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Chaos and Control: Nanotechnology and the Politics of Emergence

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Chaos and Control: Nanotechnology and the Politics of Emergence

Entia non sunt multiplicanda praeter necessitatem

Ockham's Razor

Control

Science is part of the cosmos it creates. Contra Descartes, science is not some method or capacity through which we are able to achieve existential externality in order to discover eternal truths. For Bergson the game that science plays in the cosmos is all about time – or in his own terms ‘duration’. He states: ‘The universe *endures*. ... The systems marked off by science *endure* only because they are bound up inseparably with the rest of the universe’.¹ That is to say that the endurance of science is provisional. Its endurance is marked by the universe it describes. This temporal dimension also introduces the possibility for variation and evolution.

Perhaps this is a statement about Science, rather than about science – a statement that is too all encompassing. We will leave such thoughts for somebody else, for here we are interested in science. We are interested in the specific interventions that particular scientists make, and are making, into the material world within the broadly defined field of nanotechnology. Indeed, it is at this level of specificity that the notion of endurance comes into its own. For nanotechnology, which is both scientific and technical (if we must bring up that old distinction), is fundamentally about making things. That is, nanotechnology is about the construction, generation and growth of objects, devices and architecture – all of which have a certain endurance. In working at the nanoscale (10^{-9} m), in the world of Brownian motion and atomic uncertainty, this kind of endurance is produced by certain forms of control – specifically the control of sub-molecular particles, of biological systems, chemical syntheses, reactions and crystal growth. If it is possible to construct a nanostructure from a few atoms or molecules, or to grow one using a protein or some process of crystallisation, the endurance of this structure is dependent on being able to control atomic-level forces that would tear it apart. Such endurance is premised on perpetual control.

Of course Deleuze was also famously interested in control, particularly in his ‘Postscript for Control Societies’. For Deleuze ‘control’ defines the political

constitution of the contemporary moment. Critical of Foucault's analysis of modern discipline, he suggests that institutions and technologies of incarceration and discipline are being replaced by the mechanisms of control. He states: 'We're in the midst of a general breakdown of all sites of confinement—prisons, hospitals, factories, schools, the family ... *Control societies* are taking over from disciplinary societies'. For Deleuze this regime of control is not about any specific mechanism, technology or institution of control. Indeed he states:

It's not a question of amazing pharmaceutical products, nuclear technology, and genetic engineering, even though these play a part in the process. It's not a question of asking whether the old or new system is harsher or more bearable, because there's a conflict in each between the ways they free and enslave us. With the breakdown of the hospital as a site of confinement, for instance, community psychiatry, day hospitals, and home care initially presented new freedoms, while at the same time contributing to mechanisms of control as rigorous as the harshest confinement.ⁱⁱ

This then is one side of control – the side of power and determinism. This is the power of *total* control and it is the dream of many nanotechnologists. This is the kind of control through which some suggest that it will be possible to 'build anything we want' simply by arranging atoms the way we would like themⁱⁱⁱ. However, for Deleuze, control is never absolute in this sense. Control is a product of a repetition of force. Therefore in the application of force and control we also see the radical possibility for creativity, lines of flight and the nomad. As such Deleuze is more interested in modes of control and modes of perpetuating coherence than in absolute control per se.

Deleuze's 'philosophy of technology' is both open and dynamic. He adopts an open *stance* in relation to science and technology. For Deleuze the link between 'basic' scientific knowledge and technical systems – which is mediated through the disciplines of engineering, design, predictability and control – is neither simple or necessary. For example, Deleuze's critique of the hylomorphic schema instead suggests that control and predictability emerge almost spontaneously. As such, and following Simondon and von Uexküll, technical objects for Deleuze are ontologically unstable, produced through processes of individuation and self-organisation in complex relations with their milieu^{iv}.

What is significant here is not the scientism of Deleuze's own thought, but rather the stance that Deleuzian thought enables one to take in relation to the emergence of technical objects and systems. Recent scholarship on the use of scientific concepts in Deleuzian thought has tended to be polarised between realist and metaphorical interpretations of Deleuzian thought – that defend the use of mathematics and physics in Deleuzian thought as either scientifically valid or allegorically salient.^v Both of these positions interpret the use of science by Deleuze in solely conceptual terms – as if what is at stake is *either* the metaphysical rigour of his use of science or its metaphorical resonance. However, this choice between realism and idealism is a false one. Both misunderstand science itself in *wholly* conceptual terms without any sense of the interconnected material practices and interventions fundamentally intertwined with the emergence of technical objects and systems.^{vi} Deleuze's use of science is much more political than philosophical, and much more attuned to the mechanisms of invention and creation to be simply cast as conceptual intellectual folly.

What is at stake in Deleuze is not Science, or even Philosophy . This is particularly the case in Deleuze and Guattari's almost 'disrespectful' treatment of the pillars of Science, Art and Philosophy in *What is Philosophy* in which they state:

The three disciplines (art, science and philosophy) advance by crises or shocks in different way and in each case it is their succession that makes it possible to speak of 'progress'. It is as if the *struggle against chaos* does not take place without an affinity with the enemy, because another struggle develops and takes on more importance – the struggle *against opinion*, which claims to protect us from chaos itself.^{vii}

Deleuze and Guattari's interpretation of science is fundamentally material. The 'affinity with the enemy' is the same relation that the artisan makes with the wood, or the blacksmith makes with the metal outlined in *A Thousand Plateaus*. In this sense, Deleuze refuses the Cartesian definition of science as simply conceptual invention. Rather for Deleuze conceptual science is one expression of this material 'affinity with the enemy' on the same lineage as alchemy, woodwork and blacksmithery. To this end, in what follows I will outline Deleuze's stance in relation to invention, creation and technology – suggesting that, in place of the reductionism of 'total' control,

Deleuze's ethic aims to vitalise technology. Deleuze aims to open up and potentialise science and technology to the internal evolution of matter 'all the way down'.

Nanotechnologies

The prefix *nano*, from the Greek *nanos* meaning small, gives an immediate indication of the kinds of interventions in the material world envisioned by this word—small ones. A nanometre being 10^{-9} m, nanotechnology is technology on the atomic and submolecular scale.

Nanotechnology encompasses work of advanced nano-scale science, particularly the increased understandings of atomic-scale interactions and the capacity to visualise (or more correctly to characterise) and control materials at sub-micron levels using the *scanning tunnelling microscope*. However, as suggested by the suffix—*technology*—nanotechnology is also a term that designates new forms of practice at nano-metre scale.

