ARTICLES AND PAPERS REFERENCED IN FOOTNOTES

1. IN THE BEGINNING


2. JURASSIC PARK: THE RISE OF RESURRECTION BIOLOGY

5. A 2013 study tried to extract DNA from copal, an ancient form of resin that precedes full fossilization into amber. The scientists failed, and as a result claimed that it’s exceedingly unlikely that DNA could be extracted from amber, which is millions of years older than copal. Jurassic Park has a great scientific premise. Sadly, it’s not a realistic one. Penney D, et al. (2013). “Absence of Ancient DNA in Sub-Fossil Insect Inclusions Preserved in ‘Anthropocene’ Colombian Copal.” PLoS One 8 (9). http://doi.org/10.1371/journal.pone.0073150 (Page 29)
6. There is just a passing mention of the *Jurassic Park* dinosaurs’ dependence on lysine in the movie. In the original book, though, lysine dependence plays a substantial role in the ensuing story. (Page 29)

7. During filming, there was an actual hurricane that hit the site. Some of the storm footage is real. (Page 29)

8. You can read more about the quest to increase environmental resilience by resurrecting the woolly mammoth in Ben Mezrich’s book “Woolly: The True Story of the Quest to Revive One of History’s Most Iconic Extinct Creature” (2017, Atira Books). (Page 32)

9. This is a real project, with a real website. You can discover more at http://www.pleistocenepark.ru/en/ (Page 32)

10. *The Tauros Program* is a Dutch initiative to create what they call a “true replacement” for the currently-extinct aurochs. You can find out more at http://taurosprogramme.com/ (Page 32)


13. Despite my portrayal of InGen’s scientists as enthusiastically short-sighted, the company’s Chief Scientist, Henry Wu (played by BD Wong), is increasingly revealed to have serious evil-scientist tendencies in subsequent movies in the series. (Page 37)


3. NEVER LET ME GO: A CAUTIONARY TAKE OF HUMAN CLONING

18. Greely was being quoted in an article by Sharon Begley in Business Insider ("Here’s why we’re still not cloning humans, 20 years after Dolly the sheep." July 5, 2016. http://www.businessinsider.com/can-you-clone-a-human-2016-7). He also noted that the world’s best polo team at the time (the horses) was made up of clones. (Page 52)


20. The US Food and Drug Administration approved the sale of cloned animals and their young for food in 2008—just in case you were wondering. https://www.fda.gov/downloads/AnimalVeterinary/SafetyHealth/AnimalCloning/UCM124756.pdf (Page 52)


25. This must surely be the ultimate “three-step program.” (Page 55)
26. Talking to my mother now, she readily admits that her view of the world has changed quite substantially over the past few decades. This is definitely not the sort of question she’d be asking these days. (Page 56)


29. There are many parallels between this discussion of how we think about and define what it is to be “human,” and discussions around the meaning and nature of “personhood.” In some ways of thinking, the idea of personhood encapsulates a set of attributes that are not uniquely tied to Homo sapiens, and as a result transcend the distinction between “human” and “non-human.” This opens the way to exploring the rights and responsibilities of personhood as it extends to animals, artificial intelligence, and other non-human life forms. However, the question remains: Who decides what the defining attributes of “personhood” are, and if it’s us that decide this, what are the chances that we’re bringing our own pro-human biases to the table? (Page 58)

30. In among these answers, I suspect there would also be a fair number of people who included “having a soul.” (Page 58)


4. MINORITY REPORT: PREDICTING CRIMINAL INTENT

32. It has to be said that, had Anderton had his head screwed on, it might have occurred to him that tracking down the person he was allegedly going to murder to make sure he didn’t, in fact, murder him, wasn’t the smartest move in the book. (Page 66)


37. In a 2008 study, researchers showed that fMRI scans of subjects’ brains indicated what decision they were going to make in a specific situation, some ten seconds before they actually made it. Eerily, this meant that the scientists knew what the subjects were going to do before they themselves realized. The research was published in the journal Nature Neuroscience. Soon, C. S., et al. (2008). “Unconscious determinants of free decisions in the human brain.” Nature Neuroscience 11: 543. http://doi.org/10.1038/nn.2112 (Page 73)


41. Xiaolin Wu and Xi Zhang’s response to critics of their work can be read at https://arxiv.org/abs/1611.04135 (Page 77)

