The Fundamental Nature of Standards: Technical Perspective

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Abstract

The transition from sequential communications systems such as railroads and telephony systems to adaptive communications systems such as the Internet, is a paradigm shift. This paradigm shift can also be identified by an emerging new class of technical standards. Technical standards throughout recorded history are a means to enable communications, inherent in all complex systems, and basic to communications engineering. The fundamental nature of standards is explored using a four strata taxonomy of standards which relates technical standards, communications systems and value systems to the major periods of recorded history. The emerging fourth stratum of standards, offering new adaptability for communications systems, is described in some technical detail.

Introduction

Without DNA, life as we know it would not exist. The discovery of Deoxyribonucleic Acid (DNA) in 1953 by J. Watson and F. Crick explained the structure of the specific molecule used to transfer the description of each species from cell to cell. DNA is the molecule found in chromosomes that is responsible for storing the genetic code of each species. The structure of DNA may be seen as a standard framework for the communications that enables the process and procreation of all living things. The recurring structures of DNA (with RNA, genes, chromosomes, etc.) are the naturally occurring, biological standards that make possible the communication of life.

Computer viruses are an example of how technical standards can support a life-like phenomena. Virus is the term for a very simple life form. Computer viruses can mimic life and exist by replicating over the Internet, a network based on Internet Engineering Task Force (IETF) standards or over a specific operating system or specific program. Without common systems of some kind, computer viruses, as we currently understand them, could not occur.

Standards appear fundamental for a life-like system to exist. Technical standards are necessary for any complex technology to exist. Technology, the fruit of invention, is basic to the long term development of any human society, and standards brings these fruits to society in a broadly useful form. Prior to the creation of technical standards, technical information, for example tool making, was only passed on by instruction and example. As society becomes more complex, technical standards provide the means to communicate necessary common technical information broadly and uniformly. Standards emerge in each and every human group; the level of standardization (language, writing, number system, monetary system, measurement system, navigational references, communications systems, etc.) in each tribe or society is an indicator of its sophistication and technological attainment. Viewed this way, technical standards appear to be inherent in all complex technical systems, fundamental to almost all forms of commerce and required for more complex communications.

Standards Relate to History, Technology, Communications, and Value Systems

The economic progress of society is closely linked to invention and innovation [1]. J. A. Schumpeter, an economist, developed the concept that all economic cycles are generated by invention and innovation. The historic periods shown in Table 1 identify the paradigm shifts wrought as the major shifts in technology enhanced communications in each historic period. Technical standards in all their forms are the means to codify technology for a society. Not surprisingly, technical standards also follow these paradigm shifts. Technical standards provide the information used to substantiate each new value system. The value system then develops into a new form of wealth.

	Historic Periods			
	Agrarian	Industrial	Information Sequential	Adaptive
Communi-cations	Barter and trade routes	Mechanized transport	Electronic (e.g., telephony)	Internet
Technology	Navigation and measuring	Powered machines	Linear processes (railroad)	Adaptive processes (computers)
Value System	Private property ownership	Invention ownership (patents)	System ownership (public utilities)	Concept ownership (branded IDs)
Strata of Standards	Units and Reference	Similarity	Compatibility	Etiquette

Table 1. The Strata of Technical Standards

Multiple standards are created and over time are winnowed down to the most desirable and culturally acceptable standards that codify the technical requirements previously developed. The same as invention, technology, and all other forms of progress, standards follow an evolutionary path. Each stratum of standards codifies a level of technology for society and requires ways to balance two conflicting objectives: one, incentives for innovation (enabling private gain) and two, the diffusion of new products, services and processes (enabling lower prices and greater usage - public good) [2]. As technology is applied in new ways, each stratum of standards continues to develop and expand. By identifying each stratum of standards, specific issues may be seen that impact society, and new approaches may be developed, to better meet society's needs.

Unit and Reference Standards

The first stratum of standards in Table 1 is unit and reference standards. Possibly the first technical standard was a unit standard - a common number system. Using a number system, the first wave of civilization, the Agrarian wave, defined units of weight and measure (unit standards) as early as 3500 BC. The definitions of such unit standards were kept by a primary authority, such as the king or temple by 3000 BC. Centuries later, after a long evolution of different unit and reference standards in each geographic area, the various different regional unit standards began coalescing into the metric system in 1799. Originally, a kingÕs forearm became the length of a cubit, a king's foot, the length of a foot measure. Later, the importance of common unit standards was better understood. The Magna Charta which King John of England sealed June 15, 1215 at Runnimede included the "measurements" pledge [3]. These examples suggest there was little room for the entrepreneur to innovate with unit standards. In fact, unit standards gain in value to society as a whole when more people use the same unit standard.

