03-030

The New Operational Dynamics of Business Ecosystems: Implications for Policy, Operations and Technology Strategy

Marco Iansiti
Roy Levien

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Marco Iansiti
Harvard Business School

Roy Levien
NERA

8/30/2002

Introduction

Many industries today behave like a massively interconnected network of organizations, technologies, consumers and products. Perhaps the most dramatic and widely known example is the computing industry. In contrast with the vertically integrated environment of the 1960s and 1970s, today's industry is divided into a large number of segments producing specialized products, technologies and services. The degree of interaction between firms in the industry is truly astounding, with hundreds of organizations frequently involved in the design, production, distribution, or implementation of even a single product. And because of this increasingly distributed industry structure, the focus of competition is shifting away from the management of internal resources, to the management and influence of assets that are outside the direct ownership and control of the firm. This shift has very significant implications for both academics and practitioners and requires an evolution in our approach to industrial organization, technology management and operations strategy, since these theories were primarily developed and tested in traditional environments.

The implications for managers are important. In networked industrial environments like the computer industry, the performance of any organization is driven in large part by the characteristics and structure of the network, which influence the *combined* behavior of its many partners, competitors and customers. This makes an enormous difference in both strategy and operations. As we saw with dramatic effect in the case of the recent .com and telecom implosions, strong, capable firms like Cisco Systems and Yahoo! suffered sudden and dramatic losses when their massive network of partners and customers faltered. Could Cisco and Yahoo! have prevented these problems? Did their behavior in previous years do anything to cause them? How should their technology and operations strategies evolve in the future to help their business networks remain healthy? Are there ways in which leading firms can encourage innovation and productivity in their networks? And how should some of the less prominent firms focus their capabilities in the future, given these complex dynamics? In order to answer these types of questions, we need a better way to understand the complex operational dynamics of highly interconnected networks of organizations, or "business ecosystems".

The dynamics of innovation and operations in highly interconnected organizational networks also have very significant implications for policy. One need only think of the recent Microsoft anti-trust trial, where the arguments around the evaluation of remedies were often hampered by the lack of established theories and frameworks with which to evaluate the role and value of central platforms like those provided by Microsoft, or the potential damages to the broader business ecosystem caused by remedies that might render the same platforms unstable. Other policy implications include the debates around public policy support for distributed, networked initiatives like Open Source or "free" software, or for current legislation around the best way to leverage, protect and distribute intellectual property in a networked environment.

The operational dynamics of network industries therefore have very significant implications for managers, academics and policymakers, in fields ranging from product design to antitrust law. In this paper, we introduce a framework for understanding the implications for the management of innovation and operations in business ecosystems. We draw heavily from the fields of complexity theory and especially evolutionary biology, which provide a motivating framework and a source of inspiration for understanding the behavior of large, loosely-connected networks. We combine these insights with the research tradition in the fields of operations and technology strategy to synthesize the initial stages of a theory for analyzing operations and innovation in business ecosystems. We first focus on the broad operational characteristics of the ecosystem as a whole, and define specific indicators of ecosystem structure and ecosystem "health". We then focus on the behavior of individual organizations and develop specific operational implications for different "types" of ecosystem strategies, which we identify as dominator, keystone, and niche firm, touching briefly on some of the essential capabilities that underlie the successful implementation of each of these strategies. In a set of appendices we extend this discussion by examining some specific examples of ecosystem strategies pursued by Wal-Mart and NVIDIA in detail, and by illustrating an application of our framework through an evaluation of the role played by Microsoft Corporation in the computing ecosystem. We conclude by summarizing some of the most important consequences for strategy, operations and policy in networked industries. Throughout this discussion, our ideas are motivated and illustrated by our empirical research and practical experience in the computer industry, which is extended by examples from other environments, including semiconductors, retail, internet services, and telecommunications.

The emergence of networked industries: the computing industry

It is important to appreciate that the networked structure we see in many industries today is a relatively recent phenomenon. Even in the computing industry, where high degrees of interconnectedness and various forms of "modularity" have long been characteristic of much of the underlying technologies, the emergence of a true networked structure is a phenomenon of only the past decade and a half. In the computing industry of 30 years ago, complete suites of products fought head-to-head for dominance, and competitors could lose market share and be displaced if they did not keep up with technological developments in a broad variety of areas. Interoperability between competing product suites was not a design goal – the objective was to create distinct integrated offerings that offered the complete functionality desired in a computer system. Firms in this industry focused on creating and owning a proprietary "stack" of hardware and software products. In this climate, firms fought to keep ahead by generating innovations internally over a broad range of domains[1], while generally viewing external "change" as a threat to firm survival.[2] Leading firms in this climate actively pursued innovations designed specifically to enhance a firm's suite of offerings, and thus often narrowly applicable to that firm's products. IBM's introductions of the first transistor mainframes during the late 1950s, and of the first commercial magnetic core memories in the 1960s, were largely constrained within IBM.[3] Solid Logic Technology, for example, introduced by IBM in 1964, provided a technological breakthrough that created the technological foundation for a generation of mainframes, but was never commercialized to any other company.[4]

[1] IBM's R&D was potentially the most striking example, as it was focused on virtually every technological driver of computing performance, from research on glass ceramics to the design of efficient software algorithms. See, for example, Emerson W. Pugh, *Building IBM* (Cambridge, MA: MIT Press, 1995).
[2]See, for example, Pugh, *Building IBM;* Charles H. Ferguson and Charles R. Morris, *Computer Wars* (New York, NY: Times Books, 1993).; Tushman & Anderson (1986); Baldwin & Clark, *Design Rules*; Iansiti & Khanna (1995).
[3] Pugh, *Building IBM*; Baldwin and Clark, *Design Rules*.
[4] Indeed, IBM limited its production of integrated circuits for captive use until 1993. While some of the ideas behind Solid Logic Technology were leveraged by other firms, no other company ever adopted a similar set of technological components, and its impact was therefore largely limited to IBM products.

The computing industry today is radically different. Today's firms are highly specialized and compete fiercely within narrow domains of expertise. From customer relationship management software companies (like Siebel and Onyx) to microprocessor manufacturers like Intel and AMD, firms in this environment focus on doing a relatively small number of things well. Indeed, the fraction of the industry's market capitalization captured by the Microsoft, today's leader, is very small relative to the fraction that was captured by IBM in the mid 1960s.[5] Firms are even specialized to such an extent that a single product is often the result of the collective efforts of many firms, with a significant proportion of those firms' contributions taking the form of offerings that would have no value on their own, outside the context of the collective effort. "Fabless" semiconductor companies like Broadcom and NVIDIA, for example, possess no substantial manufacturing assets and rely instead on third-party foundries like TSMC and UMC. In this environment, traditional R&D is focused on improving performance in narrow domains. This results in rapid parallel advances in many areas as each is propelled by highly focused domain-specific innovation. The goal is no longer to lock out entire vertical stacks with proprietary advantage, but to be the best in a chosen area of specialization.[6] This means that the destiny of many organizations is now linked together, and interaction between firms has become an increasingly critical and complex phenomenon, sharing elements of both cooperation and competition through a rich network of interrelated products, services, and technologies.[7] Crucially, this interaction is not along traditional industry boundaries, but connects the destinies, strategies, and

[5]Pugh, *Building IBM*; Baldwin and Clark, *Design Rules*.

operational capabilities of customers and suppliers, partners and competitors, and reshapes competitive and operational dynamics at the most fundamental level.

Managing operations and innovation in networked industries

This sea change[8] in competitive structure forces us to reexamine the ways in which we – policy makers, academics, and managers – look at fundamental processes like innovation and operations, and at how we assess industry health and formulate policy. The networked structure of today's computing environment demands that we develop an understanding of how networks and key firms within them support or inhibit innovation, how they enhance or damage business productivity, and of how they provide healthy environment for the creation of new firms and products.[9]

Our understanding can be advanced by comparing networked industrial environments to biological ecosystems[10]. Like their biological counterparts, these "ecosystems" are characterized by a large number of loosely interconnected participants who depend on each other for their mutual effectiveness and survival.[11] In what follows

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[6] Moreover, this distribution of innovative activity brings the opportunity to innovate closer to the loci of innovative thinking and problem solving, thus enhancing the quality and relevance of innovations. See, for example, von Hippel (1994); von Hippel & Thomke (2002).

[7] See, for example, Moore (1996).

[8] The transformation described here occurred gradually and involved a significant intermediate stage in which "modular" designs, notably the IBM System/360, were the rule. (see Baldwin and Clark, *Design Rules*) This set in motion a process of fragmenting the industry into a wide variety of diverse organizations, each providing different product and service components, and focusing on different capabilities. The forces unleashed during this period gradually led to the industry structure we see today, in which a large number of specialized firms operate in many distinct segments.

[9] Disagreements about how to evaluate the networked structure of the computing industry – about the best way to organize it, and about the role played by influential firms – is a high stakes matter. Indeed, the landmark antitrust litigation against Microsoft is (or can be seen as) largely a debate about how best to organize such networks.

[10] It is important to state at the outset what will become clear as we proceed: that we are not arguing here that industries *are* ecosystems or even that it makes sense to organize them *as if they were,* but that biological ecosystems serve both as a source of vivid and useful terminology as well as a providing some specific and powerful insights into the different roles played by firms (see for example Moore, 1995). Moreover ecological terms help animate and focus some very technical and generic terms from the general complexity literature. Finally the ecological analogy builds a metaphorical bridge to the literature on biological integration and complexity building, which provides an important part of our framework. (For a conflicting viewpoints on the value of ecology as a metaphor for industries see "Business as a Living System: The Value of Industrial Ecology A Roundtable Discussion," *California Management Review* (Spring 2001).

[11] It is instructive to keep in mind that this applies not only to the firms that make up the computing ecosystem, but also to the technologies, products, and services that they create.

we argue that because the health of individual firms and the utility of individual products depends so much on the health of other firms and products in the ecosystem, it is especially important to develop ways to characterize the *collective* health of the ecosystem. We propose three cardinal measures of ecosystem health, developed from analogies with biological ecosystems: productivity, robustness, and niche creation. We then go on to argue that firms can influence the health of their ecosystem as well as their own performance through the appropriate choice and operational execution of three types of strategies: keystone, dominator, and niche firm. We discuss these strategies drawing from examples from a variety of environments. In an appendix (see Appendix C), we elaborate this framework in the context of an analysis of the strategies pursued by Microsoft with respect to its ecosystem and suggest that important insights, for both policy and practice, can be gleaned from further research guided by this perspective.

Traditional Views on Operational Capabilities

Over the last decade, research in a number of industries has documented wide variation between competitors in critical dimensions of performance such as productivity, quality, time-to-market, customer satisfaction, and profitability.[12] This empirical evidence underscores the success of some firms in creating and sustaining significant advantage over their competitors. While strategic moves (such as capacity additions, investments in R&D and advertising, and alliances) and structural considerations (e.g., strategic groups and barriers to mobility) may partly explain observed differences in performance, research on the sources of those differences points to critical capacities for action that are far more effective in practice at some firms than at others. Some firms are simply more capable than others in ways that matter in competition, and these differences may be ascribed to operational capabilities.

This connection between capability and competition has also been an important theme in recent work in economic history and business strategy.[13] The notion of a firm's "distinctive competence" has a venerable history in the study of business policy, but more recent work on the resource-based view of the firm, the notion of core competence, and the learning organization has emphasized the dynamic nature of the operational capabilities that are critical to sustainable firm performance.[14] Recognizing the dynamic nature of the interaction between the market, technical environment, and competence

[12] E.g., Garvin (1986); Clark and Fujimoto (1991); Christensen (1992); Flaherty (1992); Henderson and Cockburn (1992).
[13] E.g., Chandler (1977); Chandler (1990); Lazonic (1990).
[14] E.g., Teece (1982); Nelson and Winter (1982); Wernerfelt (1984); Hayes, Wheelwright, and Clark (1988); Dosi, Teece, and Winter, (1990); Prahalad and Hamel (1990); and Leonard-Barton (1992); Rivkin (2000).

base of the firm, work by a variety of authors has also focused attention on the importance of innovation in building and renewing capabilities over time.[15]

However, most of the work performed so far has focused on the internal nature of these operational and innovative capabilities. In the deep tradition of work studying the management of operations and operations strategy, Skinner, Hayes and others have emphasized the management of internal resources, in areas ranging from quality improvement practices to human resource management.[16] And in their work on core competencies, Prahalad and Hamel emphasized the role of internal competencies, such as Honda's capability for engine design. This emphasis on internal capabilities pervades both the management of operations and of innovation and has several common themes: capability building commonly linked to the management of manufacturing improvement and learning, the internal implementation of information technology, the management of focused product development teams, and the management of resource allocation.[17] Even when authors have focused on the operational challenges in managing the relationships between firms, the typical focus has been on bilateral relations or at most in relations between small groups of organizations. Examples are relationships between manufacturer and supplier, user and manufacturer, or designer and manufacturer.[18] A common thread runs through most of this work: the tighter the coupling between parties (manufacturer and supplier, co-design team members, etc.) the better the performance. The same is also true for many theories of quick response in supply chains, in which the better the relationship between firms, and the tighter the exchange of information, the

[15] Penrose (1958), Rosenberg, (1982), Wernerfelt (1984), Prahalad and Hamel (1990), Chandler (1990), Teece, Pisano, and Shuen (1994), Dosi and Marengo (1993), Iansiti and Clark, (1994), Tushman and O'Reilly (1997), Eisenhardt and Sull (2001).
[16] Hayes and Wheelwright (1984), Hayes, Wheelwright and Clark (1988).

better the performance of the supply chain system. [19] Relatively little attention has been focused on the study of extended supply networks, characterized by vast loosely coupled networks of organizations, and fraught with a variety of problems ranging from deep information and incentive asymmetries to the imperfect quality of information.[20]

The innovation management literature has generally followed this same focus. Much of the work so far has focused on the fragile nature of competitive advantage in situations of significant technological and market upheaval. Authors have applied punctuated equilibrium models to understand the impact of technological change on organizations, but the nature of the change has generally been treated as an exogenous variable.[21] Authors have analyzed changes that are competence destroying, attacking the firm's "core", architectural, or disruptive to the firm's business model. But in virtually all cases, the changes were analyzed as an exogenous shock or trend that influences a single firm (or even a single organization within the firm). The critical interaction between that firm and its network of business partners is left largely untouched. Even in Christensen's work, although the interaction of the firm with its "value network" is analyzed, this interaction is generally perceived as a problem, increasing the challenges faced by an organization.[22] The network here is seen largely as a source of inertia, not as a dynamic factor in innovation, productivity and firm renewal.

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[17] Bowen, Clark, Holloway, and Wheelwright (1994), Wheelwright & Clark (1992), Adler & Clark (1991).
[18] Nishiguchi (1996); Clark and Fujimoto (1990), Von Hippel (1988).
[19] Much of the literature on supply chains is based on the field of operations research, which is more focused on problems like production forecasting and capacity optimization, rather than on the more general managerial implications of network interactions and network structure.
[20] The work of Ananth Raman, Nicole DeHoratius and Zeynep Tom is a notable exception, with their strong early research on imperfect supply chain networks, targeting problems caused by asymmetric incentive structures or bad data.
[21] E.g., Abernathy and Utterback (1978), Clark (1985), Tushman and Anderson (1986), Anderson and Tushman (1990), Henderson and Clark (1990), Christensen (1997).
[22] E.g., Baldwin and Clark (2000), Shapiro and Varian (1998), Gawer and Cusumano (2002).

However, a stream of literature in the finance and strategy domains has recently underlined the importance of industry fragmentation and industry networks. This literature highlights the general impact of modularity, product standards, and network externalities. Most notably, Baldwin and Clark (1999) introduce the concept of an "industry cluster", made up of the many organizations that are linked to each other via modular interfaces in the design of a product, and set the stage for the significant operational implications of this phenomenon. And as Carl Shapiro and Hal Varian point out, "There is a central difference between the old and new economies: the old industrial economy was driven by economies of scale; the new information economy is driven by the economics of networks..."[23] Gawer and Cusumano extend this perspective by highlighting the critical role played by industry "platforms" such as Intel, Microsoft, and Cisco, and argue for the importance of standards and distributed innovation. These writings clearly highlight that distributed industries behave differently, but the implications for the management of innovation and operations are still underdeveloped.[24] The operational challenges of managing innovation or operations in the kinds of very large, loosely connected networks that are beginning to characterize a number of key industries are thus largely unexplored.

Here, analogies from other fields are helpful. The literature on a wide range of highly interconnected systems—from phase transitions and the dynamics of weather patterns, to foraging patterns in ants and the process of complexity building in biological evolution—highlights the essential fact that such systems behave very differently from isolated and tightly coupled systems made up of few components. Moreover, this

[23] Shapiro and Varian (1998).

literature emphasizes the fact that a ubiquitous process of “complexity building” over a wide range of scales and in a vast array of domains has produced similar networked structures with characteristic dynamics throughout the natural world.[25] In the next section, we will examine some of this literature, to motivate an organic, networked view of innovation and operations management.

[24] E.g., Baldwin and Clark (2000), Shapiro and Varian (1998), Gawer and Cusumano (2002).
[25] See for example Chaisson (2001) and Wolfram (2002).

Business Networks as Ecosystems

The computing industry is not alone in having evolved a network structure. Complex networks of firms and products have become an increasingly common feature of the business landscape in general[26] and their presence has critical implications for policy formulation, economic theory, and management practice. In order to understand how many industries work today, we must understand networks. What network structures are most effective? What do we mean by effectiveness and how can it be measured?

Networks as complex systems

There is a growing appreciation that many phenomena in both the natural[27] and the man-made[28] world can be productively viewed as "complex systems."[29] From the understanding of the spread of forest fires[30], to the accurate portrayal the effects of crowd panic in a burning building[31], complex system approaches are yielding insights that conventional approaches have failed to produce. Similarly, there is a growing awareness that by structuring problems so that they can be viewed as networks of smaller problems, difficult tasks can be completed more efficiently. This basic insight is the inspiration for a wide variety of applications[32], from the design of routing algorithms in communications networks[33], to traffic flow management on highways[34], and has even inspired the military

[26] Examples include automobiles [e.g. Dyer (1996), Moore (1996)], construction [Eccles (1981)]; and biotechnology [Powell, Koput, & Smith-Doerr (1996)]. For a general review see Ebers (1997).
[27] E.g., food webs [William & Martinez (2000)]; ecosystems [Polis (1998)]; many natural patterns [Goldenfeld & Kadanoff (1999)].
[28] Arthur (1993, p. 144).
[29] "The greatest challenge today, not just in cell biology and ecology but in all of science, is the accurate and complete description of complex systems" Wilson (1998, p. 85); Strogatz (2001), Polis (1998), Goldenfeld & Kadanoff (1999).
[30] For this, and many other examples see Sole and Goodwin (2001).
[31] Helbing, Farkas, & Vicsek (2000).
[32] Anthes (2001), Scott (2002).
[33] Di Caro & Dorigo (1997).
[34] See Helbing & Treiber (1998), Resnick (1997).

thinkers to take a serious look radical approaches ranging from "fire ant warfare"[35] employing "swarms" of small, lightweight networked vehicles and munitions as a replacement for the costly and vulnerable monolithic components in use today[36] to the use of fruit flies as a model for battlefield communications.[37]

A general conclusion of this literature is that by connecting even simple components *in the right way*, complex and difficult problems beyond the abilities of the individual components are solvable, and new capabilities are acquired.[38] The network becomes much more than the sum of its parts. Indeed, in almost every field, from geopolitics to medicine, there are advocates of "network approaches" and "swarm intelligence" who argue that breaking things up into large numbers of small interconnected components will solve almost any problem and make the system as a whole almost magically better.[39]

But what is the right way to connect components? Are some network structures more effective than others? The answers to these questions lie at the heart of an understanding of how complex systems work,[40] and are essential for the analytical framework we seek to build here.

