INTRODUCTION

Cornelis Disco and Barend van der Meulen

In 1970 the United States Atomic Energy Commission announced a plan to bury long-term radioactive waste in the salt mines of Lyons, Kansas. Ten years of careful investigation had demonstrated the safety of salt mine disposal and the suitability of Lyons as a trial site. Public acceptance seemed a matter of course. However, efforts to implement the plan aroused a major public outcry. A well-researched and presumptively routine technology became a practical impossibility. What had gone wrong? Since its founding shortly after World War II, the Atomic Energy Commission had done its best to monopolize decision-making on nuclear waste disposal. Accordingly it had worked out a highly ‘bureaucratic’ and ‘technological’ solution for radwaste disposal which excluded other organizations and groups. Against the background of this legacy, Lyons was a bridge too far. The Atomic Energy Commission’s actions there produced a vocal opposition composed of both old and new opponents. Lacking allies, the Atomic Energy Commission was forced to recall its carefully constructed plans (De la Bruhèze).

In 1985 the famous cruise ship Queen Elizabeth II was renovated. Among other things the owners were interested in upgrading the efficiency of the propeller system. An entirely new type of propeller system was proudly presented at conferences as an example of the manufacturer’s capabilities. However, at the sea trials of the renovated Queen Elizabeth II the propeller blades broke off. Two years later, the manufacturer was able to market a similar propeller system only after assuring the public that the entire design process had been overhauled. The new design was publicly touted, stressing the R&D investments, the thorough tests and the systematic nature of the design process. Apparently, not only the blades of the Queen Elizabeth II had been damaged in that first voyage, but also the standards, design rules, testing procedures, and the reputation of the manufacturer - and all had to be repaired. The ‘misbehavior’ of a couple of propeller blades had not merely destroyed a propulsion system, but an entire, carefully planned, socio-technical order and had forced the manufacturer to create a new one (Van der Meulen).

In 1964, Gordon E. Moore, the research manager of Fairchild Semiconductor, noticed a pattern in the development of memory chips. He observed that about every year and a half the number of logical gates in the largest chips had roughly doubled. He predicted that this trend would continue. Events have borne out Moore’s prediction; so much so, that ‘Moore’s Law’ has become accepted as a kind of natural law describing the growth of memory chips. But in fact this growth can hardly be explained by the technology of chip-making itself. Instead, Moore’s Law becomes true because the producers of memory
chips themselves try to achieve what Moore’s Law predicts - because this is what they expect the competition to be doing and this is what they expect customers (those who incorporate memory chips in their products) are planning for. So instead of the ‘law’ being a description of an autonomous technological process, it frames expectations which shape actors’ efforts and so it becomes a self-fulfilling prophecy (Van Lente and Rip).

What do these vignettes tell us about getting new technologies together? First, they all, in different ways, demonstrate that technological artifacts are inevitably embedded in social order. They show that it makes no sense to speak of, to design, or to implement technological objects without considering their societal context. In fact, they suggest that getting new technologies together requires shaping social orders no less than designing technological objects. These are simply different aspects of a single process, the making of ‘socio-technical order.’ Second, the vignettes show that getting new technologies together successfully requires coordination among many different actors at different locations and through time. This coordination can be achieved in many ways: by markets, through organization, by knowledge, by standards, and even by expectations about what will likely be the case. The stories suggest that the ways in which this coordination is achieved and maintained will have consequences for the future development of the technology.

The first story emphasizes that getting new technologies together also requires getting societal actors together and that poor strategy on the second count can come home to roost. The Atomic Energy Commission’s failure at Lyons was not simply due to the ad hoc emergence of a powerful opposition to a potentially risky plan but was a result of the very way the Atomic Energy Commission had been developing radwaste technology over the years - especially its exclusion of meddlesome but important actors. The Atomic Energy Commission’s pursuit of a bureaucratic and technological radwaste technology simultaneously antagonized important actors in the radwaste domain. In this context, Lyons was a bridge too far. By linking issues and actors throughout the years, opponents of the plan succeeded in mobilizing the legacy of antagonisms and the Atomic Energy Commission found itself facing a solid wall of nay-sayers - and a debacle for its carefully prepared salt mine deposition technology.

