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World of Open Source

Enabling Global Collaboration

How Open Source Leaders Are Confronting the Challenges of Fragmentation

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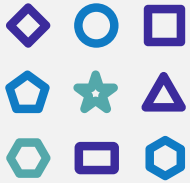
Infographic: Enabling Global Collaboration

Fragmentation is a double-edged sword, where attempting to solve fragmentation challenges could hurt innovation and competition.

There is considerable heterogeneity in the software landscape when it comes to fragmentation: Some domains are highly fragmented, and some are highly consolidated.



The principal downsides of fragmentation include increased costs and complexity for consumers and vendors of open source solutions.

Once firmly rooted in the United States and Western Europe, today's open source community is increasingly global and cosmopolitan.

Language, culture, and geopolitics remain barriers to participation in open source communities.

Diversity and inclusion are critical to building a robust open source talent pool.

Techno-nationalism poses a severe threat to open source collaboration, with geopolitical tensions creating regional silos in global innovation communities.

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Securing and safeguarding critical open source infrastructure should be a focal point for collaboration.

The need for enhanced collaboration extends to a range of Internet governance issues, including cybersecurity, intellectual property, and antitrust.

Foreword

Starting in the late 1960s as a way to share computer software, open source has become one of the most influential global collaborations representing the collective sum of humanity's knowledge due to its fundamental values of equal access, community-driven development, transparency, and inclusiveness.

In the recent past, open source has faced numerous challenges regarding security, sustainability, and legal and license compliance. Owing much to their resiliency, open source communities have collectively worked together in each instance to tackle these issues.

But there is a newfound concern. Software fragmentation, politicization, weaponization, and techno-nationalism could negatively impact open source as a collaborative framework and knowledge base for humanity; As such, these could broadly undermine the original spirit of open source innovation.

This report represents an open source practitioner's view of these challenges through extensive interviews, validating how global communities can work together to navigate complexities so that the open source mission as a global knowledge base and collaboration platform for humanity remains intact.

We express our sincere gratitude to Hilary Carter of Linux Foundation Research and Anthony D. Williams of DEEP Centre Inc., who shared our vision for this research topic and worked diligently from ideation to fruition. We also thank the many partners who participated and contributed to this research. We trust that this report will serve as a resource for all curious about the power of open source, inspiring participants worldwide to become active contributors to open source projects.

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Executive Summary

Over two decades, the open source community has grown immensely. In 2000, there were a handful of high-profile open source projects and a small number of companies and organizations to help steer the community's evolution. Today, the global open source ecosystem consists of millions of projects and an equally large and regionally diverse constellation of participants.

Growing global participation in open source software (OSS) is a testament to the ecosystem's success. However, the proliferation of open source projects and organizations also raises a vital question: Is fragmentation in the open source community impeding its progress?

This report draws on interviews with open source leaders to examine fragmentation in the open source ecosystem and investigate why it occurs, where it is beneficial, where it is problematic, and what key stakeholders are doing to confront the challenges of fragmentation. Specifically, the report examines three domains where fragmentation poses challenges: the development of open source solutions, the integration of diverse contributors from various regions of the world, and the governance of open source communities, including the role of foundations in safeguarding critical open source infrastructure.

The key findings from the research are as follows:

1. **Fragmentation is a double-edged sword**. While open source leaders acknowledge some fragmentation-related challenges in developing open source solutions, they argue that a decentralized ecosystem will always have an inherent degree of fragmentation and duplication. Moreover, the freedom to independently modify open source code produces a diversity of approaches to solving problems and generates superior solutions. While fragmentation can sometimes result in an inefficient allocation of resources, open source leaders caution that efforts to reduce fragmentation could stifle competition and innovation. In other words, solving the fragmentation problem risks killing the open source goose that laid the golden egg.
2. **There is considerable heterogeneity in the software landscape when it comes to fragmentation**. Ecosystem leaders observe that some domains are highly consolidated, whereas others are highly fragmented. Typically, fragmentation follows a maturity curve, where fragmentation is highest in the early stages of a technology's development and then consolidation increases over time. Examples of consolidated domains include operating systems (Linux), web servers (Apache), and web browsers (Chrome). Fragmented fields include embedded devices, machine learning, and blockchain.

3. **The principal downsides of fragmentation include increased costs and complexity for consumers and vendors of open source solutions**. Several open source leaders argued that the explosion of projects on GitHub signals an abundance of duplication and risks a diffusion of the community's resources. For vendors, the proliferation of competing projects places a more significant burden on their capacity to support customers. However, end users of open source solutions maintain that the proliferation of projects makes it more challenging to identify, test, and deploy suitable code libraries. Fragmentation can also reduce the open source effect of having a large community collaborate around a shared platform or standard. Finally, the most unhealthy or disruptive forks are those implemented for non-technical objectives, specifically for techno-nationalist reasons.

4. **Once firmly rooted in the United States and Western Europe, today's open source community is increasingly global and cosmopolitan**. China, for example, is a significant consumer of and contributor to open source technologies. Not only do nearly 90% of Chinese firms use open source technologies, but Chinese users are also the second most prolific group on GitHub after users from the United States.[1] However, China is not alone. Many emerging economies contain large communities of open source developers, including India, Russia, Korea, and Ukraine. For low- and middle-income countries, engagement with open source communities is giving rise to new entrepreneurial ventures and accelerating the pace of economic development.

5. **Language, culture, and geopolitics remain barriers to participation in open source communities**. While open source is flourishing globally, open source project leaders outside of North America point to language, culture, and geopolitics as genuine obstacles to their ability to maximize the participation of talented developers. Although the open source community is increasingly international, several leaders argue that organizations headquartered in the United States have outsized influence in shaping most open source projects. Open source leaders fear that a failure to address diversity and inclusion issues will curtail the open source community's access to talent and ingenuity.

6. **Diversity and inclusion are critical to building a robust open source talent pool**. The challenges of integrating different languages and cultures into open source communities are not new problems, and there is considerable confidence in the ecosystem's capacity to foster global inclusion. However, open source leaders agree that the community can do more to promote global inclusion. For example, interviewees underlined the need to invest in rapid machine translation capabilities for project communications. Leaders also discussed the importance of promoting open source norms, taming the industry's macho "bro" culture, and fostering professionalism in community dialogues and decision-making.

7. **Techno-nationalism poses a severe threat to open source collaboration**. Over the past decade, the United States and China have introduced increasingly stringent measures to restrict the transfer of critical innovations beyond national borders. Meanwhile, the war between Russia and Ukraine has heightened geopolitical tensions and made the security of technology supply chains a policy imperative. Numerous interviewees cited evidence that geopolitical tensions are creating national or regional silos in global innovation communities. Many open source leaders worry that rising protectionist measures could restrict the distribution of open source code and undermine the community's unfettered approach to international collaboration.

8. **Transparent open source development protocols are the best antidote for techno-nationalism**. To counter techno-nationalism, open source communities must alleviate fears that national interests or malicious actors could taint or corrupt

open source projects. Ecosystem leaders see reputation frameworks with enhanced peer review and third-party audits as a means to instill trust in the software development process. Interviewees also called for open source foundations and projects to position themselves as impartial actors and neutral homes for collaboration. They argue that establishing neutral, inclusive, and transparent structures for cooperation will not only broaden participation but can also reduce incentives for ecosystem participants to create parallel efforts along national or regional lines.

9. **The creation of new open source projects has seen a commensurate increase in the number of new foundations.** One empirical study found over 100 active entities across a wide range of open source projects. Ecosystem leaders say the proliferation of new foundations and initiatives is leading to a growing sense of engagement overload and vendor fatigue, with some enterprises choosing to be more selective about how and where they engage. However, as open source becomes increasingly global, many ecosystem leaders welcome the creation of new open source organizations around the world. For example, stakeholders recognize that some regional or sector-based foundations can more effectively cater to the needs of their unique constituents.

10. **Ecosystem leaders want foundations to do more to align open source projects.** Open source foundations are reluctant to play a lead role in identifying and championing winning open source projects, arguing that picking winners is a marketplace function. However, leaders do see a need for better project curation and want foundations and other ecosystem participants to make greater efforts to align projects with similar objectives. To accomplish this, foundations need to enlist skilled community managers with the experience and know-how to compel diverse stakeholders to forge alignment around shared goals. Leaders also called for foundations to bring similar projects under a shared umbrella to eliminate duplication, economize on overhead, and reduce so-called "vendor fatigue."

11. **Securing and safeguarding critical open source infrastructure should be a focal point for collaboration.** All ecosystem leaders agree that building trust and confidence in OSS and supporting the ongoing maintenance of critical open source infrastructure are urgent imperatives. Decentralized innovation is producing a remarkable tapestry of open source components that are being widely deployed to support the digital economy. However, leaders observe that maintaining these disparate components is a complex challenge that requires a transparent and coordinated approach and a more significant deployment of funding and resources from the principal beneficiaries of open source infrastructure.

12. **The need for enhanced collaboration extends to a range of Internet governance issues**. Several ecosystem leaders argued that the open source community has not been as influential or assertive in technology policy dialogues as it should be. They maintain that the absence of a coordinated open source response to such issues has left the playing field open to domination by larger, better-resourced entities. Many would like joint efforts to advance open source advocacy on Internet governance issues, including cybersecurity, intellectual property, privacy, and antitrust. Ecosystem leaders say greater alignment on policy issues among open source foundations would be helpful, along with the creation of open source program offices (OSPOs) in the public sector to facilitate engagement.

Introduction

Over two decades, the open source community has grown immensely. In 2000, there were a handful of high-profile open source projects and a small number of companies and organizations to help steer the community's evolution. Today, the global open source ecosystem consists of millions of projects and an equally large and regionally diverse constellation of participants.

