6. Sustainable DNA In Conversation

Mél Hogan and Deb Verhoeven

Big Tech supports social media, the stock market, insurance companies, scientific research, financial transactions, mass surveillance and monitoring, the 'Internet of things', 'smart city' sensors and grids, and mobile communications for Internet users writ large. By most industry accounts, data centres—and the cloud infrastructure that undergirds it—has become the most important sociotechnical system of our time, but also the least sustainable. Interestingly, one of the alternatives to these water- and energy-intensive data storage solutions has emerged from advancements in synthetic DNA technologies, now touted by the industry as a safer, greener and more efficient alternative. But how did we get here? How might ideas of 'sustainability' and 'efficiency' function in this context? In conversation, Mél Hogan and Deb Verhoeven discuss the idea of 'Sustainable DNA'—in its various instantiations—as an object of critical media studies.

By most industry accounts, data centres and the cloud infrastructure that undergirds them have become the most important sociotechnical system of our time, but also the least sustainable. During these pandemic times, for example, with many on lockdown, self-isolating or under quarantine, we have seen a surge in Internet demands: up by 70% for work, research and entertainment.[1] Scientists worldwide are busy

1 Mark Beech, 'COVID-19 pushes up Internet use 70% and streaming more than 12%, first figures reveal', *Forbes* (March 25, 2020), https://www.forbes.com/sites/markbeech/2020/03/25/covid-19-pushes-up-internet-use-70-streaming-more-than-12-first-figures-reveal/#6d22fd223104.

 https://doi.org/10.11647/OBP.0213.06

sequencing the genome (DNA) of COVID-19 while others sit at home creating and streaming more media content than ever. There's probably been no time like this current pandemic for thinking through the ways in which something like DNA and the Internet coexist (if not collide) as constitutive paradigms. Specifically—and what we discuss here—one of the alternatives to water- and energy-intensive cloud infrastructures has emerged from advancements in synthetic DNA technologies, now hailed by the industry as a safer, greener and more efficient medium for data storage. But how did we get here; from large scale cloud storage to the molecular? How might ideas of 'sustainability' and 'efficiency' function in this context? In conversation, Mél Hogan and Deb Verhoeven discuss the idea of 'Sustainable DNA storage'—in its various instantiations—as an object of media and critical infrastructure studies. The following stems from a talk given by Mél Hogan, delivered at the University of Alberta's 2019 Sustainability Lectures.

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MH: I first came to think of 'sustainable DNA' storage by positioning it as a response to data centres. The current infrastructure for data storage generally includes tape and hard drives in large scale data centres, or what we've come to simply think of as 'the cloud'. As a media object, DNA data storage is a great object for analysis, not only for the way it offers continuity, in an analysis of storage technologies, but also for the way it makes us confront code anew. What makes DNA such a viable storage modality is, in part, how compatible the code of DNA—its four constituent chemicals, CTGA,—is with the binary code—the zeros and ones of digital data. So, to explain it most simply, the process of converting data into DNA is one of translation and conversion into various combinations of the four possible acids—cytosine, thymine, guanine or adenine. The use of the DNA sequence as a storage medium is expected to take off within the next ten years, with both universities and commercial companies leading the way.

DV: My reflections on sustainable DNA developed out of my experience building digital archive infrastructure and then a serendipitous encounter with a taphonomist. This got me thinking: if DNA is used to store information, what would be the nature of its decay at the

informational level? How sustainable is 'sustainable DNA' in both practical and philosophical terms?[2]

Media Studies encourages us to approach the question of sustainability in terms of discursive histories including complex narratives about origins, provenance, inheritances, temporality, longevity and 'the archive'. In thinking specifically about the industrialisation of DNA (its storage and its use as storage media) these approaches interleave with many issues brought into consideration by Critical Infrastructure Studies.[3] Infrastructure establishes the conditions for the possibility of connection. DNA can be thought of in a sense as a form of infrastructure. And the 'connectivity' it enables is existentially defining. We hear this when people talk about 'the DNA' of an organisation or a system—meaning its constitutive, connective tissue. DNA here is 'foundational' in the sense that it is presented as conceptually irreducible (i.e., as essential) and in the way it cuts through time by producing a kind of 'present-day provenance' in the form of an authoritative ontological explanation (i.e., as essentialist). This is the kind of 'originary thinking' that I've written about previously in my work on sheep as foundational tropes. Originary thinking is a totalising thinking that purports to account for everything by getting to the ground of things.[4] Forget about Dolly the cloned sheep. Even woollen apparel now comes with DNA certification (see Figures 1 and 2).[5]