42. Beyond the cadre of science fiction writers who have dabbled with this idea over the years, the philosopher Nick Bostrom argued in a 2003 paper in Philosophical Quarterly that we are already living in a computer simulation (available at https://www.simulation-argument.com/simulation.pdf). This idea appeared to be debunked in 2017 by two researchers from Oxford University whose theoretical
research suggested there is not enough matter in the universe to create a classical computer system capable of simulating it. What is even more interesting is that, despite their paper being near-impenetrable to the vast majority of people on Earth, it still got a sizable amount of press coverage. You can read it—or attempt to—in the journal Science Advances. Ringel, Z. and D. L. Kovrizhin (2017). “Quantized gravitational responses, the sign problem, and quantum complexity.” Science Advances 3(9). http://doi.org/10.1126/sciadv.1701758 (Page 80)

43. In Europe, the recently-introduced General Data Protection Regulation, or GDPR, addresses some of these concerns as it sets out to protect the privacy of individuals in a data-rich society. But experts are skeptical as to the extent to which it can truly prevent massive amounts of data being collected and used against individuals. (Page 82)


5. LIMITLESS: PHARMACEUTICALLY-ENHANCED INTELLIGENCE


46. It should be pointed out here that, because we have a habit of defining success as what humans do, we’d think we were phenomenally successful whatever we achieved as a species. (Page 88)

47. “SF Peak Performance meet-up: biohacking, fitness tech, nutrition.” https://www.meetup.com/PeakPerformance/ (Page 89)


49. I checked—they can. Maybe not with the psychedelics included, but neuralgnite, Neuro Spark, Genius Joy and many other concoctions are but a click away. Who knew? (Page 90)

51. Taken from “The World of Caffeine: The Science and Culture of the World’s Most Popular Drug,” by Bennett Alan Weinberg and Bonnie K. Bealer (Routledge, 2002). Balzac had a stupendous coffee habit, and ended up eating the grounds to achieve the enlightenment he craved. He died at age forty-nine, not necessarily from hacking his brain with the brown stuff. (Page 91)

52. There’s surprisingly little evidence that Adderall does increase performance in healthy adults. There’s more evidence to suggest it can enhance how well you think you’re performing. Sadly, university professors rarely grade on how well you think you’ve done. (Page 92)


56. Admittedly, this one may be difficult to detect in academics. (Page 93)


58. It’s amazing how readily we compare the human brain to the latest form of digital technology. Yet in reality our brains are nothing like the chips in our smartphones or laptops, or even the processors at the hearts of supercomputers. (Page 95)


60. Most likely not all respondents were scientists or academics, but given the source of the poll, it’s likely that many were. (Page 97)

61. The use of cognitive enhancers isn’t unique here: Social pressures around working long hours, being hyper-productive, drinking, and many other behaviors, raise similar questions around what we expect of people, and the degree to which they are in control of their lives. (Page 98)

63. In 2013, President Obama launched the multi-year, multi-million-dollar US BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies)—a public-private partnership that’s researching how the brain works in order to better treat neurological diseases. The same year, the European Commission launched the Human Brain Project, focusing on advancing brain research, cognitive neuroscience, and brain-inspired computing. (Page 100)

64. Just in case it isn’t clear, I’m being sarcastic—our capacity for delusion is only matched by that for hubris. (Page 105)

65. I actually did a search for "humility pills" while writing this, thinking how telling it is that so many people are interested in substances that purportedly increase how smart they are, but not how humble they are. To my surprise, I came across the following paper, which isn’t about humility pills as such, but is about how we might think more broadly and ethically about cognitive enhancement. Goodman, R. (2014). "Humility Pills: Building an Ethics of Cognitive Enhancement." The Journal of Medicine and Philosophy: A Forum for Bioethics and Philosophy of Medicine 39(3): 258–278. http://doi.org/10.1093/jmp/jhu017 (Page 108)

6. ELYSIUM: SOCIAL INEQUITY IN AN AGE OF TECHNOLOGICAL EXTREMES


67. The petri-dish ear was just one of three tissue constructs produced by Atala and his team to demonstrate their technique. They also bioprinted a mandible fragment of a similar size and shape to something that could be used in facial reconstruction, and a rat skullcap bone. Kang, H.-W., et al. (2016). “A 3D bioprinting system to produce human-scale tissue constructs with structural integrity.” Nature Biotechnology 34: 312. http://doi.org/10.1038/nbt.3413 (Page 116)

68. Andrew Meiklejohn’s three-part history of lung diseases of coal miners in Great Britain provide a fascinating insight into the early understanding of coal miner’s


