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How to Harness Open Technologies for Digital Platform Advantage

As businesses reorganize around platforms, shared digital infrastructures are becoming increasingly important to build competitive advantage. Ecosystems of open software and hardware technologies, known as "technology commons," are increasingly dominating the lower levels of digital infrastructures (i.e., below the user-interface level). To leverage technology commons for platform advantage, businesses need to play the "digital commons ecosystem game." We highlight the motivations and four strategic maneuvers for playing this game, present a five-level strategic roadmap for mastering the game and provide recommendation on who should play it.[1,2]

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Growing Importance of Open Technologies Means Businesses Must Play "the Digital Commons Ecosystem Game"

Open technologies are becoming an increasingly important strategic tool for digital and nondigital businesses. In 2019 alone, Facebook released 170 new open source projects.[3] React (an open source front-end JavaScript library for building user interfaces or user-interface components), which was released by Facebook in 2015, currently powers over 2 million websites[4] and React proficiency is now one of the most sought-after skills for front-end developers. The Open Compute Project (OCP) Foundation develops open source hardware and software for data center management and is fed by contributions from over 4,000 engineers working for companies such as Facebook, Microsoft, ATT and Intel.[5] The Telecom Infra Project (TIP, a collaborative telecom technologies community) was launched in 2016 to "help connect the unconnected" in world regions with insufficient infrastructure and currently includes over

1 Varun Grover and Kalle Lyytinen are the accepting senior editor for this article.

2 The authors thank Varun Grover and the members of the review team for their thoughtful feedback and guidance throughout the review process.

3 Vinnik, D. *Facebook Open Source: 2019 Year in Review*, Facebook, available at https://engineering.fb.com/2020/01/13/open source/open source-2019/.

4 *React Usage Statistics*, BuiltWith Pty Ltd, available at https://trends.builtwith.com/javascript/React.

5 Van Slyke, D. *Open Compute Project Market Impact Surpasses $1 Billion in 2017, Announced New Initiatives*, blog post, March 20, 2018, available at https://www.opencompute.org/blog/open-compute-project-market-impact-surpasses-dollar1-billion-in-2017-announced-new-initiatives.

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Definitions of Concepts and Terms Used in this Article
Open source: Refers to any publicly accessible intellectual property (IP) that has highly permissive and nonexcludable licensing conditions that allow users to freely use and further contribute to it.
Commons resources and commons ecosystems: In the economics literature, the term "commons resources" describes resources used by many individuals in common in an agreed way.[10] A commons ecosystem is a community of users and contributors that jointly develop and build up commons resources. As a rule, commons ecosystems do not feature financial transactions among ecosystem participants.
Digital commons ecosystems: When the open source IP is a digital technology, we refer to it in this article as "digital commons." A "digital commons ecosystem" is a community of users and contributors that replenishes and deploys open source digital technologies—i.e., digital commons.
Value ecosystem: A community of hierarchically independent stakeholders, usually organized around a co-alignment structure (e.g., a digital platform) that collectively creates an ecosystem-level output targeted at a defined audience. Value ecosystems create financial and non-financial benefits for their stakeholders and feature financial transactions that ultimately underpin the economic sustainability of the ecosystem. Supply-side participants of a value ecosystem may harness digital commons created in digital commons ecosystems for the creation of financial benefits (i.e., "value") for demand-side participants. A given supply-side participant of a given value ecosystem may be an active participant in one or several digital commons ecosystems and harness digital commons from other ecosystems for the production of value in the value ecosystem.
Nonexcludable and rivalrous commons vs. digital commons: The economics literature refers to non-excludable and rivalrous commons resources: anyone can access them, and the physical resource is diminished by consumption (e.g., oil reserves, fish stocks). Rivalrous commons resources can be subject to what's known as "The Tragedy of the Commons," [11] as users compete for access to diminishing resource stocks, triggering a "race to the bottom." In contrast, intangible, knowledge-based resources, such as cultural and intellectual resources (including digital commons) are non-rivalrous: they are not diminished by consumption. Someone's use of open source code does not affect someone else's access to it. In fact, unlike physical resources, non-rivalrous resources can increase with consumption, as cultural experiences inspire new cultural products, and knowledge consumption facilitates related learning.

500 members, including Deutsche Telekom, Telefonica, Intel, Nokia and Vodafone. Incumbent telecoms technology providers continue to contribute to collaborative open source TIP initiatives, even though (as the CEO of Ericsson admitted in 2020) TIP projects will soon start eating into their service revenues.[6]

The open source movement is having a major impact on businesses. In 2015, Facebook reported $2 billion savings from an OCP design project to reduce its hardware costs. This project also eliminated 400,000 metric tons of CO2 emissions, equivalent to emissions from 95,000 cars.[7] Google reported that 10% of its employees contributed to open source projects in 2019.[8] The RISC V foundation, a Berkeley University project developing an open instruction set architecture (ISA) for microprocessors, has more than 1,000 members and was described by *The Economist* as the gravest challenger of ARM, a Cambridge, U.K.-based global leader in microprocessor design.[9]

Examples such as these show that open source has established itself as a central strategic

6 Le Maistre, R. *Ericsson CEO Sees Open RAN Impact from 2023*, available at https://www.telecomtv.com/content/open-ran/ericsson-ceo-sees-open-ran-impact-from-2023-39986/.

7 Krill, P. *Facebook Nets Billions in Savings from Open Compute Project, InfoWorld*, March 11, 2015, available at https://www.infoworld.com/article/2895067/facebook-open-compute-project-billions-in-savings.html.

8 *Open Source by the Numbers at Google*, Google Open Source Blog, August 5, 2020, available at https://opensource.googleblog.com/2020/08/open source-by-numbers-at-google.html.

9 "A new blueprint for microprocessors challenges the industry's giants," *The Economist*, October 5, 2019, available at https://www.economist.com/science-and-technology/2019/10/03/a-new-blueprint-for-microprocessors-challenges-the-industrys-giants.

10 See, for example: 1) O'Mahony, S. "Guarding the commons: How community managed software projects protect their work," *Research Policy* (32:7), February 2003, pp. 1179-1198; and 2) Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, 1990.

11 For more information, see *The Tragedy of Commons*, Environmental Justice Organisations, Liabilities and Trade (ejolt) blog, available at http://www.ejolt.org/2012/12/the-tragedy-of-the-commons-hardin%E2%80%99s-mistake/..

tool for leaders and followers in digital sectors and even beyond. As businesses reorganize their value-creating activities around digital platforms, the shared digital infrastructure is becoming an increasingly important determinant of competitive advantage. Yet few platform businesses pay any attention to what we call the "digital commons ecosystem game" that shapes these infrastructures and even fewer know how this strategic game is played and how open source dynamics connect to the overall strategies of platform businesses. (The "commons" concept and other terms used in this article are described in the text panel in the preivous page. To get the most from the rest of this article, readers should understand these. Readers unfamiliar with the term "digital commons ecosystem" may find it helpful to think of it as an "open source technology ecosystem".)

In terms of digital infrastructures and platforms, the digital commons ecosystem game is played largely "beneath the surface" at the lower levels of the infrastructure. Though open source projects help power the upper level—i.e., the interfaces through which platform businesses such as Facebook, Google and Amazon connect and interact with their customers and other stakeholders in their platform ecosystems—they usually elude strategic scrutiny. But open source projects are also embedded throughout the multilayered digital infrastructure that powers digital platforms on the surface, and they shape how the infrastructure evolves and how the value ecosystem game is played on the surface.

Sometimes, digital commons may even be used as a strategic weapon to dislodge incumbents from their dominant positions. When Google released Android,[12] a Linux-based operating system kernel for smartphones, this seriously undermined Nokia's then-dominant position in the smartphone market by shifting the critical control points away from the supply chain to applications and data. The impact on Nokia was so great that it exited from the smartphone business a decade later.

To better understand how the digital commons ecosystem game is played below the surface and how it connects to the "value ecosystem game" played on the surface, we undertook a comprehensive study of the open source activities of Facebook and Google and the various open source communities they are active in. For open source software, we looked at multiple projects within different layers of the technology stack that makes up a digital infrastructure, and for open source hardware, we looked at multiple initiatives within a given project until no significant new insights emerged from the data collection. (More details of our research method are in the Appendix.)

Our inquiry focused on five broad questions: (1) What are the motivations for firms to become active players of the digital commons ecosystem game? (2) How is the game played? (3) How does the commons ecosystem dynamic connect with and contribute to the value ecosystem game played on the surface? (4) Who should play the game? (5) What are the risks?

