Managing Diversity to Manage Technological Transition

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Abstract Technological transition is one of the hardest questions in architectural studies. This paper examines how technological transitions take place in the Internet. In the first half of this paper, we sort out the patterns of technological transition in the networking industry, and hypothesize that diversity is requisite to cope with an "unplanned" technological transition. At the same time, however, excessive diversity would be harmful since it could cause chaos or uncontrollability. In the latter half, we measure some diversity trends of Internet Architecture, and observe a phase mismatch between layers. One can assume that such a phase mismatch helps to avoid excessive diversity as a whole, and helps the sustainability and evolvability of the Internet.

1. Patterns in Technological Transition

1.1 Difficulties of Technological Transition

Technological transition is basically hard. There are a number of reasons for this. First, successful technology generates a positive feedback loop, which promotes successful dissemination even more. For example, the more the number of users, the more benefits of the users increase with less cost. Also an eco-system would easily be established due to a bandwagon effect. Second, people using a paradigm recognize the environment and conditions as a matter of course, and put an implicit pre-conditions. It makes them put effort solely for the improvement or extension to the existing technologies and make it difficult to find new technical possibilities.
Classic books give us a perspective on these difficulties:
"The scientific paradigms preceding and succeeding a paradigm shift are so different that their theories are incommensurable — the new paradigm cannot be proven or disproven by the rules of the old paradigm, and vice versa." [1]
"What all sustaining technologies have in common is that they improve the performance of established products, along the dimensions of performance that mainstream customers in major markets have historically valued. Most technological advances in a given industry are sustaining in character. An important finding revealed in this book is that rarely have even the most radically difficult sustaining technologies precipitated the failure of leading firms." [2]
"To be truly innovative and competitive in today's world, the team that created and built a presently successful product is often the best one for its evolution — but seldom for creating its replacement." [3]
And needless to add, it is easy to find such examples in this industry, i.e. various lock-in effects to the existing systems, including the difficulty of migration to IPv6.

Having said that, regardless that people hope or not, technological transitions happens. Technologies do vary across the ages.

1.2 Patterns in Technological Transition

In this chapter, we sort out the patterns of technological transition in the networking industry. To start with, we may need to separate "planned" transition from "unplanned" transition, since the

designing/engineering methodologies should be different.
In a “planned” transition, a community has a common objective, predefines a value of the post-transition status, defines the scope of the system, and thus applies what amounts to a set of top-down system design/engineering methodologies. Examples of such “planned” transition include 3GPP cellular/mobile systems. 3GPP unites 6 telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TTA, TTC), and constantly publishes technical specifications called a “release”. The 3GPP technologies from these groups are constantly evolving through Generations of commercial cellular/mobile systems. [4]

On the other hand, it is sometimes hard for a community to have a common objective, to predefine a value of the post-transition status or the scope of the system. In that case, “planned” transition rarely happens.

The latter case is the case for the Internet. It is difficult to “plan” the transition, due to its bottom-up emergent culture and its architectural principles. - “Nobody owns the Internet, there is no centralized control, and nobody can turn it off.” “Its evolution depends on rough consensus about technical proposals, and on running code.” “Engineering feed-back from real implementations is more important than any architectural principles.” [5] “A grass-roots solution seems to be the only means to the success. Top-down mandates are powerless.” [6]

So we tried to identify “unplanned” transitions happened in the industry, and observed the following patterns.

(1) Swing-over between Opposing Concepts:
An underlying construct for a preferable technology of the period tends to swing-over between the opposing concepts, for example:
- Stateless <-> Stateful
- L3 <-> L2
- Distributed <-> Centralized
- Connectionless <-> Connection Oriented
- Overlay <-> Hop by Hop
- Virtual <-> Physical
- Dynamic <-> Static
- Separated <-> Integrated
- Loosely-coupled <-> Tightly coupled
- Etc..

(2) Conflict, Co-existence and/or Selection:
There may be multiple technologies that achieve similar objective. Such technologies could compete, co-exist, or be selected over time. Examples include:
- X.25 -> Frame Relay -> ATM
- ATM -> Switched Ethernet
- GOSIP -> TCP/IP
- ISIS, OSPF
- AppleTalk/DECnet/IPX -> IP
- VXLAN, NVGRE, STT
- DS-Lite, 4RD, MAP-E..
- Etc..

