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The High Variability Discourse of LTS Studies

How do social scientists construct large technical systems and networks? For a long time, academic studies of technology in the social sciences were not unduly concerned with technical ensembles like LTS: because technology research is not part of the canon, and because the social sciences outside the history of technology did not begin to engage in technology research on a broad scale until the early 1980s. At that point, Renate Mayntz, Thomas P. Hughes, Todd LaPorte, Gene Rochlin and others opened up a new research field: "large-scale technological systems" or "large technical systems" – LTS, "the modern transportation, communication and supply systems, which one might subsume under the heading infrastructural systems, since their primary function consists in enabling a multitude of specific activities to take place . . .." (Mayntz, 1988: 233) – An international research network was developed and cultivated, a series of conferences took place in Berlin (1986), Cologne (1987), Berkeley (1989), Sidney (1991), Vadstena/Sweden (1993), Autun (1995), a number of conference publications appeared (Mayntz and Hughes, 1988; LaPorte, 1991; Summerton, 1994b, this book). Empirical and comparative research got underway in various places; something like a research community, with its characteristic "discourses," evolved.[1]

How do members of this particular research community (to which belong historians, economists, and sociologists of technology) talk about large technical systems? In giving a few answers to this, I will cultivate that peculiar form of empirism which seems to move only within other writings, without trying to say much about "the systems out there." But doesn't what counts in research lie behind or under the verbal carpets? Perhaps, but scientists tend to cover "one and the same thing" with texts of very different fabrics. The following observations aim at an appreciation of (some of the) patterns of LTS discourse and at demonstrating that behind a label signalling conceptual consistency and a common theoretical focus, LTS-research appears to be a highly variable discourse. As in other fields of research, notably in the experimental disciplines,

> (n)ot only do different scientists' accounts differ; not only do each scientists accounts vary between letters, lab notebooks, interviews, conference proceedings, research papers, and so on; but each scientist furnishes radically different versions of events within, say, a single recorded interview transcript or a single session of a taped conference discussion. (Mulkay and Gilbert, 1992: 312)

Since high variability is not a distinctive feature of any one discipline, my discussion must not be construed as a facile critique of LTS-studies. The field of SCOTS (the social construction of technological systems), for instance, as presented as a more or less unified approach by Trevor Pinch and Wiebe Bijker in the Introduction to the well-known reader of the same title is, when read closely, enormously varied in its conceptual claims and implications.

The following is not meant as another view from above, i.e., a series of meta-statements on LTS research. Rather, I present a sideways view of some discursive practices within a field somebody aptly has called "a Floating Seminar". I will concentrate on the contributions from two volumes on the subject ("The Development of Large Technical Systems", Mayntz and Hughes, 1988, and "Social Responses to Large Technical Systems", LaPorte, 1991), but will also take into account other relevant texts (Hughes, 1987; Weingart, 1989, Braun and Joerges, 1994b, Summerton 1994, Mayntz, 1993). These texts will serve me for compiling characteristic formulations and weaving them into "intertexts", which will in turn be used as a basis for further observations.[2] In the intertexts, all citations can be reidentified on the basis of the endnotes.

Quasi-Definitions and Quasi-Generalizations

Traditional methodology has it that an iterative research process, which continually doubles back unto itself, should begin with the work of definition, taxonomy and classification, and end with generalized statements regarding empirical relationships. Accordingly, I shall begin with a note on these matters. Later, I will deviate from standard methodological assumptions and examine at greater length certain metaphorical aspects and narrative structures of large technology discourse.

How do LTS authors deal with the problem of basic terminological attributions; how do they approach definitional work? Definitions do more than just determine and protect language. They are powerful filters for distinguishing what should be considered of scientific significance or irrelevance. They often not so much delineate as exclude a particular object, taboo certain aspects of reality and the language which must to be acceptable in order to deal with them.

Basic terms

Interestingly, there is not much space devoted to clarifying the *systems* concept, as the first little intertext shows.[3]

The different components of it form a system – they are all needed and they interact. – Because components of a technological system interact, their characteristics derive from the system. – Social scientists' discussion and efforts towards a more precise analytical conceptualization proceed on the basis of such "systems" as are characterized by network-like structures, geographic distribution and a considerable concentration of capital. They are thus primarily characterized by the interaction of economic, political and technical-scientific systems. – Although very many empirical systems incorporate some kind of technology, only a subclass of these are organized around a particular form of technology. In cases where one can theoretically eliminate the technology without necessarily implying the absurdity of the remaining organization, the system involved is not a large technical system in the sense applied here.[4]

These are the few attempts to explicate the systems term I found in the Mayntz and Hughes and LaPorte volumes.[5] The systems concept as such does not receive much attention, then, perhaps on the assumption that certain powerful preconceptions associated with this concept (see below à propos the systems metaphor) do the job.

Somewhat more attention is devoted to circumscribing the distinguishing criteria of *large* (as opposed to smaller) and *technical* (often as opposed to social) systems.

Thus, the two characteristics of those systems which we shall here define as "large" technical systems, for lack of a better term, are: "technical specification" in connection with the interaction of technical artefacts and social organization. Both characteristics indicate that we are concerned with systems where the technology is "expert intensive" and whose operation is thus highly professionalized. – The system is a large system because of its sheer size in manpower and capital, and because in an advanced state of development, it encompasses most of the territory of a society. – Since the system in this case is extremely large (including one firm which was until recently the largest private business corporation in the world) . . . – And there was a paradox. While the system as a whole contracted, technological innovation continued at a rapid pace. – From the technical means of transaction we can distinguish social media of transaction . . . Technical transaction media refer to wire, microwaves or laser.[6]

In LTS discourses, classifications and basic differentiating criteria tend to remain close to the material and are often adopted from practical usage, that is reflect the naming practices of the field under scrutiny. Certain phrases serve to make it more plausible that large technical systems do in fact form a passably circumscribed, definable object, conducive to collective analysis. In the first place, concrete LTS are often equated with the large corporate organizations and monopolistic utilities which develop and operate them: the telephone system with Televerket or with Bell, electricity generation with Vattenfall or, rightfully of course, EDF, the railroad system with SJ or the Bundesbahn or the SNCF. This creates the problem of losing from sight the incredibly vast fields of activities invested by actors other than the large operating organizations: users of all kinds, pre-service operations of all kinds, LTS research and so on and so forth. One also runs the risk of ignoring such technical structures as do not lie within the control radius of the relevant dominant organization.

Important keys to understanding are often couched in references to the unspoken: ". . . we may have been inclined to focus too much on types of hierarchical or centralized control, and have tended to frame the issue in terms of centralization/decentralization. I think we should include explicitly different modes of self-regulation of technical systems . . ." (Mayntz in LaPorte, 1991, p. 182). It suddenly becomes clear here that to speak about systems in LTS research implies notions of hierarchy and centralization, although these criteria were never introduced as defining features in the first place.

Lacking generally accepted criteria, LTS studies at times simply fall back upon colloquial assertions to the effect that one happens to be dealing with unique structures, the extreme nature of which is immediately apparent. And yet a sense of uneasiness remains palpable.

Admittedly, the boundaries are fluid . . . but extreme examples that could be subsumed under the heading of "large-scale technologies" highlight what is meant here. – (These) are only some of the more spectacular examples of the close collaboration between science, technology, and politics in the implementation of megatechnology. – Efficient regulation has to take into account that LTSs are unique systems.[7]

The largest common denominator in the discussion on common characteristics and classification criteria is probably the notion that LTS might best be described as *multi-actor sys-*

tems – whether in the sense of groups assuming certain roles within organizations viewed as enveloping LTS or in the sense of interorganizational networks.

(T)he "ensemble" of what can be termed the "System of . . ." . . .consists in the activities of essentially three kinds of actors: First the operator, then the manufacturers, and last the state, in its role as legislator. – First and above all: The development of the system is driven by decisions of a limited number of actors. If a certain amount of momentum developed, this is not a result of forces inherent in an autonomous technology but of purposive action constrained by the sediment of previous decisions about technological alternatives. – The motive force of this first wave of spatial integration is an interaction between actors at three distinct levels. At the central state level it is (X). There are regional actors, such as (Y). They often cooperate with their political allies at the local level, in the city halls. – Three groups of actors are involved: engineers eager to create, senior executives concerned with safeguarding the rights of the State and lastly, the Parisian bankers, anxious to venture only where wise, yet at the same time unwilling to let an opportunity slip to make what might be a sizable profit.[8]

Technical systems/social systems

A recurrent issue in LTS discourse has to do with the distinction of and the boundaries between "technical" and "social" characteristics of systems (or between technical and social systems).

