FINDINGS ON ELASTICITY

PARS FOUNDATION
LARS MÜLLER PUBLISHERS

[1]**elastic** *[ɪ'læstɪk]* *adj* **1)** buoyant, resilient **2)** capable of being easily stretched or expanded and resuming its former shape **3)** capable of ready change; flexible, adaptable — **~ity** *n*

[2]**elastic** *[ɪ'læstɪk]* *n* **1)** an elastic fabric usu made of yarns containing rubber **2)** easily stretched rubber, usu prepared in cords, strings, or bands

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FOREWORD

For this second volume in the Atlas of Creative Thinking, Pars invited creative thinkers from around the world to share with us their findings on elasticity. These, ranging from quirky, humorous and beautiful, to mind-bogglingly complex and disturbing, are what make this book. Why elasticity? Well, we're surrounded by elasticity, whether it's in the shape of our skin, the price elasticity on the Stock Exchange that plays havoc with our spending power, or a piano string that stays in tune for as long as its tension remains constant. It also never ceases to amaze me how resilient people can be in the face of adversity; somehow we manage to pick ourselves up by the hem of our lives and bounce right back.

What actually is elasticity and how does it relate to our everyday lives? Take something as ostensibly simple as the elastic band. It has length, width and thickness. They make perfect slings and keep post packages together. I remember as a nine-year old being sprinted after by a surprisingly athletic pensioner, round the flowerbeds poshing up the car park in front of the service flat where my grandmother lived. I had aimed my sling at his window that stood invitingly open on the second floor, and with some success. He had happened to be sitting on the edge of his bed tying his shoelaces when the clump of earth came whizzing past, cut a path across his bedroom, flew down the hall and finally gunged the door of the fridge in the kitchen. When the old man, choking in equal measures on physical exhaustion and outright indignation, eventually related this rather remarkable trajectory to my grandmother, my initial fear quickly swelled into Amazonian pride. I can't remember the punishment I received or the gist of the lecture (there will almost certainly have been one), but I can clearly recall inwardly rejoicing at how my skills with the elastic band, which had been wrapped around a package delivered with the morning post, had been more successful than I could have ever wished for. I learned early on in life that elasticity can boost one's self-esteem enormously.

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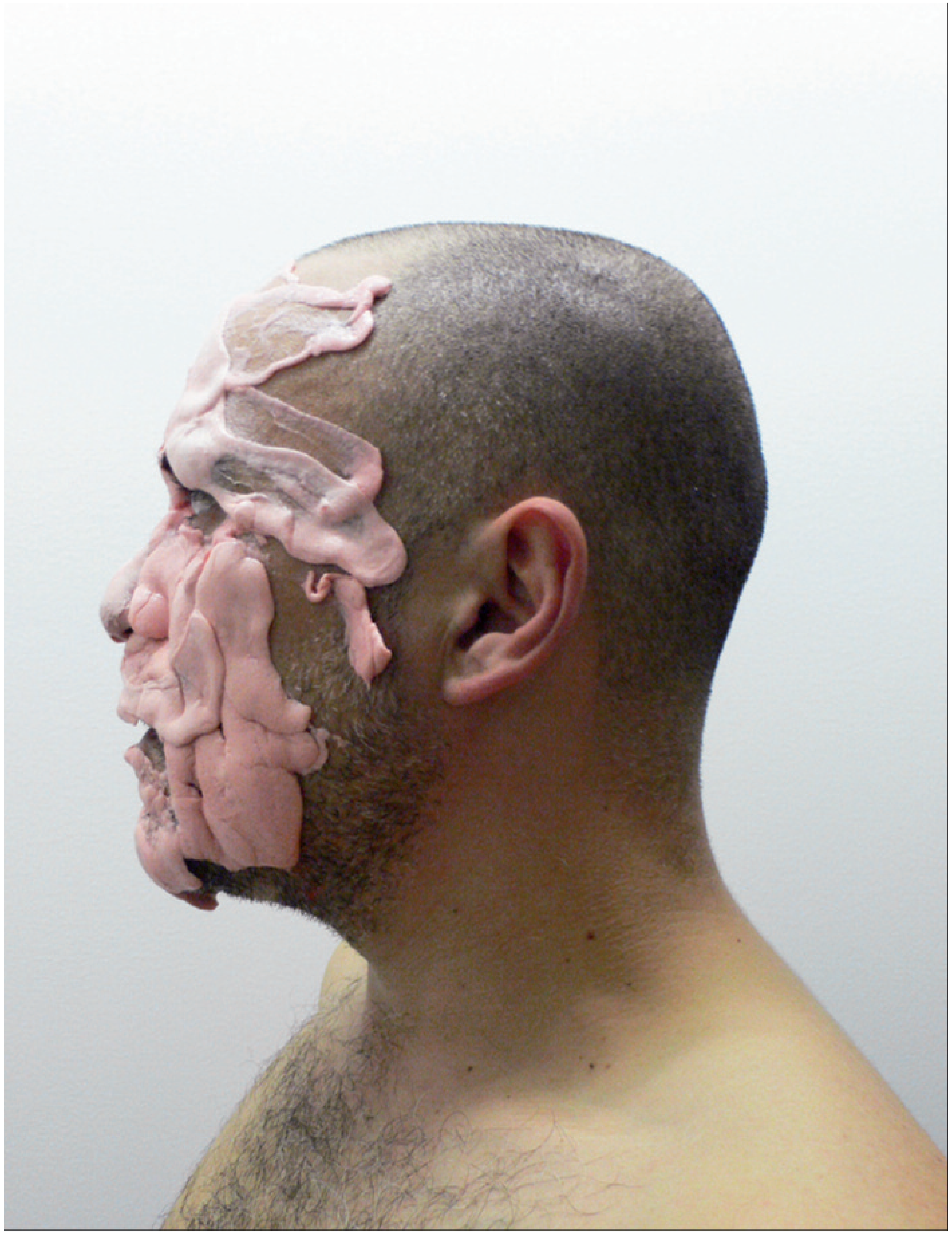


05

THE SEMI-LIVING

LIFE OF FRAGMENTS

How much can a body be fragmented before it is no longer a body? How much can life be stretched before it can no longer be called life? It is not death we are talking about here, but the semi-living. The artistic research project of the authors, The Tissue Culture and Art Project (TC&A), has been exploring and actualising these questions for more than a decade. We coined the term 'semi-living' to describe the type of in-between life forms that result from maintaining and growing parts of bodies in artificial conditions. By doing so, we try to engage with liminal life; with the notion that life can be stretched to places that greatly challenge our definitions and perceptions of what life is.[1] We explore ways in which the semi-living extend life to a point of no return. Although alive in some sense, and surely not dead yet, these entities are no longer part of the bodies and life that they once belonged to. Like slime mould, they might be able to reaggregate into a new kind of body or even migrate and rejoin some discrete bodies.

