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Time Matters

Temporal harmony and dissonance in nanotechnology networks

Cynthia Selin

ABSTRACT. Temporally bound concepts operate regularly yet opaquely in the management of new technologies. Emerging technologies are particularly caught in time and can be said to be in a process of becoming. Yet works concerned with innovation tend to leave time black-boxed as the future, the past and a now. What is missing is a recognition and confrontation of the diversity of temporal horizons and, more broadly, the constructions of time that are negotiated by heterogeneous actors within any technological frame. This article delves into the anatomy of time in new technologies and seeks to understand the coding mediations that occur in the nanotechnology arena. The case of nanotechnology – due to its emergent properties, affinity with science fiction and inexhaustible promises – is taken up with an analytic exploration of network participants' perspectives on time. Departing from empirical evidence within the nanotechnology arena, the focus is to explore the meanings and dilemmas implicated in disparate temporal horizons. Particular emphasis is placed on the effects of temporal diversity latent in discourses of the future as they relate to the formulation of a new technological domain. KEY WORDS • expectations • heterogeneity • innovation • nanotechnology • timescapes

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> What, then, is time? I know well enough what it is, provided that nobody asks me; but if I am asked what it is and try to explain, I am baffled. (Aurelius Augustine, AD 354–430)

Introduction

Time and technology

Time and technology are intimately bound in the fabric of our daily lives. Technology enables night vision, metronomic harmony, virtual rendezvous, and first-class travel in space. While many works on time and technology seek to discover if technologies have time (Horning et al., 1999), time regimes, temporal norms (Giddens, 1984), or perhaps how to develop a technology first (Hoppe, 2002) or how techno-time domesticates, controls or diminishes (Mumford, 1934), this work is set apart due to its assumption that time is not inherent in technology.[1] Instead, this piece shows that time is scripted in technology within particular circumstances and that temporality is instrumental in constituting a new technological domain.

What is interesting is the way that new technologies, such as nanotechnology, are caught and constrained by ideas about expectations, good timing and opportune times. This is not to suggest that there is a temporal logic inherent in nanotechnology to be revealed, but rather points to a temporal dimension coded in the way that nanotechnology is framed and represented. The concern is with highlighting the temporal coding within developmental discourses attending the technological domain. In this article, *timescapes* (Adam, 1998) evident in nanotechnology actor-networks are interrogated and implicated in some of the problems in meaningfully grasping the field as a whole.

This is to say that one of the often-overlooked elements in the innovation process that befuddles smooth communication and interaction within emergent networks is time. In the case of nanotechnology, actors attempt to define the field by their own disparate expectations disrupting an across-the-board, field-level comprehension. The temporal inscriptions attending nanotechnology are represented differently, and thus are directed and managed differently by the actors who comprise and create the nanotechnology space. The aim is then to notice the dynamics of these disparate temporalities and question what kind of role they take in the development of a new technological domain, and what kind of problematics they present for mutual understanding and orientation.

Nanotechnology

All things in small packages, all things *nano* (10^{-9}), threaten and promise futures. Nanotechnology is an emerging field of material, social, political and

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institutional apparatus that temporally and spatially bridges, confuses and fuses traditional scientific and engineering disciplines. It is difficult to speak of nanotechnology as a concrete phenomenon for it is rather a cloudy accumulation of various disciplines and traditional measures of a technological regime. Nonetheless, there are historical accounts and materialities that begin to structure what nanotechnology is.

Beginning with an inspired challenge in 1959 to push the scale of science and technological development towards miniaturization (Feynman, 1960), nanotechnology was explained in a prophetically oriented book entitled *Engines of Creation* (Drexler, 1986).[2] In more recent years, despite very few actual commercial developments deemed nanotechnology (with the notable exceptions of carbon nanotubes and computer chip lithography), the dreams and challenges of such visions have reached magnificent proportions (Wood et al., 2003).

Nanotechnology as a field is problematically defined by scale (10^{-9} metres) when instead most representations are referring to the 'latest developments' or 'newest frontiers' in different enclaves physics (materials), computer science (chip fabrication), optics and chemistry (supramolecular proteins) regardless of strict scale criteria. Aside from scale-based definitions, the other extremely diverse depictions of nanotechnology are united in terms of future deliverables. Nanotechnology promises to relieve global economic tensions, enable cheap space travel and alleviate environmental catastrophes. Researchers envisage short-term drug delivery systems with sensors made of nanowires (Allen and Cullis, 2004), while others are expecting small machines to eat cancer cells from human blood streams (Drexler, 1986). Alternatively, nanotechnology threatens to subsume human freedom, proliferate madly and create corroding, monstrous grey goo (Joy, 1996; Kurzweil, 2000). These different scripts, or stories laying out the possibilities of nanotechnology, are full of abundant and contrary expectations.

