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Standardisation of information infrastructure: where is the flexibility?[1]

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We discuss how STS theory might help us understand the nature of the processes, especially the key issue of standardisation, through which information infrastructure (INI) is developed. A selection of relevant STS concepts is reviewed in this connection.
We suggest that current STS concepts fail to adequately capture a number of the characteristic properties of INI including: how the formal and systemic nature of INI gives rise to non-continuous processes of standardisation and how flexibility presupposes standardisation. We develop an empirically based intermediate position between regarding the theoretically based "technology enables/ constrains" positions which also allows the question of relative degrees of flexibility to be posed.

The theme of this paper is the development of information infrastructure (INI)[2], concentrating on the crucial issue of standardisation, and how concepts from STS may improve our understanding of this process. Our aim is two-fold. Firstly, we hope to inform the ongoing process of design through a firmer grasp of the challenges facing standardisation of INI. We intend to engage in the ongoing, at times heated debates concerning design, and not only study historical material or practice "modest sociology" (Law 1994, 13-14). Standardisation is expected to have far-reaching implications of economical, technical and social nature (Bradley, Hausman, and Nola 1993; OECD 1991;

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[2] INI is not a homogeneous concept. It is related to a number of concepts, some of which denote existing technologies (communication technology, inter-organisational systems (IOSs) and electronic data interchange (EDI) and some do not (information or electronic highways). In particular, INI is currently being developed and shaped. It is this, as yet non-existing, INI we are interested in. But to get at INI, we have to study the more basic communication technology, which most likely will become the basic for tuture INI.

Scott Morton 1991). Secondly, we provide critical remarks to the current understanding of standardisation within STS. In the present stage of elaboration, STS concepts do not adequately capture the specific properties of the process of standardisation of INI, in particular the quite unique combination of the formal and systemic character of INI to be spelled out in more detail below.

Standardisation and flexibility[3] are two seemingly opposing notions. In what follows, we discuss this in greater detail both for the special case of INI and on a more general level as expressed in STS literature. It will become evident that the relation between standardisation and flexibility is more complicated than one of plain opposition in the case of INI. Flexibility on one level presupposes standardisation on lower levels of the systems hierarchy. The strictly layered composition of INI is one of the distinguishing properties of this technology. Standardisation may be regarded as one of the key issues within STS as, for instance, ANT may be portrayed as a framework for describing the standardisation or stabilisation of claims into "facts". The notions of "boundary objects" (Star and Griesemer 1989) and "standardised packages" (Fujimura 1992) may be regarded as further elaborations. STS accounts of standardisation in relation to INI are relatively rare (Schmidt and Werle 1992, 325). Existing accounts tends to bypass discussing the implications for STS concepts regarding standardisation (Kubicek 1992; Kubicek and Seeger 1992; Webster 1993). Our paper aims at giving a description of the unique interplay of standardisation and flexibility within INI from which we discuss the adequacy of present STS concepts.

The remainder of the paper is organised as follows. We review a selection of relevant STS concepts, focusing on SCOT and ANT. The purpose is to discuss how they capture the specific ways standardisation and flexibility operate in the case of INI. One important line of argument is that so far STS has not been sensitive enough to the specific properties of the technology and how these influence the concrete mechanisms of standardisation and flexibility. To substantiate this claim, we describe in some detail how these mechanisms operate and relate to properties of INI. The empirical basis of our discussion is two existing systems which are likely to form the basis for future INI. We develop what might be called an empirically based intermediate position in relationship to more theoretically based positions maintaining that technology enables some actions while constraining others (Akrich 1992; Bijker 1993; Callon 1991; Giddens 1984; Sørensen 1994). We claim furthermore that the issue of relative degree of flexibility (that is, inquiring whether one artifact is more flexible relative to the flexibility of another) is relevant for such an intermediate position.

[3] We use "flexibility" synonymously with "interpretative flexibility" or "localisation".

Relevant concepts from STS

Standardisation denotes a wide range of semingly disparate phenomena. One may consider successful employment of language as a result of standardisation: the intended meaning of a spoken utterance is grasped by a hearer exactly because the utterance, in its context and despite a high degree of flexibility, has a sufficiently standardised meaning (Cargill 1989, 13). A less far-fetched variant of standardisation is the development of special concepts and notions within specific domains, for instance among professional groups, academic disciplines or social groups. An example of this is the study by Bowker and Star (1994) of the ICD coding system used by WHO for classifying medical diagnosis. Yet another variant is that of standardised practices, routines or procedures, for instance, certain work procedures (Fujimura 1992). Finally, and closest to the focus of this paper, we have the stadardisation and stabilisation of how to perceive and use a technical artifact.