The canonical story of the origin of nanotechnology is familiar and oft told. The Nobel Prize winning physicist Richard Feynman's now famous lecture, 'There is plenty of room at the bottom' is commonly regarded as the first public musings by a scientist about the possibilities of technology on the nano-scale.^{viii} He wondered 'Why cannot we write the entire twenty-four volumes of the Encyclopaedia Britannica on the head of a pin?'. His notion that there is no physical barrier to the extreme miniaturisation of technology operates as a central motivating discourse around which nanotechnology operates. Indeed in subsequent controversies around what counts as 'fact' and 'fancy' proponents have often claim that they are simply expressing the implications of Feynman's original vision.^{ix} For example, Eric Drexler's now (in)famous nanotechnology manifesto: *Engines of Creation: The Coming Age of Nanotechnology*, in which he outlines a Feynman-ian notion of the sheer physical possibility of molecular nanotechnology technology as an alternative to modern 'bulk technology':

Coal and diamonds, sand and computer chips, cancer and healthy tissue: throughout history, variations in the arrangement of atoms have distinguished the cheap from the cherished, the diseased from the healthy. Arranged one way, atoms make up soil, air, and water; arranged another, they make up ripe

strawberries. Arranged one way, they make up homes and fresh air; arranged another, they make up ash and smoke.^x

For Drexler nanotechnology represents a mode through which life may be understood *physically*. Drexler's manifesto mirrors Feynman's vision: that there is no physical barrier, or practical reason why current technology – medicine, information technology and engineering – cannot operate with precision at the nano-scale.

Nanotechnology is fundamentally technological, it is about technique, process, and precision. Drexler's manifesto, which self-consciously mirrors science fiction in developing possible future nanotechnology scenarios, does not break new ground in terms of scientific knowledge regarding the atom. Rather it is the preparatory exploration, outlining the possible implications of the convergence of abstract atomic knowledge with increased technical ability at these scales.

Nanotechnology and reductionist returns^{xi}

The reductionism implicit in contemporary genetic technologies^{xii} is both extended and intensified in Drexler's account of nanotechnology.^{xiii} For Drexler all things, both organic and inorganic, are simply a collection of atoms and molecules. In this sense Drexler's determinism is fundamentally physicalist. Whereas for genetic determinism it is assumed that life forms are determined by the *process* of heredity, for Drexler life itself is determined simply by its physical constitution. In this sense, life itself is absolutely divisible, and therefore manipulable. The only difference between material objects is the alternative arrangements that such atoms take. Indeed, the radical possibility that Drexler presents is that, when control over the structure of matter is achieved, it will be possible to make 'almost anything' from the 'bottom-up'.^{xiv}

The root of this physicalist determinism is Schrödinger's essay *What is Life? The Physical Aspect of the Living Cell*. In this essay Schrödinger outlines a physicalist understanding of life and matter upon which the dreams of an unlimited material abundance, produced by nanotechnology, are based. Indeed he initiates a 'materialist turn' in biology by suggesting that biological processes may be explained physically. Schrödinger asks:

How can events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?

To which he gave the following answer:

The most essential part of a living cell – the chromosome fibre – may suitably be called *an aperiodic crystal*.^{xv}

Schrödinger signals the fundamental idea that living cells are physical – that they are composed by physical elements, atoms and aperiodic crystals – and as such can be conceptualised in physics and chemistry as well as biology. The notion, articulated by proponents of nanotechnology, that such technology maybe able to cure diseases, remedy pollution and create clean energy, relies on this most basic premise of the atomic physicality of ‘life’. Therefore Schrödinger’s physicalism is paradoxical in that it also heralds a reductionist notion of the absolute divisibility of all life. In this sense the physical itself becomes nothing less than an instrumental concern in the technologisation of life and nature.^{xvi}

There is a rich double meaning to Schrödinger’s essay *What is Life?* His notion of matter and of life is irreducibly vitalistic. He is interested in *life* – in the physics of life. In one sense this life is about the physicality of life, its material and atomic bases, yet in another it is about a certain physical life or liveliness of matter. Schrödinger introduces a notion of the vital life of the atomic. Schrödinger captures the movement, variation and digression of the material at atomic and molecular scales. Crandall embraces Schrödinger’s move in his vision of nanotechnology:

This stumbling, stumbling dance allows molecules all possible ‘mating configurations with the other molecules in their local environment. By variously constraining and controlling the chaos of such wild interactions, biological systems generate the event we call life.’^{xvii}

For Crandall the *promise* of nanotechnology is of a technology of ‘molecular construction’, the miniaturisation of macro-scale manufacturing techniques enabling the precise placement construction of objects atom by atom. Similar Drexler’s vision is of nano-scale replicators – autonomous, self-replicating machines will enable such techniques of atomic precision to be infinitely multiplied. Building upon

enhancements in the characterisation of atomic structures and the precision with which these structures may be controlled, Crandall positions nanotechnology as the ability to create nano-scale *machines* and to construct material objects from the bottom up, through the precise alignment of sub-molecular materials.

For both Crandall and Drexler the simple fact that biological life is accomplished through the selective control over the movement of atoms and molecules demonstrates the possibility of similar human designed processes. Their ontology of the atomic, though emphasising the internal movement, variation and flux, operates only as the technical limit upon what is possible. For Drexler and Crandall the technical limits of nanotechnology are ‘set’ by the nature and being of atomic scale matter (its ontological status). At the core of the Drexlerian vision, as expressed by Crandall, is a notion of control. If the ‘event we call life’ is generated by the ‘wild interactions’ of particles at the nanoscale, the broad goal of fundamental nanoscale research must be toward achieving control over these interactions so that they may be directed in desired ways. As such, the Drexlerian vision of the *possibilities* for self-replicating nano-scale robots has become a programmatic definition of nanotechnology as the ‘total (or near total) control over the structure of matter’.^{xviii}

The mechanistic reductionism of nanotechnology also has its roots in a logic of what might be properly termed a ‘biological turn’ in theoretical physics and mathematics. This ‘biological turn’ may be identified in the move toward the mathematical modelling of complex and naturally occurring phenomena – particularly in swarm and game theory. Of particular significance in the development of nanoscience and nanotechnology is von Neumann’s mathematical modelling of self-reproducing systems. Von Neumann’s theory of automata – modelled on the functionality of the neuron – is an expression of the sheer algorithmic possibility of computationally recreating naturally occurring self-reproducing systems. His is a vision of what is ‘logically possible’ as he states:

A new, essentially logical, theory is called for in order to understand high-complication automata and in particular the central nervous system.^{xix}

As such, von Neumann's thesis suggests that naturally occurring self-replicating systems may be modelled mathematically. For von Neumann, the key to the mathematical recreation of cellular automata is the inherent logic imbedded within the very complexity of such systems – what he terms 'complication'. At a high degree of complication – or complexity – are able self organise themselves. The key therefore is to discover the mathematical logic and laws through which systems of such high complexity operate:

All these are very crude steps in the direction of a systematic theory of automata. They represent, in addition, only one particular direction. This is, as I indicated before, the direction towards forming a rigorous concept of what constitutes 'complication' (or complexity). They illustrate that 'complication' on its lower levels is probably degenerative, that is, that every automaton that can produce over automata will only be able to produce less complicated ones. There is however. A certain minimum level where this degenerative characteristic ceases to be universal. At this point automata which can reproduce themselves, or even construct higher entities, become possible. ^{xx}