While unit standards may inhibit innovation of competing unit standards, unit standards were a significant factor in the development of early civilization. Taxation provides a more reliable form of state income than tribute. Unit standards provided the weights and measures used for taxation (by barter) and therefore assisted in the rise of the first great city states of Babylon and Egypt. Reference standards of economic value (currency) are the basis of monetary systems, and expanded commerce from barter to purchase.

Similarity Standards

The second stratum of standards in Table 1 is similarity standards. P. David, an economist, identified a three level taxonomy of standards [4]: standards for reference and definition, standards for minimal admissible attributes (similarity standards), and standards for interface compatibility. Similarity standards describe similar realizations with common properties. While unit standards (e.g., gallon) may define the units to measure the carrying capacity of a barrel, similarity standards define how similar in construction one barrel is to the next. Making each barrel similar offers significant economic advantage in manufacturing as well as distribution, selling and using.

Similarity standards emerged during the second great wave of civilization, the industrial revolution, to codify the results of repetitive processes. Initially similarity standards were solely private specifications. The barons of the emerging 18th century industrial age were supportive of ÒstandardsÓ so long as they controlled them. They created rail systems of many different gauges so as to prevent the operation of their competitorÕs trains on their right-of-way (tracks).

By the early 19th century, the growing use of mechanized process instigated the powerful concept of interchangeability (the transposition of similar parts). Interchangeability of parts was originally conceived for the rapid repair of guns after a battle. In the earliest systems, interchangeability was possible only among the guns from one manufacturer. In this manner, interchangeability was privately controlled and competition was limited. Examples of private products with interchangeable parts that precluded competition: guns, train track spacing, fire hydrant flanges, custom nuts and bolts.

By the mid 19th century, machine tools and measuring devices had progressed sufficiently that it was practical to create a drawing (specification) and machine parts to match. By using these specifications, multiple companies could manufacture interchangeable parts. These specifications were, in effect, early standards. During the same period, society began to realize the importance of having all train tracks or nuts and bolts or fire hydrant flanges interchangable; the result was the beginnings of the systems for standardization in use today.

Now even products that do not need any form of interchangeability have similarity requirements (public and private) for safety, usage, environment, shipping, etc. Examples include: the standards for emergency exit signs, motor vehicle speed limits, the definition and marking of specific plastics for recycling, or the markings for the transportation of hazardous goods. As these examples suggest, similarity standards, when they represent the minimum admissible attributes relating to public safety, are often referenced in government regulations.

Compatibility Standards

The industrial revolution is replete with new systems for production (assembly line), transportation (railroads), as well as new systems for water, sewage, gas, electricity, telegraph and telephony that are sequential. These sequential systems transport the desired product from service provider to consumer (or the reverse in the case of sewage), with considerable efficiency and little flexibility. These sequential systems were a new form of operation and organization that also required new concepts and procedures. The particular type of sequential systems of interest here are those providing water, sewage, gas, electricity and telephone services - often termed utility systems. Utility systems as they emerged in the 19th Century brought forth a new concept - compatibility.

Public utilities or state regulation of private utilities prevent commercial advantage where there is the potential for a "natural monopoly" [5]. Natural monopolies have five characteristics:

1. Provides a necessary product or service
2. Has a dominant position over similar products or services.
3. Controls the supply of the product or service
4. The natural monopoly's product or service may be increased with little relationship to cost
5. Unique and specific arrangements are necessary to use the product or service.

The unique and specific arrangements are compatibility specifications (private standards). Compatibility describes a relationship between two or more dissimilar entities. The systems for water, sewage and gas require only the simplest compatibility standards for pipe coupling and content. The pipe and the coupling are not similar, but if sized and threaded properly, can mate. Outside threaded pipe built to a similarity standard could mate with an inside threaded coupling built to another mating similarity standard. But when the aspects of both the pipe and coupling necessary to allow mating are described in one document, it is an early version of a local compatibility standard. An electrical system requires only slightly more complex compatibility standards. Public interconnection to telephone systems requires yet more complex compatibility standards that define an interface.