Once in place, standardisation may be exploited - by uttering a sentence, denoting domain specific concepts, imposing a practical routine or introducing an artifact - as a means towards establishing a social order. All above forms of standardisation are needed as methods for accomplishing social order, as Law (1994, 24) reminds us: "But, and this is the problem, left to their own devices human actions and words do not spread very far at all.".

From these more general observations we turn to STS. Rather than being comprehensive and systematic, we discuss selection of STS concepts which we find relevant to the present purpose of illuminating the case of INI. We focus on SCOT and ANT.

Studying science and technology through controversies is one of the key elements within STS in general and SCOT in particular: how facts and artifacts are indeed negotiated among actors, relevant social groups (Pinch and Bijker 1987) or core set (Collins 1981). The principle of flexibility (Law and Bijker 1992) - the notion that any object, institution or process may mean different things to different people - forms the core of the SCOT research program. In short, it means that nothing is in principle immune to dispute, negotiation, or reinterpretation, that is, anything may at any time become the subject of a controversy.

Flexibility plays several important roles. It is the core concept when disposing of technological determinism (Bijker 1993, 118). By identifying more than one interpretation of an artifact, technological determinism is simply "falsified." Emphasising the always-present flexibility of an artifact must also be recognised as a strategy for intervention in the following sense. Focusing on flexibility encourages varied patterns of use. It thus "empowers" the many users at the expense of the relatively small and privileged group of designers and developers (Sorensen 1994). Flexibility in use is hence regarded as an ideal.

However, simply observing and asserting the flexibility is not sufficient for understanding the nature of facts and artifacts. The next stage concerns the mapping of mechanisms for the closure of debate or for the stabilisation of an artifact. "Closure occurs in science when a consensus emerges that the "truth" has been winnowed from the various interpretations; it occurs with technology when a consensus emerges that a problem arising during the development of technology has been solved. When the social groups involved in the designing and using technology decide that a problem is solved, they stabilise the technology. The result is closure (Bijker, Hughes, and Pinch 1987, p 12)." Or, as Misa (1992, 109) describes it, "closure has come to mean the process by which facts or artifacts in a provisional state characterised by controversy are moulded into a stable state characterised by consensus."

A difficulty with these accounts is that the interplay between flexibility and standardisation (or closure, stabilisation) is not described clearly enough. In connection with INI one would for instance be interested in how flexibility is hampered or enabled after closure is reached.

ANT may be seen as an attempt to move beyond pointing to different interpretations. It provides us with concepts which throw some light upon the technology's structuring or stabilising abilities. We find an elaboration of ANT by Callon (1991, 1992, 1994) particularly relevant. He introduces the concept of irreversibility, which describes how translations between actor-networks are made durable, how they can resist assaults from competing translations. Callon (1991, 159) states that the degree of irreversibility depends on (i) the extent to which it is subsequently impossible to go back to a point where that translation was only one amongst others; and (ii) the extent to which it shapes and determines subsequent translations. In the end, this process will lead to normalisation, when all the interfaces between the actors are standardised and their reactions are totally predictable.

SCOT has clearly captured valuable insights through the notion of flexibility. Now the challenge is to push further. The constant concern with flexibility makes it conceivable that we lose interesting distinctions. It seems to us that SCOT may state that "Yes, artifact A allows flexibility and artifact B allows flexibility" but cannot (or will not?) propose that "Artifact A allows greater flexibility than artifact B" or "Artifact A in this phase allowed greater flexibility than artifact A in that phase. In due course, we will argue that this issue of relative degrees of flexibility is vital in connection with INI. One might accordingly say that we develop an empirically based - as opposed to a more theoretically based - intermediate position in relation to the debate within SCOT concerning the role and extent of flexibility (Winner 1993; Woolgar 1991) or the "epistemological chicken" debate Collins & Yearley vs. Callon & Latour (Callon and Latour 1992; Collins and Yearley 1992).

With regards to ANT, a major strength, the immediate pay-off for the many forms of symmetries, is that every form of standardisation may be approached with the same methodological equipment. There is no need for tailor-made analytical tools for every form of standardisation. One does not want to distinguish between types of technologies; all forms of technology are to be tackled using the same, uniform analytic concepts. An important feature of the analysis is the constant, gradual, and continuous reshaping of the technology which takes place. This small-step, social process of building alliances, establishing acceptance and of translating interests gives rise to the near-continuous transformation of the artifact. In what follows, we intend to challenge or modify this principle of symmetry by arguing empirically that a number of the characteristic properties of INI are not accounted for satisfactory.

