"The Ilulissat Statement"

Synthesizing the Future

a vision for the convergence of synthetic biology and nanotechnology

This document expresses the views that emerged from the Kavli Futures Symposium 'The merging of bio and nano: towards cyborg cells', 11-15 June 2007, Ilulissat, Greenland.

Approximately fifty years ago, two revolutions began. The invention of the transistor and the integrated circuit paved the way for the modern information society. At the same time, Watson and Crick unlocked the structure of the double helix of DNA, exposing the language of life with stunning clarity. The electronics revolution has changed the way we live and work, while the genetic revolution has transformed the way we think about life and medical science.

But a third innovation contemporaneous with these was the discovery by Miller and Urey that amino acids may be synthesized in conditions thought to exist on the early Earth. This gave us tantalizing hints that we could create life from scratch. That prospect on the one hand, and the ability to manipulate genetic information using the tools of biotechnology on the other, are now combined in the emerging discipline of synthetic biology. How we shape and implement this revolution will have profound effects for humanity in the next fifty years.

It was also almost fifty years ago that the proposal was made by Feynman of engineering matter at the atomic scale – the first intimation of the now burgeoning field of nanotechnology. Since the nanoscale is also the natural scale on which living cells organize matter, we are now seeing a convergence in which molecular biology offers inspiration and components to nanotechnology, while nanotechnology has provided new tools and techniques for probing the fundamental processes of cell biology. Synthetic biology looks sure to profit from this trend.

It is useful to divide synthetic biology, like computer technology, into two parts**:** hardware and software. The hardware – the molecular machinery of synthetic biology – is rapidly progressing. The ability to sequence and manufacture DNA is growing exponentially, with costs dropping by a factor of two every two years. The construction of arbitrary genetic sequences comparable to the genome size of simple organisms is now possible. Turning these artificial genomes into functioning single-cell factories is probably only a matter of time. On the hardware side of synthetic biology, the train is leaving the station. All we need to do is stoke the engine (by supporting foundational research in synthetic biology technology) and tell the train where to go.

Less clear are the design rules for this remarkable new technology—the software. We have decoded the letters in which life's instructions are written, and we now understand many of the words – the genes. But we have come to realize that the language is highly complex and context-dependent: meaning comes not from linear strings of words but from networks of interconnections, with its own entwined grammar. For this reason, the ability to write new stories is currently beyond our ability – although we are starting to master simple couplets. Understanding the relative merits of rational design and evolutionary trial-and-error in this endeavor is a major challenge that will take years if not decades. This task will have fundamental significance, helping us to better understand the web of life as expressed in both the genetic code and the complex ecology of living organisms. It will also have practical significance, allowing us to construct synthetic cells that achieve their applied goals (see below) while creating as few problems as possible for the world around them.

These are not merely academic issues. The early twenty first century is a time of tremendous promise and tremendous peril. We face daunting problems of climate change, energy, health, and water resources. Synthetic biology offer solutions to these issues**:** microorganisms that convert plant matter to fuels or that synthesize new drugs or target and destroy rogue cells in the body. As with any powerful technology, the promise comes with risk. We need to develop protective measures against accidents and abuses of synthetic biology. A system of best practices must be established to foster positive uses of the technology and suppress negative ones. The risks are real, but the potential benefits are truly extraordinary.

Because of the pressing needs and the unique opportunity that now exists from technology convergence, we strongly encourage research on two broad fronts:

Foundational Research

1. Support the development of hardware platforms for synthetic biology.
2. Support fundamental research exploring the software of life, including its interaction with the environment.
3. Support nanotechnology research to assist in the manufacture of synthetic life and its interfacing with the external world.

Societal Impacts and Applications

4. Support programs directed to address the most pressing applications, including energy and health care.
5. Support the establishment of a professional organization that will engage with the broader society to maximize the benefits**,** minimize the risks, and oversee the ethics of synthetic life.
6. Develop a flexible and sensible approach to ownership, sharing of knowledge, and regulation, that takes into account the needs of all stakeholders.

Fifty years from now, synthetic biology will be as pervasive and transformative as is electronics today. And as with that technology, the applications and impacts are impossible to predict in the field’s nascent stages. Nevertheless, the decisions we make now will have enormous impact on the shape of this future.

The people listed below, participants at the Kavli Futures Symposium 'The merging of bio and nano: towards cyborg cells', 11-15 June 2007, Ilulissat, Greenland, agree with the above statement

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