Figure 1. Pam McKinlay and Jesse-James Pickery, *He puira hirahira (A Special Chromosome)*, 2017, muehlenbeckia, muka, three gauges of monofilament, plaster mask.

PAM MCKINLAY AND JESSE-JAMES PICKERY
WITH JULIA HORSFIELD

# The GENE-ration Game

Figure 2. "DNA" From: Francis Crick Papers, Wellcome Library. [2]

Since 1869 when Johann Frierich Miescher first discovered nucleic acid (which he called "nuclein") the study of genetics, and more recently, genomics, has been at the forefront of medical research. We got our first glimpse into what the structure of DNA might look like in the silhouettes of X-ray crystallography by Rosalind Franklin and others in the Wilkins lab and the pencil sketch of the double helix by Francis Crick of 1953. But what was the chemical code, as Schrödinger called it, and how was it sequenced? This was the question posed to the Human Genome Project (HGP), "completed" in 2000, when researchers announced they had successfully "decoded" the human genome, at the time described as "a race to the start".[1]

## HE TAONGA IRANGA TUKU IHO - A RICH GENETIC HERITAGE

In one of the great science classics of the twentieth century, *What is Life?* (1943), Erwin Schrödinger envisioned a "chromosome fiber" embedded with a secret complex chemical code, "the entire pattern of the individual's future development and of its functioning in the mature state" that stored our hereditary potential, nga taonga tuku iho.

DNA is a programmed series of chemicals, with the capacity to self-replicate. All cells of an organism contain the same genetic material, the regulation of which catalyzes the development of an individual from a single cell, through its embryonic journey onwards to adulthood whereby it can then collapse itself from a multicellular organism into a single cell once more at the moment of sexual reproduction.[3] This cycle carries a species through time.

> Every complete set of chromosomes contains the full code ... The chromosome structures are at the same time instrumental in bringing about the development they foreshadow. They are law-code and executive power —or, to use another simile, they are architect's plan and builder's craft —in one.[4]
>
> Schrödinger

## PAINT BY NUMBERS – DNA: THE BIG PICTURE

Molecular biologists unravel chromosome structure to identify and record the location of genes within the nuclear landscape. By mapping the distances between genes on a chromosome, the role of non-protein coding genes (such as enhancers and regulators) on gene expression also becomes clearer.[5] These relationships, explored in cohesin research, map where proximities of sequences in TAD diagrams and "heat maps" are found.[6]

These interactions can also be explored in other cluster diagrams. Software used in sequence and genomic analysis, such as CIRCOS, map cluster contact points to determine the key regulating elements. These look like stylized spider webs inside a tube.[7] Two-dimensional diagrams can be derived from these, and from the two-dimensional can be further extrapolated three-dimensional visualizations of the structure of the compacted chromosome.

The iconic image of DNA as a rigid twisted ladder is reimagined as one of dynamic looping strands in supercoiled form.[8] How to pack almost 2 meters of this stuff into each and every cell nucleus is the incomprehensible "DNA packaging problem" — there are up to 50 trillion cells in a body, each with 1.8 m of DNA in each cell. [9] The length is coiled by wrapping around proteins called histones which act like molecular spools.[10] The histone "spools" solve the packaging problem, but present a new problem – one of accessibility. [11] If the functional units of DNA (genes) are coiled tightly, then they can't be read.[12] Enzyme "switches" in the genes turn the spooling "on" and "off", thereby "relaxing" the DNA to make certain sections accessible, while other sections remain coiled and hidden.

## HOMAGE TO WATSON AND CRICK[14]

Siddhartha Mukherjee, in *The Gene (2017)*, writes that the three most profound ideas which "ricocheted throughout the twentieth century were the atom, the byte and the gene" — the atom, as the smallest particle or basic unit of matter, the byte as the smallest unit of digitized information and the gene — the "bit" of heredity or biological information.[15]

The vast amount of data we have gathered has been sourced from our own genetic material. However, we are limited by our methods of inquiry; the parameters established by molecular biology necessitate fragmentation of the chromosome — so we can process and make intelligible the gross quanta inherent to the DNA. The very way we observe DNA requires that we kill the cell. If we can gather this much information from a corpse, imagine what we can gather from a living, unperturbed observation.