Nothing underlines the open source community's growth and global reach like GitHub. In 2010, the social coding platform hosted roughly 100,000 users and 1 million code repositories.[2] As of October 2022, GitHub hosts 83 million developers, 4 million organizations, and over 200 million open source code repositories.[3] Some 74% of its global user base resides outside of the United States, with a significant increase in the share of developers based in Asia, Latin America, and Eastern Europe. Meanwhile, several breakthrough OSS innovations have come from places such as Japan (Ruby), Finland (Linux), and South Africa (Ubuntu).

Growing global participation in OSS is a testament to the ecosystem's success. However, the proliferation of open source projects and organizations also raises a vital question: Is fragmentation in the open source community impeding its progress?

On the surface, the open source community's recent track record would suggest otherwise. After all, two-plus decades of open collaboration have resulted in a potent array of reusable software components and fostered unrivaled innovation and creativity in the digital economy. One recent estimate (and most others) suggests that 70% to 90% of most modern application stacks consist of OSS, from operating systems to cryptography and networking functions to the enterprise applications running mission-critical operations for global corporations.[4]

On the flip side, open source ecosystem leaders are raising legitimate questions and concerns about whether fragmentation in the community could undermine several essential functions vital to a sustainable and thriving ecosystem. For example, consider the following three domains:

Innovation and collaboration

The freedom to see, modify, and distribute code has always been the open source community's central tenet, along with the community's decentralized production model, which frequently results in hundreds and sometimes thousands of independent contributors collaborating to build and refine open source code libraries. Even the most ardent of competitors often work together to address shared challenges, thereby avoiding the duplication of effort while moving faster to develop and adopt emerging standards and innovations.

The potency of the open source model notwithstanding, the staggering existence of 200-million-plus projects on GitHub has stirred a debate. Some open source leaders say the continued proliferation of new projects and coordinating bodies creates healthy competition between rival approaches, and competition drives innovation. Other participants argue that the explosion of projects signals an abundance of duplication and risks a diffusion of the community's resources. To what extent could increasing fragmentation in software development efforts create inefficiencies and clutter in the marketplace for open source solutions? And if fragmentation is indeed a problem in some domains, what steps should the community take to align its projects, talent, and resources?

Global inclusion

While open source is flourishing globally, open source project leaders outside of North America point to language, culture, and geopolitics as genuine obstacles to their ability to maximize the participation of talented developers. At the same time, rising global trade tensions and political conflict risk politicizing decision-making and participation in open source development communities. Rising techno-nationalism, for example, has the world's advanced economies engaged in a high-stakes contest to reign supreme in key technological domains. Could techno-nationalist policies balkanize OSS development into regional silos and frustrate efforts to foster greater inclusion and deepen the community's talent pool? Or could open source be the key to avoiding balkanization across technology? As the scope and diversity of the community increase, how can open source project leaders integrate diverse participants and successfully promulgate open source norms, ethics, and best practices?

Open source governance

Good governance is increasingly paramount as OSS becomes a vital component of critical digital infrastructure. For example, quickly identifying and rectifying security vulnerabilities requires timely and effective coordination across the globally decentralized open source community. Several open source foundations have stepped in to help steward new initiatives designed to address the ecosystem's vulnerabilities. However, the population of new open source foundations continues to multiply, raising concerns about the impact of organizational silos on cosystem governance. Are smaller, more focused organizations more efficient and effective in addressing narrower mandates defined by specific industries, regions, and application spaces? Or will the continued proliferation of projects and organizations impede efforts to create global standards, address security vulnerabilities, and promote the adoption of open source solutions?

This report draws on interviews with open source leaders to examine fragmentation in the open source ecosystem and investigate why it occurs, where it is beneficial, where it is problematic, and what key stakeholders are doing to confront the challenges of fragmentation.

- Section 2 of the report discusses the benefits and potential pitfalls of fragmentation in the development of open source code.
- Section 3 examines the internationalization of open source and highlights the tools and methods project leaders are deploying to overcome potential barriers to participation in open source communities.
- Section 4 assesses the implications of techno-nationalism for open source collaboration and proposes strategies for reducing the risks of regional balkanization.
- Section 5 provides stakeholder reflections on the state of open source governance and identifies several priorities for increased collaboration between open source foundations.
- Section 6 provides a summary of key findings and recommendations.

Enabling Innovation and Collaboration

In a study of fragmentation in OSS ecosystems, Professor Christopher Yoo at the University of Pennsylvania Law School posits that the inherent freedom of action that characterizes OSS development creates the potential for excessive fragmentation. Excessive fragmentation, Yoo alleges, creates a host of challenges for the open source community. As Yoo put it:

> "On the one hand, users' freedom to customize software is integral to the open source movement... On the other hand, infinite flexibility creates costs for the open source community by requiring the diffusion of effort and the duplication of work across multiple projects. Fragmentation also harms device manufacturers and app developers by limiting interoperability and by requiring them to adapt their products for what are now separate platforms."[5]

Yoo's research refers principally to the problem of forking in open source development projects. He argues that the most extreme form of fragmentation occurs when a contributor to an open source project customizes the community's source code to the extent that it is no longer fully interoperable with the rest of the project. The result is to divide the system into two distinct and incompatible versions. Given the economic inefficiencies that ensue, Yoo concludes that "some constraints on the flexibility of open source are thus inevitable."[6]

In discussing fragmentation with open source leaders, a starting point for many is the recognition that forking and duplication are inevitable and often desirable consequences of a decentralized ecosystem.

Decentralization, several argued, is not necessarily an optimal design for efficiency, but it is a powerful engine for innovation. "The whole open source world is a testament to the power of decentralization," said Rod Beckstrom, former CEO of ICANN and director of the U.S. National Cybersecurity Center. "One consequence of decentralization is overlap and redundancy. You cannot end the overlap without central control. You can evolve or nudge a decentralized system, but there is no means to control it."

Moreover, most participants of the study are comfortable with the reality that a decentralized open source ecosystem will always feature some inherent degree of disorder. As Mark Surman, president of the Mozilla Foundation, put it, "The point of open source is that it's decentralized. The ability to gather a set of people to collaborate around a particular problem or domain has always been the challenge and opportunity of open source. Can we pool our resources in a way that we can get enough value back out from the resources that I am putting in? The freedom to convene and collaborate means you will never have perfect order."

More fundamentally, open source leaders argue that forking is part of the standard workflow for open source projects and an essential aspect of how software systems evolve and improve over time. "In good forks, you take a code library and address a problem that the community has not previously addressed," said Tim Bird, a senior software engineer with Sony Mobile Communications. "Developers split off to address the new problem and eventually come back together to reintegrate the new code into the larger ecosystem." In practice, Jim Zemlin, executive director of the Linux Foundation, points to several reasons to fragment or fork a component, such as addressing a significant technical problem or solving security issues.

The freedom to independently experiment with an existing code library is especially beneficial when developers go off to try new

ideas, add new features, and explore new use cases for OSS. "The codebases get stronger and stronger as a result," said Mike Dolan of the Linux Foundation, "because developers address their specific use cases without breaking things for everybody else." He adds, "The key part is that developers bring those new fragments back into the core upstream open source project."

Ultimately, ecosystem leaders agree that decentralized collaboration has resulted in a remarkable tapestry of independent open source components that developers can put together to do something bigger and more useful. "We have a huge variety of software to choose from now," said Bird. "In many ways, we are in the golden age of open source." Jim Zemlin amplifies this point, noting that a typical software package has 4,000 to 5,000 open source components. "The availability of lots of reusable components dramatically increases the efficiency of software development and speeds time to market," said Zemlin. "Enterprises can innovate around the edges. They don't have to build everything from scratch. The availability of reusable components also prevents a lot of fragmentation because everyone is drawing from the same code libraries. Nobody is taking the Linux kernel and creating a new version."

Even when fragmentation produces overlap and redundancy, open source leaders warn that attempts to control or curtail the freedom inherent in open source development could be more harmful than the fragmentation itself. "Fragmentation is the innovation engine," said Mike Milinkovich, executive director of the Eclipse Foundation. "Developers must be allowed to foster new ideas and projects. Anything that brings a draconian order to the production side of the equation is doomed to fail."

"Over time, competition between rival approaches gives way to increasing consolidation as market forces separate the winners from the losers."

Fragmentation across the software landscape

Open source leaders concede that fragmentation is not a grave problem in the open source ecosystem but part of the essential life cycle in how the community develops software. Fragmentation is not only normal but largely healthy as well. As Astor Nummelin Carlberg, executive director of OpenForum Europe, put it, "The resilience of the system increases when there are competing alternatives. Competition can also drive innovation. The distributed nature of open source produces a diversity of thought and different approaches to solving problems."

However, looking across the software landscape, there is considerable heterogeneity in the degree of fragmentation, and leaders suggest that not all of it is desirable. Some domains are highly consolidated, while others feature a multiplicity of different software packages. Typically, the level of fragmentation follows a maturity curve where experimentation (and thus some inherent duplication of effort) is highest in the early stages of developing applications for a given domain. Over time, competition between rival approaches gives way to increasing consolidation as market forces separate the winners from the losers.

Several open source leaders point to Linux as a quintessential example of healthy consolidation. "Linux has been around for 32 years," said Alan Clark of the CTO Office at SUSE. "It's very mature. Sometimes you get new community distributions of Linux, but they occupy particular niches. In short, we see creativity around the edges, with developers incorporating their innovations into the main kernel."

Jerry Cuomo, an IBM fellow and VP and CTO of Technology & Consulting, adds that the open source community's ability to foster broad participation in developing and using shared platforms has been enormously beneficial. "Linux has been inviting for diverse collaboration for decades, but it also invites fierce competition," said Cuomo. "You can contribute your piece to the kernel and then pull in

proprietary components to compete with other vendors. The key to its success is the architecture and heavy-handed prescription about keeping people focused on the core Linux kernel. The Apache web server is another example of this. There is only one Apache server, and the Web wouldn't be the same without it."

