructive violence: in a dispute the dominated will give way to the dominant. These dominance hierarchies are however undermined by mimesis.

The word *ape* has two meanings: the noun is a type of primate, and the verb "to ape" means "to imitate". However, humans are remarkably better imitators than any other animal, including apes [65]. Through imitation, information can be mediated through generations and be accumulated. Humans' propensity to imitate is a condition of possibility for the development of collective intelligence and culture. However, the necessity of imitation or mimesis for culture does not prevent it from extending into situations in which it becomes problematic.

This is the central idea of Girard's Mimetic Theory of culture: that mimesis, which is a condition of possibility for culture, causes new forms of intra- and inter-group violence, namely in the form of mimetic rivalry and mimetic violence [65]. Humans do not only mimic techniques, language or any other 'functional' attributes; they also mimic each other's desire. The imitation of desire, or mimetic desire, operates through triangulation between the one who desires, the desired object (material object, status, mate...) and a mediator of desire. This causes humans to converge on the same goal, and desire certain things not necessarily because they are inherently valuable (often they are not), but because they are desired by others.

Mimetic desire cannot be regarded as inherently bad, for it drives the acquisition of numerous behaviours. The learning of languages, tool making, rituals, food preparation, dance and song are all initially acquired though mimesis. Mimesis becomes problematic in situations of conflict and violence. Mimetic desire simultaneously creates new instances of potential conflict, and increases the potential cost of conflict in the form of escalating forms of violence. If two individuals desire the same thing then they become rivals and there is a risk of conflict. This conflict can give way to violence unless there is a mechanism by which the conflict can be resolved. In animal societies, this is solved by a dominance hierarchy. The risk of unregulated inter and intra-group violence is referred to as mimetic rivalry and mimetic violence.

In Girard's theory, acquisitive mimesis leads to mimetic rivalry which, in the absence of any intrinsic regulatory mechanism, leads to escalating forms of violence. Mimetic violence makes it possible for an 'all against all' situation with no intrinsic regulatory mechanism. According to mimetic theory, the mimetic crisis would only have been resolved by being replaced with a 'all against one' situation.

Both mimetic theory and Darwinian evolution share the characteristics of being highly non-agential, generative theories. According to mimetic theory, culture emerges out of the necessity to regulate the ever present risk of violence in general and mimetic violence in particular. These emerge once mimesis is strong enough. Human culture arises naturally when a certain threshold of pre-reflective mimesis is reached. At a certain level of mimesis, mimetic conflict becomes unavoidable and a mechanism to resolve it become a necessity. According to Girard, the solution that emerged was the victimisation mechanism; the society which is divided by mimetic conflict is cured by directing the sum total of the violence to a single individual (or small group) which is eliminated, either by expulsion from the group or, more probably, collective murder. A single element of the society is sacrificed to avoid the disintegration of the whole. All other forms of ritual and prohibitions are centred around this danger of mimetic conflict, which is the eternally present danger in human societies.

In Girard's *Things Hidden Since the Foundation of the World*:

> *We have to show that mimetic rivalry, which is already very much in evidence at the level of primates, destroys dominance patterns and it gave rise to progressively more elaborate and humanised forms of culture through the intermediary of the surrogate victim. At the point when mimetic conflict becomes sufficiently intense to prohibit the direct solutions that give rise to the*

> *forms of animal sociality, the first 'crisis' or series of crises would then occur as the mechanism that produces the differentiated, symbolic, and human forms of culture. [...] In order for us to suppose that things did in fact happen this way it will be necessary and sufficient to show that mimetic power must increase not only during the process of hominization but even prior to its being set in motion and to a degree great enough to set the process in motion. [65]*

To make this theory fully generative, one must provide an explanation of how the mimetic threshold was breached. Mimetic theory's explanatory power begins from the premise of prereflexive mimesis. This is its starting point; it does not include a generative hypothesis for how humans came to reach and breach the mimetic threshold which set the cultural process in motion.

What conditions would optimise the development of mimesis? As was argued in the previous chapter, play only makes evolutionary sense as a contributor to development. This means that from an evolutionary perspective, a type of play should be understood in terms of its broader contribution to the behavioural ecology. The following section will look at what role dance would have played within the broader development of culture. If culture is to be described by an autopoetic theory, it must be able to explain the transitions between low mimetic societies and those in which mimesis is foundational.

3.5 The Role of Dance

In this chapter, the aim was develop the possible role of dance in the emergence of cultural traits more generally and its effect on broader social transmission capabilities. According to Girard, culture would emerge out of necessity once a certain threshold of prereflexive mimesis was breached. It follows that if it can be shown that the initial mimetic threshold for dance would be lower than what it was for fully developed culture, then dance would have an important role in the origins of culture in general. It was Aristotle's belief that poetry emerges as a natural consequence of humans' innate sensitivity for both imitation and rhythm:

> *Imitation, then, being natural to us—as also the sense of harmony and rhythm, the metres being obviously species of rhythms—it was through their original aptitude, and by a series of improvements for the most part gradual on their first efforts, that they created poetry out of their improvisations [5].*

All activities are constrained by inherent physiological and motor-neural control limitations. Any functional activity has the additional external constraints of having to fulfil the task. Even in certain forms of mimicking, the physical form is additionally constrained in having to resemble whatever is being mimicked. In playful dance however, the movements have no additional constraints beyond those attributable to inherent physiological and motor-neural control limitations. As a consequence, internal constraints can emerge without compromising or displacing any preexisting function. Playful dance is an activity where internally constrained physical forms, and therefore codification can take place.

In evolutionary theory, a point of convergence is sometimes called an attractor: a state towards which a biological or cultural system is likely to converge. An attractor is a point of convergence either due to internal or to external necessity. It seems that imitating each other's movement is an attractor as a mechanism for forming and demonstrating shared intentionality, and bonding. Imitative courtship rituals occur in several bird species including crows, greebs, penguins and albatrosses [183]. Similar observations have been made of mimicry having a positive social effect in humans [154]. It would appear that synchronised movement rituals are an example of convergent evolution, and therefore an example of order from noise satisfying a preexisting necessity. The specific movements of the ritual themselves however are inwardly determined: it is complexity from noise; it is an example of an endogenous system (the specific physical movements) being contained within the context of exterior necessity. There is no determining constraint on the specific movements (beyond the realm of physiological possibility), but there is a necessity that these movements should be endogenously fixed, otherwise there would be no imitation ritual.

Why such a ritual functions is a separate question. Courtship rituals are generally believed to be a demonstration of genetic fitness: showing coordination, strength and general health [138]. Therefore, to understand the function of an imitative courtship ritual, one must be able to explain what is being demonstrated through imitation that cannot be demonstrated by individual coordinated movement alone. In general, an imitative ritual is fundamentally collaborative; it is not exclusively dependent on any given individual but the physical performance of two (or more) together. It is a demonstration of intrinsic characteristics of individuals, such as their ability to accurately perceive the other's movements and coordinate their own accordingly; but it also has characteristics that transcend individuals in being a demonstration of shared intentionally. Fink argues that in the case of human ritual there is an extra level of conscious control of the meaning that is being communicated: " Ritualized communication is observed in many animals; but the capacity to voluntarily alter symbolic meaning through movement patterns, and thus deliberately express (or withhold) meaning, seems to be unique to humans."[138].

Dance is an autotelic activity; it is a self-incentivised activity (it is self-rewarding for the individual and for the group). Human infants are born with the ability to process musical structures of sound; namely frequency, rhythm, and timbre [114], as is the capacity for entrainment. It has been shown that synchronised movements, such as those performed in dance, tap into the endorphin system in the brain (which is the principal pharmacological system of social bonding in primates) [49] [160] [26]. Moving in response to auditory rhythm and coordinating movement between participants correlates with positive emotion [91] [137]. This capacity has implications for other behaviours beyond social bonding, play and dance, as argued by Ian Morley:

> *The ability to genuinely engage in entrainment may be directly related to the development of the abilities for sophisticated mimicry of gesture and corporeal expression, as well as having implications for abilities in turn-taking (critical in social interaction) and holding expectations about future events on the basis of patterns of events [114].*

The significance of an autotelic activity is that it represents the smallest possible feedback loop to justify itself. Evolutionary theory works from the assumption that all traits emerge from some form of positive feedback loop with the environment. Positive, feedback loop means that the trait will have some form of causal effect on its own replication, for example a genetic trait that gives a selective advantage in the environment, facilitates its own replication by increasing the reproductive fitness of the organism within which it has emerged. A similar argument can be made for culture in general, although it is not necessary correlated with reproductive success (see Williams argument in section 1.3).

Although we seemingly have only marginal differences from other primates in terms of anatomy and genetics we are drastically different in terms of cognition and social behaviours such as music, dance, language, stories, religion and others [50]. Therefore, in order to explain this disparity between humans and the rest of the natural order, one would have to propose a structure of feedback loops that must have been present in humans, and not in any other animal. Given that the ecological, genetic and anatomical differences are marginal [50] while the social and cognitive differences are drastic, the feedback loops that must have been present during homonization are likely to have involved the very characteristics that make humans unique.

For any characteristic to have an effect on the evolutionary trajectory of a species, it must be persistent in time. There are various ways to achieve this. In normal natural selection, if a trait depends on a specific genetic configuration, that trait will persist in the population if it can be reproduced from one generation to the next. A cultural trait needs to replicate by cultural transmission, and this is highly dependent on transmission fidelity [101]. Functional behaviours that are distinctively human such as complex tool use and language, while these are persistent over time, they are dependent on extensive preexisting factors. In the case of tool use there are social demographic constraints and in the case of language there is the need for repetition of sounds, a social group and the internally defined codification of sound amongst others. To explain the emergence of these distinctively human behaviours without resorting to needle in the haystack explanations, requires some form of scaffolding process. Preexisting activities would have had to be persistent in time and have engaged the requisite cognitive and social environment for all the other persistent group activities to emerge. I suggest that the distinctively human activity that can remain persistent over time, and thereby stabilise the traits that are required for other behaviours to build on, is dance and music.

Under what circumstances can culture be regarded as an attractor? Why has culture not emerged in any other species other than humans given the apparent payoff in doing so? According to mimetic theory, culture becomes an attractor once a threshold of mimesis is breached. What has been suggested in this chapter is that the threshold would have been breached in a playful activity in which mimesis *is* the function. In the following chapter we will try to model some of the consequences of having individuals constrained by both endogenous and exogenous constraints.

4 Computational modelling of culture

The aim of this chapter is to build a computational model of cultural evolution and examine the consequences of mimesis on the evolutionary dynamics across a population. Given that culture is a highly multifaceted phenomenon which is far too complex to fully describe computationally, it is nevertheless possible to build an extremely simplified model that can capture some of the implicit consequences of mimesis on the evolutionary trajectory of the population. The models will be interpreted through the lens of the evolution of dance and culture more generally.

This model will be based on the idea of the cultural phenotype which was motivated in section 1.2.1, where a set of cultural traits can be described as a cultural phenotype and can be represented by the binary string:

Cultural space	Cultural phenotype
C_1	1
C_2	0
C_3	0
$\vdots$	$\vdots$
C_i	1
C_j	1
$\vdots$	$\vdots$
C_d	1

Table 3: Cultural phenotype

The set of cultural traits $\{C_d\}$ describes a d-dimensional binary space and the cultural phenotype represents a cultural individual in the space.

One of the benefits of computational modeling is that it makes it possible to simulate complex physical systems that involve multiple parameters that cannot be isolated from each other. It is difficult to study the effects of culture (especially its origins) because it is embedded and entangled with social, ecological and biological factors [153]. The emergence of a cultural phenomenon such as dance depends on factors distributed over these multiple domains [103]. Furthermore, as was seen in the gene-culture coevolution hypothesis, there is a mutually reinforcing relationship between different domains: social-organisms that are more dependent on their social group are expected to have biological characteristics that support social behaviour to be selected [51]. The defining characteristic of complex evolutionary systems it that there is no single parameter or variable [93]; the rules that govern the system are distributed over different parts and effect each other over different scales.

In this chapter, the primary aim will be to model the combined effect of the external, ecological constraints on a population as well as the internal constraints emerging from the group. As has already been discussed in this thesis, the fitness and the incentives of a social organism do not interact with the environment independently of its social group. Understanding the constraints underpinning evolutionary phenomena is key if we are to understand how behavioural traits emerge [152]. Models studying genotype-phenotype maps in high dimensional spaces are a valuable tool for studying complex adaptive systems in evolutionary biology and have been applied to empirical biological data [2]. However, these models are not yet adapted to explain the evolution of cultural traits, which have important distinctions from genetic traits in the way we define fitness. Computational models of cultural evolution are relatively new, but models adapted from those used in physics have already contributed insights into cultural evolution more generally [105]. Simulations of evolution over rugged fitness landscapes [118] can be used to describe the mapping between genotype and fitness. If such a mapping is to be made between cultural traits and fitness, it would need to account not only for its presence in the individual but also its prominence within a group. In general, the fitness of certain cultural traits depend not only on individuals possessing it, but on group distribution. For example, language allows humans to communicate and coordinate their behaviour to a level of complexity, precision and variety unparalleled in the rest of nature; it has undoubtedly increased human fitness. However, the fitness advantage of language only exists if it exists across a group. An individual possessing the capacity for language would acquire no fitness benefit if it is the only member of the group who possesses it; he would be able to communicate with no one. Other examples, such as hunting or food preparation, which are key to a group's survival [97], only provide a fitness advantage if they are exercised across a group. More precisely, culture introduces behavioural characteristic which are not reducible to innate capacities of individuals; the conditions for their existence are distributed across the populations.

