

FILMS FROM THE FUTURE: THE TECHNOLOGY AND MORALITY OF SCI-FI MOVIES

ARTICLES AND PAPERS REFERENCED IN FOOTNOTES

1. IN THE BEGINNING

1. An open letter from JANA partners and CALSTRS to Apple, Inc., January 6, 2018. Accessible at <https://thinkdifferentlyaboutkids.com/> (Page 19)
2. For a good working definition of responsible research and innovation, I'd recommend a 2013 paper by Jack Stilgoe, Richard Owen, and Phil Macnaghten. "Developing a framework for responsible innovation." *Research Policy* 42(9): 1568-1580. <http://doi.org/10.1016/j.respol.2013.05.008> (Page 22)
3. For more on risk innovation, I'd recommend reading this 2015 article. "Why we need risk innovation." *Nature Nanotechnology* 10: 730–731. <http://doi.org/10.1038/nnano.2015.196> (Page 23)
4. In 1993, the British artist Damien Hirst produced an exhibit with the title "Mother and Child (Divided)." It consisted of a cow and calf, each sliced in half, pickled in formaldehyde, and mounted in a display cabinet. <http://damienhirst.com/mother-and-child-divided-1> (Page 25)

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)
11. In 2009, a team of scientists synthesized an artificial form of DNA with six nucleotide building blocks, rather than the four found in naturally-occurring DNA (Georgiadis, M. M., et al. (2015). "Structural Basis for a Six-Nucleotide Genetic Alphabet." *Journal of the American Chemical Society* **137** (21): 6947-6955. <http://doi.org/10.1021/jacs.5b03482>). More recently, scientists reported in the journal *Nature* that they had created a semi-synthetic organism that used artificial six-letter DNA to store and retrieve information (Zhang, Y., et al. (2017). "A semi-synthetic organism that stores and retrieves increased genetic information." *Nature* **551**: 644. <http://doi.org/10.1038/nature24659>). (Page 35)
12. Venter's team's work is described in the journal *Nature* in 2016. Callaway, E. (2016). "'Minimal' cell raises stakes in race to harness synthetic life." *Nature* 531: 557–558. <http://doi.org/10.1038/531557a> (Page 35)
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)
14. The paper was titled "Deterministic Nonperiodic Flow" and was published in the *Journal of the Atmospheric Sciences*. Edward N. Lorenz (1963). "Deterministic Nonperiodic Flow". *Journal of the Atmospheric Sciences*. 20 (2): 130–141. [http://doi.org/10.1175/1520-0469\(1963\)020<0130:DNF>2.0.CO;2](http://doi.org/10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2) (Page 40)
15. James Gleick (1987) "Chaos: Making a New Science." [Viking, New York](#). (Page 41)

16. Nidhi Subbaraman and Jessica Garrison (2017) "Here's What Happened In The Hours After Hurricane Harvey Hit A Chemical Plant, According To A Staff Log" *Buzzfeed*, November 16, 2017. <https://www.buzzfeed.com/nidhisubbaraman/arkema-chemical-plant-houston-timeline> (Page 43)
17. Charles Perrow developed his ideas in his 1984 book "Normal Accidents: Living with High-Risk Technologies" published by Princeton University Press. (Page 43)

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)
19. Although, as New York Magazine pointed out in September 2016, "Paying \$100,000 to Clone Your Dog Won't Give You Your Dog Back." <https://www.thecut.com/2016/03/why-do-people-get-the-same-pet-over-and-over.html> (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)
21. General Assembly Adopts United Nations Declaration on Human Cloning by vote of 84-34-37. March 8, 2005. Accessible at <http://www.un.org/press/en/2005/ga10333.doc.htm> (Page 53)
22. George Dvorsky (2014), "9 Unexpected Outcomes Of Human Cloning." io9, July 17 2014. <http://io9.gizmodo.com/9-unexpected-outcomes-of-human-cloning-1606556772> (Page 53)
23. Admiraal, P., Ardila, R., & Berlin, I. (1997). Declaration in defense of cloning and the integrity of scientific research. *Free Inquiry*, 17(3), 11-12. (Page 54)
24. Raël (2001) "Yes to Human Cloning." <http://www.rael.org/download.php?view.2> (Page 54)
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)
27. "Do IVF babies have souls?" Posted on the website Catholic Answers Forums, January 2015, <https://forums.catholic.com/t/do-ivf-babies-have-souls/387786> (Page 57)
28. "The United Nations Universal Declaration of Human Rights." <http://www.un.org/en/universal-declaration-human-rights/> (Page 58)
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)
31. Boeke, J. D., et al. (2016). "The Genome Project-Write." Science 353(6295): 126-127. <http://doi.org/10.1126/science.aaf6850> (Page 59)

