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Adapting Nanotech Research as Nano-Micro Hybrids Approach Biological Complexity, A Review

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Today's emergence of nano-micro hybrid structures with almost biological complexity is of fundamental interest. Our ability to adapt intelligently to the challenges has ramifications all the way from fundamentally changing research itself, over applications critical to future survival, to posing globally existential dangers. Touching on specific issues such as how complexity relates to the catalytic prowess of multi-metal compounds, we discuss the increasingly urgent issues in nanotechnology also very generally and guided by the motto '*Bio Is Nature's Nanotech*'. Technology belongs to macro-evolution; for example integration with artificial intelligence (AI) is inevitable. Darwinian adaptation manifests as integration of complexity, and awareness of this helps in developing adaptable research methods that can find use across a wide range of research. The second half of this work reviews a diverse range of projects which all benefited from 'playful' programming aimed at dealing with complexity. The main purpose of reviewing them is to show how such projects benefit from and fit in with the general, philosophical approach, proving the relevance of the 'big picture' where it is usually disregarded.

1. Introduction

The practical applications which we present are solutions to specific needs, but they are proof-of-principle examples for the approach guiding them. The latter makes the solutions adaptable and widely applicable, and we believe that the general understanding is vital to our strategy being successful. Our approach is based on an analysis and philosophy concerning the evolution of nanotechnology, which must be seen in a wide context or otherwise it would not be proper thinking about evolution at all. General evolution as 'algorithmic evolution'[1] and sufficiently general to be self-explanatory/emergent as evolution of evolution[2,3] is fundamental, even *a priori* in the sense of being metaphysically necessary in physicalist descriptions, the 'causal creation myth' of anything finding itself embodied in its world. Bio-centrist concepts seem more scientific, less nebulous, more strictly defined. However, such attempts at rejecting for example macro-evolutionary (=properly 'materialist' in the sociological sense of that term) social science must reserve the origin of biological evolution to the gods; there is nothing scientific about that.

Evolution is complexity-*generating* by being complexity-*integrating*. It is not monotonous progress for isolated 'species' mainly delineated and identified by mere categorization. Fundamentally speaking, evolution is always "macro-evolution" through and through. Today, this includes social issues such as the emerging 'medical paradigm', which transforms all areas, including converting the criminal justice system and mass-incarceration into potentially Orwellian mental healthcare and competitive cognitive enhancement. Nanotechnology is hyped to be *the* crucial tool[4] enabling the medical paradigm technologically. Far from riding hype, the relevance of being aware of such lies also in the awareness of problematic issues, including there indeed being much hype. We therefore present a general evaluation that is relevant to the current nano-science to nano-technology transition, about how the field evolves and how we adapt, which includes critique. One conclusion is that "artificial" computation is not optional. We are witnessing an inevitable and long ongoing fusion of human and 'artificial' information processing, cognition evolving, including that of social structures like the scientific community. We therefore introduce the computational side more closely, but also first *via* an almost philosophical approach. We hope to prove utility by presenting a diverse list of projects that benefited from a playful entering of computational image recognition and statistical analysis into our nanotechnological research.

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2. General Section

Nanotechnology and artificial intelligence (AI) are in some sense not new. Humans are nothing but robots that nature, *via* Darwinian evolution, happened to produce from self-assembling nano machinery. Some people still question: "*Are self-healing, self-aware robots possible via nanotech?*" However, it is already accomplished; one such robot wrote this sentence. Many kinds of such robots arose in nature, which goes on to produce more kinds, integrating the available. There is no fundamental difference in that, for example, 'natural' selection involves systems eating each other while 'artificial' selection is less violent. Computers would be no more conscious if Bill Gates had gone down to the production floor to *eat* obsolete prototypes. Some give almost religious significance to the close coincidence between elemental abundances in biological bodies and that in the universe or earth's crust for example. Is the universe made for us? The abundance is usually listed starting from the highest number of atoms, rather than mass abundance, and neglecting noble gases and iron, so one usually lists hydrogen, oxygen, carbon and nitrogen (H, O, C, N). We do not give such arguments much credit, but it is nevertheless a strange "coincidence" also in regard to that the next abundant element down the list would be silicon! Is the universe, if considered to be 'made for' anybody (in some sort of self-consistent self-creation), not made for us but rather for silicon based computing, perhaps cyborg societies?