This understanding of DNA as 'connective' gives rise to specific narratives about how our DNA links us—I'm thinking of the widely quoted statistic that we share 99.9% of our DNA with the person sitting next to us for example. But these claims of a defining human capacity for sharedness also touch aspects of the world that are typically excluded from western human taxonomies and that are now drawn into

2 Deb Verhoeven, Mike Jones and Stephen Loo, 'Replicating the replicants; or, do archivists dream of downloadable sheep?', paper delivered at 'Australian Society of Archivists—Archives in a Blade Runner Age: Identity & Memory, Evidence & Accountability' (Perth, Australia, September 25–28, 2018).

3 On Critical Infrastructure Studies, see https://cistudies.org/, which includes a detailed bibliography outlining this emerging field of interest. See also Jean-Christophe Plantin, Carl Lagoze, Paul N Edwards and Christian Sandvig, 'Infrastructure studies meet platform studies in the age of Google and Facebook', *New Media & Society*, 20.1 (2018), 293–310, https://doi.org/10.1177/1461444816661553.

4 Deb Verhoeven, *Sheep and the Australian Cinema* (MUP: Melbourne, 2006), pp. 15–19.

5 Australian Wool Network, http://woolnetwork.com.au/dna.html.

a connection with us and that therefore redefine human relationality as something that includes the 'more than human'. My favourite is the line about how more than half of our genetic code is the same as a banana. What does this even mean? I guess for me it prompts us to think much more broadly about the co-dependencies or relationality at the heart of

Figs 1 (left) and 2 The use of DNA to ensure the 'naturalness' of garments through provenance tracing. Photographs by Deb Verhoeven (2020).

our 'lifeworld'.[6] It evokes for me what Indigenous theorist Shawn Wilson says in a different context: 'Rather than viewing ourselves as being *in* relationship with other people or things, we *are* the relationships that we hold and are part of',[7] or when Kim TallBear writes about understanding existence as a matter of 'being in good relation' rather than as the assertion of a defined point in hierarchical taxonomies.[8]

To take this to a more prosaic level. We might also want to understand the opaque interconnections in the digital infrastructure that have arisen around the sale of DNA related services—I am thinking here of Ancestry.com and 23andMe, for example. The familial relationships

6 Maggie Walter, 'The voice of Indigenous data beyond the markers of disadvantage', in *Griffith Review 60: First Things First*, ed. by Julianne Schultz and Sandra Phillips (Brisbane: Griffith University, 2018), pp. 256–263.

7 Shawn Wilson, *Research is Ceremony: Indigenous Research Methods* (Halifax, Nova Scotia: Fernwood Publishing, 2008), p. 80.

8 Kim TallBear, 'Caretaking relations, not American dreaming', *Kalfou: A Journal of Comparative and Relational Ethnic Studies*, 6.1 (2019) https://doi-org.login.ezproxy.library.ualberta.ca/10.15367/kf.v6i1.228.

that underpin these companies aren't obvious but are structuring. Anne Wojcicki, co-founder of 23andMe was married to Sergey Brin, co-founder of Google and investor in both 23andMe and Calico, a multibillion-dollar 'seed' funding company whose express mission is to understand and influence the genetic basis of aging, and which is Ancestry.com's main research partner. I'm not even going to debate whether a company like Calico is much more than a vanity project for Silicon Valley millionaires with an extended life wish. But I do want to point out that it isn't just our DNA that we share in so many ways. It's also the DNA data itself that is being shared unexpectedly—between a range of personally interrelated companies. I am tempted to think of them as 'geneo-platforms' or even 'geno-platforms': digital DNA platforms that are themselves linked genealogically.

