The Information Continuum Hypothesis of Evolution

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Abstract

Life is information dancing through time, embedded in matter and shaped by natural selection. Few biologists or philosophers concerned with evolution would object to this description. This apparent accord could be taken to indicate universal agreement on the forces shaping evolution; but the devil is in the details and disagreement is apparent if one looks behind the curtain. The decade strong prevalent paradigm of the Modern Synthesis holds the position that evolution happens by random changes and natural selection acting on genomic inheritance. But there is a new kid on the block; the proponents of an Extended Evolutionary Synthesis argue that inheritance is more than genomes and includes epigenetic information, niche constructs (ranging from the meerkats dens to humans railroads) and culture among other factors – and that these factors are both inheritance and a force shaping evolution. Here we introduce *The Information Continuum Hypothesis of Evolution*; a conceptual framework that focus on the inherited information rather than the diverse representations this inherited information may have (DNA, RNA, epigenetic markers, proteins, culture etc.). As a tool we introduce the concept "hereditome" to describe the combined inherited representations of information. We believe this framework may help bridge the apparent gap between the Modern Synthesis and the Extended Evolutionary Synthesis.

The Information Continuum Hypothesis of Evolution

Evolution of life is brought about by natural selection of traits encoded by gradually changing hereditary information relayed through generations. For a generation of biologists trained under neo-Darwinian Modern Synthesis (MS) paradigm, our heuristic model of evolution asserts that the hereditary information is found in the genome. The genome, in turn, is shaped by natural selection among a collection of genomes brought about by random mutations, recombinations and reorganizations. Furthermore, according to the MS, while the genome dictates what phenotypes an organism can display, adaptive information is not transferred to the genome other than through differential survival. Hence, to most biologists evolutionary adaptation takes place during the transition of generations, and since the genome *is* the hereditary information interchanging the terms would not matter much. But it is important to realize that the genome *is* not hereditary information. Just as book *is* not a story, but a representation of language that may be interpreted as a story. Neither does the genome *contain* hereditary information – again, just as a book contains a representation of a story and not the story itself. The genome contains a representation of hereditary information and the information inferred depends on the living cells in which the representations are interpreted by the cellular machinery[1].

The above may seem an unimportant distinction. But embrace for a second that a vital mitochondrial gene is non-sensical to the cytosolic ribosomal machinery only micrometers away; that the same genome produces as different cells as those found in brains and muscles; or the convincing fact that when transferring the nucleus of one species to the enucleated egg of another, the resulting organism is not representative of the species from which the nucleus originated[2]. The living world is rife with examples illustrating that genomes contain *representations* of information that may be read in very different ways, just as religious texts are read in very different ways by highly educated scholars.

Genomes are not the only repository of inheritable information. Epigenetic methylation is inheritable and affects genome organization and gene expression[3-6]. Pathogen derived RNA molecules, with no corresponding representation in the nuclear genome, can confer inheritable immunity towards the pathogen[7]. Proteins can confer inheritable structural information affecting e.g. cellular organization and metabolic activity of descendants[8,9]. Epigenetic methylation patterns, lost during the post zygotic demethylation, appear to be reinstated based on transcription factor binding patterns – an intriguing example of information being relayed via alternating routes; methylation and protein binding [10]. The microbial flora of termites show colony to offspring inheritance and human maternal bacteria colonize a fetus with lifelong effects on the child's health; both examples of inheritance not confined to the germ cell[11-13]. Culture – another example of a non-germline inheritance – is yet another source of evolutionary important information affecting the fitness and evolution of those sharing it [14,15]. The point should be very clear by now; hereditary information of evolutionary importance has diverse representations and may travel along various, even alternating, routes. We suggest that the full gamut of hereditary information representations should be referred to as the *hereditome*.

The different components of the hereditome have different properties. The genomic hereditome is usually inherited from both parents and remarkably constant, while crucial variability is ensured by mutations, reconfigurations and recombinations. The mitochondrial hereditome, in contrast, is usually maternally inherited and does not exhibit recombination, which renders it different evolutionary properties[16]. While both the nuclear and mitochondrial genetic hereditomes are quite stable across generations, the epigenetic methylation hereditome is more dynamic with potential for rapid modifications within both generations and cell types[17]. Where the epigenetic methylation hereditome relay hereditable differences associated with the genome, the RNA hereditome and protein hereditome may be equally dynamic, but are able to confer information *not* represented in the genome[7,8]. In addition, the RNA and protein hereditomes are inherited in a non-mendelian manner just as is the maternally inherited bacterial flora[7,8,13]. To some it may seem a bridge too far, but we will argue that cultural inheritance has adaptive significance and therefore should also be considered a component of the hereditome – a part with capacity for very rapid evolution affecting all members sharing the same culture. The above examples are not exhaustive and additional hereditome components, with yet different evolutionary characteristics, exist. And further hereditome components are likely to remain to be identified.