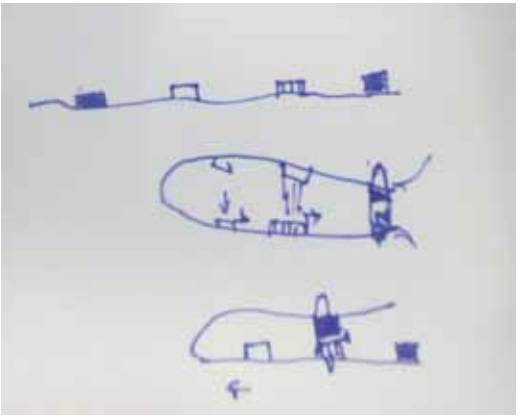

Figure 3. Drawing from sketchbook during conversation with Julia Horsfield. In the diagram, the sequence of square 'genes' represented is, from left: "off", enhancer or "on switch", "off."The two "off's" should be held at the juncture of the loop by the cohesin so that the on and enhancer can talk to each other. If the offs are misaligned within the loop, then the gene and the enhancer can't talk to each other. It is thought that cohesin is a complex that controls the stability of the loop – by maintaining the correct length of the loop and therefore access to the "on" and "off" genes, thereby having a significant effect on gene expression. [13]

> We feel clearly that we are only now beginning to acquire reliable material for welding together the sum total of all that is known into a whole; but, on the other hand, it has become next to impossible for a single mind fully to command more than a small specialized portion of it.
>
> Schrödinger

We have learned most recently from the HGP that most of the genome does not "code" (only about 2% does). Most is dedicated to the proteinaceous architecture and the regulators that determine the position of the active genes. The dynamic structure is constantly folding and moving in a complex of cellular choreography, where timing in space is everything within the cell cytoskeleton.[16]

> It is these chromosomes, or probably only an axial skeleton fibre of what we actually see under the microscope as the chromosome. [17]
>
> Schrödinger

> The cytoskeleton ... structures give the cell its shape and help organize the cell's parts. In addition, they provide a basis for movement and cell division. [18]

At the nano-level, quantitative image analysis uses CYTOSIM, a computer simulation to study cellular architecture from a *mechanistic* perspective.[19] "Bio-mechanical or bioinformation transfer is thought to be facilitated by the self-organising structures which form a unique cellular geometry of microtubules within the cell and associated proteins."[20] These cells contain a specific distribution of filaments that enable them to change their shape, to move and to divide. Microtubule patterns of geometry can be observed using enhanced dark-field light microscopy in conjunction with hyperspectral imaging to observe nanomaterials such as kinesin in cells.[21] These filaments and the associated proteins form the *cytoskeleton*, and are to the cell what bones and muscles are to the body.[22]

> Cellular structures are established and maintained through a dynamic interplay between assembly and regulatory processes. Self-organization of molecular components provides a variety of possible spatial structures: the regulatory machinery chooses the most appropriate to express a given cellular function.[23]

A static image exploring the story of the 3-D structure was created in the second of the art works made in response to discussions with Julia Horsfield.

> Contrary to what I had believed, the process of experimental science does not consist in explaining the unknown by the known, as in certain mathematical proofs. It aims, on the contrary, to give an account of what is observed by the properties of what is imagined.
>
> François Jacob, *The Statue Within*[24]

We imagined an unfolding chromosome, the unravelling of DNA, bound into a rigid shape, at the moment of stasis — some sections closed in the twist of the double helix and sections with free-roaming loops being thrown out in space and time during transcription.[25] Our chromosome would in the wild be one of many restless strands, layered with the marks of the past, which had crossed

Figure 4. Pam McKinlay and Jesse-James Pickery, *He puira hirahira (A Special Chromosome).*

thousands of years, carrying the code from the ancestors we can name and beyond to the very beginning of before-time, the void, Te Ao-marama, Te Po, Te Kore. He pūmanawa o nga ira tangata, people live and die but their gifts transcend time.