Hubs and robustness

The beginnings of an answer to these questions can be found from a close examination of a diverse literature on a wide variety networked phenomena, in both the

[35] Henley (2000).
[36] Dao & Revkin (2002).
[37] Grimes (2002).
[38] Bonabeau, Dorigo, & Thereaulaz (1999).
[39] Pedersen (2002).
[40] "As we are just beginning to realize, however, there is a[n …] aspect to [complex] systems which may be even more important and which has so far received little attention, and that is the pattern of interaction between agents, i.e. which agents interact with which others" Newman 2002 preprint; Strogatz (2001), Galaskiewicz & Marsden (1978).

complex systems literature and elsewhere. Much of this literature suggests that networks of many kinds naturally posses "key players" or "hubs" that enhance certain kinds of network stability.[41] This phenomenon is worth examining closely: not only does it directly address one of our questions, namely what network structures foster network health; it provides us with our first candidate for a generally applicable measure of that health: robustness.

Many networked structures ranging from relationships among friends[42] to the pattern of links in the World Wide Web[43] (see Figure 2) exhibit a characteristic property: they have a pattern of connections in which a small number of nodes in the network are much more richly connected than the vast majority of the other members of the system.[44] It turns out this structure will always emerge if networks evolve their connections over time and if these connections are "costly" to traverse or establish—for example, if they are constrained by physical location (participants need to be near one-another to interact), or require specialization (a plant requires special adaptations to live near the roots of another), or simply take time (as in navigating the Internet).[45] Critically, these "hubs" form regardless of the nature of the system, the internal details of the participants within the system, or the specific nature of the connections between members of the system, and this pattern is widely observed in nature. Hubs "are not rare accidents in our interlinked

[41]See for example: Albert, Jeong, & Barabasi (2000), Patch (2001), Bianconi & Barabási (2001), Cohen (2002).
[42] Newman (2001), Girvan & Newman (2001).
[43] Jeong, Albert, & Barabasi (1999), Huberman & Adamic (1999), "The Web Is A Bow Tie" (2000), Lawrence & Giles (1999), Klaffy (2001).
[44] See, for example: Liljeros, Edling, Amaral, Stanley & Aberg (2001), Jeong, Tombor, Albert, Oltvai, and Barabási (2000), Jeong, Albert, & Barabási (1999), Newman (2001), Watts & Strogatz (1998), Albert & Barabasi (2002), Bianconi & Barabasi (2001), Albert & Barabási (1999), Barabasi, Jeong, Albert, & Bianconi (2000).
[45] Huberman (2001), Kaufmann (1993).

universe. Instead, they follow mathematical laws whose ubiquity and reach challenge us to think very differently about networks."[46]

One important property of networks with hubs is that degrees of separation between nodes – the number of network that, on average, need to be visited to get from any one node to an arbitrary other node – are small. Indeed, hubs are part of the reason behind whimsical "six degrees of separation" rule.[47] Perhaps the most dramatic illustration of this rule of network structure is the pattern of links among sites on the World Wide Web.[48] Here a system with a huge number of diverse participants and no initial macro-scale structure evolved rapidly to have a structure in which a vast number of sites can be reached through a surprisingly small number of "jumps".[49]

There are both positive and negative consequences arising from the existence of a hub structure. For example, Web hubs make hundreds of millions of pages accessible through about 19 degrees of separation[50], but the "bow tie"[51] structure of the Web has left many sites stranded in fragmented "tendrils". If the system is subject to growth or change, especially rapid or discontinuous change, hubs can be displaced over time as new hubs emerge to take over their function: hubs will always exist, but specific hubs will rise and fall. Often early movers in such "scale free" networks are more likely to become hubs than those who join the network later. Moreover, the sudden removal of a hub results in the loss of a disproportionate number of network connections, resulting in the

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[46] Barabási (2002, p. 64).
[47] "The Oracle of Bacon at Virginia," The University of Virginia, Department of Computer Science web page, <http://www.cs.virginia.edu/oracle/> (2002).
[48] "Clicking onto the Web's patterns" (1999), Adamic & Huberman (2001).
[49] Huberman & Adamic (1999).
[50] Huberman & Adamic (1999).
[51] Broder, Kumar, Maghoul, Raghavan, Rajagopalan, Stat, Tomkins, & Wiener (2000).

effective collapse and fragmentation of the network. Networks with hubs are vulnerable to malicious or targeted attacks.[52]

Despite the danger from targeted attacks, network hubs exhibit an important and unambiguous aspect of network "health": they are robust in the face of random disruptions. It is hubs that account for the "fundamental robustness of nature's webs."[53] Removal of arbitrary nodes from networks with hubs leaves most of the network intact.[54] Robustness of this kind has been documented both theoretically and experimentally for a wide variety of networks with hub-governed structures.[55] Conversely, it has been clearly shown that "the tolerance of networks to different types of perturbation depends critically on the network structure",[56] specifically that networks lacking hubs are far more vulnerable to random disruptions. In such networks, local disruptions can have far-reaching effects that damage or destroy the entire network.

The literature on network structures thus suggests that one potentially important attribute that distinguishes healthy networks is robustness in the face of specific kinds of perturbations. Moreover this literature provides us with a paradigm for the part of the framework we seek to build: a direct link between network structure and system health. However, this literature says little about other potential measures of system health. More importantly, this literature says even less about *what kinds* of strategies hubs and other members of the system can pursue to actively improve system health. There are some

[52] Albert, Jeong, & Barabási (2000), Cohen, Erez, ben-Avraham & Havlin (2001).
[53] Albert-László Barabási (2002): 8.
[54] Albert, Jeong, & Barabási (2000), Cohen, Erez, ben-Avraham & Havlin (2001).
[55] See references above and Sole & Montoya (2001), Jain & Krishna (2001). Reviews in Barabasi (2002), Watts (2002).
[56] See Tu (2000).

intriguing suggestions, however, in both the social network[57] and business practitioner literature[58] that by pursuing specific strategies that foster ecosystem health, hubs can also ensure their own survival.

Ecosystems as networks: the role of keystones

The biological evolution literature provides a crucial way to extend this perspective on networks and evaluate the role played by network hubs. Here the literature on biological ecosystems[59] is explicit: It suggests that a species that serves as a hub in food webs or other networks of ecosystem interactions, can improve overall chances of survival in the face of change by *providing benefits to the ecosystem as a whole*. This literature identifies "keystone species"[60] as having specific characteristics that produce such benefits for the ecosystem and its members.[61] Removal of biological keystones can have dramatic cascading effects through the entire ecosystem[62], while removal of other species, even species involved in many interactions, can have little effect beyond the loss of those connections[63]. These effects include decline in important measures of health, such as loss of diversity, loss of productivity, and extinctions.[64]

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[57] Padget and Ansell (1993) analyze the ways in which the Medici manipulated the social networks at which they were the center to effectively consolidate a stable modern state around them. (See Figure 1.)

[58] Gawer and Cusumano (2002) provide numerous examples of how "platform leaders" can – and indeed must – act to ensure their own success by fostering complementary innovation in the network of firms in their industries; Shapiro & Varian (1998) discuss strategic implications for firms in networked industries where information and IP are of paramount importance..

[59] Throughout this paper we follow the popular use of the term "ecosystem" and use it interchangeably with the term "community". In the biological literature both terms have specific meanings, and what were are discussing here is in fact closer to the generic-sounding "community". For purposes of this discussion, we follow the use of others in choosing "ecosystem" because it captures both the fact that we are discussing a complex system and the fact that we are working with a biological analogy.

[60] The ecological literature contains many conflicting definitions of the term 'keystone' and some debate the extent of its relevance (see, for example Mills, Soule, & Doak (1993)). It's original use was quite narrow (Paine (1992)) but current usage sometimes ranges to the indiscriminate; here we use the term in it's most neutral and least technical form: a keystone is simply a species that governs most important ecosystem health, often without being a significant portion of the ecosystem itself. See for example (De Leo & Levin (1997)) and subsequent commentary (e.g., Khanina (1998)).

[61] Other analogies can also be found in social network theory. Padget and Ansell (Robust Action and the Rise of the Medici, 1400-1434, *American Journal of Sociology*, 98(6):1259-1319, 1993) analyze the ways in which the Medici manipulated the social networks at which they were the center to effectively consolidate a stable modern state around them.

[62] Indeed, this relationship is an element of the criteria used in the Endangered Species Act to evaluate the ecological value of species.

[63] Dramatic examples include the passenger pigeon and American chestnut. See Primack (2000).

[64] Tilman & Downing (1994), Holling, Schindler, Walker, & Roughgarden (1995).

Keystones maintain the health of their ecosystems through specific behaviors or features that have effects that propagate through the entire system (such as preferentially preying on certain species[65], or providing key nutrients that form the foundation for many ecosystem niches[66]). When these effects are beneficial to the system, the species is serving as an effective keystone. It is important to appreciate the significance of this characteristic of keystone species: it is essential that they encourage the health of their ecosystems—specifically of the *other members* of their ecosystem. If they do not, they will find themselves alone, effectively dominating the entire ecosystem.

This suggests a contrasting "dominator" role that is also discussed in the ecological literature.[67] Dominators are easily recognized, and easily distinguished from keystones, first of all by obvious metrics of physical size or abundance – in contrast with dominators, keystones are in fact often a small part of their ecosystems, by many measures. Secondly, by the simple fact that to the extent that they fail to encourage diversity, dominators must take over the functions of the species they eliminate, or eliminate those functions altogether. Ecosystems that are in the grip of an invasive weedy species are a good example of the effects of a dominator: not only is much of the biomass of such ecosystems made up of the invader, these systems simply "do" less. This is the fate of many North American wetlands, which have become dominated by the invasive Purple Loostrife[68]. These wetlands have become increasingly uniform swaths of a single

[65]Sea otters (Estes & Palmisano (1974)) and star fish (Paine (1992)) are well-known and well documented examples. See figure 4.
[66] A variety of fig species serve, for example, as critical foundations for communities in the Neotropics, where their complex aseasonal fruiting patterns provide a reliable source of food for a wide variety of animal species even in times of fruit scarcity and where they additionally provide a source of specific important nutrients that are not readily available elsewhere. See Nason (1998), Lambert & Marshall (1991), O'Brien (1998).
[67] Domination of ecosystems is a major theme of the literature on conservation ecology. Threats to many native ecosystems from non-native invaders often take the form of domination of the ecosystem by the invader. See for example, Drake (1989).
[68] Thompson, Stuckey, & Thompson (1987).

plant species, and have lost many native species of plants and animals—in effect they *become* the single dominating species.

Of course, conspicuousness alone is not sufficient to make a species a dominator or to disqualify it from being a keystone.[69] Some species, such as kelp in the near-shore ecosystems in the Pacific Northwest, are keystones partly because of their conspicuous presence. But such species leave many thriving niches unoccupied, and their removal damages the health of the entire system.[70] The fundamental distinction we wish to highlight here is that keystones do not occupy a large number of the nodes in the ecosystem network, while dominators do.[71] Dominated ecosystems often suffer the same fate as systems with poor keystones: they can become unstable or vulnerable to disruptions. This most commonly occurs when they become subject to some external shock or stress, and is largely the result of the fact that dominated ecosystems simply do not have the diversity to respond to these changes.[72]

Business Ecosystems

The ecosystem analogy is very useful in providing a model for loosely connected business networks. As with biological ecosystems, business ecosystems are formed by large, loosely connected networks of entities. As with species in biological ecosystems, firms interact with each other in complex ways, and the health and performance of each

[69] There is considerable debate in the ecology and conservation biology literature about the correct terminology for the various flavors of keystone species and the details of the variety of ways in which they have their effects in specific ecosystems. We need not concern ourselves here with this debate.
[70] Estes & Duggins (1995).
[71] In business ecosystems, as we shall see, both the number of nodes in the network and the number occupied by the keystone can grow over time: as long as the network is growing new nodes, and as long as the keystone does not dominate a relatively large number of these nodes, it can remain a keystone, even if the absolute number of nodes the keystone occupies is large in absolute terms and increasing over time.
[72] Diversity, for example, is an effective barrier against "invasion" by foreign species (e.g, Kennedy (2002) and a general correlate of ecosystem health (Naeem, Thompson, Lawler, Lawton, and Woodfin (1994)).

firm is dependent on the health and performance of the whole. Firms and species are therefore simultaneously influenced by their internal complex capabilities and by the complex interactions with the rest of the ecosystem.

It is worthwhile to underline that one of the more interesting differences between the approach that we suggest here and the more traditional analyses of technological transitions is that unit of analysis is not the industry, but the particular ecosystem area that an organization finds itself in. The "boundary" of the relevant ecosystem area need not (and typically does not) correspond to traditional industry boundaries, but is instead defined by the strength and type of organizational interactions that occur. For example, ecosystems may be defined by the sharing of tools and technological components, as in the Microsoft developer network ("MSDN"), or by buyer-supplier interactions as in Wal-Mart's supplier network. Organizations in these communities are driven in large part by the collective health of these networks. Because of this, ecosystems may span several traditional industries. The computing ecosystem discussed here at length not only includes the software and significant segments of the hardware industries, but extends into many other industries that rely on computing and information technology and devote resources to adapting them to their needs.

Because of these factors, the effects of ecosystem health and dynamics will easily breach traditional industry boundaries. A dramatic recent example is the case of computing, in which advances in the computing *industry* have resulted in widely distributed productivity gains in a wide variety of industries throughout the computing *ecosystem*. This crossing of traditional industry boundaries can work in the opposite direction as well. When many unrelated industries in an ecosystem experience simultaneous disruption or contraction, these effects can propagate back to the "core" of the ecosystem, as they have in the case of the computing ecosystem in the last several years. This definition of business ecosystems, while it contrasts with traditional industry definitions, is in the same spirit as the definitions used in biology, where what matters is the strength and nature of interactions, rather any preconceived categorizations.

Moreover, as with biological ecosystems, the boundary of a given ecosystem is often difficult to establish.[73] Organisms may interact with each other even if there are significant barriers between them at a point in time. Similarly, firms may interact with each other even if they appear distant at first glance. This means that rather than establishing a static and clear boundary between ecosystems, as the we often do for the boundary between industries, it is better to gauge the degree of interaction between different firms and depict ecosystems as communities of firms characterized by a given level and type of interaction (e.g., market relationships, technology sharing and licensing agreements, etc.). This is essentially the approach followed in the analysis of social networks, which conceptualize structure as lasting patterns of relationships among actors.[74]

Another important similarity between biological and business ecosystems is that, as with species in biological ecosystems, firms can play different roles, which can be viewed as operations strategies, for the purpose of our framework. Three are of particular importance: dominator, keystone and niche firm. Keystone firms are especially important in business domains that are characterized by frequent or significant external

[73] Turner (2000) provides an intriguing example of how meaningful boundaries for dynamic systems are not easily drawn even in biological systems where such boundaries might, at first glance, seem easily established. The obvious boundaries based on the

disruptions. The diversity they support serves as a buffer, preserving the overall structure, productivity, and diversity of the system in the face of disruptions that may eliminate other non-keystone species.[75] Keystones thus have the potential to preside over significant turnover in ecosystems over time. The individual members of the ecosystem may change, but the system as a whole, along with its keystones, persists.[76] The successive waves of transformation that have spread through the software industry (starting with the rise of the PC, and followed notably by the rise of the GUI and the rise of the Internet), for example resulted in significant changes in the software ecosystem, but its overall structure, productivity, and diversity have been unhurt, and its keystones, among them Microsoft, IBM, and Sun, have persisted.

Similarly, keystone species often displace or hold in check other species that would otherwise dominate the system (i.e., not just taking over the keystones role, but also the roles of many other species).[77] Moreover, because keystones can preside over significant turnover within an ecosystem, and because diversity and responsiveness to change preserve the ecosystem against encroachment, keystones improve the chances of their survival by either directly or indirectly *encouraging* change.[78] This is what the IBM-Microsoft-Intel ecosystem achieved with respect to Apple: For many years, Apple refused to license its operating system, and produced a highly integrated product (including hardware, software platform and many applications) that performed the functions of many potential other "species"— acting in effect as a dominator. But it

characteristics of the nodes in such systems (living vs. non-living) fail, in many cases, to capture the relevant boundaries for understanding how the system works (e.g., energy flow).

[74] Wasserman & Faus (1994), Scott (2000), Wasserman & Galaskiewicz (1994), Wellman & Berkowitz (1988), Leinhardt (1977).

[75] Despite uncertainty about the mechanisms involved, or their applicability over many temporal and spatial scales, there is general agreement that over many scales diversity plays an important role in ecosystem health. (See reviews in Loreau (2001), Hector (1999).

[76] See Brown et. al. (2001) for results of recent long-term field work.

failed in the face of Microsoft, IBM and Intel which acted as an effective keystone: Microsoft focused its business model on software platforms, licensed its platform and tools broadly, and distributed innovation to a wide variety of ISVs and other technology and business partners. The sheer diversity of approaches, productivity, and the pace of innovation that Microsoft's keystone approach unleashed could not be matched by Apple's approach. Many other examples of failed attempts to "dominate" a business ecosystem exist in both the computer and other industries – from the failure of all computer technology vendors that failed to open up their stacks in the 1960s and 1970s (Wang is a classic example) to the rise of the open VHS standard over Beta, which was controlled by Sony.

It is important to note that despite their beneficial effects on the ecosystem as a whole, keystones will not be viewed by all members of an ecosystem as being directly beneficial specifically to *them*. This is particularly true in cases where "keystone predators" improve the productivity of their ecosystems by directly removing or limiting the numbers of species that would otherwise reduce productivity.[79]

In addition to keystones and dominators a third kind of species is implicit in the literature's discussion of ecosystem structure: these are "niche" species[80] that are neither

[77] The sea otter's role in controlling sea urchins is a textbook example. See Estes & Palmisano (1974).
[78] Even if they are not directly responsible the inventions behind change.
[79] An example such a "keystone predator" is the sea otter. The reduction in sea otter populations in coastal ecosystems in the Pacific Northwest in the previous century resulted reduction in near-shore productivity of a wide variety of species of fish and other organisms. This collapse of costal ecosystems occurred because sea otters are apparently the only (non-human) predator capable of effectively controlling populations of sea urchins, which, left unchecked, overgraze a variety of invertebrates and plants, including kelp, which in turn supports a food web that is the engine of near-shore productivity. (Estes & Palmisano (1974)) Recent re-introduction of sea otters has in fact resulted in the reestablishment of kelp in the areas affected and led to a parallel increase in productivity in a variety of fish and invertebrate species, and has even reduced costal erosion. (Estes & Blaricom (1988), Estes & Duggins (1995)).
[80] The term 'niche' is used in two parallel senses in the ecological literature, one which focuses on a species' "profession", that is what it does while the other focuses on its "address", that is, where it lives and the set of conditions or environments in which it thrives. Though the former meaning has fallen somewhat out of favor in biological science because it of difficulties in measurement, it is the most useful for is here, where our interest is in the functions performed by firms. In our use of the term there then, we mean primarily *what a firm does* and only secondarily the *unique conditions in which a firm exists*. Specifically, it will not be of much interest, for

dominators nor keystones. Niche species individually do not have such broad-reaching impacts on other species in the ecosystem, but collectively they constitute the bulk of the ecosystem both in terms of total mass as well as variety. They are thus critical to shaping what the ecosystem is. In a sense, keystones shape what an ecosystem does while niche species *are* what it does. In business ecosystems, most firms follow (or should follow) niche strategies. Examples may be NVIDIA and Broadcomm in the chip industry, or Siebel Systems and AutoCad in the Software Applications industry. These firms focus their businesses on areas of narrow expertise by leveraging powerful platforms provided by others. For instance, along with hundreds of other companies, NVIDIA leverages the process technology and manufacturing capabilities provided by TSMC (Taiwan Semiconductor Manufacturing Corporation), and focuses (al least for the moment) on the design of high performance graphics ICs. In this way, the company benefits greatly by being able to focus on the development of critical competencies in a narrowly defined arena, and shares its destiny (along with many other fabless semiconductor design companies) with that of its keystone firm – TSMC. These concepts of keystone, dominator and niche player will form the core of our analysis of the roles played by firms in shaping the health of business ecosystems.