THE CELL AS THE BASIC LEVEL OF LIFE

Even though life seems to defy clear definition, an exercise in contemporary progressive reductionism will lead to the point at which death is no longer the outcome of expiry. This point, unsurprisingly, is most commonly referred to as the basic unit of life: the cell.

CELL THEORY

The idea of the cellular body dates back to Aristotle (340 BC) and Theophrastus (320 BC), who both described animals and plants as being made up of unified elements; blood and sap, flesh and fibre, nerves and veins, bone and wood. Later scientists such as Marcello Malpighi (1675) and Nehemiah Grew (1682) theorised that these elements are literally 'woven' into tissues of still finer elements.[2] In 1667, Robert Hooke, using one of the earliest microscopes, observed cell structures in a thin slice of cork. He coined the word 'cell' as the structure reminded him of a honeycomb. The second important development was the realisation that the cell, although part of a 'collective' body was in fact an autonomous agent, a 'little body' by itself. In making this claim, H G Wells and Julian Huxley argued that the term 'cell' was misleading, and they expressed their disapproval in their book, *The Science of Life: A Summary of Contemporary Knowledge about Life and its Possibilities* (1929):

> *Nothing could be farther from the reality. The proper word should be 'corpuscle' (little body) and not cell at all.*[3]
> *We may compare the body to a community, and the cells to individuals of which this vast organized population is composed… It is very important to realize that this is not a merely allegorical comparison. It is a statement of proven fact, for—we resort here to the stress of italics*—single cells can be isolated from the rest of the body, and kept alive.[4]

It was a botanist Matthias Schleiden (1838), and a zoologist, Theodor Schwann (1839), who were the first to formulate modern 'cell theory' as we now know it. Schwann wrote:

> *One can thus construct the following two hypotheses concerning the origin of organic phenomena such as growth: either this origin is a function of the organism as a whole—or growth does not take place by means of any force residing in the entire organism, but each elementary part possesses an individual force. We have seen that all organisms consist of essentially like parts, the cells; that these cells are formed and grow according to essentially the same laws; that these processes are thus everywhere the result of the same forces. If, therefore, we find that some of these elementary parts… are capable of being separated from the organism and of continuing to grow independently, we can conclude that each cell… would be capable of developing independently if only there be provided the external conditions under which it exists in the organism.*[5]

ONE AS MANY, MANY AS ONE

While almost all multi-cellular organisms tend not to separate into discrete independent parts and rejoin again, and as a rule no complex organism can, there are a few exceptions. Among the most noted creatures that can easily shift from the unicellular to the multicellular is the slime mould. This odd life form is classified as a kind of fungus, which at different stages of its life cycle resembles unicellular animals such as protozoa, or a multi-cellular structure. The individual cells seem to flow into a higher form of organisation depending on external conditions. The idea that the same thing can be one and many is what makes these creatures so fascinating. But as soon as animals become more complex and their parts more specialised, this feat can no longer continue. With complex animals the idea of many discrete entities becoming as one was delegated to the social realm.

Due to modern day science and technological mediation, complex organisms can separate into many, and reintegrate into some sort of unified being as long as this process takes place outside the organism and in an artificial support mechanism.

1 A term used by Susan M. Squier in her book *Liminal Lives: Imagining the Human at the Frontiers of Biomedicine*, Durham NC: Duke University Press, 2004.
2 Ibid
3 Wells, Huxley & Wells, *The Science of Life*, p.26.
4 Ibid. p.27.
5 Theodore Schwann (1839) cited in White, *Cultivation of Animal and Plant Cells*, pp.188–190.

CELLULAR SENESCENCE

Most cells extracted from complex organisms usually have a finite life span, also called cellular senescence or the Hayflick limit.[6] Cells seem to go through degradation at the tip of their chromosomes, in an area called telomeres. After around 50 cell divisions these cells can no longer divide. Another issue with cell extraction is that when many cell types reach their ultimate function they cannot divide or reproduce any more—they go through terminal differentiation. It is believed that both cellular senescence and terminal differentiation are major contributing factors to the ageing of complex organisms. Research is currently under way to reverse the effect of ageing on a cellular level.

Some cells such as cancer cells, however, are considered to be immortal, in that they can theoretically keep on dividing forever. This can only happen once they are removed from the host body into artificial life support, as cancerous cells can kill the body that supports them. Telomerase, an enzyme that regenerates other telomeres at the tip of the chromosomes, has been used to try and make normal cells immortal.

Primary cells, the cells that are taken directly from an organism and have a limited lifespan, are increasingly seen as having the potential of reintroduction into bodies for the purpose of healing the organs or the body. This is the premise of regenerative medicine. Transdifferentiation is a process of reprogramming specialized cells and directing them to go down an alternative differentiation pathway, making new cells and organs from adult cells taken from the patient's own body. In a sense, the fluidity of life as manifested in the slime mould, in which cells can disintegrate and reintegrate, is being revisited through the more recent 'technologisation' of complex bodies and their parts.

THE SEMI-LIVING ARE NOT NEW

Parts of bodies have been sustained and grown, cultured, for more than a hundred years now. This is not 18th century Galvani-style reanimation, which relied on external, electrical charges, but the continuation of life processes and functions of parts that have been removed from bodies, be they organs, tissues or cells. Tentative attempts to keep body fragments alive were initially performed by Wilhelm Roux, who in 1885 kept embryonic chicken tissue alive for short periods of time. Ross G. Harrison grew a frog nerve cell outside of the body in 1907. In 1913 Harrison wrote:

> *… it seems rather surprising that recent work upon the survival of small pieces of tissue, and their growth and differentiation outside of the parent body, should have attracted so much attention, but we can account for it by the way the individuality of the organism as a whole overshadows in our minds the less obvious fact that each one of us may be resolved into myriads of cellular units with some definite structure and with autonomous powers.*[7]

The first ongoing living existence of fragments—the semi-living—came about as a result of the more systematic and sometimes occultish practice of Alexis Carrel. Carrel cultured cells, tissues and later organs from 1913 to the 1940s. However it was not until 1948 that a continuous line of cells, originating from the one organism was established. The 'strain L mouse cell line' is still widely used in laboratories to this day.[8] Strain L was followed by the first continuous human cell line: the HeLa cells.