This implies that one needs to be sensitive to the specific characteristics of INI. Programmatically stating the social and political contents of standardisation processes is rapidly becoming a cliche. When, for instance, Webster (1993, 15) points out that:

> These political and economic agendas have become encapsulated within EDI standard setting procedures and within the standards that are generated. (...) EDI standards are not merely technical artefacts, neutral solutions to issues of electronic communication. They are also the embodiment of the social relations of economic competition in the late twentieth century.

most scholars would agree. The challenge, however, is connected with identifying, with the maximum of precision, exactly how and where these non-technical agendas show up. What is required, we believe, is not only the relatively weak acceptance of technical issues as legitimate:

> This is not to suggest that EDI standards are composed purely of social and economic relations, or to focus on the social at the expense at the technical. (...) (T)here are technical considerations involved in standardising an EDI message, such as adhering to agreed definitions of data elements and maintaining consistency of coding. (...) Rather, (this paper) is concerned to emphasise the social, political and economic aspects of the standardisation process. (ibid., 2-3 [last two emphases are added])

The problem, we believe, with accounts like Webster 1993, despite their claims of the opposite, is that they do not attempt to track the basis for the social and political controversies to the specifics of the technology. Rather, they tend to leave the technology alone and only take into account the non-technical issues in the controversy. Instead of observing that the overall effect on the standardisation process itself is "intensely political" (ibid., 14), we need to learn more about how the minute, technical issues - including data definition and coding - mesh with the non-technical.[4]

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[4] Lobet-Maris and Kuster (1993, 140) face a similar problem when they end their inquiry by suggesting that EDIFACT is "open" (read: flexible) because it is not a proprietary standard without discussing how this flexibility is exercised. (EDIFACT stands for Electronic Data Interchange in Administration, Commerce and Transport and is a United Nation standard for defining EDI messages). Likewise, Trauth, Derksen and Mevissen (1993) locate flexibility at a national or cultural level.

Standardisation

We describe in some detail standardisation of INI. More specifically, we define INI closer by pointing out a number of the technological components and applications which are likely to be included in future INI. Secondly, we explain how standardisation of INI takes place by describing (i) the role of standards, (ii) the types of standards and (iii) the formal standardisation processes. As explained above, the fact that INI does not yet exist forces us methodologically to pursue an indirect route by studying its embryonic manifestations. The empirical basis for our discussion is Open Systems Interconnection (OSI[5]) and Internet[6] (Tanenbaum 1989), the two most likely candidates for future INI.[7] Thirdly, besides providing historical cases, OSI and Internet are relevant also for another reason. They exemplify two distinct approaches to the development of INI. We will later, using Callon's (1991, 1992, 1994) notion of irreversibility, discuss how these two approaches have implications for the flexibility of INI. Fourthly and finally, we critically discuss an "application" of STS to the standardisation of INI. The crucial issue is here how to appropriate a number of specific properties of INI related to standards.

INI standards

The term INI has become widely used only during the last year or so. Electronic super-highways is used as an almost synonymous concept. INI will be built as computer networks by linking together existing networks and integrating telephone, computer, TV and cable-TV networks. New applications like video-on-demand, interactive TV, telemedicine[8] and EDI will be added. The basic, lower level, communication services will be improved by offering higher bandwidth (that is, speed) and wireless connections. INIs will be computer networks, but their heterogeneity, size and complexity will be well

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[5] OSI was developed by the International Standardisation Organisation (ISO).

[6] Internet started out as a research project in the late sixties aiming at establishing a communication network between a number of institutions involved in ARPA (Advanced Reseaarch Projects Agency) sponsored research.

[7] A challenging project for STS would be to provide an account of the processes, the social constructions of OSI and Internet. As explained already, this is not our current aim. We study these cases only as a means to learn something about future INI.

[8] Telemedicine is the electronic, real-time transmitting of images from various medical equipment. Examples include: telecardiology (ultra sound images of the heart), teleradiology (X-ray images) and telepathology (microscope).

beyond what exists today. This implies that the number of different protocols is likely to grow rapidly and use of the different protocols will be tightly intertwined.

The two most well known visions for INI are the Clinton/Gore plans for building electronic super-highways and the European Unions' plan for Pan-European information infrastructure. The debate about the former has largely evolved around consumption related information distribution like video-ondemand and other forms of electronic publishing. The latter focuses on European integration through electronic information exchange within European companies and public administrations.