Technological systems contain messy, complex, problem solving components. They are both socially constructed and society shaping. Among the components in technological systems are physical artefacts, such as the turbogenerators, transformers, and transmission lines in electric light and power systems. Technological systems also include organizations, such as manufacturing firms, utility companies, and investment banks, and they incorporate components usually labeled scientific, such as books, articles, and university teaching and research programs. Legislative artifacts, such as regulatory laws, can also be part of technological systems. Because they are socially constructed and adapted in order to function in systems, natural resources, such as coal mines, also qualify as system artifacts. (Hughes, 1987, p. 51)

This much-quoted passage has proved a very influential, quasi-definitional formulation. Hughes' exhortation not to forget the "social" components of "technological" systems is invoked almost ritualistically at the outset of many studies concerned with materialized technology. Elsewhere I have refered to this as the 'Tom Hughes paradox in the social study of technology'. The paradox lies in the fact that sociologists rather seem to need a reminder that technology consists of dams, turbines and grids, too. Thus, Hughes was and is used by sociologists of technology justify and legitimize approaches in which materialized technologies play only a minor or nominal role.

Another aspect of the quote in which I am interested here is the persistent tendency, despite Hughes' insistence on seamlessness, to perpetuate the categorical distinction between "social" and "technical" in LTS research and beyond. In Luhmannian terms, one might say that technology research in the social sciences operates under the code "techn(olog)ical /social," not "techn(olog)ical/non-techn(olog)ical." Symptomatic for this state of affairs are countless formulations in which technical artefacts are declared not to be social by nature "as such," as though technical artefacts could also be said to exercise "non-social" functions and carry out "non-social" operations:

In the strict sociological sense, technology is the environment of social organization, but until now, conceptualizations have dealt unsatisfactorily with technological determination: technology remains excluded from sociological analysis. One must therefore add the opposite perspective: social organization is the environment of technology. Only with this double perspective could justice be done to the fact that we are dealing with two classes of phenomena: on the one hand, with technological systems in the sense of systems of artifacts, which . . . demand a certain form of organization; on the other hand, with social systems in the sense of organizations, which create certain technologies and continually adapt them to suit their own operational strategies. (Weingart, 1989, p. 178)

One dominant formula of LTS discourse is then that there are complex multi-actor "social" systems and complex "technical" systems; the latter somehow interact with the social ones (and may therefore be labeled "socio-technical"), but remain of a different sort.

So much for the definitional level. It seems that it was not deemed important enough to raise it much above the trivial. But lest this sounds like a critique: why should we expect our authors to start off with elaborate definitions and then, at the end of a research cycle of extended hypothesis testing, arrive at carefully derived empirical generalizations? In practice, researchers quickly move over, long before the empirical harvest is in the barns, to more or less sweeping generalizations. These generalizations, or 'generalities' as I shall now say, take over the task of delineation not accomplished by preliminary quasi-definitions.

In scientific usage as in everyday speech, it is often difficult to distinguish once and for all between *useful* generalizations, or generalities, and vapid platitudes. Statements may easily move from one category to the other, and much depends upon the context: what theoretical debates are to be elaborated, who is to be addressed, what is to remain excluded, what is the further end of the argument? Let us look at three such generalities of LTS discourses.

Risky systems/uncertain systems

One ubiquitous formula is the on about large technical systems being complex and over-complex. Elsewhere I suggested that the "complex-speak" of LTS research makes it possible to latch on, not only to high quality theoretical but also to all kinds of public debates.[9] This effect is also achieved through another generalization, which capitalizes on the attractiveness of the concept of risk.

The objects of public anxiety about the possible widespread loss of capacity and interrupted service (the more effective it is, the more likely the anxiety) . . . The source of alarm about the consequences of failures to users and outsiders of serious operating failures, . . . and subsequent public expressions of fear and demands for assurances of reliable operations. – Moreover, they may have 'catastrophe potential,' that is to say that a malfunction may have consequences that are potentially uncontrollable in temporal and spatial terms and therefore with implications for the political and economic spheres as well. – The illusion of control has serious implications for other large-scale technical systems that involve considerable potential risk. – The practical political grounds for interest in large technical systems lie in the experience with technologies and the way in which they are portrayed in public discussion, namely as "almighty," i.e. uncontrollable, highly complex and expansive as well as especially risky.[10]

The risk issue was less predominant at the beginning of LTS research (Mayntz and Hughes, 1988) than in the third round in the Floating Seminar (LaPorte, 1991).[11] The thematic orientation in this phase ("social responses") prepared the stage for interpretations of public debates on especially risky systems (LaPorte, 1988; Oster, 1991; Andersen, 1991) and technology-related catastrophes (Pinch, 1991; Rochlin, 1991).

Extending generalized risk assumptions to cover all large systems is a certain way of gaining public relevance. When belief in progress wane and confidence in science and in the controllability of technology falters, then anything that is opaque and complex as well as large seems necessarily to be perceived as dangerous. The occasional references to environmental problems in connection with ruptures in systems development seem only a side-line here. Perhaps one may even see the risk refrain as a rhetoric actually enabling LTS research to avoid in-depth ecological discussions (see below).

The risk discourse is almost always a discourse of uncertainty. Uncertainty is a state of the knower as much as of the knowable.

With regard to this system, everything is uncertain, everything eludes prediction; it is impossible to assign a destiny to these new enterprises. – These hazards explain the wavering of the actors who found themselves engaged in a game with unknown rules. – . . . for it was precisely from the 'certainty trough' . . . that the decision makers were drawn. They had a deep commitment to the technological institution involved, but were insulated from the uncertainties of those with direct responsibility for producing knowledge . . . – The high-momentum systems of the interwar years give the appearance of autonomous technology. Because an inner dynamic seems to drive their course of development, they please managers who wish to reduce uncertainty and engineers who need to plan and design increased system capacity. [12]

The discourse about uncertainty and incomplete knowledge is at the same time one about trust: trust in systems as opposed to personal trust and trust in securely embedded social relations (Giddens 1989, Wagner 1994). Trust in systems is predicated on trust in system trustees, though. These are "the authorities", drawing on various sources of legitimacy to represent the systems, foremost on professional expertise. And not only social science expertise sometimes tends to overdo the risks and the uncertainties in the interest of legitimizing the representation: "Measures of floating-point performance, while influential and often quoted as if unproblematic, *hide a Pandora's box of issues*, most obviously what kind of floating-point operations, performed with numbers expressed to what degree of accuracy."(MacKenzie 1991, p. 172, emphasis BJ)

The risk/uncertainty discourse clearly is a sciences-of-the-artificial discourse. Its roots are in engineering and cybernetics, and its metaphors are technical. But there is another systems theoretical field where systems are right from the beginning not conceived as artefacts but as evolving and emerging entities.

Self-organized systems/self-regulated systems

A third generality has to with the notion that LTS may be self-organizing systems. The notion of self-organization seems here to revolve around two controversies. Are LTS inherently own-logic (*eigenlogisch*) and self-guiding – or subject to outside control? Are they homeostatic and harmonious – or crisis-ridden, in danger of collapse, chaotic? Note that LTS are conceived as self-controlled, self-generating, self-enhancing or self-destructive formations from both viewpoints. On the other hand, talk of "own dynamic," self-regulation and self-organization seems to hold the promise of ambitious theoretical interpretations, treating LTS as special cases of differentiated self-organizing social systems.

The system develops a direction and goals and as it "grows, it acquires momentum." – The organization also develops a "culture" which fosters this growth. – There are "direc-

tions of technical development that are cumulative and self-generating." – As systems mature, they acquire style and momentum. – The high-momentum systems of the interwar years give the appearance of autonomous technology. Because an inner dynamic seems to drive their course of development, they please managers who wish to reduce uncertainty and engineers who need to plan and design increased system capacity. – Such systems appear to be closed ones, not subject to influence from external facts or from the environment. – Large technical systems have an inherent tendency to expand. The question is under what conditions they succeed and under what conditions they fail.[13]

Such passages indicate that many authors see LTS as phenomena whose development, growth and problems can, for the most part, be explained as self-organizing processes. This does not follow directly from the underspecified sense in which the system concept is generally applied. On the other hand, it corresponds well with the equally persistent theme of LTS' uncontrollability and gives welcome support to this idea.

The toss-up remains then between a systems concept prevalent in the engineering sciences on the one hand (implying steerability) and the sociological systems concept on the other hand (self-organization, supporting certain theories of uncontrollability). Although the talk of inner-system dynamics, autonomy, self-propelling "momentum" and poor influenceability from without are part of a standard repertoire, one cannot say that LTS research is dominated by a generalized discourse of self-dynamics and self-control, aimed at an ambitious theorization of technical systemicy. Renate Mayntz' proposals to this intent (1988, also 1993) have been hesitantly accepted. For terminological and disciplinary reasons, her conceptual challenges did not induce the LTS community to develop a generally accepted systems model in line with a theory of societal differentiation. Although the self-professed target was and is (in general) to come up with generalization across systems, time and space in the end, narrative approaches and case studies have predominated in practice, inviting generalizations on the one hand but excluding any serious sorting out of them on the other.

Metaphors of LTS Discourses

In the discourses on large technology which are drawn on here, not only is the system concept itself used metaphorically, but a series of metaphoric leitmotifs is apparent throughout: the hero motif, the evolution metaphor with its variations harmony/conflict, the technology/economy complex, and the technology-state theme. The imagery used in talk about large technical systems potentially serves as a theoretical resource, in that it creates unlikely analogies between LTS and something seemingly utterly different, and thus can produce surprising insights. Donald McCloskey (1985) put it beautifully for the field of economics: every model, no matter how abstract, has its origin in metaphoric images. Conversely: metaphors are theories *in nuce*, pretheoretical models. In this sense they are the opposite of (hi)stories, even though they always tend to be accompanied by narrative elements, with their implicit normative pointers: the moral of the story.