Scientists regularly use computer modelling to create visualisations of the shape and structure of the packaged DNA molecule. These can be animated as revolving GIFs — for example, the wikipedia revolving GIF of human telomeric G-quadruplex[26]. Our puira hirahira was a "static image", made as a physical model and then filmed to simulate a computer-generated GIF as a kind of narrative space device. Since the time of the Renaissance, narrative space in art has provided a platform for continuous narrative in which several events can be shown in a single setting. However, the story need not be a story in the traditional sense, nor a linear narrative — a narrative space may be a space which is used to convey or explore different themes and meanings, such as a time-scape in a three-dimensional landscape. If, as Kant says, time and space are two of the fundamental categories that structure human experience, then narrative is how we communicate the story or sense of that experience. It is a way of organising our experiences and making meaning. Is there actually such a thing as a non-narrative space?[27] The static image encapsulated a combination of phases in the chromatin story — from the microscopic to the sub-atomic view of the cellular stage; cohesin bindings; interstices and flashing between them — the fleeting web of cellular communication, the transfer of energy at the speed of light and at the centre an enigmatic signal processor — pungao o te ira.

Figure 5. (detail).

Figure 6. (detail).

Figure 7. Shadow drawn on wall, cast by the 3-D object /chromosome.

Figure 8. Pam McKinlay and Jesse-James Pickery, *He puira hirahira (A Special Chromosome)*, 2017, muehlenbeckia, muka, three gauges of monofilament, plaster mask.

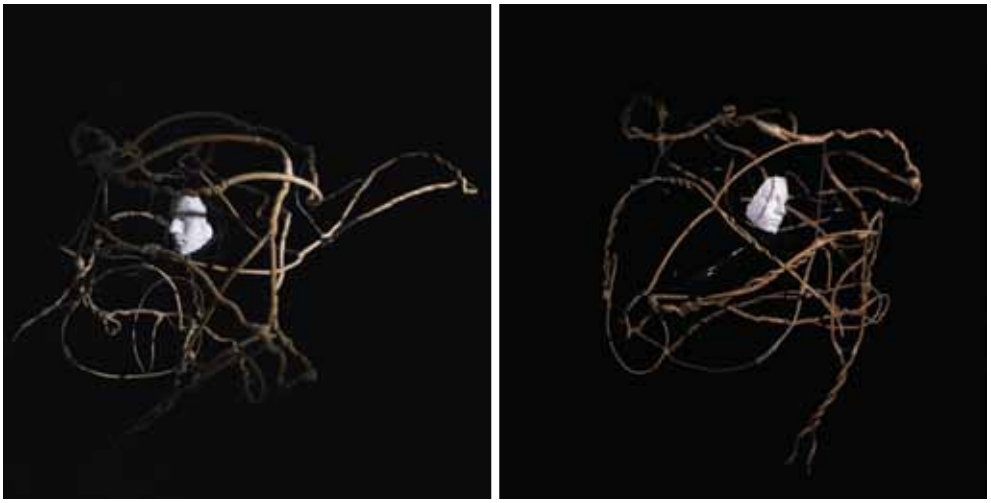

Figure 9 and 10. Pam McKinlay and Jesse-James Pickery, *He puira hirahira (A Special Chromosome)*, 2017, muehlenbeckia, muka, three gauges of monofilament, plaster mask.

Figure 11. (detail).