THE TECHNOSCIENTIFIC BODY

Maintaining and growing living fragments—the semi-living—involves the creation of a surrogate technological body (or epi-body) in which to grow the cells. This body —which we call technoscientific—provides the conditions that will allow the cells to grow and proliferate. In its most basic terms, this includes providing the right temperature, nutrients and other substances, and in some case substrates that promote cell growth. These fragments are unquestionably alive, satisfying at least the basic functions of a 'living' organism; they metabolise, grow and multiply. In the last couple of decades we have seen cases where the technoscientific body and the semi-living have formed a cyborgian entity in which function and feedback made it a responsive and effective unit.

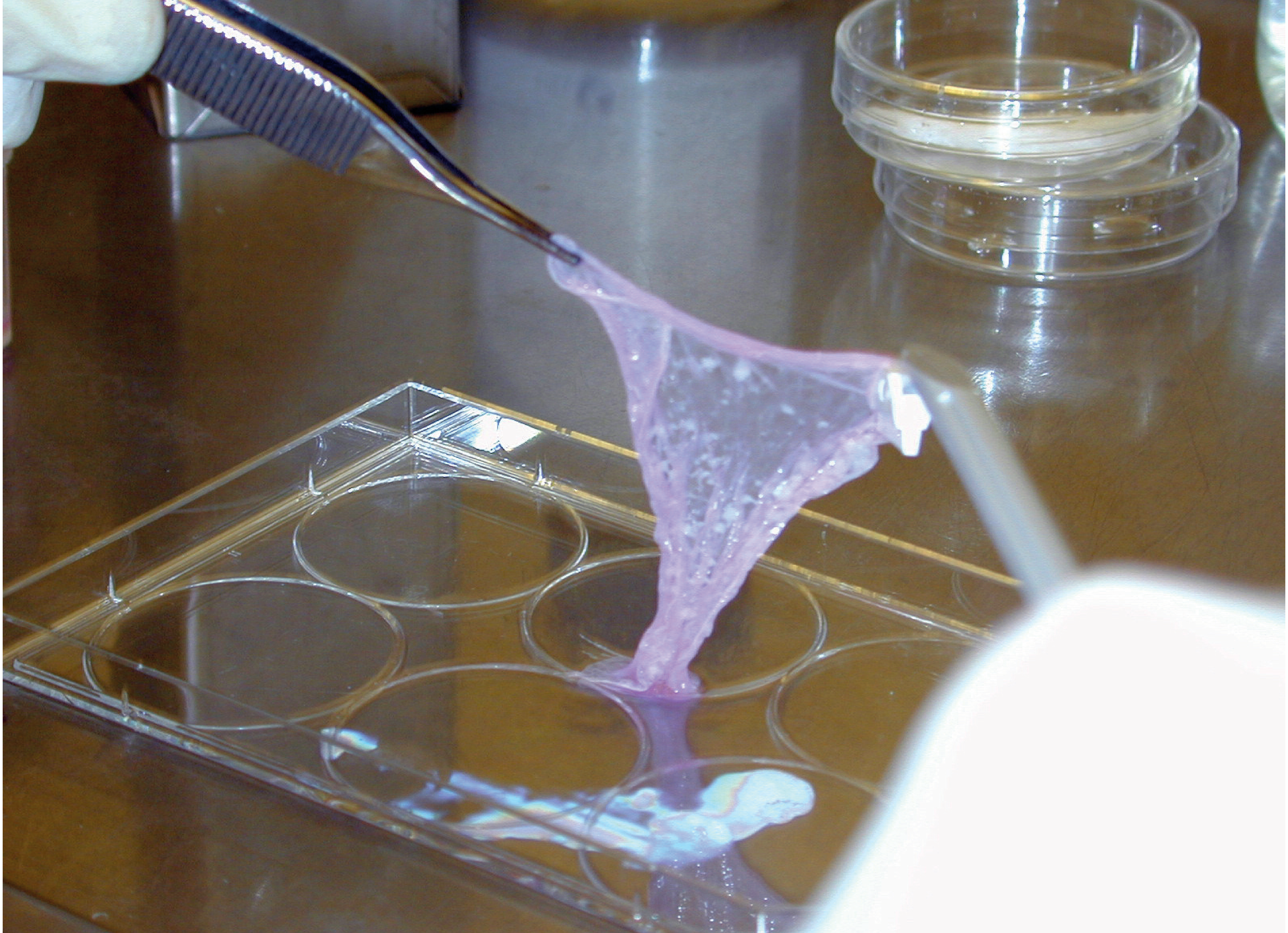
Technoscientific bodies have been designed and built mainly for medical, pharmaceutical and military purposes. A small group has been building these technoscientific bodies for the purpose of philosophical and artistic reflection, observing and learning from the semi-living as evocative objects/subjects that are rapidly populating our human-made environment. Conversely, we are equally interested in registering the response of humans to the semi-living.

CELL FUSION

In some cases the cells of the semi-living fuse. Cell fusion is 'the nondestructive merging of the contents of two cells by artificial means, resulting in a heterokaryon that will reproduce genetically alike, multinucleated progeny for a few generations.'[9] When an undifferentiated stem cell fuses with a mature differentiated cell, the resultant cell retains the mature cell phenotype.[10]

Cell fusion among different species and different families along the evolutionary tree has been carried out successfully since the 1970s. Cultured Xenopus

6 In the early 1960's Leonard Hayflick and Paul Moorhead discovered that human cells derived from embryonic tissues can only divide a finite number of times in culture.
7 Ross Harrison, 'The life of tissues outside the organism from the embryological standpoint.' *Transactions of the Congress of American Physicians and Surgeons*, 9 (1913) 63–75.
8 NCTC clone 929 (Connective tissue, mouse) Clone of strain L was derived in March, 1948. Strain L was one of the first cell strains to be established in continuous culture, and clone 929 was the first cloned strain developed. The parent L strain was derived from normal subcutaneous areolar and adipose tissue of a 100-day-old male C3H/An mouse.
9 http://medical-dictionary.thefreedictionary.com/cell+fusion.
10 http://www.medterms.com/script/main/art.asp?articlekey=32440.