The Systems Metaphor

Since the usage of the term system in LTS discourse is virtually never supported by definitional work, the word is either taken for granted in its self-evident connotations (à la Webster: LTS are called systems because they obviously represent "regularly interacting groups of items forming unifies wholes") – or else, it is used metaphorically. I suggest, that the – one may almost say – refusal to elaborate systems concepts implies that the notion of technology as systemic by nature is itself indeed metaphoric. Staudenmaier (1985) has given us a memorable analysis of the varied uses historians of technology have made of the systems term. To what extent do our authors rely on a pretheoretical systems metaphor and what could be the consequences?

In most of the statements in which LTS texts mention systems, this occurs in an everyday fashion: every listener or reader knows that one is speaking about something connected, something integrated, without any further specification. But especially where authors stress the expression 'system' in a way meant to signal a special viewpoint, superior to other perspectives, they are using the expression metaphorically in the sense of "unexpectedly is like . . ." or "surprisingly functions analogously to . . .". Hughes, for instance, used the concept of system in order to point out and celebrate hitherto unacknowledged connections between a multiplicity of technical and other cultural artefacts, and called men capable of establishing such connections on a grand scale "system builders." In a retrospection on LTS research, he noted:

> Recently . . . I discovered – too late to correct the misunderstanding – that most of my historian colleagues assumed that the system builders of whom I spoke were and are little more than business entrepreneurs and that their system-building differed and differs little from the founding and development of business firms. It also dawned on me . . . that my colleagues use mechanical metaphors to explain relationships while I use ones borrowed from electrical engineering. My metaphors tend to circuits, fields, and systems; theirs to mechanical trains of cause and effect. (Hughes, 1991, p. 188)

Hughes' – if I may say so – 'electroform' version of the systems metaphor has left its imprint on much in early LTS research and points to the more general condition that LTS discourse on the whole takes its metaphors from the tradition of systems and control theories in the engineering sciences. LTS resemble things cyberneticists talk about.

But the observations with regard to the "auto-dynamic" character of large-scale technical systems also show that social science versions – Parsonian, Luhmannian or Mayntzian – are at work as well. LTS are also social systems of the kind that concern sociological systems theoreticians. Sometimes an uneasy amalgamation between cybernetic control theory and theory of self-regulation is entertained, as in certain versions of the governance concept in LTS development put forward by Mayntz and Schneider: "Governance is understood as the institutionally structured process of *self-regulation of social activities*. A governance perspective has close affinities to *cybernetic theory and related concepts such as control, regulation and guidance*." (Schneider 1991, p. 19, emphasis BJ)

Before I started re-reading, I felt sure that LTS discourse was teeming with active and reflexive figures of speech, describing LTS as self-referential and self-reproducing quasi-actors: systems act, observe, communicate, observe each other and themselves, develop themselves, organize themselves, differentiate themselves.

This is true enough. But upon closer examination, the use of the self-organizing-system metaphor remains, on the whole, without much consequence for further theoretical or policy oriented interpretation of LTS, and nowhere is the hermetic quality of a (Luhmannian) theory of social systems adopted. Similarly, where one hears slight intonations of a certain systems mystique, it is relativated and likely shown to be a "first order construct", one that is taken from the talk of system members: "(T)he concept of the network acquired a powerful mystique among system managers and workers . . . One system, one policy, universal service." (Galambos, 1988, p. 141, 143); or else: "(A)ll were guided by a progressionist and nationalist ideology and sought above all to create an operational instrument capable of increasing their social influence out of all proportion . . . Seen in that light the System took on symbolical meaning . . ." (Caron, 1988, p. 73)

Heroes and Giants

There is something heroic about LTS. Again, his theme has much to do with Thomas Hughes and his concept of the "system builder," focusing on a superior power to get things done:

Because they are invented and developed by system builders and their associates, the components of technological systems are socially constructed artifacts. Persons who build electric light and power systems invent and develop not only generators and transmission lines but also such organizational forms as electrical manufacturing and utility holding companies. Some broadly experienced and gifted systems builders can invent hardware as well as organizations, but usually different persons take these responsibilities as a system evolves. One of the primary characteristics of a system builder is the ability to construct or to force unity from diversity, centralization in the face of pluralism, and coherence from chaos. This construction often involves the destruction of alternative systems. (Hughes, 1987, p. 52)

The picture of large systems promoted by heroic system builders, historic leaders and grand strategists (a faint echo of Clausewitz) and engaged in titanic struggles with rivaling systems sometimes evokes martial images: couched in a code of domination and submission it comes across as a peculiarly masculine metaphor.

Outstanding examples of independent inventors and their radical inventions that sowed the seeds of large systems that were presided over by new organizations are . . . – Further German penetration was . . . held up . . . because the French manufacturers were hostile to the practice . . . They feared indeed an invasion of their market. – The monolith is challenged. – The rise and fall of the German system suggests some interesting conclusions. – X himself issued the first telegraphic order to control trains . . . The engineer would not obey the order, and X himself drove the locomotive to the next station. – This sets the stage for a battle between the Y and Z interests for control of the nation's . . . system.[14]

Galambos (in LaPorte, 1991) noted that prominent individuals were strongly represented in LTS case studies, adding that systems are often reduced to their powerful spokespersons for pragmatic reasons. (One need only write Mrs./Mr. Smith, instead of always giving involved descriptions such as "the director of the government program for the control of . . .".) To this extent, one should not overestimate the significance of this characteristic. Personal attribution nevertheless carries another significance: there is a marked tendency to link positive effects, successes and achievements to individuals; failures and negative effects, on the other hand, are easily relegated to the diffuse level of "the system." Failure of the system is practically never associated with a name in these studies.

But the heroic image does not only function as a means of celebrating the exceptional role of system builders. In a broader sense, it also stands for the way in which LTS (or more precisely: the large organizations running them) can be envisaged as powerful "super-persons." And sometimes heroic men stand for machines, or heroic machines for men.

Evolution

The evolutionary metaphor has always been popular with historians and sociologists of technology. An easy biologistic rhetoric would have it that LTS are conceived and born, that they grow, survive and die.

The American railroad network . . . started its life unaware that it would institute sharp breaks with past business traditions. – The birth of the Bell System. – However, its painful birth made the characteristics and limits of the telephone system clear. – The early technological development in this sector abroad gave Germany the advantage of being able to adopt complete, proven and functioning systems which had already passed their teething troubles. – The American railroad network as a vital and progressive large scale technical system reached its apogee in the period between 1900 and 1914. – It (the French railway system) was sure to survive and revenues would suffice not only to meet operating costs but also to guarantee ample return on the capital committed in the vast undertaking. – Because a system usually has embodied in it characteristics suiting it for survival in a particular time and place, manifold difficulties often arise in transfer at another time or to a different environment. – This chapter has dealt with the patterns of growing or evolving systems. Countless other technological systems in history have arrived at a stage of stasis and then entered a period of decline.[15]

One might say that this is common parlance and in this sense to call it metaphorical is giving these texts undue poetic significance. But the metaphor of evolution carries deeper meanings, beyond such almost idiomatic usage: aside from the affinity to the complexity discourse referred to above, LTS are often portrayed as generally adaptive, as contingent upon mechanisms of mutation and selection for their survival, as fitted into niches and as subject to processes of maturation.

Fixed on his aim, he even opposed "small steps" that were improvements of the status quo; he did not understand that complex systems have to prefer evolution to revolution because big steps lead to extreme rates of change in other subsystems and thereby endanger the whole system. – What happens is adaptation and not radical change. – The technological mutation taking place between the 1870s and 1900 must therefore be understood first of all in terms of the harmonization of the different branches. – Suppliers are consequently put through a ruthless selection process. – The overwhelming response of the social environment shows that the specific historical situation evokes system innovations and makes the superior system variant the superinnovation of bridging space. – Other favorable conditions were the maturity of the new technology at the right time and the personal engagement of open-minded entrepreneurs--men who were familiar with the new technology, convinced of its success, had the economic and political knowledge to push its introduction. – Because of these obstacles and because of the dominating influence of the traditional technologies . . ., the system found its first employment in niches or when really no other system . . . was appropriate. – . . .whereas the technical system proper attained a degree of maturity that ensured its efficient working in economic terms.[16]

One may feel that the evolutionary metaphor does not agree well with ideas of planning and control implicit in the "system-builder" concept and in other heroic metaphors. But, at least in the Darwinian version which apparently underlies most uses of evolution metaphors, one finds that a series impersonal mechanisms are postulated ("competitive struggle," "adaptation," "mutation/diversification") which strategic action might conceivably latch on. Indeed, the history of Social Darwinism shows, that the metaphorics of evolution are flexible to an extraordinary degree; they can serve as a vehicle for very different views of society and politics. In an essay "On the Darwinian View of Progress," Amartaya Sen recently argued that evolutionary thinking can provide the basis for both pessimistic or fatalistic positions and humanistic reforms (Sen, 1993). But the tension remains and, as will be demonstrated below, generates different stories (or a contradictory story) of "The Development of Large Technical Systems."