It has been an accepted fact almost from the advent of digital communication technology that this technology cannot diffuse unless it is based on shared international standards (OECD 1991). This applies in a strong sense as standards are absolutely necessary for the INI to exist at all; without standards there is no such thing as INI. This absolute requirement for standards within INI is different from the usual role of standards in technology. To communicate at all, the communicating partners have to use a shared protocol. The alternative to standards is bilateral agreements. Non-standardised communication technology would be very expensive (due to the need for gateways to translate between them) and demand a significant number of bilateral agreements. *EDIFACT messages are mainly construed to solve specified tasks,* But when standardising messages, one strives for as general standards as possible. This situation may easily lead to a huge number of overlapping and integrated standards.

A distinction is often made between formal, de facto and de jure standards. Formal standards are worked out by standardisation bodies. Both OSI and Internet are formal according to such a classification. De facto standards are technologies standardised through market mechanisms. De jure standards are imposed by law. Formal and de jure standards must become de facto standards to diffuse and be put into actual use.

OSI and Internet

The OSI model consists of two parts, namely the communication model consisting of seven layers and the communication protocol. There is one communication protocol for each layer, except the seventh which contains several. The seven layers of the OSI model are called the physical, link, network, transport, session, presentation, and application level. A protocol, or more precisely, a protocol element, is defined by three aspects: the protocol it follows in communicating with an equivalent element, the services it provides to the components that want to communicate using this protocol element and how the protocol is implemented on the basis of the services of other, lower level protocols.

Internet is in principle organised in the same manner. The difference is only that it is very much simpler. It only has three layers: IP (roughly corresponding to the network layer of OSI) and TCP (roughly corresponding to the transport layer) and the application layer (where we find services like e-mail, News, ftp, gopher, WAIS and WorldWideWeb (see Krol 1992). The strictly layered configuration of OSI and Internet is what corresponds to so-called "functional" standards. The important point, for our purposes, is that a functional standard black-boxes each layer. How a given layer accomplishes its tasks is not the concern of the standard, only what it accomplishes. This property, we will later argue, has important repercussions for how flexibility in INI operates.

Standardised communication protocols are put forth as alternatives to proprietary ones, usually developed by computer vendors like IBM, Digital and HP. Those protocols make data exchange between computers from the same vendor possible, which is the kind of exchange the vendors support. Standardised protocols are put forth in order to make communication across computers developed by different vendors possible. Accordingly, it has been important to keep the development process of the standards independent of specific vendors. Thus, the protocols should be developed according to procedures making it difficult for anyone to be too influential. Vendor independent standards are considered as more flexible simply because it makes interchanging of protocols across different vendors possible.

Some standards, like the OSI and Internet protocols, are general and global. Others, for instance EDIFACT messages, will be specific for one area of business or geographical region. However, standards with more narrow scope may partly conform (or overlap) with other similar standards. For instance, purchasing orders are different for different business sectors, but they also share a number of features.

The development of OSI and Internet followed different patterns (Rose 1992). The development of OSI followed quasi-democratic procedures (Lehr 1992). Any nation could participate in the development process, and standards were approved according to voting procedures where each country had a number of votes. National representatives were appointed by their respective national standardisation bodies. Because of the formal and political status of OSI protocols, most Western governments have decided that INI in the public sector should be based on OSI protocols. They also have specific national OSI profiles[9] which give detailed information on which OSI protocols that should be chosen.

[9] An OSI "profile" is a defined selection among the many options the standard itself offers. As the number of options is significiant, the description of a profile is a voluminous document. Every country has its own.

OSI protocols have been developed by first reaching a consensus about a specification of the protocol, then it has been implemented as software products by vendors. However, the implementation and diffusion of OSI protocols have not proceeded as anticipated by those involved in the standardisation processes. One of the main reasons is that it has been developed by large groups of people that have been specifying the protocols without any required implementation and without considering compatibility with non-OSI protocols. This has resulted in very complex protocols and serious unforeseen problems. The protocols cannot run together with other networks, only within closed OSI-islands. The protocols are big, complex, and ambiguous, making it very difficult to implement in compatible ways by different vendors.

The development of Internet protocols followed a different pattern (Rose 1992). The protocols have been developed and diffused through numerous iterations through an "develop-use-evaluate" cycle. Before a protocol achieved the lowest status level, a specification and a free available implementation had to exist. For each step towards obtaining status as an Internet protocol, the number of implementations and users of the protocol had to grow at a significant rate. This process ensured that several features were improved, the protocols were lean and simple, and they were compatible with the installed base of networks.