Collectively, these hereditome components comprise information representations with a continuum of evolutionary qualities; some hereditome components are stable while other are more dynamic; some are readily modified by external cues while other are more static; some may cross species boundaries with relative ease whereas others do not[3,8,18]. Sometimes hereditary information switches between hereditome components on the journey through time, as illustrated by information alternating between epigenetic methylation and protein binding representation[10]. At other times, information more permanently move from one hereditome component to another, which is well illustrated by the migration of mitochondrial genes to the nuclear genome[19]. Furthermore, one hereditome compartment may leave imprints on other compartments, as may be illustrated by culturally defined killer whale ecotypes where the cultural hereditome leave imprints on both the genomic and mitochondrial hereditomes through founding events and subsequent differentiation [14]. In symbioses the hereditomes of the symbionts are allowed variable degrees of entanglement occasionally bestowing the involved symbionts with traits depending on their combined hereditomes[20,21]. In practical studies it is important to take into account that observed traits may be concerted manifestations of information conveyed by different hereditome compartments. For instance, the success of termites is best, if not only, understood by considering both information embodied in the microbial and genetic hereditome components[13].

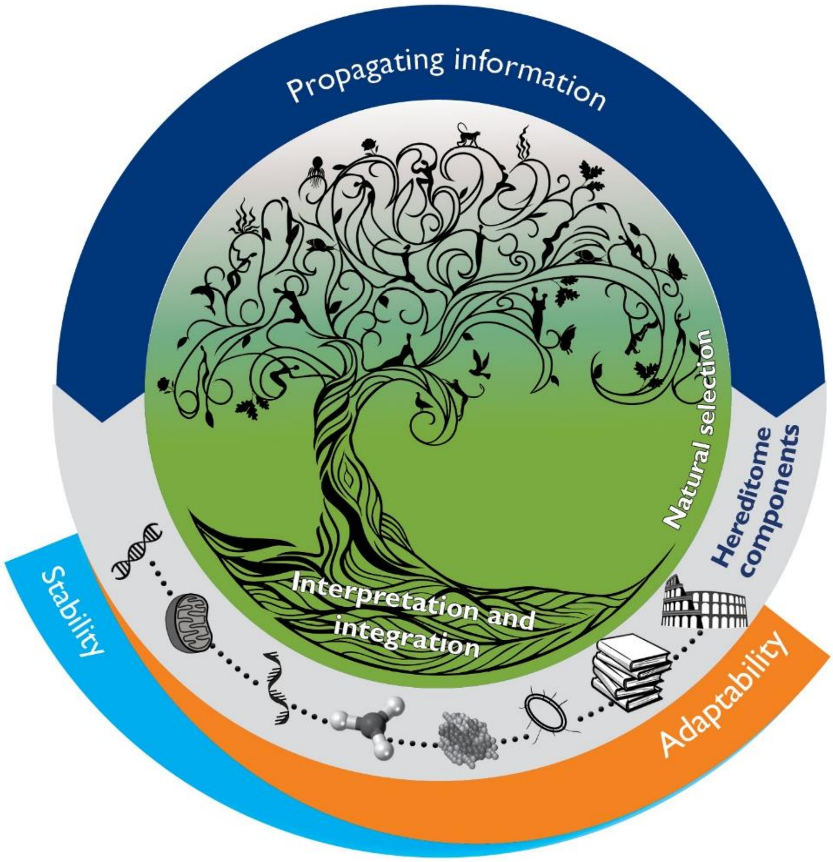

Figure 1. A conceptual representation of the Information Continuum Hypothesis of evolution. Hereditary information is represented in the Hereditome components. The represented information is expressed through interpretation and integration by the system the hereditome component is part of. Natural selection acts on the manifested integrated expression and governs what information remains represented in hereditome components. The hereditome components illustrated here are, from left to right: DNA, mitochondrion, RNA, methylation (of DNA and histones), proteins, microbiome, knowledge and culture. The list is not exhaustive and the localizations along the stability-instability axis is tentative.

In summary, the central paradigm in the Information Continuum Hypothesis of Evolution (Figure 1) is that *life is propagating information* and that the substrate for natural selection therefore is *information* - not genes, RNA, proteins or other representations of information in and of themselves. This information is embodied in the hereditome which comprise various components (genes, RNA, proteins, microbiome etc.) with a continuum of evolutionary qualities. Since natural selection is the result of the dissimilar ability of information to propagate itself, it tautologously follows that introduction of variation in the hereditome during propagation is indispensable for adaptation. So, in contrast to the common notion that natural selection should promote hereditome replication fidelity [22], evolution promotes mechanisms that strikes the degree of *infidelity* just right. Some parts of the hereditome are able to undergo very rapid changes and evolution is therefore a continuous process - not a dotted line of events occurring at the transition of generations [6-8,23]. Finally, since natural selection operate on the information represented in the hereditome, it follows that the selection acts at the level of information manifestation (selection may for instance occur at the level of a community inherited symbiont bacterium, rather than at the level of the host).

The Modern Synthesis model of evolution has been, and remains, a formidable tool. The challenge is that "when all you have is a hammer (MS), then all you see is a nail (genome)". This may righteously be argued to be caricature[24] - but this caricature describes our common heuristic model of evolution too well to be ignored. We know there is more to heredity and evolution than genomes - and understanding how the qualitative and temporal attributes of the hereditome components affects adaptive capacity is crucially important in an age of rapid environmental changes[25,26]. As argued by the proponents of the Extended Evolutionary Synthesis; our understanding of evolution will benefit from expanding our selection of tools beyond the versatile hammer[27,28]. It is our hope that the Information Continuum Hypothesis may be such a tool.

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