Several leaders argued that, in some domains, too much consolidation is a more significant concern than too much fragmentation. "In the core areas where open source is prominent, do we have the opposite problem?" asks Mark Surman of the Mozilla Foundation. "Is open source too concentrated? And when is concentration okay? There's a big difference between the collaborative maintenance of an open standard and the dominance of a single product. In browsers, you could argue that we need more fragmentation, not less. Look at Google's Chrome. It dominates the market."

By contrast, fragmentation is prominent in domains that are earlier in the maturity cycle and where open source is less established. "Look at various aspects of AI," said Surman. "It's still early days. There are many players. Perhaps there is some fragmentation in machine learning frameworks. But it should be up to the market to decide which solutions, standards, and products will prevail."

Where else do open source leaders see challenges with fragmentation? As Tim Bird of Sony put it, "If you don't see the fragmentation, you are not looking very hard. Just look at a range of stacks. There is way too much software that does similar things. It becomes a burden. Both the consumer electronics and automotive industries have issues. Fragmentation in graphic APIs is very painful. There are no standards. Everyone is doing their own thing."

Both Bird and Clark describe the embedded device space as rife with fragmentation. "In embedded electronics, there is a natural tendency to fragment," said Bird. "It is different from the desktop and enterprise software space. To conserve resources, you tighten down the screws and build software solutions that are highly customized to the manufacturer's hardware. For example, the television stack is very different across different manufacturers. Developers code the software close to the metal to optimize performance. That causes a lot of fragmentation."

Gabriele Columbro of FINOS and Linux Foundation Europe, on the other hand, calls blockchain one of the most fragmented domains. "There are too many foundations, platforms, standards, and currencies," said Columbro. "Many players call themselves open source but not openly governed. The result is a proliferation of forks. You don't get consolidation when you don't have clear and transparent governance."

Fragmentation challenges and solutions

"Open source is reducing fragmentation, not causing it."

Several leaders consulted for the study see what they describe as problematic instances of fragmentation in the development of open source solutions. So, what are the potential costs to the ecosystem? The principal downsides of fragmentation are increased cost and complexity for consumers and vendors of open source solutions. Fragmentation can also reduce the open source effect of having a large community collaborate around a shared platform or standard, resulting in a less efficient deployment of resources.

For vendors, the proliferation of competing projects places a more significant burden on their capacity to support customers. "The disadvantage of fragmentation is that it increases costs and causes vendors to deploy more resources," said Alan Clark of SUSE. "You must track what is going on, assess the efficacy of different approaches, and sometimes you have to support multiple solutions for your customers. The duplication of effort equals more resources and more cost. And then it creates a challenge around standards and compatibility issues."

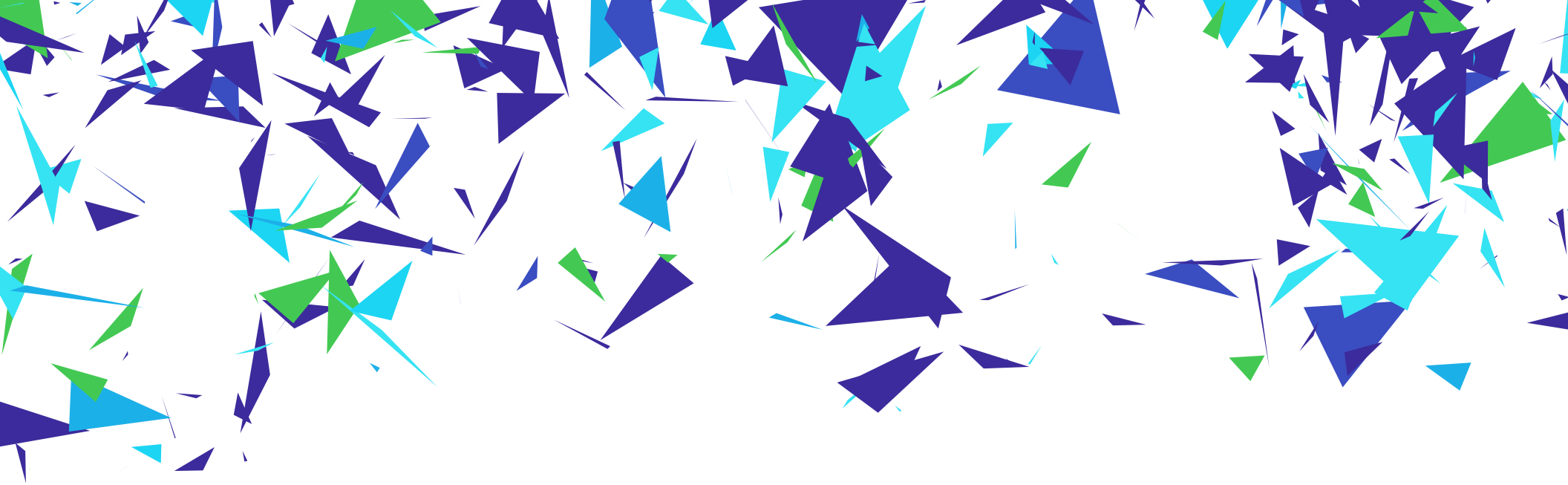
"Without open source, the redundancy and fragmentation just happen behind closed doors with lots of individual proprietary projects." **—STORMY PETERS**

On the other hand, end users of open source solutions maintain that the proliferation of projects makes it more challenging to identify, test, and deploy suitable code libraries. Tim Bird of Sony, for example, argues that fragmentation in the software environment adds time and cost to the development process for device manufacturers. "We look for open source code libraries to tackle particular problems," said Bird, "but when the open source projects proliferate, it requires a lot of research and customization to find a library that is suitable for our needs." Maintenance is another challenge, according to Bird. "When new forks emerge, it splits the community and results in fewer developers on each fork to fix bugs or address security concerns. Fragmentation creates duplication of effort. We lose the open source effect."

According to Jerry Cuomo of IBM, fragmentation can create additional inefficiencies in the marketplace for solutions. "For open source to work well on the business side, you need a healthy ecosystem of competing solutions that orbit around shared platforms," said Cuomo. "An enterprise that uses open source needs to know that the vendor will support its solution. Can I trust it? Is it secure? What if the vendor lets you down? What do you do?" Cuomo and others note that enterprises can freely move from vendor to vendor when the vendors work around a shared platform. "They can go for better prices and better solutions," said Cuomo. "It creates healthy competition and lowers lock-in and switching costs for enterprise users. Non-fragmented ecosystems create an open economy. When it's fragmented, you don't have that as much."

For the broader ecosystem of contributors to open source solutions, there is an argument that duplication and redundancy represent an inefficient deployment of the community's resources. "On the one hand, you can argue that overlapping or redundant efforts are a waste of talent and resources," said Astor Nummelin Carlberg of OpenForum Europe. "On the other hand, we also see gaps in the marketplace, with competing projects in high-demand areas and less focus on critical areas that demand attention."

In the final analysis, fragmentation is a double-edged sword. On the one hand, the software ecosystem needs healthy competition between rival ideas and approaches. Nobody consulted for the study wants to reduce fragmentation at the expense of competition and innovation. Moreover, looking across the entire software landscape, there is a solid case to be made that open source is reducing fragmentation, not causing it. As Stormy Peters of GitHub put it, "Without open source, the redundancy and fragmentation just happen behind closed doors with lots of individual proprietary projects."



On the other hand, leaders acknowledge that a decentralized open source ecosystem will inevitably produce duplicate projects and, thus, some inefficiencies for vendors and other participants. “For a company like SUSE and other vendors,” said Clark, “duplication creates a challenge because we need to be selective regarding which projects we will support. Which projects offer the most robust solution and a supportable future? Which solutions are the most relevant to our customers?”

Some enterprise leaders suggested that open source foundations could intervene in fragmented domains by helping to identify and champion winning solutions. However, foundation leaders pushed back on this idea, asserting that market forces rather than foundations should determine the winners. “We help competitors, suppliers, and customers all work together and build things in a neutral forum,” said Mike Dolan of the Linux Foundation. “And, in an open forum where anybody can participate, people vote by showing up. If they show up with their developers, resources, and buying power, those projects can become de facto standards. That’s how the tech industry picks winners.”

Most open source leaders agree that when the ecosystem follows open source principles, the fragmentation and duplication of effort get resolved over time. “We want to see different ideas in a new space, and we want them to try them out in rapid succession,” said Mike Milinkovich of Eclipse. “Open source is the best way to do that. You do not want to corral that innovation; we want to encourage it. Competition will determine the winners and losers. Over time, projects will consolidate, and the ecosystem can move forward.”

Open source leaders also insist that intelligent project design can go a long way toward reducing unnecessary fragmentation. Establishing neutral, inclusive, and transparent structures for collaboration will broaden the tent and reduce incentives to create parallel efforts. “When we launch a project, we do it in a way that says this is going to be neutral,” said Mike Dolan of the Linux Foundation. He points to Kubernetes, where Google went to great lengths to distribute control over the project and reassure other contributors that Google was ready and willing to collaborate. “Google could have open sourced Kubernetes and kept all the maintainer control,” said Dolan. “Instead, they handed off key parts of the codebase to other companies and leaders who proved very capable of doing it. In doing so, Google got broad buy-in and helped make Kubernetes the de facto standard for the industry.”

Promoting Global Inclusion

Once firmly rooted in the United States, today's open source community is increasingly global and cosmopolitan. China, for example, has become a significant consumer of and contributor to open source technologies. Not only do nearly 90% of Chinese firms use open source technologies,[7] Chinese users are the second most prolific group on GitHub after users from the United States.[8]

With China intent on boosting its software prowess, Chinese participation in open source will increase dramatically in the years ahead. China's Ministry of Industry and Information Technology (MIIT) has expressed concerns about its domestic software industry's international competitiveness and sees deeper participation in international open source projects as a means to place itself on an equal footing with global players.[9] Among the plans to improve the state of homegrown software, the MIIT is investing in a series of software parks, implementing additional policy supports, and creating two or three open source foundations or communities to bolster China's international influence.