Business Ecosystem Fallacies

Our framework helps to dispel three widespread fallacies about the role of key firms in industries. The first is what one may call the "all peers" fallacy. It is sometimes argued that an industry with many small equivalent players or "peers" fiercely competing

example, for some set of potentially 'livable' conditions for a firm to exist if no firm occupies that "niche" or if the firms occupying that niche do not produce distinct products.

in all domains would be more productive, stable, or innovative because that is the natural way. However, as we discuss below, the reality is that there is very little evidence for this kind of system in nature. Almost all evolved networks of interacting elements (from biochemical pathways[81] to social networks) have their stability and function governed by keystones, hubs, or some form of centralized or shared control. Even “neutral” hubs (such as often occur in social networks or as is the case in the Web) help reduce important measures of complexity, while active keystones (such as keystone herbivores) additionally encourage diversity where it can do the most good in increasing stability and productivity. This fallacy is more often perpetrated more by the popular press than by economists, who are well aware of the limited capacity for innovation and productivity improvements in low-barrier and low-differentiation industries, which end up being characterized by vast numbers of equivalent players such as, for example, lobster fishing. This fallacy is quite widespread however among advocates of “distributed approaches” to problems, though even here there is often an acknowledgement that the “hard part” is in devising globally applied (and therefore centrally disseminated) rules for coordinating the activities of individual components.[82]

A second fallacy is the “dominator” fallacy. The fact that keystones persist over time in the face of what is often significant turnover within the ecosystem, and the fact that they influence, directly or indirectly, the behavior of a majority of the participants in an industry, leads to the mistaken view that they must somehow “dominate” that industry. However, biological keystones are often “small players” by most obvious measures, and

[81] See Figure 7.
[82] See for example, Noah Schactman “A War of Robots, All Chattering on the Western Front,” *The New York Times* (11 July 2002): E5.

have no presence at all in most “niches” in their ecosystem. Their influence is exerted not by size, but by the relationships that make them essential for the overall health of the system. One way of differentiating dominators from keystones is to focus on the ratio of “biomass” to impact. In contrast to dominators, keystones can often exert an impact on the ecosystem that is many times greater than what would be expected from their relative share in biomass. Business keystones, similarly, often have impact that extends far beyond the number of nodes they occupy in their business networks.

The third is the “inhibitor” fallacy. Because keystones sit astride critical pathways in the network of interactions that make up an industry, it is often suggested that they occupy “choke points” that inhibit both innovation and the free flow of information and value through an industry. But a “keystone” that followed this strategy would quickly be displaced. To survive and prosper, a keystone should seek to increase the resilience and diversity of the ecosystem. Thus, firms in an industry and that industry’s keystones both seek to increase the pace of innovation throughout the industry and the obstruction of important flows (of information, value, intellectual property) through any of the critical pathways would be against the keystone’s own interests.

Integration and business ecosystem evolution

Though biological ecosystems share many properties with networks of firms like the computing industry and are a source of potentially powerful metaphors, there are important differences between communities of organisms and communities of firms. In particular, organisms have limited capacity for recombination into new organisms[83], and innovation – an important aspect of business and economic health – is not a focus of either ecosystems or the literature about them.

Here the broader literature on the evolution of complex systems is instructive. Much of this literature focuses on the ways in which networks of loosely interconnected and often independent entities become increasingly interdependent and tightly integrated over time. From the evolution of social insect "superorganisms" from solitary ancestors[84] to the creation of the cellular machinery of animals and plants from once independent bacterial precursors[85], this literature highlights the fact that a process of increasingly tight integration creates a stable core around which new capabilities can be built.

Indeed, many of the novel capabilities often popularly attributed to distributed networks in general are dependent upon the existence of a highly stable and tightly integrated "core" around which the loosely connected network of agents operates. The stunning information gathering and processing capabilities of honey bee colonies, for example, are predicated on the fact that all information is exchanged in tightly confined spaces[86] using a language that is simple and entirely hard wired. Moreover, the mere fact of cooperation at the level required for such free exchange of information is only possible because of the near genetic identity of the apparently independent agents.[87] This is often not appreciated because the individual agents are so conspicuous in their apparently independent behaviors: the entire notion of "independence" in the sense that we

[83] The cases where this, or a similar process has occurred, represent dramatic transformations in evolutionary history (see for example Margulis & Sagan (1995), Wilson (1998), Buss (1987)).
[84] Wilson (1971), See also Wilson (2001) for a general discussion of some of the intermediate stages in this process in various other groups of organisms, and Turner (2000) for an intriguing discussion of how non-biotic components of an organism's environment can participate in this process.
[85] De Duy (1996) and Margulis (1981).

appreciate it is completely absent from almost all natural systems that exhibit "swarm intelligence". The notion of "self" exists only at the level of the centralized *invisible forces* governing the tight integration of the colony unit that are a prerequisite for the more conspicuous distributed networks of *interactions we actually see*.

This is an important obstacle to our appreciation of the importance of integration. We are generally unaware of the fact that a process of progressive integration of once separate components has lead to much of the rich complexity and remarkable capabilities of the natural world. This is largely due to the fact that once distinct components are obscured by their current tight integration so that we often lack even words for describing them as separate entities. The intricately complex machinery of our cells, to cite just one example, is assembled from a huge array of once independent components over a wide range of scales, from free-living bacteria (our present mitochondria)[88] to self-replicating RNA fragments (the likely precursors of important parts of our genetic machinery)[89]. Despite the difficulty in discussing these as separate components, it is instructive to imagine what the world would be like today, specifically what biological systems as a whole would be capable of, if the process of integration had been obstructed at some point in the ancient past. Instead of towering trees that store sunlight in chemical bonds, insects that can build arches and farm fungus or build towering perfectly air-conditioned structures, or brains that can execute landings on the Moon, life would still be a "flat" soup of self-replicating chemical fragments. As a whole then, the evolution literature

[86] Seeley (1996).
[87] Wilson (1998).
[88] I Interestingly for our present discussion; the tight integration of the bacterial precursor to our mitochondria and the rest of our cellular machinery may not have occurred through a process of peaceful symbiosis; the mitochondrial precursor may have been *eaten*. (See Gray, Burger, & Lang (1999) for a review of several possible origins).
[89] Gesteland et. al. (1999)

suggests both that the capacity for creating novel functions is an important measure of system health, and, critically, that the process of integration is an important way of achieving such novelty.[90]

This line of thinking resonates with the literature on technology integration, which highlights the importance of innovation through integration.[91] In networked industrial environments, products are the integration of a vast variety of technologies, components, or processes. This means that innovations most often cannot be identified with a single isolated invention, but are instead the integration of a multitude of different inventions with existing product and process components. Take the commercialization of graphical user interface computing, for example. This was not the result of a single technological development, localized within a single organization, but integrated advances from a large variety of sources ranging from the invention of the "mouse" (which dates back to Douglas Engelbart at SRI in the 1960s)[92] to the Graphic User Interface (which has its roots in a variety of projects at Xerox and also SRI),[93] to a set of critical application programs (developed at Xerox, Apple and other companies),[94] to a broad range of advances in semiconductor component technology (dispersed across the industry). Consistent with the work of Freeman,[95] it took more almost 20 years between the invention of some of the more crucial product components and the broad

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[90] In fact, a recent thinking by some authors (see Margulis & Sagan (2002)) argues that the process of integration may be an important and underappreciated *driver* of biological evolution—at least as important as mutation. This line of thinking has intriguing parallels with our arguments here about the relative importance if integration and innovation in business contexts (see, for example, Iansiti (1995)).

[91] See, for example, Henderson and Clark (1990), Iansiti (1998), Christensen (1997).

[92] See SRI International. "The Beginning of the Global Computer Revolution," SRI Timeline web page <http://www.sri.com/technology/mouse.html> (2002).

[93] See Xerox PARC. "PARC's Legacy," Xerox PARC web page <http://www.parc.xerox.com/history.html>.

[94] See Apple Corporation. "Apple History," web page <http://www.apple-history.com/history.html> and "PARC's Legacy".

[95] See note 97.

commercialization of the first products, such as the Xerox Star, the Apple Macintosh and the Windows operating system, and their associated impact on society.

The process of technology integration therefore provides a critical engine of business evolution, as the products and technological components provided by ecosystem participants are recombined to create constantly improving product and service offerings. The process is critical to both to keystone organizations, which must constantly integrate the latest technological developments into the platforms they provide, and to the niche players, which integrate components provided by the keystones and by other technology providers into their own offerings. When Microsoft made the decision to componentize Internet Explorer 3.0 in 1996 (its first internally developed internet browser), the decision was essential to maintain consistency with its traditional keystone strategy. In this way, Microsoft ISVs like Intuit Corporation or Autocad could leverage IE 3.0 components to web-enable their individual applications, and rapidly turn the diffusion of the World Wide Web from a threat to a business opportunity.

Measures of Ecosystem Health

In what follows we will switch focus to the implications of our framework for innovation and operations strategy. We will use the ecosystem as a metaphor, and borrow heavily from the broader literature on the evolution of complex systems to assess the ecosystem that a firm finds itself in, develop measures of its health, and construct a framework for assessing different strategies that firms can adopt.

A direct implication of our framework is that the performance of a firm is a function not only of its own capabilities, or of its static position with respect to its competitors, customer, partners, and suppliers, but of its dynamic interactions with the ecosystem as a whole. Our approach therefore directly tackles the collective impact of network interactions of ecosystem participants on the operating performance of the firm. At the lowest level, we can translate this line of argument into the fundamental question of ecosystem health.

What makes a healthy business ecosystem? It is important to appreciate the novelty of this question. We are not assuming anything about given metrics of economic-theoretical "health" such as number of firms or abstractions like "competition" or "consumer choice" but instead are asking a different question: how can we asses the health of an entire business ecosystem of firms, products, and consumers? What we seek are measures of the extent to which an ecosystem as a whole is *durably growing opportunities for its members and for those who depend on it*. It is not sufficient that an ecosystem provide choice, if the choices are not meaningfully different, nor is it acceptable that an ecosystem generate or supply novelty, if the entire ecosystem vanishes or collapses at the first disruptive change in the environment. To asses the health of business ecosystems in the sense we seek to capture, we propose three aspects of the ecosystem health, inspired by our biological metaphor and expressed in terms of our ecosystem analogy: robustness, productivity, and niche creation.

Robustness

Existing frameworks for the analysis of the impact of technological innovation[96] are generally shaped by a view[97] that sees technological change advancing in discontinuous waves through industries as organizational response is impaired by inertia. But ecosystems governed by these idealized dynamics are not healthy in the sense we seek here. In order to provide durable benefits to those who depend on it, a biological ecosystem must persist in the face of environmental changes. Similarly, a business ecosystem must be capable of facing and surviving perturbations and disruptions.

Part of the problem is that technological innovation literature often focuses on the firm's reaction to novelty as an exogenous threat that leads to catastrophic change.[98] In this way, it fails to capture the ways in which firms can influence the changes, offer solutions to multiple ecosystem participants, or buffer themselves through connections with their business partners and competitors.[99] It emphasizes internal capabilities, rather than the integration of these capabilities with external network relationships.[100] While catastrophic change is indeed an important part of evolutionary and business history, it is

[96] See Dewar and Dutton (1986), Christensen (1997), Henderson and Clark (1990) and Tushman and Anderson (1986).
[97] See, for example, the population ecology work of Hannan and Freeman (1977).
[98] Arguably this view of the frequent displacement of incumbent firms grows out of a misreading of evolutionary theory; a view in which destruction and turn-over is emphasized at the expense of persistence and adaptation and the creation of novelty from existing raw materials.
[99]See Pachepsky, Taylor, & Jones (2002) for an example of an ecologically inspired model that highlights the importance of the stability-enhancing buffering effect of the exchange of inputs and outputs between network members. This model could easily be adapted to business ecosystems.

far from the rule, because natural and business systems exhibit precisely this sort of integrative buffering. The kind of ecosystem health we hope to capture here seeks emphasize robustness in the face of precisely the kinds of disruptions that are generally considered destructive in these "evolutionary" models of progress.

Measures of robustness[101] should first of all examine survival rates in a given ecosystem. In its most basic form, a healthy ecosystem will promote the survival of a diverse set of firms, populating a variety of niches, and managing through the variety of inevitable disruptions. Survival rates are only the most basic indicators, however, and more sophisticated analyses should focus on a variety of types of metrics:

> *Survival rates:* Ecosystem participants enjoy high survival rates, either over time, or relative to other, comparable ecosystems.
>
> *Persistence of ecosystem structure:* Changes in the relationships among ecosystem members are contained; overall the structure of the ecosystem is unaffected by external shocks. Most connections between firms or between technologies remain.
>
> *Predictability:* Change in ecosystem structure is not only contained, it is predictably localized. The locus of change to ecosystem structure will differ for different shocks, but a predictable "core" will generally remain unaffected.
>
> *Limited obsolescence:* There is no dramatic abandonment of "obsolete" capacity in response to a perturbation. Most of the installed base or investment in technology or components finds continued use after dramatic changes in the ecosystems environment.
>
> *Continuity of use experience and use cases:* The experience of consumers of an ecosystem's products will gradually evolve in response to the introduction of new technologies rather than being radically transformed. Existing capabilities and tools will be leveraged to perform new operations enabled by new technologies.[102]

Not all of these measures will apply or be available in every circumstance, but as a collection they should provide an effective set of tools for assessing robustness. As

[100] See Iansiti (1997) and Eisenhardt & Sull (2001).
[101] Extensive discussions of robustness and its implications for many fields, along with a review of various definitions for the term can be found online at the Santa Fe Institute's robustness website (<http://discuss.santafe.edu/robustness/>).
[102] Interestingly, this continuity may lead to an under-appreciation of the extent to which an ecosystem is responding constructively to potentially threatening innovations. The assimilation of digital photography as a core part of both Windows and the Macintosh platforms over the last few years has occurred with little remark, partly because of the continuity with which it has been achieved. This contrasts with more noticeable failures to achieve similar integration, such as the incorporation of Memory Stick slots into most recent Sony televisions.

highlighted above, such an analysis should not necessarily be centered on whole industries characterized by firms competing in similar markets, but more generally on networks of firms that share common nodes. For example it may be interesting to compare the robustness of the Windows, Java, and Open Source parts of the computing ecosystem, and assess the role played by the different keystone organizations.

As established in our discussion of the literature on networks, there is strong general evidence that networks with certain structural features – notably the presence of hubs – are more likely to exhibit the persistence of structure and predictability in the sense defined here. In a networked structure, the hubs will effectively leverage the network to mount responses to new, uncertain conditions – new product components or new service characteristics can be provided to a customer by leveraging the capabilities of other network participants, as long as enough diversity is present. As a result, the presence of a stable hub and a diverse community of interconnected entities will be a strong indicator of ecosystem robustness.

Productivity

It is not enough that an ecosystem survive and exhibit a stable structure: ecosystem members must benefit from their connection with the ecosystem. In conservation literature on biological ecosystems, the term "productivity" is a widely used measure of ecosystem health and of its benefits to those who use it: how effectively does the ecosystem convert raw materials into living organisms. This approach is a very good analog to total factor productivity analysis used routinely in economics, but applied to different ecosystems or ecosystem areas. However, in biological ecosystems the set of inputs do not change significantly over time. The business ecosystems we are interested in are strikingly different: they are constantly subject to new conditions, in the form of new technologies, new processes, and new demands. By analogy then, measures of productivity should also capture the effectiveness of an ecosystem in converting the raw materials of innovation into lowered costs and new products and functions. This suggests at least three types of productivity-related metrics:

> *Total factor productivity:* Leveraging techniques used in traditional economic productivity analysis, ecosystems may be compared by the productivity of their participants in converting factors of production into useful work.
>
> *Productivity improvement over time*: Do the members of the ecosystem and those who use its products show increases in productivity measures over time? Are they able to produce the same products or complete the same tasks at progressively lower cost?
>
> *Delivery of innovations*: Does the ecosystem effectively deliver new technologies, processes, or ideas to its members? Does it lower the costs of employing these novelties, as compared with adopting them directly, and propagate access to them widely throughout the ecosystem in ways that improve the classical productivity of ecosystem members?

The last measure is an important one, because it encourages us to follow specific novelties as they are developed and delivered through the ecosystem, and then to asses the costs and benefits of employing them, but the first measure can serve as a convenient proxy: it allows us to at least demonstrate that innovations are having a real collective effect on ecosystem members in cases where we are unable to examine individual innovations.[103] Note also that we require that productivity improvements be sustained: it is not sufficient that an ecosystem provide one-time improvements to those who join it.

[103] The first measure serves an additional important function. A healthy ecosystem should be capable of improving productivity in the *absence* of any changes in environment: the structure or the ecosystem and the interactions among its members alone should have this effect.

Niche creation

Robustness and productivity do not completely capture the character of a healthy biological ecosystem; both in the ecological literature and in popular conception, it is also important that these systems exhibit variety or diversity—that they support many different species. But while diversity is often considered a positive attribute of these ecosystems, it is by no means an absolute good; some highly productive and valuable ecosystems are, for example, not diverse.[104,105] Moreover, as has already been mentioned, there are many business ecosystems that are characterized by considerable diversity, but which are stagnant or in decline. Furthermore, like evolved complex systems such as social insect colonies, business ecosystems have the capacity to create entirely novel capabilities through integration and innovation.

For all of these reasons, diversity alone does not does not map directly to a positive health measure for business ecosystems. What matters in these systems is more the capacity to increase meaningful diversity over time through the creation of new valuable functions. In terms of the ecosystem metaphor: the capacity to create new valuable niches. We can thus begin to asses this dimension of ecosystem health with two related measures:[106]

> *Variety*: The number of new options, technological building blocks, categories, products, and/or businesses being created within the ecosystem in a given period of time.
>
> *Value creation*: The overall value of new options created.

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[104] The case of figs (see Nason (1998)) is again instructive: one might argue that a greater diversity of fruit sources, in place of figs might enhance the stability of the ecosystem. But diversity alone is not sufficient. Unless these sources also provided all of the platform benefits on which the ecosystem relies – complex fruiting patterns and specific sets of nutrients – increasing diversity at this level could actually destabilize the ecosystem by undermining the predictability of its foundations and leading to a loss of diversity at all other levels.

[105] Artificial agricultural "ecosystems" are an example. See Huston (2000) for a critique of the view that diversity and productivity show any consistent relationship.

[106] Baldwin and Clark (1999) focus on the relationship between available technological options and value in great detail.

Note that these metrics are connected to our productivity measures, particularly to the delivery of innovations: one way of delivering innovations is through the creation of new businesses. Thus, a fairly direct way of measuring niche creation will be to determine the extent to which new technologies are appearing in the form of a variety of new businesses and products.

It is important to note that because it is not just any diversity that matters, but diversity that creates real value, it is essential that the new categories of business be meaningfully new; that they provide new functionality, enable new scenarios, or expose new technology or ideas.[107] One way of exploring this important aspect of ecosystem health is to examine the relationship between diversity and consumer experience: does the variety of firms and their products map to a variety of consumer experience and to convenience and effectiveness in achieving those experiences or building downstream products?

It is also critically important to appreciate that although healthy ecosystems should exhibit net creation of niches over time, it does not follow that old niches need persist: diversity of niches may actually decrease in some areas. In fact, as we shall explore in some detail when we examine the computing ecosystem, it may be the case that decreases in diversity in some areas enables the creation of niches in others.[108] This is consistent with the process through which new system-level capabilities arise in

[107] Baldwin and Clark *op. cit.* provide an interesting classification of different "modular operators" which carve out products to provide new technological configurations

[108] This view requires a change in perspective that may not come easily: eliminating diversity so that integration can occur as a precursor to and enabler of "downstream" diversity. But this is not an entirely new phenomenon. By the 1850's, observers of the evolution of railways became keenly aware of the extent to which the huge diversity of local railway lines and railway companies represented an obstacle to the development of new capabilities, such as long distance or express travel. Interestingly for our present discussion of ecosystem health, to these observers it was also clear that railways (from rails, to wheels, to engine, and from coach to station and schedule) were in effect "like a vast machine" whose *stability* was threatened with "self destruction" if it continued to be "worked by a number of independent agents". (See Schivelbusch (1977))

biological evolution: diversity at one-level is reduced to create a "platform" that enables greater and more meaningful diversity at higher levels.[109,110]

Taken together these measures define what we mean by a healthy business ecosystem that is "durably growing opportunities for its members and for those who depend on it". They represent relatively clear, measurable metrics that can be applied to the direct comparison of different ecosystems and ecosystem areas.[111] (See Appendix C for an elaboration of these health measures as applied to Microsoft's effect on the computing ecosystem.)