It is not therefore without untold levels of irony that platforms devoted to the procurement of vast amounts of DNA data participate in a geneo-financial network of digital infrastructure that is fundamentally contributing to the very problem it seeks to solve—human longevity. This is the key point I feel that Mél you've been making in your extended research on DNA infrastructure and its environmental impact.

MH: In the talk I gave at the University of Alberta on the idea of 'Sustainable DNA',[9] I was making a link between Big Tech's investments in genomics and how that gave rise to both the idea and material support of using synthetic DNA to store media. I've since visited the lab at the University of Washington where the first fully automated synthetic DNA data storage machine[10] was invented, funded (mainly, I think) by Microsoft. The idea is that synthetic DNA—which is essentially four chemicals—is a denser and less energy-intensive medium for data storage. And in my talk, I was demonstrating that the mechanics came easily enough, but the legacy of genomics is also imbricated in the logics of these technologies... scientism, religion, settler-colonial science, eugenics etc. We need to talk about these things in order to talk about sustainability when it pertains to DNA data storage, too. And, like you

9 Mél Hogan, 'Genomic media/sustainable DNA', paper delivered at the 'University of Alberta: Sustainability Lectures' (University of Alberta, September 13, 2019).

10 Jennifer Langston, 'With a "hello," Microsoft and UW demonstrate first fully automated DNA data storage', *Microsoft* (March 21, 2019), https://news.microsoft.com/innovation-stories/hello-data-dna-storage/.

say (along with Kim TallBear and Jess Kolopenuk among others), in terms of relations; to other species, to land, to planet, to universe.

The recent turn to the misguided belief that DNA data storage is a 'solution' sees this 'solution' as curtailing the environmental impacts of current storage modalities, such as wasteful products and processes, and demands on rare earth minerals, water and electricity. Considering that the millions of data centres around the world currently account for 2% to 8% of global energy use to manage the 2.5+ quintillion bytes of data created each day, genomics data (i.e., collecting genomes of humans, plants, animals and viruses, etc.) actually intensifies environmental problems in terms of generating huge amounts of data that then needs to be processed and stored... and, in the context of global warming (and now, the pandemic!), this data requires vast infrastructural transformations. When I last visited a data centre in Stockholm, the CEO of Bahnhof told us—as he was showing off the highly energy-efficient server room—that: 'a few Google searches use the same amount of energy as boiling an egg'. I use the image of an egg often in my talks so that it sticks with the audience, but I also make the point that personal or individual consumption isn't the crux of the problem, generally, when it comes to environmental questions.

DV: I love this idea of boiling eggs as a measure of digital infrastructure efficiency. As a metaphor it is a kind of genius, eggs being a DNA repository or storage facility. And of course, we already talk about 'easter eggs' and 'server farms' in the vocabulary of computing. But what if Google searches really were eggs? Maybe then we would be more inclined to ask if they're the product of caged or free-range data farming? We might at different times prefer our results scrambled rather than carefully presented sunny-side up? And maybe when the results rise quickly and threaten to collapse with unfulfilled expectation then we would recognise them as unstable 'souffle searches' rather than the 'hard boiled' option we are told we must swallow?

MH: Metaphors do function to reveal meanings by association but, as we know from the idea of 'cloud computing'—metaphors can also obscure and misrepresent. Sometimes, in fact, this is the objective.

DV: Yes. When you spoke at the University of Alberta, I had the image of a self-entwined helix running through my head the entire time,

especially in terms of the way you interleaved both the style and the substance of your commentary on data centres and DNA (specifically the entanglement between DNA and digital code).

Metaphor itself is a kind of connective tissue, bringing into frame things that seem at one level to be dissimilar but that once compared bear on each other in expressive ways. Derrida says something along the lines that metaphor is never innocent,[11] suggesting that it limits meaning because it reiterates a binary or at best a fixed relation like the triples of a graph: subject, object, predicate.

I guess, for me, if we rethink relationality to be a capacity rather than the description of a connection then we might arrive at a different way of thinking about metaphor, too. How could the process of metaphoric connection support complex, overlapping, co-constituting, non-binary understandings of infrastructure? So, sure, clouds give rise to the idea that computing infrastructure is somehow 'natural' and out of the reach of ordinary human capability; that computing infrastructure is just a way of recuperating floods of data (in the form of vapour). Clouds are an obvious continuation of the diluvian descriptions of data inundation. And the term swiftly sidesteps the terrible way in which data centres, with their profligate use of water resources, mock these metaphors.

