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The Dangers of Modularity

By placing a premium on predictability in their product development efforts, companies create a technology landscape that's easier to navigate — but one that may produce fewer true breakthroughs.

by Lee Fleming and Olav Sorenson

Nobel Prize-winning economist Ken Arrow had a succinct, almost poetic, way to describe technological advances: "The process of innovation is, virtually by definition, filled with uncertainty; it is a journey of exploration into a strange land." Indeed, this mysterious terrain can be viewed as a mountainous landscape with soaring peaks and deep valleys, the summits corresponding to breakthrough inventions, the chasms representing dismal failures. We have recently charted this landscape in quantitative terms, drawing on more than 200 years of U.S. patent office data.

Specifically, our research investigated how the innovation process is affected by the number of an invention's components and their degree of interdependence. We confirmed the existence of a long-suspected trade-off between the predictability of advances and their ultimate importance. And we found evidence that companies typically overvalue predictability.

We started with a simple premise: Inventions result from the combination of components (either physical things or ideas) in new and useful ways. As a gross simplification, one might think of the automobile as an amalgamation of various preexisting parts, including the steering wheel and gears of a bicycle; the wheels, axles, and general structure of a horse-drawn carriage; and the internal combustion engine.

The interdependence of the components has an enormous effect on the pace and complexity of the innovation process. In modular designs, changing one component has little influence on the performance of others or on the system as a whole. An example is the Walkman, which Sony's engineers first developed from a wide range of standard, interchangeable parts. But when components are highly interdependent, a change in one can drastically affect the performance of the others, and these effects can cascade, leading to the failure of the entire system. Consider the inkjet printer. First proposed by Lord Kelvin in 1867, it took more than a hundred years to become commercially viable, even after millions of dollars of investment by Stanford researchers, Sperry Rand, IBM, and Hewlett-Packard. The culprit: severe interdependence of the components, including the chemistry of the ink, the physical layout and composition of the resistors, and so on.

When visualized, the technology landscapes that the inkjet printer and the Walkman inhabit look very different. Think of each peak in a technology landscape as a specific invention within a region of technology — in this case consumer electronics. The Walkman terrain resembles Mount Fuji, with its gentle slopes rising steadily to a single summit that researchers can identify, approach, and
ascend with relative ease. The ink-jet printer's landscape is more like the Swiss Alps, with abrupt peaks separated by deep valleys, making it difficult to see, much less reach, the area's high points.

Our analysis of the Patent Office data—which involved nearly 350 billion calculations concerning the impact of each invention and the number and interdependence of its components—highlights the benefits of climbing in the Alps. It's true that modular designs can lead to landmark inventions; after all, Mount Fuji, though lower than the Matterhorn, is still an impressive peak. But on the whole we found that even though interdependent components make innovation much more uncertain and difficult, using them often results in breakthrough products. Simply put, traversing rugged terrain is a high-risk, high-return endeavor.

Our findings call into question the trend at many companies toward highly modular designs. Although such designs make product development more predictable, many companies appear to use modularization techniques to the point where they undermine the innovation process by reducing the opportunities for breakthrough advances. Moreover, the predictability inherent in modular approaches raises the odds that competitors will develop similar products.

Our research indicates that intermediate levels of interdependence produce the most useful inventions. We thus recommend that companies take a contingent approach to product development. Engineers should seek ways to make technologies that exhibit extreme interdependence more modular, perhaps by supporting standardization efforts. But past a certain point of modularity, lab directors need to encourage inventors to tinker with more interdependent technologies to maximize the likelihood that a breakthrough will occur.

Changing the modularity of components is only one way to alter a technological terrain; we are currently studying the effectiveness of other approaches, as well. Working with a large Fortune 500 corporation and two high-tech start-ups, we are investigating, for instance, whether long-term investments in fundamental or applied science can mitigate the risks of investing in highly interdependent componentry. Further research will help determine procedures for companies to use to move from high-interdependence landscapes to more modular ones or vice versa. The overall goal is to enable organizations to sculpt their technological terrain to suit their competitive strengths.

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