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[109] See note 104.

[110] The example of television technology is illuminating: here, the effective lack of any platform for recent technologies means that *consumers* must in effect perform the *integration* process *themselves*. In order to implement a simple decision such as viewing HDTV or even watching DVDs at their full potential resolution, for example, consumers must assemble all the right components and connectors—learning a myriad of different names and acronyms, and mastering confusing branding of technologies. The cry for "one box that does it all" has been made more than once! Indeed, it is likely that a significant battle over just this terrain is likely in the next several years, notably between Sony and Microsoft.

[111] It is important to note however that these features by no means define network health in any general sense. There are a wide variety of networks designed to achieve a wide variety of goals, and these goals that may be quite different from those of productive, stable, and creative business networks. One need only think of the dramatic counter example of terrorist networks like al-Qaida (see Krebs (2002)). Such networks are neither interested in creativity nor productivity, but are focused primarily in survivability and invisibility. Moreover, while survivability superficially a kind of "robustness" it is precisely the opposite of the kind we believe is important for business networks: terror networks are most concerned with being invulnerable to targeted malicious attacks, and so avoid the presence of hubs altogether. Such networks would have a very different set of network health measures.

Innovation and Operations Strategy in a Business Ecosystem

Traditional work on Operations and Innovation Strategy defines a set of factors that should influence the pattern of decisions made by an organization. This pattern of decisions should be consistent with the overall strategy and positioning decisions made by an organization.[112] In a networked setting, these decisions should also be influenced by the structure and dynamics of the ecosystem that the firm finds itself in, and be consistent with the role that it decides to play.

Our review of the ecosystem literature identified three roles that can be played by species in biological ecosystems in the way they influence ecosystem health and evolution: niche player, dominator, and keystone. All of these have their place in shaping the health of the ecosystem and provide a useful framework for analyzing the pattern of decisions made by firms in business networks.

Keystone strategies

Keystones are the obvious regulators of ecosystem health. They are richly connected hubs that provide the foundation for creating many niches, regulate connections among ecosystem members and work to increase diversity and productivity. They provide a stable and predictable platform on which other ecosystem members can depend, and their removal leads to often catastrophic collapse of the entire system. They ensure their own survival and health by directly acting to improve the health of the ecosystem as a whole.

[112] Porter (1985), Gemawat (1991), Hayes, Wheelwright and Clark (1988), Rosenbloom (1989).

Examples of effective keystone strategies can be found in a variety of business environments. In the software industry, several organizations have provided critical platform technology that has fueled a tremendous amount of third party innovation. The most successful example is possibly Microsoft Corporation. Since the earliest days of the microcomputer industry, its programming tools and technology platforms have fueled innovation by thousands of other organizations. Since the early 1980s, Microsoft's operating systems have enabled a community of independent software vendors to write personal computer applications by leveraging standard Application Programming Interfaces (APIs) without having to worry about machine specific details such as device drivers. Microsoft's keystone strategy over the past 20 years has been defined by a combination of operating systems (e.g., DOS and Windows), re-usable programming component models (such as OLE, COM, Visual Forms, etc.) as well as tools and integrated development environments (e.g., Visual Basic, Visual Basic for Applications, and Visual Studio). The operating system provided the hub through which a vast variety of application providers (the ISV community) could connect to a vast variety to technology providers (the PC and device vendors) without each having to master the specific characteristics of each individual interaction.

Microsoft worked hard to enhance the health of the computing ecosystem. Microsoft promoted ecosystem productivity by constantly improving its tools and focusing massive resources on nurturing its community of developers and technology partners. (See figure 5 for some examples of Microsoft's keystone strategy in action.) Furthermore it enhanced ecosystem robustness by rapidly incorporating technological changes (e.g. visual computing, Internet browsing, Web services) into its platforms, and by encouraging the formation of a diversity of technology suppliers and application providers. Finally, it encouraged niche creation by designing its platforms to be extendable in a variety of new domains (e.g., media or peer to peer communication), and by investing to promote R&D and basic infrastructure that could be leveraged by new niche players (e.g. broadband infrastructure).

Microsoft's keystone strategy is not unique. Other firms have played similar roles in very different industries. TSMC is a notable example from the semiconductor industry. Here, again, the combination includes a critical hub that separates software and hardware, reusable technological components, and tools. TSMC has exerted an enormous impact on the rapidly evolving "IP industry" (the community of integrated circuit designers) by offering a comprehensive manufacturing platform that largely avoids the need by designers to worry about complex manufacturing (the "hardware") and optimize their designs (the "software") to the characteristics of a plethora of semiconductor process equipment vendors. Moreover, TSMC offers the industry a comprehensive component library which is optimized to run best on its own process (at no charge, like Microsoft offering COM technology or Visual Forms). Finally, TSMC works with semiconductor design tool companies to offer the industry tools to further optimize their designs to run on TSMC processes.

Keystone examples are not limited to traditional technology industries. Here Wal-Mart serves as a striking example. Early in its history, Wal-Mart introduced "Retail Link" a system that delivers real time sales information to its supplier network. Wal-Mart was unique in retail space to offer this kind of service. In many ways, Retail Link played a role that was analogous to that of Microsoft's programming platforms. Retail

Link became a supply chain hub that connected the systems of manufacturers like Tyson Foods or Proctor and Gamble to the retail channel, without having these providers connect to each individual store. Moreover, through the software and hardware it disseminated, Wal-Mart provided the tools and technological components that enabled its vast number of supply chain network partners to make Retail Link an integral element in their respective supply chains. To this day, Wal-Mart remains the only source of real time retail data for a large community of suppliers. By providing this data, as well as through other contributions, such as centralization of its supply-chain structure, numerous operational efficiency improvements, and cost reductions achieved through aggressive use of suppliers throughout the developing world, Wal-Mart effectively provides a low-cost, high efficiency and information-rich platform for the sale and distribution of retail products. This essential keystone role played by Wal-Mart goes a long way to explaining its position as industry leader. (See Appendix A for a detailed discussion of Wal-Mart's keystone strategy.)

In summary, keystone strategies provide a critical service to an ecosystem by promoting its health by increasing its productivity, robustness and niche creation capabilities. They appear to be founded on three technological foundations: hubs, components and tools. They enhance productivity by simplifying the complex task of connecting network participants to each other, and by making the creation of new products by third parties more efficient. Furthermore, they increase network robustness by consistently investing in and integrating new technological innovations, and by providing a reliable reference point and interface structure for other ecosystem participants. Finally, they encourage niche creation by offering the innovative technologies to a variety of third party organizations and investing in new fundamental infrastructure.

Dominator strategies

As with keystones, dominator firms occupy critical hubs in their ecosystem. However, unlike keystones, dominators progressively take over their ecosystem. They start by eliminating all other species in their closest niche and gradually move on to other niches. The analog in business ecosystems is clear: these are firms that eliminate all other firms in their market, often expanding into new markets which they subsequently dominate or even eliminate. Dominators typically damage the health of their ecosystems by reducing diversity, eliminating competition, limiting consumer choices and stifling innovation.

Business history is filled with dominator firms. Examples range from the early days of AT&T to the more recent history of IBM and Digital in the mainframe and minicomputer markets. In each of these examples, the firms provided the comprehensive set of products and services that was necessary for an end customer to perform its tasks, and left no space for other organizations to leverage their services and enhance them by providing additional functions. In the early 1960s, IBM produced every technological component that went into its mainframes, and provided virtually every service that the customer needed to leverage the most out of the products it bought, from the creation of memory components to custom software applications, and from installation services, to financing. Similarly Digital leveraged internal components and services for its line of minicomputers.

To preserve their futures, dominators must invest in internal R&D, to make sure that substitutes cannot be created that offer its customers better price/functionality characteristics. To a dominator, technological innovation is an internal necessity, a hedge against potential competitors. Thus, Bell Laboratories and IBM T.J. Watson Research were created for the explicit task of making sure that their parent companies could never be blindsided by a competitor that offered superior technologies.

Over time, a dominator will reduce the diversity of organizations that populate its ecosystems, and reduce its robustness to external shocks. This means that it is quite likely that over time the entire ecosystem occupied by the dominator will be threatened by neighboring ecosystems that offer substitute functionality. And if these competitive ecosystems are characterized by a healthier structure, including one or more effective keystones, the dominated ecosystem will likely be replaced. Such was the fate of both the mainframe and minicomputer ecosystems when the PC ecosystems started to provide comparable performance. The dominated ecosystems, each largely driven by the efforts of a single firm, simply could not compete with the combined efforts of the thousands of organizations linked by the PC platform.

Clearly, our approach in this work suggests that keystone strategies are preferable to dominator strategies, since they encourage long term innovation and niche creation for the ecosystem, and appear to be a more effective and sustainable way for leading organizations to do business. Dominator firms may produce extraordinary returns in the short and medium term, but will eventually lead to ecosystem collapse, massive dislocation, and the creation of a substitute keystone structure.

Interestingly, many of the classic examples of incumbent failure captured by leading authors (minicomputers, mainframes, glass making, automobiles, disk drives, etc.) can be related to the ineffective behavior of dominant firms.[113] In the case of both minicomputers and mainframes, for example, we see ecosystems that are dominated by players (IBM and DEC) that did not open up their platforms to third party organizations. They leveraged proprietary hardware (such as IBM's SLT technology in the 1960s, or DEC's Alpha Chip in the early 1990s) and proprietary software (such as IBM's MVS and DEC's VMS operating system). Despite many predictions to the contrary, neither ecosystem threatened the other (since their rate of innovation was comparable). But when a different type of ecosystem structure began to encroach into their territory (the personal computer, with its vastly more productive and innovative keystone structure) both minicomputer and mainframe ecosystems collapsed – virtually simultaneously.

This contrast between dominators and keystones suggests one particularly clean way of distinguishing between the two. Both strategies potentially increase the number of niches "occupied" by a firm over time, but with a critical difference: When a keystone firm takes actions that increase the number of niches that it "occupies", it also, as a consequence, increases the *total* number of niches in the ecosystem, resulting in a relative decline in the fraction of niches is occupies. Dominators, on the other hand, grow their presence at the expense of the ecosystem as a whole.

[113] See, for example, Henderson and Clark (1990), Christensen (1997), Tushman and Anderson (1986).

Niche strategies

We define a niche player as an organization that exhibits typical (or less than typical) levels of connectivity with other ecosystem participants.[114] Niche players would at first glance appear to be the least influential members of an ecosystem; but this is not always the case. In addition to their being the most numerous members of the ecosystem, many of them are also located at the "fringes" of the network, where new innovations are actively being pursued and where new products and services are being developed and new markets explored. These "edge firms" are critical to the health of the ecosystem because they are the locus of precisely the kind of meaningful diversity that we seek to capture with our niche creation measures.

Examples of effective niche players are numerous and range across a variety of industries. We have mentioned NVIDIA (discussed in more detail in Appendix B) in the semiconductor design domain and Quicken in software applications. NVIDIA and Quicken are well established players, and occupy well defined segments in their industries – graphics accelerators and personal accounting software. Examples of "edge" firms (niche players that are currently opening up new ecosystem niches) may be Groove Networks and Mobilian, the first in peer to peer applications, while the second in wireless connectivity solutions.

The fundamental advantage of a niche player is focus. Niche players focus by leveraging the services provided by the keystones in their ecosystem, and by concentrating on the acquisition of business and technical capabilities that directly

[114] Naturally, a great of precision can be added to the word "typical". One could assume a certain distribution of connectivity for certain classes of networks, and define a precise level below which organizations are defined as edge players. For the purpose of the current discussion, the more casual definition will suffice.

support their niche strategy. It would be madness for Quicken to squander its resources on the technical details of disk compression or TCP/IP stack implementations (which are Microsoft's concern), or for Mobilian to invest its precious cash in the creation of manufacturing facilities (as TSMC does). Their advantage instead resides in their ability to build and nurture capabilities that are unique to their niche. And as long as the uniqueness of their niche remains, this strategy will succeed and their niche will continue to be distinct and profitable.

The first step in defining a good niche strategy is therefore to analyze the firm's ecosystem and map out the characteristics of its keystone players. Do strong keystones exist? Are there multiple keystones that compete to play the same role? How many keystones should the firm tie into? Niche strategies must therefore tradeoff risk with productivity – ideally, if a good keystone is present in the niche player's ecosystem, there may be no apparent reason for it to connect to multiple keystones. Great economies can be found by focusing resources on a single platform. However, because of the risk of possible keystone collapse and keystone holdup, niche players may want to diversify and invest in connecting with multiple hubs.

The second key step in defining a niche strategy is selecting an ecosystem niche that is truly different, and whose differences will sustain over time. A classic mistake made by a variety of new ventures during the venture capital boom of the late 1990s, was selecting niches that had no sustainable staying power – examples would be web calendars and web-based invitation services (e.g., evite.com and mambo.com). Over time, it was inevitable that these new niches would merge with existing ones. The services are now broadly offered, but the firms that started developing them have ceased to exist as independent entities. In those cases in which the skills and capabilities that characterized new ecosystem niches were distinct enough to justify a focused strategy (take personal financial accounting or customer relationship management software), these strategies have endured for many years, and enabled the growth of large and successful firms (such as Siebel Systems and Intuit). It is also important to point out here that a well executed niche strategy, because of its focus, will exhibit strong defenses against a keystone and dominator trying to expand. Quicken is again a strong example here, with its continued success against Microsoft Money.

Critical to a niche firm's success is that it leverage the tools, technologies, and standards provided by the keystone. NVIDIA, for example, makes extensive use of libraries of chip designs produced by Artisan and made available in optimized form by TSMC. Moreover, it relies on standards and standard testing processes implemented by TSMC, Microsoft's Direct3D API, and SGI's OpenGL API, and outsources the fabrication of all of its graphics processing units to TSMC. This allows NVIDIA to stay focused on the places where it directly adds value. (See Appendix B.) The crucial keystone leveraged by NVIDIA is TSMC, which supplies "libraries" for standard chip functions, which NVIDIA can access in the process of its own chip design as seamless part of its own operations: As Morris Chang, founder and Chairman of TSMC says, "The emphasis is for the customer to access the information they need without any human intervention. We have a library of technologies available for them and they should be able to find out 90% of our technologies without any human assistance." This integration of access to platform libraries and components into NVIDIA's process allows NVIDIA to focus on its core business of chip architecture and packaging; conversely, "[t]he fact that

[TSMC does not] do any design and [does not] compete with any of [its] customers is a big advantage”, because it means they can be an “honest broker on intellectual property”. TSMC also provides free initial access to many of the library components it brokers, relying on royalties later, which is can be of critical importance for firms like NVIDA where cash flow is an issue. Fabrication of NVIDIA’s chips is also tightly integrated with TSMC. Although NVIDIA is entirely “fabless”, relying exclusively on TSMC’s facilities, the firm is able to manage the process almost as if it were occurring in its own facilities: “We get daily feeds on where every single wafer is in the process,” raves NVIDIA CEO Huang Jen-Hsun, and can even can make late engineering changes or cancel an order at the last minute without unreasonable penalties.

A classic niche firm in the software industry is IDe, which leverages Microsoft’s platform (relying greatly on technologies like Active Server Pages, ActiveX, COM, and ADO) to build its products. Because IDe can rely on Microsoft to provide stable and evolving tools and components, IDe is able to stay completely focused on building Internet-based development chain management (DCM) solutions. Moreover, by integrating its products into Microsoft Project and Microsoft Excel, IDe in effect, allows users to leverage these applications in their own deployments of IDe’s products.

IDe is also typical of a firm pursuing a niche strategy in that it effectively takes the platform provided by a keystone for granted, as a kind of foundation upon which all else relies. Not only do Microsoft’s technologies free IDe from worrying about all kinds of details that have little or nothing to do with its focus on DCM,[115] but because tools like Visual Studio “hide a lot of things that it intimately integrates,” developers are able to focus on the correct "level of abstraction" in their work, which, among other things, greatly facilitates IDe's ability to rapidly "throw things in front of customers and ask for feedback" which is "critical for IDe's business effectiveness." One indicator of the extent to which niche players rely on the efficiencies they achieve through effective leveraging of keystone platforms is CTO Ralf Brown's response to a hypothetical scenario in which his firm is forced to stop using Microsoft's platform (even if it only means switching to another one): "It would be the end of the world."

To the extent that niche players focus their own activities narrowly on a specific domain, while using existing solutions for everything else, they improve their own productivity and efficiency. This has important implications for product architecture: niche firms need to view their products not as standalone entities designed from the ground up, but as "extensions" of an interconnected network of elements in which conventional product boundaries may not be distinct or clear. This presents considerable challenges as firms must balance the need to distinguish and brand their products with the ecosystem forces that demand a kind of "anonymity" or granularity that may not easily map to clear product identity. But this has positive implications for overall ecosystem health: niche firms are driven to distinguish themselves not through artificial or superficial attributes, but through the core contribution of their products to other members of the ecosystem. As a result, one would expect to find that many successful firms in healthy business ecosystems are "cryptic": they have pervasive and important impact on the ecosystem though they are not consciously branded or directly visible to many ecosystem members.

[115] Examples cited by Ralf Brown CTO, importantly, include things like "threading models" that other platforms, such as IBM's

Finally, niche players may find that over time they come into conflict with keystones. Niche players that do not or cannot actively advance and evolve their products towards the edges of the ecosystem[116] may find that the frontier of the advancing platform eventually approaches the niche they occupy.[117] Such firms face a crucial decision between dealing with the keystone in ways that promote the incorporation of their products into the platform, or resisting this process. Recognizing when this decision needs to be made, and choosing the correct path are important elements of a niche firm's strategy that have important implications for ecosystem health.[118]

Interestingly, firms that are niche players in one context can become keystones in another. Here again, NVIDIA serves as an example. (See Appendix B for details.) By following a successful and focused niche strategy, NVIDA built a firm foundation for the next step: the transformation of its niche into an ecosystem in its own right, with NVIDA as its keystone. For effective niche players, this is not an unexpected evolution. If a niche has the potential to grow and serve many functions, the deep expertise and focus that defines an effective niche strategy has the potential to translate directly into a

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WebSphere do not "hide" effectively.

[116] This highlights an important corollary of the role of keystones in driving the continued expansion of the platform: this process also drives all firms in the ecosystem "outward" towards new functionality and new niches at the edge of the ecosystem. Many firms that fail to (or choose not to) follow this path in domains that are not durable as distinct segments may find themselves in a high-risk (but also potentially high stakes) game for which they may be unprepared.

[117] This situation can also arise when a firm simply stakes out a niche that is "too close" to the frontier of the platform. Netscape and Real are arguably examples of firms that, famously, have "set up shop" too close to the advancing frontier of the Microsoft platform.

[118] Vermeer Technologies, the source of Microsoft's FrontPage technology, is an example of a firm that choose to use its "platform frontier" position effectively in striking a lucrative deal with Microsoft that contributed to overall ecosystem health and ensured the continued survival of the firm's products and technologies (in much the same way that a single bacterial cell, by being absorbed into the "eukaryotic platform", ensured its position as the ancestor of every mitochondrion on Earth). It is worth noting that in following this path, firms must resist the desire to preserve a clear identity for themselves: this creates an important dynamic in growing ecosystems that pits inertial forces of firm identity against the free flow of components among products, most notably into the platform.

keystone strategy,[119] as focus on the subtleties of what matters in a domain translate into an appreciation of what is possible in that domain.