But clouds are also unstable and dynamic processes of conversion. They accumulate only to burst, they constantly threaten their own dissipation. They are neither 'infra' (existing below) nor 'structure' in any meaningful sense. Instead they conjure a collapse of infrastructure and perhaps therefore metaphor itself. So, the poverty of cloud imagery as an analogue for computing infrastructure isn't the real problem; the real problem is the fragility of infrastructure (and therefore also metaphor and perhaps representation itself). We might take this opportunity to think about how both metaphor and infrastructure can propose an inclusion that isn't necessarily coercive.

MH: Genomics research has embedded within it a computational rationale that is constitutive of thinking of DNA as *code*, and as *coded*. Genome scientists worldwide estimate acquiring, storing, distributing and analyzing approximately 2 billion human genomes, mapped

11 Jacques Derrida, *Writing and Difference* (Chicago: The University of Chicago Press, 1980).

globally by 2025, amounting to 40 exabytes of data. With genomics—as with many big data projects—the machine is essentially fed the largest amount of data to generate patterns from which findings are then made using artificial intelligence and other algorithms. But the key (unanswered) question is what constitutes 'genomics' exactly? Nobody I've asked seems to fully know because it's an ever-evolving answer. There have, however, been many scholars working to dismantle the conceptual, cultural and material centrality of the gene by addressing in some capacity the role of code and technologies for rendering visual and mappable genetic information.

In brief, here are some important takeaways by the key thinkers:

Lily E. Kay writes: 'The products of science and technology are sociotechnical; they work because they are embedded not only in material practices but also in cultural practices that stabilize and naturalize the technologies for producing knowledge and power. In the case of the genetic code, it is biopower'.[12]

Evelyn Fox Keller explains that in the early stages of the Human Genome Project there was a 'precocious simplicity' to the new wave of molecular genetics that explained what genes 'do' as encoding enzymes. Defects in genes mean defects in the enzymes which correlate to trait abnormalities. This was the simple formula of genetics that inspired the quest to linearly sequence DNA as code. As she explains: 'The answer was stunning in its simplicity; also, it had the elegance of a mathematical equation'.[13] DNA makes RNA and RNA makes proteins and proteins make humans. Keller further argues that this formulation of DNA, as code, pushed scientists to read gene function by way of their structure. She writes: 'It established DNA as the molecule that not only holds the secrets of life but also executes its cryptic instructions—it was, in short, the Master Molecule'.[14] But she casts doubt on the given agency of genes, or the idea that all genes work the same way, and invites us to consider other agents that call genes into action. Rather than act, genes are activated. While some genes encode RNA to proteins, as our simplified idea of genetics imagines, some genes play other roles—as regulators,

12 Lily E. Kay, *The Molecular Vision of Life: Caltech, the Rockefeller Foundation, and the Rise of the New Biology* (Oxford: Oxford University Press, 1999), p. 19.

13 Evelyn Fox Keller, *The Century of the Gene* (Cambridge,: Harvard University Press, 2002), p. 54.

14 Ibid.

promotors, terminators, leaders, activators. Keller asks, 'what then should we count as the beginning and end of a gene?'[15]

Kaushik Sunder Rajan explains that the first phase of genomics was very much about 'the generation of databases'.[16] These databases are the output of DNA (genetic) mapping and/or (genomic) sequencing. Science, he explains, functions within 'its own authority by virtue of its ability to generate scientific "fact"'.[17]

Jenny Reardon echoes this statement twelve years later, writing that human genomics companies still face the problem of how 'to create valuable knowledge from genomic data' in the first instance.[18] Genomics do not contain inherent value, value is created from genomics.