It is the dreamy aspect of nanotechnology that makes it an apt case for looking at the role of time and technology. Since the term was coined and the field first began to take shape, nanotechnology has been saturated in futuristic promises and threats. Both the uncertainty and expectancy of nanotechnology lend a certain degree of fantasy or science fiction to most characterizations. The promises infused in nearly all description of nanotechnology make time and the future a distinguishing characteristic of nanotechnology as a research area. Seldom can one locate a technology so firmly floating in speculation, expectations and distant future benefits.

Nanotechnology is largely about potential and theoretic possibility, but the reins of time are being drawn in, manipulated, obscured and ravaged by different actors in the field (Selin, 2002). Development is under way but far from complete. The question of *when* these scientific advances will happen is on everyone's mind (European NanoBusiness Association, 2004). For example, a

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director of the California Nanotechnology Initiative confirms, '[p]eople in politics, like [the current director of the National Nanotechnology Initiative] in the White House are more willing to say when'. The scientists, however, are more hesitant to date their promises as 'they know what they don't know, and they are always interested in what is just beyond' instead of the far future.[3] Others in the nanotechnology space are clear that nanotechnology is commercially viable now and is 'a hot area anointed by the technology press where investors flock in like heat-seeking missiles'.[4] Based on empirical observation of the field, I propose that the confusion over what counts as nanotechnology is aggravated by the multiplicity of time concepts apparent in the field.

The case of nanotechnology clearly suggests that temporal perspectives, including visions of the future, are necessary to the understanding of this field. Such a concert of disparate temporality in terms of future benefits and opportunities leads to conflicts and widespread miscommunications over what counts as nanotechnology (Selin, 2002). The fight for who creates legitimacy in the field hinges on time perspectives and the pace of development. Clearly, the temporal divisions require further explanations and an analysis that can unravel the implications of their disparity.

Theoretical inspirations

The kind of work that goes into creating and coordinating a new technological domain is manifold and involves a broad range of networked actors and scripts (Akrich, 1992). A new technology is not merely the work of a lonely inventor or visionary writer, but rather a whole host of interlinked actors, human and non-human, that work to usher in a new technological domain (Latour, 1987; Law and Hassard, 1999). This is to say that science and technology are actively made through claims in time (and in space) and not born or evolved inevitably. New developments are actively created through funding decisions, societal demands, market incentives and other such easily quantified indicators, as well as through negotiations of what the future holds for the technology and other types of support.

The expectations surrounding the technology, the promises made, and the pay-offs guaranteed all contribute to the success, strength and efficacy of the resources poured into a new technology. More explicitly, it is the temporally bound claims and counterclaims that testify for the technology and serve to bring it to life (Rip and van Lente, 1998; Brown et al., 2000). This view focuses on what meaning technology is given in regular practices and how such significances are embedded in institutions, project plans, investment schemes and so on.

To grasp the meaning of time in technology, or the meaning of technology in time, is not only to explore the social worlds (i.e. venture community, firm

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culture, governmental programmes) that embed the technology. Nor can a 'pure' look at technology alone provide clues to the meaning of time. Temporality in new technologies is more than socially constructed and more than overtly determined. While the rigidity of these departures can be eased by a nod towards embeddedness and contextualization, we must push further into a zone of less comfort where meaning is found *in between time*. We move into the space where technology can only be understood as becoming, as neither solely constructed, nor determined, but amid the conceptual territory of the two perspectives. This leads to the spaces lurking between strict past–present–future constructs becoming the meanings made *in time*.

Interviews with actors involved in the nanotechnology space brought to the surface the dilemmas around time, as the future and the development of nanotechnology appeared as key differences and points of contention. This article largely draws on 17 personal interviews, as the aim here is to extract time concepts *in actual use* and their relation to the innovation process, to timing and the constitution of the new domain.[5] The fieldwork is inspired by the epistemological departures found in actor-network theory (ANT) (Latour and Woolgar, 1979; Latour, 1987; Callon, 1999; Law and Hassard, 1999) and the methodological guidance of Kvale (1996). Discursive positions are framed as timescapes (Adam, 1998) and analysed to see how the future and time concepts are bound in working definitions and productive perspectives on nanotechnology.