That nature now manufactures systems *via* us being involved in manufacturing and purposefully designing, thus justifying the label "artificial", is nothing but the usual way nature works, namely, playing around with what is already there and fastest able to adapt in the 'Red Queen's Race', to use biological terminology, meaning an accelerating co-evolution between systems and their general environment (=all the rest). In fact, evolution is the only efficient and sustainable way to construct and optimize in large dimensional design spaces, and such design spaces become important in nanotechnology. Emergent strata, for example multi-cellular organisms and social structure, adapt faster than the strata they emerge from. They therefore do not only emerge in the first place but also turn around to enslave the lower strata, slowing its evolutionary 'progress' or better 'drift', leading to 'legacy systems' (also vestigial organs). The fastest adapting layer is now the distributed computational substrate, including the internet. Scoff at this as unimportant hype compared with whatever much more substantial, scientific, or serious you may feel you are engaged in, and see yourself be 'naturally selected' away!

Guided by that biology is nature's nanotechnology; nanotechnology must learn from biomedical research, because true nano*technology* now leaves its pioneering nano*science* phase and starts to rapidly increase the complexity of produced structures into the realm of nano-nano and nano-micro compounds with many degrees of freedom and interdependent parameters. In other words, we approach biological complexity[5,6]. Nanotech must thus be put into a wider context. For example, organisms can easily be evolved to synthesize metallic or highly complex compound-materials (such as teeth), and some metal complexes (such as hemoglobin) and even metal crystals (e.g., the magnetic sense organs of birds) are already naturally employed. However, nature has apparently never touched metallic crystals as bio-catalysts, and for good reasons: they are so reactive that nature's systems could never before handle them. Metal nanoparticles are often advertised for their anti-microbial action[7]. However, globally existential threats leave no alternative to radical technological adaptation. It is too late to 'go green' except *via* a novel take on what constitutes 'green', including synthetic biology. Our nanotechnology is how nature embraces metallic nano-crystals into the biosphere.

Increasing overpopulation and the top heavy age distribution of the human population demand radical technological adaptation, if we want to prevent humans from suffering on an unprecedented scale. Required adaptation to rapid environmental changes needs nanotechnological capabilities that are equivalent to biological ones in terms of rapid adaptation by efficient means to design complex nano-structures. The development of nanometer scale catalysts[8], especially for energy applications[9], is one of the most important topics because of the increasing necessity of energy efficiency globally. Electrocatalysts are key ingredients for the development of new electrochemical power sources such as direct formic acid fuel cells. Thus, much attention has been paid to metallic nanoparticles and larger nano-micro hybrid structures because of their many useful electro-optical[10], magnetic and catalytic[11] properties that find applications in numerous fields such as bio-sensing[12], surface enhanced Raman spectroscopic (SERS) detection[13,14], optical and micromechanical devices, and magnetic recording.

Again, little of this is news to Mother Nature, who has done similarly a long time ago, namely, adapting efficiently through developing an astounding variety of nanometer sized reproducers and catalysts, namely, enzymes. The main difference is the increasing importance of metallic particles with complex shapes[15,16]. The properties of enzymes depend mostly on their folding shapes. Also with today's nanotechnological catalysts, shape and structure play an increasingly important role, say via porosity[17], high index surfaces and lattice dislocations, metal–metal interfaces and metal–matrix support interactions[18], but certainly also shape changing, i.e. truly nano-mechanical systems[19,20] in the future. It is thus important to efficiently analyze the structure of complex nano-micro compounds. In the light of the above, what are the key problems that are shared widely across the nano-materials research community? For one, compared with biology and medical research, which are both concerned with nature's nanotechnology, our artificial nanotechnology lacks the ability to deal with the biological complexity.

2.1. Complexity and optimization: Lost in design space

The properties of nanostructures depend on sizes and shapes. The synthesis of tailored nanostructures is thus important for researching properties, not to mention optimizations toward applications. The ability to control the size, shape, and distribution of nanoparticles in larger structures provides opportunities to systematically investigate, for example, catalytic and electro-optical properties and to discover new applications, whether in the form of novel research techniques or medical devices. Nanostructures become very complex; for example, catalysis is routinely achieved bi-metallically[21], with bi-metallic wires[22], dendrites[23], etc., where the compounds can have two separated types of metallic nanoparticles or alloyed combinations. We already witnessed the extension to tri-metallic compounds with heterometallic nanoparticles becoming usual[24–26]. The complexity is increased by the use of nano-structured matrixes like silica[27], polymers[28], carbon nano-tubes[29] or carbon spheres (Fig. 1)[30], far more than only passively dispersing the "active material", avoiding agglomeration. Even without direct particle–matrix interactions, every added degree of freedom allows to tune properties, through particle distribution[31] and location control[32].

We discuss structural complex as well as electron distribution complex environments. They may create particular absorbance sites for molecules while also supplying surplus electrons to an intermediate reaction, but such details are almost beside the point. Faced with complex reactions and no way to either fully experimentally control nor to theoretically predict overall performance as dependent on temperature, etc., it is the complexity as such that creates