Figure 1 identifies three different types of standards documents that are used to define similarity and compatibility standards associated with communications. Device standards most often specify similarity, describing the minimum attributes of the device. Interface standards usually define compatibility, and are implemented by defining the transmitted signals that pass across the interface and using the minimum definition of the receiver functions necessary to ensure compatibility. Wireless air interfaces standards for cellular systems are an excellent example of a compatibility standards. Protocol standards (e.g., X.25, Q.931) are used to define both the transmitter and receiver function at the same time. Protocol standards may have attributes of both compatibility standards and similarity standards. Complex communications systems achieve compatible operation by utilizing multiple interface and/or protocol standards.

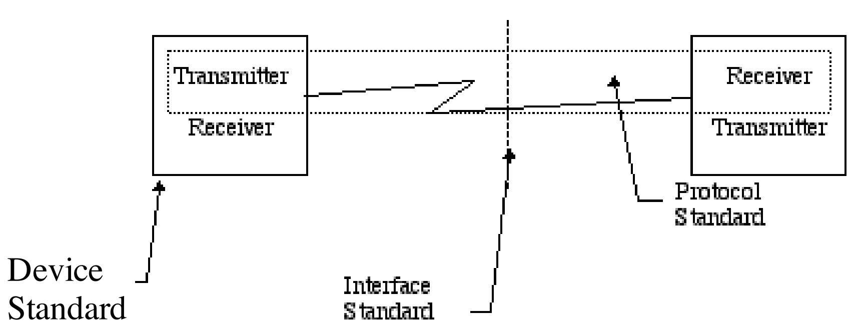

Figure 1. Diagrammatic representation of standards documents.

The segment of the public communications market that is willing to acquire and use proprietary communications systems is in decline for basic reasons. Compatibility standards for public communications are becoming too important for the public to allow any private organization an overwhelming proprietary advantage. For this reason broad market acceptance of privately controlled specifications rarely occurs in public communications systems.

Public voice and early data communications (telegraph) were recognized to be a public good (e.g., universal service) very early in their development [6]. Early public voice and telegraph communications systems used similar equipment and systems to achieve compatibility. Achieving compatibility by requiring similar equipment is one of the characteristics (#3) identifying a natural monopoly. As public telephone and telegraph companies meet all the characteristics of a natural monopoly, many states determined to control the industry via a public utility or regulated private utility. Data communications evolved through its development and use in large organizations and was not recognized as a public good until recently (i.e., the Internet). IBM pioneered modern data communications systems and developed many proprietary compatibility specifications (under the proprietary system Synchronous Network Architecture), but these, often technically superior, private specifications have been rendered obsolete by the market's desire for public data communications compatibility as exemplified by the Internet. The success of the Internet and the failure of IBM SNA may be partially explained by the perceived value of public compatibility standards rather than proprietary compatibility specifications.

There are three significant ways to create public standards:

1. State intervention (via regulation or public utility)
2. Formal consensus standardization
3. Market acceptance (culminating in standardization) of private specifications.

Due to the natural monopoly potential of telephone systems, these public voice communications systems, after an initial period, became public utilities or state owned companies. Now these public voice communications systems are evolving away from state control and moving toward commercial control, i.e., systems that are publicly available for a fee and privately held [7]. The transition of the public voice communications companies to commercial control, without falling back to a natural monopoly, is partially made possible by the growing acceptance of formal consensus standardization. The privatization of many major Public Telephone and Telegraph (PT&T) organizations world wide is one indication of this commercialization trend.

Too often, all standards are equated with state control. Reviewing the history of standards, unit and reference standards have required state involvement to achieve wide spread utilization. Similarity standards, when they affect the public good, are often referenced in state regulation. However, products that use compatibility standards evidence greater self-reinforcing effects, the combination of effects that cause product demand to increase with increasing market penetration [8] and therefore require less state enforcement. The need for state participation appears to decline with each later stratum of standards.

Etiquettes

Etiquettes are a new form of standards made possible by the use of adaptive systems. The emergent adaptive communications period (Table 1) is exemplified by the Internet and enabled by programmable computers for all the functions that support communications. High speed programmable computers provide the means to implement basic communications yet adapt to utilize new communications programs and allow proprietary communications technology. Once all communications functions are programmable and changeable, they can be adapted, in real-time, to support any new communications invention (within the constraints of the resources available) and still allow backward compatible operation. What is necessary is a simple protocol that shuttles back and forth between the communicating ends to negotiate which specific protocol(s), data sets and options will be used for compatible operation. Such a "protocol of protocols" (a meta protocol) is termed an etiquette.