Timescapes in Nanotechnology

Time

Innocently looking towards time, we see a clock with seconds ticking discretely and hours passing sequentially which lead to days turning into years and so on, as far as we can imagine. This is *chronos* as defined as the exact quantification of time, which is often simply called 'clock time'. Time, as in a ticking clock, is linear and objective. However, since Einstein, concepts of time tend to honour fluidity, subjectivity and the flow of experience. These concepts are in direct contrast to the main features of clock time: an even and continual flow, free from contingent events and periodicities, precise and quantifiable. Chronological time is abstract, singular and unified and can be easily coded. On the contrary, following this fresh concept of time, we speak of *times*, not time, and *futures*, not the future. Time is now considered relative, plural and bound to experience.

The *experience* and *naming* of time are inseparable from some temporal absolute. Time is not just the clock ticking, but also about speed, simultaneity, pace, tempo, pause, transitional periods, urgency, precision and repetition, and the relations between the past, present and future. It is about good times and bad

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times. As Clark (1985) explains, 'time is in the events and events are defined by organizational members' (p. 36). It is not enough to say that time is subjectively experienced, for time also determines social events and disciplines human behaviour and experience in peculiar ways.

Codes

Codes are a means to organize experience and make sense of past, present and future constructs. The codification of time refers to the way that a multiplicity of temporal experiences, associations and representations become resolved and simplified into a shorthand reference. In other words, coding refers to how diverse temporal information is set into quick representations. Butler (1995) explains codes in the way that 'the present is preceded by a whole series of events and decisions which become sedimented into some kind of order codifying out experience' (p. 928). Such order is resolved in codes that 'signify states learned from past action and enable communication about those states to actors in the present' (p. 928). We can also imagine temporally analogous, symmetrical codes that are oriented towards the future instead of the past. Some codes, for instance those bound to promise–expectation claims, signify states of anticipated action that also 'enable communication about those states to actors in the present' (p. 928). Such chimerical codes authorize decisions by specifying potential consequences instead of historic experience. Either way, codes are intersubjective devices that provide a common terminology to relate to sequence and pace, dissonance and harmony, and synchronization or coordination.

Timescapes of nanotechnology

Codes link together to formulate *scripts*, or stories, about the unfolding of events. Storied or scripted representations of the movement of time are products of ongoing interactions of networked actors. Temporal coding is thus about the way that time is built into stories. Such stories are analysed here as *timescapes*.

'Timescape' is a term borrowed from Barbara Adam (1998) who, in her study of environmental risk, positioned time not only as the key to analysis but, more importantly, as a concept that can be readily translated to other settings. As a landscape architect designs spaces, a timescape artist renders time visible and focuses on the design of temporality. This notion of timescape includes multiple time concepts, from rhythm and tempo to harmony and dissonance, and seeks to reveal the veiled temporality of artefacts and stories. In this next section, timescapes of nanotechnology are resolved as stories of trajectories, disruptive, indeterminate, emerging and immediate.

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On trajectories or paths

One of the most evident views on nanotechnology relates to a deterministic characterization of nanotechnology as travelling along a set path. Some like to use the terminology ‘technological trajectory’, suggesting that the activity of technological progress is limited by the economic and technological trade-offs born of a specific technological paradigm or regime (Dosi, 1982). One of the more famous and in-vogue expressions of a technological trajectory is Moore’s law.[6] Moore’s law is appealing for its simplicity and for its precedence in the chip industry and seems to cause no loss of faith in the notion that we can predict the development of nanotechnology, as evidenced by the inexhaustible popularity of the Moore’s law chart at conferences, scientific meetings and other such showcases of nanotechnology. This is an extrapolation model that considers predictability not only in terms of *what* will happen, but also in terms of *when* certain developments will come to fruition.

Akin to Moore’s law is the notion of path dependency. Path dependency assumes that there is a tight coupling between elements of technological systems that are resistant to change. Such elements interlock with each other as they are built over time, resembling a tree with intertwined roots. In this case, technological alternatives and fundamentally new technologies have a hard time pushing into existing regimes. Path dependency often manifests in the nanotechnology space as a continuum from microsystems (MEMS) to nanosystems (NEMS) as new ideas build on existing knowledge and only incremental innovation may be foreseen.