Any representation of the fitness landscape of cultural traits would need to account for this quality of culture: fitness does not depend innately on the ecological context but on the distribution of the capacity for the trait within the group. According to Hoffman's interface theory of perception [43] and Merker's model of perception [111], perception of an organism should correlate with the fitness landscape it occupies. For this to happen at the level of the group in which cultural traits are properties of groups and not only of individuals, then the perception, or the value hierarchy of the individual (what drives at motivates it on an individual level), needs to be causally connected with other members of the group before these are possible. Since no presumption of foresight can be admitted, the local incentive for individuals to perceive a trait as desirable in the absence of the payoff of fully developed culture: the shift in perception must have preceded it.

One can explain this shift happening via early forms of cultural technology and techniques. However, in the context of the space of possible avenues through evolutionary space, this would be an extremely narrow path through which to evolve. One would expect an organism which develops in these domains, but also through other, neutral paths in the evolutionary landscape would develop culture more quickly. It is possible that dance and music did have a payoff for the group; but even if it were merely a neutral contribution or a minimal payoff, the fact that they are autotelic on the local level, that it engages the motor-auditory neural links, and it is an activity in which there can be the development of endogenously defined movements and sound would be enough for it to be significant on the ultimate timescale for increasing the number of paths through the evolutionary landscape.

Fitness landscapes

Fitness landscapes are a mapping of a vector to a real number

$$F : v \to \mathbb{R}. \tag{2}$$

Generally fitness landscapes are intended to represent a measure of reproductive fitness. In this case, we instead want to model what traits are locally incentivised to an individual. The fitness landscape is a measure of the 'attractiveness' of a particular trait to an individual. The fitness of the organism depends on its position in the high dimensional space. However, in the case of individuals living in social groups the fitness cannot be simply a mapping of the individual, but must have some coupling to the fitness of the population, which is a function of the trait distribution within the population

$$F : P \to \mathbb{R}. \tag{3}$$

The position of the population in the hyperspace is an aggregation of the positions of the individuals within it. Each individual has their own value hierarchy which governs these individual level movements in the hyperspace. Extending the value hierarchy beyond being dependent on inherent characteristics of the individuals and instead be causally connected to the position of others, greatly increases the space of possible states the population is likely to explore.

There is a space of possible states that a population can take. Which state it is in is determined by the states that the individuals that constitute it take. If the individuals move to certain states depending on their individual value hierarchies, a population of individuals will always be constrained to the subspace to which the agents are driven. A population of individuals with instinctual value hierarchies will always be constrained to a space that emerges from individual level experience. Extending the value hierarchy of the individuals within the group opens the possibility to explore a much larger space of possible states. The value hierarchies of the individuals are open to selection at a level beyond itself. Let us assume for now that meaning value hierarchies can be imitated. These hierarchies can be selected for at a higher order; one that cannot be reduced to any individual for any value hierarchy may not make sense to a particular individual, but in the context of a group leads to the emergence of phenomenon that increases the overall fitness of the group (where is the fitness of the group is a measure of the probability with which it will produce a new generation). For example, certain initiation rituals are costly to the individual while being important to the cohesion of the group, thereby increasing the fitness of the group [151]; the individual therefore values a certain behaviour only because of it being in the context of a group.

The ability to extend the value structure of individuals is crucial for the potential evolutionary dynamics of the population. Emergent value from the collective actions of the individuals in the group are not obviously perceived at the individual level (even in principle). It is not possible to disentangle the value of a specific action if its merit depends on its coordination with other actions. It is necessary, therefore, for emergent behaviour to be sustained by the individual hierarchies so that the individual level hierarchies be selected for not at the individual level, but at the level of the group, or the level where the emergent behaviour giving the pay-off takes place. The extended hierarchies are therefore a translation of group level value to an individual level. This assures that the individuals will perform the necessary actions that sustain the group level action that is being selected.

The extension of value hierarchies extends the possibility for endogenous stable states to emerge at the population level.

4.1 Introduction to the Model

We begin with the simplest minimal model that captures the relationship between a background fitness and internal constraints. In this simulation the fitness of an individual will be a coupling between a background fitness that is independent of the group, and a coupling fitness, or an endogenous fitness, that is dependent only on the relative position of all the members of the population relative to one another.

Here the term fitness to refer to the metric in the landscape, however, in this model the fitness is not representing reproductive fitness, but rather the perception of the individuals in the population. According to the interface theory of perception, an organism's perception, and by extension its behaviour, correlates with the fitness landscape which it occupies [80]. In the case of social animals in general, and humans in particular, the behaviour of the individual is coupled with that of the group: that which is perceived as desirable does not depend on what incurs an external payoff from the environment, but on the behaviour of the group itself.

What will follow is a minimal model of such a relation; the 'fitness' of an individual represents the evolutionary tracts it perceives as viable. In this model, each individual is described by a D-dimensional binary string, with each entry of the string representing a distinct trait. For a given entry of the string: a 1 indicates that the trait is present in the individual, and a 0 indicates that it is absent. The evolutionary space accessible to each individual is therefore described by a D-dimensional unit-hypercube where each vertex of the cube describes a unique set of traits. In any given simulation, there will be a population of size P. Each vertex is connected to D adjacent verticies; the verticies that differ in exactly one position. A population of P points are said to *evolve* in the cube by moving from one vertex to adjacent verticies, thereby acquiring or losing traits one at a time. How the population of P points (which will be referred to as agents) diffuse (evolve) in the cube will depend on the fitness value of the traits.

The probability of a trait or a set of traits being assimilated by other members of the population depends on inherent characteristics of the set of traits: eg. a set of traits that increases the amount of food available to the group. This is a fitness component that is inherent to the set of traits in question; it depends on the environment in which the population is. We will call it the *background component* and denote it by B_i which is the background fitness of individual i. The fitness of a set of traits also depends on the other sets present in the group, i.e. two sets of traits that have equivalent fitness value with respect to the environment may not have the same probability of transmission. One set may be closer to the sets already present in the population and therefore will have a greater chance of being transmitted within the group. In our model this would be represented by one set of traits requiring only a few changes in order to be assimilated, there are others that require more changes, although equally as performant with respect to the environment will have a much lower reproducibility or fitness. This can be thought of as a component of fitness that depends on the set of traits already present in the population; we call this the *endogenous component* denoted E_i, which is a measure of the Hamming distance of the set of traits from all the other sets of traits present in the population.

The fitness F_i of an individual i is the sum between a background fitness, which is dependent on the position of the individual in the space; and an endogenous fitness, which is dependent on the relative position of all the members of the population:

$$F_i = B_i - \gamma E_i. \tag{4}$$

Here B_i is the background fitness, E_i is the endogenous fitness and γ is a weight factor that we will call the *coupling strength.* By varying the coupling strength it will be possible to analyse the relationship between the two metrics.

The position of an individual i is represented by a d-dimensional binary vector $v_i = (v_{i_1}, \cdots, v_{i_d})$ where $v_{i_s} \in \{0, 1\}$ for all $s \in \{1, \cdots, d\}$. The population P is a set of of such individuals $\{1, \cdots p\}$.

The background function B_i is a mapping of the position of individual i to a real number.

$$B_i : v_i \to \mathbb{R}$$

The endogenous function is a mapping of the position of individual i relative to the set of all individuals in the group P_{-i}

$$E_i : \{(v_i, v_j)_{\forall j \in P_{-i}}\} \rightarrow \mathbb{R}$$

Position v_i and $v_i^{'}$ are *neighbours* when $||v_i - v_i^{'}||= 1$. An individual i at v_i can move to a neighbouring point $v_i^{'}$ with a probability dependent on the difference in the fitness metric. The assumption, in this model is, therefore, that individuals will have a greater fitness benefit for traits that are the most present in the group.

$$\Delta F_i = F_i^{'} - F_i$$

The aim of this model is to analyse the qualitative differences that will emerge under different values of the parameter space namely the population number p, the dimensionality d and the coupling strength γ.

The following simulations used Python 3.6.4 with Anaconda custom (64bit) distribution. The code can be found on https://github.com/phannay101/Social˙memes/blob/master/Hypercub

4.2 Linear background

To explore the behaviour of the model, we begin with the simplest possible, non-trivial example of a background fitness so that the effects of the coupling can be evaluated in isolation from the specific background landscape. The background fitness will be initially defined as the magnitude of the vector of the individual. This is not intended to be an accurate representation of reality, instead the aim is to understand the basic relationship between the variables, making it possible to examine some of the implicit properties of the model.

$$B_i(v_i) = ||v_i||= \frac{1}{d} \cdot \Sigma_{s=1}^{d} v_{i_s} \tag{5}$$

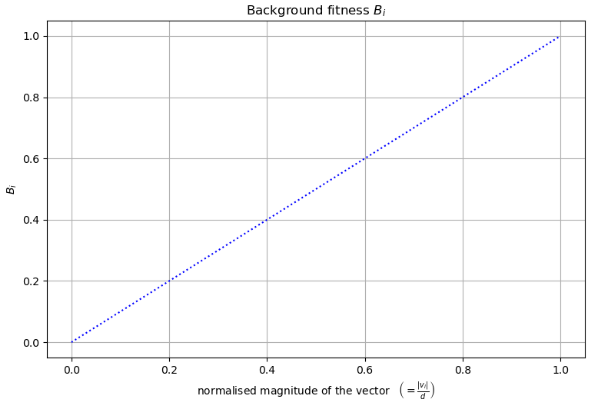


Figure 1: Linear background fitness: The background fitness B_i of the individual i (y-axis) against the normalised magnitude of the vector $||v_i||$ (x-axis)

In the review of the literature of cultural evolution, mimesis was stressed as being fundamental to the existence of culture, therefore, the choice of the endogenous fitness function has to reflect this property; it must reward mimetic behaviour and penalise differences. The simplest measure of the endogenous function is the negative of the sum of the difference of the positions in the population

$$E_i(v_i, P_{-i}) = \frac{1}{p \cdot d} \cdot \Sigma_{j=1}^{p} ||v_i - v_j||. \tag{6}$$

The fitness of the individual is penalised in proportion to the average hamming distance from all of the other members of the population.

There is therefore a tension between the background fitness and the coupling fitness. A particular move in the hyperspace may provide a gain from the perspective of the background fitness, but if it increases the average hamming distance from the other members of the population, it will incur a penalty. Whether the move would then represent a net increase or a net decrease in fitness depends on the precise gain and cost of the move and the strength of the coupling constant.

For the initial simulations the coupling strength γ was set to one

$$\gamma = 1 \tag{7}$$

which will then be varied in later simulations. With this simple model it will be possible to isolate the effect of the coupling fitness E_i on the movement of the population in the landscape. Without the coupling fitness term, the simulation would be trivial, the agents would simply climb up the cube to the point of highest fitness, but with the coupling interesting behaviours emerge.

At time step 0 all the agents in the population are located at vertex $(0 \cdots 0)$ and therefore all start with fitness zero. At each time step an individual is offered the possibility to move to an adjacent vertex with probability $p = 0.5$. (This probability is introduced because the acquisition of new traits is not determinate; this probability factor introduces stochastic variation). The individual then moves to the neighbouring vertex if the position increases the individual's fitness:

$$p(v_i \rightarrow v_i^{'}) = \begin{cases} 1, & \text{if } \Delta F_i \geq 0 \\ 0, & \text{if } \Delta F_i < 0 \end{cases} \tag{8}$$

Without the coupling (i.e. when $\gamma = 0$), The population simply climbs up the cube to the point of maximal fitness unconstrained:

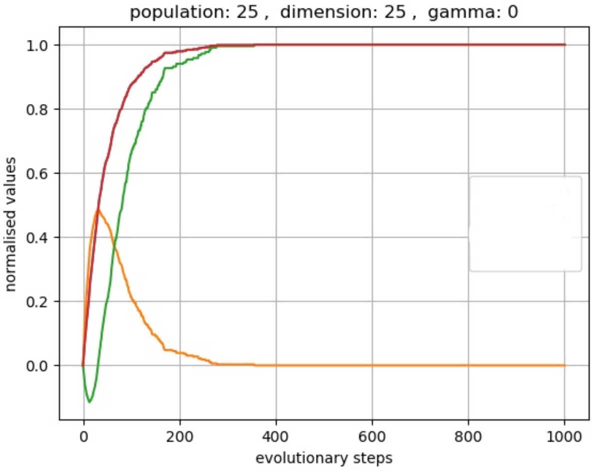
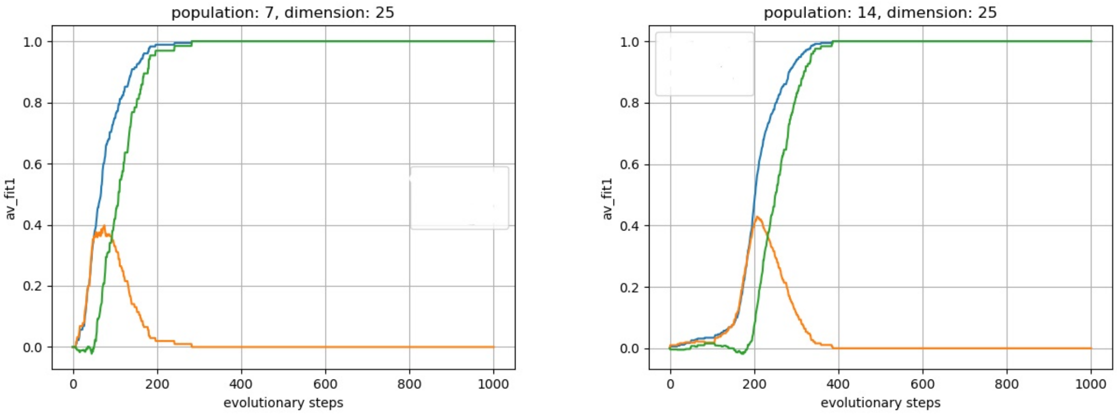


Figure 2: At coupling strength $\gamma = 0$ the population can move to a position of high fitness unconstrained. The normalised average fitness functions (y-axis) are plotted against the number of evolutionary steps (x-axis).
This simulation represents the circumstance in which the evolution of the individuals in the population are decoupled from each other and so only depend on background fitness. The average *net-fitness* $\frac{1}{p} \cdot \sum_i F_i$, the average *background fitness* $\frac{1}{p} \cdot \sum_i B_i$ and the *magnitude* of the average *coupling fitness* $|\frac{1}{p} \cdot \sum_i E_i|$ are represented by a *green line*, a *red line* and an *orange line* respectively.