Current examples of etiquettes used to negotiate with remote systems include the International Telecommunications Union (ITU) V.8 used by telephone modems to negotiate remote compatible operation with the far-end modem. This is how older and newer telephone modems (e.g., V.34 and V.90) find a common way to communicate. In Group 3 facsimile, the negotiating protocol ITU T.30 is an etiquette that has also been very successfully extended (e.g., from 4800, to 9600, 14400 and 28800 bit/s) for over thirty years. In the IETF, standards track RFC 2543, Session Initiation Protocol (SIP) negotiates multimedia communications. SIP has many properties of an etiquette but includes an operational call signaling protocol which may hinder forward compatibility. The recently completed ITU Digital Subscriber Line (DSL) standards use an etiquette (G.994.1) which maintains backward compatibility with the earlier North American DSL standard T1.413 and is planned to support forward compatibility with future standards G.vdsl (very high rate DSL) and G.shdsl. (single-line high speed DSL) Etiquettes may also be applied to the local interfaces between software processes in a single system to support compatibility over time (upgradeability).

Etiquettes simplify the process of maintaining compatibility between systems. Compatibility is a basic part of connectivity; it is fundamental when communications is considered a necessity rather than an option. Compatibility may be considered in three dimensions:

- Over time: forward or backward (in time) compatibility
- Across space: local, remote and multi-user compatibility
- Through matter: conversion using a separate interworking system

Using etiquettes, separate systems can operate in different ways to find compatible modes of operation: two separate voice-over-the-Internet devices (Internet telephones) attempt to negotiate a common voice codec using a common etiquette. If the two devices do not share a common voice codec, then one or both devices could go to a "well known voice codec downloading web site" (e.g., a batch interworking system) where a common voice codec could be downloaded. In this case, the etiquettes negotiate across space to determine the changes needed. This example may also be seen as providing compatibility over time if the download is a new voice codec (upgrade) for one of the systems. Or they could go to a "well-known voice codec conversion web site" (e.g., a real-time conversion system) and each Internet telephone could pass its coded voice stream to the web site for near real-time conversion to the voice codec used by the opposite Internet telephone. This is an example of compatibility using a separate interworking system and also a commercial example of an Active Network, networks that provide services beyond that required for connectivity [9].

The use of in-network processing for conversion as suggested by the Active Network model is a difficult form of compatibility to deploy. A similar deployment problem also occurred in ISDN networks where a network conversion system was postulated to support conversions between analog (modems) and digital (ISDN) data communications. But there was little incentive to provide such network conversion systems and the ISDN conversion system was not deployed widely. Similarly, requirements for end user applications that support Active Network functionality don't exist until network nodes that support Active Network functionality exist, the "chicken-or-the-egg" problem. So it is also difficult for Active Network implementations to emerge without incentive. The branded ID concept, discussed below, may offer a means to implement such incentive.

Etiquette standards create new ways to implement, control and add value to communications systems. The negotiation defined by an etiquette can support all types of compatibility, and can also support proprietary enhancements using a standardized way of passing proprietary information. In the etiquette, a character string (or similar) is used to provide concept ownership. In Group 3 facsimile, the standardized way to support proprietary enhancements is called ITU T.30 Non-Standard Facilities (NSF). Each NSF is identified by a unique information sequence: ITU country code (T.35), manufacturer's unique code (registered by an in-country organization) and then any information may be exchanged because the communicating ends have uniquely identified each other. In SIP, a reverse domain name is used to provide the unique identity. Other examples of ways to provide the necessary unique identity currently in use include: ASCII representation of tradenames, Internet domain names and ASCAP (American Society of Composers, Authors and Publishers, ASCAP) requirements. Each of these different unique identifiers, including those in T.30 NSF and SIP, may be considered owned by the organization that implements them, and there is legal precedent to suggest that that such ownership would be legally recognized. These information sequences become the identification that communicating systems use to verify design ownership - a "branded ID." By using the branded ID, the communications equipment manufacturer maintains legal control over any proprietary features that are enabled or transferred after the branded ID.

Understanding the operation of an etiquette and why it must be implemented separately requires an understanding of the etiquette's structure. A proper etiquette is an independent protocol containing the etiquette revision level, the parameters the etiquette is negotiating: a listing of protocols supported and associated revision level and options of each protocol, this is followed by any proprietary enhancements (beginning with a branded ID). Etiquettes require an unambiguous tree structure in priority order to ensure that revisions remain fully backward compatible. Using an unambiguous tree structure ensures that additions are always proper super-sets. If it were practical to be certain that all changes to an etiquette were a proper super set then any etiquette would not require revision control. Likely this is not practical and the etiquette must transmit a revision level to allow for changes that are not a proper superset of the previous version. Since in the worst case, systems desiring to be fully compatible would need to support all etiquette revision levels, additions to etiquette revision levels should be made with great care. Since operationally functionality is more likely to change, including it in the etiquette is not desirable.

