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COOPERATIVE SIGNALING BEHAVIOR: SIGNALS FOR OPEN SOURCE PROJECT HEALTH

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The core contribution is a critique of signaling theory from investigating cooperative signaling behavior in the context of organizational engagement with open source projects. Open source projects display signals of project health which are used by organizations. Projects and organizations engage in cooperative signaling behavior when they work together to create signals. Signaling theory is critiqued in the cooperative context of organizational engagements with open source projects by describing how cooperative signaling behavior occurs in three processes: identifying, evaluating, and filtering new signals. The contribution is informed through engaged field research and interviews, which are presented as a thick description of the CHAOSS Diversity & Inclusion Working Group and of how its community members create D&I signals. A contribution to literature on open source is a description of how signals for open source project health are created.

Open Access

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1 Introduction

Open source project health is the potential that an open source project will continue developing quality software (Naparat, Finnegan, & Cahalane, 2015). A problem with assessing open source project health is that it is a hidden quality, which can only be inferred from signals (Ho & Rai, 2017). Organizations form an opinion of project health to make decisions about engaging with open source projects (Linåker, Regnell, & Damian, 2019; Link & Germonprez, 2018). Research shows that organizations do not know which of many different signals are effective when assessing open source project health (Crowston, Howison, & Annabi, 2006; Goldman & Gabriel, 2005; Ihara, Monden, & Matsumoto, 2014; Schweik & English, 2012). An unawareness about what signals are important reduces an organization's ability to clearly identify risks involved in organizational engagements with open source projects (Germonprez, et al., 2017), including the risk of project health failures.

Consequences of project health failures can have significant impacts, considering the widespread use of open source software. For example, the Heartbleed vulnerability existed in the open source software library OpenSSL, which was maintained by two community members who did not earn a living from this important work (Eghbal, 2016). The lack of funding for development served as a signal when considering that a majority of servers worldwide used OpenSSL to secure internet connections (Durumeric et al., 2014). As a consequence of not observing and acting on this signal, organizations risked compromising sensitive information. As another example, the Struts/Equifax data breach (Sally, 2017) demonstrated that organizations are at risk when they do not act based on open source project health signals. Apache Struts had announced a release with a security fix (a positive signal), but Equifax did not act on this signal, failing to secure its server infrastructure (Sally, 2017). As a result, hundreds of millions of people had their personal information compromised.

The commonality between these cases is that organizations leveraged open source software without paying attention to signals of project health. After these project health examples, the realization spread that signals of open source project health are not well understood (Danes, 2017). The question of which signals open source projects and organizations should display and use was even raised by lawmakers. For example, the United States Congress sent a letter to the Linux Foundation, asking how open source project health failures can be avoided in the future (Walden & Harper, 2018). In another example, the EU-Free and Open Source Software Auditing project systematically creates an inventory of open source software used by European institutions and compares relevant signals for project health (European Commission, n.d.). These examples demonstrate that finding effective signals of project health in an effort to limit the risk and impacts of project health failures is an increasingly important issue for open source projects and organizations.

We know that signals are used for assessing open source project health (Ho & Rai, 2017; Linåker et al., 2019; Link & Germonprez, 2018) and that projects have many signals to choose from (Crowston et al., 2006; Schweik & English, 2012). Open source projects can choose which signals to display and influence how organizations perceive them (Spence, 1974) and projects have an incentive to appear healthy to organizations because it increases the chance that organizations start contributing to the project (Bacon, 2012; Fogel, 2015). How projects strategically display signals can be observed in practice with the Hyperledger project. In a press release, the Hyperledger project signaled that it had a vibrant community by displaying the number of developers and companies who contributed to its latest release.[1] Thereby, Hyperledger signaled to organizations that the project had wide industry support and had the potential to meet organizational needs in the future, both considerations of open source project health.

Literature on signaling theory provides evidence for how signals are used when information is unevenly distributed (Connelly, Certo, Ireland, & Reutzel, 2011), but does not provide a definitive answer for how to identify effective signals. Studies on multiple signals are inconclusive regarding how signals interact with each other and what makes one set of signals more effective than another (Drover, Wood, & Corbett, 2017; Miyazaki, Grewal, & Goodstein, 2005). Signaling literature treats sender and observer choices for which signals to display and use as non-cooperative (Connelly et al., 2011).

However, open source is inherently cooperative. Open source projects and organizations have been shown to cooperatively work on such things as standards that facilitate their interactions (Gandhi, Germonprez, & Link, 2018) and code bases that define their outputs (Wright & Druta, 2014). Similarly, projects and organizations may cooperate to overcome challenges of signaling open source project health. Therefore, the cooperative space of open source provides a good context in which to *critique signaling theory* as more than a non-cooperative endeavor.

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[1] Hyperledger did this in announcing Fabric 1.0: https://www.hyperledger.org/announcements/2017/07/11/hyperledger-announces-production-ready-hyperledger-fabric-1-0

Spence (1974) speculated that senders and observers can benefit from working together to overcome signaling challenges and to create signals. However, Spence (1974) did not empirically explore this speculation. As such, I explore senders and observers collaboratively creating signals in open source, an inherently cooperative context. As projects and organizations engage in cooperative signaling behavior to create signals, it presents a research opportunity to *critique signaling theory* (Mathiassen, Chiasson, & Germonprez, 2012) and shed light on how signals are cooperatively created. The cooperative creation of signals is not well documented, because literature investigates signaling in non-cooperative settings to evaluate effects of existing signals (Connelly et al., 2011). Hence, the goal of this study is to investigate how signals are created through cooperative signaling behavior. To reveal this complexity and to critique signaling theory, the following research question guides this research:

RQ: How do open source projects and organizations create signals for open source project health?

Beyond theoretical contributions, the question of how open source projects and organizations create signals of open source project health is a timely applied topic. Open source projects and organizations benefit from an investigation of complexities involved in assessing open source project health. Specifically, open source program officers, open source foundation members, and open source project members can better inform their engagement decisions through signals by understanding how open source project health signals are created.

2 Literature Review: Open Source

An open source project encompasses open source software and a community that develops the software. For software to be open source, it must be licensed under an open source license. Open source software licenses build on the copyright system and grant anyone permission to use, modify, and distribute the software without restrictions. The Open Source Initiative[2] is an industry collaboration to check licenses for these attributes.

When open source emerged, it was a social movement, and the idea that volunteer communities could develop software that competed with commercial software intrigued researchers (Aksulu & Wade, 2010; Kelty, 2008; Stallman, 1983; von Krogh & von Hippel, 2006; Weber, 2004). We learned what motivated contributors to participate in open source (Von Krogh et al., 2012), how open source projects were organized (Mockus, Fielding, & Herbsleb, 2002), and that there is more to open source than the production of software (Aksulu & Wade, 2010).

From the many streams of open source research (Aksulu & Wade, 2010), the one stream most relevant to my research discussed implications that emerging open source practices may have on organizations and on software economics (Benkler, 2002, 2013; Lerner & Tirole, 2002). Empirical studies focused on individual companies and investigated the basics of how organizations engaged with open source projects (Bonaccorsi, Giannangeli, & Rossi, 2006; Chan, 2013; Dahlander, 2005; Dahlander &

[2] https://opensource.org/licenses/

Magnusson, 2005; Dahlander & Wallin, 2006). As more organizations began to embrace open source as a software development method, research conceptualized the implications that organizational engagement has for open source projects (Feller, Finnegan, Fitzgerald, & Hayes, 2008; Fitzgerald, 2006; Germonprez, Kendall, et al., 2013; Kelty, 2013). While organizations have engaged with open source projects for a long time, much has changed since this earlier work (Germonprez, Link, Lumbard, & Goggins, 2018).

The emergence of organizational engagement as a phenomenon can be observed in the evolution of the Linux Foundation, which was founded in 2000 by organizations that were using the Linux Kernel and contributing to its development. The initial goal was to provide a stable home for the Linux Kernel project, pay Linus Torvalds to oversee the development, and promote the project. After building experience and expertise with brokering open source projects, the Linux Foundation expanded its focus "to help establish, build, and sustain some of the most critical open source technologies."[3] By 2015, the Linux Foundation hosted about 15 collaborative projects. Since then, the number of projects increased to over 150 at the start of 2019.[4] These projects advance strategically important but non-differentiating technologies that organizations develop together, including the Linux Kernel project for advancing an operating system, the Kubernetes project for advancing container orchestration software, and the Hyperledger project for advancing blockchain technology. Today, the Linux Foundation is a trade organization with more than 1,300 paying member organizations. On average, a new member joined the Linux Foundation every day in 2017 and 2018, doubling memberships

[3] https://www.linuxfoundation.org/about/
[4] https://www.linuxfoundation.org/projects/

in only two years and demonstrating that organizational engagement with open source projects is on the rise (Zemlin, 2019).

An increase in organizational engagement with open source projects raises new research questions and opens new streams of research (Germonprez et al., 2018; Link & Jeske, 2017). While not fully comprehensive of the organizational engagement research landscape, research has come to hone in on five categories presented by Germonprez et al. (2018), which will be discussed in following sub-sections (see Table 1).

Table 1. Stream of research categories relevant to organizational engagement with open source projects (Germonprez et al., 2018).

Category	**Description**	**Section**
Conceptual	Research on organizations engaging with open source projects.	2.1
Production	Research on issues related to producing open source projects.	2.2
Legal and Regulatory	Research on legal and regulatory issues, especially as they pertain to open source licenses.	2.3
Adoption and Implementation	Research on how developed software and practices become adopted and implemented.	2.4
Performance Metrics	Research on how open source project development can be understood through metrics.	2.5

2.1 Conceptual: Organizational Engagements

Organizational engagements are exchanges between for-profit organizations and open source projects. Open source projects provide a platform for organizations who are otherwise competitors to engaged in a shared advancement of non-differentiating technologies (Germonprez, Allen, Warner, Hill, & McClements, 2013). Open source community members have a shared goal to advance the software and self-organize necessary activities (Kelty, 2008). Shared community goals can align with organizational goals, for example, to solve a technical challenge like building a reliable operating system. Organizations are attracted to projects where goals align, which can facilitate whether an organization chooses to become a member in an open source project (Linåker et al., 2019; Link & Jeske, 2017).