Path dependency relies on the powerful influence of the past on the present and future, which is to say new paths can be based on old paths as evidence in this story of NASA’s nanotechnology initiative. NASA uses road maps to represent expectations and desires, the past and the future. When asked about how they create road maps for nanotechnology, the director of NASA’s nanotechnology effort explained, ‘First, we consider what we know technologically now. Even if nothing else happens, it will take 10 years for that to be developed as a viable product on Wall Street. [Ten] years is even conservative, maybe it takes 15 years. Then you think of a wish list . . . and factor it with the existing technology.’[7] Such a wish list is predicated on what is conceived as a scientific or technological possibility at the time. This means that current research is strongly predicated on past systems and the new visions serve to continue momentum along a path.

Path dependence can also emerge from less procedural input and instead result from an emotional or social foundation. In the case of cooperation between university and industry in California, the past figures largely into the possibilities for the future due to trust and credibility built over time: ‘The faculty here and the researchers at the company are colleagues, and essentially

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[innovation] doesn't work unless there is a well established working relationship that arises out of the scientific community.'[8]

Discontinuous and disruptive

Some of the interviewees represented the development of nanotechnology as occurring not as a straight path, nor as a linear process, but instead as an open space susceptible to disturbances, gaps in development, and discontinuity. For instance, common terms affectionately used are 'disruptive technology' and 'discontinuous innovation'. A discontinuous innovation involves new technologies that produce a gap, or 'chasm,' between production and possibility in customer demand (Moore, 1991, 1995). This update of life cycle interplay between product and market evolution portrays a blip in linearity of progressive growth and prosperity. However, such a lack of customers is not the end of the road but rather part of a larger process in which different types of customers gradually accept the technology. First, the 'techies' fulfil their gadget fantasies and 'visionaries' astutely incorporate the technology into business models. The mainstream customer remains cautious or at least turned off for a time and classic marketing techniques are unsuccessful. The technology is deep in the chasm, until, by some managerial genius, the company 'crosses the chasm' and encounters an avalanche growth in sales, which is known as the 'tornado'.

The CEO of a start-up dealing in optical switching in Silicon Valley lives by Moore's notion of discontinuous innovation and sees himself as an innovator able to overcome the chasm. He follows the crossing-the-chasm philosophy and explains the failure of similar companies by way of the theory. He is active in teaching this perspective to others, particularly the marketing aspect to scientists and engineers.[9]

This is a neat theory that can explain the failure or hold-up of some technologies. It is an explanation of a lack of commercial success through bad timing (which can only be so after the fact, *ex post*). For example, some technologies depicted as being stuck in the chasm are voice recognition, AI, and the electric car. Others have died in the chasm, such as the Newton PDA and the gyroscopic mouse. The notion of disruptive technology gives a break to unfettered progress and growth; it allows interruption, offers the inspiration for perseverance, and tempers unrealistic expectations. If a technology fails to deliver on a promise, then managers, entrepreneurs and investors take respite in the idea that it is really just the chasm and that executing X, Y, and Z will restore them to grace. They are on the road of righteousness – it is just a bumpy ride.

Uncertain and indeterminate

The nanotechnology space is also populated with actors that characterize nanotechnology as out of control and uncertain. While this is a less common view, it is still evident and adopted by some powerful players. Not without irony, such

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perspectives are often touted by people further away from the technology, like marketing gurus who deal more with the customer side of demand. Management consultants and futurists who wish to sell services to companies or venture capital firms on how to manage the uncertainty usually present this view. For example, a retired computer engineer, now a due diligence processor for venture firms, notes the dilemma surrounding emerging technologies: ‘what appears to be the future for many is already the past for some, who are now unfolding it into the present’.[10] This reflection demonstrates how temporal meaning making is implicated in the potential of nanotechnology.

Akin to the idea that nanotechnology is inherently uncertain is the notion of nanotechnology’s development as an active, emergent and continually ongoing process. Emerging technologies are understood to be derived from radical innovations or evolutionary technologies derived from previously separated research streams (Day and Schoemaker, 2000). Conditions such as an expanding knowledge base, innovations in application within existing markets, and/or the development of new markets can help to bring about new technologies. One nanotechnology entrepreneur explains, ‘I am at the forefront and willing to take a risk when there are so many unknowns. I have to have direction and focus and keep everyone else focused. Managing risk is my primary task.’[11] Of critical importance in the case of nanotechnology is the idea that emerging technologies stretch the future from the past. The rhetoric about nanotechnology found on the TechnoFutures website in 2002 (www.technofutures.com) exemplifies this position; ‘nanotechnology, as a multi-disciplinarian, system level arena of scientific and technical development, is rapidly evolving away from the realms of academic obscurity, and into becoming the transitional threshold of an emergent industrial revolution’. Such a transition rewrites history *and* creates the future.