While NVIDIA acts as a niche firm with regard to its use of manufacturing facilities and chip libraries, it in turn provides a platform for manufactures of a wide variety of devices, from PCs to game consoles. NVIDIA's core graphics processing units (GPUs), provide manufacturers of these devices with graphics capabilities significantly beyond that available through the basic graphics functionality embedded in central processing units. In addition to these components, which provide computers with the ability to run applications (games, simulations, visualizations, etc.) which would not otherwise be possible, NVIDIA also provides extensive support to manufactures in the form a variety of tools, educational resources, initiatives, and services that enhance the effectiveness of these firms in deploying NVIDIA products in their own.

NVIDIA's chips and add-in boards are well known and much publicized, indeed a little known fact that highlights the importance of NVIDIA's products as components of others that leverage them is that, according to Forbes estimates, Microsoft pays about $30 for each of Intel's Pentium III chips it uses in its Xbox, compared with about $55 for NVIDIA's chips. Just as do other keystones, like Wal-Mart or Microsoft, NVIDIA enhances the utility of these platform components through a constellation of complementary supporting activities. Notable among these efforts are its Select Builder Program (which provides marketing, sales, and technical support) and its developer tools efforts. The latter include workshops and training that ensure that firms that leverage the NVIDIA platform are able to quickly and efficiently learn the skills and techniques

[119] It is possible to see Microsoft as having undergone precisely this evolution: from a niche player in software development tools,

necessary to make optimal use of the platform's capabilities, as well as the introduction of, Cg, a high-level C-like language and complete suite of supporting tools that, in the quintessential keystone language of NVIDIA's CEO "will dramatically increase the speed at which increasingly sophisticated and exciting graphics features are adopted." "Cg will do for GPUs" he boasts "what C and C++ did for CPUs."

Firms like NVIDIA play a crucial role in structuring the complexity of an ecosystem in ways that make it accessible and manageable. In effect, they represent rungs in a ladder of complexity building that magnify the power of platform leveraging: hardware manufactures that build on the "NVIDIA platform" are not just leveraging NVIDIA's products; they are also leveraging those of TSMC. This "serial leveraging" that is enabled by firms like NVIDIA that are both niche players (focused experts in a domain) and keystones (platform providers) is a critical source of the productivity and rapid advance in capabilities of the computing ecosystem.

leveraging the hardware on which they ran, to a keystone in the software platform domain.

Implications for Policy and Practice

Clearly, this paper merely scratches the surface with regards to the dynamics of networked industries. Our analysis possibly opens more questions than it answers. We plan to pursue these and other questions in future research and it is our hope that this framework will also serve to promote similar work by others. Despite the early stages of this work, however, several important implications already become apparent.

Implications for practice

The dynamics of business networks have important operational implications for business practitioners. By recognizing their position within the ecosystem – niche player, dominator, or keystone – and pursing strategies appropriate to their role, firms can set realistic expectations for themselves and their investors. By understanding how innovations propagate through the network of firms in an ecosystem, innovative firms can better target their relationships. By understanding the dynamics of integration and niche formation, product architects can craft their designs in anticipation of how these will fit into the ecosystem as a whole. Perhaps most importantly, all ecosystem members can better understand their operational challenges, and respond to and synergize with the collective behavior of their ecosystems.

In essence, these implications are important because mastering the complex distributed dynamics of a business ecosystem requires the development of capabilities that are quite different from those that are necessary for competing in a more traditional environment. The differences are both structural (e.g., influencing basic brick and mortar strategies with regards to the development of infrastructure, facility strategy, capacity planning, etc.) and infrastructural (influencing the development of “software” assets such as intellectual property and human resources).

For starters, operating in a networked environment requires mastery in leveraging assets that are external to the firm. This immediately puts an enormous premium on the capability for technology integration over traditional internal R&D. No single firm, in a distributed business ecosystem, will ever have the range of capabilities to cover all possible technologies, to develop all options internally. This means that not only niche players but also keystone firms will need to focus on the integration of external technological opportunities as a key capability. A healthy ecosystem will form a market for innovative technological components, and each firm will need to learn how to play this market and leverage components in its internal offerings. Niche players will need to master how to integrate technologies into its focused offerings, keeping its product lines fresh and attractive to their customers. Keystones will need to constantly monitor the ecosystem for new technological components, and integrate them into their platform as needed. In this way they will promote even greater innovation by facilitating the integration of technological components by third party developers.

Dominator players are put at a tremendous disadvantage by these dynamics. Their rate of innovation will not match that of other keystone-niche player combinations. Despite continued investment in internal R&D, and despite potential advantages offered by their ability to integrate product components more tightly, our theory predicts that they will eventually be overtaken and displaced.

Perhaps the most critical managerial implication of our framework is that the destiny of different ecosystem participants is inextricably intertwined. An ecosystem hub will benefit by the health, productivity and innovation of its neighbors and be hurt by their fragility and stagnation. The ecological analogy is therefore powerful. Central firms should commit to a strategy that fosters broad ecosystem health and stay away from dominating behavior.

The recent .com and telecom implosions appear to provide clear illustrations of how quickly and decisively these reinforcing dynamics may act to engender the collapse of unhealthy ecosystems. Early hubs in the internet services ecosystem like Yahoo! and AOL acted quickly to leverage their power in steering network traffic to network partners. But unlike Microsoft and TSMC they did not liberally provide open APIs and inexpensive (or even free) tools and technological components that enabled a massive network of organizations to share in the opportunities provided by the ecosystem. The toughness of the traffic sharing agreements (and the many of millions of dollars that were demanded) that ensued significantly damaged the business model of a broad variety of .com firms. Some of these firms may have had poor business models to begin with – but even the marginal firms, with business models that might have worked with better keystones, were brought significantly below any reasonable models for achieving profitability. The behavior of a handful of hubs may thus have been quite material to the collapse of the entire .com sector and its closely connected telecom industry. Naturally, this collapse did not also hurt the many niche players in the ecosystem, but also the keystones themselves.

This underlines the need for managers in firms that form critical industry hubs to think carefully about their roles and explicitly foster the practices that promote keystone behavior. They should monitor the health of their ecosystem, promote reasonable business models and relationships, and invest in the kinds of platforms, technological components, and tools that enable third party productivity, diversity, and innovation. Furthermore, they should do so at terms that promote the continued and sustainable growth of ecosystem participants. A healthy ecosystem means a healthy keystone and vice versa.

Implications for policy

Policy implications are of particular urgency. In the United States and Europe, for example, many of Microsoft's practices are under intense scrutiny, both in courts and by government regulators. Unfortunately, many of the arguments that are being used to frame the role played by Microsoft are founded on very traditional views of markets, competition, and innovation. Many of the concerns and complaints these governments are pursing should instead focus on Microsoft's role in its ecosystem: is it contributing to the health of the software ecosystem or harming it? (See Appendix C for an evaluation of Microsoft's effect on the health of its ecosystem.)

In the United States, much recent trial testimony has focused on the fear that Microsoft will dominate an endless succession of markets; that it will "retain the ability to exclude or marginalize all manner of telephone services, messaging products, video or music offerings, Internet services, and other 'utilities' of modern life."[120] This view would greatly benefit from a thorough analysis of Microsoft's interactions with its ecosystem. Our outlook implies that Microsoft's keystone role has an important beneficial effect on the ecosystem as a whole; and that selective reduction in diversity,

[120] U.S. Department of Justice. DoJ web site: SBC's comments on the Proposed Final Judgment: <http://www.usdoj.gov/atr/cases/ms_tuncom/major/mtc-00029411.htm> (2002).

such as that in platform components, may in fact enable much *more* meaningful and extensive diversity elsewhere in the ecosystem (e.g., in making it easier and more productive to write software applications).

More broadly, the framework outlined in this paper suggests that we need to reexamine the question of what regulatory regime is appropriate for a firm like Microsoft. While the current paper does not address that question directly, it suggests that in formulating regulations, a guiding principle should be an evaluation of the effectiveness of such regulations in encouraging and facilitating effective keystone behavior.[121]

Another example of important policy implications has arisen in the context of the current debate about the role of Open Source as a model for software development. In Europe, several governments are contemplating various forms of official adoption of Open Source software to the exclusion of Microsoft's. There are many reasons for this, but an important underpinning of the argument in favor of this move is the sense that the Open Source ecosystem is potentially more productive and innovative than the one "dominated" by Microsoft. But is this actually true? Is the Microsoft ecosystem inherently less capable and less healthy than the Open Source ecosystem? Our framework proposes clear ways to make these comparisons, along the lines of productivity, robustness and niche creation.

Future examination of these and other specific research questions established in our framework should help answer these questions and guide informed policy decisions.

[121] An examination of the remedies proposed by the non-settling states in the Microsoft anti-trust trial is enlightening here. Regardless of whether Microsoft has been an effective keystone *in the past*, these remedies should be rejected because they directly target important aspects of Microsoft's role as a keystone in the future. Many provisions of these remedies seek, for example, to effectively "un-integrate" the Microsoft platform and to make it difficult or impossible for Microsoft to continue the integration process. Our analysis would argue that such provisions are a perfect example of the kind of regulation that should be avoided, because they undermine Microsoft's ability to serve as a keystone *in the future*.

The implosion of the .com and telecom industries has motivated rampant uncertainty and strong concerns about the future strength and stability of the technology sector. Polarizing arguments have ensued among communities of academics, policy makers, analysts, and practitioners challenging basic notions of innovation, intellectual property and competition in the technology sector. We suggest that much of the disruptive confusion around these subjects may have been prompted by the fundamental changes in the technology industry discussed here, and caused by the frequently surprising collective behavior of distributed networks of organizations. We hope that the frameworks presented in this paper will motivate new, structured debates on the dynamics of business ecosystems. We believe this would have important implications for a wide range of domains, from product architecture and operations to business strategy and policy.

Appendix A: Wal-Mart as Keystone

One of the most important roles played by keystones is their creation of a stable platform that simplifies the complexity of the world in which the members of their ecosystem operate. Perhaps the most dramatic successes in this regard is the retail giant Wal-Mart, the number one company on the Fortune 500 and the world's largest retailer. Few of Wal-Mart's competitors (direct competitors such as K-Mart and Target, secondary competitors such as Marshalls, CVS, or Walgreens, or tertiary competitors such as local shops) would accept this characterization. These firms would see Wal-Mart as an aggressive dominator that crushes its competition. But to accept this view is to draw the ecosystem boundary in the wrong place. Wal-Mart's ecosystem extends not to competing retail stores, but instead embraces a vast web of firms that constitute its supply chain stretching from manufacturer to consumer. Seen in this way, Wal-Mart's role takes on a different character.

Over several decades Wal-Mart has established a centralized supply chain infrastructure which has significantly improved the efficiency of the retail ecosystem and, thereby, lowered prices for consumers. In developing this ecosystem Wal-Mart has created a substantial new channel for vendors large and small to reach consumers worldwide. The creation of the immense and robust Wal-Mart retail ecosystem has been enabled largely through the relentless implementation of business processes and technologies which improve the efficiency of the retail supply chain, streamlining information flow and interaction between Wal-Mart and the firm's thousands of vendors. Wal-Mart's successful efforts to continuously improve the efficiency of the entire supply chain from factory to shopping cart has allowed it to create a thriving ecosystem of partners, suppliers, and vendors, displacing the competition in the process.

Wal-Mart's keystone success has been enabled through its use of innovative technology and carefully structured business processes focused on continuously improving the productivity of the entire Wal-Mart supply chain. The company's efforts in these areas date back decades, but gained prominence in 1987 when a partnership was forged with Procter & Gamble to improve supply chain efficiency. As noted in Business Week in April 2002,

> *"…in-stock rates improved, and inventory fell… it really changed things from an adversarial price negotiation to a win-win situation."*[122]

Today, Procter & Gamble's $6 billion per year relationship with Wal-Mart is so important to both firms that P&G maintains a 150-person office in Bentonville, Arkansas, Wal-Mart headquarters.[123] Vendors such as Procter & Gamble are given full access to real-time data on how their products are selling, store by store. By sharing information that other retailers guard, Wal-Mart allows suppliers to plan production runs earlier and offer better prices.

Information management

A striking example of Wal-Mart's information management skills was provided on September 11, 2001 and in the days following the terrorist attacks on the United States. This example is worth recounting in detail, because it captures the extraordinary power of Wal-Mart's integrated platform form managing the entire network of

[122] Tsao (2002).
[123] "Hicks with bags of tricks," *The Australian* (14 December 2001): 34.

information and resources that flow through its ecosystem. As noted in the Wall Street Journal on September 18, 2001:

> *Sales from every scanner in Wal-Mart's stores are instantly tabulated, sorted and analyzed by a giant computer system at the corporation's Bentonville, Arkansas headquarters. The proprietary system, called Retail Link, a technological behemoth whose database capacity is second only to the U.S. government's, offers a look into the psyche of the American consumer during a week of widespread uncertainty… last week was hardly average. Wal-Mart says sales nationwide on Tuesday, the day of the attack, were 10% below the same day a year earlier. At Wal-Mart stores around New York and northern Virginia, where the terrorists struck, sales plummeted as much as 30% to 40% for the day, the retailer says…by evening, however, customers began flooding back, stocking up on staples and emergency supplies. Sales of gas cans spiked 895%. Gun sales jumped 70%, and ammunition sales surged 140%. Sales of TV sets jumped 70% and antenna sales leapt 400%. On Tuesday, Wal-Mart sold 116,000 American flags, compared with 6,400 the same day a year earlier… the chain sold 200,500 flags on Wednesday, compared with 10,000 a year earlier… Wal-Mart says by Friday its overall customer count had returned to within normal ranges, and comparable-store sales gains returned to around 5%. Still, the size of the average purchase lagged, the company said.*[124]

Process efficiencies

Building on this information management "platform", Wal-Mart has created an extraordinarily efficient system for managing inventory and vendor relations that benefits all members of Wal-Mart's ecosystem. In an effort to effectively manage hundreds of thousands of SKUs (stock-keeping units) from thousands of vendors, Wal-Mart has a formal vendor-compliance program, which governs the preparation of store-ready merchandise as well as transportation and logistics issues. When Wal-Mart Stores introduced these rules for suppliers in the early 1990s, vendors were concerned with the impact on their business. Wal-Mart suddenly was dictating how the goods they received would be labeled, how they'd be packaged, anything that made it easier for them to receive and handle goods and clear them through the store with minimum inventory. One key element of this strategy was the push for prepackaged vendor displays, which cost more to ship but required less store labor and time to handle once they get to the store.[125]

Despite the resistance, these new business processes proved successful, and have since grown to be considered best practices. As noted in the Journal of Commerce in August 1999:

> *A recent survey by The Performance Measurement Group, a subsidiary of PRTM, confirmed what many have been saying - that companies that emphasize supply- chain issues can gain a huge advantage over their competitors. The best companies have cut their supply-chain management costs to as low as 4 percent to 5 percent of their sales. That provides a huge advantage over companies that spend up to 10 percent of sales on distribution, transportation and other supply-chain activities. For a company with $500 million a year in sales, the supply-chain efficiency can mean $25 million to $30 million in savings. Market leaders with sound supply-chain strategies are earning 75 percent higher profit than their less successful competitors, the study found.*[126]

Wal-Mart's integration of business processes with its suppliers is enabled through the use of technology and promoted through a corporate philosophy of sharing inventory, logistics, and even detailed financial information with suppliers. As noted in Chain Store Age in October 1997:

> *When Wal-Mart sits down with its manufacturer partners, both sides' cards are on the table. It was clear by the number of questions directed at Wal-Mart CIO Randy Mott during The Chicago Summit that many would like to duplicate its successes. But doing that right isn't easy. "We share everything with our vendors that they need to know to have a profit-and-loss statement with Wal-Mart," Mott said. "We share markdown information, return information, claims, sales, shipments and inventory*

[124] Zimmerman, Ann and Emily Nelson, "In hour of peril, Americans bought guns, TV sets – Wal-Mart's giant computers detected 'pantry loading' giving way to 'CNN effect'," *The Wall Street Journal* (18 September 2001): B1.
[125] "Distribution Network Slated for Expansion," Mass Market Retailers 17(8) (20 March 2000): 67.
[126] Atkinson, Helen, "Survey: Supply chain oversight helps everyone," *Journal of Commerce* (31 August 1999): 13.

> *levels. We actually put that information out on the applications that we supply to the vendors so they know what their profitability is. We give them a comparison on how they do within their category, a sort of benchmark. "When they come in to sit down with a buyer, there's not a lot of wondering whether they have inventory bulges or markdown or return opportunities," he continued. "Both parties know the same information, so the discussion centers around actions. We think that's a very constructive relationship."*[127]

Competing retailers at the same Chicago meeting admitted that their systems and processes were not as detailed or as advanced

> *Other retailers agree. "We don't do as much knowledge sharing as Wal-Mart," said Office Depot CIO Bill Seltzer. "We offered to do that with our vendors, but most of them can't handle the information. There's a great deal of opportunity for all of us in that, and I think Wal-Mart has really led the way in teaching us that." Sears CIO Joe Smialowski hopes to see data sharing feed more than the vendor/buyer relationship. Such partnering, he feels, can do more. "Up until very recently, when we talked about cooperation and data sharing, we focused primarily on sales and inventory and margin-related information for a particular vendor," Smialowski said. "But I think the relationship now is going beyond that. If we are partners, we need to do a lot of things together. One is joint forecasting. Retailers should be working with their suppliers to improve manufacturing processes, the way raw materials are sourced and the way goods are packed and shipped."*[128]

Some of Wal-Mart's strategic business processes are not entirely dependent upon advanced technology, but instead are focused on frugality, common sense, ethical standards, and cooperation. Some of these business practices were detailed in a Harvard Business School Case Study (*#9-794-024)* in 1996, further emphasizing Wal-Mart's awareness of its role in the broader business ecosystem:

> *Wal-Mart was known as a no-nonsense negotiator. When vendors visited the company's headquarters in Bentonville, they were not shown to buyer's offices, but into one of about 40 interviewing room equipped with only a table and four chairs. Wal-Mart eliminated manufacturers' representatives from negotiations with suppliers at the beginning of 1992,*

[127] "Chicago Summit Retail Systems '97: Demand-Side Economics," *Chain Store Age* (1 October 1997): 19B.
[128] "Chicago Summit Retail Systems '97: Demand-Side Economics," (1997).

> *at an estimated savings of 3%-5% (a matter the reps tried unsuccessfully to take to the Federal Trade Commission). The company made it a practice to call its vendors collect, and centralized its buying at the head office, with no single supplier accounting for more than 2.4% of its purchases in 1993. It also restricted sourcing to vendors who limited work weeks to 60 hours, provided safe working conditions, and did no employ child labor. Each Wal-Mart department also developed computerized, annual strategic business planning packets for its vendors, sharing with them the department's sales, profitability, and inventory targets, macroeconomic and market trends, and Wal-Mart's overall business focus. The packets also specified Wal-Mart's expectations of them, and solicited their recommendations for improving Wal-Mart's performance as well as their own. The planning packet for one department ran to 60 pages.*[129]

Selective domination

Finally, like many keystones, one way that Wal-Mart delivers keystone benefits to its ecosystem is through domination of selective niches. This is felt dramatically overseas, in its interactions with foreign suppliers and service providers. In February 2002 Wal-Mart moved out of Hong Kong and into the Chinese mainland, setting up a sourcing center in Shenzen that will be responsible for buying and distributing $4 billion worth of Chinese-made goods a year.[130] Wal-Mart's everyday low price guarantee is made possible in large part thanks to its use of suppliers in China and throughout the developing world, where low-cost labor is readily available and vendors are anxious to access the lucrative U.S. marketplace.