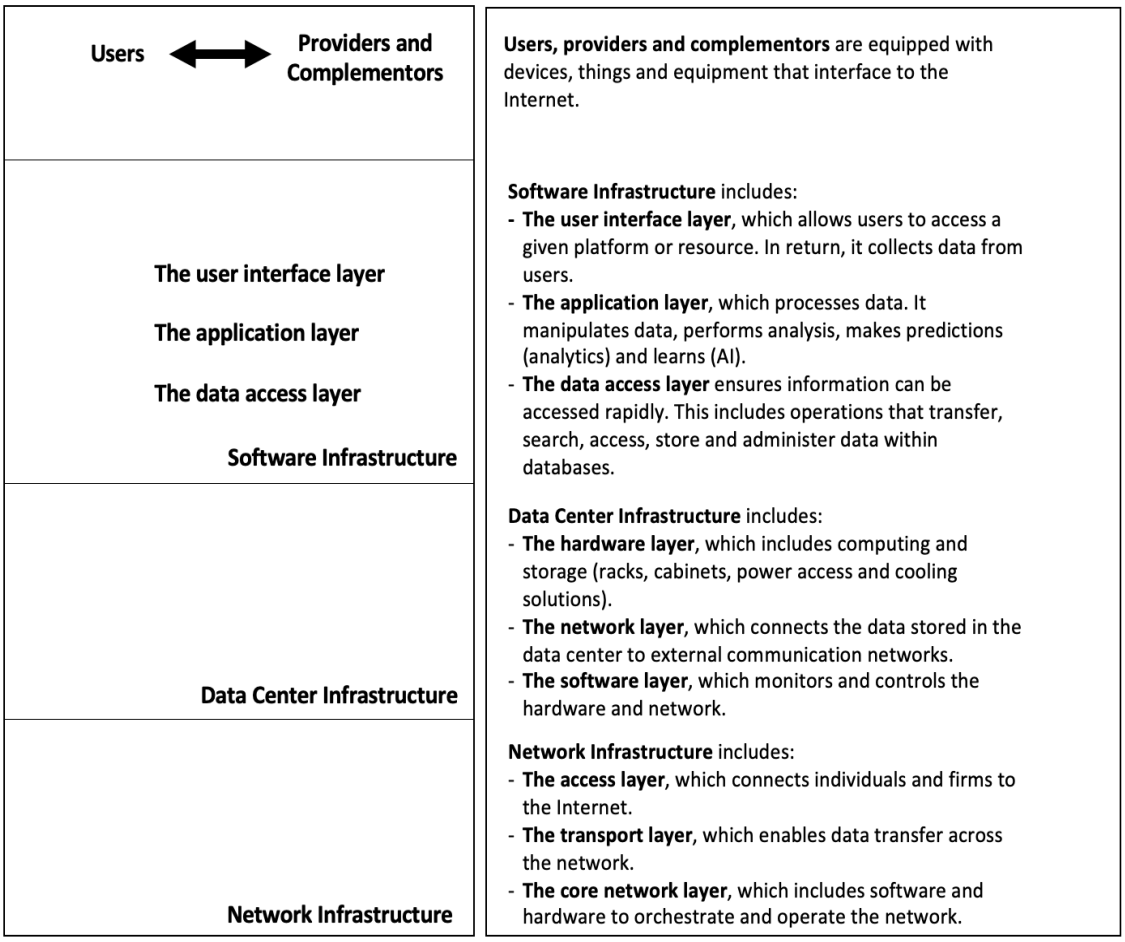
Multilayered Digital Infrastructures Underpin Competition in Platform Ecosystems

Competition in digital platform businesses differs from competition in more conventional manufacturing industries in three important respects: 1) the nonrivalrous character of digital services (the service is not diminished by its consumption), 2) the partial nonexcludability of productive assets, and 3) the winner-takes-all dynamic promoted by network effects. First, whereas conventional manufacturing firms sell proprietary and rivalrous goods on open markets, digital platform firms offer unique yet nonrivalrous services through their proprietary platforms. This makes platform scaling a very attractive proposition for digital platform owners.

Second, in conventional manufacturing industries, a firm's competitiveness is largely determined by its ability to harness valuable and excludable resources and know-how to create superior products. In contrast, a digital business's "productive machinery" is its multilayered digital infrastructure, which is mostly assembled out of open source building blocks that are shared with competitors that use them to build their own proprietary platforms on top of the digital infrastructure (i.e., the digital platform, its functionalities and data). Because, for the most

12 Android's current market share in smartphone operating systems is over 70%.

Figure 1: Multi-Layered Architecture of Digital Infrastructures



part, this multilayered digital infrastructure is nonexcludable but may constrain what the proprietary platforms can do, digital businesses have a strong incentive to monitor and influence how this shared infrastructure evolves.

Third, digital platform businesses are famously subject to self-reinforcing network effects, which can amplify early leads into hypergrowth and unassailable market dominance. Although digital services are nonrivalrous, users of the services tend to be rivalrous, in the sense that a given user is more likely to get locked into a given platform service than would be the case in conventional manufacturing sectors. This creates a strong incentive for digital competitors to attract as many early users as possible and harness the momentum thus created to drive dominance in their sector(s).

Companies such as Facebook and Google are prime examples of digital businesses that have experienced runaway success and, as a result, have had to deal with the challenge of managing massive levels of traffic on their platforms. Although their services are nonrivalrous, the ability of both Facebook and Google to service their users and clients is still constrained by the capacity and functionalities of the underlying digital infrastructure. While Facebook and Google users see a seemingly unchanging interface, beneath the surface there is a continuously growing mass of code, infrastructure, and digital resources supporting and extending these firms' operations, with new code constantly being deployed and new infrastructure being

added (e.g., server farms) in incremental steps.[13] To succeed, Facebook and Google have had to manage two interconnected ecosystem dynamics: the digital commons ecosystem dynamic that manages and manipulates the multilayered digital infrastructure that supports their platforms, and the value ecosystem dynamic through which they cash in on their proprietary platforms and related resources, notably their data.

We distinguish between three aspects of the multilayered digital infrastructure that underpins digital platforms: 1) the software infrastructure that comprises a user interface layer, a service layer and a data access layer; 2) the data center infrastructure that comprises a hardware layer, a network layer and a software layer; and 3) the network infrastructure that comprises an access layer, a transport layer and a core network layer (see Figure 1).

Understanding the Motivations for Playing the Digital Commons Ecosystem Game

The digital commons ecosystem game is played in the multilayered digital infrastructure depicted in Figure 1. In our research, we found that the strategic moves made by Google and Facebook sought to enhance their ability to extract more value from their proprietary platforms and resources—notably data. Their motivations to play the game were varied and included mobilizing users and contributors to develop shared resources, removing bottlenecks, attracting developers, reducing development costs, blocking potential challengers, and extending the scope of their value-creation and -capture activities.

Figure 2 shows some of the open source projects we studied at Facebook and Google for each of the three digital infrastructure layers. Our aim was to better understand the various motivations for platform firms to play the digital commons ecosystem game, what kinds of benefits they could achieve, and how the digital commons ecosystem dynamic connects with and contributes to the value ecosystem dynamic.

As we iterated between archival data, interviews and open source community repositories containing vlogs and conference recordings, a clear blog started to emerge. It comprised three distinct groups of motivations: operational, community-level and strategic. Operational motivations cover the immediate benefits the firm can derive from participating in digital commons ecosystems and how related benefits are linked to the current scope of the firm's value offerings. Community-level motivations cover the way platform owners play the digital commons ecosystem game to increase participation within existing and future digital commons ecosystems and ultimately drive further operational and strategic benefits. Strategic motivations are played out on the surface of the digital infrastructure at the value ecosystem level. These motivations involve either extending the firm's current value offerings, creating value offerings, undermining strategic competitors or proactively blocking threats to the firm's ability to continue extracting value from its proprietary resources. The three groups of motivations are summarized in Figure 3.

Below, we discuss our findings relating to the three groups of motivations for playing the digital commons ecosystem game, illustrating them with the open source projects shown in Figure 2.