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)
33. Ian Sample (2017), "Brain scans can spot criminals, scientists say." The Guardian. Published online March 13, 2017. <https://www.theguardian.com/science/2017/mar/13/brain-scans-can-spot-criminals-scientists-say> (Page 68)
34. The original research was published in the Proceedings of the National Academies of Science. Vilares, I., et al. (2017). "Predicting the knowledge—recklessness distinction in the human brain." Proceedings of the National Academy of Sciences 114(12): 3222-3227. <http://doi.org/10.1073/pnas.1619385114> (Page 68)

35. The research was published in 2011 by Jeffrey Valla, Stephen J. Ceci, and Wendy M. Williams in the Journal of Social, Evolutionary, and Cultural Psychology. Valla, J. M., et al. (2011). "The accuracy of inferences about criminality based on facial appearance." *Journal of Social, Evolutionary, and Cultural Psychology* 5(1): 66–91. <http://doi.org/10.1037/h0099274> (Page 71)
36. Satoshi Kanazawa (2011) "Criminals Look Different From Non-criminals.," *Psychology Today*. Posted March 13, 2011. <https://www.psychologytoday.com/blog/the-scientific-fundamentalist/201103/criminals-look-different-noncriminals> (Page 71)
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)
38. In this case the research—published in 2017 in the journal *Cell*—showed that facial images seen by macaque monkeys could be reconstructed by monitoring specific brain cells. Chang, L. and D. Y. Tsao (2017). "The Code for Facial Identity in the Primate Brain." *Cell* 169(6): 1013-1028.e1014. <http://doi.org/10.1016/j.cell.2017.05.011> (Page 73)
39. This study by Emily Faulk and colleagues was published in the *Journal of Neuroscience*. Falk, E. B., et al. (2010). "Predicting Persuasion-Induced Behavior Change from the Brain." *The Journal of Neuroscience* 30(25): 8421. <http://doi.org/10.1523/JNEUROSCI.0063-10.2010> (Page 74)
40. Their paper, "Automated Inference on Criminality using Face Images" was uploaded to the scientific paper archiving website arxiv.org in November 2016. Wu, X. and X. Zhang (2016). "Automated Inference on Criminality using Face Images." *Arxiv* 1611.04135v1. <https://arxiv.org/pdf/1611.04135v1.pdf> (Page 77)
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)
44. The report “Dismantling Predictive Policing in Los Angeles” was released on May 8, 2018, and garnered considerable press attention for its echoes of a Minority-Report-like approach to pre-crime. It’s accessible at <https://stoplapdspying.org/wp-content/uploads/2018/05/Before-the-Bullet-Hits-the-Body-May-8-2018.pdf> (Page 83)

5. LIMITLESS: PHARMACEUTICALLY-ENHANCED INTELLIGENCE

45. Andrew Maynard (2009) “Ten emerging technology trends to watch over the next decade” Posted on 2020 Science, December 25, 2009. <https://2020science.org/2009/12/25/ten-emerging-technology-trends-to-watch/> (Page 85)
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)
48. Sara Solovitch (2017). “Tweaking brains with ‘smart drugs’ to get ahead in Silicon Valley.” *Washington Post*, June 11, 2017 https://www.washingtonpost.com/national/health-science/tweaking-brains-with-smart-drugs-to-get-ahead-in-silicon-valley/2017/06/09/5bc9c064-0b35-11e7-93dc-00f9bdd74ed1_story.html? (Page 89)
49. I checked—they can. Maybe not with the psychedelics included, but neuroignite, Neuro Spark, Genius Joy and many other concoctions are but a click away. Who knew? (Page 90)