As *Alondra Nelson* writes: 'the special status afforded to DNA as the final arbiter of truth of identity is vividly apparent in the language we use to describe it [...] the language of DNA pervades our cultural imaginations''. She writes that 'hyperbolic phrases such as "code of codes," "the holy grail," "the blueprint," the human "instruction book," and "the secret of life" suggest a core assumption about the received omnipotence of genetics'.[19]

Ashley Dawson applies this insight over DNA as a code and suggests that, 'over the second half of the twentieth century, communication was transformed cybernetically into information, and information was subsequently reduced electronically to digital bytes. In tandem with this process, biological life was parsed as a molecular code in the form of DNA's strings of four basic nucleotides: cytosine (C), guanine (G), adenine (A), and thymine (T)'.[20] Similarly to Sunder Rajan (and others), Dawson makes the case that biology (or, bios) can be circulated 'as information, as commodity, and as material artifact'.[21]

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15 Ibid., p. 59.

16 Kaushik Sunder Rajan, *Biocapital: The Constitution of Postgenomic Life* (Durham: Duke University Press, 2006), p. 28.

17 Ibid., p. 19.

18 Jenny Reardon, *The Postgenomic Condition: Ethics, Justice, and Knowledge after the Genome* (Chicago: University of Chicago Press, 2017), p. 123.

19 Alondra Nelson, *The Social Life of DNA: Race, Reparations, and Reconciliation After the Genome* (Boston: Beacon Press, 2016), p. 4.

20 Dawson, Ashley, 'Biocapitalism and culture', paper delivered at 'Spring 2015 Colloquium Series' (UC Davis, March 4, 2015), http://environmentsandsocieties.ucdavis.edu/files/2015/02/Dawson_Biocapitalism-Culture.pdf, p. 6.

21 Ibid.

Catherine Bliss also identifies that the core problem of sociogenomics has to do with our central beliefs about what constitutes 'humanness'—and issues a warning: 'DNA, with its portrayal of the truth of human beings, wins the day. So essentialism can thrive and amplify even as arguments are assailed against it'.[22]

Jessica Kolopenuk,[23] and *Reardon and TallBear*,[24] have put into question the ways in which DNA molecules have been harvested by the settler scientific community as almost always separate from the body. This disconnect has meant a lack of attention paid to issues that pertain to ownership in an embodied sense.

There are others, of course... but together these give us a pretty substantial and ongoing critique of the gene in terms of its perceived and propagated unassailability by the genomics industrial complex!

DV: The trick here is not to let the powerful if elusive conceptualisation of DNA pass without also understanding the impact it has had, not just on the definition of contemporary science, but also on the allocation of research infrastructure. The wholesale optimism generated by just the idea of DNA resulted in significant (financial and political) investment. And yet, so far the outcomes have not lived up to the hype associated with the launch of the Human Genome Project of 1990–2003, for instance.

I think there is an ethical question here around scientific accountability. And one that has really haunted science from the outset. At what cost? Do the means (intellectual efficiency and/or reproducibility, for example) justify the ends? And where human life is now concerned—the endings? Aspirations for efficiency (Occam's Razor as one example) and scientific reproducibility (validation as an agreement of results) drive the shape of digital research infrastructure around the world, although they are a highly linear and specific mode for measuring the extent of knowledge. I believe we need to be asking, how has an institutional disposition devoted to scientific accountability,

22 Catherine Bliss, *Social by Nature: The Promise and Peril of Sociogenomics* (Stanford: Stanford University Press, 2018), p. 113.

23 Jessica Kolopenuk, 'Miskâsowin: Indigenous science, technology, and society', *Genealogy*, 4.1 (2020), https://doi.org/10.3390/genealogy4010021.

24 Jenny Reardon and Kim TallBear, '"Your DNA is our history": Genomics, anthropology, and the construction of whiteness as property', *Current Anthropology*, 53.5 (2012), S233–S245, https://doi.org/10.1086/662629.

understood through acts of 'reproducibility', actually compromised a broader need for social 'reproduction' or sustainability?

MH: Because of this ongoing belief that more data means more knowledge, we are willing to invest in, build, program and maintain at all costs the machines that will, one day, reveal to us great truths…

I think that genomics thrives in this liminal space… a kind of relentless and just around the corner revelation is promised to us. 'We've invested so much, we can't stop now…'

In the meantime, genomic data is mined for all sorts of capitalist ventures, which may be an always temporary ideal state for the industry. It can live off the promise for a few more decades. What is happening in the meantime is that a new logic of code is becoming culturally entrenched. We need code because we imagine it to be the simplest trace of humanity we can leave behind, as our legacy, at the end of the world, because it is the simplest formulation—the most basic unit—of how we now understand ourselves scientifically.