The proprietary enhancements section of the etiquette would include the branded ID, market segmentation fields, and any proprietary enhancements (or a pointer to them). Adding new protocol identifiers to etiquettes allows the support of additional protocols without affecting the compatible operation of existing protocols, as a proper etiquette receiver must ignore what it does not understand. Verifying such transparency is a difficult etiquette conformance testing task. The maintenance of etiquette standards also requires more care than previous strata standards. Etiquette standards will be used for far longer periods than compatibility standards. As example, T.30 in Group 3 facsimile has been used for over 30 years while the various compatibility standards (modems) that T.30 negotiates have changed at least four times. Careful standards maintenance is necessary to ensure that each change is a proper super-set and that revisions are transparent to the installed base.

Over time, desirable proprietary enhancements may become standard and may be added to the standardized parameter sets. Ricoh, a Japanese facsimile machine manufacturer, offered proprietary higher speed G3 facsimile to its corporate customers. Then, years later, higher speed operation similar to what Ricoh pioneered was included in the G3 facsimile standard.

Keeping revisions fully backward compatible in very complex protocol stacks or software processes is currently impossible, because it is not possible to identify or test all the ramifications of a change. Thus changes to add features or fix ÒbugsÓ can result in more Òbugs.Ó Since etiquettes can negotiate protocols (including different revisions), it is possible for an etiquette to negotiate the ÒbestÓ protocol or revision for a specific application. Where multiple choices of protocols or data sets are possible, the logic for choosing may not be obvious. As example, higher data rate is an obvious choice when there is a selection of data rates as is lower error rate when there is a selection of error rates. But when the etiquette offers a choice of both, some applications may give priority to lower error rate rather than higher data rate. Such priorities need to be communicated, and the rules for choice defined, in the etiquette.

As companies develop unique communications features, they can add them to the proprietary enhancements field, as Ricoh did with higher speed facsimile. In this manner, companies can add value yet support compatible communications or interfaces. In the proprietary enhancements field, the use of a branded ID may provide a legal way to control the proprietary enhancement and therefore may represent a new form of intellectual property.

Such enhancements are not limited to allowing private inventions such as higher data rates or better compression. Etiquettes using a branded ID can also control market segments to increase profits by offering specific capabilities to specific market segments. For example, the banking industry may negotiate stronger encryption, the radiologist market may negotiate higher resolution, the wireless market may negotiate better error control. Market segmentation via the etiquette can also be applied to the distribution channel, allowing individual equipment dealers and distributors to automatically poll their specific customersÕ equipment for usage billing (e.g., copier market), problem analysis, and maintenance support (automatic ordering of replacement parts). In these automatic polling cases, the etiquette may include the branded ID and perhaps a customer ID added by the machine dealer to uniquely identify their customers.

In summary, the properties of a proper etiquette appear to include:

1. End-to-end operation (servers may be considered an end node in some applications).
2. Negotiation services rather than operational functionality.
3. Single tree, unambiguous, logical structure.
4. Receiver ignores what it does not understand.
5. Tree structure priority order unless otherwise communicated.
6. Extensible proprietary functionality.
7. Etiquette revision level.

Etiquettes and the Internet

The Internet is built from a compact series of protocol standards (TCP, IP, UDP, etc.) used to enable end-to-end communications between various programmable computers. This model is perfect for the use of etiquettes. Up until recently, etiquettes have been developed for point-to-point physical layer communications while the Internet has been built out of a series of similarity and compatibility standards. New concepts such as agents (a program that acts on behalf of a user, e.g., Java) and mobile agents (not bound to the system where it begins execution) may also operate as a meta protocol. Adding the concept of an etiquette to the current concept of agents seems to increase agent compatibility and flexibility. Active Network developments, where the network actually processes - rather than just passes - the data stream, also could utilize etiquettes for greater compatibility and flexibility. The next evolution of the Internet is just beginning.