Evolutionary theory has developed, too, since Darwin. The old dispute over whether natural history advances "gradualistically," in measured steps, or whether it moves "catastrophistically," in erratic forward (and occasionally backward) leaps, is still being waged in theories of "punctuated equilibria" and the like. The LTS field seems to support the gradualists in this respect. Not so with regard to another seasoned controversy in the general theory of biological and other systems: do systems seek to attain a state of equilibrium or do they, on the contrary, usually operate far from it? In social systems theory, this controversy was tantamount to a debate over the explanation of social change. In the following section on Harmony/Conflict I will argue, that many LTS researchers adopt catastrophistic stances in this regard.

Whatever the nuances, evolutionary metaphors accomplish the important task of *naturalizing* LTS: to posit them as part of a natural social order, amenable to objective analysis, not as cultural and discursive artefacts open to constant reinterpretation.[17] In doing so, the young specialty of LTS studies (and social science technology research more generally) can follow the lead of mainstream economics of technology which has been made firmly evolutionist in orientation in the recent past.

Yet I think there is an important phenomenon here that is glossed over when technological trajectories are thought of, as they often are, as 'natural' (see Nelson and Winter 1982, pp. 258-62). For I suspect that the sense of a path of technical development as being natural, as corresponding to the inherent possibilities of a technology, is a post hoc effect of the self-fulfilling prophecy.[18]

These two points then – naturalization and tie-in with an upmarket economic theoretical discourse – go some way in explaining the power of evolutionary imagery.

Harmony and Equilibrium/Crisis and Conflict

Here, LTS research finds itself in considerable conflict. Do systems evolve towards harmony and equilibrium?

The technological mutation . . . must therefore be understood first of all in terms of the harmonization of the different branches. – This required a harmonization of the different components of the system. – The days of trial and error end . . . when the institutional system achieves an equilibrium, albeit fragile, that can no longer be challenged. – . . . system leaders try to preserve harmony and peace and overlook ways to make money. – (T)he system, which had comparatively good labor relations at the time and which was making satisfactory profits, decided not to let technological change upset a care-fully worked out harmony.[19]

Or are they going through a "perpetually refueled crisis," as Bertho-Lavenir entitles a chapter of her analysis (1988, p. 158), plagued by conflicts and the permanent threat of immanent collapse?

The system . . . was in a state of crisis by the year x and collapsed altogether after the . . . revolution. – When systems operations collapsed . . . the companies had no means of adjusting the numbers of their staff to cope with the new situation. What was more, the pre-

vious organization into skilled and functional technical departments was rusty. – The history of the system, in fact, is dominated by a "crisis" situation. – Only with the collapse of the giant agency . . . did its managers, as well as government and union leaders, begin to question the old managerial system.[20]

A toss-up, again. The way the systems metaphor is used and reified tends to place issues in a homeostatic frame. And yet, observation of concrete systems clearly suggests that most move from one precarious state to another most of the time.

LTS are likened to biosystems then, they evolve. At another level, the meanings of LTS and the explanations offered for their emergence turn around a whole series of oppositions which I call metaphorical because in all these cases core concepts from one competing sub-discipline in the interdisciplinary field of LTS research, say economics, are taken up by another subdiscipline, say political analysis, in a metaphorical way. Central concepts from one field are borrowed and exploited as highly persuasive focusing devices for observations and arguments that have to a large degree been generated in quite different fields. I will shortly point to two such crossovers which are particularly rich in their implications for the further elaboration of mechanisms of system generation as well as LTS policies: the tendency of viewing LTS as primarily (essentially) economic systems as opposed to claiming some essentially extra-economic substance for them; and the manifold views of the relationship between LTS and (nation) states construed in terms of their similarities and dissimilarities.

Economy/Technology.

All LTS are wholly economic!, say some; they are technical, as the name says!, say others. How is, taking this particular instance of the technical/social divide which has its parallels elsewhere, the interrelationship between economic and technical efficiency construed? What are the metaphorical resources tapped in playing the economic versus the technological card? Note too, in the following passages, the ongoing subtext about the equilibrium/conflict between them.

Even though technological constraints might prevail in the end, it is hard to believe that economic forces . . . do not play a part in the emergence of the system and do not eventually shape its structures. – This combination of "imperatives" leads to a fundamental and abiding tension between technical safety and reliability on the one hand and economic efficiency on the other. . . – This situation is underlined . . . by the premature shutdown of system components whose construction is a scientific-technological success, but a disaster in economic terms. – System component designers must make trade-offs among conflicting demands of producing a component that is easy and inexpensive to construct, inspect, maintain, and operate. To be a commercial success, the component must also perform a wide variety of missions in terms of . . . loads, distances, and operating environment with a high degree of scheduling reliability. Both unnecessary cost resulting from overdesign and inadequate reliability from underdesign can lead to . . . disaster.[21]

At the first international LTS conference[22] there was too much talk of technical efficiency, "load management" and the like for the taste of Charles Perrow. Turning to Tom Hughes, he called out, "It's economics, economics are the mountains." But if economics are the mountains, if the scale and scope of a technical network is determined by its economic trimmings, then, one might say, technology is the invisible part of the iceberg. Determining conceptually (let alone measuring) what proportion of the dynamics of non-technical (for example economic) system parts is due to dynamics of a technical origin, proves difficult however. At this level, LTS discourse sounds suspiciously like the jargon of system managers: caught in the self-made trap of categorically distinguishing between "social" (here economic) and "technical" systems, one falls back, in most attempts at empirical specification, on parasiting on the speak of certain groups in the system.

State-Technology/Technology-State

Another semantic field is occupied by a set of metaphors having to do with the affinities between states and LTS. In a certain sense, some authors seem to be telling us, states are like LTS and LTS are like states, they have a lot to do with one another and cannot exist without each other. But again, high variability is at work. Let us call this field state-technology versus technology-state and look for a subtext which places the state in the center of the stage. The next intertext weaves together certain references alluding to political theories and convictions "acting in the background" (and maybe sometimes behind the backs of their authors . . .).

From the very start, system development was contained within the bounds of rigid administrative regulations. – The companies lost the control of rates. They were prohibited from signing private agreements . . . They were subjected to financial control and they had to obey the rules of administrative accounting. The price paid for the monopoly, the extension of the network and the investment security was administrative tutelage . . . – The . . . crisis merely served to highlight the operational difficulties of the system. State tutelage had become too burdensome . . . The State levied heavy charges on the companies without compensation . . .- In the process of policy formation and the subsequent allocation of regulative burdens business associations and semi-public institutions are often used as mechanisms for interest intermediation.[23]

LTS are what they are by virtue of state regulations, and the State enacts regulations whereby it profits from the systems. LTS and the State are closely interdependent, and the relationship is *parasitic*: the State regulates and reaps the benefits, free-riding as it were. At times, however, the State also impedes LTS development. It is power-crazy and avaricious, and whenever it intercedes with regulations, it does not act to the benefit of the LTS. A typical State-technology, LTS.

Yet there is also another, friendlier picture, of the Technology-State.[24]

Only the State could build the system because it alone sought no return on its capital. – The government systems engineers do everything they can to promote the emergence of a national industry. – With considerable encouragement from . . . industry, the Federal government reluctantly accepts responsibility for licensing operators, inspecting equipment and supervising the use of local installations and operating safety. – By a series of legislative acts, the French state has assumed . . . complete control over the development of the system, and over the procedures preparatory to building new major components. – The existing state system monopoly offers the central government a focal role in the introduction of the new technological system from the start, and the existing . . . network makes the plan of a nation-wide extension of the new service feasible.[25]

LTS are what they are by virtue of state cooperation and promotion; each is dependent on the other; the dependency is *symbiotic*.

Inextricably interwoven with this discourse, which should be called metaphoric on account of its likening two apparently very dissimilar phenomena, is a subtext having to do with processes of nationalization/privatization. This theme, which continues into the narratives of responsibility taken up below, has certainly gained prominence in the course of the LTS-conferences.[26]

To sum up these observations concerning LTS metaphors: there is an amazing variety of interpretations, constructions and stories *in nuce* flourishing around the notion of Large Technical Systems. A few recurring root metaphors stand out more distinctly; others may easily be traced as well. Particularly the examples from the semantic field of technology/economics/state show that here, too, one can adopt Thomas Hughes' memorable phrase and speak of "seamless webs." This image was conceived to characterize the systems "out there," but it is also a good description of the way large technical systems are treated in the history and sociology of technology.

Narratives of LTS Discourses

On first sight, most LTS studies may read like relatively straightforward case studies or historical reconstructions of concrete systems, simply telling how it all happened. But as with the level of metaphoric imagery, one discovers that there are several distinct narrative structures in evidence. Two patterns, in particular, recur throughout the multiplicity of accounts of concrete technical networks: the division into stages, phases, eras and ages of development, i.e. stories about the orderly nature of LTS growth processes; and the attribution of responsibility, i.e. stories of who or what steers LTS.