50. Chaterjee, A. (2004). "Cosmetic neurology. The controversy over enhancing movement, mentation, and mood." *Neurology* 63: 968–974. <http://doi.org/10.1212/01.WNL.0000138438.88589.7C> (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)
53. See Maxwell J. Mehlman (2004) "Cognition-Enhancing Drugs." *The Millbank Quarterly*, volume 83 issue 3, pages 483–506 <http://doi.org/10.1111/j.0887-378X.2004.00319.x> (Page 92)
54. Sahakian, B. and S. Morein-Zamir (2007). "Professor's little helper." *Nature* 450: 1157. <http://doi.org/10.1038/4501157a> (Page 93)
55. Maher, B. (2008). "Poll results: look who's doping." *Nature* 452: 674-675. <http://doi.org/10.1038/452674a> (Page 93)
56. Admittedly, this one may be difficult to detect in academics. (Page 93)
57. Giurgea, C. (1973). "The 'Nootropic' Approach to the Pharmacology of the Integrative Activity of the Brain." *Conditional Reflex* 8(2): 108–115. <https://link.springer.com/article/10.1007/BF03000311> (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)
59. The press release can still be read using Wayback Machine on the original WABDA website, set up especially for the occasion. <https://web.archive.org/web/20080409091357/http://wabda.org:80/News.html> (Page 96)
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)

62. In 2008, Henry Greely and a number of colleagues published an opinion in the journal *Nature* calling for more efforts to support the responsible use of cognitive enhancers by healthy people. Greely, H. and colleagues (2008) "Towards responsible use of cognitive enhancing drugs by the healthy" *Nature*, 456, 11, pages 702-705. <http://doi.org/10.1038/456702a> (Page 99)
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

66. Joseph Stiglitz (2011) "Of the 1%, by the 1%, for the 1%." *Vanity Fair*, May 2011. <https://www.vanityfair.com/news/2011/05/top-one-percent-201105> (Page 110)
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

- pneumoconiosis: Meiklejohn, A. (1952). "History of Lung Diseases of Coal Miners in Great Britain" Part I, 1800-1875. British Journal of Industrial Medicine 8(3): 127-137. Part II, 1875-1920. British Journal of Industrial Medicine 9(2): 93- 98. Part III, 1920-1952. British Journal of Industrial Medicine 1952: 208-220. (Page 120)
69. Frank Swoboda, "Coal mine operators altered dust samples" Washington Post, April 4 1991. <https://www.washingtonpost.com/archive/politics/1991/04/04/coal-mine-operators-altered-dust-samples/b0fec1b0-fe9c-4847-b900-7de6f4fc3d46/> (Page 120)
 70. Howard Berkes (2017) "NPR Continues To Find Hundreds Of Cases Of Advanced Black Lung" NPR, July 1, 2017. <http://www.npr.org/sections/thetwo-way/2017/07/01/535082619/npr-continues-to-find-hundreds-of-cases-of-advanced-black-lung> (Page 121)
 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)
 72. Takala, J., et al. (2014). "Global Estimates of the Burden of Injury and Illness at Work in 2012." Journal of Occupational and Environmental Hygiene 11(5): 326-337. <http://doi.org/10.1080/15459624.2013.863131> (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)

76. I wrote about this in 2016. Andrew Maynard (2016) "Will driving your own car become the socially unacceptable public health risk smoking is today?" Published in The Conversation, September 26 2016. <https://theconversation.com/will-driving-your-own-car-become-the-socially-unacceptable-public-health-risk-smoking-is-today-65891> (Page 123)
77. Erik Brynjolfsson and Andrew McAfee. "The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies" W. W. Norton & Company, 2016. (Page 124)
78. Rachel Hallett and Rosamund Hutt (2016) "10 jobs that didn't exist 10 years ago." World Economic Forum <https://www.weforum.org/agenda/2016/06/10-jobs-that-didn-t-exist-10-years-ago/> (Page 124)
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)
83. Rolfe Winkler (2017) "Elon Musk Launches Neuralink to Connect Brains With Computers." The Wall Street Journal, March 27, 2017. <https://www.wsj.com/articles/elon-musk-launches-neuralink-to-connect-brains-with-computers-1490642652> (Page 128)
84. <https://www.neuralink.com/> This was posted on the Neuralink home page as of October 9, 2017. (Page 128)