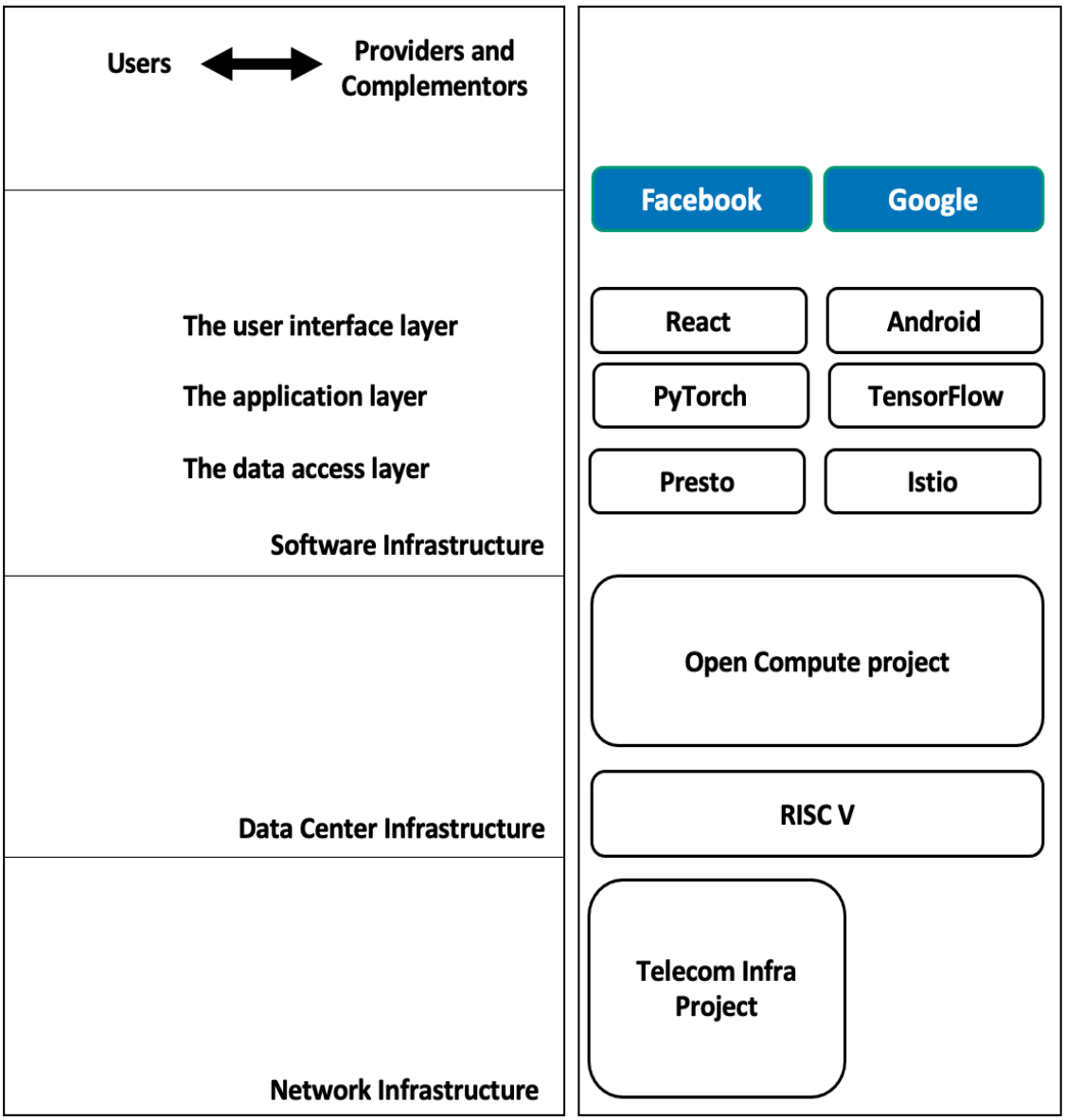
Operational Motivations

The operational motivations directly or indirectly involved enhancing a firm's capabilities to extract more value from its current proprietary resources and related value offerings. Enhanced capabilities drive corollary benefits in the form of cost savings, increased revenue and improved profitability. The most prevalent operational motivations were:

1. The need to attract, motivate and retain skilled employees
2. A desire to reduce costs by deploying a digital infrastructure that scales the firm's value offering
3. The ability to improve the firm's development capabilities and absorptive capacity
4. A wish to strengthen the firm's reputation both within and outside the digital commons ecosystem.

13 See Feitelson, D. G., Frachtenberg, E. and Beck, K. L. "Development and Deployment at Facebook," *IEEE Internet Computing* (17:4), July 2013, pp. 8-17.

Figure 2: Projects Analyzed at Different Layers of the Digital Technology Stack



First, the best developers will generally be attracted to working in businesses that deploy open source applications. Open source development is a meritocratic and transparent process where individual contributions can easily be verified in public repositories.[14] This enables developers to demonstrate their talent for potential employers. Top developers will also want to be part of companies that play an active role in open source communities because this resonates with the open source ethos. Having benefited from digital commons and having built reputational capital through their contributions, developers will usually want to be associated with employees who also actively contribute to digital commons ecosystems. A former Facebook open source leader described this effect:

> *"a lot of people who have joined Facebook in the past three or four years ... want to work at a place where something like React*

14 See O'Mahony, S., op. cit., February 2003.

Figure 3: Motivations for Playing the Digital Commons Ecosystem Game

> *can be created. It is not even necessarily just about React or GraphQL or some of our other open source technologies. It's about wanting to work in an environment where you are allowed to share what you work on with the rest of the world."*

One of our informants confirmed that some companies join open source projects simply because it helps them recruit better software developers.

The second operational motivation comes from the potential cost savings of using open source to develop and scale digital infrastructures. Digital commons reduce software costs through the reuse of resources that have already been developed, debugged and enhanced by an ecosystem of users and contributors. They also reduce development costs by harnessing multiple contributors to a project to help build high-quality, reliable software that has been scrutinized by a large community of developers. Facebook was developed through open source technologies—Linux, Apache, MySQL and PHP—right from the start. The Facebook platform has also used open source software such as Hadoop for its data infrastructure, which has helped Facebook build and scale its software infrastructure for a fraction of the cost of using proprietary technologies.

The third operational motivation is the desire to enhance the firm's software development capabilities. Digital commons ecosystems help speed up the development and deployment of new technologies because they can be tested and deployed as soon as they become available in a public repository. By becoming active contributors, ecosystem participants can improve their ability to absorb new developments faster. Moreover, companies releasing their software under open source licenses are challenged to upgrade their skills to meet high open source standards, as attested by a Facebook representative: "We find we write better, cleaner code. We are forced to create more modular, pluggable technologies that can work both within and outside the Facebook infrastructure."[15]

The fourth operational motivation for playing the digital commons ecosystem game relates to the reputation of companies. Contributing to digital commons ecosystems signals good citizenship and enhances the reputation of the

15 See *Facebook's James Pearce: Open Source Creates More Quality Code*, The Linux Foundation, 2015, available at https://www.linuxfoundation.jp/blog/2015/02/facebooks-james-pearce-open source-creates-more-quality-code/.

company. Google, for example, contributed its open dataset of nine million images annotated with 20,000 labels so the images could be used to train image recognition systems. In 2020, Google also used open technologies to develop AI tools and models that monitor the spread of Covid-19 and provide real-time information to decision makers. In addition to signaling good citizenship, such moves help reinforce the norms of reciprocity among ecosystem participants and maintain the open source ethos of sharing and contributing.

Community-Level Motivations

Community-level motivations were only indirectly connected to the value ecosystem game. Instead, they were involved with amplifying the benefits the company could derive from digital commons ecosystems by:

1. Increasing the generation of digital commons
2. Mobilizing resources to resolve infrastructural bottlenecks
3. Expanding the commons dynamic to cover more levels of the multilayered digital infrastructure.

A more dynamic digital commons ecosystem drives corollary benefits in the form of greater participation in the ecosystem, improved ability to eliminate bottlenecks and further growth of both digital commons and digital services.

First, the most frequently seen community-level motivation focused on attracting more users and contributors to the digital ecosystem, and thus increasing the generation of digital commons. Successive releases of related and mutually reinforcing technologies under open source licenses help attract more adopters and contributors. As users and contributors intersect in the ecosystem, this promotes better quality and greater trust. For example, Google released Kubernetes under an open source license to automate the management of microservices that facilitate the adoption of Cloud solutions. Subsequently, two other Google projects, Istio[16] and Knative, were released under an open source license to manage traffic between microservices and deploy code in Kubernetes. Istio and Knative complemented Kubernetes and reinforced its ecosystem by attracting further users and contributors to it.

Attracting more users and contributors also requires opening up the governance of digital commons. Previously, proprietary projects were often transferred to nonprofit foundations to coordinate the digital commons ecosystem. These transfers promoted collective governance where all ecosystem participants jointly influence technology roadmaps together with the original owner of the project.[17] Such open forms of governance promote the development of de facto industry standards that benefit everyone across the digital sector and sometimes beyond.

Another community-level motivation related to increasing resources was a desire to cultivate the next generation of open source contributors. To promote open source, Google organizes the annual Google Summer of Code, a program that awards stipends to students who successfully complete an open source project during the summer. Young developers are free to experiment and learn, and in consequence, come to appreciate the benefits offered by digital commons. Repositories and online community tools make it simple not only to access digital commons, but also to contribute to the commons.

Because most of today's developers started out in an open source environment and are comfortable with the digital commons culture, they would be reluctant to move back to a closed mode of software development. Typically, individual contributors might have started out by reporting bugs and subsequently progressed to making more substantial original contributions. For example, the developers of Lyft benefited from digital commons, and the Lyft start-up subsequently became a major contributor to Google's Istio project.

Motivations to increase the generation of digital commons is linked to two key characteristics of a multilayered digital infrastructure: its modularity and openness. As shown in Figure 1, each layer can be further decomposed into interlinked digital resources accessible through standardized interfaces. This reduces complexity and enables rapid, autonomous innovation of digital commons

16 By August 2021, Istio had amassed 27,400 stars in GitHub, signaling very strong adoption.

17 See O'Mahony, S. and Karp, R. "From Proprietary to Collective Governance: How Do Platform Participation Strategies Evolve?" *Strategic Management Journal* (in press).

through the separation of design activities and reuse of common assets. Equitable collective governance of digital commons is a key facilitator of resource amplification and mobilization.