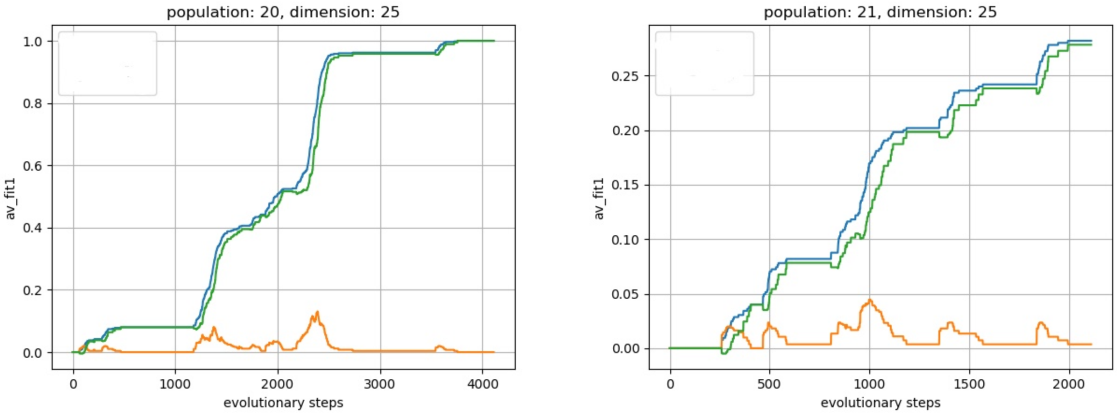
From the point of view of cultural evolution, this would represent a case in which individual learning of a set of traits is easy to acquire and that therefore the average fitness of the population can increase easily. The fitness of the individual trait is independent of its distribution in the population. The magnitude of the coupling fitness peaks at 0.5 approximately when the background fitness is also 0.5 because it is at the half way point in the cube that the maximal number of verticies have the same background fitness. When there is a fitness penalty for variation between individuals (i.e. when $\gamma >> 0$) we would expect for there to be a lower peak in average distance between individuals. This is indeed what is seen in the following two simulations: at low and medium population size (population = 7 and 14 respectively) the progress up the cube is mildly perturbed relative to the decoupled case. The coupling fitness is still characterised by a single peak coinciding with the middle of the cube, however the peak value is just over 0.4 as opposed to 0.5. This is an indication that the average variation in the group is being reduced as a result of the coupling fitness.



(a) $p = 7$, $d = 25$, $\gamma = 1$ (b) $p = 14$, $d = 25$, $\gamma = 1$

Figure 3: At Low and medium population, size (population 7 and 14 respectively) and $\gamma = 1$, the agents can move up the cube relatively unconstrained. However, the peak average distance between members is just over 0.4 as opposed to 0.5 in the decoupled case indicating that the coupling reduces variation within the group.
The average *net-fitness* $\frac{1}{p} \cdot \sum_i F_i$, the average *background fitness* $\frac{1}{p} \cdot \sum_i B_i$ and the *magnitude* of the average *coupling fitness* $|\frac{1}{p} \cdot \sum_i E_i|$ are represented by a *green line*, a *blue line* and an *orange line* respectively. (This will be consistent up to figure 6)

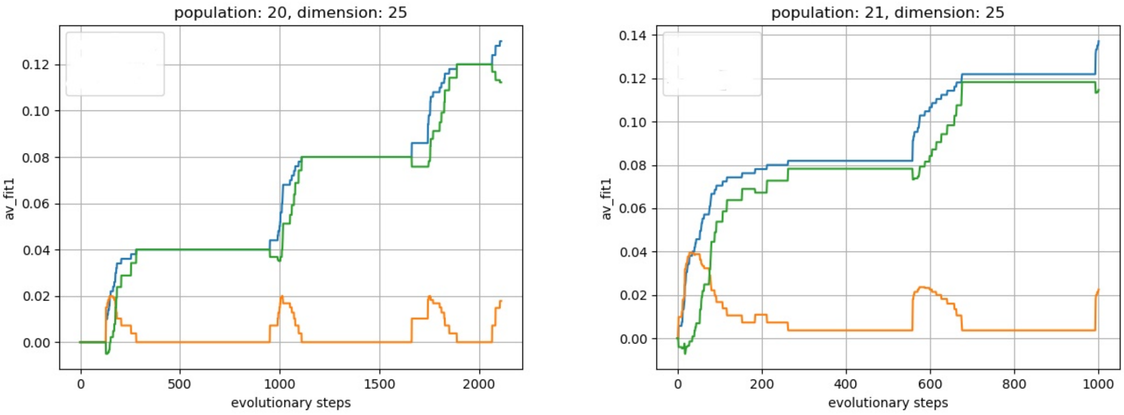
At population 14 there is a slightly extended initial phase before the main peak relative to the simulation at population 7. The increased size of the population increases the number of agents that there can possibly be a distance between, therefore when the whole population is at the same vertex (when there is perfect mimesis), the probability that the individual will make a move that will give it a positive fitness is lower. This becomes more apparent if the population size is increased further: at higher population sizes *'stepping'* behaviour starts to occur. The evolution of the population starts to alternate between progression and stagnant plateaus. The population begins to constrain itself from moving to a position with higher average fitness because of the penalty incurred from an increase in the average distance from the rest of the population



(a) $p = 20$, $d = 25$, $\gamma = 1$ (b) $p = 21$, $d = 25$, $\gamma = 1$

Figure 4: At higher population size (20 and 21 respectively) and $\gamma = 1$, a step like progression up the cube starts to emerge. The average background and net fitness B_i and F_i alternates between increasing and stagnation phases. These coincide with increases in the average hamming distance between members of the population.

In figure 4 at population 20 and 21, the population alternates between phases of variation and progression up the cube, and phases of low or no variation and stagnation within the cube. The periods of stagnation occur when there is little variation within the group: the magnitude of the coupling fitness is at zero or near zero as see in the following two examples.



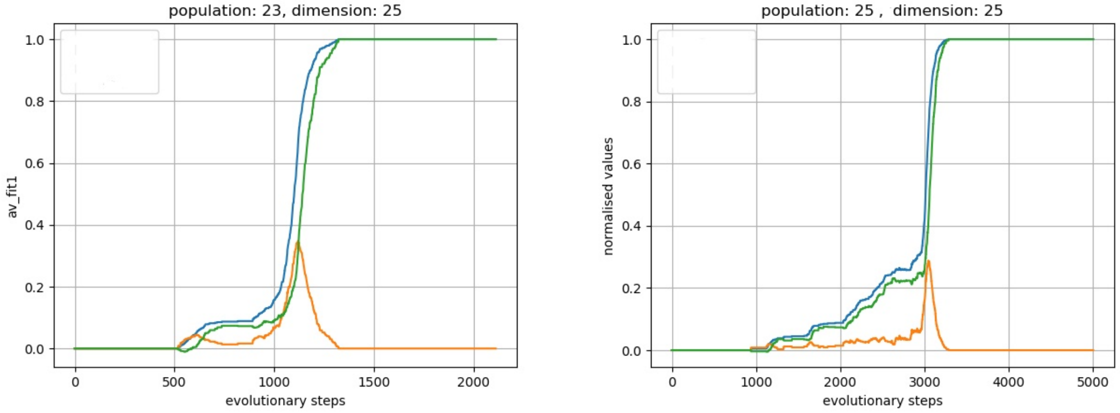
(a) $p = 20$, $d = 25$, $\gamma = 1$

(b) $p = 21$, $d = 25$, $\gamma = 1$

Figure 5: Stepping coincides with either low or absent variation in the population ($\gamma = 1$). The phases of progress coincide with greater variation and the phases of stagnation coincide with little or no variation.

From the point of view of cultural evolution this would be an example in which a population is overly incentivised to imitate each other so that the average net-fitness is kept below optimal. When there is more variety in the population, progression relative to the background fitness increases since there are more paths available which simultaneously increase local fitness and the average net-fitness of the population. At higher population size, there is more pressure for the population to stay closer together. There are fewer moves away from each other that would increase their fitness.

However it is not impossible for the population to find a smooth way to the top even when the coupling fitness is present ($\gamma = 1$). The following two simulations are examples of smooth progression up the cube with the characteristic single bump from the coupling fitness. This suggests that once a certain threshold of coupling fitness is breached, i.e. the population has a certain amount of variation within it and there is no sub-optimal consensus hindering the progress, the probability that the agents on the population will be offered moves that increase their fitness is high and a smooth progression takes place. Below this threshold, the population is more likely to group back together and stepping behaviour emerges.



(a) $p = 23$, $d = 25$, $\gamma = 1$ (b) $p = 25$, $d = 25$, $\gamma = 1$

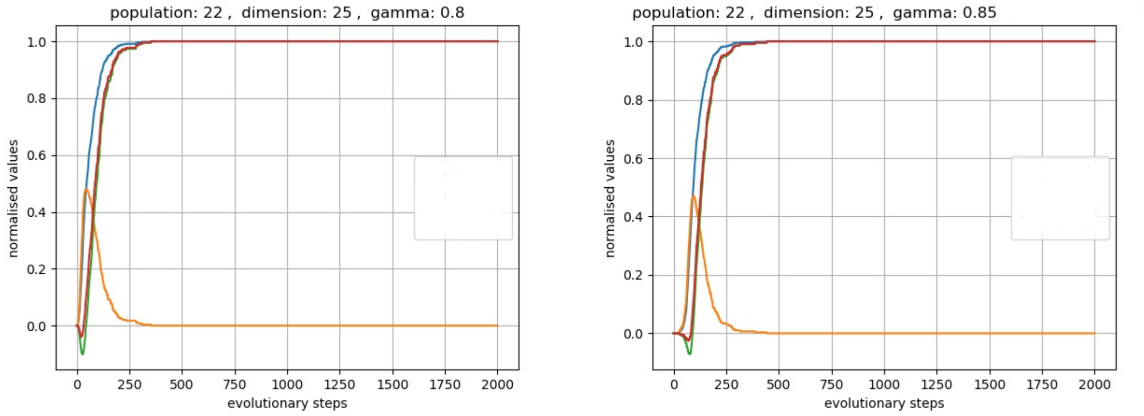
Figure 6: There are nevertheless examples of smooth, rapid progression at high population sizes for $\gamma = 1$. These are characterised by a single bump in the magnitude of the average coupling fitness.
The peak in the variation of traits coincides with the phase of most rapid progress. There is a threshold of variation which is breached by which point the coupling fitness is no longer a constraint

The qualitative characteristics of the simulations are an emergent property of the dynamics of the population's evolution. A key feature of the simulations is that every step from a static point (either the initial move or a move from a static point in the stepped simulations) coincides with a dip in the average fitness of the population. This means that every move of the population up the cube is initiated by a fraction of the population first taking a move away from the static point, increasing their own individual fitness and thus reducing the net-fitness of every agent that has stood still. By making a move up, the moving agents increase the coupling fitness of those who do not move (which makes a negative contribution to the net-fitness). This results in a dip in the average fitness of the population. However the fitness of the population quickly recovers and passes the previous fitness level. For the average fitness of the group to increase it must first be capable of allowing it to drop.

At very high population size, the probability of being offered a move that increases their fitness is too low from the start and the population will stagnate at its starting point indefinitely. For populations greater than 30 there are no examples of any evolution. The population have very little possibility in increasing their fitness and remain at zero.