85. "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)
86. Emily Yoshida (2017) "A Beginner's Guide to the Ghost in the Shell Universe" <http://www.vulture.com/2017/03/a-beginners-guide-to-the-ghost-in-the-shell-series.html> (Page 130)
87. 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)
88. Although the physical manifestation of 2501 in the movie has sex-associated attributes, 2501 has no clear gender. (Page 132)
89. You can read more about the details of this incident on Steve Mann's blog. Steve Mann (2012) "Physical assault by McDonald's for wearing Digital Eye Glass" Eyetap, posted July 16, 2012. <http://eyetap.blogspot.com/2012/07/physical-assault-by-mcdonalds-for.html> (Page 134)
90. You can read more about Zoltan Istvan's aspirations and vision on his personal website: <http://www.zoltanistvan.com/> (Page 135)
91. Aimee Mullins (1998) "Changing my legs — and my mindset." TED. https://www.ted.com/talks/aimee_mullins_on_running (Page 137)
92. Aimee Mullins (2009) "My 12 pairs of legs." TED. https://www.ted.com/talks/aimee_mullins_prosthetic_aesthetics (Page 137)
93. 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)
94. Daniel Engber provides a compelling account of Kennedy's work in a 2016 Wired article titled "The Neurologist who Hacked His Brain, and Almost Lost His Mind." Wired, January 26, 2016. <https://www.wired.com/2016/01/phil-kennedy-mind-control-computer/> (Page 143)
95. 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)
97. Hugo Campos (2015) “The Heart of the Matter,” published in Slate, March 24 2015. http://www.slate.com/articles/technology/future_tense/2015/03/patients_should_be_allowed_to_access_data_generated_by_implanted_devices.html (Page 147)
98. England, R., et al. (2007). “The ethical and legal implications of deactivating an implantable cardioverter-defibrillator in a patient with terminal cancer.” *Journal of Medical Ethics* 33(9): 538. <http://doi.org/10.1136/jme.2006.017657> (Page 148)
99. Muddy Waters Research report on St. Jude Medical, Inc. August 25, 2016. <http://d.muddywatersresearch.com/research/stj/mw-is-short-stj/> (Page 150)
100. FDA, August 29, 2017. “Firmware Update to Address Cybersecurity Vulnerabilities Identified in Abbott’s (formerly St. Jude Medical’s) Implantable Cardiac Pacemakers: FDA Safety Communication.” <https://www.fda.gov/medicaldevices/safety/alertsandnotices/ucm573669.htm> (Page 150)

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)
105. Thierer’s blueprint can be downloaded from the website permissionlessinnovation.org: http://permissionlessinnovation.org/wp-content/uploads/2016/04/PI_Blueprint_040716_final.pdf (Page 160)

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)
107. See “Dear Elon Musk: Your dazzling Mars plan overlooks some big nontechnical hurdles.” Published in The Conversation, October 1 2017. <https://theconversation.com/dear-elon-musk-your-dazzling-mars-plan-overlooks-some-big-nontechnical-hurdles-84948> (Page 165)
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)
111. Nick Bostrom (2014). “Superintelligence: Paths, Dangers and Strategies.” (Oxford University Press) (Page 168)
112. An Open Letter: RESEARCH PRIORITIES FOR ROBUST AND BENEFICIAL ARTIFICIAL INTELLIGENCE. Published by the Future of Life Institute. <https://futureoflife.org/ai-open-letter/> (Page 169)
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)
114. Max Tegmark (2017) “Life 3.0: Being human in the age of artificial intelligence.” Published by Alfred A. Knopf, New York. (Page 170)
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)

116. It's worth reading "Defining Intelligence: A Conversation With Stuart Russell." Published in Edge, February 2, 2017. https://www.edge.org/conversation/stuart_russell-defining-intelligence (Page 172)
117. Alan M. Turing (1950) "Computing Machinery and Intelligence." Mind 49: 433–460. <https://doi.org/10.1093/mind/LIX.236.433> (Page 175)
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