Lemma Let $\theta(s)$ be a solution of the EL-eqn's (with or without contact) with $\theta(s) \to 0$ as $s \to \infty$.

Then $p \leq 0$.

Proof EL eq can be written as

$$-\frac{1}{2}\theta'^2 + \frac{1}{2r^2}\sin^4\theta - \frac{M}{r}\sin\theta(1-\cos\theta) - p(1-\cos\theta) = 0.$$

Close to $\theta = 0$ this gives

$$-\frac{1}{2}\theta'^2 + \frac{1}{2r^2}\theta^4 - \frac{M}{2r}\theta^3 - \frac{p}{2}\theta^2 \cong 0$$

If $p>0$, then to highest order $-\frac{1}{2}\theta'^2 - \frac{p}{2}\theta^2 \cong 0$ $\lightning$.

$\square$

<GRIN>

A PAGE FROM MY ARCHIVE, CA. 2002

It was the word <GRIN> at the bottom of the page that caught my attention. Through seven years of other work and unrelated thoughts this exclamation conveyed to me pleasure, pride and hope. Because for a mathematician the proving of a theorem—called a lemma in this case—is many things at once: a tool of the trade, a mark of craftsmanship, an intellectual achievement, a step forward, the answering of a question and, most of all, the opening of doors that lead further along the path of science.
The topic is the theory of elastic rods, in this case rods that wind around a cylinder.

11 [image elastic rod around cylinder]

You might ask why we study such a strange setup. The long answer is too long; the short answer is ‘start with simple problems, then move on to the more complicated ones’. In mathematical terms, a rod around a cylinder is a simpler problem than a ‘free rod’, as these examples suggest:

12 [6 images of free rods]

The lemma states a property about elastic rods, or to be precise, about models of elastic rods. The Euler-Langrange-equation

$$-\frac{1}{2}\theta'^2 + \frac{1}{2r^2}\sin^4\theta - \frac{M}{r}\sin\theta\,(1-\cos\theta) - p\,(1-\cos\theta) = 0$$

is a differential equation that any rod at rest should satisfy. The lemma states that p, the compressive force applied to the rod ends, can only be negative or zero. In other words; if one pushes the ends of a rod-wrapped-around-a-cylinder towards each other, the rod will collapse onto itself. (Note that one should keep the rod in contact with the surface of the cylinder all the time during such an experiment. Some things are easier in mathematics than in real life).
Clearly I was happy with this little result. Going back through the files of that time I can no longer reconstruct why. Over the years the property proved in this lemma has worked itself into my intuition, so much so that now I can hardly imagine ever doubting it. I should add a property to the list above: the proving of a theorem also modifies the intuition of the mathematician, and in that way shapes the development of the scientist as a human being.

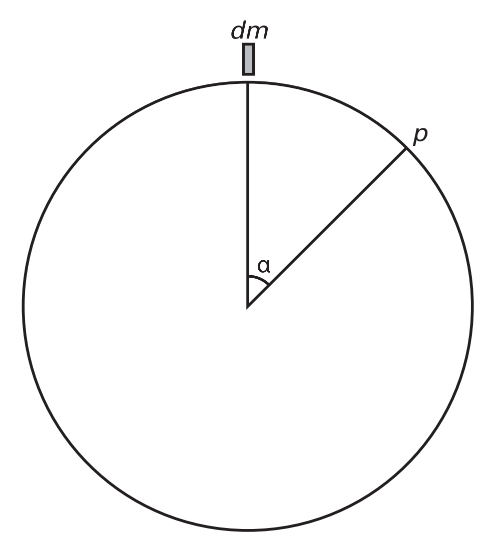
I can't say the word *relationship*

A TOUGH CRUST

The Earth is an elastic material or body and is deformed by a variety of sources. Elastic deformations caused by gravitational attraction from the Sun, the Moon and other planets are known as direct elastic deformation. However, the Sun and the Moon also cause harmonic circulations in the ocean, which give an indirect contribution to elastic deformations at the surface of the Earth. Elastic deformations generated by the oceans are known as 'ocean loading'. Similarly to ocean loading, atmosphere pressure loading caused by ice sheets, glaciers etc. can also contribute to elastic deformations, measurable at the Earth's surface by various geodetic techniques such as GPS
23 (Global Positioning System) and VLBI (Very Long Baseline Interferometry).

Modelling the elastic loading deformations requires a representation, in time and space, for the surface load (e.g. ocean, ice and atmosphere) as well as one for the Earth's structure. W. E. Farrell first published the standard method for determination of the elastic loading effect in 1972.

To compute the elastic loading effect from, for instance, the oceans or the atmosphere, a point mass dm is considered, located at a distance α, from the observation point P.



The point load has the unit of 1 kg and the mass is concentrated at a single point. The elastic loading effect is given by,