4.2.1 Varying the values of the coupling strength γ

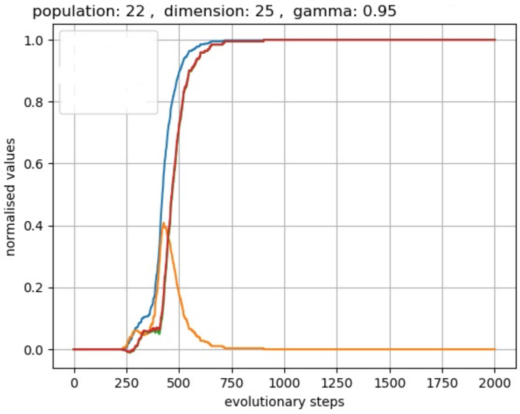
The higher the population size the greater the coupling fitness constrains the movement of the individuals. One would expect that by lowering the coupling strength γ we would relax the constraint due to population size and would start to see more progression up the cube even at high populations. This is indeed what we see. At population size 22 and dimension 25, where we would previously have seen stepping behaviour when $\gamma = 1$, the progression becomes smooth when $\gamma = 0.8$ or 0.85



(a) $p = 22$, $d = 25$, $\gamma = 0.8$ (b) $p = 22$, $d = 25$, $\gamma = 0.85$

Figure 7: When the coupling strength is reduced to $\gamma = 0.8$ and $\gamma = 0.85$, the constraint due to population number is ineffective. There is rapid progression up the cube for the same populatin and dimension numbers that saw plateauing occur when $\gamma = 1$.

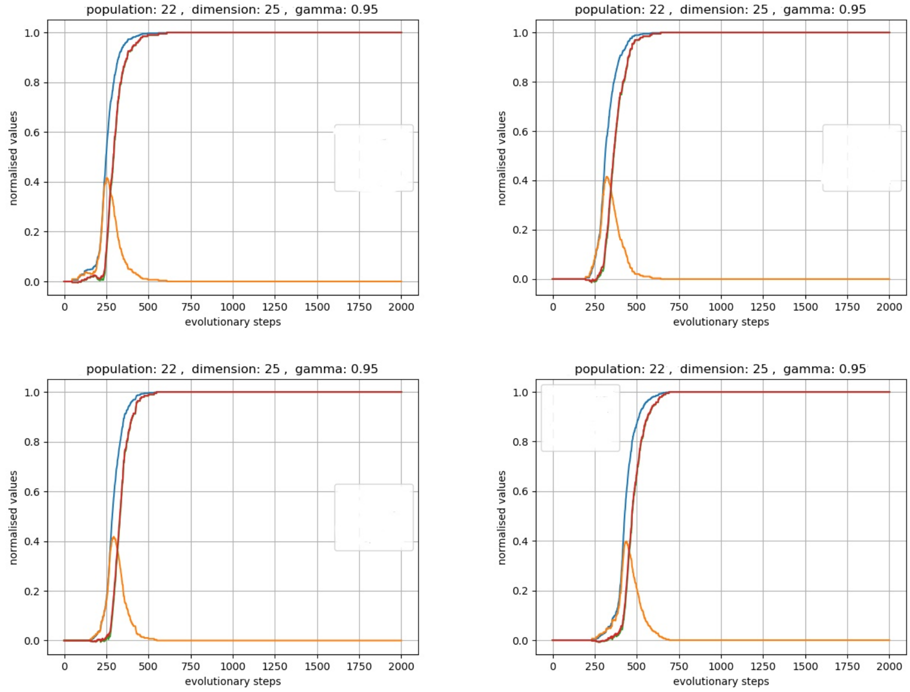
Only when the coupling strength is increased further to $\gamma = 0.95$ do we start to see some perturbation.



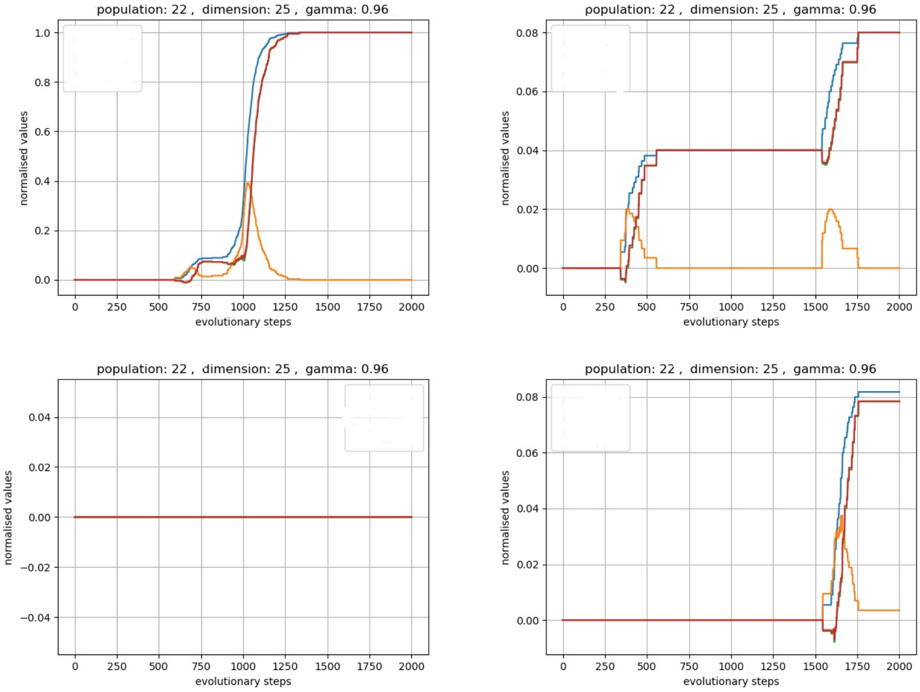
(a) $p = 22$, $d = 25$, $\gamma = 0.95$

Figure 8: In this simulation the coupling fitness is set to $\gamma = 0.95$ and the progression of average population fitness stagnates for 250 steps. Once the population passes a certain threshold of average variation at around 400 steps then there is rapid progression up the cube.

Between coupling strength 0.95 and 0.96 there is a qualitative difference in the behaviour of the simulations. The top row of four simulations are at coupling strength 0.95, and the second row of four simulations are at coupling strength 0.96 :



(a) Four simulations at $p = 22$, $d = 25$, $\gamma = 0.95$
There a consistently smooth progression to the point of highest fitness

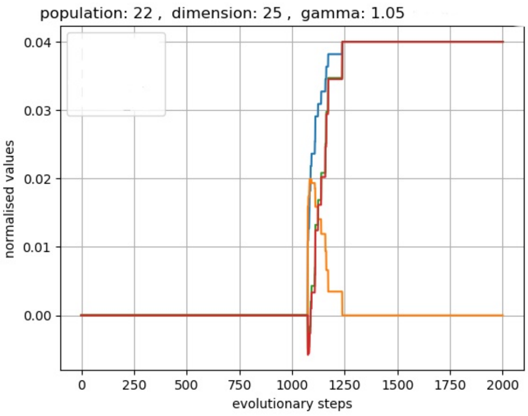


(b) Four simulations at $p = 22$, $d = 25$, $\gamma = 0.96$
There is a variety of different outcomes; smooth progression becomes rare although still a possibility.

Figure 9: There are drastic qualitative differences between the simulations at coupling strength $\gamma = 0.95$ and those at $\gamma = 0.96$.
In the first four figures 9a progression up the cube occurs relatively unperturbed; there is the familiar plateau and spike at around 250 steps. This is in direct contrast with the simulations in 9b where the behaviour is constrained by the internal dynamics of the population: the first example in figure 9b there is rapid progression after 900 steps. The general trend at $\gamma = 0.96$ is little or no progression as shown by the three other examples where there is either a very restricted progression to an average fitness of 0.08 or no evolution at all.

Figure 9 is significant as it shows that a small difference in the degree of coupling can cause a dramatic difference in qualitative behaviour. At coupling strength 0.95 there is a consistent smooth progression up the cube (after an initial stand still), but at $\gamma = 0.96$ only one of the four examples exhibit this property, the three others either step or flat-line. There is a clear transition for these different values of the coupling strength. This shows that after a certain threshold in mimetic strength, there is a qualitative discontinuity in the evolution of the population. This is consistent with the propositions put forward in chapter 3.

For coupling strength above one $\gamma > 1$, the evolution becomes severely constrained and almost no evolution takes place.



(a) $p = 22$, $d = 25$, $\gamma = 1.05$

Figure 10: For coupling strength $\gamma = 1.05$ the progression becomes heavily stagnant. The perceived fitness penalty from the coupling with the group is preventing any evolution happening at all.

Simulation 10 is an example of the evolutionary dynamics that occurs when $\gamma > 1$. The coupling strength penalises any differences between individuals very highly: there is a very strong disincentive to have any deviation form the rest of the group. There is a very low rate of evolution as a result. In simulation 10 at $\gamma = 1.05$, there is total stagnation until around 1075 steps where there is an increase to an average net-fitness of 0.04 at 1250 steps. The population then resumes its stagnant phase with zero variation between them as see from the flat coupling-fitness (orange line). Beyond $\gamma > 1.05$ however there are no examples of evolution happening at all. From the point of view of cultural evolution, this would represent a population in which the desire to mimic each other perfectly is too strong and therefore no evolution takes place. Mimesis hinders the evolvability of the population if it is over whelming the possibility for new traits emerging.

Mimesis may be necessary for new traits to spread within a group once these are discovered, however, in a context in which the background fitness always offers a beneficial move and the search space is simple for all individuals in the population, mimesis hinders the evolvability of the group. In the following subsection we will introduce different kinds of noise into the model.

4.3 Two sources of noise: T and β

In this section we want to examine the effect of noise on the evolutionary dynamics of the simulations. In cultural evolution we cannot presume a fully deterministic system;

there are variables that are down to chance and circumstance. Perceived fitness from the point of the individual is never absolute and this quality needs to be reflected in the model. Then there is the question of background fitness; it is implausible to consider a perfectly smooth landscape in which the order of the trajectory does not have an effect on fitness. Both of these aspects of cultural evolution need to be introduced into the model. The first source of noise will be called the *temperature* T (this is in reference to the Boltzmann probability distribution [165] which gives the probability of a certain state as a function of its energy and the temperature). In our model, the fitness is analogous to the energy of the state and the temperature represents the tendency of individuals to move regardless of a local drop in fitness (section 4.3.1) . The second source of noise β (section 4.3.2) introduces noise into the background fitness landscape. This represents a circumstance where all the trajectories up the cube are not equally viable. As was argued in section 1.2.1, cultural traits are not independent from one another some depend on the preexistence of other traits. This background noise β introduces this aspect of culture into the model.

4.3.1 Noise to fitness constraint T

Until now the dynamics of the agents was entirely constrained by the changes in the fitness function.

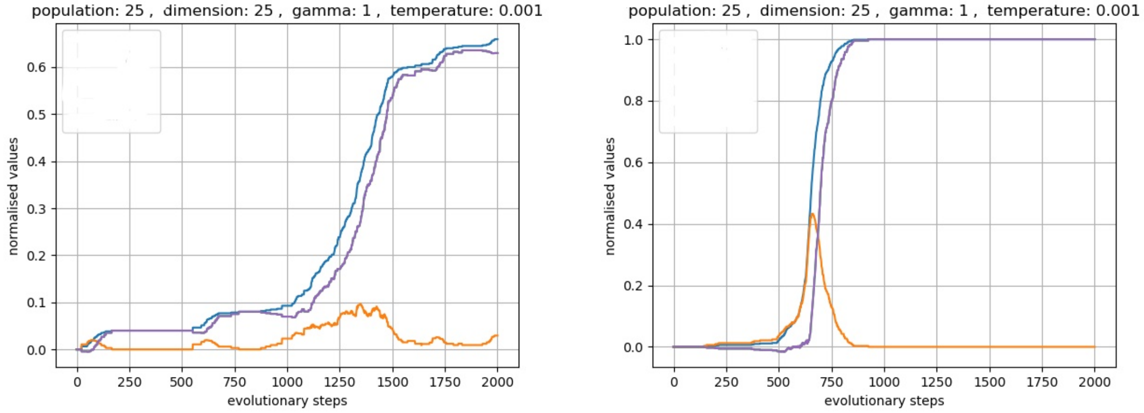
$$||\delta v_i|| = \begin{cases} 1, & \text{if } \Delta F_i \geq 0 \\ 0, & \text{if } \Delta F_i \leq 0 \end{cases} \tag{9}$$

We now relax this constraint by generating a non-zero probability $\exp(\frac{\Delta F_i}{T})$ for some positive constant $T > 0$ which we call temperature. This probability is analogous to the Boltzmann factor. If $\Delta F_i \leq 0$

$$||\delta v_i|| = \begin{cases} 1, & \text{if } \Delta F_i \geq 0 \\ \exp \frac{\Delta F_i}{T} & \text{if } \Delta F_i \leq 0 \end{cases} \tag{10}$$

It is now possible for an individual agent to move to an adjacent vertex when the gain in background fitness is insufficient to offset the cost in endogenous fitness.

The higher the temperature, the higher the probability that an agent will make the move to a vertex of lower fitness. Since the probability that it will take a move to a vertex of higher fitness stays the same we would expect that the total number of moves the agents can take will increase, so that the stepping behaviour we see in high population sizes will diminish. This is indeed what we see; at low temperature $T = 0.001$. Although some degree of stepping does still occur, the points of stagnation are not as absolute as the simulations without the Boltzmann factor dependence (in the following simulations the net-fitness function is represented by a purple line).