The second type of community-level motivations dealt with mobilizing resources to remove infrastructural bottlenecks. There are two types of bottleneck: 1) infrastructural bottlenecks that constrain the ability of value ecosystem participants to scale their value offerings and offer specific value-adding functionalities, and 2) proprietary resource bottlenecks where the proprietary control of a critical ecosystem resource by a vendor limits the ability of value ecosystem participants to appropriate value from their own proprietary resources. The first results from the absence of resources to increase capacity and add functionalities. The second arises from the dependence of ecosystem functionalities on complementary, proprietary resources that are needed for value creation and appropriation.

Mobilizing resources to resolve the first type of bottleneck represents the flip side of the operational motive to increase speed or achieve cost savings by harnessing digital commons contributed by others. Many open source projects are launched with the explicit intention of speeding up capacity building and mobilizing contributors to develop new value-enabling functionalities. This explains why Google has, in recent years, emerged as a global leading contributor to basic research advances in AI and machine learning. Its initiatives to mobilize collective efforts to build momentum around a sweeping generic technology, drive technology standards in this emerging domain and develop novel functionalities have enabled Google to extract greater value from its proprietary data resources.[18]

To overcome proprietary resource bottlenecks, the commons dynamic will need to be extended to layers of the digital infrastructure that have hitherto been dominated by proprietary resources, so that digital firms can also reap commons benefits in these other areas. An example is Facebook's Open Compute Project (OCP), which brings together companies with the heterogeneous capabilities needed to design hyperscalable data center technologies. OCP currently includes many hardware and software projects for data centers—a domain currently dominated by vendors of proprietary systems. OCP was started at a time when open hardware was considered to be synonymous with hobbyist projects. The success of OCP demonstrates that the commons dynamic can also cultivate hardware commons. From the outset, this initiative was organized as a foundation and, over time, major platform firms such as Microsoft and Google have joined it. OCP has reduced both the cost of hardware and vendor dependency for adopters of its technologies.

Moreover, OCP has helped Facebook and others to advance "circular economy" practices. Facebook buys hardware that can last up to nine years, but it upgrades its server farms every three years to benefit from the latest technological developments. Thanks to the modular and open architecture of OCP, decommissioned servers can be resold to other companies with less stringent demands. This extends the life of the equipment and reduces the CO2 impact of data centers. OCP is a good role model for embedding hardware-rich digital commons ecosystems deep in the multilayered technology stack of a digital infrastructure.

Strategic Motivations

The strategic motivations for playing the digital commons ecosystem game related to extending and sustaining the firm's value-appropriation capability beyond its current realm in four ways:

1. Extending the reach of the firm's current and future value offerings
2. Undermining competitors' proprietary offerings
3. Blocking future competitors from gaining dominance through proprietary bottleneck technologies
4. Minimizing vendor dependence.

These strategic moves block threats and expand opportunities to extract value from the focal firm's proprietary resources and connect the commons and value ecosystem dynamics. These are future-oriented strategic actions deployed at the value ecosystem and cross-ecosystem levels. They also drive long-term corollary benefits in

18 Hartmann, P. and Henkel, J. "The Rise of Corporate Science in AI: Data as a Strategic Resource," *Academy of Management Discoveries* (6:3), September 2020, available at https://doi.org/10.5465/amd.2019.0043.

the form of cost savings, increased revenue and improved profitability.

An example of a strategic move to extend a firm's current value offerings to new audiences involves harnessing the commons dynamic to extend the reach of digital infrastructures to new user audiences. Facebook Connectivity Lab's mission is to extend internet access to previously unconnected sections of the world population and improve connectivity in urban and rural areas with insufficient coverage. The Facebook vice-president responsible for the lab described the program as follows:

> *"We are focused on working with industry partners to make data-driven choices about where to deploy capacity, how to optimize network designs and deployments, how to reduce costs (including operational and capital expenses), and how to drive efficiency through innovation."*[19]

The lab has applied Facebook's AI capabilities to 350 TB of images to help mobile operators plan and optimize their networks.

A related Facebook project is Tetragraph, an open source wireless system for large dense urban areas. Tetragraph uses commercial off-the-shelf components and has been tested with mobile operators in Hungary and Malaysia. Facebook was also instrumental in setting up the Telecom Infra Project (TIP), a collaboration for the telecoms sector modeled on Facebook's Open Compute Project that brings together more than 500 firms. TIP's Open RAN (radio area network) has been tested in Peru. Positioned as a technology that will support the deployment of 5G, Open RAN is not a digital commons as such, but it features open interfaces that allow for the separation of software from hardware, so that hardware from multiple vendors can be connected to the software. In the long run, Facebook will gain benefits from Open RAN because it will extend the accessibility of the Facebook platform to previously unreachable audiences.

The second strategic motivation revolves around undermining competitors by challenging their proprietary offerings. These motivations relate to the upper layer of a digital infrastructure and reinforce the motivation to extend the reach of the platform's value offerings. Consider, for example, online map offerings. The maps within Google Maps are proprietary to Google, which sells other companies access to Google Maps. To challenge this proprietary resource, OpenStreetMaps (OSM) was created in 2004 as an open source community effort to map the world. A recent OSM community wiki page mentions 1.5 million contributors and 4.5 million daily map changes and additions.[20] Since 2018, corporate contributions to this effort have risen exponentially, with Apple, Amazon and Facebook taking the lead. Microsoft has released satellite imagery that has now been integrated into the OSM editor.[21] Apple has a company volunteer initiative with 5,000 staff contributing to OSM.[22] Facebook has been using its AI technology to accelerate mapping in some South Asian countries, with nearly 1 million new streets and over 0.5 million kilometers of roads added to the OSM map for Thailand alone.[23] While this open source initiative has not seriously dented Google Maps' dominance, it does offer an option to those wishing to avoid dependency on Google Maps. Accelerating the development of OSM also signals the intent of companies such as Facebook to offer new digital experiences embedded in the real world with augmented reality applications.

Undermining a strategic competitor's proprietary resource by offering an equivalent digital commons resource for free can also extend the reach of a firm's current offerings because it makes it attractive for the competitor's user base to migrate to the newly available commons resource. We previously highlighted how the Linux-based Android smartphone operating system was developed by Google and released under a license that allowed the members of the

19 See Rabinovitsj, J. *Accelerating Innovations in Infrastructure and Advancing Global Connectivity with Our Partners*, Facebook blog post, February 20, 2020, available at https://engineering.fb.com/2020/02/25/connectivity/mobile-world-congress-2020/.

20 See Morrison, J. "OpenStreetMap is Having a Moment," *Medium*, November 18, 2020, available at https://joemorrison.medium.com/openstreetmap-is-having-a-moment-dcc7eef1bb01.

21 Although OpenStreetMaps has not dislodged Google Maps as the market leader, it does allow companies such as Apple to be independent of Google Maps. Apple currently uses OSM and its own proprietary maps. It stopped buying Google Maps in 2012.

22 See Yates, D. *How Facebook, Apple and Microsoft Are Contributing to an Openly Licensed Map of the World*, Open Data Institute, August 14, 2018, available at https://theodi.org/article/how-are-facebook-apple-and-microsoft-contributing-to-openstreetmap/.

23 *Facebook AI-Assisted Road Tracing*, available at https://wiki.openstreetmap.org/wiki/Facebook_AI-Assisted_Road_Tracing.

handset alliance to install the operating system on their devices for free. Releasing Android as a digital commons transformed mobile phone manufacturers and users into participants in Google's value ecosystem because Android facilitates sharing mobile user data with Google and connecting users to Google services. This allowed Google to further extend its proprietary resource—user data—and extract value from it. As Nokia lacked a similar proprietary resource, competing instead through the proprietary control of its supply chain and the Symbian ecosystem, Google's strategy undermined Nokia's position in the mobile handset market.

Although Android also helped Google competitors such as Amazon create their own apps marketplaces, this did not stop Google from gaining a dominant share of the mobile market. Google has subsequently made a similar move in the automotive market. Android Automotive, an open source digital commons offered to car manufacturers, is embedded in a vehicle's dashboard and connects Android devices to the vehicle's infotainment system.[24]

The third strategic motivation to play the digital commons ecosystem game is aimed at proactively blocking potential future competitors from gaining dominance that could undermine the focal firm's ability to extract value from its own proprietary resources. This *modus operandi* is becoming more widespread among providers of software infrastructure products, with many new initiatives being launched as "open source by default" or as "open source first," to preempt any form of proprietary dominance later. As an example, we studied competition among multiple open source projects in the AI field. Google's machine learning framework, TensorFlow, was released in 2015 under an open source license. In September 2016, Facebook released its own machine learning framework, PyTorch. These machine learning frameworks are capable of training specific models—for example, the GPT-3 language model released by OpenAI (a San Francisco-based artificial intelligence research laboratory), which produces human-like text. OpenAI initially used the TensorFlow framework before switching to PyTorch.

TensorFlow and PyTorch have become de facto AI standards for academics, computer science Ph.D. students and data scientists.[25] Not only do these two open source initiatives help cement a central role for Google and Facebook in AI development, but the two firms also use these AI frameworks to increase the value of their proprietary data and to accelerate the development of digital commons in other fields. This example shows that the digital commons ecosystem game is increasingly played strategically at an early stage of the development of new generic technologies. This strategic approach makes it challenging for any proprietary solution to compete against digital commons ecosystems and blocks future proprietary competition by default.