For von Neumann 'self-reproduction, evolution – *life* in brief – can be achieved within a cellular automaton – a toy world governed by simple discrete rules not unlike those of a solitaire game'. ^{xxi} Von Neumann's search was for the laws that governed the formation and functioning of cellular automata. His logical route is from the big to the small, from the complexity of self-organisation to simple, discrete laws. Von Neumann offers a bio-mimetic logic where existing biological systems may be modelled through such laws and the precise control of the parameters of such systems. As such von Neumann's notion of the algorithmic recreation of complex systems masks an extreme reductionism in which simple laws control complex systems. ^{xxii}

The importance of Von Neumann's work in nanoscience and nanotechnology is two-fold. Firstly, his basic thesis is that self-replicating automata are *logically* possible casts matter and the material as simple instrumental concerns. For von Neumann – and also for Dexler – if self-replicating automata are logically possible they must also, by necessity, be physically possible. Secondly, the combined effect of Schrödinger's physical understanding of life and von Neumann's logic of the self-replicating automata is to suggest that chemical and biological processes may be understood functionally as code or information. Von Neumann suggests that natural occurring automata conform to algorithmic logic and that they may be technically recreated by

manipulating the parameters of algorithms. This reductionism offers the possibility of total control of such biological and chemical systems. In this way biological systems become a set of mathematical and computational instructions that may be technologically re-ordered. Lehn echoes this understanding of biological and chemical processes by suggesting that forms of ‘living’ or ‘complex’ matter may be created by controlling the informational exchange at the heart of chemistry and biology. In what he terms ‘supramolecular’ chemistry he suggests:

Supramolecular chemistry has paved the way toward apprehending chemistry as an information science through the implementation of the concept of molecular information with the aim of gaining progressive control over the spatial (structural) and temporal (dynamic) features of matter and over its complexification through self-organisation, the drive to life.^{xxiii}

Both the ‘materialist turn’ in biology and the ‘biological turn’ in mathematics and physics are concerned with a set of logical possibilities. Schrödinger’s conception of the physics of life and von Neumann’s mathematical theory of automata have the effect of converting life itself into discrete physical entities which operate as a form of information or code. This double move has the paradoxical effect of rendering the physicality of biological and chemical systems as merely an instrumental concern in the hylomorphic application of computational models onto material substrates. Combined with Feynman’s vision of atomic scale machinery nanotechnology operates as a set of theoretical promises and possibilities for gaining ‘progressive control’ over the structure of matter in the design and manufacture of nanotechnologies. Life itself is cast as absolutely divisible. The mechanisms of reproduction and self-organisation are themselves recreatable, given the precise control over the parameters of chemical synthesis of biological systems.

This rhetorical move from the big to the small, from the complex to the simple and from the chaotic to the organised parallels the overall imagination of nanotechnology as the ability to precisely control the ultimate building blocks of life. This logic is also comparable to the reductionism at the heart of some versions of complexity theory. Broadly speaking whereas chaos theory works in the reverse direction – small events producing large results – complexity theory suggests that simple structures emerge and self-organise in the context of complex and dynamic systems.^{xxiv} Though inherent

to theoretical accounts of complexity theory is the spontaneous emergence of organised structures, its technological operationalisation often reveals a reductionist drive toward simplification and predictive control.^{xxv} It is in the construction of complexity theory as a unifying project, through which total systems understanding, simplification and predictive control may be achieved, that complexity theory is at its most reductionist. For example, Capra defines complexity theory as:

A new mathematical language and a new set of concepts for describing and *modelling* complex nonlinear systems. Complexity theory now offers the exciting possibility of developing a *unified* view of life by integrating life's biological cognitive and social dimension' (emphasis added).^{xxvi}

By unifying biological, chemical and physical knowledge, complexity theory, is thought to enable an enhanced capacity to model non-linear systems. By extension complexity theory is seen to enable the precise control and recreation of such systems.^{xxvii} The rhetorical move from the complex, the large, and the extensive to the simple, the small and the intensive is ambiguously reductionist. Given this ambiguity complexity theory masks a 'reductionist return'^{xxviii} in contemporary *technoscience* inherent that is revealed in the currency of notions such as predictive control, modelling, law and total systems knowledge.

This reductionism mirrors the rhetorical efforts of miniaturisation and simplification made by Feynman, Schrödinger and von Neumann. The combined effect of Feynman, Schrödinger and von Neumann is to cast biological, chemical and material 'life' as absolutely physically divisible and created through mechanisms that are ultimately controllable. Indeed, nanotechnology operates as a similar 'unifying' project as complexity theory – combining traditional scientific disciplines of physics, chemistry, mathematics and biology with technically oriented disciplines of engineering and computing. Rhetorically nanotechnology also relies upon a similar rhetorical move from the big to the small as the ultimate technical expression of the miniaturisation imperative. Thus for Drexler, following Feynman, Schrödinger and von Neumann, the sheer logical possibility of nanoscale engineering and manufacture is established absolute divisibility of all forms of life and materiality to the atom and the technical possibilities for building things 'atom by atom'.

Unity vs. singularity

The reductionism of advanced nanotechnology is also deeply political. The vision of nanotechnology as heralding the ability to remake the world ‘atom by atom’, and as leading to the ‘next industrial revolution’, is also a State sanctioned vision of the power of science to revolutionise material practice.^{xxix} The reductionism of nanotechnology, that demands total control of the atomic scale, is deeply entwined with this politics. This is what Deleuze calls the politics of the State, or the ‘apparatus of capture’, in which the unifying project of reductionist science works toward the total control demanded by the State.

Deleuze’s ontology is of an entirely different order. Deleuze neither moves from the complex to the simple, nor from the simple to the chaotic. Rather Deleuze starts with the singular or – more properly – the singularity. Whilst in nanotechnology the unity represents the absolute divisibility of life Deleuze starts with the notion of the singularity as the basis for molecular variation and flux. Deleuze’s ‘philosophy of difference’ fundamentally concerned with revalorising the singular, over and above the particular. He deploys an explicitly monistic ontology—a material pantheism whereby the singularity of matter is alive with the creative potential of endless evolutions and innovations. Deleuze states:

There has only ever been one ontological proposition: Being is univocal. There are not two ‘paths’, as Parmenides’ poem suggests, but a single ‘voice’ of Being which includes all its modes, including the most diverse, the most varied, the most differentiated. Being is said in a single and same sense of everything of which it is said, but that of which it is said differs: it is said of difference itself.^{xxx}

What Deleuze does here is to free ‘the singular’ from ‘the particular’, giving it an individuating capacity. Deleuze’s notion of singularity is at once an absolute rebuttal of both the Platonic and Aristotelian metaphysics of matter and a valorisation of the creative vitalism of the material. He refuses the categorical difference, established by the metaphysicians, between matter and form or between the subject and the object. Rather, all things are *formed* through repetitious individuation of the same substance—the monadic singularity—intensities, riffs, sublimations in a singular key. Rethinking monadology in explicitly materialistic terms enables Deleuze to insist upon a materialism that is ‘roughly equivalent to an ongoing Big Bang, permanent

Creation'^{xxxii}, precisely because whilst this evolution is both permanent and multiple, the substance upon which these operations is performed is singular. Thus it is not simply that 'matter is singular' as a universal substance. Rather matters are singularities—momentary agglomerations in the creative evolution of the singular, monistic substance.