The impact of Wal-Mart's keystone interactions with its own partners and suppliers have had a ripple effect throughout the industry, forcing competitors to improve their own productivity through improvements in systems and processes for supply chain management. Thus, the company's roles as dominating presence in the retail industry

[129] Foley et. al. (1996).

and as a keystone in its ecosystem are innately linked, as Wal-Mart continues its drive to increase the productivity of the retail ecosystem and provide even more consumers worldwide with the "everyday low prices" that are the company's ultimate goal. Significantly, these keystone contributions have had a ripple effect extending far beyond its own ecosystem and out into the wider economy: as noted by Bradford C. Johnson in "Retail: The Wal-Mart Effect":

> *More than half of the productivity acceleration in the retailing of general merchandise can be explained by only two syllables: Wal-Mart.*[131]

[130] "Hong Kong faces big losses in exodus of shippers," *South China Morning Post* (24 May 2002): 5.
[131] Johnson, Bradford C., "Retail: The Wal-Mart Effect," *The McKinsey Quarterly* 1 (2002): 40-43.

Appendix B: NVIDIA's Keystone and Niche Strategies

NVIDIA is textbook case of a highly successful niche player in the business ecosystem of semiconductors and integrated circuits. By leveraging platform components – the tools, libraries, standards that comprise the platform on which its products are based – provided by several keystones, most notably TSMC, NVIDA is able to stay highly focused and effective in its core domain: the design, development and marketing of graphics and media communication processors and related software for PCs, workstations and digital entertainment platforms.

Use of tools

As a "fabless" chip company, NVIDIA outsources all fabrication of its graphics processing units to TSMC, a keystone in the integrated circuit ecosystem. NVIDIA's fabless manufacturing strategy leverages the expertise of industry-leading, ISO-certified suppliers such as TSMC and others in such areas as fabrication, assembly, quality control and assurance, reliability and testing. This enables NVIDIA to avoid the significant costs and risks associated with owning and operating manufacturing operations. These suppliers are also responsible for procurement of most of the raw materials used in the production of NVIDIA chips. As a result, the company can focus resources on product design, additional quality assurance, marketing and customer support.

Through its niche-keystone relationship with TSMC, NVIDIA CEO Huang Jen-Hsun can log onto a TSMC web site and track the production status of its chips in Taiwan. "We get daily feeds on where every single wafer is in the process," raves Huang. He can make late engineering changes and even cancel an order at the last minute without incurring a heavy penalty. "A lot of people would like to have our business,"' says Huang. But the "chemistry" he says his engineers have with those of TSMC is a major reason NVIDIA gives the foundry some $500 million in orders every year.[132]

NVIDIA graphics processors are primarily fabricated by TSMC and assembled and tested by Advanced Semiconductor Engineering, ChipPAC Incorporated and Siliconware Precision Industries Company Ltd. The company receives semiconductor products from subcontractors, performs incoming quality assurance and then ships them to CEMs, stocking representatives, motherboard and add-in board manufacturer customers from a Santa Clara, California warehouse and third-party warehouses in Singapore and Hong Kong. Generally, these manufacturers assemble and test the boards based on NVIDIA design kit and test specifications, then ship the products to the retail, system integrator or OEM markets as motherboard and add-in board solutions.[133]

Use of libraries

Through its partnership with the keystone firm TSMC, NVIDIA is able to improve the efficiency of its graphics processor design and fabrication through use of chip design libraries maintained by TSMC. As part of its growing emphasis on customized service, TSMC uses the Internet to make information on designs and products available to customers 24 hours a day. "Access to our fabs is very important, so we are turning to e-commerce," says TSMC Chairman and founder Morris Chang. "The emphasis is for the customer to access the information they need without any human

[132] Einhorn, Bruce, Frederik Balfour, Cliff Edwards, and Pete Engardio, "Betting Big on Chips: Why TSMC boss Morris Chang is spending billions despite the tech slump," *Business Week* (30 April 2001): 18.
[133] NVIDIA SEC 10-K filing for fiscal year ended 27 Jan 2002.

intervention. We have a library of technologies available for them and they should be able to find out 90% of our technologies without any human assistance."[134]

The concept of a technology library is at the center of TSMC's new business model. Chang sees the company as not just a manufacturer but a design and technology broker. For example, if NVIDIA has designed a new graphics chip and needs a standard circuit to link the chip with other computer operations, a search TSMC's database will provide such a circuit. TSMC can then pull the designs together to make a single, integrated product. Chang calls this "acting as the honest broker on intellectual property," adding: "The fact that we don't do any design and don't compete with any of our customers is a big advantage."

TSMC launched its design library in August 1998 when it signed an agreement with Artisan Components, a Silicon Valley design house. Artisan doesn't charge TSMC any fee up front, but receives royalties when TSMC produces chips using Artisan designs. In effect, TSMC customers such as NVIDIA get free initial access to the designs, making their cash flow easier – an important consideration for companies both small and large.[135]

Use of standards

As with most 3-D chip companies, quality and performance are NVIDIA's number-one concerns when testing out prototype ICs. Once in production, millions of these devices are shipped. Anything less than the best would not only disappoint customers, but would also provide many competitors with an opportunity for gain. The

[134] Bickers (1999).
[135] Bickers (1999).

high level of complexity in these devices makes it a challenge to bring them into production quickly with a high level of quality. For instance, NVIDIA's latest integrated circuit includes 15 million transistors in a 0.25µm CMOS with a complexity on par with today's leading microprocessors, including a high level of logic function, internal caches and speeds of 200 MHz and beyond.[136]

As a fabless semiconductor company, internal testing resources for testing prototype ICs are not available. Instead, many fabless companies can rely on outside services such as DTS in San Jose, CA, which has the type of sophisticated testing equipment needed.[137] NVIDIA hardware and software development teams work closely with these external testing services, certification agencies, Microsoft Windows Hardware Quality Labs and OEM customers to ensure that both boards and software drivers are certified for inclusion in the OEMs' products.[138] Quality standards for chip production are maintained by TSMC; Microsoft's Direct3D Application Programming Interface, or API, and Silicon Graphics, Inc.'s, or SGI's, OpenGL API on Windows operating systems and Linux platforms

Keystone roles

NVIDIA has grown rapidly to become not only a vibrant niche player in the integrated circuit ecosystem, but also to serve in some ways as a keystone itself, supporting the development of firms in the adjacent hardware and software communities. By following a successful and focused niche strategy, NVIDA built a firm foundation for

[136] Katcher, Keith (Director of Product and Test Engineering, NVIDIA), "The Virtues of Virtual Test for Fabless IC Developers: A Fabless Company's Case Study" *Integrated Measurement Systems, Public Relations* (9 Mar 1999).
[137] Katcher (1999).
[138] NVIDIA SEC 10-K filing for fiscal year ended 27 Jan 2002.

the next step: the transformation of its niche into an ecosystem in its own right, with NVIDA as its keystone.

NVIDIA's "Select Builder" program supports system builders for PCs, laptops, and workstations. NVIDIA also maintains reseller and distributor partner programs for firms that promote the NVIDIA line of products.[139] In addition, the firm supports an active "NVIDIA Registered Developer" program to provide software developers in sectors ranging from video games to engineering simulation with training, tools, and support for application development tailored to exploit the unique capabilities of NVIDIA graphics processors.[140] Perhaps most significantly, NVIDIA has entered into a strategic partnership with Advanced Micro Devices (AMD), chief rival to Intel in the CPU market. The firm's new Nforce graphics processors were designed in collaboration with AMD beginning in 2000; they move graphics processing from a stand-alone chip into the chipset, an essential building block that serves as the link between the microprocessor (AMD's Athlon) and the rest of the system.[141] This combination of relationships with channel partners, applications developers, and AMD makes NVIDIA an keystone in the technology ecosystem, with a role that is likely to increase in significance over time.

NVIDIA libraries and components

[139] NVIDIA Channel Partner web site, < http://www.nvidia.com/view.asp?PAGE=channel> (2002).
[140] NVIDIA Developer web site,<http://developer.nvidia.com/> (2002).
[141] NVIDIA Press Release (3 June 2002).

NVIDIA providers developers with a library of code that is compatible with the company's GPU family. This includes compression plugins, vertex cache aware stripification of geometry, memory management, public image files, and a wide range of special effects. Along with the introduction of the Cg Language Specification (discussed below), NVIDIA also offers a Cg Toolkit that includes a Cg Compiler, Cg Browser, CgFX file format, Cg Standard Library and a collection of pre-written Cg shaders which can be used for a variety of applications, ranging from game development to digital content creation and computer-aided design. NVIDIA also provides a forum for developers to comment on the code library and offer their own additions.

NVIDIA tools

NVIDIA's core products, the Quadro, Nforce and GeForce graphics processing units (GPUs), provide manufacturers of desktops, laptops, and workstations with graphics capabilities significantly beyond that available through the basic graphics functionality embedded in core central processing units. In that fashion, these products may be considered "tools" which provide computers with the ability to run applications (games, simulations, visualizations, etc.) which would not otherwise be possible. NVIDIA GPUs are provided in computers from Apple, Compaq, Gateway, MicronPC, HP, and Toshiba, as well as a variety of systems offered by service providers and systems integrators. NVIDIA works closely with these PC OEMs, system integrators, motherboard manufacturers, add-in board manufacturers and industry trendsetters to define product features, performance, price and timing of new products. The company also employs application engineers to assist these partners in designing, testing and qualifying system designs that incorporate NVIDIA products.

NVIDIA promotes its GPUs to hardware manufacturers and integrators through the Select Builder Program. Select Builder provides members with marketing and promotional resources as well as increased sales and technical support, including:

- NV Online Select Builder http://selectbuilder.nvidia.com , a comprehensive Web site which serves as a complete resource of marketing, sales and technical materials for NVIDIA product offerings.
- NVIDIA Select Funds, a co-operative marketing initiative, which offers Program Members joint marketing dollars based on volume purchases of NVIDIA products.
- Access to key communication tools including the NVIDIA Select Builder newsletter and special program member announcements featuring product and promotional opportunities specifically tailored for system builders.
- Increased sales and technical support, provided by dedicated NVIDIA sales and engineering professionals as well as Web-based tools offered via NV Online Select Builder.

NVIDIA's role as a "keystone tools provider" extends beyond hardware. The firm also provides NVIDIA "registered developers" with resources to ensure that they are able to quickly and efficiently learn the skills and techniques necessary to make optimal use of the capabilities provided through NVIDIA GPUs. Workshops and training classes are offered at industry conferences such as SIGGRAPH, and a variety of instructional resources are made available through the NVIDIA developer's web site.

Furthermore, on June 13, 2002 NVIDIA introduced the Cg Language Specification - C for Graphics. Cg is a high level programming language that enables content developers to create cinematic-quality real-time graphics easier and faster. Developed in close collaboration with Microsoft, Cg gives developers a new level of abstraction, removing the need for them to program directly to the graphics hardware. The C-like syntax enables rapid development of real-time shaders and visual effects for graphics platforms, and is compatible with Microsoft's recently announced High Level Shading Language for DirectX 9.0.[142]

NVIDIA standards

In an ongoing effort to shape and define standards in the graphics industry, NVIDIA announced on April 17, 2002 that it is working with the Arapahoe Work Group to help develop the graphics bandwidth capabilities of PCI Express, the new Intel Corporation third-generation Input/Output (I/O) specification that connects computing subsystems and peripheral components at high-bandwidth speeds.[143] NVIDIA has developed a high-speed graphics interconnect designed to evolve current PCI technology and address the increasing bandwidth demands of emerging graphic applications.

NVIDIA has also extended its efforts to improve and promote standards for the interconnection of PCs and display devices. On May 21, 2002, recognizing the increasing use of digital displays in both home and corporate environments, NVIDIA announced a new AGP riser card technology initiative, called the Digital Display Port (DDP).[144] NVIDIA's DDP specification provides OEMs, system builders, and motherboard manufacturers an opportunity to offer end-users a way – through the use of an AGP add-in card – to connect digital displays, including flat panel monitors and high-definition televisions, to PCs designed with an NVIDIA integrated graphics solution and an AGP expansion port. Although the first DDP-based add-in cards will only work with nForce-based motherboards and PCs, NVIDIA has designed DDP as an open standard

[142] NVIDIA Press Release (13 June 2002).
[143] NVIDIA Press Release (17 April 2002).
[144] NVIDIA Press Release (21 May 2002).

that can be implemented royalty-free by other PC core-logic designers and manufacturers.

Appendix C: Microsoft and the Computing Ecosystem

How do the three operational ecosystem strategies of keystone, dominator, and niche firm play out in shaping the health of business ecosystems? This question is of particular importance in the case of Microsoft, which has come under considerable recent scrutiny for the way in which it exercises its influence over the computing industry. In what follows, we examine the health of the computing ecosystem and elaborate this framework for characterizing firm behavior as we evaluate the ways in which the strategies pursued by Microsoft have influenced ecosystem health, focusing on the interplay between keystone and dominator strategies.

The popular press (and even occasional academic arguments) has often framed the debate on Microsoft's role in the computer industry in a simple way – it has a large market share of desktop operating systems, which is bad for competition, bad for innovation, and therefore bad for the industry. We believe that the picture is much more complex, and also much more interesting. The framework developed in this paper provides a more useful way to structure this debate, essentially by investigating the following question: is Microsoft the equivalent of a dominator or of a keystone in the computing ecosystem? This provides a much more constructive way to assess the impact of firms like Microsoft on fundamental issues like innovation and overall computing ecosystem health.

Microsoft in its ecosystem

There is no question that Microsoft's reach and impact is on its ecosystem is enormous – it is certainly no "niche species". By almost every obvious measure of influence, Microsoft is the significant player in the computing ecosystem, and we will not belabor that point here. It should be sufficient to point out that because of Microsoft's business model and evangelization methods, Microsoft has had an important influence on the way businesses and independent software vendors (ISVs) develop software. Indeed Microsoft's influence extends well beyond the number of software products that Microsoft licenses or the number of developers that it employees. An obvious way to measure the importance of Windows to software developers is to examine the number of firms and developers that create software for Windows platforms. One source for these data is Corporate Technology Information Services (CorpTech, since acquired by One Source), which collects annual data on high-technology companies.[145] The CorpTech data contains observations for more than 11,000 software firms based in the United States in 2000. The data, modified as described by Josh Lerner,[146] indicates that approximately 84 percent of software firms developed at least some software for a Microsoft platform. Surveys published by the Evans Data Corporation (EDC) provide further support for the assertion that a majority of developers and IT managers (upwards of 70%) use Microsoft platforms to write most of their applications.[147,148] Many additional studies also report consistent results.[149] (See figure 6 for a depiction of Microsoft in its ecosystem.)

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[145] Corporate Technology Information Services (CorpTech), "Corporate Technology Directory."
[146] Lerner (2002).
[147] EDC publishes two surveys that are relevant. First, the North American Developers (NAD) survey consists of a panel that includes both corporate and ISV developers. About 50 percent of respondents develop software for use primarily inside the company. The other half design custom or commercial software for sale to clients or customers outside the company. The survey includes developers working for companies of all sizes in a wide variety of industries. The survey considers two important questions. First, it asks respondents for "the operating system that they run primarily on the computer they use to do most of their programming." In total, 77 percent of respondents said that they primarily used a Windows operating system (95, 98, NT, or 2000) to develop software applications. Second, the survey asks "which target OS best describes the type of apps you work on most often?" About 72 percent of respondents say that they are primarily targeting Windows operating systems. 69.1 percent of developers say that they will primarily target a Windows operating system in 2001, with a big shift in focus from Windows NT to Windows 2000. About half of developers say that they will begin to target Windows 2000 in the next 12 months and another 17 percent say it will take more than a year to begin developing applications for Windows 2000.
[148] This is the Enterprise Development Management Issues (EDMIA) survey, which consists of interviews with 400 senior IT managers employed at corporate enterprises with 2,000 or more employees.[148] The survey instrument is similar to the one used for the

But we believe Microsoft achieves this influence without dominating its ecosystem. If we take Microsoft's ecosystem as the business partners that provide components to the Microsoft products and platforms and those that leverage those same products and platforms, a definition that encompasses a very large number of organizations – ranging from component providers like Intel and AMD to system providers like Dell and HP, and from ISVs like AutoCad and Intuit to enterprises like American Express and Merrill Lynch – Microsoft is quite a small firm by comparison. Currently, the company has around 40,000 employees, mostly located in its Redmond Washington campus. While this is a sizeable number, it pales in comparison with the number of developers not at Microsoft that currently program on Microsoft's platform, which currently numbers more than five million people.[150] The story is essentially the same if one looks at Microsoft's revenues over time. Microsoft's revenues were $20 billion for the year 2000, which corresponds to slightly over 11% of total packaged software revenues,[151] and is less than one percent of the total revenues if we include

NAD survey. About 72 percent of respondents to the EDMI survey said that they used a Windows platform (NT, 9x, 2000) to do most of their programming. This represents a slight increase from the 2000 survey in which 66 percent said they primarily used a Windows platform. About 69 percent of respondents say that they are targeting "most" of their applications to Windows platforms, a decline from 74 percent in early 2001. Moreover, 77 percent of respondents say that they intend to develop applications for Windows XP at some point in the future.

[149] For example, Microsoft has hired an outside market research firm to conduct surveys of developers, including independent software developers (20 percent of respondents), corporate MIS departments (40 percent of respondents), and third party software consulting firms (about 40 percent of respondents). The results of the most recent study, conducted in October 2001, are consistent with the CorpTech and Evans data. They show that a majority of developers target their software development to multiple platforms, but that Windows remains the primary target operating system. 59 percent responded with multiple answers when asked, "For which of the following computer operating systems do you currently target applications?"[149] 91 percent responded with at least one version of Windows when asked, "For which of the following computer operating systems do you currently target applications?" 75 percent responded with some version of Windows when asked, "Which is the *primary* operating system to which you target applications?"

[150] Prepared Text of Remarks by Craig Mundie, Microsoft Senior Vice President, "The Commercial Software Model," The New York University Stern School of Business, May 3, 2001, available at <http://www.microsoft.com/presspass/exec/craig/05-03sharedsource.asp>.

[151] Source: IDC Worldwide Software Review and Forecast, 2001.

hardware and component vendors (naturally much less, if we include the entire ecosystem).[152]

Another interesting point of analysis focuses on Microsoft's market capitalization. While very large, Microsoft's market cap is only a fraction of the market capitalization of the entire industry, ranging between 10 and 20% of computer component, systems, software, and services providers in 2001. This is in deep contrast with IBM, which during the 1960s enjoyed more than 80% of the total market capitalization of that same part of its ecosystem, as well as most of its revenues. It is interesting to compare the percentage of employees to the percentage revenues to the percentage market capitalization. In strict measures of size (e.g., employees), Microsoft takes up a much smaller fraction of the industry than in measures of value (revenues and, even more so, capitalization), which is exactly what one would expect from a keystone firm.

In biological ecosystems, keystones typically have their pervasive system-wide effects despite being a small part of their ecosystems by most measures. What is perhaps surprising is that the same holds true for Microsoft. Unlike dominators, it is not "taking over" the ecosystem, and the fraction of "industry mass" that it contains is relatively small, while the impact and value it has is very large. This suggests that Microsoft is operating as a keystone in its industry.

Microsoft as keystone

Is Microsoft currently acting as a keystone in the biologically inspired sense we define here? Specifically, is it ensuring its own survival and success by acting to improve

[152] This pales in comparison with similar revenue share numbers by IBM during the 1960s, for example. See Ferguson & Morris (1993).

the health of the ecosystem as a whole? In what follows we provide an initial analysis of Microsoft's impact on the health of its ecosystem factored according the basic aspects of ecosystem health defined above. We believe that this analysis highlights the usefulness of our framework as a lens through which to examine the behavior of influential firms in their ecosystems and suggests the value of using it to guide future research.

Productivity

It is natural to begin our analysis with direct improvements in productivity, since Microsoft's very first product was a tool for creating other products: a Basic compiler for the MITS Altair computer, a product that was quickly licensed to every major microcomputer manufacturer of the time and had an enormous impact on its industry. Improving developer productivity has been central to Microsoft's strategy from start, and has led to a variety of innovations and improved product features, ranging from the p-code incremental compiler to the introduction of Visual Forms and programming components. Microsoft has also actively focused on ways to enable developers to leverage and reuse solutions created by other developers, through technologies like Visual Basic Controls, ActiveX, and by their integration into developer tools. Indeed, Microsoft has inspired the growth of thriving industry segments around the construction and exchange of such components.