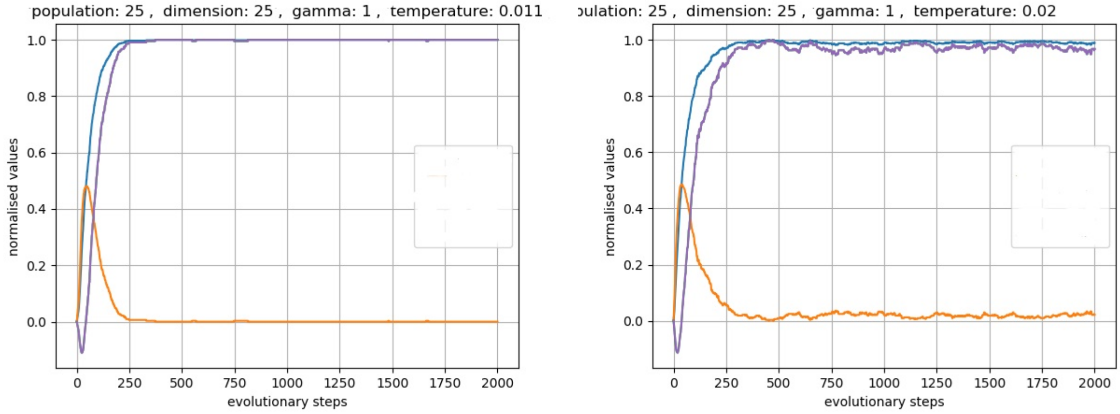


(a) $p = 22$, $d = 25$, $\gamma = 1$, $T = 0.001$ (b) $p = 22$, $d = 25$, $\gamma = 1$, $T = 0.001$

Figure 11: At temperature $T = 0.001$, the progression up the cube is characterised by an elongated phase at low magnitude.
The average *net-fitness* $\frac{1}{p} \cdot \sum_i F_i$, the average *background fitness* $\frac{1}{p} \cdot \sum_i B_i$ and the *magnitude* of the average *coupling fitness* $|\frac{1}{p} \cdot \sum_i E_i|$ are represented by a *purple line*, a *blue line* and an *orange line* respectively. (This will be consistent up to figure 13)

The two simulations 11a and 11b have identical initial parameters but very different emergent behaviours after 2000 steps. In the left hand simulation, the population only reaches an average fitness just above 0.6 and is about to reach a new plateau at 2000 steps. This is in direct contrast to the simulation on the right, which although has an initial stagnation up to 500 steps, quickly progresses up the cube and reaches the point of highest fitness after around 800 steps. Why should there be such a striking difference in behaviour given identical initial conditions? The key to the analysis is the coupling fitness (orange line) and the average net-fitness (purple line): In the left-hand simulation, the population never has an average hamming distance happening between the individuals above 0.1 which it reaches at around 1350 steps. The low average distance between the individuals means that the average net-fitness (purple line) remains positive at all times. However, this has a cost in terms of the evolvability of the population. The population are close to each other therefore any extra separation is costly to the individuals and there is a lower local incentive to climb up the cube. In the right-hand simulation, after the initial stagnation ends at around 500 steps, the average net-fitness dips into negative figures and the average hamming distance climbs rapidly to peak just over 0.4 around 600 steps. This means that the population is more spread out within the space; because there is more variation within the population, the relative cost of moving away from the other members of the group is low. Indeed the negative average net-fitness stays approximately constant until the peak spread is reached when the average background fitness is 0.5, at which point the average spread collapses and the average net-fitness climbs to 1.

What can be concluded from the qualitative differences in these results which were consistent over many runs? In the case where there is a constant background fitness, it seems that the incentive to be close to each other, i.e. to mimic each other, hinders the progress of the entire group. The background fitness is what is exterior to those acquiring the traits. In the case of a dance class, the background fitness is analogous to the dance being demonstrated by the instructor. If in the class there is a strong tendency to mimic one another rather than being influenced primarily by the instructor then the progress of the group as a whole is hindered. Likewise in a culture, which is in an environment in which new variation in technology receives a payoff, more variety in the group is beneficial while too much pressure to mimic would be a hindrance. In a smooth landscape therefore, any parameter that decreases the influence of the coupling-fitness is beneficial for the overall evolvability of the population (in a rugged or flat landscape this may not be the case). This is indeed what we see if we increase the temperature a little more to $T = 0.011$:

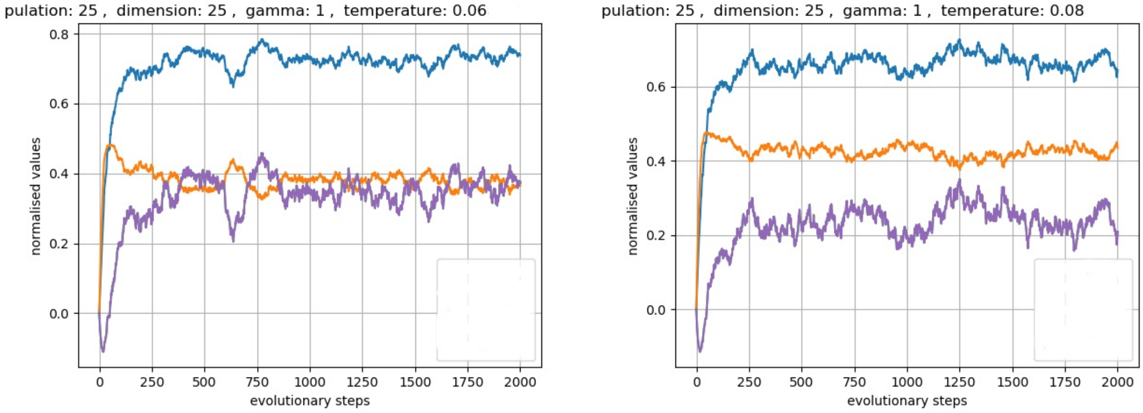


(a) $p = 25$, $d = 25$, $\gamma = 1$, $T = 0.011$

(b) $p = 25$, $d = 25$, $\gamma = 1$, $T = 0.02$

Figure 12: At temperature 0.011, There is an immediate progression up the cube, no restrictions. However, at temperature 0.021, the population can no longer sustain maximal fitness, it begins to oscillate about a equilibrium position just below maximal fitness.

The population climbs up the cube almost completely unconstrained. The population is also still capable of approaching the maximal fitness. However, if the temperature is increased more (to $T = 0.209$ in this case), the maximal fitness cannot be reached because the probability of taking a move which lowers fitness is too high. At high temperatures the populations do reach a stable point of maximum fitness that they oscillate around. A balance is reached between the temperature and the fitness constraints.

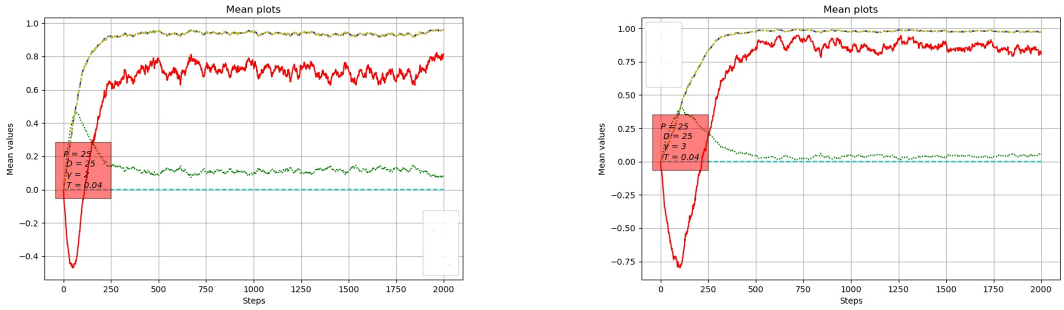


(a) $p = 25$, $d = 25$, $\gamma = 1$, $T = 0.06$

(b) $p = 25$, $d = 25$, $\gamma = 1$, $T = 0.08$

Figure 13: As the temperature continues to rise, the maximal fitness that the population can reach decreases. If the temperature is too high, then there is no longer a strong enough incentive to reach a point of maximal fitness. In simulations 13a and 13b, the populations oscillate around net-fitness 0.35 and 0.25 respectively.

As the temperature increases, the maximal fitness that can be reached is substantially reduced. A high temperature would represent a situation where the individuals within a population will take a local fitness penalty in favour of novelty. This is because there is too high a probability that the individuals will take a step that decreases their overall fitness; the dynamics of the cube become increasingly decorrelated with both its background fitness and its net-fitness incentives. However, this could be countered by increasing the coupling constant γ. When the coupling constant is increased, while there is no extra incentive from the background fitness function B_i, the population is better able to converge to higher orders of background fitness because variation is penalised more harshly. This correcting effect can be seen in figure 14 where there are two simulations at temperature $T = 0.04$ but different values of *gamma*.

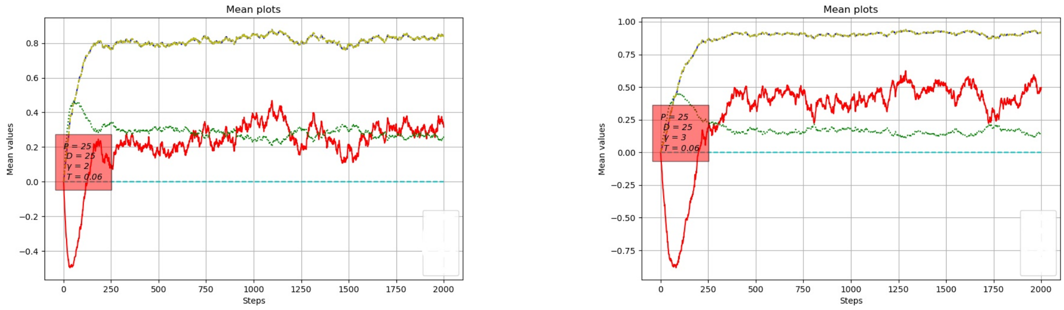


(a) $p = 25,\ d = 25,\ \gamma = 2,\ T = 0.04$

(b) $p = 25,\ d = 25,\ \gamma = 3,\ T = 0.04$

Figure 14: At temperature 0.04 increasing the coupling strength increases the average maximal fitness reached. At $\gamma = 2$ the average maximal net-fitness is at 0.7 and $\gamma = 3$ it reaches 0.85
The average *net-fitness* $\frac{1}{p} \cdot \sum_i F_i$, the average *background fitness* $\frac{1}{p} \cdot \sum_i B_i$ and the *magnitude* of the average *coupling fitness* $|\frac{1}{p} \cdot \sum_i E_i|$ are represented by a *red line*, a *yellow line* and a *green line* respectively. (This will be consistent up to figure 16)

Similarly for high temperatures $T = 0.06$ shown in figure 15:

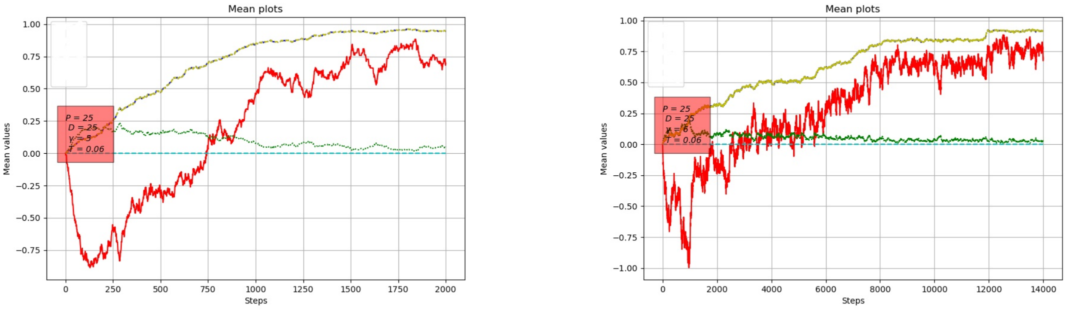


(a) $p = 25,\ d = 25,\ \gamma = 2,\ T = 0.06$

(b) $p = 25,\ d = 25,\ \gamma = 3,\ T = 0.06$

Figure 15: At temperature 0.06 increasing the coupling strength from$\gamma = 2$ to $\gamma = 3$ has a drastic effect not only on the maximum the net-fitness F_i and minimum average coupling fitness E_i, but on the average maximal background fitness B_i as well: being stable at 0.8 for $\gamma = 2$ and 0.9 for $\gamma = 3$

The increase in coupling strength increases the average net-fitness and reduces the effect of noise. Relating this to the question of cultural evolution, this simulation would represent a situation in which there is a high amount individual penalty being taken: there are moves that have a clear fitness cost that are being taken regardless; this is seen by the very large dip in fitness in the initial stages. However, because this individual risk is combined with a very strong mimetic urge, when a point of high fitness is reached by the majority of the population, the fluctuations are reduced. This shows up again in the final two simulations in figure 16 where at temperature 0.06 the coupling strength is increased further to $\gamma = 5$ and $\gamma = 6$ respectively.