71. More information on workplace fatalities in the US. can be found in the NIOSH Worker Health Charts, published by the Centers for Disease Control and Prevention https://wwwn.cdc.gov/Niosh-whc (Page 121)


73. Despite nearly two decades of research on the potential health and environmental risks of some engineered nanomaterials, some companies continue to use these as if they are, by default safe. This was brought home afresh to me in 2016 in the wake of seeming ambivalence over the potential health risks of using carbon nanotubes—a material that may, under some circumstances, behave like asbestos if inhaled. Andrew Maynard (2016) “We don’t talk much about nanotechnology risks anymore, but that doesn’t mean they’re gone.” The Conversation, March 29 2016. https://theconversation.com/we-dont-talk-much-about-nanotechnology-risks-anymore-but-that-doesnt-mean-theyre-gone-56889 (Page 122)

74. One example of innovative and socially responsible corporate leadership here is the B Corp initiative, where for-profit companies are assessed by an independent organization to meet high standards of social and environmental performance, accountability, and transparency. (Page 122)

75. For more details of this extensive poll on attitudes toward automation, see the article by Aaron Smith and Monica Anderson: “Automation in Everyday Life." Pew Research Center, October 4 2017. http://www.pewinternet.org/2017/10/04/automation-in-everyday-life/ (Page 123)


79. Under the leadership of its current president, Michael Crow, Arizona State University is embarking on an ambitious plan to redefine the role of the public research university into one where higher education serves the needs of a changing world, and is as accessible, impactful, and socially relevant as possible. Part of this involves fully utilizing online teaching platforms to make educational resources accessible to a growing number of people, including those often excluded by more conventional educational models. But more than this, the ASU model is striving to ensure that how we think about and deliver education keeps up with the needs and ambitions of the technological future we’re creating. It’s why I work here. (Page 125)

80. In 2012, I launched the YouTube channel Risk Bites as a platform for helping people make sense of risk, including the potential risks and benefits of emerging and converging technologies. http://youtube.com/riskbites (Page 126)

81. As long as they are in a country that doesn’t block the website. (Page 126)

7. GHOST IN THE SHELL: BEING HUMAN IN AN AUGMENTED FUTURE

82. @elonmusk, on Twitter, posted June 4, 2016 https://twitter.com/elonmusk/status/739006012749799424 (Page 128)


84. https://www.neuralink.com/ This was posted on the Neuralink home page as of October 9, 2017. (Page 128)
“Fog computing” or “edge computing” uses a growing network of internet-connected devices to push data processing out of the cloud, and to the devices that are collecting and using information on everything from our personal habits to the environment around us. It’s the next iteration in distributed computing architectures that combines a vast array of relatively low-power devices with more centralized data processing to massively expand how large amounts of data are utilized. (Page 129)


This emphasis in Ghost on death of the individual as an essential part of the growth across generations is especially intriguing, as it’s contrary to a lot of Western-style thinking that celebrates the ability of technology to prolong individual lives, possibly at the expense of future generations and social well-being. (Page 132)

Although the physical manifestation of 2501 in the movie has sex-associated attributes, 2501 has no clear gender. (Page 132)


You can read more about Zoltan Istvan’s aspirations and vision on his personal website: http://www.zoltanistvan.com/ (Page 135)


The ruling by the IAAF, “IAAF Council introduces rule regarding “technical aids”” can be found on The Internet Archive, at https://web.archive.org/web/20080617001525/http://www.iaaf.org/news/Kind%3D512/newsId%3D38127.html (Page 138)


Alpha O. Royal (2012) “2051.” Available at amazon.com. (Page 143)
96. For more on neural dust sensors, see “Considering ethics now before radically new brain technologies get away from us.” Published on The Conversation, September 14 2016. https://theconversation.com/considering-ethics-now-before-radically-new-brain-technologies-get-away-from-us-65215 (Page 143)


8. EX MACHINA: AI AND THE ART OF MANIPULATION

101. The Terminator sadly didn’t make the cut for this book. It is, nevertheless, one of the classics of the dystopian AI-gone-rogue science fiction movie genre. (Page 153)

102. This is from Benjamin Jowett’s 1894 translation of Plato’s The Republic. (Page 154)

103. Musk’s Falcon 9 wasn’t the first rocket to successfully return to Earth by landing vertically—that award goes to Jeff Bezos’ New Shepard rocket. But it was the first to combine both reaching a serious altitude (124 miles) and a safe return-landing. (Page 159)