(3) Disruption:
Disruptions happen from outside of the community. In 1995, Toshiba Research started work on what eventually was published as RFCs 2098 and 2129 – a cell-switched router, which used a basic ATM infrastructure to connect an IP network, and optimized it with dedicated cut-through VCs for large data flows. The following year, Ipsilon commercialized the idea. Cisco and IBM proposed an alternative model called “Tag Switching”, which was eventually standardized as MPLS. The effect was to give large operators the ability to traffic engineer their networks, which IP Routing was not designed to do, and the way IP Routing works in those networks fundamentally changed.
The recent Openflow boom could also be seen as a disruption.
- IP Switch/MPLS
- Openflow/SDN

Figure 1 shows these technological transition patterns found in the networking industry.

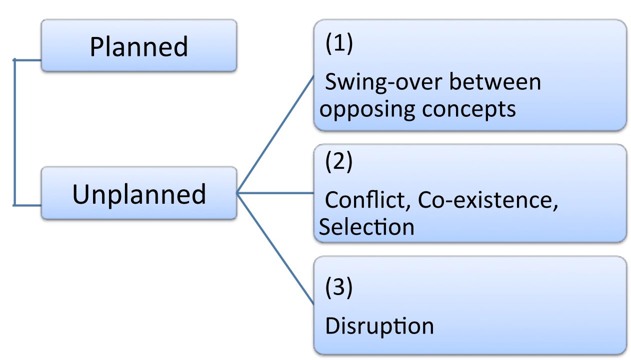

Figure 1: Patterns in Technological Transition

1.3 To manage technological transition

Technology adoption and the deployment would be smoother in "planned" technological transition. But as for the Internet, the first challenge is to address should be how to manage "unplanned" transition.

The observed patterns in the previous section lead us to the following hypotheses.

- There are no "absolutely-correct" technologies.
  - Technology preference varies based on application area, conditions, and across the ages.
- Natural selection is the driving force behind the process of evolution.
  - Naturally selected technologies are by far more robust than technologies forced by authorities.
- Diversity plays a key role in natural selection process, and also for coping with disruption.
  - Disruption can be a crisis to the system. But if the system is diverse enough, then some elements of the system can accept it, include it and redefine it, just as IETF did in response to the IP cell-switch.

Ashby's law of requisite variety [7] also supports these hypotheses. Therefore, for the Internet Architecture and the community, we recommend retaining and promoting conceptual diversity. This can follow and inform the evolution of technology, turning "unplanned" transitions into "planned". In addition, one answer for a theme of the ITAT workshop, "what makes protocols designs successful" [8], could be a thorough review from various viewpoints of multiple diverse parties.

A problem with the diversity, however, is that diversity that merely increases entropy is usually harmful, and could cause chaos or uncontrollability. In the next chapter, we try to observe the trend of diversity in the Internet Architecture.

2. Diversity trend in Internet Architecture

2.1 Motivation for the measurement

In the Internet Architecture, as the hourglass diagram depicts, the Internet layer acts as a convergence layer at the middle of the hierarchy, and absorbs the other layers' diversity and the transition. This could be comparable to a hierarchy of potential stable "subassemblies" by H.A. Simon [9], which explains the evolution of complex systems.
However, IPv4 address space has been depleted, and due to the difficulties to deploy IPv6 all at once, a lot of IPv4/v6 co-existence and migration technologies have been being proposed. So the current IP layer may no longer be stable nor able to absorb the other layer's diversity and transformation. It may be worthwhile to measure the diversity trends of each layer to understand what is happening these days.

2.2 Measurement method

In order to measure the diversity, we reused the Shannon's entropy calculating formula [10]. Entropy (in the Information Theory context) measures the uncertainty associated with a random variable.

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i$$

$p_{i} - p_{n}$ depicts a probability of occurrence, or a share, of each technology option. The idea is that the more different and the more diverse technology options there are, the more uncertainty there is in the selection of a technology.

We set scopes of the observation as below (Table 1).

Table 1 Scopes to observe diversity

	Topics	Reference Data
Datalink Layer	Internet Access Methods (Consumers)	MIC, Communications Usage Trend Survey [11]
IP Layer	Proposals on IPv4/IPv6 co-existence and migration technologies	IETF Softwire WG meeting minutes [12]
Application Layer	Peek period Traffic/Application Composition	Sandvine Global Internet Phenomena Report [13]

2.3 Datalink Layer

The Japanese Ministry of Internal Affairs and Communications publishes the statistics on the communication usage trend survey every year.