Because membership in open source projects is tied to people engaging in the community, organizations are increasingly initiating organizational engagements by directing employees to participate in open source projects in pursuit of organizational goals (Dahlander & Wallin, 2006; Linåker et al., 2019). The level to which an individual organization engages with open source projects and practices can be observed in employees' involvement, the level of transparency a company maintains for internal software development, and the degree to which internal software development practices are similar to open source development practices (Link, Gill, & Khazanchi, 2017).

The level of organizational engagement with open source projects varies between open source projects though it is increasing in many cases. Today, about half of open source development is paid work (Riehle, Riemer, Kolassa, & Schmidt, 2014) and some projects are dominated by organizational employees (Kelty, 2013). The increase in organizational engagement results from several large organizations, such as Oracle, IBM, and Red Hat, realizing how open source benefits their business model and publicly championing its use (Weber, 2004). The trend is evident in a 2016 survey which reported that 65% of responding organizations actively contributed to open source projects and intended to increase their contributions (Black Duck Software, 2016).

Organizational engagement can take several forms (Linåker et al., 2019). When an organization uses open source software in organizational innovation processes (Dahlander, 2005; Germonprez et al., 2017; Levy & Germonprez, 2015), it may choose to only use open source software without contributing back (Dahlander, 2005). However, engaging in a project and learning through contributing can yield better business results (Bonaccorsi et al., 2006; Nagle, 2018). Organizations engage with open source projects to collaborate with outside experts (Germonprez, Allen, et al., 2013), where shared innovation remains in a public space for everyone to benefit (von Hippel & von Krogh, 2003). Engaging with an open source project is also beneficial because organizational changes to open source software are difficult to maintain locally within an organization and are best maintained in the original open source project (Ramsauer, Lohmann, & Mauerer, 2016). Engaging with open source projects and influencing the development requires organizational representation and a good standing of employees within open source projects (Linåker et al., 2019). Employees who have a good standing in an open source project are more likely to influence the project in ways that are beneficial for their employer (Dahlander & Wallin, 2006).

Organizational engagements can benefit from having an open source foundation that provides financial, legal, administrative, and technical support (Riehle, 2010). Foundations provide a legal home for open source projects and serve as a fiscal sponsor. Foundations shape the way open source projects operate and the way organizations engage with projects (Link & Germonprez, 2016). The additional support structures and the use of proven governance models make projects more reliable for organizations to use in their innovation streams (Germonprez, Kendall, et al., 2013).

Table 2. Summary of select literature on the conceptual understanding of organizational engagement with open source projects.

Select Literature	Summary of how literature is relevant
von Hippel & von Krogh, 2003	Theoretical discussion of organizational engagement with open source projects making the case for research into how innovation is done in open source projects.
Weber, 2004	Book on the basics of open source and what may result from an increase of organizational engagement with open source projects.
Dahlander, 2005	Empirical analysis of five organizations and their different approaches to engaging with open source projects.
Bonaccorsi et al., 2006	Empirical analysis of strategies of organizations that engage with open source projects shows that engaging with open source projects yields benefits.
Dahlander & Wallin, 2006	Empirical analysis of how organizational employees engage with open source projects showing that organizations have more influence in an open source project if their employees have a good standing with the project community.
Kelty, 2008	Book on the history and workings of open source showing that open source projects self-organize their activities.
Riehle, 2010	Theoretical discussion of organizational engagement with open source arguing that foundations provide value in these engagements.
Germonprez, Allen et al., 2013	Empirical analysis of organizational engagement with the open source project OpenMAMA showing that otherwise competing organizations work together to develop non-differentiating technology in open source projects.
Germonprez, Kendall, et al., 2013	Empirical analysis of organizational engagement with open source projects showing that open source projects are stabilizing their practices in response to organizational needs.
Kelty, 2013	Position paper about the increasing influence of organizational engagements on open source projects proposing that open source as a social movement was replaced by open source as a collaboration model for organizations.
Riehle et al., 2014	Empirical analysis of contributions to open source projects concluding that a about half of all contributions result from organizational engagement with open source projects.
Levy & Germonprez, 2015	Empirical analysis of organizational engagement with open source projects showing how organizations innovate in open source projects.
Black Duck Software, 2016	Industry survey of organizations and their engagement with open source projects showing an increase in organizations engaging with open source projects.
Link & Germonprez, 2016	Empirical analysis of organizational engagement with open source projects showing that relationships between open source projects and organizations are influenced and shaped by open source foundations.
Ramsauer et al., 2016	Method development for analyzing patch stacks that organizations maintain when modifying open source projects without contributing changes upstream showing that maintaining a local patch stack is more work than maintaining changes in the open source project.
Germonprez et al., 2017	Empirical analysis of organizational engagement with open source projects showing how open source projects and organizations enable productive interactions.
Link & Jeske, 2017	Theoretical discussion of organizational engagement with open source projects providing potential streams of research and research questions.

Select Literature	Summary of how literature is relevant
Link et al., 2017	Survey development for evaluating the level of open source practices adoption in an organization showing ways to assess how engaged organizations are with open source projects.
Nagle, 2018	Empirical analysis of organizational engagement with open source projects showing that organizations get more value from open source projects when engaging with them compared to only using open source software.
Linåker et al., 2019	Empirical analysis of decisions that organizations make when engaging with open source project showing that organizations can strategically select how to engage with open source project to further business goals by gaining influence.

2.2 Production: Financing Open Source Work

How open source projects work and create software has been well-researched (Aksulu & Wade, 2010). Processes in open source projects are adjusting to organizational engagement (Fitzgerald, 2006; Germonprez et al., 2017). With increasing organizational engagement, an increasing number of contributors are paid for producing open source software (Kelty, 2013; Riehle et al., 2014). However, paying contributors is at odds with the original conception of open source that neither considered monetary exchanges nor was designed for them (Benkler, 2002; Kelty, 2013; Stallman, 1983). As a result, open source contributors and project maintainers struggle to sustain a living from their work in open source (Eghbal, 2016). Simultaneously, organizations like Red Hat, IBM, Microsoft, Facebook, and Google capture value created in open source projects and turn that value into profits. Organizations leverage open source software, a communal artifact, in developing services and products (Germonprez et al., 2017). In 2018, mergers and acquisitions, private equity, and initial public offerings for organizations that leveraged open source for their core product exceeded $70 billion USD (Zemlin, 2019), which demonstrates that financial resources are available for work in open source.

Open source projects, organizations, and foundations have realized that open source projects are not healthy if they rely on contributors and maintainers who subsidize their work on open source software by working unrelated jobs (Eghbal, 2016). From this realization, many funding platforms have been created.[5] The Core Infrastructure Initiative[6] (CII), for example, looks for open source projects that are widely used but do not have a sustainable financial foundation. One of the first projects CII provided financial support for was the OpenSSL library, which then conducted a security audit and fixed vulnerabilities in response to Heartbleed. A variety of other initiatives propose different mechanisms for funding open source work, including the following examples. At the task level, GitCoin[7] is a blockchain solution through which contributors can get paid for working on specific issues from people who are willing to pay for issues. Bountysource[8] allows donations for specific features that contributors can develop to claim the money. Hackerone[9] is a platform where funding is specifically tied to finding and fixing software vulnerabilities in open source. At the project level, OpenCollective[10] is a platform that provides fiscal sponsorship to projects with a transparent ledger to provide trust in how projects use donated money. CommunityBridge[11] is a platform that integrates fiscal sponsorship, with mentorship and vulnerability inspection. Finally, TideLift[12] is a company that sells assurances to its clients for open source projects they

[5] As of March 13, 2019, http://oss.fund/ lists 44 funding platforms.
[6] https://www.coreinfrastructure.org/
[7] https://gitcoin.co/
[8] https://www.bountysource.com/
[9] https://www.hackerone.com/
[10] https://opencollective.com/
[11] https://communitybridge.org/
[12] https://tidelift.com/

rely on. TideLift then pays maintainers in those projects and works with them to ensure the health of these projects.

Many of these initiatives assume that financial support must be given to volunteer contributors, which raises concerns about increasing financial incentives to work in open source and inadvertently changing the dynamics in open source projects (Hansson, 2013). Experiments of paying contributors have caused concern in established open source project communities (Gerlach, Wu, Cunningham, & Young, 2016). However, research finds that paying volunteers does not diminish intrinsic motivations but rather increases volunteers' contribution activity (Fiorillo, 2011; Roberts, Hann, & Slaughter, 2006). In many open source projects, community members are already paid for their work because it is part of their job (Kelty, 2013; Riehle et al., 2014) and resources available to open source projects are important in the production of open source software (Arantes & Freire, 2011).

Research aims to understand incentives and compensation of contributors as they align with values and ideals of open source projects in light of increasing organizational engagement (Rao, Link, Marti, Leak, & Bodo, 2018). New forms of structuring financial incentives for software development have been theorized to incentivize the creation of secure software (Rao, Parkes, Seltzer, & Bacon, 2015). Reimagining how work in open source can be financed has the potential to lead to healthier projects, new forms of work, and changing the market dynamics around open source projects (Link, Rao, Marti, Leak, & Bodo, 2019).

Table 3. Summary of select literature on the production of open source software in the context of organizational engagement with open source projects, specifically issues of financing open source work.