The second vignette radicalizes this point in showing that artifacts are never isolated objects, but always elements of complex networks of hybrid elements. Artifacts emerge from those networks, reflect back on them and in so doing shape their futures. This story shows that the new propeller system is an exponent of its design network; the artifact embodies the network’s particular standards, modeling practices, and organizational arrangements. When the artifact is submitted to practical trial, the entire design network is too. And when, as in this case, the artifact fails, the entire network fails as well. In order to recover, to re-establish credibility, it is not enough simply to redesign the propeller system itself. The entire design network must be overhauled as well, for there is no reason to trust knowledge, procedures and norms that have produced a dramatic failure in the past.
The third story shows that actors involved in competitive games (like technological competition) may evolve norms to regulate the rate and nature of their R&D investments. The more objective such norms appear to be, the more predictable will be the behavior of other actors and the easier it is to adjust one’s own behavior. With a naturalistic ‘law’ describing technological progress, chip manufacturers tacitly agreed to cooperate in making it come true - hence enabling them to act rationally in a dynamic and potentially open-ended process. In this case, although the market is supposed to regulate competition among firms, it is clear that this does not structure the situation sufficiently. Simply trying to outpace competitors, with no idea of where they are going, can lead to self-destructive efforts like overinvestment, hasty marketing, poor R&D strategy. Instead, norms for expected (and desirable) outcomes coordinate the players. Their mutual expectations now constrain and structure their behavior. They have immersed their economic game in a well-defined structure of expectations which allows them to proceed with less risk.

**Technological Determinism and Social Constructivism**

These three vignettes illustrate a perspective on technology development which has emerged over the past decade, among other places at the Department of Philosophy of Science and Technology at the University of Twente, where most of the contributors to this volume are located. The stories - and the chapters of this book - exemplify the broadly shared conviction at Twente (and indeed within the field of Science and Technology Studies in general) that technology is not an exogenous and autonomous force but a contingently constructed phenomenon resulting from what actors do and think and how and with whom they interact. At the same time the contributions to this volume emphasize that this construction is also itself a structured process - because in the process of construction actors are always constrained and enabled - by history, by norms, by their own expectations, by the logic of competitive games. Of course, emergent and embedded technologies are themselves also an important structuring agent in society and history, but that is another story for another book.

The Department of Philosophy of Science and Technology at Twente is widely considered one of the founding centers of the new social studies of technology. This approach builds on a number of traditions which achieved an uneasy rapprochement at two international conferences held at Twente in the second half of the 1980s. The contributions to these conferences (Bijker, Pinch and Hughes 1987; Bijker and Law 1992) exhibit a shared horror of technological determinism and a strong commitment to several varieties of social constructivism. Technological determinism avers that technologies develop according to an inner logic (or in more sophisticated versions as a reflex of scientific discovery) and are therefore more or less impervious to human influence. On this view you can’t hurry technology, but neither can you restrain it once its time has come. Social constructivism argues, contrariwise, that technologies are shaped by the actions, strategies and interpretations of
human actors. Now at Twente, almost ten years down the road, horror of technological determinism is as vigorous as ever, but so are concerns about how to avoid getting bogged down in utter contingency - in approaches which represent technologies as endlessly malleable and freely interpretable by groups of actors. Some strains of social constructivism seem to be taking this course.

Other and earlier social science explanations of technological development also attacked technological determinism. Long ago, Adam Smith, and after him Marx, Engels, and Schumpeter explained the development of production technologies as a reflex of capitalist competition. Contemporary adherents of labour process theory like Harry Braverman (1974), David Noble (1984) Edwards (1979), economists like Dosi (1982), Nelson and Winter (1982) and other students of the innovative behavior of firms like Abernathy and Clark (1985) have pursued different aspects of this tradition. At another level, social critics like Lewis Mumford (1963) and Jacques Ellul (1964) have made grand efforts to explain technologies as the outcomes of the political and cultural forces of an epoch. Studies like these are laudable because they study technology and its development as part and parcel of broader societal processes. In this sense they clearly adumbrate the program of social construction of technology. Nonetheless, these efforts are ultimately disappointing because - unlike social constructivist studies - they tend to black-box technological artifacts and their development and see technologies as direct reflexes of social structures and strategies - thus committing the inverse of the sin usually ascribed to technological determinism, i.e., economic, political, cultural, or social determinism. These are a small improvement over technological determinism. History of technology, in other words, cannot simply be reduced to economic, cultural or political history, but has its own specific dynamics.

