The Biotechnological Revolution Will Not Be Televised – Do Androids Dream of a Fair Society?

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There is no consensual definition of intelligence. For some, it is the ability to acquire and apply knowledge, and in biology it is broadly formulated as an organism's ability to adapt to its environment. When it comes to details, further criteria are often added, such as self-awareness, abstract reasoning and learning, planning and creativity.

The addition of these elements typically occurs to place a dividing line between us, humans, as intelligent beings, and animals who are somehow different – even though it is blatantly obvious that they are but *differently* intelligent. They may be overall less intelligent by certain measures, and yet they may be actually more intelligent in specific areas. Migratory animals have superior spatial cognition. Dogs have a fantastic sense of smell. Animals' innovative use of tools was recently amply demonstrated by a sea lion, captured on video footage, using an octopus to slap a kayaker in the face.[1]

In other areas, animals are not lagging so far behind as some imagine. It seems that even pigeons may experience cognitive dissonance.[2] Rhesus monkeys showed observational learning based on witnessing the conditioned fear reactions of their fellow cellmates in a famous (albeit somewhat unsatisfying) 1967 experiment.[3] Many more random examples could be offered, but ultimately the question shall be asked: Why are all of the above-listed manifestations of intelligence required, all at once, for us to call an organism intelligent?

This might carry relevance for a magazine issue looking at „smart" technologies and tools of all kinds. If we are ready to deem a phone *smart*, and to regard algorithmically learning software as *artificial intelligence*, why would we stop short of referring to all living organisms as intelligent, even as they are intelligent to different degrees and in distinct ways?

We often think of artificial intelligence as something to be constructed in the form of hardware and software. In fact, the field of synthetic biology is where practitioners are by rule involved in creating partly or fully artificial, intelligent entities.

Call it another way of reaching technological singularity (or artificial superintelligence) if you wish, especially keeping in mind that organic and inorganic intelligence can be combined. Having considered this, the issue becomes not whether biological can be smart, but how synthetic biology masters *the kind of smart* that is biological. As Emily Leproust, CEO of the firm *Twist Biotechnical* puts it: "The last century was about computers, and now we are entering an era of biology."[4]

For the interest of historians: the choice of any milestone development to mark the beginning of this era of synthetic biology is bound to be arbitrary by nature, but a useful reference point may be 2004. That is when M.I.T.'s "Synthetic Biology 1.0" conference, the first annual worldwide convention of synthetic biologists, was held in Cambridge, Massachusetts.

Otherwise, people have sought to manipulate biology since a very long time. Ever since the beginning of animal-breeding and plant cultivation, in fact. Humanity worked to perfect plant and animal species for its needs, through selection, generation by generation, and through cross-breeding. This may have been the beginning of the real Anthropocene, transforming much of the biomass that surrounds us, globally. Animals have since been cloned, from mice (in 1986) to macaques (2017). The history of animals and plants genetically modified in laboratories begins in 1974 and 1983, respectively.

Genome-altering has become much easier by today, with the availability of technologies such as CRISPR/Cas9. Already before the millennium, viral vectors (retroviruses) have been used to insert functional genes into the DNA of children suffering from a fatal genetic disorder called X-linked SCID, successfully correcting the disease phenotype in a number of cases.[5] Jellyfish and coral genes have been combined into other organisms' DNA through recombinant DNA technology (rDNA), from mice to chicken, rabbits and pigs, to add the trait of bioluminescence (glowing in the dark) to individuals of these species. CRISPR/Cas9 is used for genome editing since 2015.

Researchers using the latter technology on animal subjects can learn more about the effects of changes to the genetic code of organisms, allowing them to model disease emergence connected to its specific genetic sources, and eventually to reverse the process by targeting human pluripotent stem cells – possibly embryonic stem cells, but also induced pluripotent stem cell cultures in a lab, for example to grow a specific organ that is free of disease. CRISPR/Cas9 has even been used to edit out viruses integrated into human cell DNA.[6]

There is a practically endless number of possible uses of genome editing. For example, for researchers who find studying bioluminescent chicken embryos (more convenient to study than mammal/human embryos in the first place) easier as a result. But bioluminescent plants and animals may be bred for a host of other reasons, too, such as to make a point in the form of art, as Eduardo Kac tried with the bunny Alba, a green-fluorescent rabbit glowing under blue light, created for him in a French laboratory, back in 2000.[7] Such creatures may also be bred for the pleasure of a pet-owner with quirky preferences.