"A global open collaboration orchestrated by an effective foundation is arguably the best way to reduce fragmentation and promote international cooperation."

Chinese technology leaders have already initiated and championed several prominent open source projects. Alibaba, for example, has one of China's most robust open source talent pools. An active participant in RISC-V, the global open source semiconductor community, the e-commerce giant recently took the bold step of open sourcing its semiconductor design development via the OpenXuantie project.[10] In another example, Baidu launched Apollo in 2017, which has since evolved into one of the world's leading open source solutions for autonomous vehicles.[11] Baidu is leveraging driverless technology in its Apollo Go robotaxi service. The autonomous taxi service currently operates in five Chinese cities, but the company plans to expand Apollo Go to 65 cities by 2025 and then 100 cities by 2030.[12]

China is a prominent example of the globalization of OSS. However, many emerging economies contain large communities of open source developers, including India, Russia, Korea, and Ukraine. Harvard Business School researchers Nataliya Langburd Wright, Frank Nagle, and Shane Greenstein observe in a recent study that "Just like their counterparts in developed economies, programmers around the globe employ open source tools, speak the vocabulary of open source, and interact with open source libraries."[13] Engagement with OSS communities, in turn, is giving rise to new entrepreneurial ventures and accelerating the pace of economic development. Wright, Nagle, and Greenstein conclude that "[OSS] represents an opportunity for low- and middle-income countries to reach the technological frontier more quickly than if they needed to develop such software from scratch or obtain it from costly sources..."[14]

Calista Redmond, CEO of RISC-V, argues that a global open collaboration orchestrated by an effective foundation is arguably the best way to reduce fragmentation and promote international cooperation. "Collaboration on open standards and software has proven throughout history that alignment to a shared collective model reduces the temptation and economic feasibility for ecosystem participants to take a proprietary approach to common building blocks," said Redmond. "We are creating a strong foundation with a global community where roughly one-third of our members are in NA, one-third in AMEA, and one-third in APAC."

"It's easier to collaborate globally now," said Redmond. "We have the technology to support globally distributed teams." Redmond points to growing global participation in RISC-V's technical working

groups. Today, RISC-V has 65+ working groups. Redmond said there could be 80 by the end of 2022. "Now we are starting to ship actual products in a variety of vertical markets, including automotive, industrials, transportation, and aerospace. It's a remarkable time. We are building a robust ecosystem across workloads, from embedded to enterprise, and accomplishing in five or six years what it took earlier microprocessor architectures 20 years to do."

The barriers to global participation

"The hegemony of North American participants can overshadow open source projects that originated in other parts of the world."

Open source leaders consulted for the study agree that global participation in open source is on the rise. However, there is also broad recognition that a failure to eliminate several formidable barriers to full participation could result in regional fragmentation in the open source ecosystem. For example, leaders point to language, culture, and geopolitics as ongoing challenges. There also remains a prevalent sense that companies and foundations headquartered in the United States have outsized influence in shaping most open source projects.

Among the first challenges raised by interviewees is the tech industry's long history of systemic discrimination, including its deeply entrenched sexism and its dismal record on diversity and inclusion. Interviewees suggest that open source communities are not immune to these challenges, despite the community's efforts to address them. "Some parts of the open source world still feel like old school 'bro' culture," said Mark Surman of the Mozilla Foundation. "That's a big issue in a world where diversity of thought and experience are key assets."

Open source leaders fear that a failure to address the open source community's "bro" culture will curtail its access to talent and ingenuity. "The people who don't feel welcomed will build technology in other ways," said Surman. "Unfortunately, that could mean that the best talent will build proprietary technology because they don't have the time and resources to contribute for free."

Ramon Roche, general manager of the DroneCode Foundation, argues that another cultural barrier to global participation is the lack of acceptance of open source methods and principles in some regions. "In Latin America, we still lack validation that open source is a key component of success and a valid way to produce software," said Roche. "Managers and decision-makers don't understand how the open source community works, and developers often fight uphill battles to contribute to open source efforts."

When Roche started creating open source code for drones 10 years ago in Mexico, he struggled to find a vibrant open source community locally and lacked the know-how to build one from scratch. "There was nowhere to go for support or help," said Roche. "Most of the open source organizations are based in North America. The established tech players like Google, Meta, and Microsoft, and the people that work there, control what is going on. They lead steering committees as well. You need to finance your seat or be a maintainer or top contributor to be visible and influential in the community."

The hegemony of North American participants, in turn, can overshadow open source projects that originated in other parts of the world. "Latin American developers and software startups would like to see more acknowledgment that we exist," said Roche. "Projects in Latin America are often overlooked. If you actively look for them, there are communities and companies across the continent, but they sit outside the core of the open source community."

Reflecting on the Japanese experience, Noriaki Fukuyasu, VP of Japan Operations at the Linux Foundation, says the pace of innovation is slower than in North America, and enterprise IT managers are less comfortable with open source. "We have fewer engineers on the user side driving innovation," said Fukuyasu. "They prefer what they perceive to be the more stable, proprietary solutions, and their reticence to experiment is slowing down transformation."

Even when Japanese enterprises adopt OSS, they are less likely to contribute their modifications back into the upstream code. "They use open source, but they tend to modify locally," said Fukuyasu. "They rarely apply the new patches, even though the patches and fixes exist." Fukuyasu attributes the dearth of engagement to the fact that Japanese enterprises outsource much of their IT management to external vendors. "They don't see open source as a core competence and, as a result, the community of open source developers is quite small relative to the United States."

For the community of open source developers in Japan, it can take time to adjust to open source norms. "Culturally, people are not comfortable showing off their thoughts in public forums, online chats, and mailing lists," said Fukuyasu. "Language is also a big issue. For example, delaying the translation of project materials when launching a new project can significantly slow down adoption by the Japanese community."

The building blocks for global inclusion

> "The scale of the challenge is much larger now because of growing participation." —JIM ZEMLIN

Creating a more equitable balance of power and promoting global inclusion are critical to the future of open source, especially its talent pool. So, what can the open source community do to avoid fragmentation along regional and cultural fault lines? Key suggestions include championing diversity and inclusion, investing in better translation, fostering professionalism, educating participants about open source norms, and using in-person events to build trust.

Open source leaders say that policies and practices that foster diversity and inclusion are vital starting points. "It's not only about gender," said Alan Clark of SUSE. "Diversity is also about being aware of the different cultures within our global developer community and ensuring that community methods are inclusive." Clark says collaboration is part of the DNA at SUSE and claims that executives have made efforts to understand and adapt the company's processes to the unique cultural dynamics in different regions of the world. "Diversity is increasingly key to building a strong talent pool. You can bring in new perspectives and insights. That integration of global perspectives has made open source more successful."

Jim Zemlin of the Linux Foundation argues that open source projects should also have DEI requirements but that policies alone are insufficient. "Having a set of collective cultural norms is key," said Zemlin. "But the scale of the challenge is much larger now because of growing participation from around the world." Zemlin points out that social coding platforms can help identify challenges in integrating diverse participation by measuring the form and nature of collaboration. "In 2022, project leaders and open source companies can measure every digital engagement touchpoint. Are there small voices and loud voices? Are you successfully onboarding new developers? How long does it take for individuals to contribute to discussions actively?"

Digital engagement data can inform decision-making. Then it's up to leaders to foster a project ethic and culture that attracts diverse participants. "What people miss is the aspect of highly skilled individual leadership," said Zemlin. "You need a technical subject matter expert with the human qualities to lead. And not just people but also the companies who are participating. Pulling these diverse international networks together takes a lot of capability."

An essential task for project leaders is taming the macho "bro" culture that pervades today's tech world. "We insist on a professional culture," said Mike Milinkovich of Eclipse. "To increase inclusion, you must focus on professionalism in your dialogue and behavior. Keeping things professional helps smooth cultural differences around conflict resolution and project communication."

At the operational level, open source leaders are also addressing language translation challenges. English may be the lingua franca of the software world, but project leaders outside of North

America insist that translating project communications into native languages drives broader participation. For example, Ramon Roche of the DroneCode Foundation claims that translation and language are genuine barriers in Latin America and has experienced the same challenges in engaging developers from Asia. "Asian communities have been eager adopters of our open source solutions for drones," said Roche. "We found that although they were using our software, they were not contributing very much back. So we hired a bilingual community manager, and she helped us reach those communities. We translated our materials into Korean and Chinese and have seen a large influx of new users." In addition to translating project materials, DroneCode started using popular messaging tools such as WeChat and then went to work translating its user interfaces. "Our Chinese membership picked up significantly once we organized a community to help with the user interface translation efforts," said Roche. "Companies that used to clone our work are now active participants."

"Rapid translation is the key to fostering greater engagement."

—NORIYAKI FUKUYASU

Manual translation is time-consuming and expensive, so open source leaders see machine translation as the future. Linux Foundation Japan, for example, is working with Japanese institutes to implement machine translation systems that will speed up the translations of project materials and user interfaces. "Rapid translation is the key to fostering greater engagement," said Noriaki Fukuyasu. "We are working on it 24/7. The scale of the translation challenge has exceeded what can be done by human resources."

Fukuyasu and others also argue that the return of in-person events in the post-COVID-19 era will expand the person-to-person connections required to solidify trust in the community. "Japanese people are generally reluctant to contribute until they have had an opportunity to meet the people they are working with," said Fukuyasu. He explains that events build trust by allowing developers to establish a rapport with project maintainers. "COVID-19 put a hold on our Linux Foundation gatherings, but we are eager to get that going again to foster those international connections."