The fourth strategic motivation aims at eliminating vendor dependence in specific layers of a digital infrastructure. Closely related to the motivation of extending digital commons benefits to new domains, this strategic goal is advanced by opening the architecture of the digital infrastructure and promoting digital commons that challenge vendors' proprietary solutions. Today, this game is often played out in the lower layers of the digital infrastructure. For instance, Google and Facebook have actively contributed to the RISC V ecosystem mentioned earlier, helping RISC V to become an increasingly serious competitor to the ARM and Intel architectures.[26] A wide array of partners support the development of tools, extensions and complementary resources to RISC V's open ISA. Google has teamed up with other companies to develop verification technologies that are essential to inspire confidence in future RISC V processors. Google engineers commented:

> *"Google has been an early, strong supporter of the open silicon community. We believe deeply in a future where transparent, trustworthy open source chip designs are commonplace. To get there, we are*

24 It is premature to predict how successful Android Automotive will be, though early signals appear positive. Car manufacturers signed up for Android Automotive include Volvo, the Renault-Nissan-Mitsubishi alliance, GM, Ford and Stellantis (PSA, Fiat and Chrysler).

25 By August 2021, TensorFlow and PyTorch had come to dominate the AI platform segment. TensorFlow had amassed 158,000 stars in GitHub, making it a top-10 open source library. PyTorch had amassed 49,400 GitHub stars.

26 Market analysts project that by 2025 there will be over 62 billion RISC-V CPU cores, compared to well below 10 billion in 2021.

committed to establishing a collaborative, community-focused open source basis for free and open silicon design."[27]

Strategic Maneuvers in Playing the Digital Commons Ecosystem Game

Having identified three groups of motivations to join the digital commons ecosystem game, we now highlight how the game itself is played. We describe four types of maneuvers that companies use to influence the evolution of digital commons ecosystems: *sponsoring*, *safeguarding*, *supporting* and *siphoning*, which we call "The 4-S maneuvers." These maneuvers differ from one another in terms of their focus (primarily community-level vs. primarily participant-level) and their relationship with value activities (value co-creation vs. value capture). Sponsoring and supporting maneuvers represent a form of enlightened altruism where an ecosystem participant helps grow the ecosystem to increase its potential benefits for everyone. Safeguarding maneuvers seek to penalize free-riding behaviors that do not advance the interest of the ecosystem community. Siphoning maneuvers are best described as the pursuit of self-interest without contributing back to the ecosystem community, and possibly at the expense of the interests of the wider community.

Sponsoring Maneuvers

Sponsoring maneuvers build up momentum in a digital commons ecosystem by recruiting new participants to the community. By helping to "increase the size of the cake," these maneuvers also increase the potential benefits for all ecosystem participants. Sponsoring maneuvers also contribute to an opening up of ecosystem governance.

Sponsoring maneuvers include promoting a joint project, recruiting new members through the active management of the community, transferring a project to a foundation (thereby enabling more participative governance), establishing equal decision rights, appointing high-profile board members in an open source foundation and relicensing a software project with a more permissive license. As an ecosystem's governance becomes more open and balanced, more users and contributors are incentivized to join. Such moves accelerate innovation and value co-creation through member contributions, and a successful open source project can even become a de facto industry standard.

A good example of a sponsoring maneuver is Google's release of Kubernetes under an open source license to automate the management of microservices that facilitate the adoption of Cloud solutions. Kubernetes was later donated to the Cloud Native Computing Foundation (CNCF). Two other Google projects, Istio and Knative, were subsequently released under open source licenses to manage traffic between microservices and deploy code in Kubernetes. These maneuvers helped establish Kubernetes as the de facto standard and attracted both users and contributors.[28] Google's motives were to accelerate the adoption of Cloud solutions, and to position itself as a leader in a competitive field where it was trailing behind Amazon Web Services and Microsoft. By making Kubernetes, Istio and Knative digital commons, Google was able to significantly increase the momentum of these interrelated ecosystems, thereby increasing related benefits to all communities while also benefiting from this momentum itself—an example of enlightened altruism.

Supporting Maneuvers

Supporting maneuvers also aim at increasing the size of the cake, this time by making direct contributions to open source projects and as a byproduct of strengthening the norms of reciprocity within an ecosystem community. Digital commons ecosystem communities nurture digital commons so all participants can ultimately benefit from the joint effort. Achieving this, however, requires ecosystem participants to make active and voluntary contributions to the commons pool. Because digital commons

27 See *Google Fosters the Open Source Hardware Community*, Google Open Source Blog, October 26, 2021, available at https://opensource.googleblog.com/2019/05/google-fosters-open source-hardware.html.

28 Kubernetes is now the de facto standard for "containers." Containers decouple applications from the underlying host infrastructure, making application deployment easier in different Cloud or operating system environments. A container image is a ready-to-run software package, containing everything needed to run an application. A March 2020 CNCF survey found that 78% of companies using containers used Kubernetes.

ecosystems are not hierarchically governed, participants who actively contribute to projects also build and reinforce the social norms that encourage reciprocity among participants. Whereas sponsoring activities seek to increase the size of the ecosystem community, supporting maneuvers seek to reinforce reciprocal contributions.

Supporting maneuvers we observed included contributing to an open source project, collaborating on the definition of the architecture and open interfaces for a project, collaborating on the development of a project roadmap for future developments, combining forces on specific parts of a project and releasing complementary resources to a project under an open source license. These are all direct and material contributions to the digital commons ecosystem. The aim of these contributions is to increase the size of the cake; the larger the cake, the larger everyone's slice and the collective value generated by the digital commons will be.

An example of a supporting maneuver is React, a JavaScript Library that was open sourced by Facebook in 2013. It is one of the most starred open source projects in GitHub with 159,000 stars—an indication of its widespread popularity. React is used by developers to design user experiences and interfaces that reside in the upper layer of a digital infrastructure. Developers also collaborate with other ecosystem participants on the development roadmap that outlines future features. React Native was open sourced by Facebook in 2015 to complement React by providing cross-platform implementations of applications. Then, in 2018, collaboration between Microsoft and Facebook helped bring React Native to the Microsoft platform.

The motives of Facebook behind these altruistic moves and its dedication to making the React project a success included promoting the recognition of Facebook as a leader in the field, benefiting from all contributions and indirectly benefiting from the development of open source digital services and applications that keep users online.

Safeguarding Maneuvers

The purpose of safeguarding maneuvers is to protect an ecosystem's value co-creation potential by calling out participants that fail to observe reciprocity norms within a project. In a digital commons ecosystem, free-riding and unilateral value-extraction behaviors can be particularly destructive, because they can rapidly undermine the motivation of participants to make voluntary contributions to the digital commons and prompt them to favor alternative projects. Typically, however, digital commons ecosystems do not have formal mechanisms for penalizing those who fail to conform with reciprocity norms; thus, community participants often resort to naming and shaming offending members. Safeguarding maneuvers might involve publicly naming and shaming companies that contributed little while themselves benefiting extensively from a project and calling out influential ecosystem participants for making self-interested moves at the expense of the wider ecosystem community. Safeguarding maneuvers therefore seek to defend the commons dynamic, describe and institutionalize expected behaviors from participating companies, and protect the ecosystem's ability to create value for the commons.

An example of a safeguarding maneuver is the reaction to Google's creation of a separate organization, Open Usage Commons, when it transferred the Istio source code into a foundation structure. Google made this move to protect its trademarks, ostensibly in an effort to retain residual control of the project even after open-sourcing it.[29] This annoyed many Istio users and contributors, who saw it as an attempt by Google to retain control of Istio while continuing to benefit from the commons ecosystem dynamic. Some participants of the Istio ecosystem reacted by publicly shaming Google for its breach of the sharing norms of the digital commons ecosystem. A representative of the U.S. Air Force, one of the leading adopters of Istio, commented: "*I reached out to Google to say that if we don't get Istio within the CNCF, we'll have to drop it.*" In April 2020, Google relented, and the CEO of Google Cloud announced that the control of Istio would be transferred to a yet unnamed foundation. Google had never promised that Istio would be donated to CNCF, but participants within the ecosystem

29 Hall, C. *Istio Community Wary of Google's New Open Source Trademark Protection Scheme*, DataCenter Knowledge, July 14, 2020, available at https://www.datacenterknowledge.com/google-alphabet/istio-community-wary-googles-new-open source-trademark-protection-scheme.

were trying to make this happen to ensure that Istio would become a vendor-neutral solution for the Cloud.

Siphoning Maneuvers

Siphoning maneuvers are actions taken by influential ecosystem members that want to "have their cake and eat it too"—in other words, they want to benefit from the digital commons dynamic while retaining a degree of control of a project or by gaining specific advantages. They could attempt to achieve these objectives by restricting the degree of openness of a project—for example, by opening up the core technology while retaining proprietary control of critical complementary resources such as complementary software or the brand of the project. Or they could seek to retain governance mechanisms with unequal distribution of rights, limited transparency and skewed distribution of influence among ecosystem participants. The aim of such maneuvers is to allow a small group of companies to retain important advantages and capture disproportionate value from the digital commons without making reciprocal contributions of similar magnitude.