And it is not just DNA that can be synthesised, but other complex molecules, too. Proteins. The cell-free synthesis of even unnatural amino acids is possible.[8] We are now at a point where the creation of unnatural molecules, cells and even organisms, as well as the re-creation of extinct species and the synthesising of full genomes based on computer data, is happening. Take the example of *Mycoplasma laboratorium,* a laboratory-engineered bacterium species, derived in 2007 from the natural *Mycoplasma genitalium* (the original bacterial DNA was simplified considerably and inserted into another bacterium species' cell whose DNA had been removed before this). In the future, B2D2B converters, that is, biological-to-digital-to-biological converters, may make it possible to quickly upload and download as well as to print out organic molecules between two connected nodes in cyberspace.[9]

Synthetic biology opens up fantastic possibilities for humanity. In fact, the question may be not how much we may need the achievements of this field, but how we could even hope to survive without these in the future.

For instance, processes of globalisation and climate change help lethal disease-spreading mosquito species, such as *Aedes aegypti*, make a home for themselves in an increasing area on all continents, bringing malaria, Dengue fever, the West Nile virus, and other pathogens closer to everyone – especially with human mobility in mind. Areas on Europe's peripheries have been gradually colonised by *Aedes aegypti*, such as Madeira or the Caucasus, while in the Netherlands these mosquitoes have recently also been imported related to human activities.[10] The release of steriles mosquitoes, genetically manipulated as such, will be an important part of the necessary response.

In another, even more important example of the kind of challenges now faced, a growing human population on planet Earth may only be sustained thanks to the continuation of the agricultural revolution, partly through genome-editing, to increase crop yields as well as plants' resistance against pests and pathogens. The world economy's fuel needs are also supported through genetically modified algae.

All of this carries major risks. Through the introduction of genetically modified organisms, horizontal genetic drift may occur and, armed with new genes captured from modified organisms (genes that thus migrate from species to species), new and lethal pathogens may appear. Alternatively, existing pathogens may opportunistically colonise hitherto unavailable ecological space from which our intervention excludes their up-till-now dominant rivals. Emergent and unexpected new qualities of crops as well as dairy and meat products may include toxicity or being allergenic for humans consuming them. In the meantime, precious biodiversity is lost, which may increase humanity's vulnerability along with its dependence on the new plant and animal variants, should new pathogens successfully attack these.[11]

Further problems arise from the complex social, economic and political environment in which synthetic biology's achievements are introduced.

The weaponisation of biology. Bioterrorists may seek to synthesise viruses and other pathogens based on genomes for which they are able to obtain their exact genetic codes, perhaps from darknet sites that share them for just this purpose, or actors that look to commercialise this information, with their services paid in cryptocurrencies.

That bioweapons per rule lead to uncontrollable or difficult-to-control collateral damage would not necessarily hold bioterrorists back: non-state actors such as the Rajneesh sect in the US or the Aum Shinrikyo sect in Japan have in the past carried out or attempted attacks using various pathogens. In fact, future advances may make the targeting of bioweapons much more precise, for instance with genetically targeted weapons developed against specific ethnicities. Genetic ancestry testing is now a widely available service that identifies with great accuracy the ethnic backgrounds of one's pool of ancestors. So-called single nucleotide polymorphisms (SNPs), that is, genome variations specific to people of a common background, may make it possible to target people with a certain dominant ethnicity on the basis of a much larger dataset now, with differences increasingly clearly mapped out.

Once targeting is possible, states will have a changed set of incentives for the development and use of bioweapons, too. Past biological weapons programmes (before the Biological Weapons Convention of 1972) often focused on limiting lethality, aspiring only to make available the means of rendering an enemy army unable to fight, and not necessarily to kill its soldiers, in part because of concerns over possible blowback. Better-targeted weapons may neutralise such considerations, even as blowback will always remain a possibility when a pathogen is released into the wild.

Resistant pathogens. Growing Antimicrobial Resistance (AMR) to drugs and treatments renders making new classes of drugs available an existential imperative for humanity, but the manipulation of the genome of various organisations may itself contribute to the emergence of multiresistant bacteria and also viruses that are able to get around interferon treatment.

Unsafe health data. A lot of health data will be generated by future research and in the process of the medical use of its results. The trend is already pointing towards increasing digitalisation in this field, which – according to current hopes – should make relevant medical data accessible and possible to share for both patients and doctors in a timely manner, for example across the EU Single Market. There will be efforts to preserve security and privacy, of course. But with the characteristics of cyberspace in mind – where *offense dominance* means that defenders not only cannot have a perfect defence against all conceivable attacks, but will usually find out about attacks only *after* the integrity of their data has already been compromised – the most sensible assumption is that *a lot of health data being accessible*, even when they are stored behind firewalls of various kinds, means *a lot of health data being hacked*, ultimately.

