System designers know that to build a large system they must use a divide-and-conquer approach: break the system into smaller parts to design and build separately. The ideas of modularity and interface are among the most basic in the designer’s tool kit. However, modularity matters not only during the design phase but also when the system is operated in the real world.

The implications of system modularity are particularly important for distributed systems operated by multiple profit-seeking commercial providers. In systems such as the Internet, modularity and interfaces shape not only technical design but also the very structure of the industry. System designers thus need to consider the industry structure that their modularity induces.

The Obvious Starting Point

The question almost everyone asks when thinking about a commercial undertaking is, how can I make money? The system designer must consider a more sophisticated set of questions that address all the system’s parts and how they fit together:

- What industry sectors do the interfaces define?
- How does each sector make money?
- Which sectors might not make (enough) money?
- Does the system fit together economically?

Most technical engineers are unfamiliar with this design space, but it significantly affects their efforts.

The Internet offers many illustrations of the relationship between interfaces and industry structure. One of the earliest examples is the interface between routers — the protocols that exchange control and routing information. The creators of the first routers argued that the complexity and uncertainty in the interfaces would make standardizing them impractical. Moreover, they contended, keeping the interfaces unstandardized would facilitate quicker upgrades and replacements. However, this approach would have prevented the emergence of a competitive router market, and the Internet designers strongly resisted the call to maintain those interfaces as private, rather than open.

Without standardized interfaces, companies like Cisco could never have come into existence. Of course, Cisco is an equipment manufacturer, not a service provider, but the open interfaces that permit router interoperability also enable different Internet service providers to interoperate. (The business arrangement behind the standards-based connection is another matter.)

We have now lived with commercial ISPs for almost a decade and the industry structure seems natural, but there is no fundamental reason that it came out as it did. The number of and relationship between ISPs, as well as the degree of vertical integration in the marketplace, is a result of the particular protocols and interfaces. For example, the Internet research community redesigned the Internet routing protocols in the 1980s specifically to allow multiple competitive wide-area ISPs and eliminate the prior structure in which NSFNet was the only wide-area service provider.

The Internet provides many other examples as well.
routers both forward packets and compute routes, for instance, but the interface between these functions is not standardized. Because it is left as a proprietary interface — almost always an internal software interface inside the router — no separate set of companies sells systems to compute routes. We could debate the advantages to this alternative structure, but it can’t come into existence because the interfaces don’t allow it.

**Consequences of Economic Modularity**

Good modularity is subjective, and achieving it is a bit of an art, so getting the system’s modularity right requires skill and judgment. In a system in which the modules represent distinct business entities, the design questions are expanded.

**The Pain of Competition**

The first question to ask about the economic implications of a proposed modular design becomes, how will the business entity representing each module make money? Again, the communications industry provides a useful example. No business interface exists between the part of the telephone company that provides the actual wires and the part of the telephone company that makes money. No business interface exists between these functions either. The same scenario has played out with the Internet. The revenue structure that was in place prior to the Internet did not require the “old” vertically integrated telephone carriers to attach to low-value bits. Only one of these bits, the “bits,” just the telephone service. The same scenario has played out with the Internet.

In the Internet, there is an open interface between basic network service (provided by the Internet protocol’s packet-transport capability) and higher-level services such as email, the Web, and so on. This interface makes it easy (indeed, it was the goal) for different players to provide the basic Internet service and the higher-level services on top. Each sector must therefore have its own strategy for making money. Further, the open interface permits multiple providers at both levels to compete to offer service. Open interfaces introduce competition.

In this structure, ISPs charge fees to the parties that attach to them, roughly in proportion to the size of the access links they use. What competing ISPs cannot do today is charge more for carrying “more-valuable bits.” Competition drives prices toward marginal cost and squeezes out options for value pricing. Services such as television, for example, require orders of magnitude more bits than others like Internet telephony. In looking at typical monthly consumer expenditures for television and telephone, even a rough calculation suggests that a provider must charge a lot more for a telephone-call bit than a television-show bit to capture an equivalent share of what users are willing to pay. This sort of pricing does not work with the Internet today; instead, ISPs are forced to be commodity carriers of undifferentiated bits.

This is analogous to the well-known history of the railroads, which used to charge more to haul a ton of valuable product than a ton of rock. When trucking and other means of competition entered the market and skimmed off these valuable products, the railroads were left with only the bulk low-value cargo unless they converted to strictly weight-based fees; economic disruption followed. The same scenario has played out with the Internet. The revenue structure did not require the “old” vertically integrated telephone companies to price the “bits,” just the telephone service. Once an open interface was inserted into the industry structure, however, those who looked ahead realized that anyone who had to charge for the bits wouldn’t make money from Internet telephony because there were so few bits to carry compared to other services.

