PREFACE

GENESIS ENGINES – WHY BOTHER?

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"Sooner or later all the people of the world will have to discover a way to live together in peace, and thereby transform this pending cosmic elegy into a creative psalm of brotherhood. If this is to be achieved, man must evolve for all human conflict a method which rejects revenge, aggression and retaliation. The foundation of such a method is love."
Martin Luther King, Nobel Prize Acceptance, 1964[i]

"To mark the paper was the decisive act"
George Orwell, "1984." Signet, 1950

All life forms we have encountered to date whether alive or fossilized in the ground are located over, on or under the surface of our planet in a thin skin called the biosphere. These forms all share a minimal set of properties. In addition to requiring the inanimate world to provide temperatures and pressures found only in the biosphere, each is an assemblage of gigantic linear molecules.

These molecules in turn are composed of subunits aligned in specific sequence order, so that the linear molecules themselves may be thought of as texts, carrying meaning in the sequence of their subunits as a language carries meaning in the sequence of its letters. One ubiquitous chemical language – DNA – carries information for many things, most critically for the successful completion of its own replication into two copies of the same DNA sequence.

The language of DNA can be translated into a sequence of subunits called amino-acids, which when strung together form a protein. The meaning of a protein-encoding DNA sequence can be known only after translation into the sequence of amino-acids they encode. Assembled from a specific DNA-encoded sequence of amino acids, a protein will then fold into a specific 3D structure that will carry its capacity to act as a catalytic or a structural element in the life form carrying the DNA that encoded it.

The cells of our bodies are constructed of only 20,000 or so different encoded proteins, and that takes up only about 1% of the 3×10^9 DNA letters of our genomic text. The rest of the DNA is given over to the software of gene expression: deciding when, where, and on what signals shall a given protein or set of proteins be made. All this is well-established. Nothing here so far, though, warrants the notion that all of these information-rich large molecules that make up life on this planet had a single and singular beginning.

That notion – the genesis of all life on this planet from a first life form - emerges separately, as the simplest explanation of a remarkable fact: almost all human DNA sequences have cognate sequences in the DNAs of other species. The simplest

complete explanation for this remarkably redundant use of a trivial fraction of the total available DNA "design space" is that all things alive or dead are constructed of information in DNAs which are related to each other, by common descent from an original family of sequences encoding their own survival.

To confirm this additional idea and go from current facts about DNA and protein-encoded life to the notion of a genesis event that one might seek to replicate in a lab, one needs one more step, provided with a century's intervention by the paired insights of Darwin on the one hand and Watson and Crick on the other. Simply put, for the game of life to have begun from a single original molecule or family of molecules, two additional cards need to be in play. First, among these must be a molecule like DNA, most likely originally RNA, which carries in its sequence information necessary and sufficient to encode its own successful copying by base-pairing. Second, the copying mechanism must be sloppy enough to permit errors to creep in at random.

Then, driven by this fuel of random error, the engine of a single genesis could in principle begin to throw off any number of new sequences, all of which might survive or not. That brings us to where we are today: a planet teeming with billions of different fertile populations we call species, and more than 10^{30} different viable DNA sequences in microscopic, but numerically dominant microbes.[ii] Each DNA sequence embedded in one or another kind of living thing, encodes its chances for survival through time in ways that are precisely good enough – and enough better than its predecessor sequence - to be the sequences that are in living forms today.

Whether or not a given novel sequence might survive, would not be the product of any design, but merely an assay of the novel sequence's capacity to help the DNA or RNA encoding it to survive. This idea is so simple, and so devoid of purpose, intention, perfectibility and meaning beyond survival of a sequence, that it remains controversial today despite the failure of all attempts to disprove it, and despite its capacity to explain, so far, any and all observed facts about the DNA sequences in today's life forms.

That denial is global: thousands of people surveyed in each of 45 countries in 2005 were asked to respond to the statement "Human beings, as we know them, developed from earlier species of animals." In every country a considerable fraction of people responded that they knew this to be untrue. Percentages certain it was not true ranged from 5% in Iceland to 50% in Turkey; the United States came in second-to last, at about 40% in denial.[iii]

Denial aside, the design space for any form of DNA-encoded life on earth to choose from is the number of possible sequences that could be written out in DNA to the length of a typical genome. Taking our genomes as typical, that tells us that this simple game has had a design space of at least $4^{3,000,000,000}$ possibilities. This game of DNA sequence survival through emergent novelty driven by random error in replication has only a few pieces, but it has a powerfully large number of moves. In fact, that's essentially an infinite number of choices. The number of elementary particles in the universe pales before it at 10^{80}.

But because of the second rule of the game – surviving novelties must emerge from already functionally surviving DNA sequences - only a vanishingly small fraction of these possibilities can have ever been tested in nature so far. Each surviving error has always emerged on the background of a sequence already good enough to be in play for survival in the first place. That means that any sequence however brilliant its strategy for survival might be, that does not share a common ancestry with sequences

that go back to the initial emergence of self-replication, cannot have ever been, or ever be, tested by nature at all.

That's bad enough for a scientist who imagines that everything about nature can be known through science if there is enough money behind the push to know it. But there is an even deeper problem for science generated by this simple game of life on earth. That is, that even among the trace fraction of possible sequences that do sift through the sieve of descent from earlier sequences, the choice by nature of which sequences will survive, is wholly without predictability. Three reasons for this barrier to prediction come to mind; any one of them would be sufficient.