An example of a siphoning maneuver is when Facebook attempted to introduce a new clause in the React license stipulating that if a React user sued Facebook on any of its patents, that user's license would be revoked. This clause was a way for Facebook to pursue its own interests on the back of the success of React. However, in trying to look after its own interests, Facebook was restricting the openness of the React project for users. This move provoked a shaming reaction from the developer community that forced Facebook to retreat and adopt MIT's widely used and permissive open source license for React. Facebook justified this move by stating: "React is the foundation of a broad ecosystem of [open source] software for the web, and we don't want to hold back progress for nontechnical reasons."

Summary of the 4-S Maneuvers

The 4-S maneuvers (sponsoring, supporting, safeguarding and siphoning) described above are summarized in Figure 4.

Strategic Roadmap for Joining the Digital Commons Ecosystem Game

Over the past couple of decades, digital technologies and infrastructures have been transforming how businesses and industries operate. This trend keeps introducing major upheavals in the "rules of the game" of industry competition, the most recent being the still ongoing transformation of industries from pipeline businesses into platform businesses, as supply chains are reorganized around digital platforms.[30] This transformation continues to disrupt traditional industry sectors and, as a consequence, businesses now have to orchestrate the drivers of competitive advantage in an ecosystem of interactions built around digital platforms, rather than having direct control of proprietary supply chain resources.

We believe that we are at the cusp of yet another disruptive transformation. Over the past ten years, the relentless march of open technologies has continued to conquer the digital world and has quietly found its way into platform ecosystem competition. As highlighted in this article, this trend has the potential to transform competition by altering how valuable resources are developed and combined for competitive advantage. The platform trend caught conventional pipeline incumbents unawares by challenging them in unforeseen ways. We believe that the digital commons ecosystem trend has much the same disruptive potential, this time by challenging pipeline and platform incumbents from "below the surface"—i.e., at the lower, less-visible layers of digital platform infrastructures. As the original platform trend continues, and its reach is accelerated by the adoption of Industrial Internet of Things (IIoT) and machine learning technologies, we predict that digital commons ecosystem competition will grow increasingly important both for platform providers and for companies outside of pure-play digital sectors.

It is therefore of paramount importance that industry leaders across all sectors have a vision of how they can create value by joining the digital commons ecosystem game. This vision must

30 Van Alstyne, M. W., Parker, G. G. and Choudary, S. P. "Pipelines, Platforms, and the New Rules of Strategy," *Harvard Business Review* 94(4), April 2016, pp. 54-60, 62.

include a recognition of the strategic importance of digital infrastructures and how their firms can exploit different shades of openness to prevent vendor and supplier lock-in, capture strategic wins and remove bottlenecks that slow down growth.

To become a master player of the digital commons ecosystem game, firms need a strategic roadmap. Below, we provide a framework for such a roadmap (summarized in Table 1). The framework comprises five levels of commons ecosystem mastery—adopting, contributing, steering, mobilizing and projecting—and for each level we describe what needs to be done, why it needs to be done and how to do it.

The Adopting Level of the Roadmap Framework

At Level 1 of the framework, the company exploits digital commons to obtain cost savings as it builds its own digital infrastructure and systems. Cost savings may result from accelerated innovation because open technologies can be easily tested and open source libraries can be tapped to create new combinations of functionalities. To be successful, companies need to ensure that their management has a good understanding of both the benefits of open technologies and the practices that need to accompany their adoption. Particularly important is the need to thoroughly understand the open technology license landscape and to systematically manage the licenses of the open technologies used.

Some companies may lack the capabilities needed to integrate open source technologies within their own systems and may need to use external specialists to manage them. The downside of using external resources is that it may prevent a company from further developing its capabilities to use and contribute to open technologies.

The Contributing Level of the Roadmap Framework

At Level 2 of the framework, the company moves beyond simply exploiting digital commons to become a contributor to the open source community. As it becomes a contributor to digital commons, its absorptive capacity (the ability to adopt open source technologies) is further strengthened, its vendor dependencies are reduced and its pace of innovation increases. Becoming a contributor also enhances the company's ability to attract, motivate and retain good developers who are keen to contribute to digital commons. The company therefore needs to leverage its contributor status in recruitment processes and allow its developers to contribute to the digital commons projects they value.

Moving to Level 2 is a strategic decision that weighs both the positives and negatives of becoming an open source contributor. This entails assessing not only the benefits offered by a given digital commons, but also evaluating the dynamism and viability of the supporting ecosystem.

Moreover, to fully take advantage of participating in and contributing to a digital commons ecosystem community and to maximize reputation benefits, the business needs to adopt and promote a digital commons ecosystem mindset, from the top management team downwards. To achieve this culture change, companies can establish an open source program office that develops open source policies and processes and also educates management on open technologies. This can be a demanding change-management effort, as moving from closed to open source resources may challenge the business's deeply held beliefs and mental models.

The Steering Level of the Roadmap Framework

At Level 3 of the framework, the company not only actively contributes to digital commons, but also increasingly seeks to drive and steer the digital commons ecosystems it participates in. Steering activities can start with specific ecosystems and projects by mobilizing users and contributors and by fulfilling specific roles within the governance of open source projects. For example, financial resources or representatives from the company can be assigned to support selected communities.

At the steering level, companies start mastering the 4-S maneuvers for playing the digital commons ecosystem game. Moreover, by moving beyond just exerting influence in individual projects, companies accelerate commons generation by helping young