Paradox or not, we would like to have our cake and eat it too. We want to retain the focus on technological detail and actor strategies characteristic of the social constructivist approach - that is, proximity to an actor-centered and materially detailed history of technology. On the other hand, we want to embed, so to speak, voluntarist accounts of technology development in structural accounts of sociotechnical order, we want to see technology development as constrained and enabled by structures of prior technology and history - which is the particular virtue of more traditionally sociological or economic approaches to technology. This book can be seen as a set of explorations into specific technologies, a sequence of dioramas portraying different kinds of technology in different settings, in which - for better or worse - these two approaches are mobilized simultaneously.

The three stories already reveal something of what progress along this track might involve. In a like manner, the contributions to this book place the constructive efforts of technology’s actors within the constraints and possibilities of existing or emergent social structures. In describing how actors and networks construct technologies, in unpacking all these black-boxes, we pay particular attention to the ways in which such construction is limited and defined - we might say pre-dicted - by the particular ways actors are already connected to one another, by the cultural norms that prevail, by the technological heuristics that are available, by expectations they have about one
another’s behavior, by the ‘objective’ constructions that emerge out of technological action itself - all of which make some outcomes more likely than others. Diverse features of the material and socio-historical context - few of them subject to the will of any individual actor - may determine what actors can see or do as they go about constructing new technologies. This framework, understood as a set of pragmatic possibilities by the actors involved, must also be understood by those seeking to understand technology development from an observer's or policy-oriented perspective. The rule now is: follow the actor as the actor follows up on the opportunities it can perceive in the structure of its situation. But also, certainly if the aim is to exert influence on the process whereby actors produce new technologies, seek to know more about the structure of the situation than the actors themselves. Following this injunction carries investigations beyond mere documentation and begins to organize knowledge for reflexive interventions in the societal process of getting new technologies together.

Societal Constructivism

We can now make a distinction between social constructivism and societal constructivism (Rip 1990). Social constructivism emphasizes the interactive construction of meaning, the basic organization of perception and action. As a mode of comprehending technology it investigates how actors and networks of actors organize their perceptions of existing technologies and how they mobilize resources to negotiate new criteria and develop appropriate technologies. Societal constructivism emphasizes how perception and action are constrained and enabled by the situations in which actors find themselves or which they have produced as the result of earlier actions. It investigates how actors and networks of actors, embedded in a particular historical situation, possessing particular cognitive and other resources, create and exploit opportunities to negotiate criteria for and to realize suitable technologies. Our collective ambition in this book is to demonstrate the fruitfulness of a societal constructivism - and, by implication, to show how mere social constructivism falls short.

A key term in this endeavor is coordination. This concept has the virtue of capturing both the active dimension of ‘construction’ and the passive dimension of ‘being structured.’ Subjects can actively coordinate other actors and processes by doling out rewards or punishments, but subjects can also be coordinated by constraints and opportunities that are already in place or manifest themselves: other actors, the rules of the game, testing procedures, legal regulations, artifacts and technological systems etcetera. Hence, coordination has both an active and a passive voice. Moreover, coordination is ecumenical. It does not have to proceed from the intentions of a human actor but can be the outcome of structures of interaction (e.g., game structures like the prisoner's dilemma, markets or organizations) or the effect of an assortment of objects and object-systems like languages, symbol systems, design norms, technological systems, and a wide variety of artifacts. This, in combination with
its active-passive symmetry, enables it to capture the fact that actors can simultaneously be engaged in arranging the elements of a successful science or technology while themselves being arranged by what has gone before or is emerging around them - partly as the outcomes of their own activities.

It is clear that coordination expresses the central notion of societal constructivism, that is, the idea that actors who are getting new technologies together are being influenced (by circumstances, by other actors, by rules and laws, by their perceptions of nature) even as they are influencing others. Coordination means that actors are somehow attuning their behaviors toward one another, that they are choosing to act in ways that are relevant to some goal shared with other actors or that are strategic moves in some game being played with other actors. But to what do actors attune their behavior? How do they know what moves contribute to collective technological goals - or to individual goals given the possible behavior of other actors?