Transcending Techno-Nationalism

While global participation in open source is increasing dramatically, the rise of techno-nationalism is pulling in the opposite direction. The competition for national technological superiority is such that ecosystem leaders worry that geopolitical tensions could undermine the international collaboration on which the open source software community depends.

For decades, technology has driven increased interconnectivity and global commerce. Yet, today, investments in technology and innovation are becoming inextricably bound up in geopolitical rivalries. In short, geopolitical rivals are engaged in an increasingly high-stakes contest to reign supreme in the technological sectors thought likely to dominate the 21st century, from robotics and artificial intelligence (AI) to the industrial Internet and advanced telecommunications networks.

Alex Capri of the National University of Singapore defines techno-nationalism as "a mercantilist behavior that links a nation's tech capabilities and enterprise with issues of national security, economic prosperity, and social stability."[15] This new brand of techno-nationalism has seen countries worldwide move to restrict the transfer of critical innovations beyond national borders, believing that doing so will spur national economic growth and foster domestic competitive advantages. As a case in point, Capri cites "the steady progression of export controls on tangible, hard technology, followed by restrictions on data access and usage, and, most recently, new controls … that will impede the free movement and development of human capital."

Some public and private sector leaders believe that borderless technologies will transcend these nationalist tendencies and drive increased interconnectivity in the years ahead, just as they have in the two decades prior. For example, at a recent meeting of the World Economic Forum, Jayraj Nair, chief technology officer of IT services company Wipro, argued that technology will only accelerate globalization. "As far as technology is concerned, the scaling of AI, or 5G, or blockchain, any of these technologies will increase the velocity [of globalization]," said Nair. "In fact, the velocity will only exponentially escalate."[16]

Other observers are less sanguine and forecast a new era of deglobalization due to the increased geopolitical tensions and the rise of protectionist measures deployed by various nations. In 2019, for example, Beijing took aim at American technology companies by ordering its government agencies and public institutions to stop using foreign-made computers and software. More recently, Washington broadened the scope of the advanced technologies covered by its export control regulations to include semiconductors. In addition to stemming the flow of critical technologies, Washington is also pursuing a worldwide campaign to block the adoption of 5G wireless technology developed by Chinese telecom giant Huawei.[17] The net effect of these measures is a decoupling of strategic rivals from global supply chains, digital platforms, and knowledge networks.

Will techno-nationalism balkanize open source?

How will techno-nationalism impact collaborative, knowledge-intensive activities such as the creation of OSS? Consultations for this study revealed a spectrum of opinions. On one end of the spectrum are those who think that techno-nationalism is fundamentally changing how global innovation networks operate by inserting political considerations into otherwise technical decisions about who participates, on what terms, and to what ends. Several individuals consulted for the study pointed to concrete examples in which geopolitical tensions resulted in national or regional silos.

Others see techno-nationalism as more of a looming threat than a real obstacle to open source collaboration at present. All agreed, however, that techno-nationalism poses a danger to global cooperation and that open source communities should commit to political neutrality.

"Code review in OSS is about improving the code quality and building trust between developers," said Han Xiao, the Berlin-based founder of Jina AI, a commercial OSS company. "Adding politics to the code review will hurt both and eventually roll back the open source movement in China."[18] Xiao identified the creation of Gitee, a state-backed Chinese competitor to the international code repository platform GitHub, as a clear sign of nationalist prerogatives trumping the open source community's predilection for unencumbered global collaboration. Gitee has become a backup plan of sorts for Chinese organizations concerned the U.S. might someday change its laws in an attempt to exclude Chinese participants from open source codebases. That is a highly unlikely scenario, given that open source is publicly available and that it is impossible to block any one country's access, but it has factored into backup plans.

"Geopolitical conflicts and tensions are fragmenting the open source community around national interests."

Rebecca Arcesati, an analyst at the Mercator Institute for China Studies, also sees Gitee and similar homegrown Chinese alternatives to foreign-owned platforms as part of a broader attempt by the Chinese government to lessen the country's reliance on American tech giants and insulate the domestic open source community from risks arising from geopolitical tensions. Arcesati argues most Chinese developers don't want to be cut off from global open source networks and are circumspect about China's direction. "The more Beijing tries to nationalize open source and create an indigenous ecosystem, the less eager developers will be to participate in what they perceive to be government-led open source projects," said Arcesati.[19]

Peixin Hou, chief software architect and community director for Open Source of Huawei, is another of those who see evidence that geopolitical conflicts and tensions are fragmenting the open source community around national interests. He says Chinese users and developers of OSS are concerned that the U.S. government might expand its trade restrictions into the open source world, which would be harmful to both sides and eventually undermine collaborative innovation between nations.

Hou and others voiced concerns that forks could emerge in key software platforms to enable national economies to control aspects of the technology domestically. And then there is the risk that techno-nationalism could diminish the global open source talent pool. "Developers in China have concerns," said Hou. "Will contributors from certain countries be discriminated against when they participate in open source projects? Could concerns about national security lead developers to reduce their participation if geopolitical tensions escalate further?" Hou worries that techno-nationalism runs the risk of excluding a significant source of talent and ingenuity. "The trust between developers and open source communities has traditionally depended upon the contributions of individual developers instead of his or her country of origin or organizational affiliation, but is this going to change?" asks Hou.

The ongoing conflict between Russia and Ukraine has also raised alarm bells for some open source projects. Ramon Roche of the DroneCode Foundation says the war in Ukraine has changed everything. "Drones are being widely deployed in the conflict," said Roche, "and that brings the security and safety of the supply chains into critical focus." Roche says the U.S. and European countries only want drones developed by trusted manufacturers. "They also want to ensure that foreign entities are not embedding malicious code in the open source systems for the drones."

"Europeans see open source as an opportunity to enhance digital autonomy and sovereignty and lessen their dependence on US tech giants."

—ASTOR NUMMELIN-CARLBERG

For years, the DroneCode Foundation worked closely with Chinese developers. As of now, Roche says end users from certain regions can't use software or hardware developed by Chinese companies. "We want open collaboration," said Roche. "We don't want to exclude any developers. They can make valuable contributions, and they can be totally innocuous. Unfortunately, we also have a big Russian community that has completely stopped contributing. We don't even talk now. We had active contributors. We had companies doing research and development in the drone space. They are now completely out of the loop."

Astor Nummelin Carlberg of OpenForum Europe claims techno-nationalism is also rearing its head in Europe. "The issue of excluding companies and other participants from standards bodies and open source projects based on nationality has become quite contentious," said Carlberg. He notes that there have been cases where European companies have been unwilling to participate in international open source projects in which Chinese companies are also present because of the perceived legal uncertainties and the risk of a policy backlash at home. At the same time, he sees European policymakers attempting to insert national objectives into open source projects. "Europeans see open source as an opportunity to enhance digital autonomy and sovereignty and lessen their dependence on U.S. tech giants," said Carlberg. As a result, "European countries often push for greater European participation in standards bodies, and there are discussions around the creation of uniquely open source projects and foundations."

Tackling techno-nationalism with transparency and trust

Despite widespread concerns, there is considerable confidence among open source leaders that transparent open source protocols can help the community transcend techno-nationalist tendencies.

Alan Clark of SUSE says he sees the risks of techno-nationalism. "It's hard to counter it," he said. "However, the solution is to be open. You can alleviate many concerns about the subversion of code to national interests or other agendas by being open and transparent with your communications and recording all your decisions and how you arrived at those decisions. We need OSS development to transcend national interests. Otherwise, we risk real fragmentation."

Chris Aniszczyk, chief technology officer of the Linux Foundation, notes that mature OSPOs are increasingly helping their organizations navigate project politics and overcome any proclivities toward techno-nationalism. Aniszczyk argues that OSPOs can help organizations "understand and navigate project politics, such as maintaining a neutral stance when multiple influential actors are attempting to steer a project or illuminating the latent political considerations of community members." He suggests that "OSPOs can help companies maintain a neutral posture on techno-nationalism and bridge political differences by cultivating personal and working relationships that transcend national boundaries and political realms. Increasingly, this value extends to the work of foundations and nonprofits, as those realms become important neutral spaces in open source."[20]

"The open source community is a great stage for track two diplomacy." **—ROD BECKSTROM**

Ramon Roche of the DroneCode Foundation agrees that transparent protocols are the key to ensuring that open source projects operate without geopolitical tensions influencing how and when they engage with talented developers**.** "If your infrastructure is secure, and you have robust processes for testing and deploying new software, then you can trust the source code no matter where it comes from," said Roche.

Rod Beckstrom goes even further, suggesting that open source communities could provide informal bridges to help reconcile geopolitical tensions. "Look at science and its rapid progression on so many fronts," said Beckstrom. "The progress continues despite the politics and the tensions between the U.S. and China." He expects open source will follow a similar trajectory to other scientific disciplines. "In fact, the open source community is a great stage for track two diplomacy," said Beckstrom. "We need to build mutual trust and respect. Open source collaboration provides an opportunity for informal networking and relationship building."

In the end, open source leaders agree that countries that close off collaboration at national borders will be less successful than those that embrace global cooperation and its benefits. "Fragmentation due to techno-nationalist imperatives is inherently misguided," said Jim Zemlin. "Policymakers are the ones creating these tensions. Many don't even realize that they are giving up the good stuff because of a lack of trust, including faster times to market and the ability to leverage a much larger developer community."

Breaking Down the Governance Silos

Most of the early open source projects, including Linux and Apache, grew out of the voluntary efforts of a small but dispersed group of individuals. As the projects gained commercial traction, concerned stakeholders came together to create nonprofit organizations that could provide the legal and economic infrastructure for ongoing community collaboration and make projects such as Linux less dependent on the individuals who initiated them. The resulting OSS foundations, including the Linux Foundation, the Apache Software Foundation, and others, are now integral to the open source ecosystem.