$$dL(\alpha) = \zeta(\alpha)\, dm$$

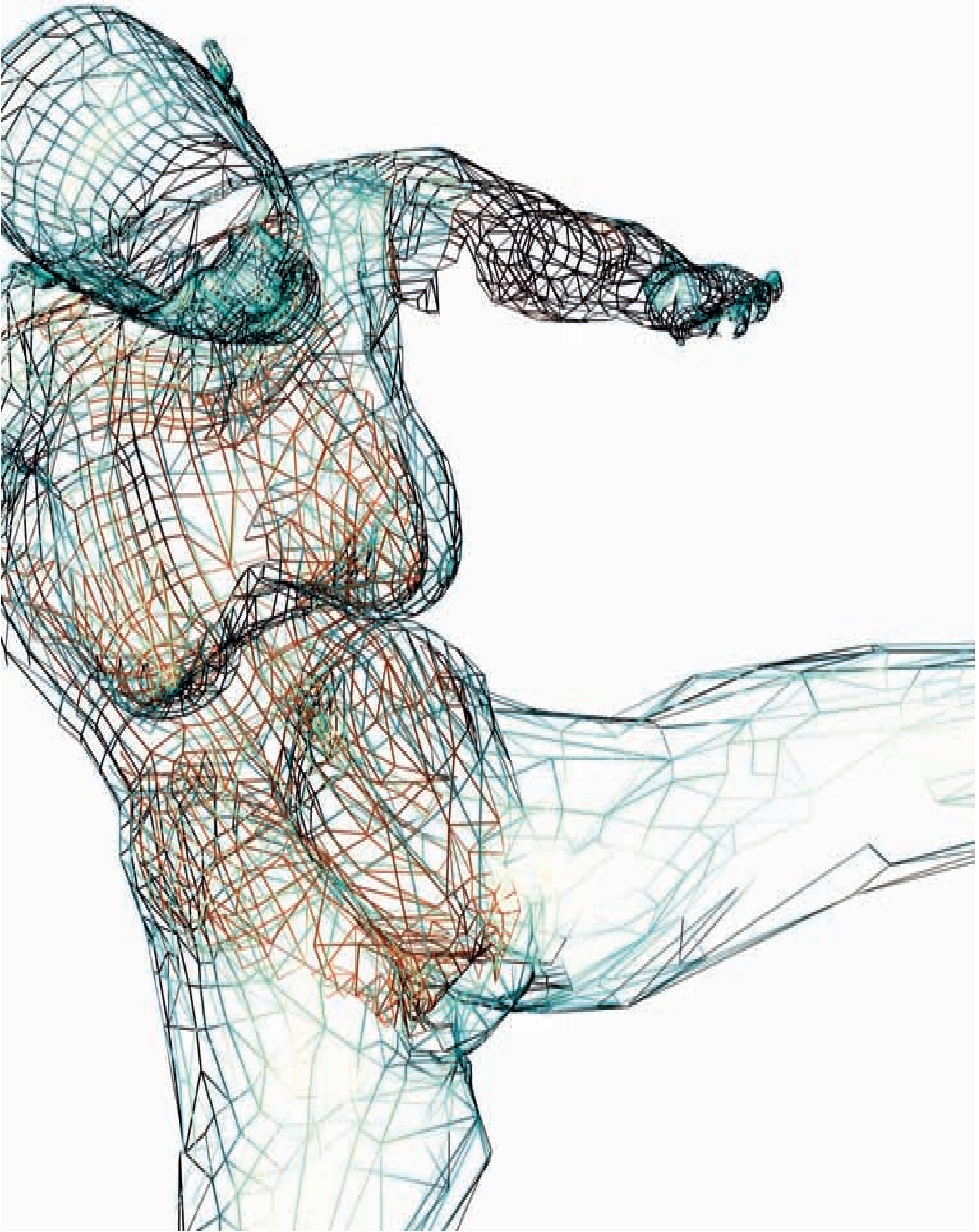
The elastic loading effect, dL, represents, for example, gravitational variations, three dimensional surface displacements, changes in the gravitational potential or tilt of the Earth's surface. ζ is the elastic Green's function, describing the effect of a delta-function excitation. The total elastic loading effect or the elastic loading effect from all of the point masses is obtained by integrating over all mass elements,