Muehlenbeckia provided the scaffolding which enabled use of the inherent twisting nature of the vine/wood. This was exaggerated with extra shaping using an improvised steam box and editing, splicing and binding to create the final form of the armature. Bindings with muka were structural and also represented the junctures of loop enclosure (cohesin) in the chromosome. When front-lit, the sculpture cast a strong shadow of curving lines, suggestive of the two-dimensional models created by researchers to explain (draw) the structure of the folding within a chromosome.

Fine monofilament was used to create the web along which a network of information can be seen as flitting light; this was an artistic response to the microtubules constantly in communication with seemingly disparate locales throughout the chromosome on which they are located and a nod to Planck (see below). The mask at the centre — a mould of one of the artist's faces, — conjured the idea of a kind of signal processor. The sculpture was exhibited so the interior of the mould was shown facing the exhibition space to make use of the *trompe-l'œil* effect of the negative (mould) appearing positive.[28] What is in front, what is the right side, what is outside, what is the inside? What is on our inside? What does our DNA mould make us to be? He taonga iranga tuku iho — a rich genetic heritage.

## THE WEB IS NOT THE NET / PUNGAO O TE IRA – THE ENERGY OF THE GENES

> In the light of present knowledge, the mechanism of heredity is closely related to, nay, founded on, the very basis of quantum theory. (16) ... A body on the large scale changes its energy continuously ... a small system can by its very nature possess only certain discrete amounts of energy, called its peculiar energy levels. The transition from one state to another is a rather mysterious event, which is usually called a quantum Jump. (17) ... If the molecule is an extended structure, you may conceive these vibrations as high-frequency sound waves, crossing the molecule without doing it any harm (18) ...[29]
>
> Schrödinger

As living entities, we are complex biochemical reactors imbedded in the fields described by classical and quantum physics. In biophysics, the organizing principle for the "flow" of information that can regulate biological functions at cellular levels was once called a "biofield", but can perhaps be more usefully thought of as bio-information systems, interactions within which "can influence a variety of biological pathways, including biochemical, neurological and cellular processes related to electromagnetism." Correlated information transfer and perhaps other means for modulating activity across levels of biology occur in length-scales from macro to micro biology.[30] (These systems are so complex that they have been the driver of new areas of mathematics such as complexity mathematics).

During the project, we were asked why we had made the web of monofilament tracery. Pam replied "because the molecule demanded it". Of course, this was no answer at all and yet in hindsight it was perhaps the only answer if we are to believe that the very basis of the workings of DNA lies in quantum theory and that "Planck's attitude even vindicates priority for it."
Life is dependent on the maintenance of order. How is this possible in the warm, messy cellular environment? And in the case of DNA, how is such order maintained without loss of information? Schrödinger suggests that order in the cell is maintained by creating disorder around it – "drinking orderliness" from the surrounding environment.

> Order, Disorder and Entropy — organization is maintained by extracting 'order' from the cell environment. (26) An organism's astonishing gift of concentrating a 'stream of order' on itself and thus escaping the decay into atomic chaos — of 'drinking orderliness' from a suitable environment -seems to be connected with the presence of the 'aperiodic solids', the chromosome molecules, (27) the 'new' principle, the order-from-order principle, to which we have pointed with great solemnity as being the real clue to the understanding of life, is not at all new to physics. Planck's attitude even vindicates priority for it. (29)[31]
>
> Schrödinger

Researchers constantly review their understanding of the content of our DNA; we have sequenced the genome and are aware of the information contained in our cells, and we understand some of its function or purpose in the complexities of the continuing folding and unfolding of the DNA story. The ultimate challenge is to find a way to observe how this information exists in 'the wild', i.e. in its natural environment. DNA is not a linear construction held in stasis, outside of time – it is a dynamic and fluid entity with the capacity to generate any and all parts of our material body, whenever needed. DNA can be likened to a seed, in the sense of a fractal representation of the whole. The seed carries the potential of a tree in collapsed space. The A,T,G and C's of the genetic code are to genetics as names are to whakapapa, each with their specific and unalterable locales, each in their order, each informing the other, all needed for eventuation of the whole we are presented with.

creatures we were once
creatures we will become again
names writ small
revealed in the Hilbert-like filing system
web interconnections in non-linear ways
sister chromatid – be my guide
shadows of ourselves thrown in relief upon the wall
start, stop, do/make something, stop
Copy.
Creation.