Select Literature	Summary of how literature is relevant
Stallman, 1983	Announcement of the GNU Project which resembles a historic document in the social movement for free software from which open source has developed.
Benkler, 2002	Theoretical analysis of open source as a coordination mechanism in comparison to organizations and markets showing that open source excels at coordinating creative work by allowing contributors to self-select work without supervisor directive (organizational coordination) or financial incentives (market coordination).
Fitzgerald, 2006	Theoretical discussion of organizational engagements with open source projects showing that projects adjust their processes to accommodate organizational needs.
Roberts et al., 2006	Empirical analysis of open source project contributor motivations showing that paying contributors increases their level of contribution.
Aksulu & Wade, 2010	Comprehensive review and synthesis of open source research providing an overview of research streams.
Arantes & Freire, 2011	Literature overview about open source project health showing that resources are important for open source project health.
Fiorillo, 2011	Empirical analysis of financial incentives on intrinsic motivations in volunteer settings showing that intrinsically motivated volunteers continue increase their effort when receiving financial incentives.
Hansson, 2013	Blog post about concerns for introducing payment for open source work arguing that financial incentives will change dynamics in open source projects.
Kelty, 2013	Position paper about the increasing influence of organizational engagements on open source projects proposing that open source as a social movement was replaced by open source as a collaboration model for organizations as more contributors are paid employees.
Riehle et al., 2014	Empirical analysis of contributions to open source projects concluding that a about half of all contributions result from organizational engagement with open source projects.
Rao et al., 2015	Theoretical development of financial incentives for deep fixes for software bugs arguing that financial incentives can be designed to align with values for quality software.
Eghbal, 2016	Industry report about the state of open source project health across projects showing that projects are unhealthy if they depend on maintainers who subsidize their unpaid open source work.
Gerlach et al., 2016	Empirical analysis of community responses to the introduction of payment for release managers in the all-volunteer Debian open source project showing that paying volunteer contributors is a contentious issue in open source projects.
Germonprez et al., 2017	Empirical analysis of organizational engagement with open source projects showing that organizations incorporate open source software in their innovation streams.

Select Literature	Summary of how literature is relevant
Rao et al., 2018	Theoretical introduction of a novel market design arguing that financial incentives can be designed to strengthen open source project health and facilitate organizational engagement in open source.
Link et al., 2019	Theoretical discussion of Rao et al.'s (2018) market design implications for open source projects arguing that a market could improve project health, create new forms of work, and change existing market dynamics.
Zemlin, 2019	Keynote at Open Source Leadership Summit 2019 showing that organizations engaged with open source projects for their core product collected $70 billion USD through M&A/PE/IPO in 2018.

2.3 Legal and Regulatory: Compliance

Organizational engagement with open source projects includes legal and regulatory issues regarding compliance with open source licenses (Germonprez et al., 2012). License compliance is important because organizations that are believed to violate open source license obligations face the risk of law suits (Wen, Forman, & Graham, 2013). Especially as open source projects have grown to be complex and containing different licenses, complying with license obligations has become more challenging (Alspaugh, Scacchi, & Asuncion, 2010). With license compliance as a major concern for organizations (Ihara, 2014), surveys confirm that organizations adopt necessary policies. The IT consultancy Gartner found in 2008 that 31% of the companies surveyed had formal policies for evaluating or cataloging use of open source software in their organization (Kemp, 2010). In 2016, the company Black Duck found that 50% of organizations had formal policies (Black Duck Software, 2016). While not fully deployed across industry, these surveys demonstrate that organizations are building and adopting policies and processes for managing risk involved with engaging with open source projects. Specifically, organizations mitigate risks from licenses through trained people, strategies, policies, and processes for tracking the use of open source software and their license obligations (Kemp, 2010). Some organizations have dedicated open source program offices that make decisions about compliance (Germonprez et al., 2012).

License compliance is important also for open source projects because a lawsuit reduces use of and contribution activity within an involved project (Wen et al., 2013). With incentives for open source projects and organizations to avoid lawsuits, projects and organizations work together to develop standards and best practices for license compliance (Gandhi et al., 2018; Germonprez et al., 2012). Specifically, open source projects and organizations engaged in the SPDX[13] open source project developed the "SPDX-License-Identifier" as a standard and machine-readable way to explicate license obligations within open source software source code. The SPDX project created a specification for a document that expresses license obligations of an open source software and can be exchanged alongside the software (Gandhi et al., 2018). In another effort, the OpenChain[14] open source project is developing best practices for organizations to make license compliance more consistent across organizations. Organizations can be certified for following these best practices, which includes having a policy on accepted licenses, having trainings about licensing for employees, and documenting procedures for identifying and tracking open source components and their license obligations. Both examples demonstrate that best practices for compliance are not developed only in open source projects or organizations but are negotiated in organizational engagements with open source projects (Germonprez et al., 2012).

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[13] https://spdx.org/
[14] https://www.openchainproject.org/

Organizations that use the open source model to develop software have several licensing options (Lerner and Tirole, 2002). Without engaging with open source projects, organizations can use open source software development practices internal to the organization to develop proprietary software, which does not require license compliance if kept separate (Sen, Subramaniam, & Nelson, 2011; Stol & Fitzgerald, 2015). When releasing internally developed software, organizations can choose a license that supports their business model (Shahrivar, Elahi, Hassanzadeh, & Montazer, 2018). In addition to purely proprietary or purely open source licenses, organizations can dual-license their software. For example, a free "community edition" can have an open source license and a paid "commercial edition" can have a proprietary license, but only the latter is accompanied with access to support and assurances (Shahrivar et al., 2018). Regardless of the license, organizations can maintain full control over the software development even if using the open source development model (Mulligan et al., 2011). However, an open source license is beneficial if the goal is to build a community that will advance software together (Feller et al., 2008) and in these cases, organizations prefer non-copyleft licenses that permit advancing the software without having to publicly release changes (Gamalielsson & Lundell, 2017).

Table 4. Summary of select literature on legal and regulatory issues in the context of organizational engagement with open source projects, specifically how open source projects and organization develop new methods for license compliance.

Select Literature	Summary of how literature is relevant
Lerner & Tirole, 2002	Theoretical discussion of the economics of open source software arguing that organizations may choose licenses in response to economic incentives.
Feller et al., 2008	Empirical analysis of how organizations collaborate to produce software arguing that collaborative creation of software is enabled by open source licenses.
Alspaugh et al., 2010	Theoretical discussion of license obligations in open source projects that have multiple open source licenses showing that some license obligations are incompatible.
Kemp, 2010	Theoretical discussion of organizational strategies, policies, and processes for engaging with open source projects arguing that license compliance needs to be integrated in how organizations engage with open source projects.
Mulligan et al., 2011	Empirical analysis of how organizations engage in the Android open source project uncovering that control is not surrendered with the open source license.
Sen et al., 2011	Empirical analysis of license choice in open source projects showing that goals of open source projects are correlated with their license choice.
Germonprez et al., 2012	Empirical analysis of compliance practices in open source projects showing that projects and organizations shape compliance practices together.
Wen et al., 2013	Empirical analysis of lawsuits for suspected violations of open source license obligations and their effect on open source projects showing that lawsuits reduce use of open source projects and reduce levels of developer activity.
Ihara, 2014	Theoretical discussion of industry questions that emerged from a survey of organizations showing that license concerns are prevalent for organizations engaging with open source projects.
Stol & Fitzgerald, 2015	Theoretical discussion of organizations using open source software development practices internally showing how license compliance is different when engaging with open source projects versus working internal to organization only.
Black Duck Software, 2016	Industry survey of organizations and their engagement with open source projects showing that only about half of surveyed organizations have formal policies for engaging with open source projects.
Gamalielsson & Lundell, 2017	Empirical analysis of license obligations in widely used open source projects showing a difference in license obligations for foundation supported open source projects compared to community established open source projects.
Gandhi et al., 2018	Empirical analysis of the SPDX standard for conveying license obligations in open source projects showing how open source projects and organizations developed the standard together.
Shahrivar et al., 2018	Literature overview of business models for open source software showing that organizations have different license strategies.

2.4 Adoption and Implementation: Standard Setting

An important aspect related to the adoption and implementation of open source software developed in organizational engagements with open source projects is how it shapes industry practices (Casile & Davis-Blake, 2002). Organizational engagement with open source projects not only creates shared software but also shared best practices that get distributed across projects and organizations (Gandhi et al., 2018). Because open source projects have the potential to establish industry standards, organizations have to understand this process as it is different from standard setting through committees (Mulligan, 2008).

Research found that open source projects tend to develop standards because of the coordination mechanisms used within projects (Egyedi & Van Wendel de Joode, 2004). The rationale is that changing open source software would hurt users who depend on the software. In striving towards stability, open source projects establish unchanging and de-facto standard interfaces for users and applications (Egyedi & Van Wendel de Joode, 2004). It was therefore suggested that the open source development model could be applied to formal standard setting (Mulligan, 2008).

Standard setting has long been researched, showing that standards influence practice, have strategic meaning for organizations, involve power struggles, and are subject to institutional forces (Aggarwal, Dai, & Walden, 2011; Backhouse, Hsu, & Silva, 2006; Casile & Davis-Blake, 2002; Grøtnes, 2009; Hicks & Goronzy, 1966; Leiponen, 2008). Organizations invest in standard setting because influencing standards and learning from the discussions to create standards has economic benefits (Hurd & Isaak, 2005). Standards are either formally defined through standard-setting organizations or implicitly through strong market players (Backhouse et al., 2006). Standard setting through open source projects can involve many different organizations and outcomes become industry standards when they have support from strong market players (Mulligan, 2008; Mulligan et al., 2011). This may be evolving as the European Commission is evaluating the role that open source projects can play in future standard setting approaches in the European Union (European Commission, 2018). Specifically, the European Commission is gathering experience reports from organizational engagements with open source projects about how software and practices from those projects have become de-facto standards in industry.

Elevating open source projects to the rank of official standard setting organization has the appeal of modernizing standard setting practices based on open source project practices (Mulligan, 2008). Specifically, benefits are believed to include improved ways to collect feedback from potential users and greater acceptance of standards because a larger community can be involved in the standard-setting process (ibid.). Potential risks for developing standards in open source projects stem from licenses and patents (ibid.). As solutions for these risks are advanced, companies are becoming more comfortable with the idea of developing standards through open source projects (Wright & Druta, 2014).