Immediacy

We often divide time into a past, present and a now. While some of the timescapes are oriented towards the past, like those dealing with trajectories, others dwell in the future, as stories drenched in uncertainty. We also find timescapes that are firmly grounded in the present. Such immediacy is evidenced in talk of opportune times, fashion and urgency. Nanotechnology is of *kairos* by implying ‘an occasion for agency that is specific not to any time, but to this time rather than another’ (Brown et al., 2000). Such *kairos* is seen when venture capitalists hedge bets and encourage investment in nanotechnology while entrepreneurs speak of burning opportunities and the time as now (Wolfe, 2002). This led one entrepreneur to state that ‘nanotechnology is at an inflection point where the whole arena is becoming a fast-paced investment space’.[12] The US National Nanotechnology Initiative was created largely on a platform of immediate needs and the timing being right. Politicians say that ‘nanotech-

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nology is trendy' and that the time is right to plough heavy governmental funding into harnessing 'the excitement about discovering where fundamental knowledge is being developed . . . at the subatomic regime'.[13]

Many speak of nanotechnology as auspicious with urgency of tone. For instance, Danish political players in the nanotechnology space actively promote new funding based on the notion that the time for nanotechnology is now and that Danish scientists should not be 'left behind'.[14] Good timing and expectations of it being the right time for nanotechnology figure largely in the field's legitimacy-building process.

Timescapes conclusions

The timescape of nanotechnologies' development can be read as scripts, staging the scene and setting the tempo of production. In this way, timescape is an element of the actor-network defining the structure of nanotechnology. These different representations of nanotechnologies' future display particular cultural, political and economic significance. They are signing, signalling, and highlighting different elements. Nanotechnologies' potential figures in each of the scripts. In this sense, the technological scripts are encoded within time in terms of innovation potential.

In a field of promises and threats, actors have to constitute nanotechnology temporally. Actors are forced into temporal delineations when making their representations of nanotechnology. This is what is qualitatively different about the technical materialities of nanotechnology and why time matters for the continuing innovation of nanotechnology.

Yet, it is also important to note that techno-social actors may primarily live in one timescape. However, such fixed linkages of actor-to-script are not absolute. While we see scientists mostly focusing on short-term developments, engineers indulging in longer-term horizons and entrepreneurs leveraging power by keeping their vision to five-quarters, we also can see moments where actors selectively adopt their timescape to suit their needs. For example, an entrepreneur may follow a disruptive script when running their business, yet when seducing investors, may adhere to trajectory script. So while we notice that venture capitalists are in tension with the visionaries who in turn are in tension with the technicians, not all socio-technical actors will always, all the time adhere to a particular script nor exclusively occupy one actor type. For instance, the nanotechnology space is host to figures such as B. C. Crandall, author of *Nanotechnology* (2000), who is also a visionary and a venture capitalist. Ralph Merkle (2004) is a particularly outspoken advocate of nanotechnology. He is a scientist by training, edited the journal *Nanotechnology*, yet also ran nanotechnology firm Zyvex and now is a professor of computing. Although the timescapes categorization is empirically linked to an actor, the actor type does

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not necessarily demand a particular timescape in all circumstances. These distinctions are critical in order to allow the analysis to focus on the dynamics of timescapes and move away from individual actors and actor types.

Revealing and cataloguing the timescapes operational in the nanotechnology arena creates a starting point for understanding the role of time in the development of a new technological arena. These timescapes evidence a diversity of time concepts in use and exchanged between actors. There is no consensus about when nanotechnology will bear fruit, or at *what time* actors should be coordinated towards some mutual aim. The potentiality of nanotechnology is definitely on the agenda, yet hotly negotiated.

Role of Diversity in Timescapes

Developmental harmony: coordinating meaning

As we have seen, time is embedded in the representations of the technology. At stake is the multiplicity of scripts and the diversity that they maintain. They reveal different temporal horizons, some near, some far. Futures can emerge quickly or incrementally over a longer period. They are implicit yet also loudly compete with one another. Does this diversity create problematic tensions?