First, the random nature of mutational novelty means that a successful variant sequence that arose once under given conditions, need not ever arise again. Second, the notion of "success" does not reduce to predictability because the successes of all other versions of DNA found in the other life forms in given place and time, provide the ever-changing context for the likelihood of success of any novelty at that time and place, in any of the genomes contributing to a given ecological system. Third, and most disturbing to our sense of being at the center of things, is the certainty that inanimate nature will in the future again throw a hammer into the supposedly finely-tuned ecologies of a given time and place, as a comet once destroyed the dinosaurs and many other species only 65 million years ago. No comet then, no *H. sapiens* now.

So there we have it: we can explain all of life's diversity, all of its novelty with time, all of its vulnerability and all of its resiliency to date, all without having any capacity to know what the chemicals that make life up are capable of, beyond what natural selection has already permitted to survive to date. The future of life on earth, rich with possibility, is thus a closed book of future DNA texts not yet written by the natural experimentation of today's version of DNA in nature, and science cannot open it in advance. So what next? That brings us to this volume.

Genesis engines are constructions by one species – ours – that attempt to model in various mixtures of chemistry and digital analysis the emergence of self-replicating information from initial chemical conditions lacking that capacity. The essays in this volume speak to the diversity of approaches and intentions of those investigators seeking to capture the emergence of self-replication, of mutational novelty, of competition and natural selection, in a chemical world of their own making.

Before we examine the possible implications of opening up this line of experimentation, let us be clear about one thing: a genesis engine made in a laboratory designed by people, would be an example of a third genesis, not a second one. The second genesis took place some millions of years ago, when a period of rapid selection for changes in hominid DNA led to the emergence in Africa some hundreds of thousands of years ago of *H. sapiens*. Our species had one selective advantage over other hominids, other mammals, and other forms of life in general: imagination. In our ancestors' hominid brains, thought had opened a new path for novelty and selective survival, but not one dependent on chemical inheritance.

Human mental states, like any thought, feeling, memory or intention, are maintained and constructed, remembered and forgotten, by cells of our brains and bodies that are themselves constructed through DNA-encoded information, but that are not at all entrained to these mental states by anything at all about the DNA that builds them. In short, any human brain can have any thought. This second genesis engine continues to play out novelty in the mental world today in each of us, whenever we have

a new idea that makes sense to others and is therefore remembered by them, and passed on in turn.

Ideas, taught and learned over generations, have been a second and wholly independent mental realm for natural selection of ideas for tens if not hundreds of thousands of years. And so the idea of a genesis engine, if it comes to fruition, would represent a remarkably elegant closing of a singular feedback loop. That loop began with DNA-based natural selection for the encoding of our human brains, which led to the emergence on our brains of the idea of natural selection and the imagination to try and fail to disprove it as an explanation for life's present diversity, and which now closes in the novel idea of experimentally recovering the initial chemical engine of inherited novelty from which our brains are themselves derived.

What we must be clear about here is that though these studies are intrinsically interesting – who would not want to have come up with chemical conditions out of which emerge self-replicating, mutating, selectively surviving entities? – they do not speak in any new way to the persistent denial of the reality of the first chemical genesis some four billion years ago. To anyone taking that position for any reason at all, whether religious or not, neither the work in this volume nor any other science is likely to matter.

The problem of denial is deeper than any question science can answer: it goes to the boundary of what science can do. Science is an unrivalled mechanism for understanding nature through the discipline of imagining a mechanism for what is interesting about nature, and casting that imagined mechanism in a form that is disprovable. If an idea is not subject to disproof, it cannot be argued with through science. In my classes I do not argue with students who tell me the world was created *ab initio* 6000 years ago; I ask instead how to disprove the hypothesis that the world was created 20 minutes ago complete with memories. As neither hypothesis is subject to disproof, neither can be debated through science.

Now let me turn this argument on its head. This discussion with a student - it does actually happen, it is not a hypothetical - is another example of an activity in our DNA-encoded brains that involves thought, in this case accompanied by irony, the wish to help someone to understand, the intuition of what that person is thinking, and the capacity of humor to bring together people who think they have nothing in common. So, inverting the priorities implicit in this book, I find in the second genesis a truly novel reason to support and applaud ongoing research into a third genesis by the work in this book.

These lines of work, coupled with parallel work in computer technology and information sciences, might lead to the construction of new chemical entities capable of nurturing a fourth genesis in turn, an emergence of thought and understanding, from our own thoughts applied to the materials of nature. I can think of nothing more interesting to see, than whether or not information we have in hand can ever be used to provide inanimate objects of our own creation with our unique human capacity to choose actions based on what one has learned, what one has thought, and what one feels as well as what one thinks one knows.

From Mary Shelley's *Frankenstein* to Carel Capek's *Robot* to Isaac Asimov's *Foundation*, this hope has always been shadowed by the fear that such a development would be bound to turn on its creators. But it seems pretty clear to me that the second genesis has already generated just that problem for the first. Our species' success

through mental activity is well along in the process of irreversibly damaging the equilibria that have nurtured chemical life's emergent novelties on this planet for billions of years.[iv] We should require that a chemical, third genesis be the source of a fourth, thinking genesis to help our species get through the paradoxical damage to the products of the first genesis caused by the success of our own, second, genesis.

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[i] http://www.nobelprize.org/nobel_prizes/peace/laureates/1964/king-acceptance.html

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