(a) $p = 25$, $d = 25$, $\gamma = 5$, $T = 0.06$

(b) $p = 25$, $d = 25$, $\gamma = 6$, $T = 0.06$

Figure 16: At temperature 0.06 increasing the coupling strength to $\gamma = 5$ and $\gamma = 6$ increases the average net-fitness of the population still to 0.75.
Furthermore, at $\gamma = 6$ we recover the stepping behaviour that had been lost by introducing high levels of temperature in simulation 12a

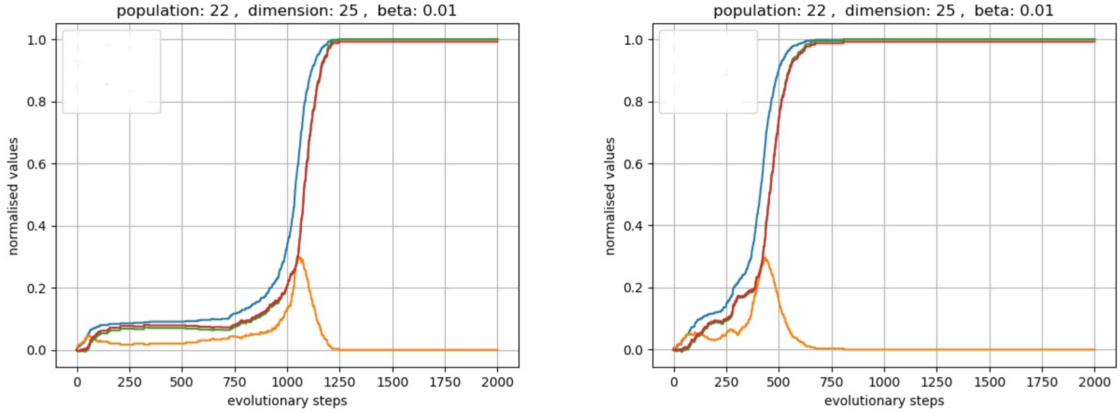
At $\gamma = 6$ the fitness cost for variation is very large, therefore the progress up the cube is much slower (note the simulation is showing 14000 steps as opposed to 2000 steps in the previous simulations). The stepping patterns in the previous models begin to reemerge. However, while the stepping behaviour in the smooth, noiseless landscape (such as simulations 4a and 4b) were a reduction in evolvability from the base rate, here the coupling is an improvement over the base rate at high temperatures. From the point of view of cultural evolution this disparity can be interpreted the following way: A smooth background with no noise is a situation where perception of the best move is clear, for example in a learning environment with a highly competent teacher which can lay out the possible ways of improving a particular set of traits or techniques. In such a circumstance it is detrimental for the individual and the group as a whole to perceive value in the traits that others possess because it causes stagnation at sub-optimal points which only have the merit of being shared by everyone. In contrast, a smooth landscape with a high amount of perceived noise would be analogous to a situation in which there is not a clearly perceived advantage to one move over another. An example could be the development of new hunting techniques where the perceived payoff is difficult to abstract over time because pay-off is highly dependent on the specific circumstances. In this case where the background fitness is difficult to gauge, imitation or mimesis is highly beneficial. While low mimetic populations with a highly noisy perception of the landscape stagnate at sub-optimal levels of fitness, highly mimetic populations can ‘bootstrap’ themselves to higher levels of fitness. Here a difference in kind (the evolution of the population) emerges from a difference in degree (the strength of the coupling within the population).

4.3.2 Noise to background fitness β

The second source of noise proposed at the beginning of this section was to the background fitness of the population B_i. In this section the background fitness function will be defined as follows:

$$B_i = \left[\frac{1}{D} \cdot \sum_{i=1}^{D} v_i + \beta \cdot r\right] \cdot \frac{1}{1+\beta} \tag{11}$$

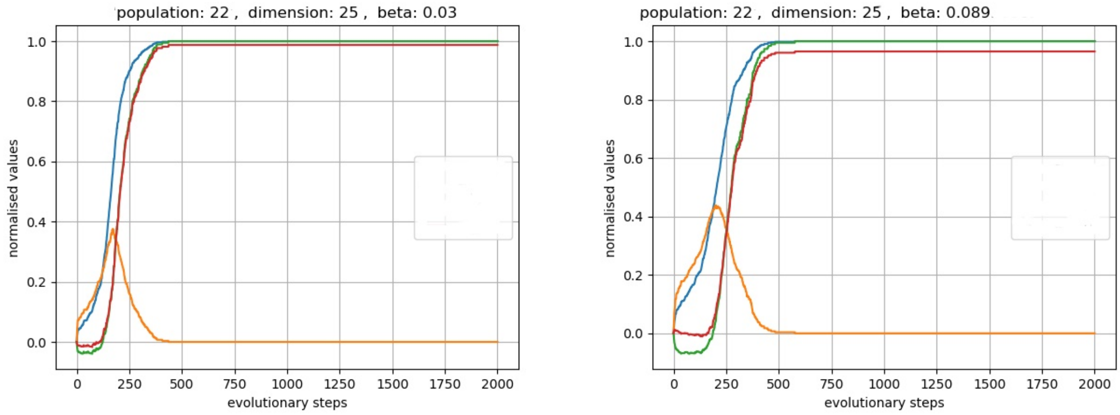
where β, is the *noise coupling strength* and $0 \leq r \leq 1$ is a random number picked from a normal distribution. Note that the background fitness is renormalised with the factor $\frac{1}{1+\beta}$. In the case of culture, the beta function would represent a situation in which not all paths are of equal value. In high dimensions we would expect there to be a range of different paths up the cube: some that are slightly better than the baseline fitness landscape and others that are slightly worse. We expect again that the noise will have the greatest effect in the areas where moves to vertices of higher fitness are rare and therefore flat lining is prominent. This is indeed what is seen; even for low values of beta, the populations move more easily away from the origin. (The simulations in this section were performed with temperature $T = 0$ to restrict all novel behaviour to the introduction of β).



(a) $p = 22$, $d = 25$, $\gamma = 1$, $\beta = 0.01$ (b) $p = 22$, $d = 25$, $\gamma = 1$, $\beta = 0.01$

Figure 17: Even a moderate amount of noise increases the progression up the cube
The average *net-fitness* $\frac{1}{p} \cdot \sum_i F_i$, the average *background fitness* $\frac{1}{p} \cdot \sum_i B_i$ and the *magnitude* of the average *coupling fitness* $|\frac{1}{p} \cdot \sum_i E_i|$ are represented by a *red line*, a *blue line* and an *orange line* respectively. The green line represents the coupling fitness if the noise was removed; it is there for comparative purposes (This will be consistent up to figure 19)

These simulations are at population 22 and dimension 25 which is where there would be stepping behaviour on the linear landscape where $\beta = 0$. Here at $\beta = 0.01$ there is a path that can overcome the coupling-fitness and once it is found, all the agents are able to progress up the cube smoothly. As we increase the noise dependence further, the initial step becomes very sharp and then continues with a sharp gradient to the point of highest fitness.

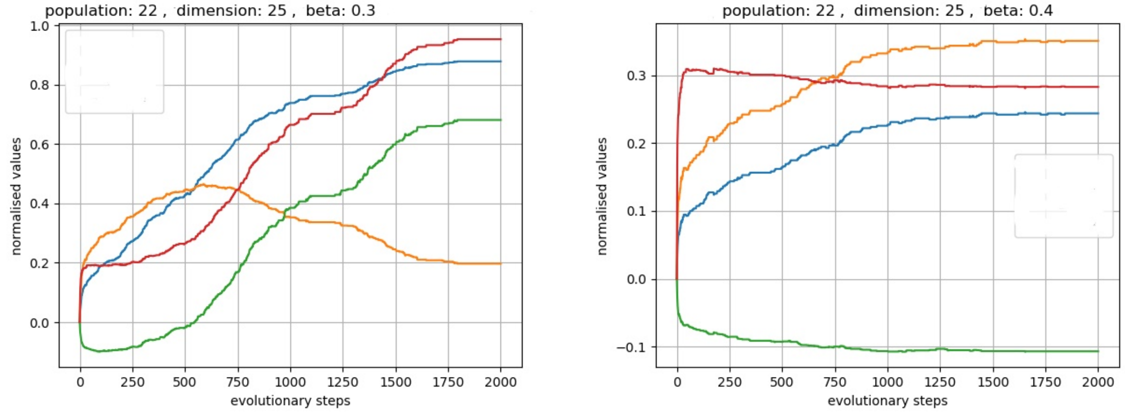


(a) $p = 22$, $d = 25$, $\gamma = 1$, $\beta = 0.03$

(b) $p = 22$, $d = 25$, $\gamma = 1$, $\beta = 0.089$

Figure 18: In these simulations, the initial step of the population, even though it results in an increase in background fitness, still begins with an initial negative net-fitness. As can be seen by the negative green line there is a greater average cost to variation rather than pay-off. However, this initial negative fitness is able not to drop any lower and it stagnates until the peak in variation is reached and the average fitness increases rapidly. This is in direct contrast to simulation 12 where the point of negative fitness is a peak.

While in figure 18 the progression of the origin was quick, is still resulted in a small initial dip in average fitness which stagnated. This shows that there is a path of neutral fitness cost within the background fitness landscape. Contrast these now with the following two simulations (figure 19) in which the populations immediately jump to a point of high fitness. The progression afterwards is compromised because there is less opportunity for the population further to increase its fitness. The initial jump is followed by relative stagnation.



(a) $p = 22$, $d = 25$, $\gamma = 1$, $\beta = 0.3$ (b) $p = 22$, $d = 25$, $\gamma = 1$, $\beta = 0.4$

Figure 19: At high values of β there is a trend for an immediate increase in fitness followed by stagnation. Although there is a point of high fitness close to the origin, this is detrimental in the long run as there is no longer any local incentive to evolve further despite there being a higher ultimate payoff. Here we see a contrast in the evolutionary trajectory of the population: at $\beta = 0.3$ there is still progress up the cube despite an early fitness payoff. The progress is less sharp than the simulations seen previously, The beginnings of a stepping behaviour reemerges. At $\gamma = 0.4$ there is a very high initial payoff which deters any further progress. However, there is still movement in the cube as can be seen by a slow decline in net-fitness (red line) and an in crease in both variation and background fitness (orange and blue lines)

When β is large then there is an increased probability of there being a point of high fitness too close to the origin. This is problematic from the point of view of the ultimate evolutionary fitness that the population can reach. There is a disincentive to move to a higher point in the cube. Increasing the background fitness hiders ultimate progress of the system. From the point of view of cultural evolution this would be analogous to a situation in which there is a low local incentive to evolve even if there is a high ultimate incentive to do so. One would predict that the coupling fitness would contribute to better overall fitness on the long time scale because once a beneficial trajectory is found, it becomes incentivised locally to the other members of the population simply because of the penalty on variation.

4.4 Complementary Models and Discussion

These early simulations have already recovered some of the evolutionary behaviour that we would recognise as distinctively cultural. There is the stark contrast between low coupling strength and high coupling strength which is in accordance with the proposition that a difference in degree of mimesis can lead to a difference in *kind* from the point of view of the evolution of traits. However, these models are highly simplified and so should only be interpreted as representing limited cases of reality. These models contrast with those seen in the literature review, specifically with Henrich's model in section 2.4.2. In Henrich's model was looking at the minimal population that would be required for traits to progress, stagnate or deteriorate and eventually get lost from the culture. Although this appears to be in conflict with this model in which high population led to slower progress (figure 4), the models are trying to capture different limiting cases of culture. Henrich is trying to model the role of population demographics, the models in this thesis were looking to capture the effect of internal coupling: they are modelling different limiting cases.

There is a literature on the relationship a fitness and the variation of traits in a population, both in the genetic and the cultural domains [106] [139] [12]. These suggest that when there is more variety within a culture there are more possible trajectories available to the population and therefore greater robustness [174]. There must be however a local incentive to increase the complexity of the culture, which would not be possible in small groups as there is only a finite amount of time to dedicate to a large set of potential traits: there must be a trade-off between complexity and local viability. In Wagner's thesis, this robustness is intimately linked to *complexity.* In biology, complexity is often naively equated with inefficiencies. Similarly a culture that has multiple technologies (bow and arrows, spears, nets, domestication of dogs, horses and cattle...) will be less vulnerable to single changes in the environment compared to a simplified culture that has comparatively few technologies [13]. But then there is the question of how the fittest behaviours arrive [174]?

The complexity question is a problematic one because while it may be true that complex culture will out perform simple ones on the ultimate time scale, we cannot presume foresight, we cannot presume that individuals could predict the emergence of complex cultures and the payoff that they would receive. There must have been a local incentive for complexity.

Future models should be refined accordingly to capture this aspect of culture. In the following section we will look at a simulation which operates within a locally flat background landscape, but in which there is nevertheless an ultimate background payoff. This landscape would represent a circumstance closer to that described above where a payoff only comes after a number of traits have been acquired.