**Pam McKinlay** has a Dip HSc (clothing/design and textile science) and a BA in art history from the University of Otago. She works predominantly in textiles , photography and sculptural installation.

**Jesse-James Pickery** seeks resonance in sound, light and earth in a cross-disciplinary practice. He is in his final year of a BVA at Dunedin School of art, majoring in ceramics.

**Dr Julia Horsfield** is a developmental geneticist based in the Department of Pathology at the University of Otago. Julia leads a research group investigating the role of chromosome structure in animal development and cancer. Her specific research interest lies in cohesin proteins.

1. Stefan Klein, "Interview with Craig Venter," in *We Are All Stardust: Leading Scientists Talk About Their Work, Their Lives, and the Mysteries of Our Existence* (New York: The Experiment, 2015).
2. Francis Crick, "Francis Crick Papers," *Wellcome Library*, https://wellcomelibrary.org/item/b16136330#?c=0&m=0&s=0&cv=0&z=-1.1472%2C-0.0833%2C3.2944%2C1.6669.
3. Siddhartha Mukherjee, *The Gene: An Intimate History*, (New York: Simon and Schuster 2017), 185.
4. Erwin Schrödinger, *What Is Life? The Physical Aspect of the Living Cell*, (Cambridge: The University Press, 1944), 7. www.whatislife.ie/downloads/What-is-Life.pdf Based on lectures delivered under the auspices of the Dublin Institute for Advanced Studies at Trinity College, Dublin, in February 1943.
5. Stefanie Kaufmann et al, "Inter-Chromosomal Contact Networks Provide Insights into Mammalian Chromatin

Organization," *PLOS Journal* (2015), http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0126125 (accessed 29 July 2017).