In principle, actors can influence other actors in an immediate, direct way. Players of the board game ‘Monopoly,’ for example, are ongoingly coordinated in a face-to-face setting as they make moves and decisions which provide information enabling other players to make relevant moves (i.e., improve their individual strategic position and collectively carry on with the game). Now the question is: what actually provides the coordinative information to the other players? In the first place, of course, the rules of the game which determine what moves are allowed, what transactions have to or may occur, and what meaning can be attributed to the various squares and markers. But in our admiration for rules we must not forget how important the board, the markers, the money, the banker is in playing a game of Monopoly. In principle one could imagine a game of Monopoly without all the physical paraphernalia supplied by the manufacturer. In this case players would have to constantly be informing one another on which square they were, which square they felt they were entitled to be going on their next turn, how many houses and hotels they had and where, who owed what to whom, etcetera. Clearly, even if the players could manage such a Lewis Carroll version of Monopoly, the stupendous effort required to coordinate the game would make it senseless as a pastime. Instead, the usual procedure is for players to delegate coordination both to physical objects and to human functionaries. The objects function as signs of the players’ strategic position and as intimations of possible future moves. Other players now only have to read the distribution of signs on the board to know what the situation is and to plot their own strategy. The functionaries (in Monopoly, the banker) facilitate the progress of the game by administrating markers and in some cases adjudicating moves.

We can analyze a Monopoly game as consisting of a set of locations (the individual players) which are coordinated by an emergent global level of object-signs - and of course by the invariant rules of the game as thought up by its inventors. At the locations decisions are made to invest or not - given an assessment of the state of the game, reflexive analysis of the position of the location, and the opportunities presented by the dice. At bottom this is all the game consists of - except the work necessary to communicate local action to the other locations and hence to coordinate the game. This requires some extra
effort on the part of each location - making payments, placing houses and hotels, moving the marker. And one player must invest part of his time and attention in producing the collective good of a banking system. The global level, which in this case serves as a collective semiotic representation of the game, is brought into being and maintained by a ‘surplus effort’ on the part of the locations.

This layered morphology, we contend, underlies social coordination in general. Stock exchanges are good examples of such layering at intermediate levels of aggregation. Here there is still face to face interaction, but there are also many tendrils connecting actors to far-away buyers and sellers. Hence the stock-exchange is itself a global actor serving to coordinate widely dispersed locations. Here too there are numerous physical constructs and markers which coordinate the buyers and sellers, but also specialized functionaries that process and recontextualize information to produce new global-level signs. Markets and politics, to take the most grand examples, are modes of coordination in which locations contribute information which is aggregated into coordinative constraints at a global level. Consumers buy specific qualities at specific prices and may have to expend effort to make the most rational purchase. Their behavior is transformed into market demand, prices, interest rates etc. by an elaborate global economic machinery. Citizens vote and pay taxes in order to maintain the representational and coordinative apparatus of democratic politics. In these sorts of intermediate and large-scale orders, like those in which new technologies are gotten together, the global level consists of far more than the physical objects and rules which hold a game of Monopoly together. Here, it can make sense for locations not only to contribute directly to the maintenance of a global level (e.g., attending a town meeting on the new sewer system) but also to delegate such concerns to global level actors, in this case, democratically responsible politicians.

Actors engaged in getting new technologies together are *nolens volens* situated at locations in large-scale global political and economic orders. These global orders exert their own coordinating force and thereby enable and constrain particular technological choices. In addition, however, actors involved in the design and implementation of particular technologies are also locations in very specific global technological orders - thus constituting what Van de Poel and De la Bruhèze (this volume) call *technical regimes*. Analyzing how such global technological orders emerge and are modified by the global-level efforts of local actors, how local actors delegate agency to emergent global-level actors and how the global level in turn enables and constrains action at a local level (in part by re-delegating to locations) is the basic program of a societal constructivist approach to technology development. It is an effort to understand the mechanisms of coordination among the heterogeneous and dispersed actors engaged in getting new technologies together.