120. Ray Kurzweil (2005) "[The Singularity Is Near: When Humans Transcend Biology.](#)" Published by Penguin Books. (Page 179)
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)
123. Working in emerging technologies, it sometimes seems that every new wave of innovation represents a new "industrial revolution" to someone. Yet, even though not everyone agrees with the World Economic Forum's terminology, there is some merit to thinking that we are in a unique period in our technological growth. As a primer on the Fourth Industrial Revolution, I'd recommend Klaus Schwab's January 2016 article on the World Economic Forum website: "The Fourth Industrial Revolution: what it means, how to respond." <https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/>. And if you want more, there's always his 2017 book, "[The Fourth Industrial Revolution.](#)" published by Crown Business. (Page 183)

124. Mihail C. Roco and William S. Bainbridge (2003) "Converging Technologies for Improving Human Performance. Nanotechnology, biotechnology, information technology and cognitive science." Published by the World Technology Evaluation Center (WTEC) http://www.wtec.org/ConvergingTechnologies/Report/NBIC_report.pdf (Page 184)
125. Drew Endy (2005). "Foundations for engineering biology." Nature 438. <http://doi.org/10.1038/nature04342> (Page 187)
126. For a comprehensive history of the emergence of synthetic biology, going back to the 1960s, it's worth reading Ewen Cameron, Caleb Bashor, and James Collins' account in the journal Nature Reviews: Cameron, D. E., et al. (2014). "A brief history of synthetic biology." Nature Reviews Microbiology 12: 381. <http://doi.org/10.1038/nrmicro3239> (Page 187)
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)
128. The articles were published as a collection under the title "Technology innovation and life in the 21st century: Views from Civil Society," and can be read at 2020 Science. <https://2020science.org/2016/01/22/technology-innovation-and-life-in-the-21st-century-views-from-civil-society/> (Page 191)
129. Jim Thomas (2009) "21st Century Tech Governance? What would Ned Ludd do?" Published on 2020 Science, December 18, 2009. <https://2020science.org/2009/12/18/thomas/> (Page 191)
130. See "If Elon Musk is a Luddite, count me in!" The Conversation, published December 23, 2015. <https://theconversation.com/if-elon-musk-is-a-luddite-count-me-in-52630> (Page 191)
131. "Unabomber" derives from the FBI codename UNABOM, reflecting Kaczynski's University and Airline BOMBing targets. (Page 193)
132. FBI, February 12, 2002. Testimony of James F. Jarboe, Domestic Terrorism Section Chief, Counterterrorism Division, Federal Bureau of Investigation, before the House Resources Committee, Subcommittee on Forests and Forest Health, Washington, DC. <https://archives.fbi.gov/archives/news/testimony/the-threat-of-eco-terrorism> (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)
134. From The Anarchist Library: Communiques of ITS. <https://theanarchistlibrary.org/library/individualists-tending-toward-the-wild-communiques> (Page 195)
 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)
 136. From The Anarchist Library: Communiques of ITS, Communiqué Eight (March 2014) <https://theanarchistlibrary.org/library/individualists-tending-toward-the-wild-communiques#toc36> (Page 195)
 137. Bill Joy (2000) “Why the future doesn't need us.” Published in Wired, April 1, 2000. <https://www.wired.com/2000/04/joy-2/> (Page 195)
 138. “The Unabomber Trial: The Manifesto.” Published in 1995 in The Washington Post. <http://www.washingtonpost.com/wp-srv/national/longterm/unabomber/manifesto.text.htm> (Page 197)
 139. Kurzweil's plot of the exponential growth of computing power can be accessed here: <http://www.singularity.com/charts/page67.html> (Page 199)
 140. As The Telegraph's Roger Highfield wrote in June 2003. “Prince asks scientists to look into ‘grey goo’” (The Telegraph, June 5, 2003). <http://www.telegraph.co.uk/news/science/science-news/3309198/Prince-asks-scientists-to-look-into-grey-goo.html> (Page 202)
 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 grey 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

142. Howard Lovy wrote a great account of the protest in Wired. Howard Lovy (2005) "When nano pants attack." Published in Wired, June 10, 2005. <https://www.wired.com/2005/06/when-nanopants-attack/> (Page 207)
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)
148. The report "Nanotechnology: Shaping the World, Atom by Atom" was published by the National Science and Technology Council Committee on Technology, and the Interagency Working Group on Nanoscience, Engineering and Technology in 1999. <http://www.wtec.org/loyola/nano/IWGN.Public.Brochure/IWGN.Nanotechnology.Brochure.pdf> (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](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