The creation of new open source projects has seen a commensurate increase in the number of new foundations. Javier Cánovas of the Universitat Oberta de Catalunya recently led an empirical study of open source foundations and found over 100 active entities across a wide range of open source projects.[21] As Cánovas observes:

> "The survival of an OSS project largely depends on its ability to retain developers, onboard new ones (i.e., newcomers), and create a community of users who promote its adoption and use. As these projects grow, developers tend to organize and build communities. Still, many lack formal governance models to structure and manage the (potentially large) community around them (and the challenges this implies). Support to deal with all kinds of organizational decisions (including legal and economic aspects) is a huge concern for all projects at this stage."

While mandates vary from organization to organization, foundations typically set the stage for collaboration on open source projects. The roles include building tools and processes to enable collaborative development, hosting a structured governance process for steering the evolution of open source projects, handling legal issues (particularly around intellectual property licensing, trademarks, and patents), and engaging with policymakers and regulators. Many foundations also play a role in education, training, and marketing. Across these domains, foundations provide a legal entity to hire staff and raise funds to pay for activities that benefit the community.

The sheer number of foundations identified in Cánovas' empirical study raises a question as to whether the governance of OSS is now too diffuse to enable sufficient progress on the challenges facing the community. For example, has the proliferation of foundations created a crowded field that could ultimately impede efforts to develop global standards, address security vulnerabilities, and promote the adoption of open source solutions? And does a crowded field make it more difficult for interested stakeholders to determine how and where to allocate their time and resources?

Several open source leaders consulted for the study agreed that the proliferation of open source foundations and projects has become problematic. They worry, for example, that the flurry of new open source projects and associations for narrow verticals will pull key stakeholders in too many directions. As one interviewee put it, "Quite frankly, none of the participants has a clue how to do open source. It is disconcerting. The probability of success is very low. Their scope is too narrowly focused. They don't understand that open source is a unique discipline they don't have the skills to master."

The proliferation of new foundations has already led some enterprises to be more selective about how and where they engage. For example, Deborah Bryant, formerly of Red Hat, notes that her OSPO was spending more time re-evaluating the firm's

participation in software foundations on a regular cadence to "ensure that [Red Hat was] getting a return on its investment."[22]

"As vendors, we must determine which foundations and projects our customers care about. It's time consuming." —ALAN CLARKE

Meanwhile, Alan Clarke of SUSE acknowledges that foundations are businesses and that they ultimately compete for members and revenues. But the imperative to increase memberships and revenues by launching new projects creates what he and others describe as "vendor fatigue" and "engagement overload." "Foundations create projects to address the sexy spaces in hopes that doing so will boost memberships and revenues," said Clark. "The result may be multiple different approaches to the same problem, and you get fragmented solutions. Then, as vendors, we must determine which foundations and projects our customers care about. Which projects will address the real market needs, and which will be successful? It's time-consuming."

Nevertheless, some argued that creating new OSS foundations is justified if they can mobilize more efficiently and effectively to address narrower mandates defined by specific industries, regions, and application spaces. "Policymakers realize that open source is a vital part of the innovation economy," said Mike Milinkovich of the Eclipse Foundation. "To protect the future prosperity of their citizens, they need to understand and participate in open source. Inevitably there will be verticals and jurisdictions where stakeholders take solace from working with organizations that speak their language and have similar norms and legal frameworks."

Until recently, most of the OSS foundations were California-based organizations. However, as open source becomes increasingly global, many ecosystem leaders concede that the present and future governance of open source communities can't be located solely in California. "Sometimes you need specialized expertise or capabilities to address the needs of a particular vertical or region," said Jim Zemlin of the Linux Foundation. "For example, the E.U. is working on technology sovereignty and seeking to harness open source to lessen the influence of U.S. tech giants. If you want to access E.U. grant funding to contribute to relevant projects, you need European experts, and your organization must also be incorporated in the E.U." To that end, the Linux Foundation launched a European branch (Linux Foundation Europe) in September 2022 to strengthen its partnerships with European constituencies and provide an on-ramp for European projects and companies seeking to harness open source solutions in the public and private sectors.[23]

In this sense, Milinkovich and Zemlin agree that one could interpret the creation of regional associations as a sign of success rather than a failure of global collaboration. They point to China, which is on the record as wanting to be an influential player in open source with its own associations and projects. "The European Commission may do the same," said Milinkovich. "These regional associations may be unsuccessful, but hopefully give rise to a competition of ideas."

"All stakeholders consulted for the study agree that improved collaboration between open source foundations is required to address the ecosystem's challenges."

Whatever their feelings on the proliferation of new foundations and initiatives, all stakeholders consulted for the study agree that improved collaboration between open source foundations is required to address the ecosystem's challenges. Indeed, with modern tools, open source leaders see few excuses for not working together to address issues of shared concern. "The foundations should be insisting on open and broad collaboration to limit the duplication of effort," said Alan Clark of SUSE. "We need to find a way to align the projects. In fact, the projects themselves need to follow open source methods. The design and development processes should be transparent. The meetings and records should be open. The discussions and decision-making should be well documented. In other words, the initiatives that foundations lead should be truly open source projects," said Clark.

Mike Dolan of the Linux Foundation also sees an opportunity for larger open source foundations to provide an umbrella for smaller projects, reducing overlap and economizing on overhead and other resources. "We might launch five projects in a quarter. GitHub is launching 5,000 new projects a day," said Dolan. The challenge is that each has a unique set of stakeholders who want a neutral, growing project that enables new cost savings or market opportunities—and they want to work on them together. Foundations enable them to work together in a structured way. Dolan argues that it is difficult in many instances to curtail the creation of new projects. However, he sees a role for foundations in helping to align efforts and streamline operations. "This innovation is happening with or without us," said Dolan, "so what we're trying to do is to concentrate on a few projects that matter and provide an umbrella structure for projects with shared objectives to come together."

Maintaining critical open source infrastructure

One area urgently calling for increased collaboration is securing and safeguarding the vast patchwork of critical open source components. Decentralized innovation has produced a remarkable tapestry of open source components, and their deployment have widely supported the digital economy. However, maintaining the disparate components is a complex challenge that requires a transparent and coordinated approach and more significant funding and resources from organizations that draw value from open source infrastructure.

Cybercriminals and other malevolent networks are ramping up their attacks, making cybersecurity essential to safeguarding the global economy and defending critical infrastructure. As a result, industries and governments have invested considerable sums in correcting the frequent security issues plaguing proprietary software. However, the recent Log4Shell software vulnerabilities highlight the need for a commensurate effort to protect open source tools, which are just as critical and often more ubiquitous than their proprietary counterparts.

Open source components are embedded in numerous pieces of critical infrastructure that provide the underpinnings for global commerce, from power grids, shipping, and transportation to electronic commerce and finance. Understanding which components are most widely used and most vulnerable to exploitation is crucial for the continued health of the open source ecosystem and the broader digital economy. As Jim Zemlin, executive director of the Linux Foundation, explains, "Hundreds of thousands of OSS packages are in production applications throughout the supply chain. Understanding what we need to be assessing for vulnerabilities is the first step for ensuring long-term security and sustainability of OSS."[24] However, as the Laboratory for Innovation Science at Harvard points out, "it is difficult to fully understand the health and security of OSS because 1) OSS, by design, is distributed in nature, so there is no central authority to ensure quality

and maintenance, and 2) because OSS can be freely copied and modified, it is unclear how much OSS, and precisely what types of OSS, are most widely used."[25]

Tracking the proliferation of OSS and monitoring potential vulnerabilities are complex tasks. Just as vexing, however, is the challenge of maintaining the vast number of critical OSS components in use today. As Kent Walker, Alphabet's president of global affairs, points out, "[In most cases] there's no official resource allocation and few formal requirements or standards for maintaining the security of critical open source code."[26] While high-profile projects, such as Linux, have active communities and receive regular attention, other projects are infrequently updated and have few watchers.

"Open source infrastructure is the classic small pieces, loosely joined with lots of independent components developed by small maintainers who are not necessarily compensated for their work," said Mark Surman. As the ecosystem addresses its sustainability challenges, Surman advises, "It is vital to remember that open source is a tremendous accelerator of innovation and the digital economy. It's not realistic to consolidate it all. So how can we ensure longevity? Are there ways to compensate those maintainers? Could we have a Patreon for open source components?"

In the absence of a distributed compensation and resourcing model, organizations such as the newly created Open Source Security Foundation (OpenSSF) will play a vital role in identifying critical components, assessing vulnerabilities, and establishing new community-based processes and standards for regular maintenance and testing. "The OpenSSF is an industry effort with a roving SWAT team," said Jim Zemlin. "They will identify the abandoned projects and then shore them up. The scorecard and SLSA frameworks we are working on are key to this. We can use these frameworks to identify the vulnerable components, including all the dependencies in the ecosystem, and then target resources to those unsupported or under-resourced areas."

"Many leaders consulted for the study would also like to see large enterprises and other significant beneficiaries pitching in to help sustain a thriving open source ecosystem."

In 2022, DARPA, the U.S. military's research arm, weighed in on the matter with a multi-million-dollar effort, over 18 months, to help identify malicious actors and prevent them from corrupting critical open source infrastructure. DARPA notes that much of the U.S. Department of Defense's computing infrastructure rests on a foundation of OSS. DARPA's so-called "Social Cyber" program will harness AI "to detect and counteract any malicious campaigns to submit flawed code, launch influence operations, sabotage development, or even take control of open-source projects." Part of the effort involves scouring through millions of lines of code to detect vulnerabilities. DARPA will also analyze social interactions on mailing lists and other forums to gain insight into the community of software developers who write, fix, implement, and influence that code. DARPA hopes that sentiment analysis deployed at scale will allow researchers to identify trustworthy contributors and the individuals and groups that justify extra vigilance.[27] However, the countereffect is that developers and open source advocates see any government monitoring as potentially harmful and intrusive. Programs like this could lead to backlash from the same project communities that governments intend to support.