Stages and Ages

Almost all LTS studies, especially those written by historians, are arranged in a series of stages more or less explicitly accounted for. Stage-devices (still close to model-building based on certain metaphors) and its attendant periodizations (closer to narrative and storytelling than models) belong to the oldest tools of the historical sciences. They help in achieving the transitions from straightforward, associative (or syntagmatic) narratives – "and then, and then, and then" – to substitutive (or paradigmatic) "or, or, or," i.e. to generalizations with reference to many other, similar cases.

Thomas Hughes (1983, 1987) has set the tone here, again, in proposing a basic scheme of LTS-stages as a frame for ordering and making sense of events across many systems and system types. The three developmental stages, which he had established studying the American, British and German electricity generation and distribution systems, comprise "invention and development"; "innovation and competition"; "consolidation and rationalization.", a script for a clearly upward and outward reaching movement resulting, if successfully played out, in mature LTS of high momentum.

The phases can be further ordered according to the kind of system builder who is most active as a maker of critical decisions. During invention and development inventor-entrepreneurs solve critical problems; during innovation, competition and growth, manager-entrepreneurs make crucial decisions; and during consolidation and rationalization, financier-entrepreneurs and consulting engineers, especially those with political influence, often solve the critical problems associated with growth and momentum. – This dynamic mechanism of success can be represented as a four-step acceleration process: (1) the existing system reaches its capacity constraints; (2) a new technology is at hand; (3)

improvements of the old technology and isolated usage of the new technology increase demand for transportation; (4) this additional demand allows the full engagement of the new technology. – An analysis of other large technical systems indicates that this pattern of development is in no way unusual . . . One might therefore conclude that this is a general pattern in the development of successful technical systems serving a specific function. – Looking at the historical development of the network, one can identify four stages of development . . . : invention and isolated introduction (localized linkage), demand-oriented construction (integration)--fulfilling only the needs of existing business centers, supply-oriented extension (intensification) . . ., maintenance-oriented "cut-back" (selection) . . . Whether system development will be successful is decided in the early stages of the process.[27]

Take for instance the development of the French railroad, recounted by François Caron; or the story of United States' telecommunication (from Bell to AT&T), as told by Louis Galambos; or that of the German road network, as presented by Heinze and Kill; or (not quite as pat an example) French electrical power, described by Lévy-Leboyer – the ease with which these and other narratives of technological history fit Hughes' scheme indicates that this model has a basic narrative structure in itself. It shows the basic plot according to which the development of many regional system networks has so often been described and actually planned. But not always: Mayntz and Schneider (1988) did not see evidence that there is a sequence of such stages operating in the development of government controlled communications systems (like Teletext). Objections were also made on the grounds that various national stories are actually rather different (Lévy-Leboyer, 1988; as opposed to Bertho-Lavenir, 1988), or, as one would expect form the above-mentioned "electroform" origins of Hughes' principle of stages, that the development paths of different technologies are not all that comparable.

Stages of development are always timed, social studies of technology always create periodizations. As noted in the context of evolution metaphors, a prevalent idea in the field of LTS research is that of an orderly, directed (if not always planned and sometimes crisis-prone) trajectory from small (young) and local to large (old) and national systems. But this form of periodization proved not entirely defensible, and its initiator Thomas Hughes gradually developed it further. Today one can distinguish three forms of periodization in his work. The first, developed in "Networks of Power," reconstructing (energy-)time from 1870 to 1930, had three stages. Maybe we have in many of the stories told in Mayntz and Hughes (1988) for the last time interpretations, harking back to the era of enthusiastic post-war reconstruction, of LTS development as the story of an inventive beginning, a tempestuous development and a stable state of maturity.

But already that same year, Renate Mayntz published her "On the Development of Technical Infrastructural Systems," and concluded by saying that at least in continental European nations

> the evident affinity between centralized government . . . ruling principles and the organizational imperatives of communication and transportation net-work technologies probably played an important role: This has encouraged both government interest in the development of these LTS and ,conversely, their development into large monopoly organizations. Mayntz goes on to argue that the historical specificity of this congruency may have brought the heyday of LTS organized on a strictly centralized, network basis may not be drawing to a close – both as a result of technical developments, which are less dependent upon the traditional network set-up and can thus be more decentrally organized, and also because the predominance of hierarchical social orders are possibly disappearing. (1988, p. 275f)

One year later, Thomas Hughes presented his second big study on the development of technical systems, "American Genesis: A Century of Invention and Technological Enthusiasm," which leads up into the 1970s. The stage model and its implicit success story were abandoned here in favor of a story of the rise and fall of large technical systems, in tune with the American self-interpretations of decline so characteristic of the Eighties. The structural-analytical concept of the "momentum" of large technical systems following the electrical pattern yields to a parable of cyclical generation and decay. LTS are now culturally threatened, are obsolete and doomed to extinction by the counterculture emerging in the '70s, with its vision of a decentralized, soft technology. Hughes was impressed that "substantial thinkers among the counterculture elite identified large-scale systems as a salient negative aspect of contemporary culture. Herbert Marcuse, Paul Goodman, and Theodore Roszak are cases in point. Oppressive technological – not political – systems were their major concern." And he maintains that out of the counterculture came post-modern thinking as well, especially in architecture. "In part, post-modern architecture is a counter response to the order and control of large-scale modern systems." (1987, p. 187)

As a consequence, Hughes has tended since to concentrate on systems like "management systems" and the technically hybrid telematic systems of the more recent past. At the same time, he seems now to interpret systems resembling grid-based energy systems as "modern" and the non-gridbased, hybrid project-, management- and information-systems of the 1970s and 1980s as "post-modern."[28] The secular metaphor has also been adjusted: the implied epochs are now distinguished into a modern era, beginning approximately with the last turn-of-the-century, and a post-modern era, drawing, it seems to me , on a pervasive and persuasive fin-de-siècle rhetoric. Be it said that this division of LTS into modern and post-modern exemplars loses some old its persuasive force because the old systems rhetoric survives in part: the thinking of systems in terms of complex causal interrelationships has not been abandoned, although it doesn't quite fit into postmodernist rhetoric. (Or else it is another case of high variability talk by one and the same scholar.)

Further interpretation would have to work out in more detail what plots underlie the transitions from one act of the drama to the next: which mechanisms are seen as transforming the systems along their path of development and maybe decline?[29] In order to pursue this at least a short way, another master narrative will be traced, which has to do with the question of who actually does – or does not – control technical development. LTS rise or fall, in these stories, is conceived of as achievement or failure, accounting for its path her always also means that somebody is held accountable.

Narratives allow for a principle of learning from history by providing a moral to the story – something that models do not accomplish, because models have to do with possible, counterfactual, not actual developments. Who are the actors, who are the heroes and who the villains of LTS? Is it the men from the politico-administrative systems, or the ones in the corporations and the stock exchanges, or who and what? Giving up the original stage theory may also be interpreted as the end of the heroic "system builders." Who then builds up, steers and controls? How should the ubiquitous ambivalence of open versus closed systems, of emergent versus designed systems be resolved? Alternating between metaphors of lawful evolutionary change and of goal-oriented action and will? In another language: do systems evolve "themselves" behind the backs of their actors, or are they the result of strategic communicative acts? After all, unforeseen developments or developments surprising in hindsight may be interpreted as contingent effects or as the unintentional results of planned action, reflecting different attributions of responsibility for what happened.

Narratives of Responsibility: Emergence and Openness versus Closure and Design

As it turns out, narrative modes closely akin to the story of phases and stages, positing system inventors, system constructors, system designers and system managers intentionally promoting and shaping their systems, are clearly retained in most studies.

Tightly coupled technically, with complex "imperative" organization and management prompted by operating requirements designed into the system, i.e., unless operations are conducted in x, y ways, there are no benefits, maybe great harm can be imagined. (This is a kind of soft technical determinism: either do it my way or it won't work and do good things for you.) – Such systems reify the models of the designers, imposing a modality of control as if an exhaustive, predictive knowledge base were in place. – Durable physical artifacts project into the future the socially constructed characteristics acquired in the past when they were designed.[30]

Peter Weingart indicates how indecisively this entire discourse vacillates between a systems and an actors perspective: almost as a rule, case histories begin with the heroic system builders, who at some point then disappear from the stage, leaving the system to anonymous forces from within or without: "It is the strategy of the 'system builders' to gain control over the 'intractable forces' in the system environment, i.e. the factors which generate uncertainty for the system, and to structure the environment to meet the demands of technology and the social systems organized around it." Weingart continues by saying that in order to secure their assets, "the systems" must eliminate uncertainties; that this in turn means expanding, insofar as a system succeeds in overcoming the opposing forces in its environment or, alternatively, restructuring the environment according to its own imperatives. "In principle . . . the system is inherently oriented towards bringing its entire relevant environment under its control. It is, however, not only impossible to achieve this goal in principle; moreover, since those parts of the environment which have been brought under control become components of the system, its expansion increases its degree of inner complexity and increases the problem of its internal regulation." (Weingart, 1989, p. 181f, translation BJ) This by now familiar piece of LTS discourse ends with formulations that posit large technical systems as selfregulating entities on their way to inevitable control crises due to the ongoing incorporation of complexity from their environments. Listen to Thomas Hughes again:

> Over time, technological systems manage increasingly to incorporate environment into the system, thereby eliminating sources of uncertainty, such as a once free market. Perhaps the ideal situation for system control is a closed system that does not feel the environment. (1987, p. 53)

The metaphors behind this (end of) story come mostly from biological and sociological theories of selforganizing, autopoietic systems which tend to exclude notions of external control and steering. Yet the beginning of the story is couched in action theoretical terms: the notion that there are agents designing and controlling systems.