Dilemmas about the way that the temporality of technology is diversely configured are connected to one of the most vexing problems of innovation management: how to get different people in different spaces or places coordinated *in sync* and aware of each other at the *right times*. Whether the distance is due to departmental walls, geographic dispersal, temporal logics, or epistemiological differences, such spaces and places present barriers to effective communication, alignment and coordination.

These divergent spaces and places particularly victimize network coordination. Technology networks span multiple domains and transcend not only firm boundaries, but also sectoral and professional domains described as the Mode 2 production of science and technology (Gibbons et al., 1994). Such networks are dispersed, thus requiring careful articulation and diffusion of knowledge (Hislop et al., 1997). Coordination here then builds on the idea that science and technology do not develop in a vacuum but involve a wide range of actors that must come together *in time* and often – though not always – *in space*.

Coordination is traditionally defined as 'combination in subtle relation for most effective or harmonious results: the functions of parts in cooperation and normal sequence' (Gove, 2002: 502). This definition calls attention to bringing together, to harmony and sequence, to time and space. In classical management literature, Mintzberg (1983) talks about coordination in terms of what is being coordinated. However, modern perspectives on coordination view networks

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functioning as meaning-making channels (Blackler, 1995; Tsoukas, 2000). As we have learned, the management of meaning is of critical importance (Smircich and Morgan, 1982; Weick, 1995); we can even speak of *coordinating meaning*. In our case, such network negotiations or mediations constitute not only what nanotechnology is today, but also grant particular significances for the future.

Coordination, in whatever guise, deals with time, timeliness, and sharing knowledge and knowledge objects. Whether determining priorities, aligning efforts within well-designed teams, or ensuring harmonious results, coordination becomes problematic in such an open-ended, as yet undefined, technological space like that of nanotechnology. There are substantial difficulties in successfully sharing knowledge and creating joint meanings across networks that are amplified in emerging technology networks. How, for instance, can the network actors come to a consensus or a shared understanding about directions, visions and goals amidst uncertainty and the kind of temporal tensions evidenced in the field? How is a promise, or any futured discourse, legitimated collectively?

Convergence and compatibility

The task in an analysis of temporal codes is to unpack the meaning implied in the codes in order to read what they are loaded with, and for whom. It is thus important to note that while codes can be shared, there is plenty of room for misunderstanding – codes can be common or divergent. The degrees of convergence and compatibility within and between the timescapes are indicators of understanding. The codes are thus instrumental in creating meaning and in the case of nanotechnology define the potential contours of the field.

Within each timescape, we can tease out attributes of the temporal code that drive the script. The scripts and codes lead to different strategies about how to coordinate, manage, create meaning, and act in the burgeoning field. Scripts discipline thought and behaviour in their prescriptions about what is to come (Akrich, 1992). One of the ways that the representations of the future structure and coordinate activity is through time discipline (Thompson, 1967). Depending on the script that one ascribes to, different concepts of time and speed (seen here in conceptions of technological change, innovation, competition and market forces) are used. The next step is then to unpack the meaning in terms of what the script consequences for convergence and compatibility. Table 1 translates the timescapes into code in order to unravel the implications for innovation strategy.

The term *trajectories* suggests more of the same, an extrapolation model that promises continuous, incremental development. The innovation strategy is straightforward with no new expansion of the network, but rather a continuation of existing patterns. *Path dependency* takes for granted that the past and present

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TABLE 1
The translation of timescapes into codes

Timescape	Temporal Coding	Innovation Strategy
Trajectories	Time as exponential	Inevitable following of patterns
Disruptive/ discontinuous	Time as anarchic	Quick reactivity; 'crossing the chasm'
Path dependence	Time as linear, intimately bound with past	Identify path and follow
Emerging	Time as now	Action, not forethought; speed
Indeterminate	Time as unpredictable	Assert desires and create meaningful futures

persist into future possibilities and enables the prediction of the fate of a new technology based on current and historical indicators, or path markers. Here we could expect a planning mentality to govern strategic practices, with perhaps a heavy investment in forecasting and industrial analysis.

The notion of *disruptive* technology assumes a displacement of another technology, a kind of battleground where the favoured technology overtakes the present technology leading to a future of winners and losers. The aim is then quick reactivity. On the other hand, an *emerging* technology sets the playing field for a broad 'ecology of innovation' of limitless possibilities, new markets and services. Rather than reactivity, this script dictates a more active stance that often translates to 'being first'. Finally, *indeterminate* technological change could lead to either desperation or an assertive, creative move to construct desirable outcomes.