Due to his emphasis on a monistic creative evolution Deleuze's materialism is inherently spontaneous. For Deleuze monism is not simply about a reductionism to the atomic, the whole, the plane or the easy to handle. Rather, in Deleuze's hands monism is about the elevation of the singular—the singular that is difference itself. Deleuze's philosophy of difference is singular precisely because it positions difference as internal to the object, rather than between (categorically different) things. Deleuze follows Simondon's drive to free *individuation* from any organising principle of the *individual*.^{xxxiii} Deleuze's aim is to compose a philosophy of difference—rather than of diversity—in the singular, where what differs is not one thing from another, but the thing from itself. This repetition of the singular, what Deleuze calls the production of singularities, imbues within objects, things, substances and bodies a dynamic sense of action. For Deleuze this spontaneity goes 'all the way down' and is not computable by law or assumptions of predictability. It is by following Simondon that Deleuze enables a dynamic theory of technology on par with the technical possibilities of nanoscience, in which the singular, the atomic and the molecular are energised in the creative production of difference. Repetition, for Deleuze, is the essence of creativity or – in Bergson's terminology – creative evolution. It is this monistic ontology of singularity (rather than unity) that imbues matter with a sense of unstable movement because the *repetition* of this monistic substance is not simply a matter of the production of equivalences, but repetition is the production of difference, the movement and creative evolution of the thing:

Repetition is a condition of action before it is a concept of reflection. We produce something new only on condition that we repeat—once in the mode which constitutes the past, and once more in the present of metamorphosis.^{xxxiii}

Though Deleuze does not have what might be termed a 'philosophy of technology' – in the manner of Heidegger or even Derrida – one would imagine a Deleuzian stance

or ethic *toward* technology that, following Simondon and von Uexküll, allows for the creative individuation of technology. Deleuze's *stance toward* technology is fundamentally a political engagement with powers of invention and creation. His basic concern is to free individuation, and the singularity, from the unifying project of 'total control'. Whereas in nanotechnology – as in other contemporary technologies – it is imagined that internal deviance, evolution and spontaneous self-organisation may either be mastered or technically harnessed, Deleuze imagines a technology that is radically open to evolution 'all the way down'. Indeed, the problem for Deleuze with philosophies of technology (either the sceptical, Heideggerian versions of technology as threat^{xxxiv} or the more positive endorsements of the social-evolutionists^{xxxv}) is that they treat technology as a distinct ontological category. Deleuze's philosophy is more an attitude or stance toward technologies that is open to the internal flux of technology, down to the molecular level.

This stance toward technology imbues Deleuze's attitude toward the 'total control' imagined control societies. For Deleuze, control is not symptomatic, but rather emblematic. It does not emanate from a particular technology, or the 'technologisation' of all forms of life itself, but is rather a kind of contemporary epistemic moment. The kind of control that Deleuze speaks of is the perpetual control of noise, variation and flux – the same modes of control over the internal differentiation of matter imagined in nanotechnology. However, this control is expressed in specific modes of control. Because, for Deleuze, control is about the minute control of flux and variation, it is itself perpetually changing and never complete. For example, he states:

Control is short-term and rapidly shifting, but at the same time continuous and unbounded (p. 181)

Nanotechnology and the Mastery of Evolution

Drexler's vision of nanotechnology is inherently mechanical. He seeks to both control and harness the movement, variation and digression of matter at atomic and molecular scales. Drexler's vision is largely mechanistic – suggesting that nanotechnologies can be produced through the hylomorphic imposition of an external design on material substrate, through the precise manipulation of matter 'atom-by-atom'.^{xxxvi} His basic

premise, following Feynman, is that there is no physical impediment to conceiving manufacturing technologies on the atomic scale. He represents this vision as a miniaturisation of existing mechanical techniques to the atomic scale. Indeed this mechanical bias of his thesis has been the source of a number of significant criticisms – primarily that the precise mechanical precision required is simply impossible^{xxxvii}. Despite the extensive criticism of Drexler, both his goal of ‘bottom-up molecular project’ and the broad project of gaining ‘control over the structure of matter’ maintain an important rhetoric in the field. In the extensive criticism of Drexler by Richard Smalley (2001; 2003a; 2003b) and latterly Richard Jones (2004), this notion of control is actually intensified. What is at issue for Smalley is whether the precise control of atomic structures, necessitated by Drexler’s vision of nano-scale manufacture, is technically possible.

Due in part to the repudiation of the vision of ‘molecular manufacture’, Drexler’s radically mechanistic version of nanotechnology has been substituted by a more conservative and pragmatic set of nanoscale possibilities^{xxxviii}. At issue is the sheer physical possibility of autonomous nanoscale machines and the precision necessary to ‘create’ them. Recent scholarship has, however, revived the radical possibility of nanoscale machinic autonomy by rethinking the very way in which such machines might be created. In this biomimetic model, such machines are grown using existing biological systems as working examples.

In the words of Bernadette Bensaude-Vincent there are ‘two cultures of nanotechnology’.^{xxxix} Both present different understandings of the relationship between *design* and matter. One version of nanotechnology is implicitly mechanical. The material world is completely atomised as simply an aggregate of *particles*. It is in this sense that it is suggested that it will be possible to create anything ‘from the bottom-up’ simply by arranging atoms and molecules in certain (desired) ways. Alternatively, Richard Jones imagines a different form of nano-scale control in which technical interventions *harness* rather than *master* the chaotic interactions at the nanoscale. He re-presents these same goals, but changes the route through which they will be achieved. He suggests that nano-scale machines will be achieved through a more bio-mimetic, or emulatory, nanotechnology which both takes its inspiration from, and actively utilises, existing biological systems.^{xl} Rather than imagine

nanotechnology as a set of mechanical interventions at the nanoscale, Jones presents a vision of nanotechnology that is modelled on naturally occurring biological systems. For Jones naturally occurring ‘molecular assemblages’ such as protein and DNA represent a functional equivalent of self-assembling and self-organising molecular machines. Jones’ thesis is that biological systems present functioning models through which more purposeful nanotechnological interventions may be made. For Jones, bionanotechnology is a route through which applications at the nanoscale may be achieved. He states his basic vision as:

My own view is that radical nanotechnology will be developed, but not necessarily along the path proposed by Drexler. I accept the force of the argument that biology gives us proof in principle that a radical nanotechnology, in which machines of molecular scale manipulate matter and energy with great precision, can exist. But this argument also shows that there may be more than one way of reaching the goal of radical nanotechnology, and that the path proposed by Drexler may not be the best one to follow.^{xii}

Significantly for Jones, this necessitates a design process that is both open to, and able to harness, molecular evolution:

Evolution needs some kind of selection pressure – some kind of way of deciding which of the many random changes in the molecular sequence should survive and prosper. ... We can devise experiments that drive molecules to evolve more complex properties ...^{xlii}