The accounts in this book seem very diverse. Nonetheless they all contribute to defining a societal constructivist approach to technology development because they all explore the relationship between locations and

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1 See also Disco et al. (1992).
global orders and hence investigate how the development of new technologies is coordinated. We consider this an improvement over the treatment of levels of action in most social constructivist approaches, where the doctrines of symmetry and seamlessness have reduced a dialectic of levels to simple hierarchies of aggregation. As will be elaborated in the conclusion, moreover, several of the contributions stretch the local-global notion in ways that emancipate it from its usual spatial metaphors. Locations may be defined not only with reference to spatial (or organizational) heterogeneity, but also with reference to temporal or discursive heterogeneity. That is, there are not only locations in space, but also in time and in systems of discourse that need to be coordinated via emergent global levels if technologies are to be gotten together successfully.

Introducing ‘coordination’ as a key term opens a second polemic front toward the extensive literature on that subject. Fortunately we have been able to fight fire with fire, by confronting the opposing strengths and weaknesses of social constructivism with those of traditional theories of coordination. Social constructivism’s strength is its emphasis on symmetry, its consequently almost naive empiricism and, in the case of technology, its special attention to the role of knowledge and artifacts. Its weakness is its inability to deal with supra-local structures and agency and its consequent suppression of local-global dialectics. The strength of theories of coordination focussing on, for example, markets, hierarchies, and networks, is precisely the centrality of such dialectics. Their weakness, from the point of view of technology dynamics, is that up to now they have said next to nothing about the special role of technology - particularly knowledge and artifacts - in effecting coordination nor about the coordination of technology development itself - except as a contingent output of market, organizational, or network coordination. They have spoken of the coordination of social orders, but not of the coordination of socio-technical orders. In this context our arguments for societal constructivism amount to:

1) the fortification of social constructivism by the ‘structuralist’ insights of theories of coordination and;
2) the fortification of theories of coordination by the heterogeneous empiricism and the sensitivity to the role of cognitions and artifacts we find in the program of social construction of technology.

The result is an enriched form of social constructivism, societal constructivism. The interest in coordination is directly related to an interest in steering sociotechnical processes. This is reflected in the literature on coordination as a sociological, political and economic phenomenon. Understanding how a distributed and possibly long-term process is coordinated may indeed provide insight into exerting effective influence - particularly where the available means depend on mobilizing cultural resources, political power or market alignments. It is however unlikely that traditional approaches to coordination can provide sufficient guidance for steering technology development. The specificity of technology as a societal phenomenon demands attention to current work in the field of science and technology studies - particularly in the area of technology dynamics. Societal construction of technology, as it is being defined here, can provide one essential bridge between scholarship and policy in this area.
The Organization of this Book