Open source projects ensure that standards are practical by innovating standard specifications alongside implementations (Wright & Druta, 2014). Innovation for specification and implementation stem from experience reports and feature requests as community members adopt a standard to their local contexts (Gandhi et al., 2018). Resulting from these discussions, standard setting in open source projects not only produces standard specifications but also best practices for using and adopting standards (ibid.). The distribution of standards therefore not only involves standard specifications, but also best practices as learned and shared within open source projects.

Table 5. Summary of select literature on the adoption and implementation of open source software in the context of organizational engagement with open source projects, specifically how it is evident in standard setting.

Select Literature	Summary of how literature is relevant
Hicks & Goronzy, 1966	Theoretical discussion of how standard setting influences practice showing that standard setting has long been studied.
Casile & Davis-Blake, 2002	Empirical analysis of how organizations respond to technical and institutional changes in standards, showing that standard setting has been studied in organizational contexts.
Egyedi & Van Wendel de Joode, 2004	Theoretical discussion of how open source project employs coordination mechanisms that lead to standardization arguing that standard setting is an inherent process to open source projects.
Hurd & Isaak, 2005	Theoretical discussion of incentives for different stakeholders to engage in standard setting showing that organizations have economic incentives.
Backhouse et al., 2006	Empirical analysis of power and politics in standard setting showing that organizations are influenced by exogenous contingencies and institutional forces when engaging in standard setting.
Leiponen, 2008	Empirical analysis of cooperative standard setting in a traditional consortium format revealing strategic considerations that organizations have for influencing standard setting.
Mulligan, 2008	Theoretical discussion of how open source practices can be used to modernize standard setting in the IT context showing potential benefits and risks for organizations.
Grøtnes, 2009	Empirical analysis of one standard setting consortium in the IT sector and its organizational choices showing how standard setting can occur outside of open source projects.
Aggarwal et al., 2011	Empirical analysis of the relationship between number of organizations engaged in standard setting and risks resulting for these organizations showing that organizations can reduce risks by engaging more organizations in standard setting.
Mulligan et al., 2011	Empirical analysis of how organizations engage in or are impacted by standard setting in the Android open source project uncovering complexities in setting standards in open source projects.
Wright & Druta, 2014	Theoretical discussion of open source projects as industry alliances that organizations can leverage to improve standard setting arguing that the software-driven approach in open source projects validates standard implementations sooner than in a more traditional specification-driven standard setting approach.
European Commission, 2018	Website about the European Commission project for evaluating open source projects as a means for standard setting showing that legislators are investigating the potential benefits of setting industry standards in open source projects

Select Literature	Summary of how literature is relevant
Gandhi et al., 2018	Empirical analysis of an industry standard as developed through organizational engagement with open source projects showing that standard setting in open source projects creates best practices for using a standard in addition to the standard.

2.5 Performance Metrics: Open Source Project Health

Organizations are looking to performance metrics as signals for open source project health when making decisions about engaging with open source projects (Link & Germonprez, 2018). Before organizations engage with open source projects, they have to compare organizational engagement to alternative means of software development (e.g., in-house development, outsourcing, or purchasing commercial solutions) for achieving business goals (Fitzgerald, 2006). A major concern for organizations that enter into a dependency with open source projects is whether an open source project will be reliable and around for the long term (Germonprez et al., 2017).

As defined earlier, open source project health is the potential that an open source project will continue developing quality software (Naparat et al., 2015). This definition has three components. First, it takes a long-term perspective in which future development is sustainable. Second, it requires an outcome of an ongoing development efforts. Third, it accommodates that a potential of a future is the closest we can assess because the future cannot be known ahead of time. It may be difficult to know whether a project is healthy but easier to identify whether a project is not healthy. Loss of contributors and poor code quality are two prominently recognized signals that indicate a lack of project health (Marsan et al., 2019).

Literature points to three dimensions along which open source project health can be assessed: (1) community, (2) code, and (3) resources (Arantes & Freire, 2011; Link & Germonprez, 2018). The *Community* dimension captures that open source projects rely on people to contribute. Relevant signals include diversity of community members, size of community, and governance of community. The *Code* dimension captures that open source projects should produce quality software. Relevant signals include vulnerabilities, quality of code, and activity in collaboration tools (Decan, Mens, & Constantinou, 2018; Khomh et al. 2014). The *Resources* dimension captures that open source projects can develop quality software using their own resources, including an infrastructure of specialized hardware, continuous integration systems, testing facilities, and financial resources. Relevant signals include availability of resources, number of sources providing resources, and how resources are managed within a project. Each of these dimensions focuses on a different aspect of open source project health and can be understood through a variety of signals (Crowston et al., 2006).

Many signals are used to assess open source project health (Head, 2016). Which signals for each dimension of open source project health should be assessed is not well understood. Related research used a quantitative perspective, calculated open source project signals, and correlated them with continued development or discontinuation of a project (Crowston et al., 2006; Schweik & English, 2012). Vetted signals based on past development activity and no study made or validated predictions about the future success of projects. Another challenge with these signals is that they are based on readily available metadata about an open source project which cannot account for the quality of an activity that produced the metadata.

From an applied perspective, practitioners find it useful to specify goals for assessing open source project health and to combine them with personal knowledge about an open source project in determining which signals best signal health and answer specific questions (Bacon, 2012; Izquierdo, 2017). This added qualitative foundation counters a problem of unintentionally misunderstanding signals, which are known to carry different meanings across open source projects (Vancsa, 2018). Because personal experience is important in choosing signals for assessing open source project health, a common method for assessing open source project health is missing (Link & Germonprez, 2018). A related unsolved challenge is to assess the health of a project's ecosystem, which includes dependencies (Marsan et al., 2019). Ecosystem health is important in light of increasing complexity as open source projects build on other projects, introducing dependencies not only in code but also in health. The SECO Health project is working to understand these inter-project dependencies and their related health dynamics (Decan, Mens, & Grosjean, 2019).

Table 6. Summary of select literature on performance metrics in the context of organizational engagement with open source projects, specifically how they inform open source project health.

Select Literature	Summary of how literature is relevant
Crowston et al., 2006	Empirical analysis of historical open source project data showing how different signals can be operationalized and how they relate to open source project health.
Fitzgerald, 2006	Theoretical discussion of organizational engagements with open source showing that organizations are strategic about engaging with open source projects.
Arantes & Freire, 2011	Literature overview about open source project health showing that open source project health can be observed through signals pertaining to community, code, and resources.
Bacon, 2012	Book about community management showing that using metrics to understand an open source project requires first knowing what questions about the project need to be answered.
Schweik & English, 2012	Book with empirical analysis of what factors lead to open source project health showing correlations between past activity data and whether a project was abandoned or continued to release software.
Khomh et al. 2014	Empirical analysis of signals related to software quality showing that activity in collaboration tools are signals for software quality.
Naparat et al., 2015	Empirical analysis of what mechanisms in organizational engagements with open source projects that influence open source projects health providing a definition of open source project health.
Head 2016	Empirical analysis of what signals developers pay attention to when choosing open source projects showing that many signals exist.
Germonprez et al., 2017	Empirical analysis of organizational engagement with open source projects showing that organizations integrate open source projects in their innovation streams.
Izquierdo, 2017	Blog post about defining a metric strategy open source projects showing that signal selection is dependent on the goals and questions of an organization.
Decan et al., 2018	Empirical analysis of vulnerabilities in open source projects showing that healthy projects address vulnerabilities quickly.
Link & Germonprez, 2018	Empirical study about how open source project health is assessed in organizational engagements with open source projects showing that there is no common method for assessing project health.
Vancsa, 2018	Blog post about challenges with using metrics to understand open source project health.
Decan et al., 2019	Empirical analysis of dependencies between open source projects showing that the SECO Health project is focusing on health dynamics that span many projects.
Marsan et al., 2019	Empirical analysis of open source ecosystem health problems and their causes showing what the most common health problems are.

3 Literature Review: Signaling Theory in the Context of Open Source

Stemming from literature, signaling theory enables a theoretical examination at how performance metrics play a role in the evolving nature of organizational engagement with open source projects. Signaling theory informs situations where an informational structure is asymmetric for senders and observers, and signals are used to overcome the asymmetry (Connelly et al., 2011; Kirmani & Rao, 2000; Spence, 1974). The information asymmetry exists with regard to a sender's hidden quality. Signaling occurs often before a sender and an observer engage and before an observer could learn about the true nature of a sender's hidden qualities. Signaling continues throughout an engagement when an observer cannot fully rely on experience to learn the hidden quality (Ho & Rai, 2017). Signaling theory describes that signals allow observers to differentiate between senders of high and low hidden qualities, but signals can also help coordinate collaborating senders and observers (Hasson, 1997). Senders can purposely display signals to shape the informational structure, thereby influencing observers (Spence, 1974). Signaling theory has been applied in settings where organizations send signals to employees (Karanges, Johnston, Lings, & Beatson, 2018), consumers (Erdem, 1998), and other organizations (Heil & Robertson, 1991). Open source projects are known to signal to volunteer members and influence their intention of continued participation (Ho & Rai, 2017).

Organizational members are not directly able to observe the health of an open source project but rely on signals. Literature on open source software adoption found that signals influence organizations' decisions when engaging with open source projects

(Dedrick & West, 2003; Nagy, Yassin, & Bhattacherjee, 2010; Poba-Nzaou, Raymond, & Fabi, 2014). Signals are meaningful as open source projects and organizations use them in their engagement even though open source projects can send signals without being aware of it (Ho & Rai, 2017; Santana, 2014). Open source projects benefit from intentionally displaying signals because it may attract additional organizations who help further the project (Bacon, 2012). Organizations benefit from using signals about open source project health because it informs decision-making (Heil & Robertson, 1991).