156. Bernard Dixon (1971) "In Praise of Prophets." New Scientist, 16 September 1971, page 606. (Page 231)
157. Sander Herfst and colleagues (2012) "Airborne Transmission of Influenza A/H5N1 Virus Between Ferrets" Science, 336 (6088) pp 1534-1541 <http://doi.org/10.1126/science.1213362> (Page 233)

158. Masaki Imai and colleagues (2012) “Experimental adaptation of an influenza H5 HA confers respiratory droplet transmission to a reassortant H5 HA/H1N1 virus in ferrets” *Nature* 486, pp 420–428 <http://doi.org/10.1038/nature10831> (Page 233)
159. Jeffery K. Taubenberger and David M. Morens (2006) “1918 Influenza: the Mother of All Pandemics”. *Emerging Infectious Diseases* volume 12, number 1, pages 15-22 <https://doi.org/10.3201/eid1201.050979> (Page 233)
160. Jocelyn Kaiser (2014) “Lab incidents lead to safety crackdown at CDC.” Published in *Science Magazine*, July 11, 2014. <http://www.sciencemag.org/news/2014/07/lab-incidents-lead-safety-crackdown-cdc> (Page 234)
161. Ed Yong (2012) “The risks and benefits of publishing mutant flu studies.” *Nature News*, March 2, 2012 <http://doi.org/10.1038/nature.2012.10138> (Page 234)
162. Cambridge Working Group Consensus Statement on the Creation of Potential Pandemic Pathogens (PPPs). <http://www.cambridgeworkinggroup.org/> (Page 235)
163. Press Statement on the NSABB Review of H5N1 Research, December 20, 2011. <https://www.nih.gov/news-events/news-releases/press-statement-nsabb-review-h5n1-research> (Page 235)
164. Heidi Ledford (2012) “Call to censor flu studies draws fire.” Published in *Nature News* January 3, 2012. <http://doi.org/10.1038/481009a> (Page 235)
165. March 29-30, 2012 Meeting of the National Science Advisory Board for Biosecurity to Review Revised Manuscripts on Transmissibility of A/H5N1 Influenza Virus. Statement of the NSABB: http://www.virology.ws/NSABB_statement_march_2012.pdf (Page 235)
166. Ehrlich, P. (1968). “The Population Bomb.” Sierra Club/Ballantine Books. (Page 238)
167. Roger A. Pielke Jr. (2007). “The Honest Broker: Making Sense of Science in Policy and Politics” Published by Cambridge University Press. (Page 244)

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

168. “The world’s worst natural disasters. Calamities of the 20th and 21st centuries” Published by CBC, May 8, 2008. <http://www.cbc.ca/news/world/the-world-s-worst-natural-disasters-1.743208> (Page 257)
169. See, for instance, Ed Yong’s 2016 book “I Contain Multitudes: The Microbes Within Us and a Grander View of Life.” published by Ecco. (Page 258)

170. Park, J., et al. (2012). "Integrating Risk and Resilience Approaches to Catastrophe Management in Engineering Systems." *Risk Analysis* 33(3): 356-367. <http://doi.org/10.1111/j.1539-6924.2012.01885.x> (Page 263)
171. Woods, D. D. (2015). "Four concepts for resilience and the implications for the future of resilience engineering." *Reliability Engineering & System Safety* 141: 5-9. <http://doi.org/10.1016/j.ress.2015.03.018> (Page 263)
172. Seager, T. P., et al. (2017). "Redesigning Resilient Infrastructure Research." Published in "Resilience and Risk. Methods and Application in Environment, Cyber and Social Domains." Editors: I. Linkov and J. M. Palma-Oliveira Springer. Pages 81-119. (Page 263)
173. Angel, R. (2006). "Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange point (L1)." *Proceedings of the National Academy of Sciences* 103(46): 17184. <http://doi.org/10.1073/pnas.0608163103> (Page 265)
174. See "Geoengineering: Does it need a dose of geoethics?" *2020 Science*, January 28, 2009. <https://2020science.org/2009/01/28/geoengineering-does-it-need-a-dose-of-geoethics/> (Page 266)
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)
176. "LOHAFEX: An Indo-German iron fertilization experiment." *Eurekalert*, January 13, 2009. https://www.eurekalert.org/pub_releases/2009-01/haog-lai011309.php (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!]