The roles of these different temporalities evident in timescapes suggest different strategies for innovation. Temporalities structure expectations about possible interventions and likely outcomes. Timescapes hold within ready-made positions about the likelihood and necessity of different kinds of knowledge exchanges. Temporal diversity creates tensions regarding what sort of work is on the agenda, with what results and with which actors, that make convergence and compatibility tricky.

Dilemmas of Temporal Disparity

This section deals with how and why convergence and compatibility become tricky with temporal disparity. It is argued that mutual understanding and orientation are challenged by the coding structures latent in the timescapes. Four

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main dilemmas are addressed here which temporality poses for coming to terms with the field of nanotechnology.

The first dilemma emerges when a domain following one timescape becomes accountable to another, as in the case of larger government programmes, where scientists must deliver results to the politicians or the public. The president of the Foresight Institute, a non-profit organization devoted to educating the public about the coming of nanotechnology, stated, 'There is a huge culture clash with scientists who think [developing nanotechnology] is difficult and see that the expectations are overblown. The public doesn't care how hard it is for the guy in the lab, they care about the overall progress . . . you have a expectation clash.'[15] Such an expectation clash creates a tension that is often difficult to articulate, much less resolve.

The second dilemma revolves around different expectations and, specifically, the problem of unmet ones. As in a previous example, we see that the credibility of scientists diminishes due to their adherence to different timescales. This phenomenon is demonstrated most prominently in the case of Eric Drexler, and the way that factions of the scientific community disparaged his vision of nanotechnology. The real dilemma is that Drexler's proposed deliverables put impossible pressure on researchers and created animosity, since he defined accountability for other members of the scientific community. In the final analysis, it was not only a problem of a sincere difference of opinions but rather a problem of scale: Drexler was thinking in terms of long (20+ years) time horizons, whereas his colleagues were thinking in terms of less than five years into the future (Selin, 2002). While different time horizons may be a benefit in some cases (Hayes and Abernathy, 1980), they are often a cause of more intractable problems. In the case of Drexler, the price was his reputation (and the reputation of his ideas) and his inclusion in the in-crowd of nanotechnologists.

The problem of temporal diversity is also about bad recipes. Recipes are a way to organize time constructs into prescriptive codes of behaviour (Schutz, 1967). While these recipes may be tacit or explicit, the codes that formulate specific actions are more evident. Since recipes are often tacitly understood, and thus unexamined, they often underlie organizational difficulties without being apparent. The problem occurs when the temporal diversity encoded in recipes undergoes change or renegotiation without a corresponding overhaul of interdependent organizational recipes. The consequence is an inappropriate sequencing of events, leading to, for instance, conflicting agendas and unfortunate investments.

Lastly, we should not overlook the obvious dilemma of there being no codes, routines or recipes. Some new technologies are off the map. This is the case when, to quote March (1988), 'except in all but the most routine decisions, where knowledge can be contained in relatively homogeneous codes, history is an ambiguous guide to present action in order to reach preferred futures'

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(pp. 13–14). There are always some ways to rely upon the past, but the degree to which the past can be coded to make sense for the future is limited.

Overall, we can see that temporality influences the degree of stability within the scripted codes. For example, unmet expectations imply a weak alignment of codes. Bad recipes, on the other hand, relate to what Callon (1991) refers to as irreversibility, or when a recipe becomes solidified and is not easily revised.[16] The codes latent in the recipe then define subsequent translations. Finally, the problem of a lack of codes exemplifies a near-total lack of alignment that leads to an absence of convergence. Convergence and compatibility are thus linked up with the often-hidden, or implicit, codes within the timescapes, thus problematizing harmonious innovation.

Conclusion

A technological regime is formulated not only from institution building, concrete scientific knowledge, engineering practices, and their associated products, skills and procedures, but also from all the other intangible resources that serve to legitimate, support and authorize productive decisions fortifying the field. All elements interact to affect knowledge and knowledge practices within a given technological domain. Heterogeneity refers not only to actors, but also to scripts and temporal codes. Variant timescapes in representational discourse are also elements of the actor-network.