3.1 Signaling Activities

Displaying credible signals is important for open source projects in communicating with organizations (Fogel, 2015). Open source projects can display signals on their website, code repository, project blog, newsletter, or metrics dashboard. Projects can also contribute content to other outlets, such as news articles, contributed blog posts, conference presentations, and interviews. In these, it is important to display credible signals, which allows distinguishing between projects of low and high open source project health.

Credibility of a signal is given when neither senders nor observers benefits from deceiving the other (Hasson, 1997). Literature considers signal display effort to demonstrate signal credibility (Connelly et al., 2011). A signal is considered credible when signal display effort is correlated negatively with the hidden quality, such that unhealthy projects have to expend more effort than a healthy project when displaying a signal. For healthy projects, the benefit of displaying a signal is expected to outweigh the signal display effort. Conversely, unhealthy projects refrain from displaying a credible signal because the signal display effort outweighs the benefits (Kirmani & Rao, 2000). The theoretical discussion of signal display effort is summarized in Table 7 (adapted from Spence, 1974).

Table 7. Theoretical discussion of signal display effort (adapted from Spence, 1974).

Signaling theory builds on game theory. Signaling theory assumes that a signaling equilibrium exists in a market. In a hypothetical signaling equilibrium, organizations rely on one signal that reliably indicates whether an open source project is unhealthy or healthy. Following is a theoretical discussion adapted from Spence (1974, pp. 18f). Changes include replacing senders and observers with projects and organizations:

To demonstrate the hypothetical signaling equilibrium, we assume what organizations decide how much to contribute to an open source project depending on their belief about a project's health. Suppose organizations believe that if y < ŷ, then projects are unhealthy, and that if y ≥ ŷ, then projects are healthy. If these are organizational beliefs, then their contribution will be a step function (Figure 1). Note that ŷ is just some number for the time being.

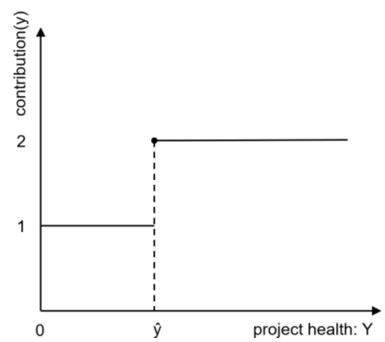

Figure 1. Organizational contributions as a function of project health. (adapted from Spence, 1974)

Given the contribution function, open source projects can determine how much effort to put into displaying the signal. Consider a project that sets y < ŷ. If it does, it will set y = 0, because signal display requires effort and until it reaches ŷ, there is no benefit to increasing y, given the hypothesized organizational contribution function. Similarly, a project that sets y ≥ ŷ will in fact set y = ŷ, since further increase would merely incur more signal display effort with no corresponding benefit. All projects will therefore either set y = 0 or set y = ŷ. Given the organizations' initial beliefs and the fact just deduced, if organizations' beliefs are confirmed, then unhealthy projects must set y = 0, while healthy projects set y = ŷ. Diagrams of the options facing open source projects are shown in Figure 2.

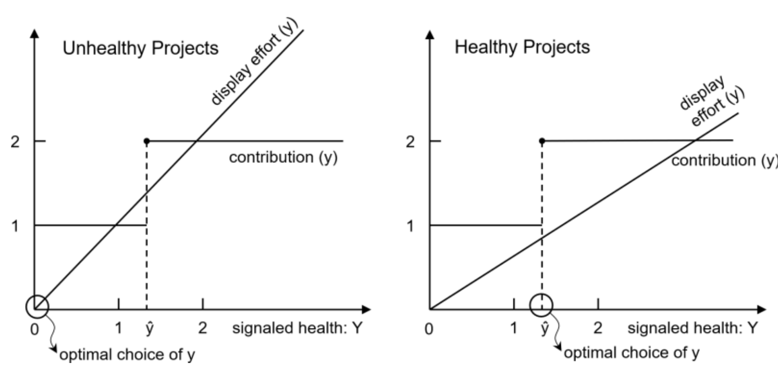

Figure 2. Optimizing choice of signal display effort for unhealthy and healthy projects. (adapted from Spence, 1974)

Superimposed upon the organizational contribution function are the signal display effort functions for unhealthy and healthy projects. Signal display effort is assumed higher (steeper slope) for unhealthy projects, and lower for healthy projects. Projects select y to maximize the difference between expected contributions and signal display effort. Given the level of ŷ in the diagram, it is easy to see that unhealthy projects select y = 0, and healthy projects set y = ŷ. Thus, in this case, organizations' beliefs are confirmed, and we have a signaling equilibrium. In this hypothetical signaling equilibrium, unhealthy projects are discouraged from displaying the signal.

Organizations use signals in their decision-making, but signals are only effective when organizations pay attention to them (Connelly et al., 2011). Through signals, organizations get a better understanding of a project's health and observe whether past decisions lead to expected outcomes (Spence, 1974). For future decisions, organizations pay more attention to signals that have correctly informed past decisions. Signals may be used differently by organizations because of varying objectives or differing beliefs about what a signal means. A signal has different relevance depending on the context it is used in, especially when a signal informs a specific aspect of a hidden quality (Hasson, 1997). Which signals an organization observes is also determined by how easily they are observable and how important a related decision is for an organization (Drover et al., 2017).

3.2 Cooperative Signaling Behavior

Cooperative signaling behavior occurs when senders and observers work together to improve their signaling activities (Spence, 1974). Spence (1974) demonstrated, using game theory, that signaling occurs in an environment with incentives for cooperative signaling behavior. Senders and observers can make signaling activities more effective by creating better signals or by optimizing signal activities. One of Spence's (1974) examples is that professionals in the job market can create a certification for their profession. Employers can then use the certification as a signal to more easily determine whether a new hire is a professional. The professionals can expect better job offers as a benefit from the reduced uncertainty about their qualification.

Cooperative signaling behavior has been little explored as research focuses on studying existing signals, not their creation (Connelly et al., 2011; Heil & Robertson, 1991). We know that signals emerge in response to trade-offs between costs and benefits for projects and organizations (Hasson, 1997). However, we do not know how signals are created in cooperative ways.

A similar incentive structure for cooperative signaling as described by Spence (1974) can be found in organizational engagements with open source projects. Open source projects have an incentive to learn from organizations which signals receive attention and are effective for differentiating healthy from unhealthy projects. Organizations have an incentive to learn from open source projects which signals are available and how to correctly interpret signals. However, projects and organizations have to overcome challenges that signaling literature identified.

Broadly, open source project health can be signaled by many indicators (Crowston et al., 2006) and has much potential for shaping an informational structure (Spence, 1974) – which signals open source projects display and organizations use. Therefore, to shape the informational structure, projects and organizations need to change the practices by which signals are displayed and used. In doing so, it is necessary to consider available signals together because they impact each other when displayed at the same time (Drover et al., 2017). A selection of a few signals can be more effective than all signals together because signals may together have a weaker effect than individually (Santana, 2014; Wang, Qu, & Tan, 2018). In some cases, the same signal is displayed to convey different but related information because fewer signals allow for more efficient communication (Santana, 2014). When projects display conflicting signals, organizations may decide to delay engagement and observe open source projects longer before deciding (Worsham & Gatrell, 2005). Conversely, when signals corroborate the same message, they support each other and serve as a stronger signal (Miyazaki et al., 2005).

To overcome these challenges, cooperative signaling behavior has the potential to provide answers to unsolved challenges, including how signals operate together, whether they strengthen each other, how many signals are optimal before an organization is overloaded with information, and what combination of signals is most effective (Kirmani & Rao, 2000). Cooperation then proves beneficial in shaping an informational structure because open source projects (senders) choose which signals to display, but organizations (observers) may pay attention to different sets of signals and interpret their meaning differently (Drover et al., 2017). Open source projects and organizations can determine, *cooperatively*, the meaning of signals and resolve the ambiguity that may arise from poorly defined informational structures.

Open source projects and organizations engaging in cooperative signaling behavior may choose to structure their interaction in open source projects and create shared signals. It makes sense to leverage established open source collaboration mechanisms, especially since open source projects are fruitful grounds for developing shared practices and standards (Gandhi et al., 2018). In defining shared signals, open source projects and organizations reflect on their respective local signaling activities for displaying signals, and for using signals. Both sides may resolve different interpretations of what signals can mean and how they should be displayed. As projects and organizations learn more about signals, they can be expected to change how they use signals to understand project health (Gomulya & Mishina, 2017).

3.3 Conceptual Framework

The research question is: *How do open source projects and organizations create signals for open source project health?* To investigate this question, I use signaling theory as a lens. Signals serve as alternative information for a hidden quality, such as project health. On one side is a sender, such as an open source project, which provides information about its hidden quality by displaying signals. On the other side is an observer, such as an organization, that uses this information to form an opinion about the hidden quality of the sender. Through cooperative signaling behavior, senders and observers create new signals to communicate about a hidden quality in new ways by displaying and using signals. Cooperative signaling behavior spans all of these activities, involving senders and observers. Figure 3 displays the relationship between concepts involved in signaling, which are summarized in Table 8. Based on this conceptual framework, the focus of this study is on cooperative signaling behavior but requires understanding all concepts.