**The Pain of Sunk Costs**

Owners of physical facilities at the base of the Internet — companies that actually install and operate fibers, wires, and so on — face another economic reality. In this “sunk-cost” industry, they must spend up front to install communication links and then try to recover the costs via subsequent utilization or resale. In industries with major sunk costs, competition tends to drive prices toward the marginal cost of providing service, and prices based on incremental costs often fail to recover the capital invested. If such industries become highly competitive, all the players risk going out of business. (In practical terms, of course, the weaker companies usually go out of business or get acquired by the stronger players until the competition becomes less demanding.)

The Internet’s architecture thus implies two painful facts for ISPs and the facilities providers on which they depend (if they don’t own their own facilities): the open interface deprives them of an important opportunity for value pricing, and it imposes competition on a sector with major sunk costs. Both of these issues signal economic stress. An observer in the mid 90s could not have predicted the industry’s full trajectory — overexuberant investment in facilities, followed by bankruptcy, an oversupply of long-distance fiber that owners can’t even afford to light, components of old-line telephone companies fighting for their economic life, and major industry consolidation raising antitrust concerns. However, all these consequences are consistent with the economic constraints imposed by slicing a competitive open interface through the middle of what had been a stable, vertically integrated industry.

**The Withering of Openness**

For now, the Internet interface seems likely to remain open, but the pressures
of commodity-bit carriage and covering sunk costs could drive the Internet industry toward consolidation at the lower levels—the ISPs and the facilities providers that support them. What might this imply for the interfaces?

An ISP that achieved significant market power might find it advantageous to offer a “modified” or “enhanced” interface. If several higher-level service providers were to adopt this interface, other ISPs and high-level service providers could be shut out of the market. In addition to causing higher prices for Internet access, the erosion of competition among ISPs could therefore erode the entire Internet model. This is why regulators and consumer advocates are watching the possible lack of competition among broadband ISPs so closely.

If an open interface is desirable for shaping the market’s structure, but the sector on one side of the interface cannot sustain competition, consolidation among players could drive the open interface from the marketplace by dominant player’s actions. Working to guarantee that all the sectors can make money is thus a key factor in ensuring that the open architecture itself survives.

Facing the Design Challenge
Experts in economics and business might be able to offer suggestions for thinking about interfaces as an economic design problem, but a few principles emerge from the discussion to this point.

Competition
Competition is a tool for imposing discipline on the market, but it is a two-edged sword: it can motivate players to invest and innovate, or it can drive them out of business. For example, introducing a feature such as endpoint-controlled routing—allowing consumers to route traffic over their choice of ISP—might increase the total competitive pressures and actually make things worse for the ISPs. On the other hand, it would let providers bring new service enhancements to the market to attract (and charge) users, who might be persuaded to pay more in exchange for real innovation and value.

Price Discrimination
Given a devil’s choice, many users might prefer price discrimination to monopoly. Few would argue for a return to the “good old days” of vertical integration, high margins, and regulated monopolies, but that might be the result if the pressures on facilities providers lead to consolidation and market exit by enough ISPs. The alternative is to let providers make a little more money, with the hope that more competitors survive. As consumers, our instinct is to build systems that appropriate all excess utility, but we might need to build mechanisms that deliberately give up some of that utility to the providers. Letting the industry sectors with sunk costs recover more of the value associated with consumer utility could be the best compromise to ensure industry stability.

A Debate of Engineering and Religion
By and large, Internet designers have resisted introducing Internet tools for price discrimination because of the fear that they would create uncontrollable opportunities for ISPs to impose new costs—even on users who did not want the tools. (One way to make a high-value tier preferable is to degrade the low-value tier.) This resistance, which is almost religious among some network architects, disadvantages those customers who would be willing to pay more for better service. The force that will mitigate abuse is competition, but the risk is real and designers face a dangerous gamble. If these tools are sufficient to sustain competition, then adding them will prove to be a good thing. If competition fails, however, they could make monopoly pricing even worse.

Leaving a feature out of an interface does not make it go away. It can drive it under the covers, outside the architecture, but not out of existence. Creative market entrants are already finding clever ways to bypass the basic interface’s architectural limitations and impose price discrimination. ISPs are seeking ways to introduce value stratification, and they will do it whether the building blocks are in the architecture or not.

This raises the question of whether such after-the-fact evolution is the right approach to innovation. Perhaps we would be better off if we had designed such building blocks into the original open interfaces, giving the facilities providers more direct access to them. One thing is clear: as system designers, we must make conscious choices on whether to design these sorts of mechanisms and interfaces, or to let them happen after we lose control.

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