In the course of the debate at one of the international LTS-conferences, Renate Mayntz insisted: " . . . the design issue, i.e., the question how the anticipation of consequences along the different performance dimensions . . . determine system design. What do system designers really anticipate? Which of the various consequences do they anticipate? And if they anticipate them, how does that enter into the design process?" (in LaPorte, 1991). LTS-studies provide scarcely any evidence on this point. On the other hand, one suspects that the blithe talk of systems design, of intention and learning, of control through technology and so on provides little in the way of conceptual accentuation: it is almost always found in connection with systems *components* (airplanes, trains, battleships, supercomputers) and hardly ever with regard to any of the extended networks linking them with so many other things . . . Remember also the basically skeptical attitude perceptible throughout these studies when it comes to the topic of systems control and controllability. This scarcely allows for a foregrounding of stories of design and closure, which has a lot to do with responsibilities for outcomes.

So what we have here is perhaps another *façon de parler* in social studies of technology, adopting, as so often happens, elements of the rhetoric of informants "in the field" and system members who, especially in early stages, have good reasons to present their schemes as well designed and under control. Inasfar as a more or less casual actors' rhetoric is retained throughout the telling of a system's story, the fundamental openness and uncontrollability of LTS development which also asserted in most LTS studies is commonly framed as a matter of unintended effects and consequences.

These hazards explain the waverings of the actors would found themselves engaged in a game with unknown rules. – It must be emphasized, however, that when the system first made its appearance their promoters had no idea that their creations would be different. – There were few who understood the new technical system and its rules. Most actors were caught in a cage of traditional thinking.[31]

The main actors in the LTS drama – wherever it is written as a story with main actors – were either system builders in Hughes' sense, monopolistic utilities, or government bureaucracies. But if research often forces the conclusion that technical systems do not evolve according to the intentions of their authors, could one not suspect that it is the recipients whose strategies determine what shape LTS take? If LTS do not follow any particular design, may one then assume that it is their users who influence their form of development? Interestingly, LTS users play no considerable part in the research examined here. Their possible influence is hardly investigated and is hidden conceptually behind metaphors like market or environmental control.[32] Except for MacKenzie (1991), in his study of supercomputing, and Rochlin (1991), in his reconstruction of the battle of the *Vincenne* in the Persian Gulf, users are not systematically introduced in these studies.

But even MacKenzie and Rochlin operate here with a metaphor coming from social studies of small-scale technical systems: that of the "hardwired user." The hard-wired user is the user in the machine, as it were, not the user before and after the machine. The notion is advanced that the machineries and technical systems under study are impregnated with a previously designed, built-in user model, forcing actual users to interpret their possibilities for action in a certain way. (But who are the end-users of a battleship?[33]) There is a mild technological determinism implied in the image of the hard-wired user which can only be demonstrated, or refuted, if and when the reciprocal impacts of systems on various user groups and users on various systems (with various wired-in users) are actually studied.

Wherever the approach tilts from an actors perspective to a systems perspective, i.e., when the LTS drama is told as a story of systems producing and reproducing themselves, the discourse of design and (possible) closure is supplanted with a discourse of indeterminate emergence and principal openness. This in turn tidies over into discourses of uncertainty and risk.

There were few who understood the new technical system and its rules. Most actors were caught in a cage of traditional thinking. – It must be emphasized, however, that when the *system first made its appearance their promoters had no idea that their creations would be different. – With regard to these systems, everything is uncertain, everything eludes prediction; it is impossible to assign a destiny to them . . . – The advent of new "technology," the process of technical progress is . . . a development similar to the succession of the seasons: one can't do anything to change it, one can only adapt to it and at most travel somewhere else where the climate is milder.*[34]

All in all, the notion that LTS are, over and beyond in those components which can be said to be "designed" in the conventional sense of the term (administrative regulations, technical standards, machinery and installations), "emergent" structures is pervasive. Aside from their characterization as "complex,"[35] the attribute "emergent" is perhaps the most common one ion LTS studies. This characterization does not in itself point to any more specific conditions for the growth of technically networked structures – except, of course, for the obvious periodization establishing LTS as an emergent phenomenon of industrialized, Western societies. Again, emergence talk achieves, I think, welcome effects of LTS naturalization and unaccountability, presumably especially for later stages of seemingly out-of-control system dinosaurs.

Stories Not Told

Semioticians tell us that it is possible to say some things only by not saying others. When Renate Mayntz noted that "(w)e may have been inclined to focus too much on types of hierarchical or centralized control, and have tended to frame the issue in terms of centralization/decentralization . . ." (1991, p. 182), it suddenly becomes clear that there is a ubiquitous systems concept in the LTS discourse which accentuates hierarchy, although systems are hardly ever explicitly linked with this characteristic anywhere in these studies. But con the unstated always so clearly be derived from what is actually said?

I see four stories which have remained largely untold in LTS studies: the cultural history and the natural histories of LTS, the everyday users/uses of LTS, and the place of space, as opposed to phase, in LTS-research.

Users and the System

Imagine a couple of hundred premodern citizens, such as for example the types that appeared in French movie houses a few years ago in the film *Les Visiteurs*. And imagine that they are herded into a large AF Airbus. The usual take-off routines are played out and the plane starts. I cannot describe to you the terror and the fears and the reactions of the passengers. But I suggest that this aeroplane cannot be flown safely because the passengers have not acquired the many cognitive, emotional and practical disciplines that make us modern air travelers safe baggage. But we are hardly mentioned in LTS-studies.

LTS studies have been conceived and conducted in a managerial perspective. Students of LTS have put themselves in the shoes of the system-builders, so to say. They have tried to understand the intra- and extrasystem mechanisms that shape the build-up, the routine management and the struggles against break-down of systems and networks. This is not to say that system users such as energy end-users, car-drivers, citizens, households and consumers have not been represented in LTS studies. They have of course. But they have not come in as an immediate object of study, or only in very rare cases. The implied users, the "model users" of LTS are passive users. Their discipline, their active contribution, and by the same token their potential for resistance, are rarely made explicit. The co-production of system services is not explicated in LTS-research. Users remain hidden, most of the time, behind abstract concepts such as demand or risk or regulation.

There is an issue in LTS debates where users come out more openly, as it were: at issue is whether user control and user participation in late-modern Communication networks such as the Internet differ from early modern technical systems such as energy generation system and other classic infrastructures. One can often hear a thesis that while old systems such as energy or transportation systems are centrally controlled systems such as, prototypically, the Internet are decentral and basically built up, managed and conducted by large numbers of loosely coordinated users. The thesis underestimates, however, or misconceives the part played by users in classic systems and it overestimates and misconceives the part played in telecommunication systems such as Internet. An energy generation and distribution system brings power to millions of everyday users who utilize this power for countless purposes: listening to Mozart, cooking spaghetti, reading the newspaper, warming the apartment and so on and so forth. In order to produce these goods they operate their household machineries.

One could say that the centrally controlled system is programmed by users to produce their purposes. The same with road systems which is variously programmed by users with the help of their cars to produce their purposes: going to work, visit friends. What happens in the Internet is not that different, apart from its technical scale.: communication in the Internet relies on relatively few monopolistic an corporate telephone networks, which are centrally controlled. Internet users and surfers program these networks with the help of their peripheral equipment for their own purposes. This is not to say that there are no differences between systems. In a user perspective, the main difference between old and new systems lies in the form of co-operation required from users. In the case of Internet, the user competences and resources required may be more visible and at least for a while more spectacular than in the case of today's electricity uses. But this does not give users more control.

Cultures and the System

Guided by the systems metaphor, LTS are preferably construed as being systemic, rational and functional. Only recently have considerations of "system culture" been gaining in importance, as for example in Rochlin's (1991) cross-national comparisons of nuclear systems. But, to recall the example of Hughes' electrical systems: things may not have been quite so rationally planned, not to talk about implemented and managed, back then around the turn of the century.

With his book "Electrifying America", for instance, David Nye (1991) wrote something like a cultural history of the "Networks of Power." He argues that, quite at variance with the metaphors propagated by the inventors and operators of electricity at the beginning of the century, early applications of electricity were anything but embryonic systems, oriented towards well-centralized and well-integrated network structures and controlled by a disciplined elite of engineers and managers. Rather, according to Nye, incipient electrical technologies were experienced as "sublime objects." Electricity was considered as a thing of terrible magnificence, whose significance, as presented to the awed and amazed masses by scientific magicians, lay in its capacity to frighten, but also to deepen and strengthen the thinking consciousness of the observer. Today, it is a natural part of the world we live in.