Figure 4: 4-S Model of Strategic Commons Maneuvers

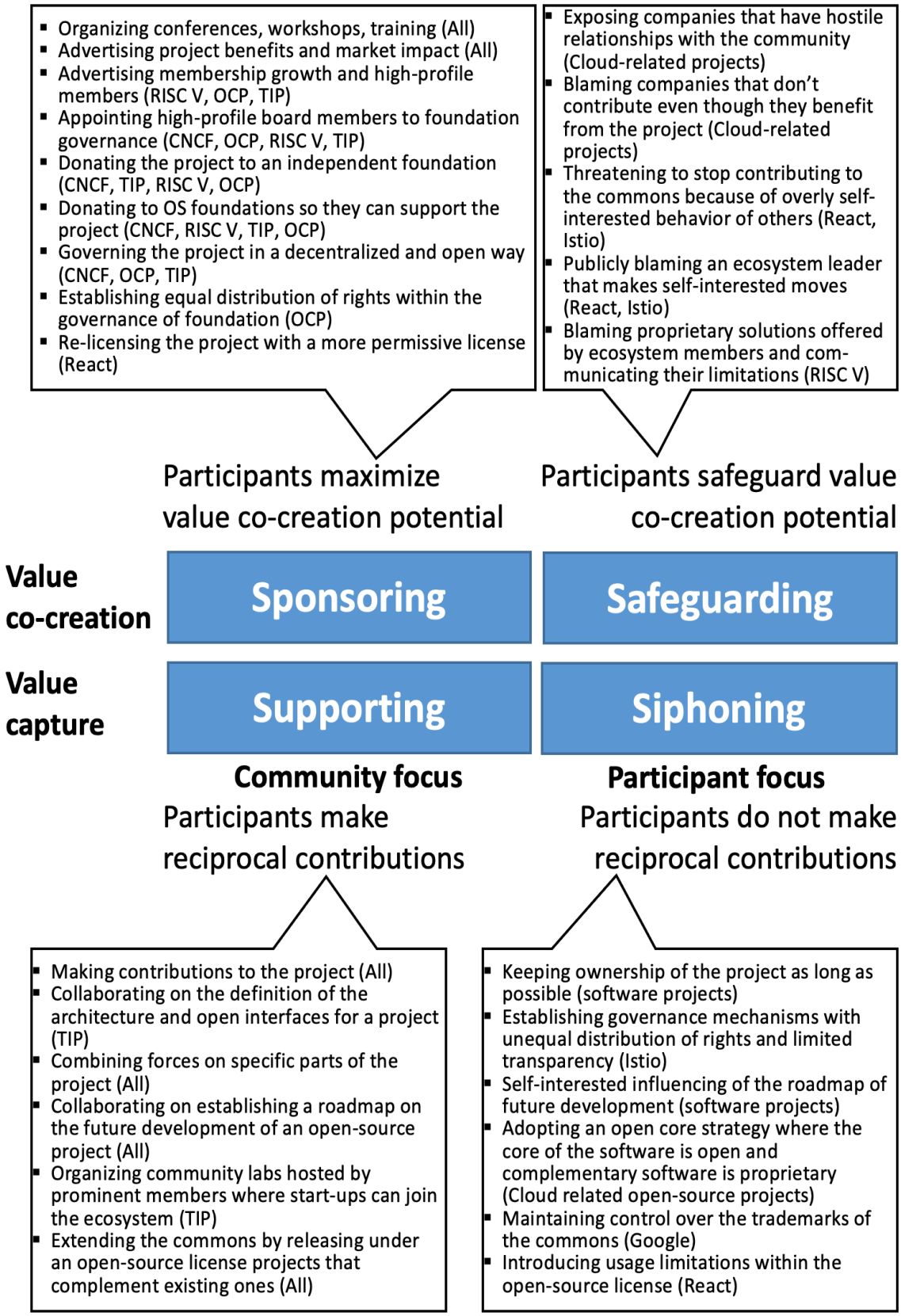


Table 1: Strategic Roadmap for Mastering the Digital Commons Ecosystem Game

	Adopting (Level 1)	Contributing (Level 2)	Steering (Level 3)	Mobilizing (Level 4)	Projecting (Level 5)
What	Tapping commons resources to build firm-level advantage.	Becoming a visible contributor to the digital commons to reap reputation benefits.	Pursuing and extending digital commons leverage.	Using digital commons to undermine competition.	Exploiting cross-layer and cross-domain leverage.
Why	Achieve cost savings when building information systems. Speed up the development and deployment of new technologies. Reduce vendor dependence.	Attract, motivate and retain the best developers. Upgrade software skills. Establish a reputation as an open source contributor.	Mobilize users and contributors in selected projects Amplify the generation of digital commons across multiple ecosystems. Consolidate and extend the reputation of the company.	Steal users from competitors. Undermine competitors' proprietary assets. Proactively block competitors from gaining dominant positions	Foster the adoption of new technology and services by using digital commons strategically across multiple layers. Extend the digital commons dynamic to other layers and domains.
How	Secure support from the legal team and ensure proper management of licenses. Gain support from suppliers that can help with the integration of open technologies. Educate management on the benefits and practices of open technologies.	Provide developers with the freedom to contribute to open source projects. Establish an open source program office. Establish clear policies and processes for open source participation. Educate management on the benefits of open source contributions. Strategically select the projects to contribute to.	Publicly support and sponsor selected projects. Establish an acknowledged leadership position in the open source community. Master the 4-S maneuvers: sponsoring, supporting, safeguarding and siphoning. Advocate the use and development of digital commons. Promote participation opportunities for other community members. Actively participate in open source governance bodies.	Integrate the digital commons dynamic in the competitive strategy of your company. Establish coalitions to undermine targeted competitors. Strategically open source hitherto proprietary domains. Adopt an "open first" strategy in emerging technology domains.	Initiate new projects that extend the digital commons dynamic to new sectors and domains. Remove multiple bottlenecks across different layers or domains.

developers make their first contributions to open technologies or by releasing advanced projects under open source licenses to the broader community. Advocating the development of digital commons further enhances the reputation of the company within and often beyond the digital commons ecosystem community.

The Mobilizing Level of the Roadmap Framework

At Level 4 of the framework, the company leverages digital commons strategically to proactively undermine and block competitors. Playing the digital commons ecosystem game at this level goes beyond operational and community-level gains and introduces broader strategic moves as part of the multidimensional, future-oriented "chess games" that companies play as they seek to build advantageous positions within their competitive landscapes. As described above in the section about strategic motivations, strategic moves at this level include using digital commons in an adjacent domain so that the company can steal users from competitors. At the mobilizing level, companies can also seek to undermine strategic competitors by eroding their proprietary advantage with a digital commons substitute. They can also proactively inhibit competitive entrants in emerging technology domains by adopting an "open first" mindset and promoting the use of open source standards in the new domain from the beginning.

All these moves require future-oriented strategic thinking. To achieve this, it will be necessary to convince senior executives that relinquishing control of assets can provide significant paybacks if executed correctly and with a strategic vision for the evolution of both commons and value ecosystems. This perspective will enable executives to recognize and realize the benefits of being an "open first" company.

The Projecting Level of the Roadmap Framework

Only a few companies have progressed to Level 5 of the framework. At this level, the digital commons ecosystem game becomes multidimensional, as digital commons leaders harness their influence and strategic position in the digital infrastructure for entry to new sectors on the surface of the infrastructure. Playing the digital commons ecosystem game at this level entails using digital commons strategically across multiple layers of the digital infrastructure and sometimes across multiple sectors on the surface. For instance, to build leadership in AI, Google has removed bottlenecks across different layers of the digital infrastructure that supports AI application. First, it released its machine learning framework, TensorFlow, under an open source license so that academics and students could easily learn and adopt it. Second, it opened rich datasets that can be used by developers to accelerate the training of AI models for new use cases in different sectors, thereby opening potential entry points for Google to these sectors. Third, Google engineers are among the leading authors of current scientific papers on the design of specialized processors for AI computing, which helps speed up the development of AI computational capacity. Google can then harness this capacity to generate more Cloud revenue.

Strategic moves at the projecting level of the framework advance openness across a multilayered portfolio of technologies to proactively eliminate bottlenecks across all the layers of digital infrastructures. Such moves help to proactively shape industry structures and accelerate the adoption of new technologies and new operational and business models. Reaching Level 5 often requires extending the digital commons dynamic to additional infrastructure layers and new domains, as illustrated by Facebook's adoption of open hardware for data centers and by open source initiatives in the telecoms sector. At this level, the company harnesses the digital commons ecosystem dynamic not only to make strategic moves against competitors but, more widely, to proactively shape the digital infrastructure itself and the diverse industry sectors it supports. In this way, activities at the projecting level help the company build future dominance across multiple sectors.

Recommendations on Who Should Play the Digital Commons Ecosystem Game and for Mitigating the Risks

Having described how the digital commons ecosystem game is played, we now provide recommendations on who should play the game

as well as when—and when not—to play it. We also highlight how playing the game might backfire (i.e., the risks involved in moving to digital commons), and provide advice on how different players should approach the game in different situations.

Digital Commons Are More Relevant for Providers of Systemic and Infrastructural Technologies

Our research shows that opportunities to play the digital commons ecosystem game tend to arise when the technology concerned is systemic, i.e., it connects with other technologies, and infrastructural, i.e., it enables functionalities that many players need to access to create value in their own business models. Stand-alone technologies and products seldom benefit from being available as commons. For example, it would make little sense for Coca-Cola to release its secret recipe as a "fizzy drink commons," given the recipe's natural excludability and stand-alone character.

If the technology is infrastructural, the provider needs to decide what benefits it can gain from releasing it as a digital commons, particularly regarding how this move would contribute to its ability to make money. The answer will be determined by the relationship of the digital commons with other resources in the technology system, notably those that remain proprietary to the technology provider. Quite often we see relatively new entrants opting for a digital commons strategy in the hope of creating and harnessing community momentum to catch up with incumbents. This was the strategy followed by Google with Android relative to Nokia, and also with Kubernetes relative to Amazon and Microsoft, both of which preferred to continue with their proprietary technologies.

Recommendations for Incumbent Providers of Proprietary Technology

Incumbents that have adopted a proprietary strategy tend to stick with this strategy for as long as possible—it can be very difficult for such a company to change its mindset from proprietary to open. Moreover, rapid changes in mindset are unlikely because incumbents are used to competing head-to-head with other providers of proprietary technologies. Incumbents therefore initially tend to downplay the impact and relevance of digital commons in their communications. But as digital commons continue to advance, they may join the ecosystem not as active contributors but as observers.

Eventually, some incumbents might be forced to adapt and ease access to their proprietary technology, which can lead to successive business model adjustments. For example, as a response to RISC V, ARM decided in 2019 to allow its users to customize instructions in its proprietary ARM chips, a key RISC V feature. However, incumbents might later decide to join the ecosystem and play the digital commons ecosystem game, which will require even more business model adjustments. Such a move can be a clever strategy for the first and second followers of the market leader. For instance, Nokia now participates in the Open RAN ecosystem, and Intel is challenging ARM through a collaboration with a RISC V start-up. However, if the incumbent's position is very strong, it can also resist the commons onslaught, an example being Microsoft's continued dominance despite the onslaught of Linux-based systems. Our research shows that incumbents better acquainted with the digital commons ecosystem game tend to resist less and leverage digital commons in parallel with their own offerings, as illustrated by Amazon and some open source Cloud complements.

Start-ups can also successfully nurture and benefit from digital commons ecosystem momentum by adopting a mobilizing (Level 4) strategy. A classic case is MySQL, which released its database application as a digital commons (with clever licensing conditions) in the early 2000s and quickly saw an active developer community form around it. The resulting momentum helped establish MySQL as the de facto standard for web-based database applications. Another example, this time in the hardware area, is Sifive, a start-up that is using RISC-V and Open Instruction Set Architecture commons strategically to scale its business. Sifive offers a platform to develop processors based on the RISC-V ISA. It has started to play a pivotal role in the industry, and Intel has announced that it will collaborate with Sifive to challenge ARM.

Risks of Playing the Digital Commons Ecosystem Game

Adopting the open source dynamic is not without risks; opening up too much or too early can backfire. For example, IBM's strategy in the 1980s to publish its PC's circuit designs and software source code in order to outsource the development of PC-DOS to Microsoft, and particularly its decision to allow Microsoft to license PC-DOS to other PC manufacturers, backfired spectacularly. IBM's attempt to regain control with its proprietary OS/2 operating system failed to help it recover control of the booming PC industry.[31,32] In hindsight, IBM overestimated the importance of its dominance in the mainframe and business markets for the emerging PC industry. Rapid advances in microprocessor technologies subsequently set the stage for IBM's eventual exit from computer hardware altogether.