Additionally, there are many anecdotal accounts that show that Microsoft's Tools and Platforms have had an important impact on a broad variety of software companies and information technology departments.[153] In rare direct productivity comparisons, Microsoft's VisualStudio.NET was shown to exhibit significant advantages over competing platforms,[154] and even fierce competitors appreciate the quality and effectiveness of Microsoft's efforts in this domain.[155]

Perhaps more convincingly, we can gauge the productivity impact of Microsoft's platforms on third party developers by looking at the revenues generated in this fashion. According to data from IDC, approximately 38 percent of worldwide packaged software revenue ($64 billion) was derived from software written for 32-bit Windows platforms in 2000.[156] Additionally, approximately 34 percent of Systems Infrastructure software revenue was derived from software written for Windows platforms; and this share is increasing. IDC forecasts that shares of packaged application software and system infrastructure software will increase, respectively to 54 and 42 percent by 2005.[157] These ecosystem niches indeed appear to be enjoying a healthy growth rate.

Microsoft's latest development tools further increase productivity enhancements by offering interoperability among programming languages, a set of powerful class libraries and a unified model of programming with Web Forms, Windows Forms, and Mobile Controls. These features are combined with a blurring of the boundaries between Web server and client that makes it far easier for developers to move software from one platform to another, or to have it span platforms.

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[153] See, for example, *Real Stories from Real Customers Building Real Applications*, Visual Studio.net Launch, February 2002.
[154] See Microsoft Developer's Network. MSDN web site: <http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnbda/html/bdasamppet.asp> (2002).
[155] "They have an awesome development program. They are focused and relentless." (Sept. 2000 quote from Sun's CTO for Java.)
[156] IDC tracks three broad categories of software: Applications Development and Deployment Software (ADD), Applications Software, and System Infrastructure Software.[156] Programs written to Windows account for a significant portion of revenues in each of these sectors. In 2000, approximately 41 percent of ADD software revenue was derived from software written for 32-bit Windows platforms. IDC expects Windows to account for 49 percent by 2005. Approximately 38 percent of Applications software revenue was derived from software written for 32-bit Windows platforms.
[157] IDC Worldwide Software Review and Forecast, 2001, No. 25569, Table 18.

Robustness

Microsoft has provided a crucial degree of stability in the software industry by ensuring that its application programming interfaces (APIs) remained consistent across different generations of technology. Application developers write programs that call on various APIs to perform routine functions, which greatly reduces the cost of writing software programs. It is important to developers that an operating system have a consistent set of APIs because it ensures that programs that work on one version of an operating system also work on other versions. Software developers can also be confident of the fact that their software applications will not break when new versions of the operating system are released. This, in turn, assures a familiar experience for developers and ultimately for end-users and reduces learning costs.

The fact that Microsoft offers a reliable, consistent, and widely-distributed operating system benefits ISVs, OEMs, businesses, and individual consumers alike. ISV's benefit from consistent and well-documented APIs and a broad base of users. OEMs benefit because a standardized Windows interface reduces consumer confusion and thus the volume of support calls for which OEMs are largely responsible. Businesses benefit in at least two ways. First, as with ISVs, businesses benefit from well-documented and consistent APIs when they develop proprietary software applications for the Windows platform. Second, because the Windows user interface is widely used and basically remains consistent across different software features, training costs for workers are reduced. Consumers benefit from having a stable and consistent platform and from having a broad range of applications to run on the platform.

In addition to Windows, Microsoft has supported, developed, or contributed to some 50 different standards ranging from Bluetooth to Universal Plug and Play (UPnP). In some cases, Microsoft has developed proprietary technologies, for example the programming language C#, and has subsequently obtained certification by a standard-setting body. Microsoft often cooperates with other firms to jointly develop standards such as Universal Description, Discovery and Integration (UDDI) (developed with Ariba, IBM, Intel, SAP) or Advanced Configuration and Power Interface (ACPI) (developed with Intel and Toshiba). In other cases, Microsoft simply supports existing standards, for example HTML, and includes them in products such as Windows and Office.

Taken together these efforts provide the kind of predictability and continuity of experience we stipulate as measures of robustness. Moreover, the general outlines of the network structure of the ecosystem parallels that of the hub-governed networks that exhibit inherent stability respect to random changes.

Niche creation

As mentioned above, stability is also about providing a buffer against external shocks so that they do not disrupt the system. In fact, an effective keystone should seek to find ways of harnessing the energy of such shocks to further enhance diversity by creating new niches. Here Microsoft's .NET strategy provides an interesting example by exploiting what otherwise might have been a disruptive and destructive new technology to the advantage of the ecosystem as a whole. The Internet represented a dramatic threat to many existing software architectures, as well as significant challenges to many businesses that rely on software. The .NET architecture, through its language neutrality, through-the-firewall exposure of business logic (via HTTP and SOAP) and facilitation of data exchange (via XML) allows existing firms and their products to evolve and participate in the Internet, rather than being threatened by it. At the same time it effectively “recruits” new participants to the ecosystem by, for example, enabling COBOL or Python programmers (and the business logic they maintain) to more easily participate in the ecosystem.

In fact, diversity creation has been an important focus of Microsoft’s efforts from the start. In contrast with other companies (e.g., IBM, Apple, Oracle, SAP, Netscape, and countless others) from the very first days of its existence, Microsoft’s strategy has been to license its programming tools to an increasingly large community of independent software vendors. These have included compilers, integrated programming environment, programming components and, most recently, web services. Microsoft tools are currently being used by more than 20,000 software companies and information technology departments. These tools have been used to develop an incredible variety of applications, ranging from wireless platforms to channel management systems. In all, more than 70,000 applications have been written for Windows, far more than for other operating systems.[158]

The number of applications written to Windows is due at least in part, to Microsoft’s business model, which places a premium on developer support and evangelization of the Microsoft platform. Microsoft dedicates a great deal of resources to encouraging developers to write applications for the Windows platform and to take advantage of new features in its operating systems. The Microsoft Developer Network

(MSDN) is key to Microsoft's relationship with developers. Through MSDN, Microsoft communicates with its community of developers and provides them with technical information and support. MSDN currently has approximately 5 million members around the world.[159] Microsoft employs at least 2,000 full time personnel that are dedicated to supporting developers and it invests more than $600 million per year to support developers.[160] According to IDC, "Microsoft is viewed as a pioneer in the developer market and is considered by some vendors to be the benchmark in the industry."[161] And the *New York Times* recently noted, "[m]uch of Microsoft's success over the years can be traced to its understanding of and catering to rank-and-file developers."[162] In contrast with many other companies in the software industry, Microsoft has thus targeted the creation of a wide diversity of applications for its platform by directly nurturing its developer community.

A fundamental part of encouraging niche creation is increasing functionality in the computing ecosystem by expanding the range of things that computers can do, increasing the variety of ways in which those things can be accomplished, and the scenarios in which they can appear. Microsoft's .NET architecture is designed to directly enhance this aspect of diversity: the combination of language independence and the potential for a unified framework of functionality available on a wide range of devices means that a greatly expanded community of developers can now reach a huge audience of potential users.

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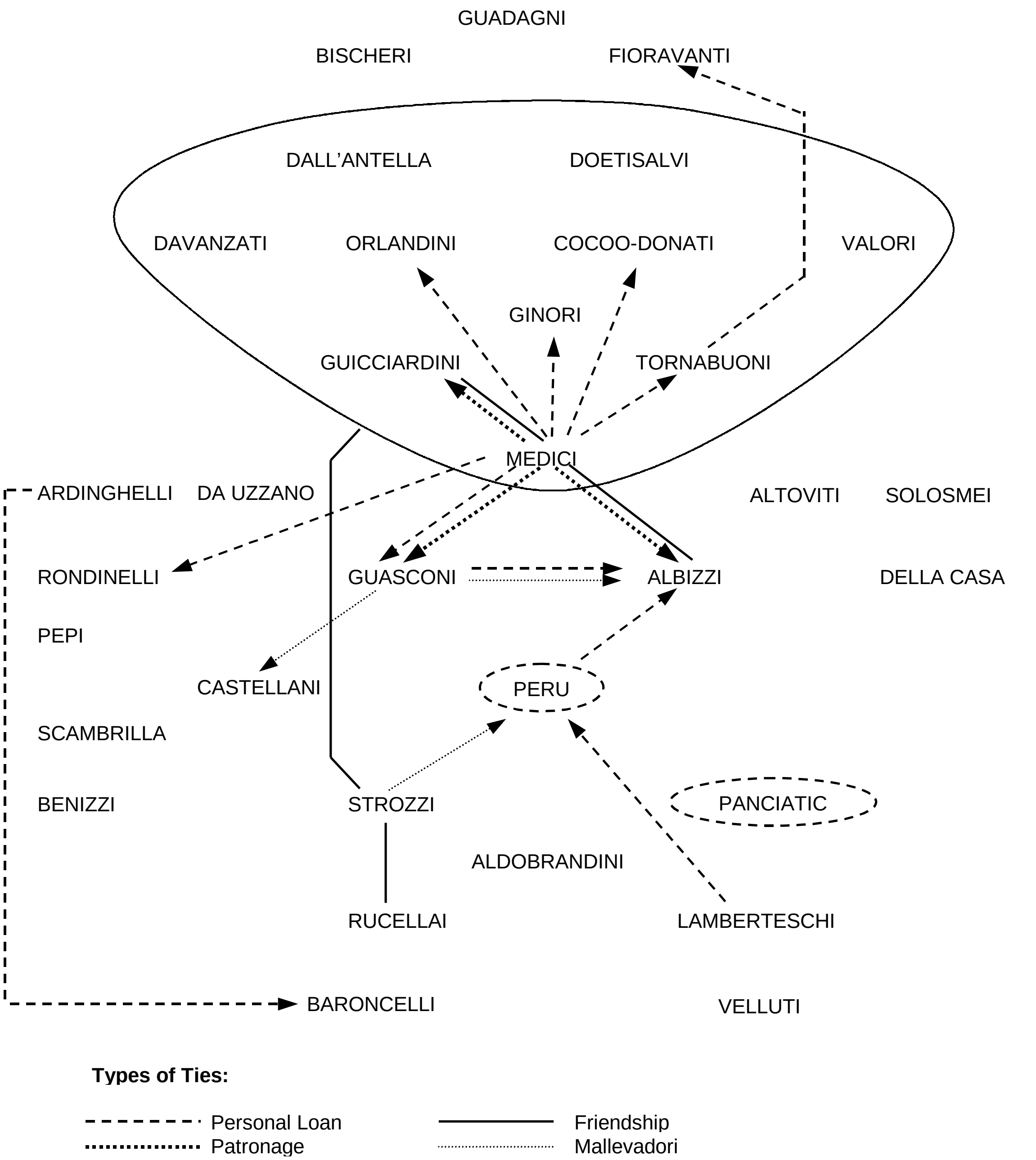
[158] *Findings of Fact*, United States of America v. Microsoft, Civil Action No. 98-1232 (TPJ), (5 November 1999): III.2.1.40.
[159] Prepared Text of Remarks by Craig Mundie, Microsoft Senior Vice President, "The Commercial Software Model," The New York University Stern School of Business, May 3, 2001, available at <http://www.microsoft.com/presspass/exec/craig/05-03sharedsource.asp>.
[160] *Direct Testimony of Paul Maritz*, United States v. Microsoft, Civil Action No. 98-1232 (TPJ), (20 January 1999): III.A.2.136.
[161] Volpi & Monaco (2001).

Overall, we believe that this review of Microsoft's effects on its ecosystem suggests that it has acted consistently as a keystone, fostering the health of the ecosystem along several dimensions. Moreover, we believe that this review establishes a useful framework for evaluating those effects, especially in the context of formulating policy with respect to Microsoft and similar firms in other ecosystems. We plan to pursue such an evaluation in ongoing research, and it is our hope that this discussion will encourage others to do so as well.

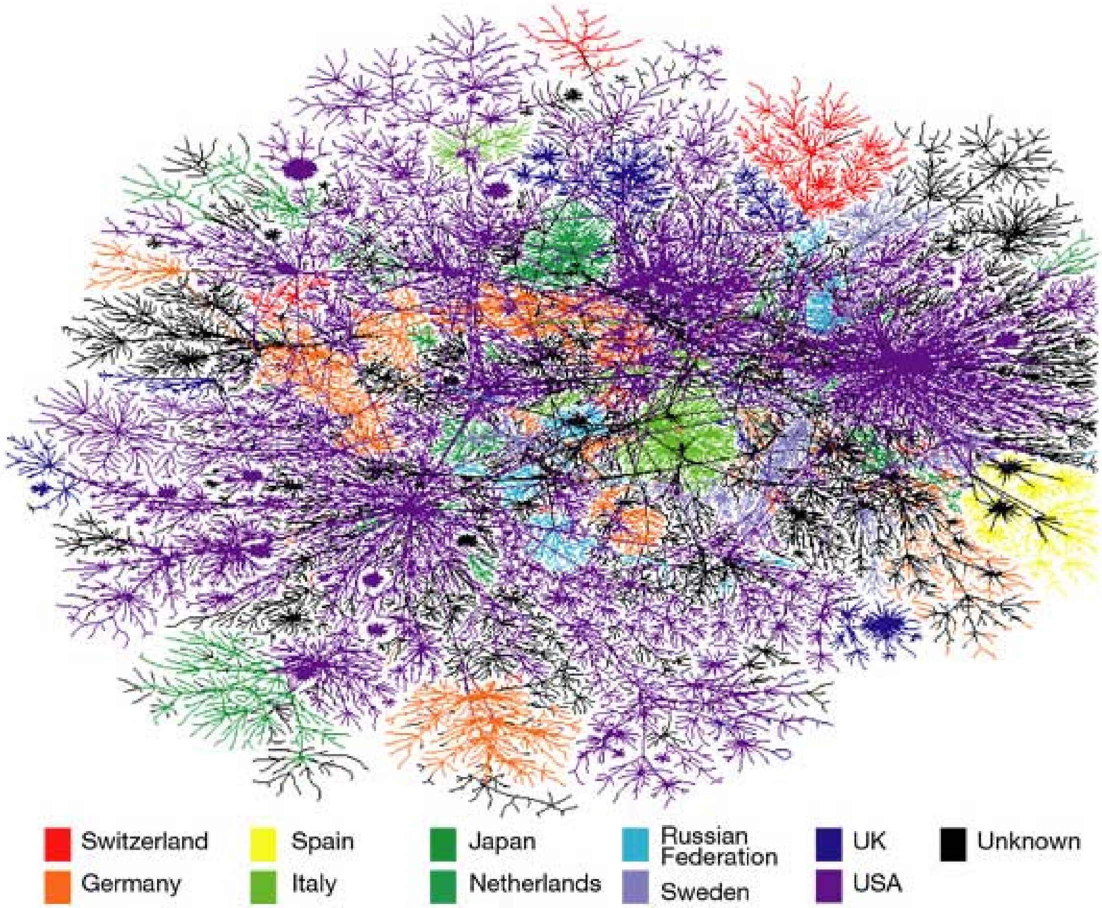
[162] Steve Lohr, "Microsoft Puts Its Muscle Behind Web Programming Tools," *New York Times*, (13 February 2002): C1.

Figure 1: Medici "Political" and friendship network



The Medici as a hub: Some of the social network relationships used by the Medici effectively consolidate a stable modern state around them.
Source: Padgett and Ansell (1993)

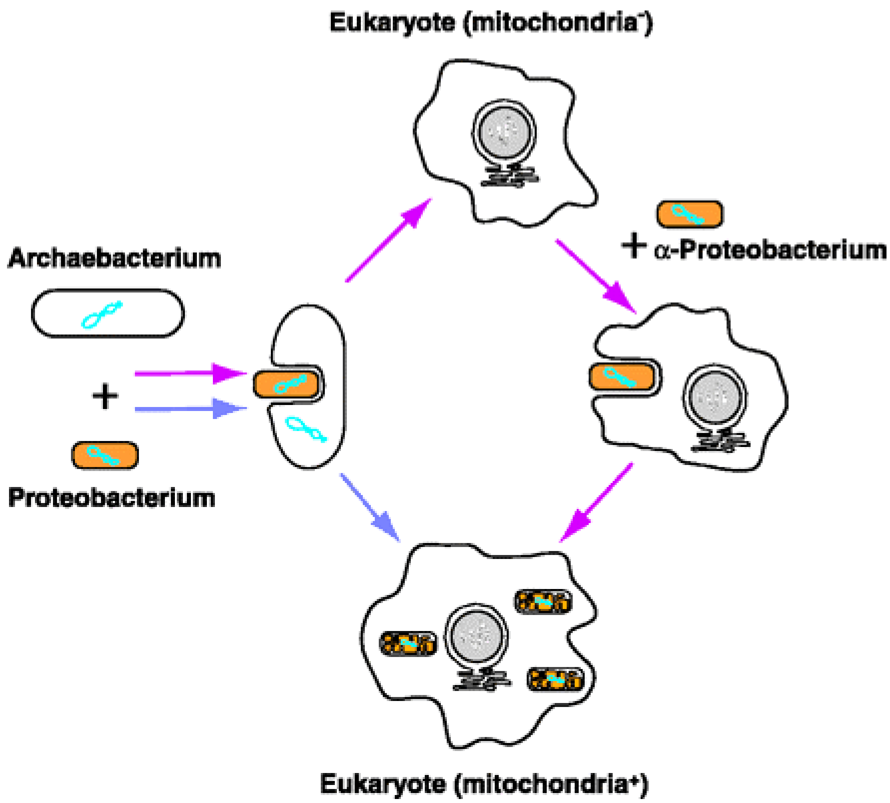
Figure 2: Internet connectivity



Hubs in the Internet: The pattern of connections in shows that a small number of nodes in the network are much more richly connected than the vast majority of the other members of the system. The lines branch represent connections between routers, with colors indicating geographic domains.