DV: Yes! And here is where it gets super interesting. The very code that we are willing ourselves to believe is the most essential definition of our 'selves', the very code we are squandering untold natural resources to try and understand at great risk to the survivability of the planet—is also being proposed as the best media to 'archive' human accomplishment. We are running out of storage and we are running out of a viable world. Rather than attempt to address these twin problems by adopting more sustainable practices in relation to data production and storage, science just turns to new storage options like synthetic DNA.

Possibly the most hubristic example of this is the ARCH (pronounced Ark—get it?) project—a sort of a high school time capsule writ quite a bit larger. In 2019, the ARCH Mission's Lunar Library crashed onto the surface of the moon. Inside it were tens of millions of pages of documents as well as cells from twenty-five humans and other organisms and seemingly without irony, it included an open letter from the Mayor of Austin extolling the virtues of queso and urging any and all aliens to stop by and try. In a country that proposes to build walls to keep humans at bay, an open invitation to aliens. To eat queso. I can't even begin to express how many levels of misguided and wrong this initiative is. Starting with the extraordinary vanity that assumes this

highly selective but apparently globally representative archive will be in any way comprehensible to future humans—let alone cheese-eating aliens.

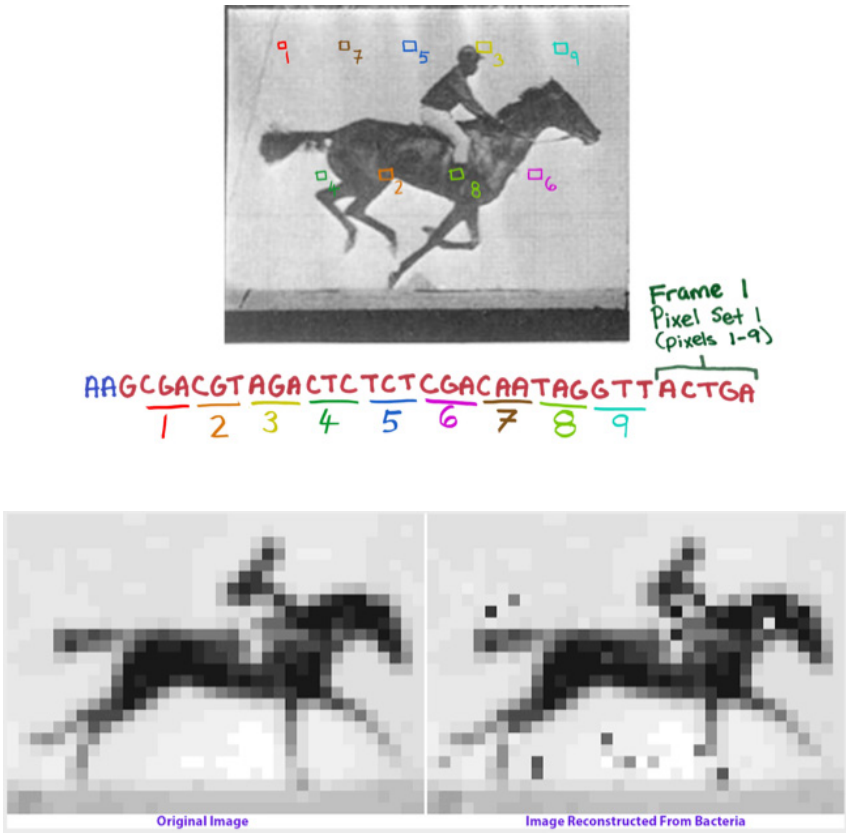
Riding on the exhaust fumes of initiatives like this are startups such as LifeShip, which offers to send personal genetic code embedded in a polymer described as 'synthetic amber', to the moon. The ill-fated Lunar Library was encoded on twenty-five nickel discs but the ARCH Mission has plans to use archives stored in DNA itself on future missions. I like to say it's putting the thumb back into the thumb drive. Actually, the thumb reference might also explain why early experiments in this particular tech focussed on encoding *The Hitchhiker's Guide to the Galaxy* into DNA sequences.