Jones maintains that nanoscale machines are both technically possible and a desirable route through which wide technical advances may be made, but suggests that the current ‘engineering approach’ may well prove unrealistic. Instead he adopts a bio-mimetic approach, suggesting that the creation of molecular machines, necessary to fulfil the radical vision of ‘bottom up’ manufacture’, may be created by copying nature – that is emulating existing self-replicating systems such as protein and DNA. Similarly, Seeman & Belcher outline this aim of ‘emulating biology’ by re-creating self-assembling systems:

A key property of biological nanostructures is molecular recognition, leading to self-assembly and the templating of atomic and molecular structures. For example, it is well known that two complementary strands of DNA will pair to form a double helix. DNA illustrates two features of self-assembly. The molecules have a strong affinity for each other and they form a predictable structure when they associate. Those who wish to create defined

nanostructures would like to develop systems that emulate this behaviour. Thus, rather than milling down from the macroscopic level, using tools of greater and greater precision (and probably cost), they would like to build nanoconstructs from the bottom up, starting with chemical systems.^{xliii}

Although there is a strong deterministic logic central to the representation of nanotechnology^{xliiv}, this sense of the momentary control describes the practice of actually building nanostructures. For example, Elder discusses polymerisation as a way in which nano-scale structures may be contrasted or grown:

Formation of the well-ordered nanophase occurs within concentrated droplets as the silica continues to polymerise, and thus it is possible to form any surfactant liquid crystalline phase. Particle coalescence may also occur. A growing body of evidence supports this phase separation mechanism. ... Structural development from disordered spherical micelles to ordered hexagonal phases in phase-separated droplets has also been observed ...^{xliv}

This is a curious model of a kind of construction where a nano-scale architecture is *grown* rather than accomplished. The resulting form, though desired, is perhaps temporary. Indeed, the object of such research is to control the growth in such a manner that it evolves in desired ways. Similarly, take Seeman and Belcher's description of the use of biological systems in building complex and functional systems:

In natural systems, macromolecules exert exceptional control over inorganic nucleation, phase stabilisation assembly, and pattern formation. Biological systems assemble nanoscale building blocks into complex and functionally sophisticated structures with high perfection, controlled size, and compositional uniformity. ... The exquisite selectivity of complementary biological molecules offers a possible avenue to control the formation of complex structures based on inorganic building blocks such as metal or semiconductor nanoparticles.^{xlvi}

This notion of construction entails capitalising on the interactions of biological systems – in this case rDNA, DNA and protein – in order to create desired patterns and objects. The object here is also control, but a control that is both provisional and active. Both of these design paradigms, though designed to achieve control, are in fact more like specific modes of control. In each, desired constructions – shapes, geometries and architectures – are the product of specific and perpetual control.

Indeed, what is entailed is the control of interactions and processes in which we always sense, as Deleuze suggest, the possibility of escape. Both Drexler's mechanistic vision of nanotechnology and the more biologically nuanced vision of the bio-mimetists create different relations with evolution. Both are ways of 'relating to' the flux caused by the internal evolution and variation of objects at the molecular scale and technical design paradigms in this context. Both cultures are ways of harnessing and (more significantly) limiting the creative force of evolution.

The other version of nanotechnology is more biologically inspired and mimetic. Instead of imagining the possibility of simply arranging atoms mechanically, biomimetic nanotechnology aims to capitalise on the functionality of existing biological systems, particularly protein and DNA. However the distinction between these two versions of nanotechnology is never strictly defined as, in a sense, both are concerned with designing nano-scale mechanisms and controlling their *operation*. For mechanistic nanotechnology it is necessary to control the 'wild' Brownian interactions of atoms and molecules to create stable and functional objects. Similarly, bio-mimetic nanotechnology requires the precise control of biological systems in order to achieve desired and designed outcomes. Despite the hubris of complete design in nanotechnology, these kinds of nano-scale interventions have produced only temporary states of order.^{xlvi} Whereas in mechanistic versions of nanotechnology it is imagined that the complex relations of atomic and molecular particles – the internal movement of matter that is the equivalent of Deleuze's machinic phylum – will be *overcome* by the disciplines of design and engineering, in biomimetic nanotechnology it is suggests that technical objects will be created by utilising this very complexity. In particular it is suggests that nanotechnologies will be created by modally or by piggybacking on existing self-replicating systems such as protein, DNA or rDNA.

At issue then is not simply a Deleuzian openness – or affirmation – of flux, variation and evolution. Indeed, whereas Deleuze appropriates Simondon's understanding of the spontaneous individuation of technology – producing a dynamic theory of technology^{xlvi} – both 'cultures' of nanotechnology seek to limit this anarchic potential for evolution 'all the way down'. Indeed, though biomimetic nanotechnology seeks to utilise existing biological machines – and the artificially evolve new forms of such machinery, the real work of such a design paradigm is

ensuring the stability of the resulting structures and systems. Take for example, Michael Conrad's model of 'emergent computation through self-assembly'.^{xlix} He presents a framework in which the 'self-organising capacities of biological systems are extended expressions of nonlinearity inherent in the time evolution of the universe.'¹ Biological systems are the emergent, and hence spontaneous, effects of non-linear processes. Conrad suggests that such machines are internally fluctuating, challenging the ways that such systems may be designed or harnessed technically. He states:

If a collection of components is allowed to self-organise in the first place ... then self-consistency is automatically ensured. In general such self-organised aggregates do not perform functions desired by the investigator observing their formation, unlike the totally macroscopic machines that are pasted together in a planned way by a designer with a definite conception in mind. However, the adaptivity of self-organising systems allows for moulding of the function in a step by step trial and error fashion, just as biological organisations adapt through step by step variation and selection. ... Simple reverse engineering of existing biological organisations cannot work, according to the fluctuation model, since they ignore the hysteretic properties of the vacuum sea.^{li}

Conrad's model is of a moulding of the functions of biological systems, by trial and error. Conrad re-imagines the place of design – 'reverse engineering cannot work' – insisting on a level of artisanal intimacy in the creation of human-directed biological machines. The incompleteness of the technical control over the atomic scale necessitates, for Conrad, a more open ended conception of the technological possibilities at this scale.

Deleuze's evolutionary ethic

Such *inventions* are provisional stabilisations of processes of chemical synthesis and biological interaction. This is patently not consistent with the vision of nanotechnology as being able to 'create anything from the bottom up'. Rather, such inventions necessitate a Deleuzian sense of the temporality of control and the individuation of technical systems. It is in this sense that Deleuze's understanding of the dynamism of control finds its material expression. Indeed, Oyama develops a notion the 'emergence of control':

Control of development and behaviour may be said to emerge in at least three senses. First, it emerges in interaction, defined by the mutual selectivity of interactants. Second, it emerges through hierarchical levels, in the sense that

entities or processes at one level interact to give rise to the entities or processes at the next, while upper –level-processes can in turn be reflected in lower-level ones. Third, control emerges through time, sometimes being transferred from one process to another.^{lii}

The crucial point for Oyama, and for Deleuze, is that *control emerges*. It emerges in interactions with the very processes that are (to be) controlled. This means both that control is partial and that design itself emerges with the object. The word emergence here is crucial. In Seeman and Belcher’s constructions of nano-geometries using DNA we might speak of the emergent self-organisation of such structures. The design, control and precision necessary to generate such nanoscale geometries emerges with the structures themselves and the processes through which they are formed.