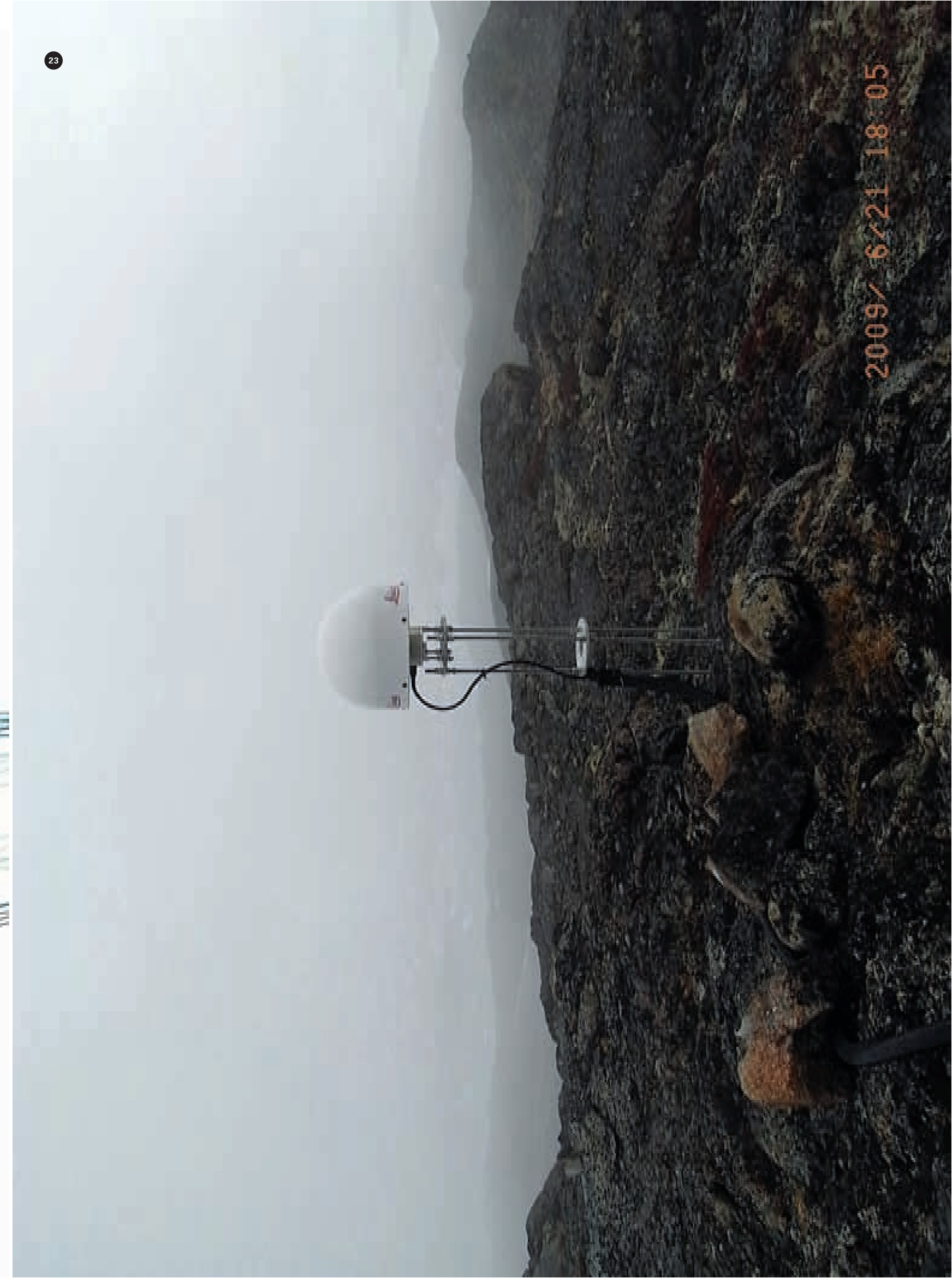
$$L = \int \zeta(\alpha)\, dm$$

This is also called the convolution integral, since the elastic Green's function is convolved with the mass load distribution.

The rapid unloading of ice from the southeastern sector of the Greenland ice sheet between 2001 and 2006 caused an elastic uplift of ~35 mm at a GPS site in Kulusuk. Most of the uplift results from ice dynamic-induced volume losses on two nearby outlet glaciers for example.

Reference
Farrell, W. (1972), 'Deformation of the Earth by surface loads', Rev. Geophys and Space Phys, 10, 761–797.

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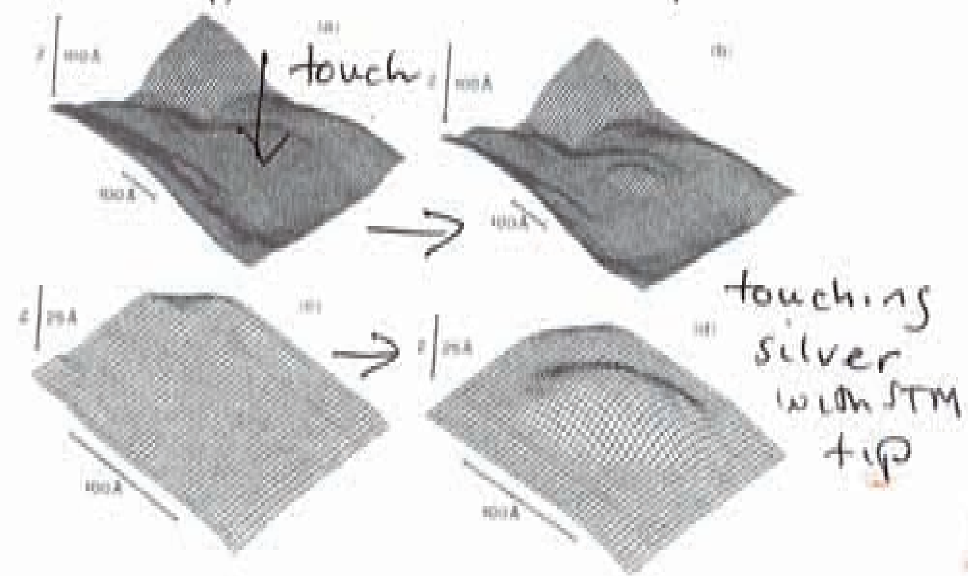
This metaphor does a good job describing people's expectations, but it does a terrible job describing what actually happens. A more accurate metaphor might describe an elastic band connecting the two individuals: the more one pushes the other via revenge, the more powerfully that person snaps back to one's psychological space. In our experiments we consistently found that people who exacted revenge felt worse than they had expected. Moreover, they felt worse than the 'control group' who experienced the same insufferable confederate but were never given the opportunity for revenge. The revenge-takers continued to ruminate about their target after the fact, and this increased rumination led to feeling worse. This dynamic created a feedback loop: the negative affect they experienced led to even more rumination, the rumination led to more negative affect, which led to more rumination, and so on.

What's most troubling is that not only do people fail to intuit this result, but also they fail to learn from experience. We asked our experimental participants at the end of their encounter about the emotional consequence of revenge. Not surprisingly our control group—who didn't have the opportunity for revenge—were quite certain that revenge would have made them feel better. But the revenge-takers—who were objectively less happy than the control group—reported that the act of revenge had made them feel better! So we have good evidence that revenge is not sweet and does not provide the anticipated satisfaction. But people tend not to believe it, even right after experiencing the downside of revenge. Indeed, keep this research in mind the next time someone slights you at a party or cuts you off on the highway; my guess is that you'll secretly believe that your revenge would be really and truly sweet.

nano-ELASTICITY

1

It began with the tip of a scanning tunneling microscope touching a silver surface. The contact being down to a single atom with a quantized conductance. We created bumps and holes on the nanoscale – the metal flowed like honey



Then we looked at molecules and saw they were "elastic" the legs of a porphyrin bent depending on the atomic grooves of the surface on gold and silver crystal faces the asymmetry of the legs let us see the angles change from 90° to 30°

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MFKLLGLTLLMAMVVLGRPEPPVNSYLPP
SDSYGAPGQSGPGGRPSDSYGAPGGGNGG
RPSDSYGAPGQGQGQGQGGYAGKPSDT
YGAPGGGNGNGGRPSSSYGAPGGGNGGRP
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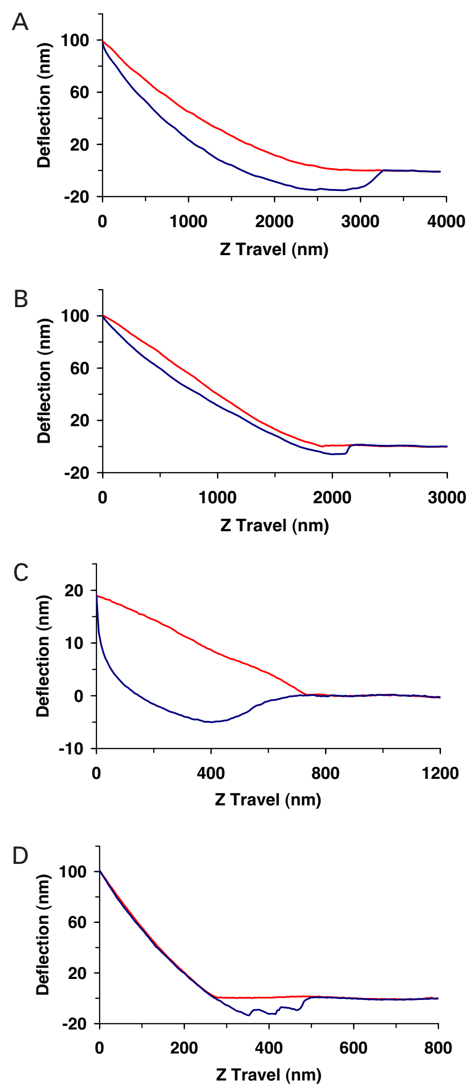