6. Ibid. The frequency of interactions can be visualised in a "heat map", and reveal Topological Associated Domains (TADs), which are zones of high 3D connectivity. The frequency interactions are what we see in a "heat map."
7. Ibid. The recent advent of conformation capture techniques has provided unprecedented insights into the spatial organization of chromatin, allowing large-scale investigation of the complexity of inter-chromosomal segment and gene contacts. See also http://www.circos.ca/images/scientific_literature/ (accessed 29 July 2017).
8. Emily Singer, "How Strange Twists in DNA Orchestrate Life," *Quanta Magazine* (2016), https://www.quantamagazine.org/dna-supercoils-change-the-way-that-cells-work-20160105/ (accessed 29 July 2017).
9. Kim Nasmyth, "How is DNA Woven into Chromosomes?" *Israel Institute for Advanced Studies*, https://www.youtube.com/watch?v=uUv86Bu9cF8 (accessed 29 July 2017).
10. Histone + DNA = Chromatin.
11. Adrian Sanborna, et al, "Chromatin Extrusion Explains Key Features of Loop and Domain Formation in Wild-Type and Engineered Genomes," *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, http://www.pnas.org/content/112/47/E6456.figures-only. A Hilbert's curve is one model of DNA packaging. A fractal globule is the prevailing model of genetic geometry. A fractal globule is extraordinarily dense, but entirely unknotted. See also in Ivan Amato, "Genetic Geometry Takes Shape," *Quanta Magazine*, (2015): https://www.quantamagazine.org/genome-architecture-in-twists-of-dna-20150225/ (accessed 29 July 2017).
12. Courtney Griffins, "Epigenetics and the Influence of our Genes," *TEDxOU*, (2012), https://www.youtube.com/watch?v=JTBg6hqeuTg (accessed 29 July 2017).
13. Katherine Feeney et al, "Cohesin: A Regulator of Genome Integrity and Gene Expression," *Biochemical Journal Vol. 428 Iss. 2* (2010), 147-161 and Figure 5 http://www.biochemj.org/content/428/2/147 (accessed 29 July 2017).
14. Francis Crick and James Watson, "Crick and Watson's DNA Molecular Model, England, 1953," Model (1953), http://www.sciencemuseum.org.uk/hommedia.ashx?id=11475&size=Large (accessed 29 July 2017). The model was a physical model made from metal rods, and clamps and thin hexagonal metal plates on a series of vertical supporting tubes.
15. Mukherjee, 2017, 9.
16. Drew Berry, "Chromosome and Kinetochore," WEHI.tv (2013), https://www.wehi.edu.au/wehi-tv/chromosome-and-kinetochore (accessed 29 July 2017).
17. Schrödinger, 1944, 7.
18. Scitable "Microtubules and Filaments," *Nature*, https://www.nature.com/scitable/topicpage/microtubules-and-filaments-14052932 (accessed 29 July 2017).
19. "Cytosim," *Nédélec Laboratory EMBL, Cell Biology and Biophysics Unit* (2011 - 2017), http://www.cytosim.org/cytosim/index.html (accessed 29 July 2017). "Cytosim" is a simulation of the cytoskeleton under active development. "Cytosim" was designed to simulate large systems of fibers with associated proteins such as molecular motors.
20. Bert Nitzsche, et al, "Quantum-Dot-Assisted Characterization of Microtubule Rotations during Cargo Transport," *Nature Nanotechnology,* Vol. 3 (2008) 552 – 556, http://www.nature.com/nnano/journal/v3/n9/abs/nnano.2008.216.html (accessed 29 July 2017).
21. "Dark-Field Microscopy," *Wikipedia* (2017), https://en.wikipedia.org/wiki/Dark-field_microscopy (accessed 29 July 2017). and François Nédélec, "Self-Organization of Microtubules and Motors," *Cytosim,* http://www.cytosim.org/misc/princeton/index.html (accessed 29 July 2017).
22. François Nédélec, "Abstract," *Cytosim*, http://www.cytosim.org/publications/these/abstract.html (accessed 29 July 2017).
23. François Nédélec et al, "Self-Organization of Microtubules and Motors," *Nature* Vol. 389 (1997): 305-308 http://www.nature.com/nature/journal/v389/n6648/abs/389305a0.html (accessed 29 July 2017).
24. Kim Nasmyth, "How Does Cohesin Hold DNAs Together?" *Israel Institute for Advanced Studies* (2016), https://www.youtube.com/watch?v=uUv86Bu9cF8 (accessed 29 July 2017). Quote by François Jacob, winner of the 1965 Nobel Prize in medicine for his work on gene regulation.
25. Ibid.
26. Iridos, "Telomere Structure.gif," *Wikipedia* (2007), https://en.wikipedia.org/wiki/G-quadruplex#/media/File:Telomer-structure.gif (accessed 29 July 2017). The colour palette used also makes reference to dark field microscopy.
27. Pam McKinlay, "On Caustics: A Conversation," *Junctures: The Journal of Thematic Dialogue*, Vol. 15 – light (2015): 68. Narrative space is a broad term which is referred to in genres and settings as varied as art, novels and film (storytelling), theatre/drama and virtual reality (role-playing video games) and real-life environments (such as exhibitions and architecture).
28. *Trompe-l'œil* is an art technique that uses realistic imagery to create the optical illusion that the depicted objects exist in three dimensions.
29. Schrödinger, 1944, 16-18.
30. Menas Kafatos, et al, "Biofield Science: Current Physics Perspectives," *Global Advances in Health and Medicine* (2015): Suppl. 25–34 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4654779/ (accessed 29 July 2017).
31. Schrödinger, 1944, 26-29.