The two approaches to developing INI

Even if never made explicit, we believe the two approaches followed by OSI and Internet could be presented as two archtypical approaches to the development of INI. We attempt to make explicit some of the underlying assumptions and beliefs.

The principal, underlying assumption of OSI's approach is that standards should be developed in much the same way as traditional software engineering, namely by first specifying the systems design, then implementing it as software products, and finally put it into use (Pressman 1992). Technical considerations dominate. There is, however, one important difference compared to traditional software engineering methods: a formal procedure for approving the standard is necessary. Beyond this no social, economical, or political issues are perceived as relevant (OECD 1991). In spite of this, most actors involved recognise the political character of the standardisation process due to the large number of participants and the interests of vendors in designing the protocols so as to enable adaption of their own products and constrain those of their competitors. The standardisation of EDIFACT messages follows OSI's approach.

The standardisation of Internet protocols is based on different assumptions. The process is close to an approach to software development less widely applied than the traditional software engineering approach explained above, namely one stressing prototyping, evolutionary development, learning, and user involvement (Schuler and Namioka 1993).

The OSI approach does not acknowledge problems in turning formal standards into de facto standards. The issue is simply not considered. Rather, as for traditional software engineering (Pressman 1992, 771), one relies on a simplistic, linear model of technological diffusion. In the Internet approach, however, the standardisation process unifies the development of formal standards and their establishment as de facto ones.

STS theory and INI standardisation

We have briefly outlined how standardisation has been conceptualised in STS and how it operates in INI. We now attempt to "apply" insights from STS to INI. We argue that STS so far has not been specific enough about the properties which characterise INI. We accordingly go through a list of properties related to standardisation of INI which we argue are not adequately captured by STS concepts.

We pointed out how STS emphasises the constant, gradual and continuous shaping of a technology. This is qualitatively different with INI. Stable standards are a precondition for the diffusion and use of INI among the members of a larger community so flexibility must be avoided. Standardisation in INI is necessarily non-continuous. The principal reason for this is simple. The fact that the artifact which is being negotiated is communicative, that is, requires the simultaneous cooperation from both sender and receiver, implies that any changes need to be coordinated. If they are not coordinated, the very rationale of the artifact vanishes: it no longer functions communicatively.[10] In addition to be being coordinated, the standard is completely formal. It is supposed to work without any form of interpretation. If, in the case of EDI, the sender assumes that byte number 87 is to represent a given numerical digit while the receiver expects that digit to appear as byte number 88, everything breaks down.

The meaning of a communicative artifact is completely dependent on joint, concerted action. This is not the case with most other types of technologies. For instance, the one variant of the bicycle with a huge front wheel and a small one at the back is still capable of transporting a person even after it "died" during the stabilisation of the bicycle (Pinch and Bijker 1987). And any existant bicycle may be interpreted and used in new and creative ways by users. One might, for instance, choose to ride backwards independent of what

[10] The characteristic of INI is common with, for instance, the telephone (Rogers 1989). What distinquishes INI from the telephone is its formal nature. the pattern of *use* of the telephone is more flexible.

others do. With INI, both the interpretation of the artifact and its use have to be standardised.

INI requires, in a strong sense, the cooperation of all involved parties for the system to function at all; if one party drops out, the very rationale for the system breaks down. INI establishes a kind of mutual dependence among the involved parties as the system locks previously independent work routines together. Markus and Connolly (1990, 372) calls this situation, where one party's benefits are contingent upon others' behaviour "interdependence." The problem, then, is how to ensure that the system will function as envisioned, that all involved parties will in fact cooperate. The option promoted by Markus and Connolly (ibid., 375), having an "unbiased manager intervene," is not available to INI for the simple reason that no common authority or manager exists, there is no obligatory passage point. INI cuts across formally independent organisations.