104. For more on Musk and his Luddite award, see “If Elon Musk is a Luddite, count me in!,” published December 23, 2015, in The Conversation https://theconversation.com/if-elon-musk-is-a-luddite-count-me-in-52630 (Page 159)

106. In 2013, entrepreneur, educator, and author Steve Blank published the best-seller “The Four Steps to the Epiphany” (published by K&S Ranch). It’s been credited with starting the lean-startup movement which, among other things, embraces the idea of failing fast and failing forward. (Page 164)


108. As if to epitomize this, on February 6, 2018, Elon Musk launched his personal cherry-red Tesla roadster into heliocentric orbit on the first test flight of the SpaceX Falcon Heavy rocket—just because he could. (Page 168)

109. To be clear, while it was often easier to bury local problems caused by technology gone wrong in the past, the impacts on individuals and local commuters were still devastating in many cases. It’s simply that they were more containable. (Page 167)

110. The Asilomar AI Principles were subsequently published by the Future of Life Institute, and endorsed by over 3,700 AI/robotics researchers and others. They can be read at https://futureoflife.org/ai-principles/ (Page 168)


113. You can read more about the “Beneficial AI 2017” meeting on the Future of Life Institute website, at https://futureoflife.org/bai-2017 (Page 169)


115. One of the biggest challenges to current computing hardware is how hard it is to build three-dimensional chips that could potentially vastly outperform current processors. That said, if we continue to make strides in 3-D printing, we may one day be able to actually achieve this. For more, see “We Might Be Able to 3-D-Print an Artificial Mind One Day” Published in Slate, December 11 2014. http://www.slate.com/blogs/future_tense/2014/12/11/3d_printing_an_artificial_mind_might_be_possible_one_day.html (Page 171)


118. In his book "Life 3.0" (see previous footnote), Max Tegmark explores how an AI might use social manipulation to improve society through nudging us toward better decisions. The ethics of this, though, does depend on who’s vision of “better” we’re talking about. (Page 177)

119. Wendell Wallach and Colin Allen (2009) “Moral Machines: Teaching Robots Right from Wrong” Published by Oxford University Press. (Page 177)

9. TRANSCENDENCE: WELCOME TO THE SINGULARITY


121. To accompany the book, “The Singularity is Near,” Kurzweil published a wonderful series of plots showing evidence for exponential growth in different areas of technology innovation. You can explore them all at http://www.singularity.com/charts/page159.html (Page 180)

122. I've tried not to be too critical of the science in the movies in this book, but in this case, I can’t help wondering how cyber-Will's nanobots also managed to retrain the person's neurological networks to make sense of the new signals coming from his eyes. Or, for that matter, how they managed to sort out the cognitive and psychological trauma the person would face as their eyes were rewired. (Page 182)


127. iGEM began in 2003, with the first competition being held in 2004. That first year, there were five teams competing. By 2017, there were 310 teams, with representatives from more than forty countries. You can read more about iGEM and the projects that past teams have worked on at http://igem.org/ (Page 188)


131. “Unabomber” derives from the FBI codename UNABOM, reflecting Kaczynski’s University and Airline BOMbing targets. (Page 193)


133. Coincidentally, there was an earlier “ELF,” in this case standing for Environmental Life Force, which was formed by John Clark Hanna in 1977 in Santa Cruz,
California, as an “eco-guerrilla combat unit.” Hanna was arrested on November 22, 1977 and the original ELF disbanded in 1978. (Page 194)


135. ITS members were not first to take an active dislike to nanotechnologists: In April 2010, three members of ELF were intercepted by Swiss police as they attempted to bomb a nanotechnology lab associated with IBM. To read more about this incident, I’d recommend Chris Toumey’s article in the journal Nature Nanotechnology: Toumey, C. (2013). “Anti-nanotech violence.” Nature Nanotechnology 8(10): 697-698. http://www.nature.com/nnano/journal/v8/n10/full/nnano.2013.201.html (Page 195)


139. Kurzweil’s plot of the exponential growth of computing power can be accessed here: http://www.singularity.com/charts/page67.html (Page 199)


141. The resulting study from the Royal Society and Royal Academy of Engineering became one of the most influential reports on nanotechnology risks to be published. It did not take the risk of gray goo seriously, stating “We have concluded that there is no evidence to suggest that mechanical self-replicating nanomachines will be developed in the foreseeable future.” Royal Society and Royal Academy of Engineering (2004) “Nanoscience and nanotechnologies: opportunities and uncertainties.” https://royalsociety.org/topics-policy/publications/2004/nanoscience-nanotechnologies/ (Page 202)
10. THE MAN IN THE WHITE SUIT: LIVING IN A MATERIAL WORLD