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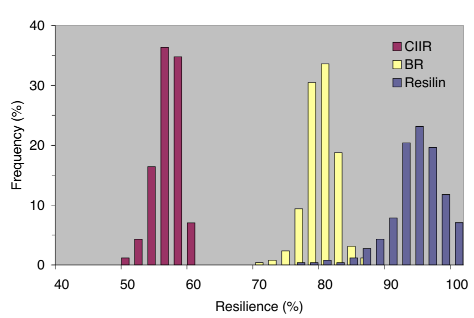

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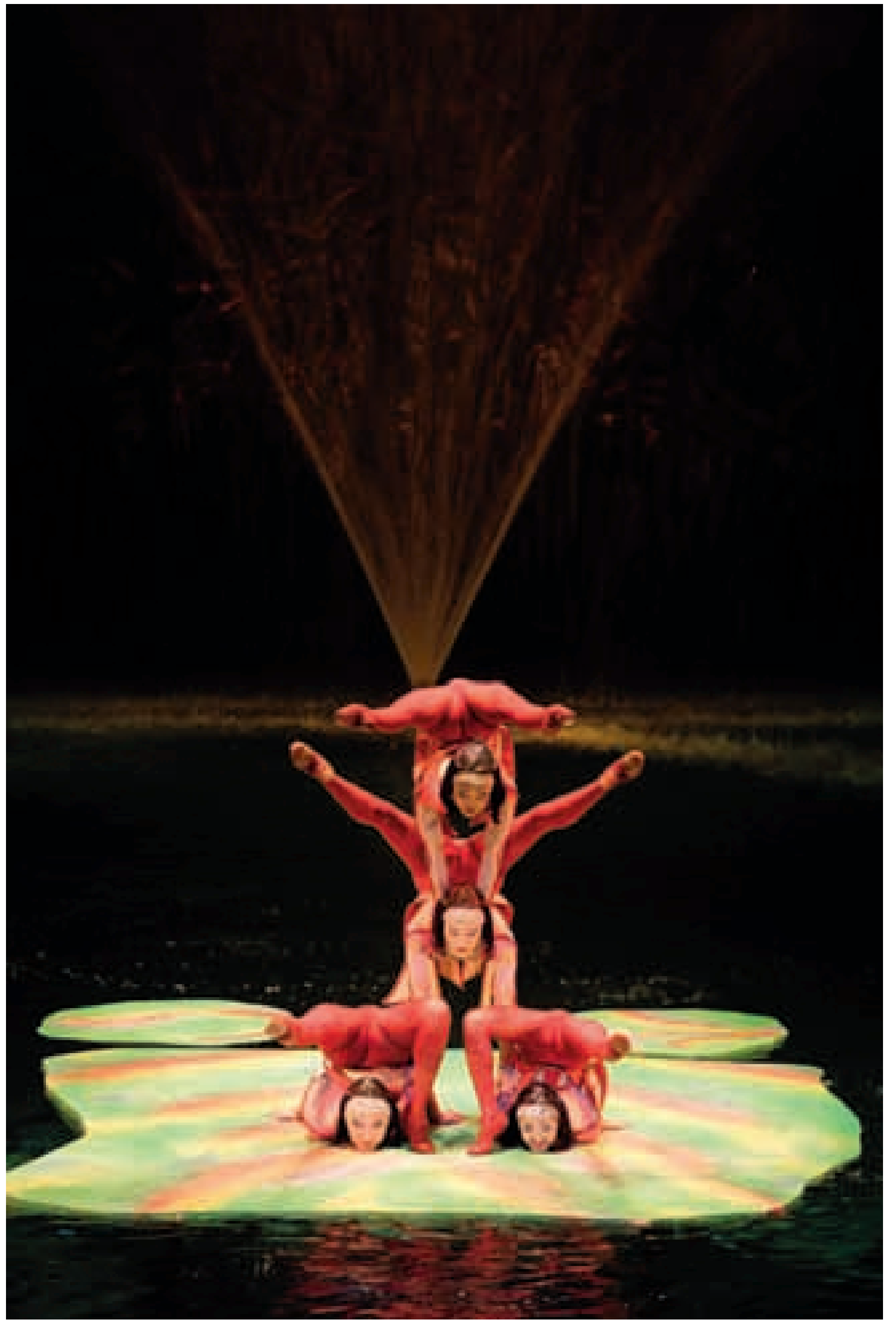