Several authors have argued that this characteristic of INI, interdependence and lack of common authority, requires that INI solutions be win-win situations (Krcmar et al. 1993; Traut, Derksen, and Mevissen 1993). We want to emphasise that this needs to be taken in a strong sense, much stronger than the notion of win-win normally suggests. More specifically, it differs in two manners. Firstly, INI needs to offer a highly developed and rich structure of incentives which goes well beyond that of a relatively straightforward win situation. Building strong scenarios, enrolling the actors through translations and establishing an obligatory passage point seems to be especially complex in the case of INI. One might ask, exactly because there are no common authorities to force reluctant parties, if enrolling them requires especially long sequences of translations? Secondly, this structure of incentives is dynamically negotiated as an integral part of the design process. In particular, this reinforces the argument by Kling (1987) that the boundary which defines the relevant groups cannot be defined a priori: not only, as Kling (1987) suggests, because the "impact" is difficult to assess beforehand, but because this boundary may be dynamically redefined as part of the process of developing an incentive structure.[11]

Flexibility

We have so far focused on the importance of standardisation of INI. At the same time, flexible standards are equally important to meet the challenges of a dynamically changing environment. It is generally accepted that a technology cannot be made "right" the first time. It is necessary to accumulate practical

[11] Lack of space makes details impossible, but such a case is described in Monteiro, Hanseth, and Pedersen (1994) from an EDI project we are involved with.

experience by testing different versions. As explained earlier, this insight is slowly gaining acceptance within software engineering through a stronger emphasis on prototyping, participatory design, and more evolutionary strategies for software development. This general lesson also applies to the development of INI and standards: useful standards need to evolve. As INI and its standards continue to evolve even after they are diffused, it is vital that they are as flexible as possible. It is a long-standing history in computer science to search for techniques, languages and tools which promote flexibility.

In the present case, the challenge is to acquire a firmer grasp of how flexibility is restricted and enabled in INI. We spell out in some details how this is played out by relating it to specific properties of INI. These properties are subsequently analysed borrowing concepts from STS.

Enabling flexibility in INI

INI consists of a highly complex and extensive physical network of inter-connected modules and layers of communication technology. The only way to cope with this is by modularisation, that is, decomposition or black-boxing. This is at the same time the basis for flexibility in INI: flexibility presupposes modularisation. The reason for this, at least on a conceptual level, is quite simple. The effect of black-boxing is that only the interface (the outside) of the box matters. The inside does not matter and may accordingly be changed without disturbing the full system provided the interface looks the same.[12]

OSI's seven layered communication model provides a splendid example of modularisation intended to promote flexibility. It is organised in a strict hierarchy. Each layer is uniquely determined through its three interfaces: the services it offers to the layer immediately above, the services it uses in the layer immediately below and the services a pair of sender and receiver on the same level make use of. This layering enhances flexibility because it makes flexible interchanging of any particular implementation of a layer with an equivalent one possible. In particular, it creates flexibility with respect to selecting vendors.

The implication works the other way around as well: lack of modularisation is a source of restricted flexibility as we illustrate below.

[12] A related argument has been advocated for software more generally by Parnas (1985). He argues, with the purpose of debunking the visions of SDI, that the formal, symbolic and representational nature of software makes it a quite unique type of technology. The interface specifications, which the modularisation give rise to, have to be 100% fulfilled.

The CCITT[13]/ OSI standard for electronic mail, X.400, has not succeeded in modularising the different parts of the standard. In more technical and specific terms, the address of a person (mailbox) needs a so-called PRMD-element, denoting a so-called private domain. A private domain will usually identifying the organisation providing the X.400 electronic mail service. This amounts to a mixing of routing and addressing information. The implications of this, in terms of constraints on flexibility, is that an organisation which decides to change its network provider will also have to change the addresses of all the electronic mail users. This creates lock-ins which hamper flexible and unconstrained selection of network provider disentangled from the selection of electronic mail services.

Internet is today what comes closest to being an existing INI. It has proved to be highly flexible, adaptable and extendable. But the principle of modularisation is violated in certain places. The specific representation scheme used to address Internet nodes causes problems for flexible scaling (Eidnes 1994). More precisely, any node is represented by four numbers each with a value 0-255. The inflexibility concerns the ways domains, that is, groups of Internet nodes, may be formed. A domain is typically an organisation, a region or an entire country. As the needs for the size of a domain vary enormously and continuously, assigning Internet nodes ought to possible in a flexible manner. This is not the case. Domains need to be assigned using the whole sequence of values 0-255, not only the sub-sequence which is actually required.

Hampering flexibility in INI

Having identified the basis of flexibility in INI as modularisation, we turn to what hampers flexibility. The resulting flexibility of an artifact is clearly the result of considering what promotes flexibility simultaneously with what hampers it. As pointed out above, OSI's seven layered communication protocol is a text-book example of modularisation. Despite this, it is fair to say that the resulting flexibility of OSI is severely hampered. This apparent paradox obviously needs a proper explanation.