Stormy Peters says GitHub is also trying to make it easier for developers to make their software more secure by providing a free and open database of vulnerability information and enabling private vulnerability reporting. However, many leaders consulted for the study would also like to see large enterprises and other significant beneficiaries pitching in to help sustain a thriving open source ecosystem.

"Technology consumers, especially the enterprises, have had a free ride for far too long," said Mike Milinkovich of Eclipse. "Some vendors include open source components in the products they use, yet enterprises rarely give anything back to the communities they rely upon for their application development. The sustainability problems are related to the lack of money and resources to do all the things that must be done." Peters agrees that the absence of funding for small project maintainers is a problem and notes that GitHub is also working on tools to help companies contribute financial resources to maintaining critical infrastructure components.

Milinkovich, Zemlin, Peters, and others claim that software vendors and enterprise users have received the memo that they need to engage in the communities from which they are drawing benefits. "It is time to recalibrate their engagement in light of where they get the code and what they need to do to ensure the code is properly maintained and sustainable," said Milinkovich. "In the end, there is no free lunch." Zemlin points to Google (one of Alphabet's subsidiaries) as one of several good enterprise stewards that have stepped up to help make code libraries bulletproof.

In 2020, for example, more than 10% of Alphabet's full-time employees (approximately 15,000) actively contributed to open source projects.[28] In addition to managing its own open source code repositories, Alphabet employees contribute to a vast pool of external projects and actively participate in boosting the security and sustainability of open source and its supply chain. In a significant sign of progress, hundreds of prominent enterprise and consumer technology firms, ranging from Amazon to VMware, have established OSPOs and dedicate comparable proportions of their workforce to developing and maintaining open source projects.[29]

Ultimately, Zemlin and others would prefer that the ecosystem address the sustainability challenge publicly, transparently, and collaboratively. "The complexity of the modern supply chain is such that we need a transparent and coordinated approach," said Zemlin. "We need coordinated disclosure of potential vulnerabilities. We need free training for maintainers of critical projects. We need regular auditing of specific projects. And in some cases, we need to augment the talent pool available to do the heavy lifting on maintaining critical components."

With so much at stake, Rod Beckstrom crystallizes the sense of urgency to act. "Global reliability is key," said Beckstrom, who spent much of his time as CEO of ICANN and director of the National Cybersecurity Center wrestling with the thorny issues of Internet governance and cybersecurity. "The market has to step in. Operation Global Blackout from Anonymous was a credible threat. The system is vulnerable, and we need to look closely at the central points of failure. That said, I don't worry too much about the open source systems. The ecosystem is rife with shepherds and custodians. Open source has added tremendous value to human life. Some people will try to break it. Those efforts will likely fail. Bottom-up will win."

Increasing collaboration on technology policy and regulation

"The foundations would be much stronger if they worked together." **—ALAN CLARKE**

Beyond cybersecurity, open source leaders consulted for the study point to a host of other Internet policy issues on which they argue there could be improved collaboration. For example, in critical matters such as intellectual property, privacy, and antitrust, there is a widely shared view that the open source community has not been as influential or assertive in technology policy dialogues as it should.

"Educating politicians can be an uphill battle," said Rod Beckstrom. "They don't always understand the complexities and nuances of Internet infrastructure and the related policy issues. But there is no shortage of critical policy issues where the open source view is needed, including patent issues, privacy, cybersecurity, antitrust, and beneficial AI."

The absence of a coordinated open source response to such issues has left the playing field open to domination by larger, better-resourced entities. "The big tech players with deep pockets and teams of lobbyists have tended to dominate the policy and regulatory conversations," said Alan Clark of SUSE. Clark says the open source community has been reactive rather than active on most policy issues. He and others would like to see open source foundations come together to propose new policies around security, transparency, privacy, and other pertinent matters. "The foundations would be much stronger if they worked together," said Clark. "The open source point of view is especially relevant today. We need an open source approach to solving global problems."

Mike Milinkovich of Eclipse calls the relative absence of open source foundations in crucial policy debates a "sin of omission." "We are not a set of stakeholders that policymakers and politicians are accustomed to dealing with." However, Milinkovich also concedes

that the current state of collaboration among open source foundations is "abysmal and almost non-existent." "Just looking after our own communities is hard enough," said Milinkovich. "Engaging with our peers is difficult. We don't have a good venue to do it. We also compete for members and projects. The bottom line is that we need to grow up and collaborate."

"We need a repeatable and trustable process that achieves public policy goals through open source innovation." **—GABRIELE COLUMBRO**

Jim Zemlin agrees that the foundations don't have a stellar track record of collaboration. However, he points out that open source is on the radar in the wake of the Log4Shell vulnerabilities. "Going forward, we have an opportunity to be much more influential in guiding the evolution of the Internet," said Zemlin. Mike Dolan adds that much of the behind-the-scenes work the Linux Foundation does may not be visible because it is not set up or resourced to be a full-time government education organization. "We do not have government education staff sitting full time in Washington, or Brussels, or Beijing, or Tokyo," said Dolan, "but we are here to protect the ability of open source communities to collaborate and thrive. We channel our members, brands, and capabilities into those efforts. I think it's been quite effective. Open source communities have been active since 1990, and, in that time, there has been no policy that killed open source. The reality is that we have big defenders. Microsoft, IBM, Red Hat, Google, Oracle, Intel, and others are equipped to stand up to the U.S. government if they try to do something that threatens the open source collaboration underpinning multi-billion dollar businesses they can't just walk away from."

Beckstrom argues that the open source community could increase its policy influence through lightweight coordination. "Convene a regular meeting circle of top foundation leaders," said Beckstrom. "Create a dialogue among the leaders, and identify the shared issues on which the ecosystem could collectively assert its voice. Then create a circle of the chief legal counsels. There could be a benefit from further collaboration between the policy leads."

Astor Nummelin Carlberg of OpenForum Europe notes that there are challenges on the governmental side as well. "In Europe, we work with the European Commission around issues ranging from product safety to cybersecurity to privacy," said Carlberg. "However, many policies and regulations in those domains are still driven by national bodies. It requires a lot of resources and staffing to participate in policy deliberations across so many individual nation-states." Carlberg argues that creating OSPOs at the national level could provide an interface for discussions around policy and regulation and notes that France has built one and Germany is in the process of doing so. "We won't have a coherent voice if we work company-by-company and foundation-by-foundation."

More broadly, there is a global opportunity for the OSS community to position itself as a rich source of solutions for public policy issues. "The biggest frontier for open source is in the public sphere," said Gabriele Columbro of FINOS and Linux Foundation Europe. "The Linux Foundation has perfected its governance models for enabling collaboration with corporations and individuals. We need a similar model and pattern of engagement with the public sector." Columbro points to digital public services, healthcare, education, and climate change as significant opportunity spaces for open source solutions. "We need a repeatable and trustable process that achieves public policy goals through open source innovation."

Conclusion

In its purest form, OSS development is a way of producing software that relies entirely on self-organizing communities of individuals who come together voluntarily to work on a software project. However, most successful OSS communities mix elements of hierarchy and self-organization and rely on meritocratic principles of organization. In other words, the most skilled and experienced community members provide leadership and help integrate contributions from the community.

This combination of decentralized innovation and effective leadership is integral to the long-term viability and success of open source projects. As Professor Christopher Yoo put it, "Success of an open source project depends on inspiring a community of people willing to work on it. In a real sense, an open source leader's authority depends on the existence of followers. In a world where all contributions are voluntary, and the community is always free to exit the community by forking the project, leaders' ability to retain their positions depends largely on their responsiveness to the needs of those led. These needs include providing fast feedback, serving as an effective moderator of technical disputes and personality conflicts, and realistic interim and long-term goals."[30]

The Linux ecosystem provides an excellent example of how leadership and strong governance can reduce fragmentation. In the early days of Linux, Linus Torvalds' role as the project leader was instrumental in averting the risk of fragmentation and project forking. Torvalds' status as Linux's creator made him the natural person to exercise authority over the community. When required, Torvalds did not hesitate to take action to prevent significant forks from emerging. However, he bolstered his authority by taking great care to document and justify his decisions. His dedication and sound judgment in managing the community fostered considerable goodwill, as did his deft touch in handling community politics and interpersonal dynamics. Ultimately, that transparency also enabled Linus to delegate decision-making for the codebase to core maintainers, who have over decades grown to be the core engine of contribution to and maintenance of the modern Linux kernel.

As Professor Yoo concludes, "To say that open source projects require a type of leadership that is somewhat different from the leadership that characterizes commercial companies that produce proprietary software is not to say that they need no leadership at all. On the contrary, ensuring that an open source platform does not fragment depends on the presence of an actor with sufficient authority to resolve disputes and to steer the platform in a beneficial direction."[31]

In discussions for the study, open source leaders offered several additional concrete recommendations to address some of the pain points described in this report. We divide the recommendations into two broad categories: a) managing fragmentation in the development and governance of open source solutions and b) confronting techno-nationalism and fostering global inclusion.

Managing fragmentation

The recommendations for managing fragmentation in the development and governance of open source solutions include forging greater alignment between open source projects, strengthening inter-foundation collaboration, and harnessing open source maturity models to help identify robust code libraries and components.

HARNESS MATURITY MODELS

While open source leaders acknowledge some fragmentation-related challenges, they warn that "solving" the fragmentation problem risks killing the goose that laid the golden egg. "When people perceive fragmentation, they often look at it from a consumer point of view," said Mike Milinkovich of the Eclipse

Foundation. “They see a broad landscape of possible solutions and wonder what is safe, what is supported, and what is sustainable.” Rather than “solving fragmentation,” Milinkovich and others suggest that an open source maturity model would make it easier to identify robust code libraries and components and thus focus the community’s efforts. As Mike Dolan put it, “The proliferation of open source projects is not necessarily bad. It just means that there are many options out there. It also means that we need better filters to make it easy for developers and end users to discover the little modules that do things that are useful for them.”