"Hacked" can mean stolen as well as erased, rendered inaccessible or manipulated. Ransomware developers have already sought with success to exploit the vulnerabilities of health data.[12] In a future where every individual's genome may be mapped and treatments may be personalised or tailor-made with a view to an individual's specific traits, data manipulation (especially when it is not discovered) could pose a new type of threat.

A rigid application of distorted market mechanisms for the fruits of biotechnology. Patents and intellectual property rights will continue to increase the rigidity with which biotechnological innovations can be marketed and used in a world that will be increasingly dependent on these. The documentary titled *The Patent Wars* (2014) spectacularly captured this trend, and it is noteworthy that there is, even at the time of writing this, a protracted legal battle over patent rights to the aforementioned CRISPR/Cas9 technology of genetic engineering. But patent wars in fact extend far beyond technological innovations, and there is a fight for patent rights to the genetic codes of modified organisms, including, prospectively, that of humans. A 2013 decision by the U.S. Supreme Court ruled that natural DNA cannot be patented, and this is absolutely welcome in that it clears the road to the development of genomic medicine. At the same time, however, it boosts the race for achieving breakthroughs in developing synthetic DNA (cDNA).[13]

This brings us to a further key consideration: the role of inequalities.

Inequalities. Most of the world's economic activity as such is embedded today in an only partially free market economy. Transnational oligopolies emerge, market failures occur, and, even as this unfolds, there is little in the way of limitations to the degree to which the provision of health benefits can be commercialised and, per consequence, withheld, based on the absence of purchasing power. The biotechnological revolution may thus create a world of hitherto unimaginable inequalities where human being to human being may ultimately compare like God to an ape.

It is the idea of just this kind of world that is long since being probed by science fiction. With the realms of the possible and the plausible expanding by the moment, it is ultimately in this literature and its scenarios that one may come across useful hints as to what may – or perhaps *should* – be expected.

The answer regarding the question in the title is not entirely reassuring. Humanity is certainly capable of coming up with intelligent innovations. It is fairness that has traditionally been the greater challenge in terms of how society organises itself – upon the application of new technologies.

Endnotes

[1] „Seal slaps kayaker in the face with an octopus." *The Guardian*, 27 September 2018. At https://www.theguardian.com/global/video/2018/sep/27/seal-slaps-kayaker-in-the-face-with-an-octopus-video.

[2] Zentall, Thomas: Justification of Effort by Humans and Pigeons. *Current Directions in Psychological Science*, 19:5, 296-300 (2010).

[3] Stephenson, G.R.: Cultural acquisition of a specific learned response among rhesus monkeys. In: Starek, D., Schneider, R., and Kuhn, H. J. (eds.): *Progress in Primatology*. Stuttgart: Fischer, 1967, 279-288.

[4] Quoted in Crow, Diana: 6 Amazing Things to Watch in Synthetic Biology. *Medium.com*, 12 October 2017. At https://medium.com/neodotlife/6-things-to-watch-in-synthetic-biology-f76666c7114e.

[5] Cavazzana-Calvo, Marina et al.: Gene Therapy of Human Severe Combined Immunodeficiency (SCID)-X1 Disease. *Science*, 288:5466, 669-672 (2000).

[6] See a basic introduction on the subject from one of the pioneer researchers in: Doudna, Jennifer: How CRISPR lets us edit our DNA. *TED Talks*, London, September 2015. At https://www.ted.com/talks/jennifer_doudna_we_can_now_edit_our_dna_but_let_s_do_it_wisely.

[7] See „Transgenic bunny by Eduardo Kac", *Genome News Network*, 29 March 2002, at http://www.genomenewsnetwork.org/articles/03_02/bunny_art.shtml.

[8] Lu, Yuan: Cell-free synthetic biology: Engineering in an open world. *Synthetic and Systems Biotechnology*, 2:1, 23-27 (2017).

[9] Crow, D., *op. cit.*

[10] See basic information on Aedes aegypti from the European Centre for Disease Prevention and Control at https://ecdc.europa.eu/en/disease-vectors/facts/mosquito-factsheets/aedes-aegypti.

[11] A good conceptualisation of types of risk can be found in: Hewett, J.P. et al.: Human Health and Environmental Risks Posed by Synthetic Biology R&D for Energy Applications: A Literature Analysis. *Applied Biosafety*, 21:4, 177-184 (2016).

[12] See, merely for example: „US hospital pays $55,000 to hackers after ransomware attack." *ZD Net*, 17 January 2018. At https://www.zdnet.com/article/us-hospital-pays-55000-to-ransomware-operators/.

[13] See information on this from the US National Library of Medicine at https://ghr.nlm.nih.gov/primer/testing/genepatents.