In analysing the constraints on the flexibility of OSI and Internet, we employ Callon's (1991, 1992, 1994) concept of irreversibility. Basically, the OSI approach had a total disregard for the irreversibility of INI.

The irreversibility of standards within INI may be attributed to three factors: technical, organisational, and acquired knowledge among the users. The specification-driven, "get-it-right-the-first-time" approach of OSI started out from scratch in the sense that, perfectly in harmony with the ideals of

[13] CCITT is the international standardisation body within United Nation concerned with telecommunications.

functional standards, whatever existed of similar systems was neglected; a completely new construction was erected. The problem with this is that it disregards the difficulties of undoing earlier decisions of promoting and spreading non-OSI standards. For a systemic kind of technology like INI, the install base of existing non-OSI INI is especially hard to change (Rose 1992). As explained earlier, any change in standards needs to be coordinated among the total population of users - a task which gets increasingly difficult as the number of users grows. In an economic vocabulary, this property of INI gives rise to "network externalities" (Callon 1994, 408), that is, a situation where the value for the users increases with the diffusion of the technology. This creates lock-ins and self-reinforcing effects (Cowan 1992, 282-283). The complexity of INIs, both in a technical and organisational sense, requires users to acquire a considerable body of knowledge of use which adds to these lock-ins effects.[14]

Internet, however, has pursued a different approach. Irreversibility is introduced and handled gradually - and it is hoped controlled - through bureaucratic measures to ensure a certain degree of practical testing, both in scope and in depth. The evolutionary approach of Internet allows experience and knowledge to develop alongside the technology itself. Though still meeting the requirements of modularisation and layered organisation, Internet thus has more of an historic or "organic" character than OSI's "synthetic" one. The standardisation process itself is recognised as a valuable occasion for learning (Lehr 1992). The Internet approach amounts to reaching closure through an iterative process. For each iteration some degree of closure is reached. As more experience is obtained, the closure may be further entrenched, or it may be dissolved and a new version negotiated. The Internet standardisation process may be viewed as a controlled and managed alternation between closure and flexibility.

Relative degrees of flexibility

A major challenge within STS is to balance between the structure/ flexibility dichotomy without being caught up in it. The aim is to express how a technology neither fully determines pattern of its use nor leaves it completely open, or alternatively, how some actions are enabled while others are

[14] Gould (1988) has described the history of the QWERTY keyboard layout to illustrate the life of technologies. This may also be recast as a case for irreversibility. He argues that when a technology is established as a de facto standard, it is usually impossible to change it. QWERTY was designed in the 1880s and became a standard soon after. It was designed to slow down typing speed to avoid jamming. Later the typing machine technology was improved, decreasing the jamming problem significantly. Keyboard layouts that improved the typing speed followed. But QWERTY had become a standard and survived all attacks. A crucial aspect of a standard is exactly that it is standard, not its technical qualities.

constrained. Several theoretical frameworks have been suggested in this connection: ANT (Callon 1991; Latour 1987), technological semiotics (Akrich 1992), borrowing from industrial sociology (Sorensen 1994), structuration theory (Giddens 1984), and technological frames (Bijker 1993). These suggestions are valuable STS contributions. Even if some are rather programmatic (Bijker 1993, 123), some - as we have illustrated in our application of Callon (1991, 1992, 1994) - may be used to clarify matters. Still, none of these frameworks pursue this to the point necessary for the case of INI, namely expressing relative degrees of flexibility, questioning whether artifact A allows a greater degree of flexibility relative to artifact B. We proceed by explaining how this issue is connected with specific properties of INI.

The primary source for the issue of relative degrees of flexibility stems from the layered property of INI. Consider the case of EDI. At the lowest level, we have the message. The standardisation of a message results in an agreement about the number, sequence, length, type and coding of the different fields which comprise the message. An illustration of how one artifact enables more flexibility than another is provided by considering two of the most prominent ways of defining an EDI message: EDIFACT and an object-oriented description (Hanseth and Monteiro 1993). With EDIFACT, all optional variants of a field in the message need to be specified. Every message needs to specify, for each option, if it is used or not. If one later decides to expand one of the fields in the standard message format with an additional, optional variant, the whole standard needs to be changed to include the new option and whether this new option is to be used or not. This lack of modularisation - that altering only one field in the message prompts a redefinition of the whole message - is exactly what is improved using an object-oriented description. Without going into details, it allows a modular description which leaves changes local to one field instead of upsetting the whole message. This shows that an object-oriented description is more flexible than an EDIFACT one.