Session Initiation Protocol (SIP) appears to be the first near-etiquette to be introduced on the Internet. The application layer meta-representation of structured documents such as XML (eXtensible Mark-up Language), along with the optional modules that define sets of tags and attributes, may create a need for other etiquettes (meta-protocols) to negotiate the desired application level data structures between remote systems. The development of etiquettes and the development of Internet based Active Network or mobile agent functionality may also be synergistic. The set of seven etiquette properties may be a helpful construct when considering mobile agent initiation and Active Network negotiation. As example, etiquettes could differentiate between Active Network data flows and programs while supporting both the proprietary (branded ID) functions and authentication mechanisms needed for the widespread acceptance of Active Networks.

Value Systems and Etiquette Standards

There appears to be an intrinsic relationship between standards and the economic value systems of society. Table 1 identifies the four forms of ownership which are the foundation for the value systems that relate to each stratum of standards. Each form of ownership creates new forms of incentive and wealth and is based on new communications technology, which is codified by a new stratum of standards.

The form of ownership associated with etiquettes, is concept ownership. In some respects, the value of concept ownership is already well established. Trademarks, brands, copyrights, even five bars of music (ASCAP requirement) have for some time provided commercial rights to created concepts. Etiquettes provide the mechanism to enable unique and proprietary concepts to be controlled (branded ID) and electronically communicated over public communications systems.

Commercial organizations that create communications products and services and wish to maximize their profits may find etiquettes a new way to profit from the inventor's or innovator's advantage. Etiquettes, by transporting proprietary information, support a new means to achieve monetary gain based on invention or innovation, while supporting the compatibility so necessary for public communications. It is conceivable that much of the current economic interest in the Internet is engendered by a sense of the possibilities that concept ownership - using the Internet as a medium for exchange - may create. The concept of a branded ID transferred via an etiquette is certainly one mechanism to couple concept ownership to the Internet. The branded ID then becomes a new form of intellectual property, offering new and possibly better ways to support private invention and yet accommodate public good in communicating systems. Each new form of ownership (see Table 1) that emerges with a paradigms shift has created enormous increase in the total wealth of society. Etiquettes, by enabling the communications of concept ownership, create similar opportunities for wealth.

Conclusions

The fundamental nature of standards appears most dramatically in the biological standards that make possible the communication of life. As human communications becomes more sophisticated, successively more complex forms of standards are needed, and technical standards develop. Now a new stratum of technical standards is emerging that makes practical dramatic and innovative opportunities. Etiquettes, when implemented by communications product developers and their sales partners, support new communications capabilities and control added product value where the market is willing. Etiquettes can maintain the compatibility of public communications systems long into the future and provide the flexibility necessary for private gain without compromising the public good.

Technical standards, once a narrow field closely tied to state control, are emerging as a discipline of their own. Viewing standards in relation to history, communications, technology and value systems, the paradigm shift from sequential to adaptive systems can be seen more clearly, new concepts appear (etiquettes) and new forms of communications products and services can be envisioned. Such insights demonstrate the usefulness of the taxonomy presented. The strata of technical standards illuminates the relationship of standards, technology and society and by doing so provides insight into the future of each.

REFERENCES

[1] Joseph A. Schumpeter, Business Cycles, McGraw-Hill, Inc., 1939. Return to text

[2] Mark Shurmer and Gary Lea, Telecommunications Standardization and Intellectual Property Rights: A

Fundamental Dilemma?, Standards Policy for Information Infrastructure, MIT Press, 1995. Return to text

[3] H. Aurthur Klein, The World of Measurement, Simon and Schuster, 1974. Return to text

[4] Paul A. David, Some new standards for the economics of standardization in the information age, Economic Policy and Technology Performance, 1987. Return to text

[5] Richard Ely, The Future of Corporations, Harper's New Monthly Magazine, July, 1887. Return to text

[6] History of Engineering and Science in the Bell System 1825-1925, Bell Telephone Laboratories, Inc., 1975. Return to text

[7] A. Rutkowski, Today's Cooperative Competitive Standards Environment for Open Information and Telecommunications Networks and the Internet Standards Making Model, Standards Development and Information Infrastructure Workshop, June, 1994. Return to text

[8] W. Brian Arthur, Self-Reinforcing Mechanisms in Economics, The Economy as an Evolving Complex System, SFI Studies in the Sciences of Complexity, Addison-Wesley Publishing Company, 1988. Return to text

[9] D.L. Tennenhouse and D.J. Wetherall, Towards an Active Network Architecture, Computer Communications Review, Vol. 26 No. 2, April 1996. Return to text

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