ENLIST SKILLED COMMUNITY MANAGERS

If effective leadership is integral to successful open source projects, then skilled community managers are the foot soldiers for building high-performing collaboration networks. Unfortunately, in a world dominated by proprietary technologies, few people understand how to create and grow an open source ecosystem. However, Calista Redmond of RISC-V points out that technologists are adapting to a new way of working as open standards increasingly overtake proprietary approaches. “Ethernet is a great example,” said Redmond, “where proprietary approaches are now nearly nonexistent.” Redmond and her colleagues have built the RISC-V community from scratch to become the world’s most popular open and widely used microprocessor instruction set architecture standard. Along the way, RISC-V encountered numerous concerns about forking, especially when companies in the ecosystem identified missing pieces and had the temptation to develop proprietary solutions.

To avoid fragmentation in the community, Redmond and her team work hard to gather participants and align efforts on the missing pieces. “We have to run really fast to catch up with our community,” said Redmond. “It’s a different skill set. Most people have built proprietary strongholds. We need people who know how to orchestrate true collaboration. Our CTO comes from Sun Microsystems, where he was responsible for Solaris. He is very community-oriented. You need to find those people with the skills for ecosystem leadership.”

ALIGN OPEN SOURCE PROJECTS AROUND SHARED GOALS

Open source foundations are reluctant to play a lead role in identifying and championing winning open source projects, arguing that picking winners is a marketplace function. However, leaders do see a need for better project curation and want foundations and other

ecosystem participants to make greater efforts to align projects with similar objectives. "We nurture multiple projects, and sometimes they overlap," said Gabriele Columbro, general manager of Linux Foundation Europe. "But the most mature foundations have a project life cycle where they can help coalesce efforts and even consolidate projects." Columbro says that survival of the fittest, or "open source Darwinism," will usually dictate which projects are ultimately sustainable. However, he and other open source leaders agree that bringing similar projects under a shared umbrella can eliminate duplication, economize overhead, and reduce so-called "vendor fatigue." In some instances, foundations could also do a better job killing or archiving projects. "We are very good at bringing projects in," said Columbro. "But it's equally important we do a great job cycling projects through the life cycle and shelving projects when necessary."

STRENGTHEN INTER-FOUNDATION COLLABORATION ON ECOSYSTEM CHALLENGES

The need for enhanced collaboration between open source projects and foundations extends to other priorities for the ecosystem, including joint efforts to advance open source advocacy on a range of Internet governance issues. Mark Surman of the Mozilla Foundation said foundation leaders could leverage the community's shared values as a starting point for collaboration. "The open source community is united by core values such as independence, decentralization, public assets, and public benefits," said Surman. "In essence, we agree on the vital role of the commons." The next step is to convene the foundation leaders and work together to identify shared policy goals. "What are possible threads of unity, and to what ends should we pull them?" asks Surman.

One goal that all ecosystem leaders agree on is the need to build trust and confidence in OSS and support the ongoing maintenance of critical open source infrastructure. "The cybersecurity order from the White House has put the ecosystem on notice," said Jerry Cuomo of IBM. "Now, the stewards of open source need to step up. It would be huge if the community had a shared ledger and audit system where we could demonstrate that the software is robust and secure. We need a transparent, ecosystem-wide view of our vulnerabilities, and we need to be able to predict potential problems. That's an OSS service that the community can trust."

Open source security and sustainability are top of mind, but ecosystem leaders point to various policy issues on which open source foundations could find common ground. "The foundations should do more to educate policymakers and work on shared issues such as data security, intellectual property, antitrust, and privacy, among other things," said Peixin Hou of Huawei. "We urgently need global action on these issues."

Confronting techno-nationalism and fostering global inclusion

The recommendations for confronting techno-nationalism and fostering global inclusion include positioning foundations as neutral actors, building reputation frameworks and audit systems for open source code, and creating tools and protocols for integrating diverse contributors into open source communities.

BUILD REPUTATION FRAMEWORKS

Adherence to transparent and secure development protocols is, ultimately, the best antidote to fears that national interests could taint or even corrupt open source projects. "To counter the techno-nationalism, we need to instill trust in the software development process," said Jim Zemlin. For example, Zemlin proposes the creation of reputation frameworks with better peer review and third-party audits. "We need trust networks that are transparent and scalable enough to work across open source communities," said Zemlin. "You can think of it as a liquidity of trust. Where you are from and whom you work for are not as relevant as knowing

that your work is trustworthy and high-quality. It's the code that is vital. So we need a reputation framework for the codebase."

POSITION FOUNDATIONS AND PROJECTS AS NEUTRAL ACTORS

In addition to reputation frameworks, positioning open source foundations and projects as impartial actors is critical to creating a neutral home for global collaboration. Establishing neutral, inclusive, and transparent structures for collaboration will not only broaden participation but can also reduce incentives for ecosystem participants to create parallel efforts. Reflecting on his work at ICANN, Rod Beckstrom said his number-one job was building a neutral zone in the domain name system that holds the Internet together. "We did everything we could to bring China and Russia into the tent," said Beckstrom. "We were doing it for the global community. Otherwise, we are starting from a position of mistrust." Likewise, building confidence in ICANN's protocols and decision-making process was critical to creating a productive relationship with countries that were suspicious of American dominance of Internet governance. "As long as the system works openly and fairly, everyone can participate," said Beckstrom. "The Internet is a global infrastructure—it must remain neutral. It's to the benefit of the world."

EDUCATE POLICYMAKERS ABOUT THE DOWNSIDES OF TECHNO-NATIONALISM

To combat techno-nationalism, ecosystem leaders must convince policymakers that restricting the transfer of critical innovations across national borders is paradoxical and self-defeating in a world where cross-border collaborations are the backbone of countless innovation communities. Calista Redmond and others argue that open source and global standards provide a superior path for both local and global economic growth because global collaboration leads to global markets with long-term strategic importance. "Every country has a home-team bias, but the growing techno-nationalism is a major concern," said Redmond. "We need to educate the community and the policymakers about the downsides of techno-nationalism. Countries can fund companies and initiatives locally, but they must participate globally. Countries won't be successful if they close off collaboration at national borders." Columbro even adopted that perspective as a motto to define the mission of Linux Foundation Europe: "Collaborate locally, innovate globally."

CREATE THE CONDITIONS TO INTEGRATE DIVERSE CONTRIBUTORS

The challenges of integrating different languages and cultures into open source communities are not new problems, and there is considerable confidence in the ecosystem's capacity to foster global inclusion. As Stormy Peters at GitHub explains, "The open source community has been integrating diversity for a long time. We have people contributing from across Europe, Asia, Africa, and South America. We have always understood the importance of international networks and communications, even more than the corporate community. We have leveraged asynchronous communications to address the fact that users in some regions had less Internet bandwidth."

The sheer number of people that GitHub and other organizations are onboarding into the global open source community provides proof of the ecosystem's progress in integrating diverse contributors. "We have proven that open source projects can operate globally," said Peters. "We are working effectively across regions and in multiple languages. We are creating OSPOs to structure the engagement of companies and organizations with the open source community."

Open source leaders agree, however, that the community can do more to promote global inclusion. For example, open source leaders underlined the need to invest in rapid machine translation

capabilities for project communications. Open source leaders also discussed the importance of promoting open source norms, taming the industry's macho "bro" culture, and fostering professionalism in community dialogues and decision-making. Finally, collaboration platforms such as GitHub can enable open source communities to integrate diverse contributions at scale. Key advances in the GitHub platform include new tools to improve collaboration, translate materials, and monitor the productivity and engagement of community members. "We believe we have the tools to bring open source collaboration to a new level," said Peters.

Final thoughts

By any yardstick, OSS is wildly successful. Hundreds of millions of users of set-top boxes, smart fridges, and other home appliances use OSS, and billions of people use it indirectly whenever they access Google, Facebook, or the myriad of other apps and websites. Whether you drive a Tesla, Toyota, or Mercedes, chances are very high it's running Linux and open source in the background.[32] So too are the supercomputers that power everything from advanced climate models to AI-enabled drug discovery and other scientific pursuits, such as astronomy, meteorology, and nuclear physics.[33]

The global open source community powering these innovations is encountering some inevitable fragmentation. Some of the fragmentation in software development is essential to how the open source community functions. A globally decentralized ecosystem may produce some overlap, but its constant churn of incremental innovation and improvement has yielded a vast reservoir of software building blocks for the digital economy.

In other instances, fragmentation in the community is creating needless redundancy, driving up costs and complexity for producers and consumers alike. Worst of all, intensifying technonationalism could introduce new geopolitical fault lines, disrupting the free flow of ideas and restricting the community's access to talented developers.

Now it is up to the community of developers, public and private sector organizations, companies, foundations, and beyond to continue to push for global collaboration. The open source community is larger, more diverse, and more capable than ever, but its progress is not forever inevitable. It is incumbent upon the community's leaders to take the necessary steps to continue these trendlines into the future.

About the Author

Anthony is the founder and president of the DEEP Centre and an internationally recognized authority on the digital revolution, innovation, and creativity in business and society. He is co-author (with Don Tapscott) of the groundbreaking bestseller *Wikinomics* and its follow-up *Macrowikinomics: New Solutions for a Connected Planet.*

Among other appointments, Anthony serves as a research director with the **Blockchain Research Institute**, an expert advisor to the **Markle Foundation**'s Initiative for America's Economic Future, and a senior fellow with the **Lisbon Council** in Brussels. Anthony was recently a committee member of the National Research Council's Committee on **Science for the EPA's Future**, a visiting fellow with the **Munk School of Global Affairs** at the University of Toronto, and chief advisor to Brazil's Free Education Project. His work on technology and innovation has been featured in publications such as the *Harvard Business Review*, the *Huffington Post* and *The Globe and Mail.*

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