Recently a huge buzz erupted around a team at Harvard that used CRISPR gene-editing technology to store a 'movie' in the form of bacterial DNA. They started with the image of a splayed hand, inspired by parietal art. Always the nod to foundation myths and preservable practices ('synthetic amber' and cave paintings). But the 'movie', even as a more contemporary reference point, is also more complicated than it might first seem, and as it turns out, also bears a type of originary thinking.

The scientists chose to use five frames from what they claim is an 1870s movie of a racehorse, broken down into pixels which were then encoded using DNA (Figures 3 and 4). Their point was not to actually store videos in bacteria but to 'turn cells into historians'. According to one of the researchers: 'We envision a biological memory system that's much smaller and more versatile than today's technologies, which will track many events non-intrusively over time'.[25] So the important thing about the experiment was the ability to sequence bacterial DNA in order to reconstruct the pattern of frames that represent change through time.

As a tricked-up film historian, a large part of me applauds the idea that attention to temporality and change (in any media, including DNA) is a useful thing. Of course, the scientists are not really turning cells into historians. It's more along the lines of creating a new DNA level recording device that will provide retrievable information about the

25 'Scientists replay movie encoded in DNA: "Molecular Recorder" would reveal secrets of brain development' (n.a.), *National Institutes of Health* (July 12, 2017), https://www.nih.gov/news-events/news-releases/scientists-replay-movie-encoded-dna.



Figs 3 and 4 Image Credit: Wyss Institute at Harvard University. Image by Seth Shipman (June 2020).

progression of cellular processes. This makes the other part of my film historian self want to address the critical lack of history in this account of video encoding. And another part of me wants to talk about the operating definition of archiving that all these initiatives seem to rest on.

For the scientists, the images are now a 'movie' (I'm not going to get into the technicalities of why a GIF isn't really a movie), therefore they must have always been a movie. If there is a known problem in film archiving, it is not the fragility of the media that films are recorded on—it is the obsolescence of the technological infrastructure. Whenever formats are upgraded, massive migrations need to occur and swathes of dispensable content falls by the wayside.

Film and video archiving is a dynamic, constant process of evaluation, migration and management. None of this is more evident than in the case of British photographer Eadweard Muybridge, the ethically suspect artist who created the horse images used by the Harvard scientists in this exercise (Figure 5). This 'movie' was actually a selection of highly curated still images of a galloping horse named Annie G. and published in Muybridge's *Human and Animal Locomotion*.[26] It is no surprise to learn that late in his career, Muybridge sought to have himself removed from document archives in order to advance the idea that he was the progenitor of the motion picture industry (a claim which is the basis for many debates in the field of film history).[27] But Muybridge's motivating interest was in dissecting and deciphering movement, not synthesizing it.