The importance, for Deleuze, of the emergence of control is that it signals the ontological incompleteness of design and the spontaneous variation of technology. This, for Deleuze, is both ontological and ethical and defines his own sense of particular stance in relation to evolution and variation. Deleuze draws strongly on Bergson’s notion of variation in developing this ethic. He finds in Bergson the idea of the constant repetition of the object (its simulacrum) that suggests that the object is opened up, repotentialised, returned as constantly differentiated, constantly multiple. In Deleuzian terms, repetition introduces a form of differentiation that replaces the term IS in the being of the object ($X = X = \text{NOT } Y$) with AND (...X AND Y AND Z AND...). ‘Substitute the AND for IS. A *and* B. ... The multiple is no longer an adjective which is subordinate to the One which divides or the Being which encompasses it. It is a noun, a multiplicity which constantly inhabits each thing.’^{liii}

Bergson offers a complex and simultaneous analysis of both the ‘thing-in-itself’ and the thing as an ‘aggregate of images’. Deleuze sees in Bergson a fundamental critique of the notion of categorical difference:

If philosophy is to have a positive and direct relation with things, it is only to the extent that it claims to grasp the thing in itself in what it is, in its difference from all that it is not, which is to say in its *internal difference*.^{liv}

Bergson’s concept of variance becomes crucial. It is a fundamental critique of the notion of categorical difference. Rather than posit a fundamental or essential

difference between objects, Bergson allows difference itself to be something. Objects differ from themselves—internally. This is not to obliterate distinction but to fundamentally reconceive the notion of natural difference. Differentiation acts, according to both Bergson and Deleuze, not between objects, but within objects. For both Bergson and Deleuze matter is anything but a boundary. Rather matter is internally unstable.

This material waywardness is not simply metaphorical, or a kind of characterisation of matter. Rather it is a waywardness that is based in Deleuze's molecular ontology – and the internal flux of matter at that scale. It is also inherently personal and ethical, defined by an openness to change and variation, all the way down to the molecular level. Take, for example, Deleuze and Guattari's description 'becoming-dog':

Your organism enter[s] into composition with *something else* in such a way that the particles emitted from the aggregate thus composed will be canine as a function of the relation of movement and rest, or of molecular proximity, into which they enter. Clearly, this something else can be quite varied, and be more or less directly related to the animal in question.^{lv}

Becoming, in this sense (though often misrepresented) is fundamentally materialist ethic – characterised by an openness to variation and internal variation. In Deleuze's ontology this 'something else' is always difference itself – the action of variation and flux, in an ethic that enters into a relation with difference itself. It is a kind of atomic flux between the object/subject (of course these terms don't mean much) and *the other*. It is precisely these same internal variations that are the subject of both design and construction in nanotechnology. Deleuze suggests that, because of such self-differentiating movement and variation, design and construction are more complex than admitted in the hubristic accounts of nanotechnology. For Deleuze design is not imposed from without, but emerges from within matter. The fundamental departure for Deleuze on the basis of such an ontology, is to conceive of *modes of relating to* the evolution of technology. For Deleuze and Guattari's this ethic – or even politics – 'is a question of arraying oneself in an open space, of holding space, of maintaining the possibility of springing up at any point: the movement is not from one point to another, but becomes perpetual, without aim or destination, without departure or arrival'.^{lvi}

Such is to adopt a similar artisanal stance as Conrad's design by trial and error. For Deleuze and Guattari, it is a question of 'arraying oneself in an open space' in the same way that Conrad imagines a trial-and-error design process. Finally then this Deleuzian stance, or attitude, is open to the paradox of the individuating endurance of both science and technology, and to possibilities for spontaneous eruption in these temporal arrangements.

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ⁱ *Creative Evolution*. (Dover Publications, New York, 1911 [1988]), p. 11.

ⁱⁱ 'Postscript on control societies'. In Deleuze, G. *Negotiations: 1972—1990*. (Columbia University Press, New York, 1990, p. 178)

ⁱⁱⁱ See Drexler, K. E. *Engines of Creation: The Coming Era of Nanotechnology*. (Anchor Books, New York, 1986); NSF. *Nanotechnology - Shaping the World Atom by Atom* (NSTC, Washington, D.C., 1999); Gershenfeld, N., *FAB: The Coming Revolution on Your Desktop--From Personal Computers to Personal Fabrication*. (Basic Books, New York, 2005); and Kurzweil, R. *The Singularity is Near: When Humans Transcend Biology*. (Viking, New York, 2005).

^{iv} Mackenzie, A., *Transductions: Bodies and Machines at Speed* (Continuum, London, 2002)

^v See de Landa's strong realist interpretation and defence of Deleuzian appropriation of concepts from mathematics and physics in *Intensive Science and Virtual Philosophy* (Continuum, London, 2002). This position is in broad agreement with that taken by Protevi and by Bonta & Protevi in Protevi, J., *Political Physics: Deleuze, Derrida and the Body Politic* (Athlone Press, London, 2001); and Bonta, M. & Protevi, J., *Deleuze and Geophilosophy: A Guide and a Glossary* (Edinburgh University Press, Edinburgh, 2004). Alternatively James Williams interprets Deleuze's use of scientific concepts as purely metaphorical in Williams, J., *Gille's Deleuze' Difference and Repetition: A Critical Introduction and Guide* (Edinburgh University Press, Edinburgh, 2003)

^{vi} See for example, Stengers, I., *Power and Invention: Situating Science* (University of Minnesota Press, Minneapolis, 1997); Rheinberger, H. J., *Towards a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford University Press, Stanford, Cal, 1997); and Knorr-Cetina, K., *Epistemic Cultures: How the Sciences Make Knowledge* (Harvard University Press, Cambridge [Mass] 2000)

^{vii} Deleuze, G., and Guattari, F. *What is Philosophy*, (Verso, London), p. 203.

^{viii} 'There's plenty of room at the bottom: an invitation to enter a new field of physics'. *Engineering and Science*, 1960 23(5), 22-36.

^{ix} See for example Drexler, K. E. *Engines of Creation: The Coming Era of Nanotechnology*. (Anchor Books, New York, 1986).

^x Drexler, *IBID*, p. 3.

^{xi} See Wynne, B., Reflexing complexity: post-genomic knowledge and reductionist returns in public science. *Theory, Culture and Society*, 22(5), 67-94.

^{xii} Identified, for example, by Nikolas Rose and Susan Oyama. See Rose, N., 'The Politics of Life Itself', *Theory, Culture and Society*, 2001, 18(6): 1-30 & Oyama, S., *The Ontogeny of Information*. (Duke University Press, 2000)

^{xiii} See for example Mody, C. C. M. 'Small, but Determined: Technological Determinism in Nanoscience'. *Hyle: International Journal for Philosophy of Chemistry*, 2004, 10, 99-128.