Table 2 Trends in the Internet Access Methods Usage (Home Users)

	2009	2010	2011	2012
FTTH	41%	52%	52%	55%
CATV	19%	14%	16%	17%
DSL	17%	12%	12%	10%
3G cellular	3%	3%	7%	9%
Fixed Wireless	7%	1%	1%	2%
Broadband Wireless	0%	1%	1%	1%
LTE	0%	0%	0%	5%
Others (Narrowband, etc.)	13%	18%	11%	2%
Diversity Index	2.26	1.95	2.02	2.02

At the beginning of commercial service of the Internet, the access method options used to be more diverse, since PSTN, ISDN, dedicated lease line, FR, etc. had been used. However, nowadays it is been pretty much converted to FTTH and CATV/DSL. The diversity index has been slightly increasing again from 2011, because 3G cellular and LTE has started to be used as a main access method for consumer Internet service (Table 2).

2.4 IP Layer

In the Internet Architecture, IPv4 used to be the only protocol at IP layer, and had acted as a "convergence" layer to absorb other layers' diversity and the transformation. This is no longer the case, since IPv4 address space is limited and migration toward IPv6 had been recommended. A problem has been that the motivation and the effort for IPv6 deployment varies depending on the position of the organization, and so various kind of IPv4/IPv6 co-existence and migration technologies are needed to address such requirements, e.g. underlying network's address design, CPE requirements, address aggregation requirements, where to place gateways, technical preference for tunnel/translation, stateless/stateful, etc.
Although it is difficult to objectively measure the diversity in this layer, we picked the number of draft proposals discussed at the IETF Softwire WG as an approximate data point. Since most of those technologies have not been deployed yet, we tentatively assumed an equal ratio for calculating the diversity index (Table 3).

Table 3: The number of Proposals for IPv4/v6 co-existence and migration at IETF Softwire WG

	2009(IETF76)	2010(IETF79)	2011(IETF82)	2012(IETF85)
# Proposals	10	20	21	16
Diversity Index	3.33	4.33	4.4	4

2.5 Application Layer

Various applications have been developed to run over Internet. However, a recent statistic shows that many applications are now converging on HTTP as a presentation layer (Table 4).

Table 4 Trends in the Application Protocol Usage

	2009	2010	2011	2012
HTTP	61%	69%	60%	64%
RTMP	16%	7%	5%	2%
SSL	3%	2%	2%	3%
P2P	5%	8%	12%	10%
Unknown	15%	14%	21%	21%
Diversity Index	1.63	1.45	1.59	1.35

2.5 Diversity Trend - Summary

In previous times, IP layer surely acted as a "convergence" layer and absorbed other layers' diversity, and built the prosperity of today's Internet. But the situation has changed.

This survey has shown that though IP layer is not stable these days, other layers are relatively stable.

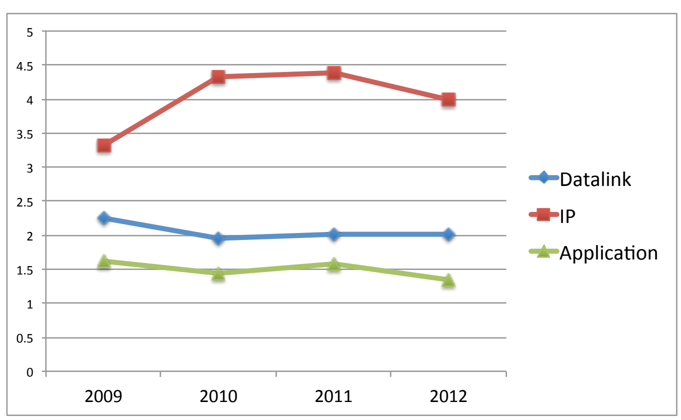

Figure 2 Diversity Trend in the Internet Architecture

One can assume that this phase difference in diversity trends among multiple layers helps to avoid excessive diversity as a whole.

3. Summary

This paper examined how the technology transitions take place in the Internet.

In the first half, we sorted out the patterns of technological transition in the networking industry, and got the following:

- There are no "absolutely-correct" technologies.
- Natural selection is the driving force behind the process of evolution.
- Diversity plays a key role in natural selection process, and also for coping with disruption.

And in the last half, we measured some diversity trends of the Internet Architecture, in order to understand how the Internet manages diversity and thus manages the technological transition.

To summarize:

a) "Planned" transition rarely happens in the Internet, but there is a way to manage the "unplanned" transition.

b) Diversity is requisite to cope with "unplanned" transition, though excessive diversity would be harmful since it causes chaos or uncontrollability.

c) Phase differences in the diversity trend among multiple layers help to avoid excessive diversity as a whole.

Consequently, our recommendation would be to retain and promote conceptual diversity, while watching to avoid diversity that merely adds entropy. Managing diversity would help to manage technological transitions, and thus enhance the sustainability and evolvability of the Internet. Also, thorough review from various viewpoints of multiple diverse parties could help to make the protocol successful as well.

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