Noticing temporality, as we have in this article, makes apparent the inevitable conflicts and messiness of an emerging field. Tensions evident in the variant timescape are more than part and parcel of the development of a new technological domain – they are a function of stable-enough alliance building. What first appears unstable, in the end, is that which creates stability through contradiction, dialogue and reconciliation. In the process of becoming, nanotechnological material temporalities dance, morph and evolve in a markedly messy way. Pickering (1995) calls this the 'mangle of practice', and others have referred to technologies' chaos as 'bricolage'. The contribution here is that time is implicated in the mess, not with linear neatness but with nomadic contrariness. Time is but one aspect of the mix, one that speaks critically to the obduracy of scripted meanings and the difficulty in distinguishing reality from fiction in science.

Issues around time and meaning conclude with the intricacies of complexity and contingency supplied by new technologies. Following Horning et al. (1999), 'it is exactly this constitution of technology which increases the potential for flexibility, the capacity to react to changing situations and to innovatively connect heterogeneous contexts' (p. 305). The flexibility engendered by the diversity of temporal constructs attending nanotechnology provides a vigour and suppleness that lead to robust, momentous expansion.

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Grasping a new field will always be difficult, yet the case of nanotechnology demonstrates the increased slipperiness in grasping an emerging area so saturated in multiple temporalities. Nanotechnology has provided fertile ground to explore the meaning and implications of temporality. In the end, I have said little about nanotechnology *per se*, and much about time and the processes of emergence in new technologies. Nanotechnology has provided the case yet we can be sure that the temporal materialities of nanotechnology will continue to be reconfigured, renegotiated, recoded, and hence retemporalized.

The permanence of this research offering is then based not only on how to grasp fleeting change processes in good time but also, once frozen, how the time concepts and temporal coding can be analysed. Slicing into timescapes is useful in illustrating the problems with time attending a new technological domain. The timescapes of nanotechnology have provided a way to open up temporally bound scripts to see how each claims its own nuances.

Notes

1. There are, of course, notable exceptions that also address time scripted in technology. See Pickering (1995) and Brown et al. (2000).
2. The term 'nanotechnology' was coined by Taniguchi in reference to his work in 1974 on ultra-precise machining, but lay dormant until Drexler's book which refers not only to molecular engineering, but also to a revolution in the tenets of capitalism (such as ownership and the distribution of wealth), life span, environmental degradation and the constraints of living on planet Earth.
3. Personal interview with Director of state-wide university–industry nanotechnology initiative, 25 February 2002, Los Angeles.
4. Personal interview with nanotechnology entrepreneur starting an imaging technology company, 21 February 2002, San Francisco.
5. A series of enquiries into the nanotechnology space have occurred from which topics bordering on the workings of time concepts are presented. The sources are drawn from such textual, material and human elements as legislature, financial instruments, universities, government labs, entrepreneurs, venture capitalists, strategic plans, public media, and last but not least, scientists and engineers. It is the scientists and engineers, those working in daily practice with nanotechnology, who are uniquely suited to discuss the future potential of their work. Given that the study is concerned with the rhetoric and conditions – the text and materiality – surrounding nanotechnology and time, marketing gurus, marketing reports, futurists, foresight studies and technology advocates are also included in the investigation. They contribute to the development of the field by their funding and interpretations. Inclusion of these sources helps to address more explicitly the future character of the technology.
6. Moore (1991 & 1995) observed an exponential growth in the number of transistors per integrated circuit and predicted that this trend would continue.
7. Personal phone interview with head of NASA's nanotechnology project, 22 February 2002.

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8. Personal interview with Director of state-wide university–industry nanotechnology initiative, 25 February 2002.
9. Personal interview with CEO of optical engineering company, 12 February 2002, Santa Clara.
10. Personal interview with due diligence expert for the nanotechnology sector, 20 February 2002, Berkley.
11. Personal interview with CEO of optical engineering company, 12 February 2002, Santa Clara.
12. Personal interview with due diligence expert for the nanotechnology sector, 20 February 2002, Berkeley.
13. Personal interview with Director of state-wide university–industry nanotechnology initiative, 25 February 2002, Los Angeles.
14. Personal interview with senior scientist initiating a nanotechnology programme in a national lab, 3 May 2001, Roskilde, Denmark.
15. Personal interview with president of a nanotechnology advocacy and education group, 29 January 2002, Los Altos.
16. The STS concept of irreversibility is mentioned while noting that it is contrary to most sociological perspectives on time, in that time is never considered reversible in social theory (see Adam, 1998).

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