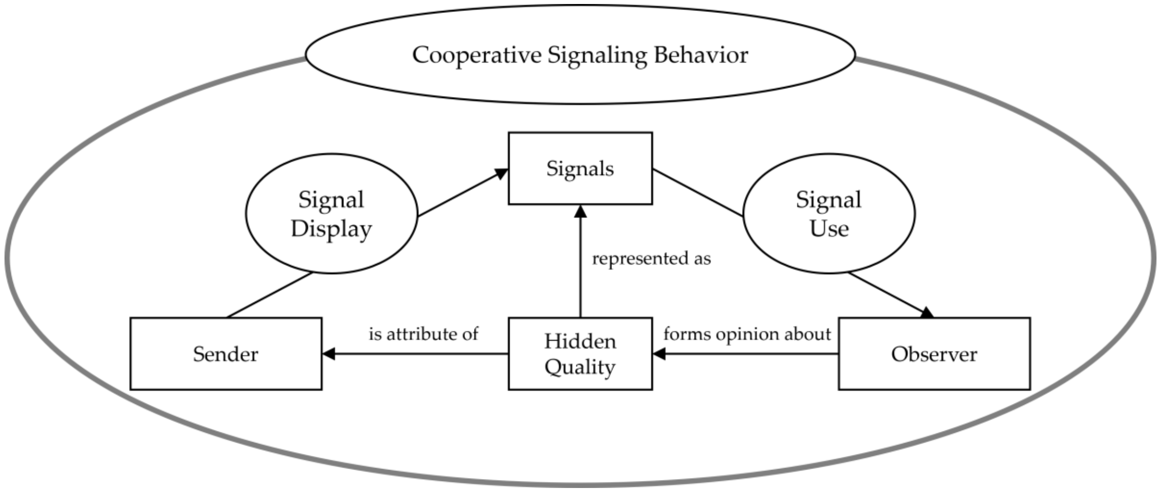

Figure 3. Conceptual framework. A hidden quality is conveyed through signals. Senders provide information about their hidden quality by displaying signals. Observers form an opinion about a sender's hidden quality based on the signals they use. Through cooperative signaling behavior, senders and observers move beyond the hidden qualities to create signals and help each other with their respective signaling activities. The entire framework is subject to cooperative signaling behavior.

Table 8. Concepts of the conceptual framework.

Concept	**Definition**	**Select References**
Cooperative Signaling Behavior	Open source projects and organizations work together to shape an informational structure by creating signals and helping each other with their respective signaling activities.	Santana, 2014; Spence, 1974
Signals	Credible alternative information. Several signals can be used to assess open source project health.	Connelly et al., 2011; Crowston et al., 2006; Kirmani & Rao, 2000; Spence, 1974;
Signal Display	Signaling activity of open source projects to provide signals.	Connelly et al., 2011; Heil & Robertson, 1991; Spence, 1974
Signal Use	Signaling activity of organizations to assess open source projects health and make decisions based on signals.	Connelly et al., 2011; Heil & Robertson, 1991; Spence, 1974
Hidden Quality	Difficult to convey information about an open source project such as open source project health – the potential that an open source project will continue developing quality software.	Link & Germonprez, 2018; Ho & Rai, 2017; Naparat et al., 2015
Sender	Open source projects want to inform organizations about their open source project health by displaying signals.	Ho & Rai, 2017; Fogel, 2015; Bacon, 2012
Observer	Organizations want to know about open source project health by using signals.	Link & Germonprez, 2018; Germonprez, et al., 2017; Eghbal, 2016;

4 Method

To explore the research question, engaged field research was conducted (Van de Ven, 2007). From this field engagement, an applied context for investigating cooperative signaling behavior was used. From the context, a theoretical critique of cooperative signaling behavior was developed and strengthened through interviews. Figure 4 shows the sequence of method components.

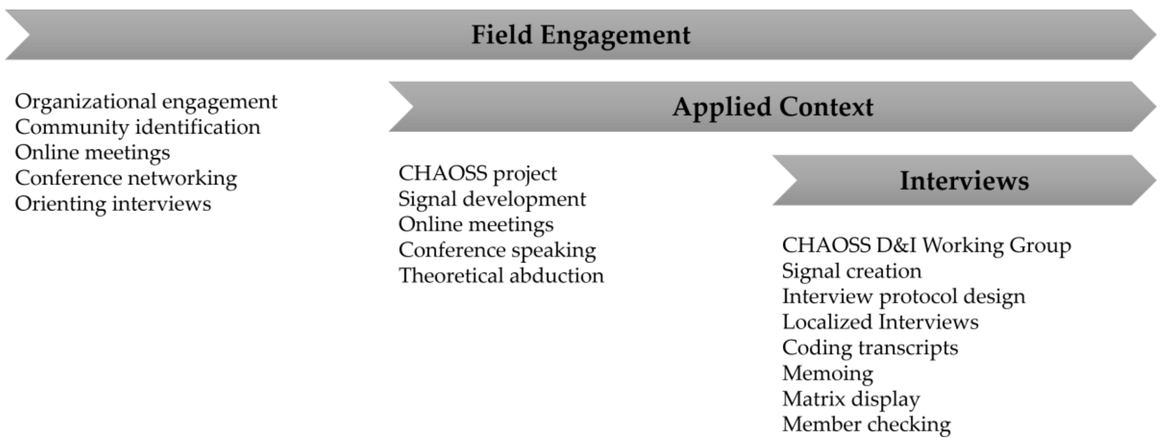

Figure 4. Methodological framework with foci and research activities.

4.1 Field Engagement: Organizational Engagement with Open Source Projects

The field engagement was informed by engaged scholarship principles (Van de Ven, 2007). Active participation in the field was a primary activity. As an active participant in various open source projects over the last decade, the work of these projects was advanced, problems were solved, and I became recognized as a contributing member. I learned about the language, governance structures, and project workflows.

4.1.1 Active Engagement in Open Source Projects

For this study, field engagement was targeted at understanding organizational engagement with open source projects. Since starting my Ph.D. in 2015, I was strategic in selecting projects that advanced an overall understanding of organizational engagement with open source projects. Criteria in selecting projects as field sites included that they were open source projects where organizations participated in the development, a criterion met by a majority of Linux Foundation projects.

Active engagement in several open source projects provided many opportunities for observing how organizations engaged with open source projects. Field sites included the SPDX project, the Hyperledger project, and the Core Infrastructure Initiative. Engagement in these projects involved a variety of different contributions. In the SPDX project, I conducted interviews about the level of adoption of their shared standard and presented findings for discussion with project members at the Open Source Leadership Summit 2017.[15] In the Hyperledger project, I evaluated different wiki tools and discussed their use with project members.[16] In the Core Infrastructure Initiative, I discussed criteria for new badging levels for the Best Practices Badge and translated the Best Practices Badge application into German.[17] Through this active engagement in open source projects, contacts with practitioners in the field were established, rhetorical

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[15] https://github.com/SPDX-CaseStudy/files/blob/master/FocusGroup.pdf
[16] https://lists.hyperledger.org/g/discuss/message/49
[17] https://lists.coreinfrastructure.org/g/CII-badges/message/407

strength was developed, problems in organizational engagement with open source projects were better understood, and specific problems were solved.

4.1.2 Participation in Open Source Conferences and In-Person Conversations

Understanding organizational engagement with open source projects was further deepened by networking at open source conferences. I participated in ten open source conferences, including Open Source Leadership Summit (2017, 2019), Open Source Summit North America (2017, 2018), Open Source Summit Europe (2017, 2018), FOSDEM (2018), Mozilla Festival (2017, 2018), and Sustain Summit (2018). At a majority of these conferences, I presented my Ph.D.-related research work. Additionally, I attended talks and presentations from practitioners who spoke about issues around organizational engagement with open source projects, all deepening my understanding of organizational engagement with open source projects.

Informal in-person conversations at open source conferences provided opportunities to orient myself in the field and to advance the understanding and rhetoric for talking about organizational engagement with open source projects. A total of 55 semi-structured interviews were conducted through video conferencing software to orient myself and gain insights to organizational engagement with open source projects. Specific findings from these research engagements were documented in published papers (Link & Germonprez, 2016; Link, Gill, & Khazanchi, 2017; Link & Jeske, 2017; Link & Qureshi, 2017; Gandhi et al., 2018; Germonprez et al., 2018; Link & Germonprez, 2018; Link & Qureshi, 2018; Rao et al., 2018; Link et al., 2019). For the purpose of this study, the engaged field work provided the necessary understanding to navigate a context for more deeply understanding how open source projects and organizations create signals for open source project health.

4.2 Applied Context: CHAOSS Project and CHAOSS D&I Working Group

An unconference session at the Open Source Leadership Summit 2017 was the start of a focused field engagement for investigating cooperative signaling in organizational engagements with open source projects. The session revealed that organizations were actively thinking about how to understand their engagements with open source projects and that health of these projects was on top of their minds. Following the session, the Community Health Analytics Open Source Software (CHAOSS) project was formally established within the Linux Foundation to combine efforts for understanding signals of open source project health and efforts for creating software tools to generate these signals. Since then, CHAOSS had a strong presence at nine open source conferences: Open Source Summit North America (2017, 2018), Open Source Summit Europe (2017, 2018), CHAOSScon Europe at FOSDEM (2018, 2019), CHAOSScon North America (2018), Open Source Leadership Summit (2018), and Community Leadership Summit (2018). Around 50 people attended each CHAOSS session at these conferences. Interest has come from organizational and foundational employees, project maintainers, and open source project members, indicating that this topic is important to various stakeholders. Figure 5 features logos of organizations that employ CHAOSS governing board members to show a sample of organizational and academic representation in the CHAOSS project.

Figure 5. Logos from organizations that employ CHAOSS Governing Board members.

4.2.1 Balancing Field Engagement and Field Observation

I helped grow the CHAOSS project as a founder, member of the governing board, and active contributor. Doing so revealed internal workings of the open source project and behavior of project members (Van de Ven, 2007). As it is important to consider the researcher's role within the CHAOSS project because of his active role in the data creation ritual (Kozinets, 2015), a challenge encountered with the engaged field research was to balance observation and engagement.

Concerns stemmed from deep engagement potentially confounding what was studied (Kozinets, 2015). As a member of the community, it was easy to pick-up tasks such as taking meeting minutes, sending summaries to the CHAOSS mailing list, or responding to other members' ideas. To strike a balance between observation and engagement, restraint provided space to observe interactions of others in a natural setting. Being immersed in community work and focusing on furthering goals of the community took attention away from observing for research. When this occurred, communication history in email discussions and collaboration platform archives served as documentation to reconstruct field observations. Observations in open source are often documented in archives and, thus, an alternating focus on research was less of a concern in the online environment than in non-digital field work. Observing and reporting on events first-hand while reconstructing event details from documents created in the moment is an accepted method for adding to a knowledge base (Whyte & Whyte, 1988).