143. The rules of effective narrative almost demand that, in many of the movies here, the science and technology that drives the plot is the product of a lone genius, entrepreneur, or visionary. In contrast, while real life is littered by charismatic figures, science and technology are almost always a team activity, with many smart people working together on their development. (Page 209)

144. As a former electron microscopist, it’s gratifying to see The Man in the White Suit using what appears to be a correctly-set-up early transmission electron microscope. (Page 210)

145. The transcript of Feynman’s 1959 lecture is posted in full on the company Zyvex’s website: http://www.zyvex.com/nanotech/feynman.html (Page 213)

146. The prize was won twenty-six years after Feynman set the challenge by physicist Tom Newman, who wrote the first page of Charles Dickens’ A Tale of Two Cities on a 200-μm square piece of plastic, using electron-beam lithography. For more information, see Katherine Kornei (2016) “The Beginning of Nanotechnology at the 1959 APS Meeting,” APS News, November 2016 https://www.aps.org/publications/apsnews/201611/nanotechnology.cfm (Page 213)

147. On September 28, 1989, IBM physicist Don Eigler used a scanning tunneling microscope to spell out the word “IBM” with 35 xenon atoms. It was the first time anyone had intentionally manipulated and moved individual atoms, and at the time appeared to open the way to achieving some of Feynman’s speculative ideas. (Page 214)


149. In the spirit of full disclosure, I was involved in the early days of the National Nanotechnology Initiative, and was the first co-chair of the interagency committee within the NNI to examine the environmental and health implications of nanotechnology. (Page 215)
150. Early in the evolution of the NNI, Drexler went head to head with Nobel Laureate Richard Smalley as they clashed over the future of nanotechnology. A December 2003 cover story in the magazine Chemical & Engineering News provided a point-counterpoint platform for Drexler and Smalley to duke it out: http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html Drexler talks about the subsequent marginalization of his ideas in his 2013 book, “Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization” (published by PublicAffairs). (Page 218)

151. I actually checked on Google Scholar to see how many people had cited the paper since its publication. Surprisingly, twenty-five people had liked it enough to refer to it in their own papers — more than I would have expected. However, at least two of those “fans” were me citing my own work, confirming that we’re all our own greatest cheerleaders when it comes to science. The paper was published in the Journal of Aerosol Science, volume 31 issue 2, pages 151-166 (2000), and can be read here, just in case you’re interested: https://doi.org/10.1016/S0021-8502(99)00035-X (Page 219)

152. One of those consequences was having to deal with the ill will of fellow classmates who felt cheated, confirming that nothing is ever “just a game.” (Page 221)

153. I’m paraphrasing, but this was the essence of the frustrated outburst. (Page 223)

154. International planetary protection regulations were established in article IX of the 1966 United Nations Treaty on “Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.” They are currently embodied in the Committee on Space Research (COSPAR) Planetary Protection Policy. (Page 224)

155. You can read more about Expert and Citizen Assessment of Science & Technology at https://ecastnetwork.org/ (Page 228)

### 11. INFERNO: IMMORAL LOGIC IN AN AGE OF GENETIC MANIPULATION


12. THE DAY AFTER TOMORROW: RIDING THE WAVE OF CLIMATE CHANGE


175. The name LOHAFEX comes from “LOHA,” the Hindi word for iron, and “FEX,” an acronym derived from Fertilization Experiment. The lead scientists were nothing if not obscurely creative! (Page 266)


13. CONTACT: LIVING BY MORE THAN SCIENCE ALONE

177. I may be slipping into hyperbole here, but over the years talking with colleagues, this is the movie that often comes out as most closely reflecting how they feel about science, and how it inspires them. (Page 272)

178. A lot has been written about how our cognitive biases and mental shortcuts affect what we believe and how we behave, including how we respond to information that jars with what we believe to be true. Two good starting points for beginning to explore this area are Daniel Kahneman’s 2013 book, “Thinking Fast and Slow” (published by Farrar, Straus and Giroux), and the 2017 US National Academy of Sciences report, “Communicating Science Effectively” (published by the National Academies Press), https://www.nap.edu/catalog/23674/communicating-science-effectively-a-research-agenda. (Page 277)
14. LOOKING TO THE FUTURE

[No footnotes!]