- ^{xiv} Indeed Drexler figure for nanotechnology *par excellence* is the *desktop assembler* in which he suggests it will be possible to fabricate almost anything on a personal computer by simply arranging atoms from the bottom up. See also Gershenfeld, N., *FAB: The Coming Revolution on Your Desktop-- From Personal Computers to Personal Fabrication*. (Basic Books, New York, 2005).
- ^{xv} Schrödinger, E., *What is Life? The Physical Aspect of the Living Cell*. (Cambridge University Press, Cambridge, 1944), p 3 & 21.
- ^{xvi} Bennett, J., De return natura. *Strategies: Journal of Theory, Culture and Politics*, 13(1), 2000, 9-22. See also Escobar, A., After nature: steps to an antiessentialist political ecology, *Current Anthropology* 40(1), 1999, 1-30; and Nordmann, A., Molecular Disjunctions: Staking Claims at the Nanoscale, in Baird, D., Nordmann, A & Schummer, J., *Discovering the Nanoscale*, (IOS Press, Amsterdam, 2004)
- ^{xvii} Crandall, B. C., *Nanotechnology: Molecular Speculations on Global Abundance*. (MIT Press, Massachusetts, 1996), p.5.
- ^{xviii} See: Dinkelacker quoted in Wood, S., Jones, R. and Geldart, A., The Social and Economic Challenges of Nanotechnology. (Economic and Social Research Council, 2003), p. 26.
- ^{xix} Von Neumann, J., The general and logical theory of automata. In *John von Neumann: Collected Works*. (Pergamon Press, Oxford, 1961), p. 311. See also Bueno, O., Von Neumann, Self-Reproduction and the Constitution of Nanophenomena. In, Baird, D., Nordmann, A & Schummer, J., (eds) *Discovering the Nanoscale*. (IOS Press, Amsterdam, 2004), p. 101-115.
- ^{xx} IBID, p.318.
- ^{xxi} Toffoli, T., Occam, Turing, von Neumann, Jaynes: How much can you get for how little? (A conceptual introduction to cellular automata. *Complex Systems*, 2, 1994, p. 1. See also McMullin, B., John von Neumann and the evolutionary growth of complexity: looking backward, looking forward ... *Artificial Life*, 6, 347-361.
- ^{xxii} Toffoli, IBID.
- ^{xxiii} Lehn, J. M., toward complex matter: supramolecular chemistry and self-organisation. *Proceedings of the National Academy of Sciences*, (99: 8, 2002), p. 4763. See also Conrad, M., Emergent computation through self-assembly. *Nanobiology*, (92, 1993); Whitesides, G. M & Grzybowski, B., Self-assembly at all scales. *Science*, (295: 5564, 2002); Huie, J. C., Guided molecular self-assembly: a review of recent efforts. *Smart Materials and Structures*, (12, 2003); and Rasmussen, S., Liaohai, C., Deamer, D., Krakauer, D. C., Packard, N. H., Stadler, P. F. & Bedau, M. A., Transitions from nonliving to living matter. *Science*, (303: 5660, 2004);
- ^{xxiv} Prigogine, I. & Stengers, I., *Order Out of Chaos*. (Bantam Books, New York, 1984); Bonta, M. & Protevi, J., *Deleuze and Geophilosophy: A Guide and a Glossary* (Edinburgh University Press, Edinburgh, 2004); Nowotny, H., The increase of complexity and its reduction: emergent interfaces between natural sciences, humanities and social sciences. *Theory, Culture & Society*, 22(5), 15-31; and Urry, J. The complexity turn. *Theory, Culture & Society*, 22(5), 1-14.
- ^{xxv} Wynne makes a similar argument in relation to post-genomics and epigenomics, suggesting that: The complex, more fluid and dynamic interactions regulating biological behaviour at myriad levels, from genes and the genome, via proteins, transcriptors, metabolic and physiological processes, back and forth and not simply one way from gene to whole-organism and its environment, have become the object of attention of 'systems biology', epigenomics, or gene-ecology. Within this complex, even the meaning and definition of the scientific object, gene or genome, let alone further collective unit terms now in use, 'proteome', ' transcriptome', 'metabolome', 'phenome' or 'otherime', have become problematic. Thus complexity coexists with its opposites, reductionism and determinism.
- Wynne, B., Reflexing complexity: post-genomic knowledge and reductionist returns in public science. *Theory, Culture & Society*, 22(5), 67-94..
- ^{xxvi} Capra, F., Complexity and life. *Theory, Culture & Society*, 22(5), 33-44, p. 33..
- ^{xxvii} See Stengers, IBID.
- ^{xxviii} Wynne, IBID.
- ^{xxix} The Drexlerian vision of nanotechnology and the possibilities of molecular manufacture – which was later to become highly contested technically – was initially important in the establishment of a National Nanotechnology Initiative (NNI) in the U.S as a vehicle through which to organise and coordinate research funding. The title of an early NNI brochure *Nanotechnology: Shaping the World Atom by Atom* indicates this resonance of this vision (NSF, IBID). See also: Kurzweil, R., Testimony of Ray Kurzweil on the Societal Implications of Nanotechnology, *Committee on Science, U.S. House of Representatives, Hearing April 9 2003*, <http://www.house.gov/science/hearings/full03/apr09/kurzweil.pdf>; and Peterson, C., Molecular Manufacturing: Societal Implications of Advanced Nanotechnology, *Committee on Science, U.S.*

House of Representatives, Hearing April 9 2003,

<http://www.house.gov/science/hearings/full03/apr09/peterson.htm>. After much scientific and technical commentary, Drexler's original vision of nano-scale replicators and assemblers was seen to be officially 'dismissed' by the publication of the *Nanoscience and Nanotechnologies:*

Opportunities and Uncertainties report by the UK Royal Society and Royal Academy of Engineers (London, Royal Society and Royal Academy of Engineering, 2004). Along side this debate is the familiar State-sponsored vision of the necessary connection between science, technology and wealth creation and the possibilities of nanotechnology to herald a new industrial revolution. See particularly: National Science and Technology Council (NSTC) Interagency Working Group on Nanoscience, Engineering and Technology (IWGN)., *National Nanotechnology Initiative: Leading to the Next Industrial Revolution*. (NSTC, Washington D.C, 2000)

^{xxx} *Difference and Repetition* (Columbia University Press, New York, 1969)

^{xxxi} Hallward, P., Deleuze and the 'world without others'. *Philosophy Today*, 41(4), 1997, 530-544.

^{xxxii} See: Simondon, G., *L'Individu et sa Genèse Physico-Biologique*. (Presses Universitaires de France, Paris, 1964); Simondon, G., *The Genesis of the individual*. In Crary, J. and Kwinter, S., *Incorporations*. (Zone Books, New York, 1992).

^{xxxiii} *Difference and Repetition* (Columbia University Press, New York, 1969), p. 90.

^{xxxiv} See Heidegger M., *The Question Concerning Technology* (Harper & Row, New York, 1977).