4.2.2 Learning from Field Notes and Theory

Field notes were collected on the CHAOSS project, including insights not available through public documents but only brought to light from talking with open source project members and observing behavior as a member of these projects. Field notes included notes taken during meetings and end of day summaries. Observations were stored in Pocket, Box Sync, Google Drive, Zotero, Evernote, and OneNote (Figure 6). Files and folders did not follow a uniform or integrated structure but were at times organized around themes, projects, events, stories, or sources.

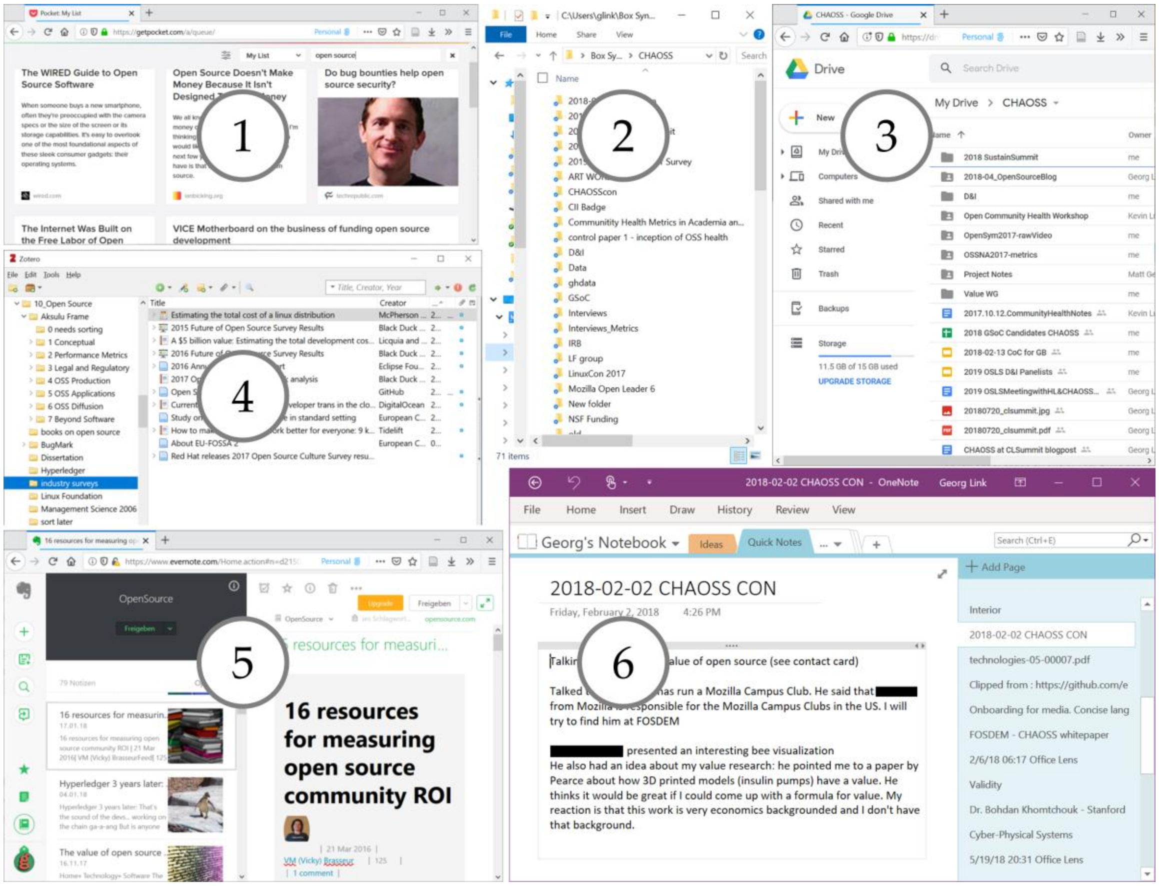

Figure 6. *Screenshots of field notes and their structure in (1) Pocket, (2) Box Sync, (3) Google Drive, (4) Zotero, (5) Evernote, and (6) OneNote.*

A hand-written research journal was created to complement work that was done digitally. The research journal was a large (13x21 cm) Moleskine “Cahier Journal” with 40 ruled pages bound in a brown cardboard cover (Figure 7). The journal helped with planning research steps, exploring challenges, recording progress, posing questions, and capturing feedback from research team members. What seemed important enough was written down, whether about method, timeline, potential new areas, or theory.

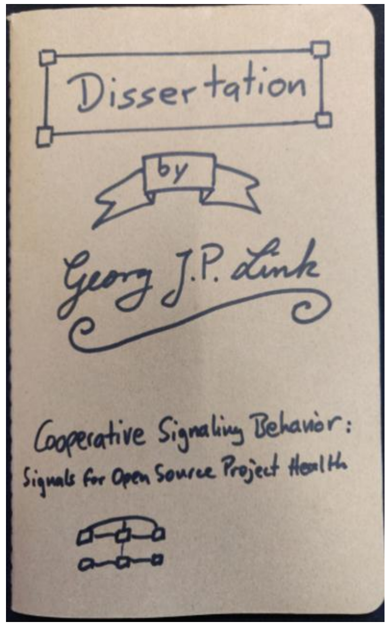

Figure 7. Front cover of research journal.

Theorizing based on field observations was done through abductive reasoning, which is the generation of conjectures that can explain observations (Van de Ven, 2007). Conjectures about signaling theory were substantiated by learning from literature about which behaviors were expected and which concepts were relevant to observe. Conjectures focused the field work on observing concepts of signaling theory. In writing down and elaborating on the emerging theoretical understanding, shortcomings in the conceptual understanding were identified and the explanatory power of conjectures was improved. These insights guided an expansion of the field engagement to search for new evidence that can help substantiate these conjectures. While much of this work was unstructured, Table 9 provides a reconstructed example of these steps.

Table 9: Example conjecture evolution from observation, literature, to evidence collection.

1. *Observation in field engagement:* Hyperledger included in a version release statement development activity metrics and a list of contributing organizations.[18]
2. *Initial conjecture:* Metrics and list of organizations are signals that Hyperledger displays to attract more organizations.
3. *Literature:* Signals are alternative information that facilitate engagement between sender and observer by overcoming information asymmetry. (Identified information asymmetry as a relevant concept).
4. *Substantiated conjecture:* Metrics and list of supporting organizations are signals that open source projects can display to attract organizations by reducing uncertainty about future support. (Incorporated information asymmetry).
5. *Evidence from interacting with community members:* Organizations pay attention to signals of how active development in an open source project is and whether well-known organizations are engaging with a project.

This example illustrates abductive reasoning, but in reality, abductive reasoning was opportunistic and did not follow a strict protocol. Some reasoning occurred from unstructured field notes in a research journal. By moving between field observations and theoretical framing, abductive reasoning helped identify what needed observing in the field. By analyzing observations through a theoretical lens, abductive reasoning helped make sense of observations and place them in context of a theoretical frame. The result was an emerging understanding of cooperative signaling behavior, which needed to be further developed.

[18] This is the same example as from the introduction. Hyperledger announcing Fabric 1.0: https://www.hyperledger.org/announcements/2017/07/11/hyperledger-announces-production-ready-hyperledger-fabric-1-0

4.2.3 Engaging Community Members in a Focus Group

To develop the emerging understanding of cooperative signaling behavior, a focus group was conducted at the Open Source Summit North America 2017. The goal was to get a deeper understanding of how project health signals would be used in decision making processes. Specifically, participants were asked to discuss what actions they want to inform with knowledge about how welcoming and inclusive open source projects are, what questions specifically they need answered, and how specific signals could help answer these questions. About 50 participants self-selected to participate in one of three groups. Each group focused on a different category of open source project health signals. The group relevant to this study focused on diversity and inclusion (D&I) signals. Notes on signals from the focus group were contributed to the CHAOSS project. These initial D&I signals were then advanced by a dedicated CHAOSS Diversity and Inclusion (D&I) Working Group.

From observations during the inception of the CHAOSS project, an understanding formed that cooperative signaling behavior was emerging. It became clear, that signals were cooperatively created. Abductive reasoning and interaction with community members provided ways to theorize about the observations and develop an initial theoretical understanding. This understanding was leveraged to design an interview protocol for collecting more pointed data from experts. Field observations directly informed what questions to ask and how to ask them. The interviews were designed to challenge the initial understanding and get additional insights that may have been overlooked in the field engagement (Lynn, 1996).

4.3 Interviews: CHAOSS Diversity & Inclusion Signals

An initial understanding of cooperative signaling behavior was constrained by what I paid attention to, took note of, and chose to put into writing (van Maanen, 1988). Yet, the initial understanding of cooperative signaling behavior may not fully reflect reality as lived by open source projects and organizations (Lynn, 1996). Therefore, an interview protocol was designed to substantiate the theoretical understanding.

Like the abductive reasoning, the interviews were localized in the work of the CHAOSS project. The CHAOSS project had two sub-communities within which signals were being developed: Diversity & Inclusion (D&I), and Growth-Maturity-Decline. To get a deep understanding and build focus of how signals were created, I localized research work in the CHAOSS D&I Working Group. The working group was selected because of my deep engagement in it, my access (convenience sampling), its organizational engagement dynamics, and strong community participation.