Flexibility in INI may be exercised on different levels or layers. In particular, one might exercise it at the level of <u>use</u> of the standard. Kubicek (1992), for instance, discusses how the standardisation of an EDIFACT message including the field "article number" failed to result in an agreement about how to assign numbers to the articles. Producers and purchasers (for instance retailers) of a given article often had local, ideosyncratic numbering systems (ibid., 25). In this situation, a standardised field, like "article number", could specifie a "menu" of options, allowing some flexibility in message content. Further standardization of the message field would severely hamper flexibility for the user.

Hørluck (1992) describes how flexible use of a standard, that is, bilaterally negotiated ways to use it (which are not specified in the standard itself), is hampered by the mere weight of the bureaucracy needed to maintain all these bilateral agreements. This may be read, at least for this case, as indicating that the flexibility of use was less than including the variants in the standard itself.

Developing INI, especially when embracing the Internet approach of evolutionary development, quite naturally leads one to consider the different "phases" of the development. This is due to the step-wise, evolutionary nature of the process in combination with the layered property. This may reasonably be described as a process which gradually establishes constraints on later development steps. Expressing this in terms of relative degrees of flexibility, we would say that early decisions constrain later ones. In particular, one would like to say that an early "phase" allows more degrees of flexibility than later ones.

This way of formulating the issue of relative degrees of flexibility seems to be favoured by Hughes (1987, 57) when he talks of activities which "predominantly" take place in "phases". Bijker (1992), however, argues against such an idea. He argues against the linear stage model of technical diffusion which is described as "static" and "forever fixed" (ibid., 75). He proceeds to document how reshaping took place in what would traditionally be called the "diffusion phase". Bijker furthermore argues that the shift from a tint to a high-energy lamp occurred in the diffusion phase, after the lamp was released commercially (ibid., 81-82). At the same time, he acknowledges that the developers had a very wide range of applications for their tint lamp in mind, applications which suggest that they were, effectively, not far from the conception of a general purpose, high-energy lamp. Allowing the question of relative degrees of flexibility to be posed would frame the problem differently: how significant, relative to other shifts, was the tint-to-high-energy shift - given that the developers, from what they already had developed, were imagining applications relatively similar to the high-energy's ones?

Conclusion

One of the principal challenges within STS is to develop convincing frameworks for tackling the tension between, on the one hand, the standardising, structuring, or stabilising abilities of technology and, on the other hand, to allow for flexible human actions. Or, as it is sometimes phrased, to develop a way to describe how technology enables certain actions while constraining others. A number of illuminating theoretical STS contributions address this problem without resolving it.

Our discussion provides an alternative way of framing this problem. Starting from an analysis of characteristic properties of INI, we argue empirically, by describing the mechanisms of how standardisation/structuring and flexibility operate, for an intermediate position. Our analysis may be recognised as a modest contribution to empirically substantiate the more theoretically based - and often programmatically formulated - positions advocating that technology enables and constrains. In this sense, we are not so much concerned with the fact that technology enables/constrains as with describing, as precisely as possible, how this operates on a concrete level.

In addition to providing an alternative way of addressing the problem, our analysis also suggests that we should pursue this to the point where the issue of relative degrees of flexibility appears as an interesting expression of this intermediate position. We recognise and acknowledge that it might generate a fear of sliding back into (a variant of) technological determinism because, apparently, there has to a reasonably well-defined "boundary" for the flexibility of the artifacts. But if it is the case, as our analysis of INI suggests, that this question surfaces empirically, we nevertheless have to relate to it.

The homogeneity of STS - tackling bicycles, hamburgers, work practices, professional concepts, and hotel keys with exactly the same tool-box - is one of its principal strengths. Our discussion could be seen as modifying or challenging the principle of symmetry which says that one should not distinguish among types of technologies. From a description of characteristic properties of INI (standardisation is non-continuous, flexibility presupposes standardisation, relevant groups are dynamically negotiated, irreversibility due to the installed base), we argue that the process of standardisation of INI fails to be accounted adequately for.

In terms of implications for the ongoing development of INI, the crucial point is coming to grips with the specific mechanisms of irreversibility and flexibility at play which arise from the characteristic properties of INI which we have attempted to map out in our analysis. The Internet approach to the development of INI is clearly more sensitive to the irreversibility of INI. The non-continuity of standardisation of INI is simultaneously a threat to an evolutionary or near-continuous development. Again, the Internet approach of integrating accumulation of practical experience and gradual diffusion with the development of the standard, serves to make the process as continuous as possible.

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