^{xxxv} Leslie White's *The Science of Culture: A Study of Man and Civilization* (Grove Press, New York, 1958) epitomises the supposed link between technology and human progress in the early anthropology and socio-cultural evolutionism. Such thinking also has its contemporary equivalents in Kurzweil, R., *The Singularity is Near: When Humans Transcend Biology*, (Viking, New York, 2005)

^{xxxvi} Significantly this vision was tacitly accepted by and during the Clinton administration with the establishment of the NSF sponsored National Nanotechnology Initiative and the publication of the pamphlet: *Nanotechnology - Shaping the World Atom by Atom* (NSTC, Washington, D.C., 1999).

^{xxxvii} Drexler was most thoroughly criticised along these lines by Richard Smalley. See, for example, Smalley, R., *Of Chemistry, Love and Nanobots*, *Scientific American*, 2001, 285, 76-77. Smalley, R., *Smalley Responds*, *Chemical & Engineering News*, 2003, 81, 39-40; Smalley, R., *Smalley Concludes*, *Chemical & Engineering News*, 2003, 81, 41-42; &

^{xxxviii} See for example Royal Society/Royal Academy of Engineers, *IBID*.

^{xxxix} Bensaude-Vincent, B., 'Two Cultures of Nanotechnology?', *Hyle*, 2004, 10, 65-82.

^{xl} Jones, R. A. L., *Soft Machines: Nanotechnology and Life*. (Oxford University Press, Oxford, 2004).

^{xli} *IBID*, p. 8.

^{xlii} *IBID*, p. 123.

^{xliii} Seeman, N. C. & Belcher, A. M., 'Emulating biology: building nanostructures from the bottom up'. *Proceedings of the National Academy of Sciences*, 2002, 99(2), 6451-6455. p. 6451.

^{xliv} Mody (2004) suggests that, though nanotechnology is yet to achieve coherence as a field, similar forms epistemic determinism inform much of the thinking in nanotechnology. He states:

For many nanoists, nano is inevitable and (nano)technology does drive (some of) history. Yet there is little fatalism in the nano community; practitioners seem more eager to ride the tiger of nano than they are apprehensive that they will be crushed by it. Nanoists seem, for instance, willing to play with the design logic made possible by the analogy between biological and artificial nanomachines. ... Nano is still an incoherent mass of often conflicting communities. Determinist arguments advance the particular interests of various kinds of practitioners within this mass, as well as various critics and supporters on the outside. (*ibid*, p. 123)

Indeed, in this vein, Drexler adopts a three-way schema for addressing *how* to build nanostructures and objects—what is 'possible', what is 'achievable' and what is 'desirable'. For example:

As we look forward to see where the technology race leads we should ask three questions. What is possible, what is achievable, and what is desirable? First, where hardware is concerned, natural laws set limits to the possible. ... Second, the principles of change and the facts of our present situation set limits to the achievable. ... As for what is desirable or undesirable, our differing dreams spur a quest for a future with room for diversity, while our shared fears spur a quest for a future of safety. (*ibid*, p.39)

Despite the radical ontological commitments of nanotechnology—Schrödinger’s understanding of the fundamentally indeterminate life of matter at the atomic scale—in his schema for how to *do* nanotechnology he adopts a relatively traditional metaphysics. His identification of the possible, the achievable and the desirable may be put another way. For Drexler what is possible depends on ‘what atoms are’—their ontological being—as ‘natural laws set limits to the possible’. What is achievable is dependent upon one’s ability to technically exploit what is possible; and what is desirable is almost a separate ethical dimension about choosing amongst a range of both possible and achievable scenarios. Drexler’s metaphysic is therefore based on a fundamental deduction from an ontology of *what* atoms are to purely technical questions of what is possible and what is achievable. Drexler’s adoption—and more broadly within nanotechnology— of Schrödinger’s ontology of the atom operates as a natural limit, the absolute context in which what is technically possible and achievable are set. Indeed what is possible and achievable are simply cast as purely abstract questions.

^{xlv} Elder, K. J., ‘Soap and sand: construction tools for nanotechnology. *Philosophical Transactions of the Royal Society London*, 2004, 362, 2635-2651, p. 2644.

^{xlvi} Seeman, N. C. & Belcher, A. M., ‘Emulating biology: building nanostructures from the bottom up’. *Proceedings of the National Academy of Sciences*, 2002, 99(2), 6451-6455. p. 6453.

^{xlvii} Jones, R. A. L., *Soft Machines: Nanotechnology and Life*. (Oxford University Press, Oxford, 2004).

^{xlviii} Compare, for example, Deleuze’s sense of the spontaneous internal creative force inherent to technological change with the grand theories of the evolution of technical systems of Gille and Leroi-Gourhan – and by extension Derrida and Steigler. They suggest a grand technological lineage linking contemporary advances with an originary technicity. Though not straying into the positivistic terrain of the social-cultural evolutionists, such a theory irreducibly links technology to the ‘human’. Though perhaps respecting the import of the theory of originary technicity Deleuze also holds out for a thoroughly non-human, spontaneous evolution in technical systems and objects. See MacKenzie’s work on transduction, in this respect, IBID.

^{xlix} Conrad, M., Emergent computation through self-assembly. *Nanobiology*, 2, 1993, 5-30.

ⁱ Conrad, M., Origin of life and the underlying physics of the universe. *Biosystems*, 42, 1997, 177-190, p. 189

ⁱⁱ Conrad, M., IBID, p. 189. Conrad’s wider thesis, following Schrödinger, is that self-organising dynamics of biological systems are an extension of quantum mechanics and general relativity. That is to say that Conrad suggests a ‘great chain of being model’ in which life itself develops on the same basic quantum dynamics as the early universe. He states:

The hypothesis that well-defined actions of organisms is underlain by a non-picturable strata of possibilities is suggestive of the subjective sense of choice, intention and decision making. In both cases, multiple possibilities are collapsed into a single coherent action. According to the vertical model, multiple possibilities that have an objective reality at the micro-physical level control the recognition capabilities of macromolecules and through this control the input-output capabilities of neurons. The latter support the self-organisation of multiple assemblies of neuronal activity and support the selection of one or a few of these assemblies to control the actions of the organism at any given time. The whole process is a hierarchical collapse from a modal world of quantum possibilities into a classical world of actuality. ... To exhibit itself in the form of coherent appreciation, choice and action the manifest stratum must accumulate intricate constraints that control and are controlled by this interplay.

Conrad, M., From brain structure to vacuum and back again: the great chain of being model. *Nanobiology*, 3, 1994, 99-121, p. 120.

^{lii} Oyama, S., *The Ontogeny of Information: Developmental Systems and Evolution*. (Duke University Press, 2000), p. 130.

^{liii} Deleuze, G. and Parnet, C., *Dialogues*. (Columbia University Press, New York, 1977), 57.

^{liv} Deleuze, G., ‘Bergson’s conception of difference’. In Mullarkey, J., *The New Bergson*, (Manchester University Press, Manchester & New York, 1956 [1999]), p. 42.

^{lv} IBID, p. 274.

^{lvi} *A Thousand Plateaus*, IBID, p. 353.