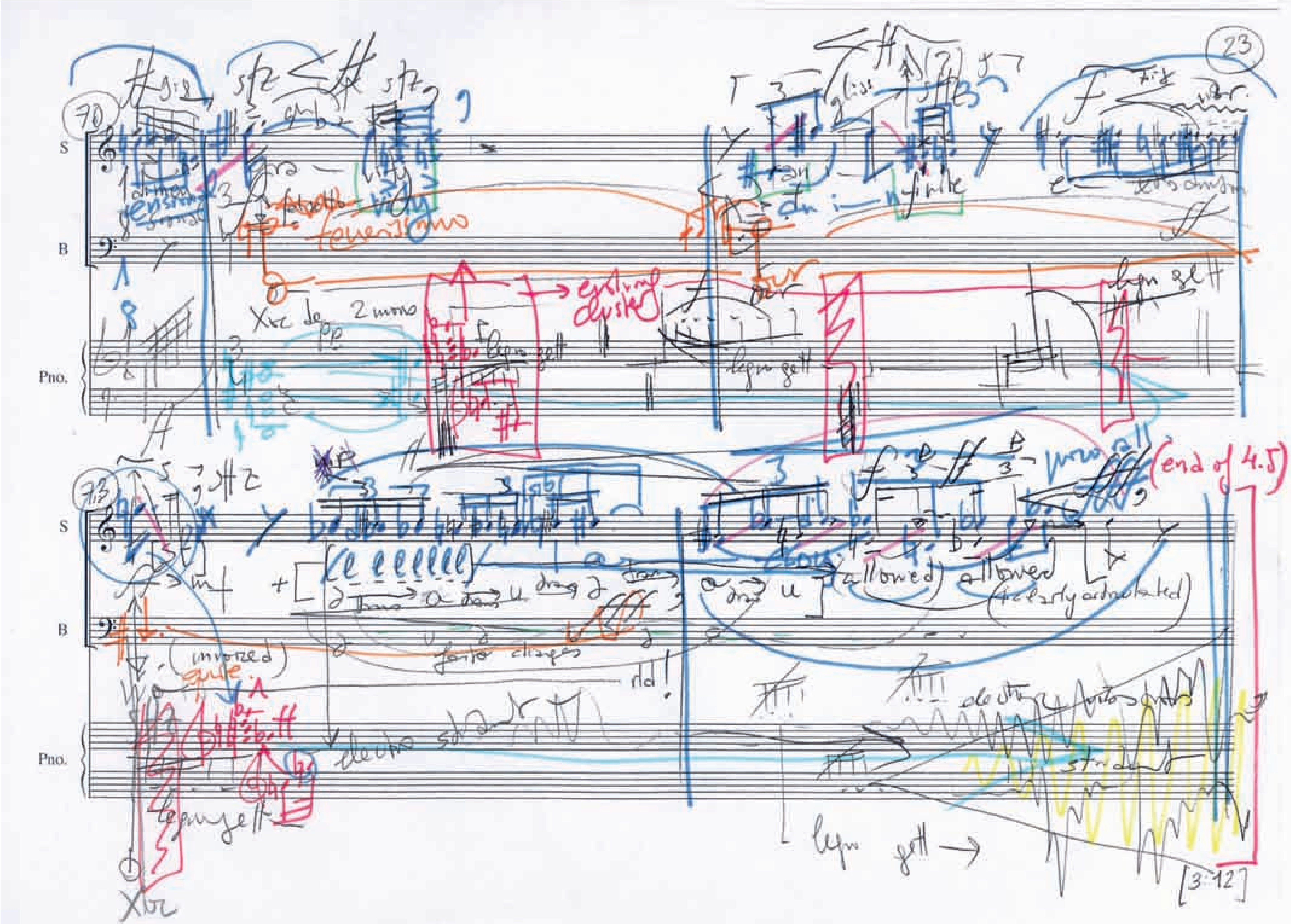
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HYPERMUSIC PROLOGUE

First draft of a page of the 4th Plane for *Hypermusic Prologue*, with libretto by physicist Lisa Randall and stage design by Matthew Ritchie. In this first musical pencil-draft, I composed the soprano and baritone melodies, and orchestral harmonies with different colours representing different musical 'materials': the deep blue for the vivid and sharp soprano expression, the orange for the long, very tender but desperate baritone, sky blue for some soft string harmonies and red-magenta for sharp and tense wind-percussion interventions.

Hypermusic Prologue is a collaboration between science, music and art. It explores the historic form of opera to generate a dramatic expression of 21st century ideas, including recent developments in higher dimensional physics and their parallels in music and art.

The soprano, experiences a deep tension between her human love and her passion for knowledge. This tension is realized dramatically through the limited spacetime experience she shares with her lover (baritone) and her belief that there is a larger world to be explored. Their interaction is disturbed and illuminated when the soprano embarks on a hypothetical trip into a warped extra dimension. Their alternative views and experiences of reality take on metaphorical meaning through this journey.

A SPIDER'S WEB

If you take a walk on a foggy morning in a meadow or head out into your own garden you will notice them everywhere, and see how beautiful they are. The functional elegance and structural complexity of the two-dimensional orb web is highlighted by the thousands of tiny dew droplets attaching to the silk threads like silvery beads on a string.

If you stop for a while and look closer at the web, you will see that it consists of more or less distinct parts. In the centre, or to be accurate somewhat north of the geometric centre as most orb webs are asymmetric, there is the hub, where, depending on the species, the spider may or may not be found. If it is not in the hub you will most likely see a signal thread leading from the hub to nearby vegetation where the spider will be holed up in its hiding place. From the hub you will see the radii running out like spokes on a wheel. They function both as support for the capture spiral and as an information highway for the vibrations emitted from the struggling prey. They provide the spider with information on the location and size of the unfortunate insect.

Due to its pivotal role in prey capture, the capture spiral takes up most of the space, consumes most of the silk used and most of the time needed to build the web. A frame from which anchor threads attach the web to its surroundings, encloses the radii and the capture spiral. If you follow these anchor threads you will notice that some of them can be very long, allowing the web to be placed out in the open.

Not only are webs beautiful to look at. They are also very impressive from an engineering perspective. A web weighing less than 1 mg is capable of stopping a 25 mg fly with an incoming speed of up to 4 m/s, or under the right circumstances even much larger insects. If you could increase the frame rate of your visual system and happened to be standing aligned to the web plane at the exact moment where the fly flies into it, you would see how the impact deforms the web out of the plane before the individual strands pull it back again. This behaviour is mainly caused by the amazing material properties of spider silk. It has a low weight and a high elasticity, but at the same time has a remarkably high tensile strength, which combined give spider silk a strength-to-weight ratio five times greater than steel and a toughness three times greater than Kevlar.

WHY ELASTICITY IS BAD

The spider has one problem with a very elastic web. The stretching of the web as a prey hits it stores elastic energy and this energy needs to be released. Imagine the web like a trampoline. If you throw something at a trampoline it will bounce right back. A web that reacts to a fast incoming fly by shooting it out in the opposite direction is no good for the hungry spider. The problem is solved by making the silk imperfectly elastic, so that more energy is dissipated by internal friction and heat production in the individual silk threads and by aerodynamic damping of the whole oscillating capture spiral, while at the same time ensuring that the prey sticks to the silk by (in the majority of spiders) coating the threads with glue. A separate, smaller group of orb spiders uses a tangle of very fine threads which adhere to the prey by Van der Waals and hygroscopic forces.

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