Source: Tu (2000)

Figure 3: Integration in mitochondrial evolution



Source: Gray, Burger & Lang (1999)

Figure 3: Integration in platform evolution

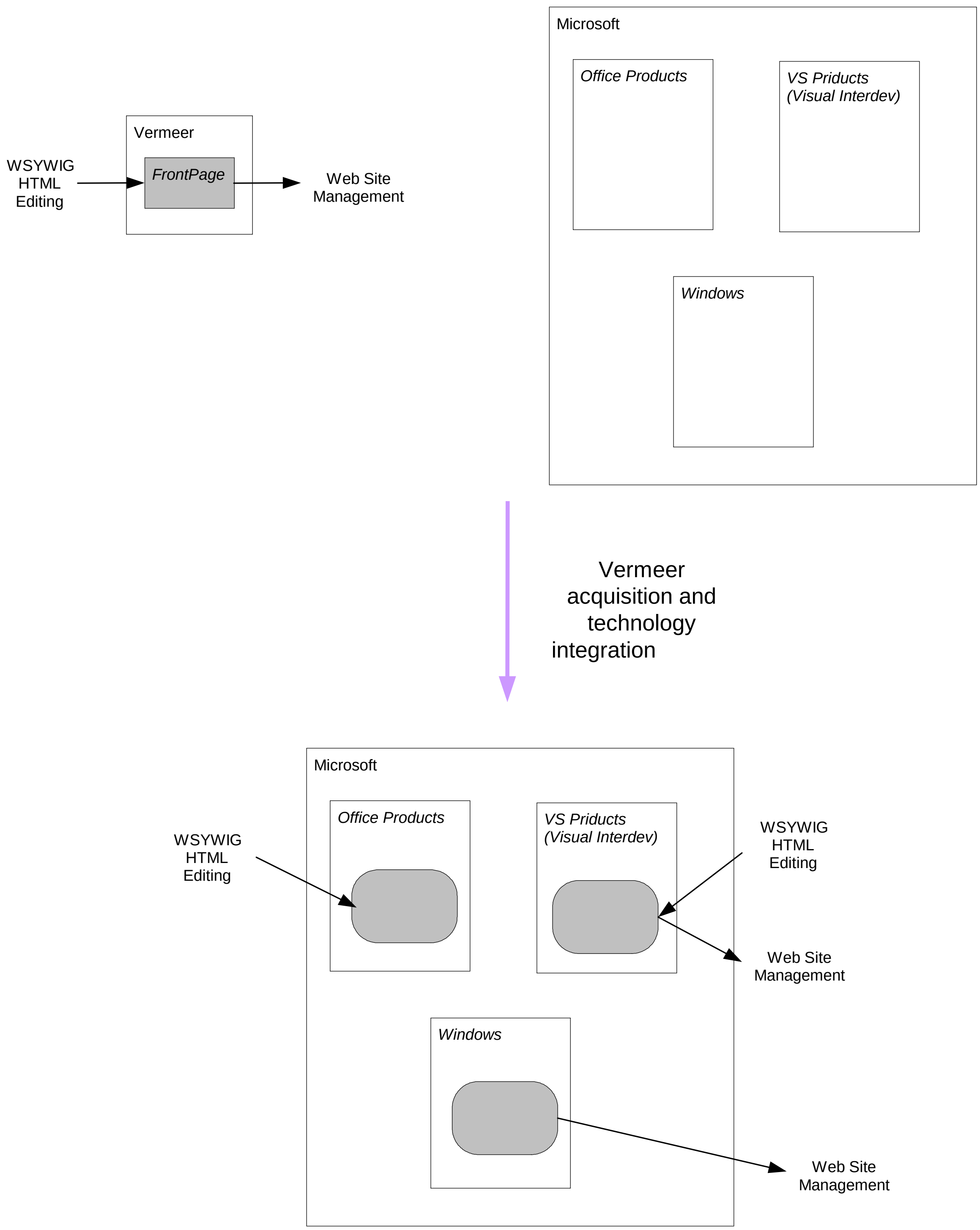


Figure 4: Example biological keystone and its effects

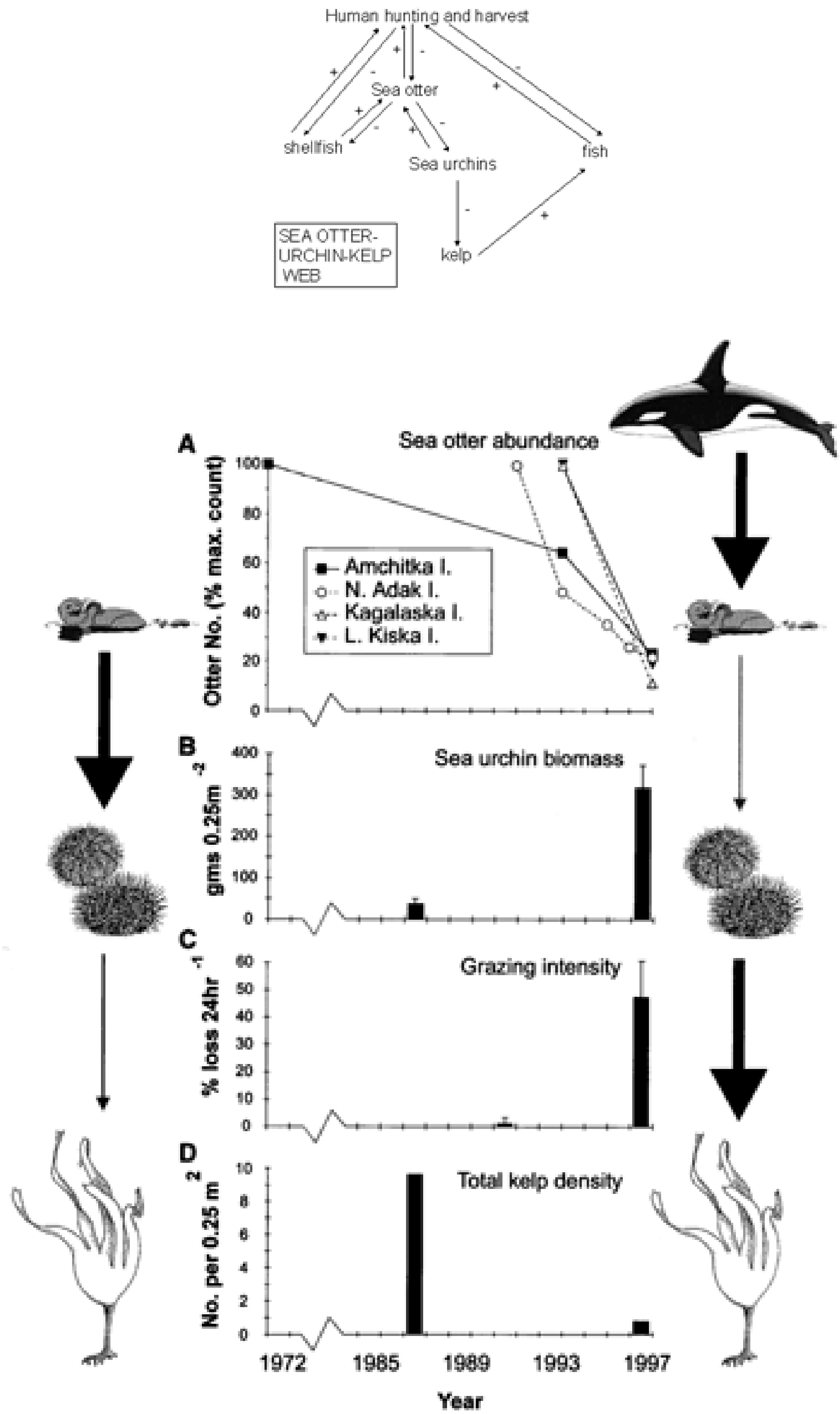
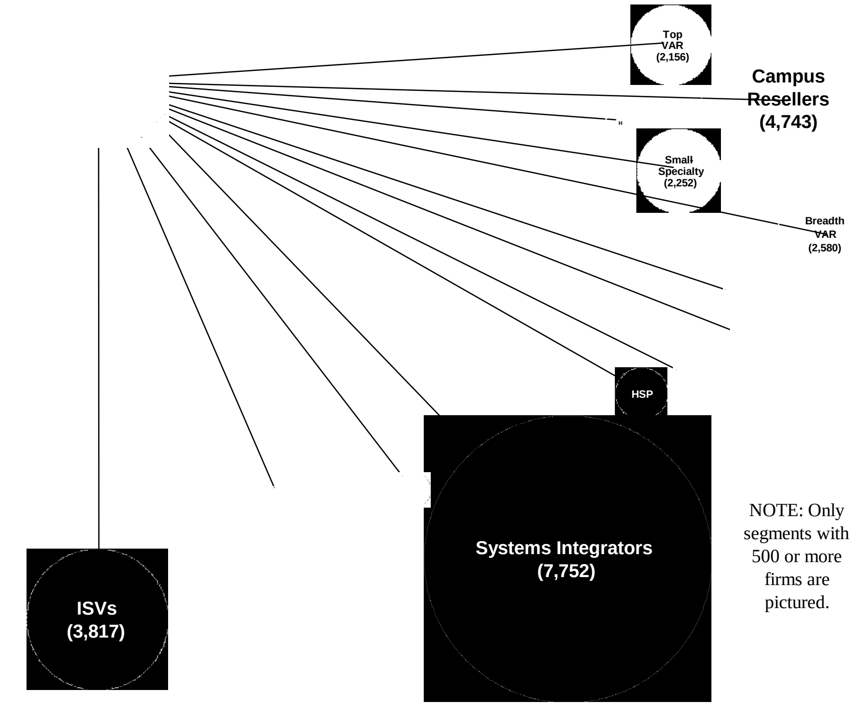


Figure 5: Some examples of Microsoft's keystone actions

Action	Effect	Examples of immediate beneficiaries	Downstream benefits
Componentization for IE 3.0	Makes generically useful components such as HTML engine available	Intuit Quicken	Standard user experience for rich text presentation; improves quality of application
Language-neutral common runtime engine (CLI) as part of .NET	Leverages existing range of languages, encourages language diversity, leverages existing business logic	National Instruments Measurement Studio	No retraining of programmers to leverage other .NET technologies, allows for faster application development
SQL Server / desktop integration via OLE & ODBC	Simplifies interaction between client application and core database	ABT PowerCampus	Simplifies and accelerates deployment of specialized applications tapping existing databases
Training, resources, & certification for network design, development, & implementation	Improves quality of partner services, aids in marketing & business development	Netivity	Customers have assurance of Microsoft certification for enterprise systems & security solutions
Training, resources, & certification for e-commerce solutions	Improves quality of partner services, aids in marketing & business development	Integrated Information Systems	Customers have assurance of Microsoft certification for e-commerce development
Suite of development tools & integrated client-server technologies	Allows firms to leverage component libraries for faster development and more reliable applications	Plural (acq. by Dell May 2002)	Customers enjoy faster application development and more robust custom information systems
Integrated capabilities of Windows 2000, Office XP, SQL Server, and SharePoint tech.	Improves ease of development and implementation of extranet / collaboration solutions	Stratis Group	Allows customers to share and process information across divisions and with suppliers, partners, and clients

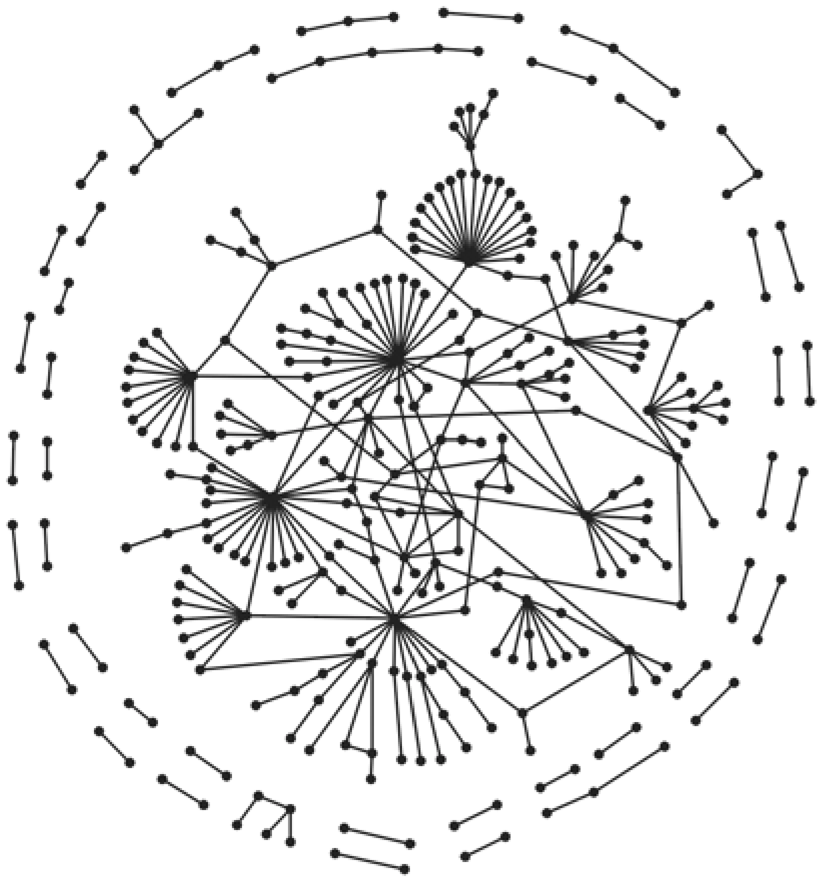
Figure 6: A Depiction of Part of Microsoft's ecosystem



MICROSOFT PARTNERS	
Total number:	38338
Partner Segment	**Firms**
Systems Integrator	7752
Development Srvc Co	5747
Campus Resellers	4743
ISV	3817
Trainer	2717
Breadth VAR	2580
Small/Specialty	2252
Top VAR	2156
Hosting Srvc Prov	1379
Internet Srvc Prov	1253
Business Consultants	938
Support	675
Hardware Outbound	653
Consumer Electronics	467
Unsegmented Reseller	290
Media Store	238
Mass Merchant	220
Software Outbound	160
DMR	105
Computer Superstore	51
ASP	50
eTailers	46
Office Superstore	13
General/Aggregator	7
Warehouse/Club Store	7
Niche/Specialty	6
Subdistributor	6
Apps Integrator	5
MS Direct (Rslr)	2
MS Direct (Msft)	1
Network Equip Prov	1
Network Srvc Prov	1

Official partners, numbers of firms. Data provided by Microsoft Corporation, through a summary report of the aggregate number of Microsoft partner firms across 32 sectors. This report reflects summary data from the current Microsoft partner database.

Figure 7: Hubs in interactions between proteins



Network of physical interactions between yeast nuclear proteins.

Source: Maslov & Sneppen (2002)

Figure A-1: Keystone Technology: Retail Link, EDI and CPFR

The development and implementation of electronic data interchange (EDI) systems during the 1970s and 80s enabled an estimated 3,600 vendors, representing about 90% of Wal-Mart's dollar volume, to receive orders and interact with Wal-Mart electronically. The program was later expanded to include forecasting, planning, replenishing, and shipping applications. Wal-Mart used electronic invoicing with more than 65% of its vendors, and electronic funds transfer with many.[163] By the late 80s, selected key suppliers, including Wrangler and GE, were using vendor-managed inventory systems to replenish stocks in Wal-Mart stores and warehouses. Wal-Mart transmitted sales data to Wrangler daily, which it used to generate orders for various quantities, sizes, and colors of jeans, and to plan deliveries from specific warehouses to specific stores. Similarly, Wal-Mart sent daily reports of warehouse inventory status to GE lighting, which it used to plan inventory levels, generate purchase orders, and ship exactly what was needed when it was needed. As a result, Wal-Mart and its vendors benefited from reduced inventory costs and increased sales.

The foundation of Wal-Mart's supply chain management today is a system known as Retail Link. Beginning in 1990, Wal-Mart's Retail Link also gave more than 2,000 suppliers computer access to point-of-sale data, which they used to analyze sales trends and inventory positions of their products on a store-by-store basis. In 1993, Wal-Mart's information systems expense was 1.5% of discount store sales, compared with 1.3% for direct competitors.[164] Retail Link was originally developed in-house as a proprietary Electronic Data Interchange (EDI) system to connect Wal-Mart with its suppliers, and was integrated with an Internet-based application from Atlas Commerce (now owned by VerticalNet) in 2000. Wal-Mart chose not to deploy the Atlas Metaprise software suite's order-management, purchasing, group buying, logistics, and forecast and inventory-replenishment features, which it already had in its existing infrastructure. Wal-Mart had favored in-house development of custom software in the past, in an effort to both optimize the technology for the company's unique requirements as well as retain proprietary control over the systems that were implemented. This latter concern was still evident in the deal with Atlas, which agreed to sign an exclusive deal with Wal-Mart prohibiting the software vendor from selling the same applications to the retailer's key rivals.

The latest version of Retail Link allows Wal-Mart to consolidate its purchasing globally and bring suppliers online to compete for contracts, much like a public electronic marketplace. The system extends Wal-Mart's existing supply-chain infrastructure, which is made up of its electronic data interchange networks and an extranet used by Wal-Mart buyers and 10,000 suppliers to cull information about sales and inventory levels in every store. The extranet is fed by a database that contains more than 100 terabytes of data. By expanding its traditional EDI system into a more open Internet-based exchange with Retail Link, Wal-Mart has been able to get better deals with existing suppliers through global contracts. The company has also been able to open up bids for contracts on new or different merchandise to all its suppliers – virtually impossible through the phone and fax negotiations which were previously the norm.

Wal-Mart's move from a closed EDI system to an Internet-based exchange and extranet was prodded, in part, by competitive developments, specifically the creation of the WorldWide Retail Exchange (owned in part by Gap, J.C. Penney, Kmart, and Target) and GlobalNetXchange (owned by Sears, Roebuck and Co. and French retailer Carrefour SA). As noted by CIO Kevin Turner in Information Week in October 2000:

> *"We owe the exchanges for helping us accelerate and solidify investments we made a long time ago." Turner maintained the importance of Wal-Mart's*

[163] Foley, Sharon, Takia Mahmood, Stephen Bradley, and Pankaj Ghemawat, "Wal-Mart Stores Inc.," *Harvard Business School Case Study #9-794-024* (6 August 1996).
[164] Foley et. al. (1996).

> *independent approach to exchanges and extranets, however, remarking that the online marketplaces favored by Wal-Mart's rivals actually "level the playing field, which is the opposite of gaining competitive advantage." While suppliers fear Internet hubs could squeeze their margins, Wal-Mart says the supply-chain savings the initiative should deliver will be derived from greater efficiencies on both sides. Turner insists suppliers will be able to do better planning with Wal-Mart's consolidated forecast data and gain opportunities by participating in online bidding on new lines of merchandise.* [165]

Wal-Mart's information systems have focused not only on gathering and sharing information, but analyzing that information to improve demand and inventory forecasts. While the technology and processes involved with collaborative planning, forecasting and replenishment (CPFR) are highly sophisticated, the mission is basic: to facilitate the exchange of information between trading partners to achieve precise forecasting and optimum product replenishment. In a joint pilot project in 1998, Wal-Mart and Sara Lee used the Internet to share highly precise and detailed information about which items were selling best, which items were to be promoted during a special sales event and which products were going to receive greater exposure on the sales floor, for example. Making this data readily available through the click of a mouse, rather than through telephone calls and faxes, marked a significant improvement in supply chain efficiency, allowing retailers and suppliers to quickly gauge exactly how much merchandise to send to each store.

Unlike electronic data interchange, which allowed companies to transmit to one another electronic versions of standard business documents, such as purchase orders and invoices, CPFR created a method of communicating other types of information that could not be easily captured in a standard format. Information that required more detailed text explanations and could vary from week to week or month to month could be forced into a static technical format such as EDI. CPFR, however, allows for the exchange of what might be better characterized as knowledge rather than merely information. For example, insight into how a sale on products in one department may spur increased sales in a related department could have a significant impact on forecasts.[166]

[165] Gilbert, Alorie, "Retail's Super Supply Chains – Wal-Mart inks deal to roll out private trading hub; Kmart readies an overhaul of its planning systems," *Information Week* (16 October 2000): 22.
[166] Hye, Jeanette, "Partners in Sales Forecasting," *Home Furnishings News*, 72(15) (13 April 1998): 10.

Figure B-1: Core of the NVIDIA/TSMC Relationship: The Virtual Foundry

THE CONCEPT
NVIDIA develops the core of a radical new chip for a game machine. Lacking its own silicon wafer plant and needing some added design features, it approaches Taiwan Semiconductor Manufacturing.

DESIGN
TSMC refers NVIDIA engineers to several ``intellectual-property companies'' that offer design elements, which are in the form of software code. NVIDIA licenses and downloads the needed ``IP modules'' from these companies, whose designs are compatible with TSMC's production processes.

PROTOTYPE
When the design is finished, NVIDIA logs onto TSMC's CyberShuttle Web site. It reserves "space" on a silicon wafer for a sample chip. Because the wafer can cost $250,000 and up, the same one is used for prototypes of other chip companies, reducing cost. The chip design, encoded on magnetic tape, is sent to a Taiwan wafer fab, and a sample chip is produced.

COLLABORATIVE TWEAKING
Engineers from NVIDIA in Silicon Valley and TSMC in Taiwan perfect the physical circuit blueprint for the chip over TSMC's Internet Layout Viewer. When finished, NVIDIA downloads the layout, runs computer tests, and corrects defects.

THE VIRTUAL WAFER
NVIDIA and TSMC engineers lay out tens of thousands of chips onto a wafer. NVIDIA analyzes data from the entire ``mask'' of the wafer, similar to a film negative, showing up to 18 layers, each with billions of interconnections, over the eJobview site.

RAMP UP
After making some test wafers, NVIDIA's chips go into production. NVIDIA need not physically touch a single chip. It can monitor the production status and physical whereabouts of each chip, from Taiwan until they are installed in the game machine, over TSMC's supply-chain Web site.

TOTAL TIME ELAPSED
Four to six months, compared with 12 to 18 months two years ago.

Data: TSMC, BusinessWeek, 30 April 2001.

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