The book opens with ‘Coordination of ship propeller design: technical models and the relation of T.Y. Draco with Queen Elizabeth II by Barend van der Meulen. This is an analysis of how the design process of ship propellers is coordinated in space and through time. Van der Meulen argues that the actor-networks which constitute specific designs (involving heterogeneous elements like artifacts, theories, insurance companies, journal articles) never emerge from a tabula rasa but are in fact discrete time-slices of a continually evolving actor-network in which all elements are continually subject to transformations. He illustrates this by analyzing how existing technical models both constrain the construction of actor-networks in ship propeller design and are in turn modified in the course of subsequent design. Next, in ‘Means of coordination in making biological science: on the mapping of plants, animals, and genes,’ Dirk Stemerding and Stephen Hilgartner examine the role of ‘centres of calculation’ and standardized material means in the coordination of two major international mapping projects in biology: the emergence of a taxonomic system in the late 18th and early 19th century and the current Human Genome project. They conclude that the success of such projects, which depend on the aggregation of dispersed results, require the prior establishment of means of coordination which enforce the standardization of work at numerous peripheral sites. However, they also insist that the construction of these coordinating means and their development cannot be explained simply as domination: the process depends on ongoing reconfigurations of center and periphery. Chapter 3, by Wim Smit, Boelie Elzen, and Bert Enserink, is called ‘Coordination in Military Socio-technical Networks. Military Needs, Requirements, and Guiding Principles. In this chapter the tribulations of achieving consensus on the design criteria for a European Fighter Aircraft and its radar system are analyzed as the construction of a supranational socio-technical network. This network necessarily emerges out of pre-existing networks at the national level. The persistence of these national networks constrains the freedom of actors at the supranational level and so coordinates the formation of the new network and the concomitant design criteria. Chapter 4, ‘Getting an experiment together in high energy physics. Big plans, big machines, and bricolage,’ by Cornelis Disco, argues that coordinating the activities of many physicists and engineers over many years is only possible if means of coordination are constructed in the process of experimentation itself. Such ‘frames’ are both summations of past agency and constraints on future agency. Two frames are identified in the experiment under study: the text of the formal proposal and the completed big machine, the detector. Both, in different ways, coordinate subsequent episodes of bricolage so that experimental goals are conserved. In the next chapter Ibo van de Poel asks ‘Why are chickens housed in battery cages?’ In answering this question, Van de Poel examines two popular types of explanation, an economic and a cultural one and concludes that while both are relevant, neither is sufficient. In order to explain the continued dominance of the battery cage and
the limited success of efforts to abolish it, multiple modes of coordination must be charted. He invokes the concept of design regime to express how the hegemony of the battery cage is the outcome of several distinct and simultaneous modes of coordination impinging on designers and users. Chapter 6, by Ellen van Oost, ‘Aligning Gender and New Technology: Early Administrative Automation,’ shows how the management of the Dutch Postcheque and Clearing Service was able to introduce computers into their organization without causing disruption by capitalizing on the masculine gender typing of the new machines and associated jobs. Because the new computers would eliminate many jobs in the manual processing of transfer orders, management had promised to recruit applicants for programmers and operators from within the organization. In allocating the limited number of jobs, management was able to bypass female employees because computer jobs were universally defined as upwardly mobile male career tracks. Dutch women did not expect careers and so they could be passed up for the interesting jobs. Chapter 7, ‘Expectations in technological developments: An example of prospective structures to be filled in by agency,’ by Harro van Lente and Arie Rip show how technology actors are coordinated by storylines in which the promise and performance of new technologies are touted. Expectations are seen as virtual actor-worlds which are yet to be realized, but which precisely because of their promise forcefully coordinate actors in making them come true. In this way, expectations become ‘prospective structures’ which nonetheless forcefully constrain and enable specific kinds of future agency. In chapter 8 exclusions, rather than expectations, coordinate the future. Adri Albert de la Bruhèze, in a chapter entitled ‘Boundary maintenance and radioactive waste disposal technology in the USA, 1945-1970,’ investigates how the Atomic Energy Commission’s exclusionary approach to designing radwaste disposal technology gradually produced a socio-technical order which forcefully coordinated opposition to implementation of Atomic Energy Commission policies at a later point in time. Tracing the history of Atomic Energy Commission initiatives in managing radwaste, de la Bruhèze shows that the Atomic Energy Commission’s bureaucratic and technological policy demanded the successive exclusion of more and more dissident actors from the process. This resulted in an excluded ‘radwaste world’ most of whose participants were easily mobilizable against the Lyons attempt to implement Atomic Energy Commission’s ultimate solution of storage in salt-layers. In chapter 9, titled ‘Meaningful boundaries: Symbolic representations in heterogeneous research and development projects,’ Elke Duncker and Cornelis Disco, question how communication is coordinated among researchers with different symbolic repertoires. They investigate two examples of collaborative research involving different disciplines and professions and conclude that communication across boundaries is coordinated in the first instance by mutual recourse to more basic and generic symbolic repertoires. In the course of time, coordination is enhanced via the construction of passive and active ‘dictionaries’ which allow researchers to translate among their different repertoires. Ultimately this can lead to the emergence of hybrid repertoires and possible new proto-disciplines. The penultimate chapter by Arie Rip and Siebe Talma on ‘Antagonistic
patterns and new technologies’ generalizes some of the lessons of previous chapters by considering how patterns of antagonistic coordination emerge around particular controversial technologies and how such patterns subsequently coordinate the conflictual introduction of successive risky technologies according to well-established scripts. The authors argue that antagonistic coordination may be productive as an occasion for social learning, inasmuch as both proponents and opponents will be interested in fortifying their points of view with robust arguments. The book closes with ‘Getting Case Studies Together’ by Cornelis Disco and Barend van der Meulen. Here the editors return to the themes broached in this introduction and assess what the case studies have in fact contributed to our understanding of how technologies are gotten together.