4.4.1 Flat landscape

Suppose the population exists in a locally flat background landscape: that is all adjacent vertices to the population have the same background fitness as the initial position of the population. This background fitness would represent a context in which all members of the population have no local incentive to move to any neighbouring node in the space beyond noise. Here there is no background incentive to move to a new vertex in the cube; if there is no noise (i.e. $T = 0$) then the evolution would be stagnant. However, with some level of noise $T > 0$ we expect some movement to occur, and furthermore, because of the coupling fitness penalising spread, the initial move should therefore incentivise later moves in the space according to some path rather than aimless wondering due to noise only. In a case where the neutral space is only local and that past a certain distance from the starting vertex, a background payoff can be found. If the endogenous constraint can bring the population to the point of highest payoff more quickly than the individuals would get there alone, then there would be a net benefit of the endogenous constraint in that regions of the space of possible states would be explored when they could not otherwise.

Consider the following background fitness:

$$B_i = \begin{cases} 1, & \text{if } \frac{1}{D} \cdot \sum_{i=1}^{D} v_i \geq 0.5 \\ 0, & \text{if } \frac{1}{D} \cdot \sum_{i=1}^{D} v_i < 0.5 \end{cases} \tag{12}$$

In terms of culture, such a landscape would describe a situation in which there is an ultimate payoff in the landscape: for example a complex technology in which none of the intermediary components are functional, but once they are assembled they provide a large payoff. Or language where if an individual is only able to make a small range of sounds then there is no (or at least negligable) payoff, but if it is capable of producing an entire set then there would be a large payoff.

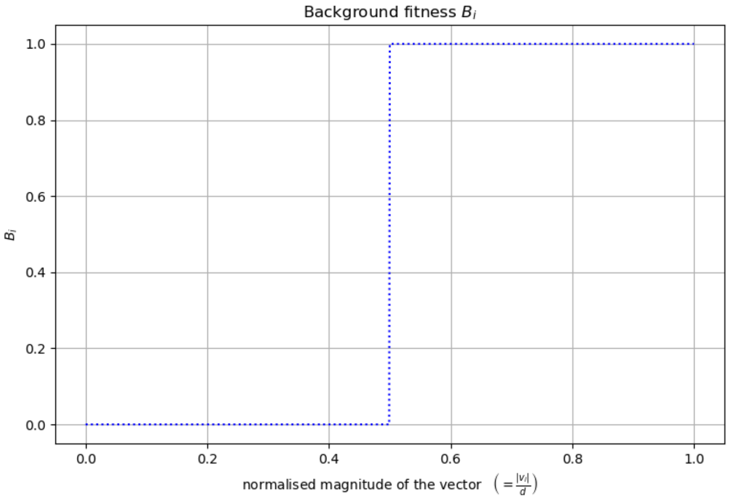
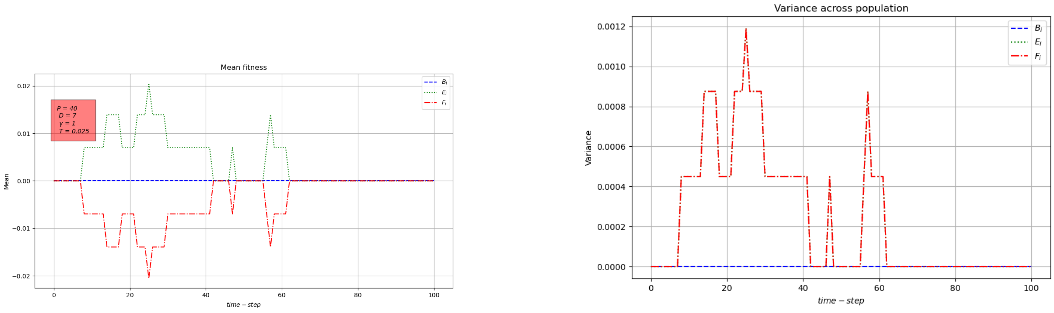


Figure 20: Flat background landscape: The background fitness B_i of the individual i (y-axis) is 0 for $||v_i||< 0.5$ and 1 for $||v_i||> 0.5$ (x-axis)

In such a context it should be expected that the endogenous coupling increases the rate at which the population discovers the background payoff that occurs at $\frac{1}{D} \cdot \sum_{i=1}^{D} v_i \geq 0.5$. In the following figures the left-hand simulation shows the average background-fitness of the population (blue line), the average magnitude of the coupling-fitness (green line), and the average net-fitness (red line); the right-hand simulation shows the variance in these respective metrics across the population with the same colours (note that the variance in the coupling-fitness is often the same as that of the net-fitness and so the green line is hidden by the red line). In such a landscape at low temperature, there is a very low level of evolvability. The following are examples of simulations in a 7 dimensional cube at temperature 0.025:

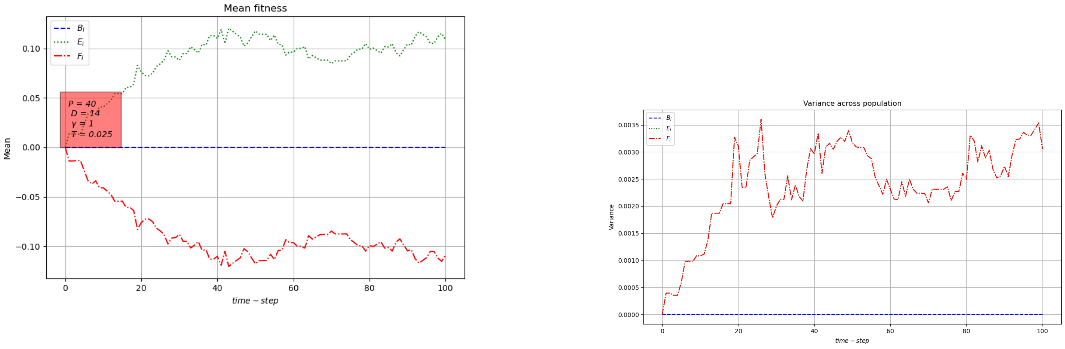


(a) Average fitness: $p = 40$, $d = 7$, $\gamma = 1$, $T = 0.025$

(b) Variance in fitness: $p = 40$, $d = 7$, $\gamma = 1$, $T = 0.025$

Figure 21: In this simulation, the spikes indicate instances where a few individuals move away from the starting point only to return to it rapidly as there is a very low incentive to move away in the locally flat landscape and still a strong incentive to have a low level of variation within the group. At dimensionality $d = 7$ there is a very low rate of evolvability: the temperature is too low to sustain large variation in the group in the absence of a pay-off to compensate for it.
The average *net-fitness* $\frac{1}{p} \cdot \sum_i F_i$, the average *background fitness* $\frac{1}{p} \cdot \sum_i B_i$ and the *magnitude* of the average *coupling fitness* $|\frac{1}{p} \cdot \sum_i E_i|$ are represented by a *red line*, a *blue line* and a *green line* respectively. (This will be consistent up to figure 26)

In this relatively low dimensional space and with a low temperature, there is a very low rate of evolvability. Some individuals in the population move away from the starting point only to converge back again. The move is not enough to incent the rest of the population to evolve. In fact the presence of the coupling fitness prevents any evolution from taking place because it incetivises those who have moved from the starting point to return to it. In a higher dimensional space with the same temperature and population size, there is more of a spread possible initially; therefore there is not a quick return to the staring point at $(0)^d$. However, there is still a stagnation in which there is only a cost to moving away from the general space of the group which the noise is not able to overcome.

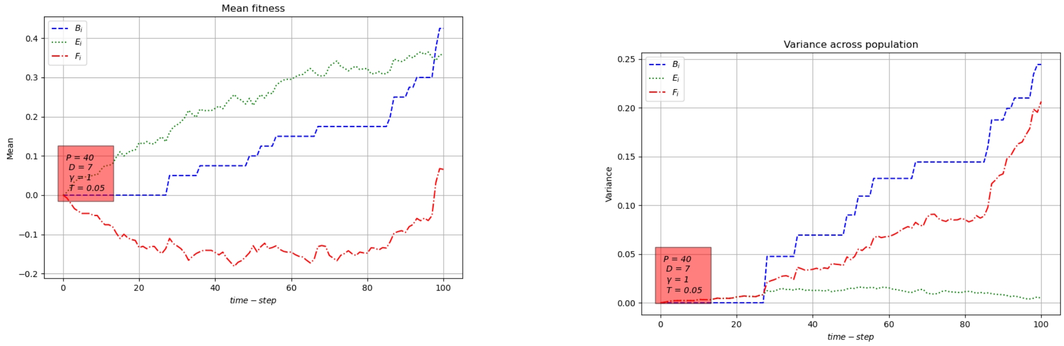


(a) Average fitness: $p = 40$, $d = 14$, $\gamma = 1$, $T = 0.025$

(b) Variance: $p = 40$, $d = 14$, $\gamma = 1$, $T = 0.025$

Figure 22: In the higher dimensional space (14) the probability of being offered a move back to the starting point is low once an individual moves away. As a result instead of the spikes seen in figure 21 there is a stable average variation in the cube at around 0.2. However, this stable state of variation is insufficient to reach the point with a background fitness payoff

At temperature 0.05 however, the individuals in the population can begin to move to the area of the cube with a higher fitness. Interestingly, at this temperature the population which is in a higher dimensional space (14) actually reaches the point of maximal average fitness quicker than the population that exists in the lower dimensional space (7), despite there being twice the amount of traits to acquire. Furthermore, the variance in average coupling fitness is lower in the higher dimensional space indicating that the population is more evenly distanced within the space.

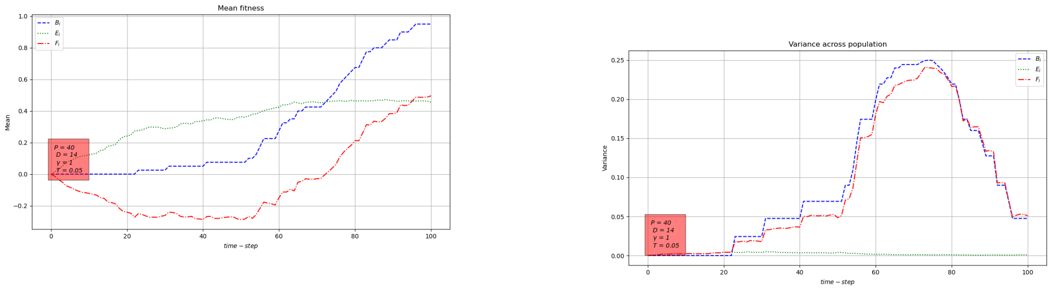


(a) Average fitness: $p = 40$, $d = 7$, $\gamma = 1$, $T = 0.05$

(b) Variance: $p = 40$, $d = 7$, $\gamma = 1$, $T = 0.05$

Figure 23: At temperature $T = 0.05$ there is enough noise to make it possible for individuals to access the point of background fitness 1, as can be seen by the increase in both variance and average fitness around 98 steps.

This behaviour is in direct contrast with that in higher dimensions. In simulation 24 There is a more rapid progress to the point of highest fitness despite higher dimensionality.

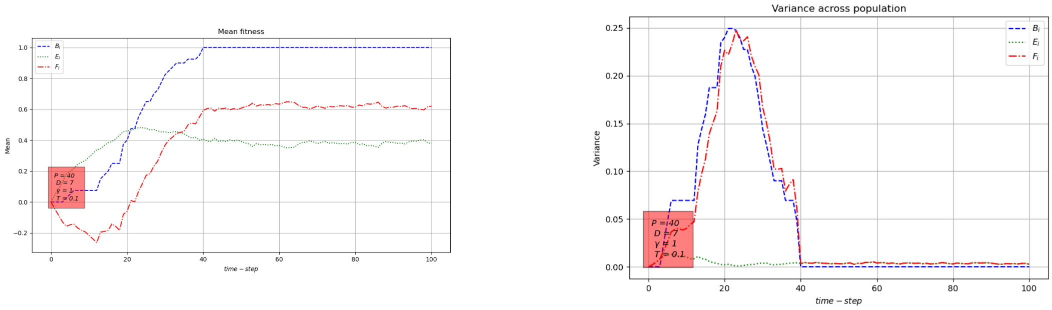


(a) Average fitness: $p = 40$, $d = 14$, $\gamma = 1$, $T = 0.05$

(b) Variance: $p = 40$, $d = 14$, $\gamma = 1$, $T = 0.05$

Figure 24: At temperature $T = 0.05$ there is enough noise to make it possible for individuals to access the point of background fitness 1. In contrast to 23 in higher dimensions $d = 14$ there is more rapid progress to the point of positive fitness. This can be seen visibly in sub-figure 24b where the bump in the variance shows the variation in background within the population increase and decreases suddenly.

Why should this be the case? When the dimensionality is larger there can be more variation between the members of the population and therefore a larger initial fitness penalty. Once there is variation in the population, any potential differences have less relative cost. If this were a cultural system, the temperature represents a readiness to move despite a local cost. At higher temperatures one would expect the coupling strength to be less of a factor and so the dimensionality of the cube to dominate the dynamics more relative to the coupling-fitness. This is indeed what is seen. For temperature 0.1, there is a much quicker progression to the high fitness payoff in 7 dimensions (figure 25) relative to the progression in 14 dimensions (figure 26).