Nye describes the quality of the early enthusiasm for electrical technology in colorful terms. Leading moralists of the day saw it as evil. For the half-educated middle-classes, it was a mysterious, sensuous, miraculously healing force. The Veblen engineering elite idealized it as a guarantee for rational social reform. If one listens to Nye, the early electrical inventions in America were highly theatrical, spectacular, extravagant and dysfunctional.

Our present day LTS "evolved" and "emerged" then from a huge muddle of technically incompatible and competing enterprises, speculations and spectacles. Cultural acceptance was achieved through public displays, especially light shows, the "conspicuous consumption" of the cities. Of course there were also representations of electricity as functional and technically neutral, but they remained juxtaposed with representations of electricity and its possibilities as breathtaking, exciting, fantastic and magic. In short: electricity was subjected to an intensive cultural tug-of-war before it became effectively naturalized and its juice could begin to flow through all conceivable expressions of life in Western societies. Only in later times was this circumstance forgotten, partly because governments and corporations engaged in retrospective falsification in writing up their own official histories.

In Western industrial societies it was a long way, then, from the scientific-technological miracle of the electric current to its effectively blackboxed technical applications in daily life, to a service reduced to a mere function and commercial product.

The emblematically sublime object of our time is the computer. Sherry Turkle, author of the most-quoted study on computers, "The Second Self," describes these machines as the "evocative objects" of the epoch: "Under pressure from the computer, the question of mind in relation to machine is becoming a central preoccupation. It is becoming what sex was to the Victorian – threat and obsession, taboo and fascination." (1984, p. 313) Today's counterpart of the nervousness of the electrical medium is clearly the autistic quality of communication in the frigid zones of electronic cyberspace.[36] And many researchers studying computer-based technical networks, that "post-modern" type of LTS, let themselves be seduced by the harp chords (or rather the synthesizer sounds) of a computer pop culture, tuned to simulacra, virtual reality and cyborgization, into raising such notions to the status of sociological constructs. Retrospective LTS research may have had difficulty in adequately accounting for cultural processes; future-oriented research may take them into account too carelessly.

Natures and the System

Just as their cultural history is passed over, another blind spot in studies of LTS tends to efface the natural histories of these systems. Because in social studies of LTS attention has almost exclusively been concentrated on the "interface" of technical/social, the relationship social/ natural in LTS development was largely ignored. In other words, whatever happened to ecological issues in LTS discourse? Except for a remark about the bad weather conditions prevalent at the time of the Shuttle/Challenger disaster (Pinch, 1991) and about the weather problem in flight control (LaPorte, 1988), the sparse allusions to natural conditions in the two weighty LTS-volumes reviewed here take merely the negative form: "Neither the British nor the Norwegian model could handle the challenges of the North Sea" (Andersen, 1991, p. 46). That is strange.

Only recently did Thomas Hughes latch onto ecological LTS discourse in the fields of human geography and landscaping, bringing into the international research network authors such as Cronon or Spirn[37]. The ecological blind spot in LTS research is perhaps also related to the fact that the basic narrative mode is a linear, story-telling, not a lateral, space-mapping one. Even Giddens, the social theoretician who probably contributed most towards giving sociology a spatial dimension, meets this demand almost only for the spatial dimension of the nation state. Processes of spatial expansion, territorial appropriation and assimilation extending beyond regional and national boundaries are as characteristic of the growth of large technical systems, especially in connection with processes of urbanization, as are the celebrated stages of successive differentiation and integration over time. They have not been very carefully delineated in LTS research up until this time.

Spaces/Places and the System

By and large, LTS discourses suffer from the general historicist bias which has been characteristic of much of social science. The guiding thread of LTS narratives has been the calendar, not the map.

Foucault had a few interesting things to say about this, albeit without any direct reference to the problems of ecology and – today one must add – ecocracy. The great obsession of the nineteenth century was, he says, "history: with its themes of development and of suspension, of crisis and cycle, themes of the ever-accumulating past . . ." Our epoch, he claims, will perhaps be above all the epoch of space. "We are in the epoch of simultaneity, . . . of the near and far, of the side-by-side, of the dispersed. We are at a moment . . . when our experience of the world is less that of a long life developing through time than that of a network that connects points and intersects with its own skein . . . " (1986, p. 22) And in another place he insists: "A whole history remains to be written of spaces – which would at the same time be the history of powers . . . – from the great strategies of geopolitics to the little tactics of the habitat, . . . from the classroom to the design of hospitals, passing via economic and political installations." (1980, p. 149) This applies to the spaces of technical networks too, from the micro-spaces of consumer technology to the macro-spaces of global communication systems.

A "reterritorialization" of LTS-research seems indeed underway, as the latest round of the international LTS-conferences indicates: both in terms of choosing cases, for instance urban networks, and in terms of conceptualizations, territory, space and place are given more thought than before. This accords with a growing emphasis in social studies of large technical systems on aspects of local embedding and the socio-cultural contextualization of disembedded technical and conceptual devices. There remains the other aspect, however: The business of system building is precisely to develop solutions for multiple applications in many places and to resist, as it were, premature closure. This seems to me the core competence of what Thomas Hughes has famously called independent inventor-entrepreneurs, or system-builders. It involves both a high awareness of the importance of local adaptation of systems solutions and the ability to offer generic solutions which then will be turned into countless local applications by others: skilled disembedding of local solutions is a distinct achievement wherever new, and particularly international spaces are to be opened. It seems to me that "reterritorialization" is a necessary step in understanding this feat of viably disembedding system solutions. How are "universal services", in the sense of service irrespective of place and space, possible?

Where to Sail?

As Renate Mayntz noted at midpoint in the conference series: "We have tried to draw . . . a very sketchy map of a new continent which needs considerable refinement before we can set sail for new shores." (Mayntz, 1991, p. 181). The two conferences since have added detail without however changing the course of LTS research. Concluding this journey over some of the verbal carpets spread out by LTS research, one may wonder about the refinements as well as the new shores.

Narrating, Interpreting, Modeling?

Could one step beyond the basically narrative, i.e., interpretative accounts of (even comparative) case studies in the general direction of systematic, hypothesis-testing and model-building, in time quantitative comparisons? William McNeill, the historian, once differentiated between two paths in the social sciences observing that "historians (resort) to narrative in every case . . . (to) surprising results from specific actions, and leaders combining old and new in a surprising future. Others (fall) back on numbers." And he contends that the real intellectual issue is "how to understand the interaction of the episodic but critical act with the underlying ebb and flow of numbers". (1987, p. 110/111)

The others here are clearly sociologists and the like. Clearly, the reading public in general prefers historifying approaches. Linnda Caporael for instance, of the Rensselaer Polytechnic Institute, concentrates her praise on the narrative chapters of Mayntz and Hughes (1988) in her discussion of this study: "For readers who can surmount (or just skip) a lifeless and jargon-laden opening chapter, it is . . . useful . . ." (1990, p. 210) In fact, by far most of the studies referred to here use a combination of narrative, historical reconstructionist and model-like, counterfactual approaches. But the old problem – "how to put numbers into stories" in the sense of quantitative modeling – remains unsolved in LTS studies, too.

Equally unsolved, however, must remain an entirely different problem, which could be called "how to control your interpretations." Around the mid-1980's, when I first began to concern myself with LTS, I looked for examples of stories and interpretations of large (overlarge) technology in literary fiction. I soon came across Alfred Döblin's "Berge, Meere und Giganten" (Mountains, Seas and Giants) which I found equally fascinating and repulsive. Döblin's expressionist envisioning of heroic, archaic, endlessly disruptive dramas of ever crazier technical schemes played out between ever less familiar social forms seemed entirely unsuited to me for transporting insights into the apparently irreversible upwardbound transformations and rationalizations of present-day and foreseeable large technical systems. Today, I see this work as a literary interpretation of the *longue durée* of LTS, which has suddenly gained in plausibility in the wake of the reversals and revolutions of the recent past, especially in the Eastern European LTS.

When I now read a latter-day American Döblin such as Neil Stephenson and his equally crazy post-cyberpunk visions in "Snow Crash" or "Diamond Age", I certainly tend to overestimate the plausibility of his vision as much as I underestimated the heuristic value of Döblin's vision. In other words, my own interpretative patterns have shifted quite a bit in rather short time in a way which I find hard to account for in the study of an empirical LTS. How can we reflexively account for such shifts and, even more difficult, for those heuristics that don't shift? One certainly should worry not only about our incapacity to put numbers into our stories; it would also be desirable to find a disciplined form for dealing with hermeneutical issues since interpretations are unavoidable and essential to modeling. as much as for storytelling.