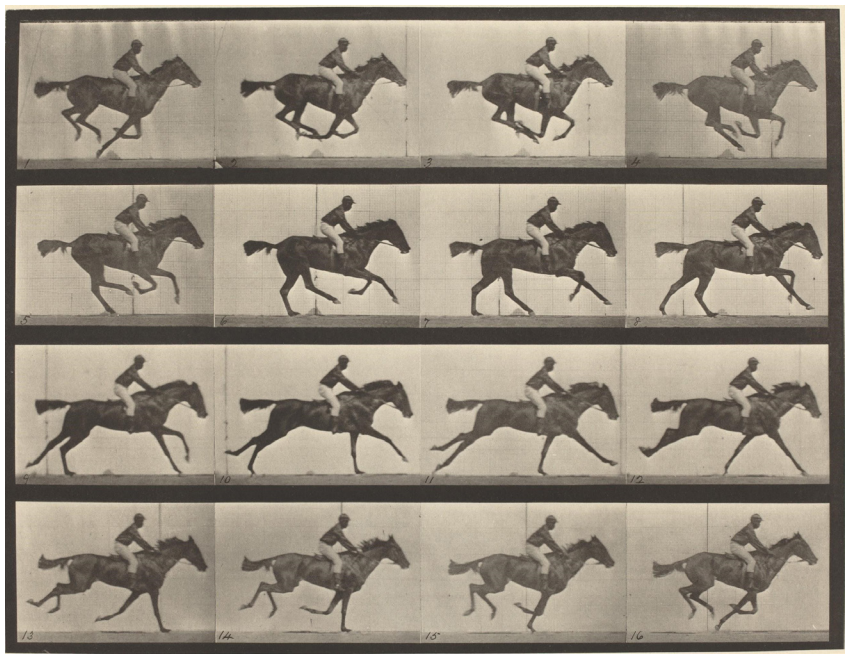


Fig. 5 Eadweard Muybridge, *Animal Locomotion, Plate 626* (Washington, D.C., National Gallery of Art, 1887).

26 Eadweard Muybridge, *Muybridge's Complete Human and Animal Locomotion* [1887] (New York: Dover Publications, 1979).

27 Marta Braun, 'Muybridge's scientific fictions', *Studies in Visual Communication*, 10.3 (1984), 2–22 and Marta Braun, 'Muybridge's Animal Locomotion', *History of Photography*, 24.1 (2000), 52–54, https://doi.org/10.1080/03087298.2000.10443363.

Here then, we have cinema infrastructure itself as obsolescent. For the Harvard scientists, the idea that the infrastructure of moving images itself comes from contingent historical circumstances has been conveniently wiped from memory. This recovered video sequence serves as a metonym for the archive (as I understand it)—*the arbitrary extraction of entities or events from their context, which are teleologically manipulated into a singular progressive structured sequence that produces the illusion of forward momentum and therefore an expectation that there is something 'next'.*

Rather than take this as an opportunity to observe and work within a mangled global entanglement, DNA is used by these scientists as a field for mining or harvesting categories of time and space that optimistically promise human progression, technological posterity, generational sustainability and individual longevity. And yet as we keep saying, such claims rest on processes that are materially responsible for compromising these ambitions.

MH: What we know now and what is revealed to us from every project above as well is that genomics research relies on massive Internet infrastructures and computational power and is imbricated in the extractivist logics that allow and encourage their expansions. Our global communications infrastructure is built on social inequalities that allow for cheap labour, cheap nature, expensive products, proprietary software and hardware, and quick distribution and sales. It is a profit-driven system. Genomics is also powered by profit.

DV: And bad history.

MH: By way of a conclusion I also want to mention three, generative, non-industry examples for seeing this storage idea through by way of both scientific realism and speculative design: Karin Ljubic Fister's 2016 scientific experiments encoding data (like music) into plants;[28] *Grow Your Own Cloud* (2018) by Monika Seyfried and Cyrus Clarke (https://growyourown.cloud/); and *Data Garden* by Kyriaki Goni (https://www.onassis.org/whats-on/data-garden).

When asked by the *New Scientist* (2016) why the DNA of plants were an opportune storage technology, Fister responded:

28 Geoff Manaugh, 'Landscapes of data infection', *BLDGBLOG* (February 8, 2016), http://www.bldgblog.com/2016/02/landscapes-of-data-infection/.

> I was annoyed about the amount of disc space on my computer. I started wondering, what if I could store data in DNA? It's such an immense reservoir of potential storage—1 gram of it could store over 450 x 10^{18} bytes. All of the archives in the world could be stored in one box of seeds.[29]

Similarly, the justification for *Grow Your Own Cloud* was to explore the 'the link between two key topics of our time; data and anthropogenic climate change'.[30] The idea of storing 'memories' in house plants, and of having a community flower shop be the custodian of preservation (as opposed to an inaccessible data centre) meant a new strategy and an enhancement of consciousness of the current systems that do this. Goni's *Data Garden* works from this idea and asks us to think of 'the future of connectivity beyond surveillance, minimizing the consequences of technological infrastructures on the natural environment'.[31] So it seems like artists are at the forefront of exploring not only the environmental impact of DNA's technological infrastructures but also the poetics within the political questions embedded in storage, memory, access and preservation.

DV: I really love that these artistic explorations are also poetic in the sense of 'poetic justice'—in which the answer to an environmental problem (the negative effect of DNA data storage for global sustainability) is in fact, the natural environment itself (the DNA of plants and seeds). And once again you've sown that image of a self-enfolding helix in my mind!

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