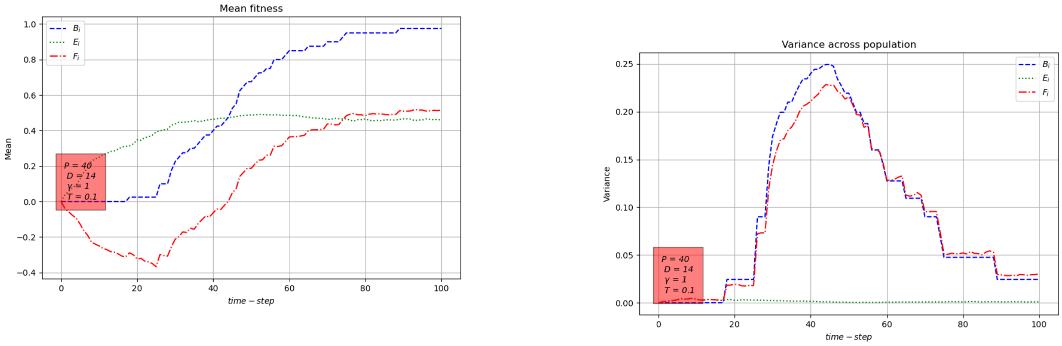
(a) Average fitness: $p = 40$, $d = 7$, $\gamma = 1$, $T = 0.1$

(b) Variance: $p = 40$, $d = 7$, $\gamma = 1$, $T = 0.1$

Figure 25: The sharp spike in variance indicates a rapid transition from the point of low payoff to the region of high payoff.

This indicates that the coupling strength is still a limiting factor. At 14 dimensions however the increase in temperature slows down the progression up the cube.

As can be seen in this comparison: when the temperature is increased, and therefore the effective coupling strength is relaxed, the progression to the point of higher fitness is slower.



(a) Average fitness: $p = 40$, $d = 14$, $\gamma = 1$, $T = 0.1$

(b) Variance: $p = 40$, $d = 14$, $\gamma = 1$, $T = 0.1$

Figure 26: At higher temperature and high dimension there is a slower progression than at lower dimensions

The flat landscape represents an environment in which there is no local background fitness with which the local payoff correlates with the direction of ultimate payoff. Future versions of the flat-landscape model should examine the effects that the coupling fitness has on the dynamics of the population. One of the recurring arguments in this thesis is that culture, as supported by mimesis, can guide individuals to a point of higher fitness even in the absence of any local exterior motivation. This model has the potential to show the relationship between the coupling fitness and ultimate fitness in a locally flat landscape.

5 Summary and Conclusions

Summary The first chapter began by arguing that because the emergence of dance is significant from multiple levels of analysis and for different fields, it is necessary to approach the question from a multidisciplinary perspective. Dance is a point of convergence of multiple different variables in cognition, culture and biology: it is irreducible to any single field. As a consequence, there was a necessity to develop a theoretical framework that could contextualise distinct data sets with respect to one another. If the question of dance requires contributions from multiple different fields, then there needs to be a framework that operates at an appropriate level of abstraction.

The framework that was developed represented culture as operating within a high dimensional space of possibility: culture enhances the fitness of humans by making them less vulnerable to variations in the environment.

While no computational model of complex systems, such as the emergence of dance or culture more generally, could ever capture the full complexity of the system, simple models can nevertheless be a valuable tool for evolutionary research if used appropriately. Computational models make it possible to test propositions on phenomena that take place on large timescales and therefore are very restricted in the amount of data that can be drawn from. Evolutionary phenomena, by definition, occur over generations and very long timescales; this makes it inherently difficult to test theoretical hypotheses because of the limitation on the experiments that can possibly be performed. Furthermore, the tape of life has only been run once [115], so comparative analyses are limited to a very narrow subset of human behaviours. Computational simulations, in principle, make it possible to test hypotheses of proposed mechanisms and parameters that were critical to the evolution of human behaviours such as dance.

The introduction was followed by a critical review of the literature review of the cultural and cognitive evolution. If dance is adaptive it must be evaluated within the context of culture and the capacity for culture more generally. Reviewing the archaeological data, there seems to be strong evidence for culture to have emerged gradually over time and that it was heavily dependent on a combination of social-demographic, ecological, genetic and cognitive factors. Again, it is not possible to reduce the emergence of culture on a single factor; it depended on a conglomeration of different factors, each of them interrelated and interdependent. The cognitive literature suggests that cognition is heavily influenced by the developmental environment of an individual, be it cultural, social or environmental. This suggests that there is a feedback-loop between culture and cognition: culture depends on certain cognitive functions; these cognitive functions are influenced by culture. Any causal theory cannot be reduced to one factor influencing another; it is the interdependence that is the determinate factor. This form of determinism is captured in the cultural niche hypothesis which postulates that culture actively modifies the internal environment of the group so as to be not only an object of selection, but also to modify the conditions of selection [98]. In other words, the culture not only acts in the environment, it also modifies the development of the following generations so as to sustain itself. In the terminology of Dupuy: culture is a program that requires its own output as an input [53]. When dealing with the question of the origins of culture no such initial input can be assumed, therefore, if we are to believe that culture is not a product of mere chance, we need to propose a mechanism by which cultural behaviour could emerge in the absence of any previous culture. This type of cultural phenomenon is what Enquist refers to as a cultural seed [54]. Because culture is by definition information that can be mediated between individuals, cultural seeds that would in principle contribute to the development of more sophisticated capacities for mediation of information are of particular interest; these would create a positive feed-back loop whereby better mediation begets more stable forms of culture, which in turn would select for better forms of meditation.

Dance is a cultural seed: it is an instinctive ability in human children who are naturally entrained to music [103]. It exists as both a cultural and a non-cultural activity. It has also been shown to promote prosocial behaviour. This motivated the comparison with play more generally, which is a condition of possibility for social group functionality (and by extension culture which depends on social interactions). Play is an activity through which an individual develops and learns social capacity on a motor-neural and cognitive capacity: a social animal that is deprived of play grows to be socially inept. It follows that a social group in which no individual would play would be impossible and that therefore play, and individual development through play, is a condition of possibility for social groups. This partly answers the question about the functionality of play: on the local timescale is recreational but on the extended timescale fulfils an indispensable developmental function. The literature review ended with the following question: what does play suggest about dance? what is it about play in particular that makes it an ideal environment for development? and what would this say about dance given that they share a number of qualities, namely both being activities that are patently not directly contributing any additional resources, while costing both time and energy?

The third chapter comprised of four main points: First was the idea of culture as an autopoetic system; culture does not only self-organise, it also facilitates the development cultural individuals. There is an inherent developmental aspect to culture which must be considered in any account of cultural origins. Second was the proposition that dance may have been a condition of possibility for the emergence of endogenous fixed points or endogenous defined physical forms, which are a prerequisite to codification. This proposition was motivated by the interface theory of perception [43] which says that the perceptual system of an organism is adjusted to the fitness landscape of the individual rather than the objective reality. This poses a problem when attempting to explain the emergence of codified systems of communication which relies on the perception and recreation of abstract, endogenously defined symbols. The proposition is that such a process would require a developmental activity for the internal definition of physical forms in a way analogous to play and that this activity was dance. The third point regarded the consequences of mediation of perceived value. For there to be culture, there must be a mechanism by which the perceived world transcends its inherent value. Humans are able to thrive in almost any habitat on earth, but it is always within a cultural niche outside of which there is no survival or reproduction [44]. It follows that the fitness of the individual is dependent on the group and therefore if an individual's perception is adjusted to its fitness, then there needs to be a mechanism by which the motivation of individuals is correlated with the culture. The perception is correct but only in a counterfactual way. The fourth point regarded the importance for all social groups to contain intragroup competition and selection. According to mimetic theory, mimesis, the very capacity that allows culture and more generally values to be mediated undermines typical instinctive controls of conflict. Once a certain threshold of mimesis is breached, the capacity that makes culture as mediated information possible, then makes culture as a regulatory mechanism *necessary.*

The final chapter examined the behaviour of a minimal computational model of cultural traits. The simulations recovered a clear qualitative transition when a certain mimetic threshold has been breached, thus being congruent with the proposition that a difference of degree in the capacity for mimesis can lead to a difference in kind in terms of the evolution of traits.

Conclusions The main contribution of this thesis was to have grounded the question of the emergence of dance with the question of the emergence of culture. The conditions of possibility for culture overlap with those of dance, namely in the form of mimesis, social bonding and endogenous fixed points. The thesis linked diverse sets of empirical data with general conceptual models of cultural evolution. It is possible to show that a change in degree of mimetic capacity can lead to a difference in kind of behavioural evolution, thus supporting the proposition that mimesis is the capacity that can make compatible both the essentialism and the continuity of humans with the rest of the natural order.

One of the main propositions was that dance, being an autotelic activity, fulfils the minimal requirements for foundational capacities of culture to develop. Because fitness is only evaluated once a trait has emerged, cultural traits that depend on the interaction of many agents must have been developed in a context where the group interaction was self incentivised. The implications of this are that any activity that would contribute to the development of humans' mimetic capacity would not be 'merely recreational' but foundational to human forms of culture in general. This is the argument made for dance. It is not merely recreational, or functional as a bonding mechanism leading to incremental improvements: dance internally incentivises the development of mimesis and the endogenous development of physical forms.

This changes the stakes of the question of the emergence of dance in human evolution and the direction in which future research projects should take. To what extent could dance or play be considered a universal feature of cultural development? Future research projects could try to approach this question using trade-off analysis developed by Bret Weinstein. Weinstein distinguishes between three types of trade-offs: statistical, allocative and absolute trade-offs [178]. Statistical trade-offs are those that arise from two independent traits being distributed over a population. In a given distribution if the probability that an individual is in the tail of one of these distributions is low relative to the probability of it being in the bulk, the likelihood that the same individual is in the tale of both distributions is even lower. In the case of statistical trade-offs there is no reason in principle why two traits could not occur in the same individual, only that it has a lower probability than to the individual having only one or neither of these traits. For example, if we assume that height and left-handedness are independently distributed across the population; the probability that a man is both tall and left-handed would be lower than the probability that it only has one of these traits. These constraints can in theory be alleviated by natural and sexual selection. If women developed a strong taste for tall left-handed men or nature favoured the combination of these two traits the individuals who lie at the tail ends of both distributions would be selected for overtime and the trade-off would relax. Allocative trade-offs arise when two independent traits depend on a common limited resource. For example, a plant can only draw a finite amount of nutrition from the environment. It must allocate the finite energy it has between growing roots and growing its shoots. The plant must compromise the growth of its shoots so that it has enough resources also to grow roots, and vice versa. These types of constraints can be alleviated if the amount of resources is increased or the dependency of one or both of the traits on that resource is relaxed [178]. Absolute trade-offs are those that are fundamentally dependent on the same physical parameters. For example teeth cannot simultaneously be optimised for grinding up vegetable matter and tearing through flesh; wings cannot simultaneously be optimised for efficient gliding and agility. Absolute trade-offs cannot be circumvented by natural or sexual selection, or by allocating more resources; one can only optimise the trade-off between the two traits [178].

Culture is information that can be mediated by means other than genetics. Mediation has a time cost attributed to it: there is only so much culture that can be mediated in a given amount of time. There is an allocative trade-off associated with culture. Similarly there are finite resources of cognitive space: the number of cognitive skills an individual and therefore a group can possibly develop is limited.

Since development is costly, then any developmental strategy must be efficient. To evolve the capacity to mediate information which is deliberately encoded in physical forms would require a minimal activity which this thesis has argued is dance.

Here we conclude by making the prediction that if there are other embodied cultural beings in the universe, they would have to have the capacity for dance, or at least would have had the capacity for dancing at some point in their evolutionary lineage, because for there to be culture, there needs to be mediation. Efficient mediation depends on endogenously defined physical forms and the minimal way to generate these in an environment with no external local constraints on the physical forms being generated, and more importantly: an activity that is repeatedly engaging and self-justifying.

Appendix

Social learning processes [82]:

1. *Stimulus enhancement*: occurs when the action or product of a demonstrator exposes an *observer* to a stimulus which has a causal effect on the behaviour of that observer at a future time.
2. *Local enhancement*: occurs when the presence of a demonstrator at a particular location where learning can take place increases the probability with which an observer is likely to visit that location.
3. *Observational conditioning*: is when the observation of a demonstrator exposes the observer to a certain stimuli, and that stimuli leads to a change in behaviour at a later time.
4. *Response facilitation* occurs if the presence of a demonstrator animal performing an act (often resulting in reward) increases the probability of an animal that sees it doing the same.
5. *Social enhancement of food preference*: this occurs when a demonstrator's diet increases the likelihood with which an observer is likely to consume that diet.
6. *Social facilitation*: occurs when the mere presence of a demonstrator affects the observer's behaviour.
7. *Contextual imitation*: occurs when, directly through observing a demonstrator perform an action in a specific context, an observer becomes more likely to perform that action in the same context.
8. *Production imitation*: which occurs after observing a demonstrator performing an action, a combination of actions or a sequence of actions that were not previously within the observer's behavioural repertoire,
9. *Emulation*: occurs when after observing a demonstrator interacting with certain objects, the observer is more likely to try and perform any actions to try and get the same result.
10. *Opportunity providing*: occurs when the products of the behaviour of the demonstrator provide the observer with an opportunity to engage in operant learning that would otherwise be unlikely to arise — for example by providing an easier, less dangerous or more accessible version of the task.
11. *Inadvertent coaching*: occurs when the response of a demonstrator to the behaviour of the observer inadvertently acts to encourage or discourage that behaviour.

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