Another risk of playing the digital commons ecosystem game is that the open source dynamic may create benefits for everyone without the participating company capturing a larger share of the cake. Google's complete handover of Kubernetes to CNCF undoubtedly helped establish it as the industry standard—but it also allowed Google's main competitors, including Amazon Web Services and Microsoft, to rapidly adopt it and offer it as part of their own Cloud service offerings. As a consequence, Google's ability to use Kubernetes to boost the distinctiveness of its own Google Cloud service was diminished. Indeed, there was an internal debate within Google on the merits of this move.[33] On the other hand, Kubernetes' strong position as the leading container orchestration platform helped Google establish TensorFlow as a leading platform for deep learning applications, allowing it to subsequently sell access to its proprietary Tensor Processing Units (TPUs) through its Google Cloud service.

Risks at Level 1 (i.e., adopting) of our roadmap framework are small and mitigated by taking care to choose digital commons with continued community support. Virtually any business can harness digital commons at Level 1. One can imagine, for example, Pizzerias using digital commons to design their web pages. But as a company's involvement in digital commons ecosystems becomes more active and progresses to higher levels of the roadmap framework, which requires more sizeable resource investments, risks also tend to increase. We have identified two kinds of risks.

First, the company may bet on a losing horse—this risk can be especially real in the early stages of digital commons. For example, the leading open source platform for container orchestration used to be D2iQ's DC/OS. However, D2iQ decided to adopt Kubernetes, and support for DC/OS was due to end in October 2021.

Second, if the digital commons is not completely open, the residual control of a dominant player may enable it to use a Siphoning maneuver at the expense of other community participants. Google used its residual control of Android[34] to push its proprietary applications on the platform at the expense of open source applications,[35] and the ongoing debate around Istio and Knative also reflects attempts by Google to retain some control over the trademarks of these projects.[36,37] To mitigate such risks, it is important to make sure that the governance of the commons is truly open and democratic—

31 Miller, M. J. "Why the IBM PC Had an Open Architecture," *PC Magazine*, August 12, 2021, available at https://www.pcmag.com/news/why-the-ibm-pc-had-an-open-architecture.

32 Edwards, B. "What Was IBM's OS/2, and Why Did It Lose to Windows?" *How-To Geek*, September 19, 2020, available at https://www.howtogeek.com/688970/what-was-ibms-os2-and-why-did-it-matter/.

33 Das, S. "Did Google Open Sourcing Kubernetes Backfire?" *Analytics India Magazine*, September 22, 2020, available at https://analyticsindiamag.com/did-google-open-sourcing-kubernetes-backfired/.

34 As implied earlier, there are shades of openness. For example, although MySQL retains the ultimate ownership of its source code, it allows free use of the code, as long as its users contribute any modifications they make back to the public domain—otherwise, they have to pay a licensing fee. Google provided handset manufacturers with free access to Android, with restrictions imposed on forking, for example. In the case of Kubernetes, Google handed all rights over to CNCF, but with Istio and Knative it sought to transfer its trademarks to a separate structure, Open Usage Commons (OUC), ostensibly in an effort to retain some say over trademark use.

35 Amadeo, R. "Google's Iron Grip on Android: Controlling Open Source by Any Means Necessary," *Ars Technica*, July 21, 2018, available at https://arstechnica.com/gadgets/2018/07/googles-iron-grip-on-android-controlling-open source-by-any-means-necessary/.

36 Hall, C. *Istio Community Wary of Google's New Open source Trademark Protection Scheme*, Data Center Knowledge, July 14, 2020, available at https://www.datacenterknowledge.com/google-alphabet/istio-community-wary-googles-new-open source-trademark-protection-scheme#menu

37 Krazit, T. "Confusion swirls around trademarks and Google's Open Usage Commons," *protocol*, July 17, 2020, available at https://www.protocol.com/google-open-usage-commons-trademarks-confusion.

and, if necessary, to publicly name and shame offenders to safeguard the community against incumbent opportunism.

Concluding Comments

In this article, we highlight the importance of playing what we call the "digital commons ecosystem game" to ensure the strategic use of open source resources in digital infrastructures, particularly at the lower infrastructure layers. We identify the operational, community-level and strategic motivations for playing the game, and describe four strategies—adopting, contributing, steering, mobilizing and projecting—that companies can use to influence the evolution of digital commons ecosystems as they play the game. These strategies naturally fit different types of ecosystem players, and the resource demands and risks tend to grow more important when progressing from Level 1 to Level 5 of our strategic roadmap for mastering the digital commons ecosystem game.

To date, only a few companies have reached Level 4 (mobilizing) and Level 5 (projecting) of our roadmap framework, both of which require a strategic understanding of the digital commons ecosystem game. However, we believe that, with the rapid adoption of industrial Internet of Things (IIoT) technologies, the digital commons ecosystem dynamic will become evermore important and its reach will widen at an increasing pace in the coming years.

We have found that the most important strategic challenge of playing the digital commons ecosystem game, which we liken to playing a three-dimensional chess game, is the need to redefine which resources are strategically valuable and can therefore operate as sources of competitive advantage—and in which combinations. As in a chess game, in the multidimensional digital commons ecosystem game played out in a multilayered digital infrastructure, winners and losers are seldom determined by a single move.

We believe that the effects of the trend toward open source digital commons will be felt widely beyond digital sectors. It is time for companies to start paying attention to this important phenomenon. They must become participants in the digital commons ecosystem game to better recognize and proactively manage competitive challenges that may emerge from "beneath the surface" of their digital infrastructures. The biggest mistake any incumbent can make is to assume that the current pillars of its competitive advantage will remain the same tomorrow.

Appendix: Research Methodology

The purpose of our research was to understand the different ways in which participating companies benefit from and support the creation of firm- and community-level advantages of digital commons ecosystems. Given that this is a relatively unexplored topic, we adopted a qualitative case study approach and performed comparative case analyses of open source projects to understand how the digital commons ecosystem game is played across different layers of multilayered digital infrastructures. Each case corresponds to an open source project or an open source initiative within a specific layer of a digital infrastructure.

The cases were selected through purposeful sampling, using a set of criteria consistent with our research intent.[38] We selected open source projects across the various layers of a digital infrastructure that have successfully attracted users and contributors. As our purpose was primarily (but not exclusively) to understand how incumbents play the digital commons ecosystem game, all projects involved participation by either Facebook or Google, or both. This helped us explore how digital commons ecosystem communities can be cultivated and occasionally steered to support firm- and community-level advantages. As active and well-established participants and contributors in hundreds of open source ecosystems, Facebook and Google provided a particularly informative window into this new and important phenomenon, enabling us to form generalized insights from these cases. For software, we looked at multiple projects within each infrastructure layer, and for hardware, we looked at multiple initiatives within a given project.

Data collection was structured around the following five questions: (1) What are the

38 Moser, A. and Korstjens, I. "Series: Practical Guidance to Qualitative Research. Part 3: Sampling, Data Collection and Analysis," *European Journal of General Practice* (24:1), December 2017, pp. 1-10.

motivations for firms to become active players in the digital commons ecosystem game? (2) How is the game played? 3) How does the commons ecosystem dynamic connect with and contribute to the value ecosystem game played on the surface of a digital infrastructure? (4) Who should play the game? (5) What are the risks?

For each case, we collected data from archival documents published by multiple sources, including the Open Source Foundation, firms involved in the projects and individuals participating in the ecosystems. Other data sources included trade magazines, podcasts and videos. To validate our initial findings and gain more granular insights, we also conducted multiple interviews among participants of the different ecosystems. Because of the collaborative nature of open technology projects, a wide array of data is available publicly. To avoid any potential bias caused by high-impact events, we systematically considered data recorded at different points in time. The data collected also reflects the complexity and diversity of each project. For example, in our analysis of the React software project, we reviewed material collected during five interviews as well as from presentations at conferences, blog contributions and 14 trade articles. For the Open Compute Project, we considered 187 project contributions, 17 interviews and presentations at conferences, 6 white papers and 42 trade articles. Data collection continued until no significant new insights emerged.

Because the research area is relatively new, we used a mix of approaches for data analysis. We combined inductive coding along three levels of conceptualization, analyzed how factors, behaviors and outcomes interacted, and employed temporal sequencing of events to understand how specific processes unfolded over time. For instance, benefits and competitive dynamics were coded inductively and the maneuvers emerged out of temporal sequencing of events for specific projects, after an initial inductive coding. These analyses were iteratively refined and we regularly revisited the data collected in the light of the findings as they emerged.

Finally, consistent with Engaged Scholarship practices,[39] we discussed our emerging insights with software industry practitioners active in developments outside digital-native sectors, who confirmed our findings and provided additional feedback. This also helped us gain further understanding of their concerns and visions for the future. They largely agreed that digital commons ecosystems would extend to new sectors in the future and also highlighted the degree to which this phenomenon challenges many established preconceptions.

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39 Van de Ven, A. H. *Engaged Scholarship: A Guide for Organizational and Social Research*, Oxford University Press, 2007.

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