Forecasts

The category of "large technical systems" held out the promise of rendering an interesting conceptual status to the those extended technical foundations without which modern societies would not be able to develop and maintain their interactions over ever increasing distances of social space and time or the breadth of their functional differentiations. Should one regard the multiplicity of the sociological discussion about LTS as an indication that it is difficult to think of LTS as a particular type of social system? Should one see it as an indication that the concepts of social systems theory, as they have entered the hybrid discipline of LTS research, do not provide the means for sufficiently sharp distinctions and enough requisite variety to enable consideration of all systematic and historical aspects? Whatever answer a reader might give to these questions, LTS research should and will contribute to our better understanding one of the central issues in an anthropology of industrial and superindustrial societies: how to make and maintain control and order at very great distances, particularly at a stage or in an age, when/where familiar, centralized, hierarchical and national-territorial forms of governance have seemingly become overextended and cannot any longer manage the trans-border, sometimes even global processes LTS have made possible and occasioned.

After this wonderfully long and overextended sentence, my final, more specific predictions are: Ambitious, sufficiently broad and necessarily comparative empirical investigations under way in a number of places will make their way from the research fields into the books and journals. The interlacing of different LTS will attract more attention. Consideration of other approaches to the study of technology – which place less faith in the systems metaphor – will add interesting accents to LTS research. Analyses of LTS from the user perspective will follow. Cultural studies of LTS will appear on the bookshelves. Place and space will gain interest over temporal considerations. Historians and sociologists of technology will put aside their quibbles. Now and then, the study of LTS will even profit from the interjection of small doses of irony and self-reflection.

The high variability of LTS discourse will, if anything, increase. This should be seen as a resource, however, rather than something to be remedied. It would be too easy to reduce the apparent paradoxicality LTS discourses – emergence or design? equilibrium or crisis? system or rhizome? – to a series of two-by-twos into which concrete instances can then be sorted. The paradoxicality resides irreducibly in the so-called systems, not in our feeble attempts to understand them. The best way of dealing with it is to understand how system actors – builders, users – deal with it.

[E]ndnotes

[1] Although I will take the stance of the outsider/analyst in the following pages, I consider myself an insider/participant of this community myself, having participated in all the conferences except Sidney and having organized a separate series of seminars with a different circle of German scholars. This has resulted in another book on LTS (Braun/Joerges, 1994).

[2] I am painfully aware that this procedure in no way does justice to the authors of the original texts, not only because my interpretations and attributions necessarily diverge from the authorial intentions, but because this form of quoting violates subtle linguistic contexts. - Largely excluded from these intertexts and my are metatexts aiming at higher level abstractions and generalisations on the basis of empirical LTS research done

elsewhere (such as Mayntz, 1988, 1993, Joerges, 1992, Braun, 1994, also Gras, 1994, Grundmann 1994, Joerges/Braun 1994, Summerton, 1994a).

[3] In the subsequent intertexts I apply, in the interest of readability, almost consistently two simplifying conventions: (i) Instead of concrete systems or system types ("the early French railroad," communication systems"), there has throughout been inserted "system(s)," a term which should always be read as "large technical system" in the context at hand; correspondingly, systems operations were "neutralised" (substituting for instance "interactions" for "transmissions"). The references clearly indicate to what type of system – air travel or telephone, for example – the neutralised systems terminology of a particular quote pertains. (ii) Differences in tense form are eliminated and all quotes are put in the present. Otherwise, occasionally conjunctive words - and, or - are omitted or added . The exact wording can be easily ascertained through the sources, which are given for each intertext in the order of the individual statements separated by hyphens.

[4]Thomas, 1988, p. 179; Hughes, 1987, p. 52; Weingart, 1989, p. 175; Weingart, 1989, p. 179.

[5] The one move to discuss categorical issues in depth comes from Beckman (1994), albeit not in the context of an empirical LTS study.

[6] Weingart, 1989, p. 180; Thomas, 1988, p. 179; Galambos, 1988, p. 135; Salsbury, 1988, p. 61; Schneider, 1991, p. 22.

[7] Weingart, 1991, p. 8; Weingart, 1989, p. 10; Andersen, 1991, p. 57.

[8] Bertho-Lavenir, 1988, p. 155; Thomas, 1988, p. 208; Thomas, 1988, p. 187; Caron, 1988, p. 72.

[9] Joerges, 1996b.

[10] LaPorte, 1988, p. 240f; Weingart, 1989, p. 10; Rochlin, 1991, p. 102; Weingart, 1989, p. 175.

[11] Even though Charles Perrow attended the first international meeting.

[12] Caron, 1988, p. 75; Caron, 1988, p. 76; Pinch, 1991, p. 153; Hughes, 1987, p. 79. See also, for the risk-theme, von Meier, 1994, Rochlin, 1994, pp. 234-247, Ekardt, 1994, p. 192-195, Kornwachs, 1994, pp. 422-443.

[13] Salsbury, 1991, p. 86; Salsbury, 1991, p. 86; Hughes, 1987, p. 56; Hughes, 1987, p. 79; Hughes, 1987, p. 79. MacKenzie, 1991, p. 165; Weingart, 1989, p. 187.

[14] Hughes, 1987, p. 58; Bertho-Lavenir, 1988, p. 166; Galambos, 1988, p. 146; Heinze and Kill, 1988, p. 131; Salsbury, 1988, p. 44; Salsbury, 1988, p. 45.

[15] Salsbury, 1988, p. 65; Bertho-Lavenir, 1988, p. 173; Galambos, 1988, p. 136; Heinze and Kill, 1988, p. 116; Salsbury, 1988, p. 61; Caron, 1988, p. 81; Hughes, 1987, p. 87; Hughes, 1987, p. 80.

[16] Heinze and Kill, 1988, p. 116; Bertho-Lavenir, 1988, p. 164; Caron, 1988, p. 96; Caron, 1988, p. 86; Heinze and Kill, 1988, p. 107, Heinze and Kill, 1988, p. 128; Caron, 1988, p.70.

[17] Interestingly, this can even achieved for artificial systems; on the naturalisation of (computer) technology see Joerges, 1991.

[18] MacKenzie, 1991, p. 166.

[19] Caron, 1988, p. 96; Caron, 1988, p. 102; Caron, 1988, p. 70; Salsbury, 1988, p. 63; Salsbury, 1988, p. 63.

[20] Caron, 1988, p. 76; Caron, 1988, p. 100; Bertho-Lavenir, 1988, p. 158; Salsbury, 1988, p. 66.

[21] Lévy-Leboyer, 1988, p. 261; LaPorte, 1988, p. 225ff.; Weingart, 1991, p. 9f; Oster, 1991, p. 127. For further discussions see von Meier, 1994, p. 211-226, Radkau, 1994, p. 71-83, Kubicek, 1994.

[22] At Cologne's Max-Planck-Institute fuer Gesellschaftsforschung.

[23] Caron, 1988; Caron, 1988, p. 78; Caron, 1988, p. 81, p. 99; Schneider, 1991, p. 34

[24] With a few exceptions (Hughes, 1989; Rochlin, 1991; Bucholz, 1994), military technology, state technology par excellence, plays no role.

[25] Caron, 1988, p. 74; Bertho-Lavenir, 1988, p. 156; LaPorte, 1988, p. 216; Lévy-Leboyer, 1988, p. 259f; Mayntz and Schneider, 1988, p. 264.

[26] See in particular Salsbury 1994, pp. 142-159, Rochlin, 1994, p. 239-255, Radkau, 1994, pp. 64-88, Kubicek, 1994, pp. 112-124, Ekardt, 1994, pp. 171-188.

[27] Hughes, 1987, p. 56f; Heinze and Kill, 1988, p. 129; Heinze and Kill, 1988, p. 105; Heinze and Kill, 1988, p. 105.

[28] Regrettably I don't have, at the point of writing this, a text from which I could quote.

[29] It would be intriguing to consider the stages/phases debate and its variations (four stages, five stages and their dramaturgical transformations) in the light of a structuralist narratology such as was first influentially developed by Vladimir Propp, 1968.

[30] LaPorte, 1988, p. 221; Rochlin, 1991, p. 118; Hughes, 1987, p. 77. For further references to the design-issue see Salsbury, 1994, p. 159, Usselman, 1994, pp. 101-106, Schneider, 1994, pp. 78-81, Rochlin, 1994, pp. 231-255, Kornwachs, 1994, pp. 430-434, von Meier, 1994, pp. 219-224, Abbate, 1994, pp. 200-202.

[31] Caron, 1988, p. 76; Salsbury, 1988, p. 38; Heinze and Kill, 1988, p. 108.

[32] For more on the role of large-scale technical background and "warranty" systems in everyday applications of small-scale consumer technologies, see Braun, 1989.

[33] It seem a bit implausible to apply the interpretation of the hardwired user to the victims of military attacks.

[34] Heinze and Kill, 1988, p. 108; Salsbury, 1988, p. 38; Caron, 1988, p. 7; Weingart, 1989, p. 8.

[35] For a more detailed account of the "discourse of complexity" in LTS research see Joerges (forthcoming).

[36] For a classic literary text on this see William Gibson's "Burning Chrome" (1986).

[37] Cronon, 1991; Spirn, 1984.

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Note

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