4.3.1 Interview Protocol Design

An interview protocol was designed using an assurance case method (Gandhi & Lee, 2009). The assurance case method provided a formal and auditable logic for developing interview questions based on the initial theoretical understanding and field observations. The assurance case method had been successfully used before to develop an interview protocol for understanding organizational engagement with open source projects (Gandhi et al., 2018). A visual assurance case (Appendix A) was constructed by deductively formulating claims informed by the conceptual framework and field observations. The theorizing described in section 4.2 and as exemplified in Table 9 (page

44) informed the claims. The top-level claim regarding cooperative signaling behavior was further refined into sub-claims through a series of rebuttals that can introduce doubts in the top-level claim. Sub-claims address a specific rebuttal and substantiate or counter the top-level claim via evidence collected through empirical evidence—interviews in this study. “As sub-claim doubts are eliminated, the assurance in the top-level claim increases. Such induction promotes high assurance by surfacing and addressing critical issues rather than supporting the top-level claim merely by observing similar repetitions through enumerative induction” (Gandhi et al., 2018, pp. 3–4). Inference rules documented what assumption underlie rebuttals and provided a place to substantiate the logic through additional rebuttals, claims, and evidence. A theoretical claim captured critiques of cooperative signaling behavior in organizational engagements as observed in the field engagement and applied context:

> **Theoretical Claim TC:** Open source projects and organizations engage in cooperative signaling behavior to create signals for open source project health.

From this theoretical claim, rebuttals were added to address each concept of the conceptual framework (i.e., cooperative signaling behavior, signal display, signals, and signal use) because it introduced doubt to the top-level claim if any are missing. To counter each rebuttal, claims and sub-claims were developed. Each branch of rebuttals and claims concluded with evidence that needed to be collected through interviews. This logic branched out as demonstrated in Table 10.

Table 10. Sample branch from assurance case demonstrates structure of claims and rebuttals.

Top-Level Claim C0: A specific D&I signal was created by open source projects and organizations.
Rebuttal R1 (*Cooperative Signaling Behavior*): Unless open source projects and organizations do not work together on the signal.
Sub-Claim C1: Informants can name what open source projects and organizations were involved in advancing the signal.
Rebuttal R1.2: Unless incentives for open source projects and organizations were not balanced.
Sub-Claim C1.2: Informants believe that incentives for open source projects and organizations were balanced.
Rebuttal R1.2.1: Unless concerns about the signal indicate that incentives are imbalanced.
Sub-claim C1.2.1: Informants have no concerns about incentives created by the signal.
Evidence E1.2: Replies showing who was involved in the development of the signal and how they balanced incentives.

Each interview question was developed from a claim and designed to be understandable by informants (Creswell, 2013). Different language used in theory and open source projects was the reason why claims used the term “signal”, but interview questions used the term “metric”. Interview questions were open-ended to allow informants to expand on a question and have room for taking an interview in any direction they associated with a question. Answers to questions provided evidence for claims. Developing a question with evidence in mind could unintentionally result in leading question formulations. Spradley (2016) provided sample formulations for eliciting desired information which helped avoid leading questions. Some follow-up questions, derived from sub-claims, directly asked for specific details from informants to help informants know what information to provide (Whyte & Whyte, 1988). Table 11 presents claims from above example and their associated questions. The interview protocol is available in Appendix B.

Table 11. A subset of claims and interview questions as identified through an assurance case method for developing an interview protocol.

Claim	Interview Question
C0: A specific D&I signal was created by open source projects and organizations.	**Q0:** I would like to focus our interview on a specific metric. Which diversity and inclusion metric would you like to focus on?
C1: Informants can name what open source projects and organizations were involved in advancing the signal.	**Q1:** What open source projects and organizations advanced the metric?
C1.2: Informants believe that incentives for open source projects and organizations were balanced.	**Q1.2:** How were incentives for open source projects and organizations balanced in the design of the metric?
C1.2.1: Informants have no concerns about incentives created by the signal.	**Q1.2.1:** What are typical concerns for using the metric?

The assurance case and interview questions were audited by research team members involved in other projects related to organizational engagement with open source projects. As a team, we traversed the logic of the assurance case together and discussed each node in the structure. Team members reflected on the logic of the assurance case with their personal experience and observations. The resultant interview protocol was piloted in practice interviews with team members, which helped to fine tune the instrument, to make certain that questions were being understood similarly across informants, and to refine the pace and tempo of interview execution. Following each pilot interview, interview questions were revised until no further changes were needed to help ensure instrument reliability.

4.3.2 Focused Interviews

Of the 55 interviews, 16 focused interviews were conducted to strengthen the field engagement and applied context. Considering that much theorizing and data was grounded in the field observations, these 16 focused interviews were conducted to identify anomalies and breakdowns in the aforementioned conceptual framework as well as to corroborate and refine it. After removing small talk, interviews lasted an average of one hour, resulted in 949 minutes audio recording, and 246 pages of transcripts.

Informants were members of the CHAOSS project with an interest in open source project health, the CHAOSS D&I Working Group specifically, and other people interested in open source project health from a diversity and inclusion perspective who may not have been active CHAOSS members. Perspectives came from within (four informants) and outside (twelve informants) of the CHAOSS D&I Working Group. Informants included men and women, but an exact count cannot be provided because they were not asked to self-identify. All but one informant agreed to have their employer listed. The person who declined to have their employer listed had just started their own business and could be deanonymized based on their employment. Employer companies included Bitergia, Cloud Foundry, Collabora, Comcast, Elastic, Forefront, Google, IBM, Intel, Mozilla, Pivotal, Red Hat, TideLift, Travis Foundation, and Works Together.

Each interview focused on one particular D&I signal to better reveal cooperative signaling behavior that shaped the signal and elevated it to be a recognized signal by the CHAOSS D&I Working Group. Informants chose from a list, provided by the CHAOSS D&I Working Group, which signal they were most knowledgeable about and wanted to explore during their interview. During each interview, the name and question of the chosen D&I signal was displayed to the researcher and informant on a shared screen to focus the conversation (Figure 8).

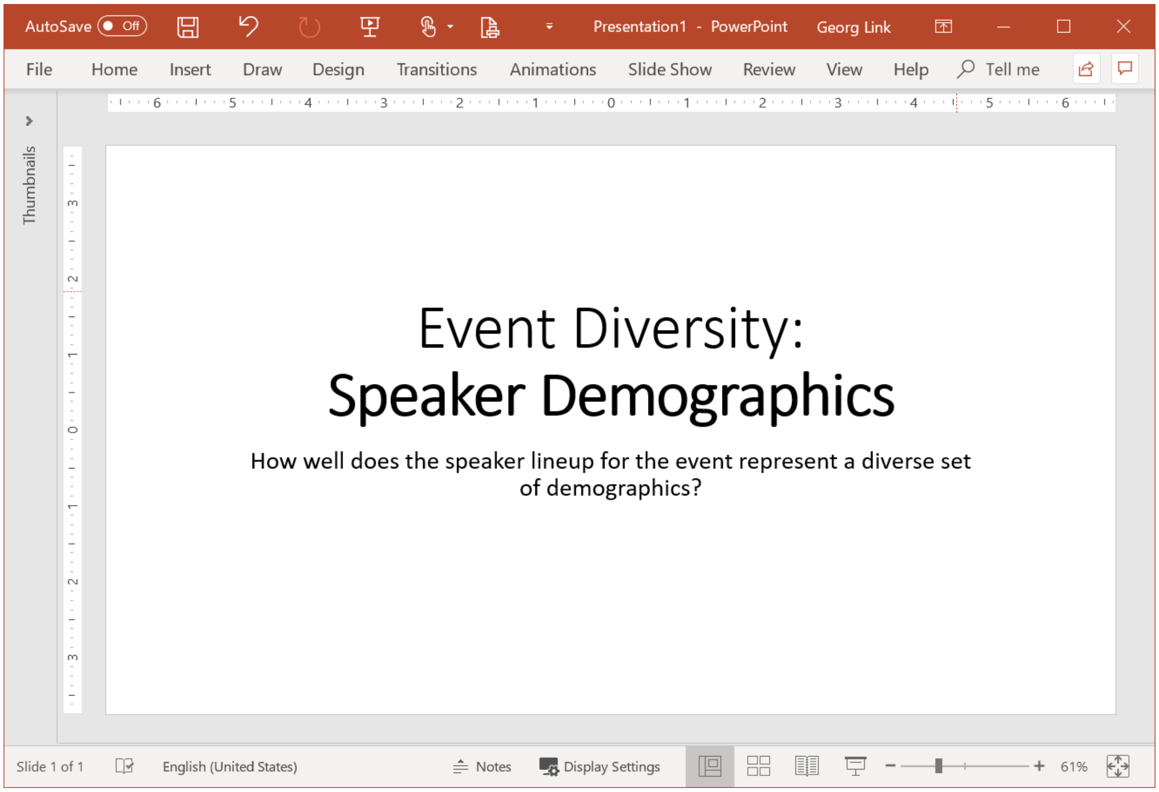

Figure 8. Screenshot of a D&I signal name and question as it was shared with informants during interviews.

Potential concerns about the quality of interview data pertains to the quality of informants. Those concerns were identified in the assurance case, specifically in the inference rule: "Informants have experience with and pay attention to D&I in open source and organizations." By collecting evidence to inform this inference rule, potential doubts regarding the quality of informants were offset. Collected evidence provides high confidence that interview data is of high quality as supported by the fact that informants demonstrated experience with diversity and inclusion in open source, participated in diversity and inclusion efforts, and represent different perspectives from projects and organizations.

4.3.3 Analysis of Interview Transcripts

Interview transcripts were closely read to ensure an understanding of the data and to identify unexpected anomalies or breakdowns of the aforementioned conceptual framework. NVivo software was used to deductively code evidence from interview transcripts (Figure 9). Codes used were informed by the conceptual framework and included: (i) cooperative signaling behavior, (ii) signals, (iii) signal display, and (iv) signal use. These codes were chosen because they focused the analysis on signals, their creation, and their subsequent display and use. Under each code, sub-codes were inductively added to better organize specific details as they emerged. Sub-codes were partially informed by the assurance case and partially informed by repeat observations.

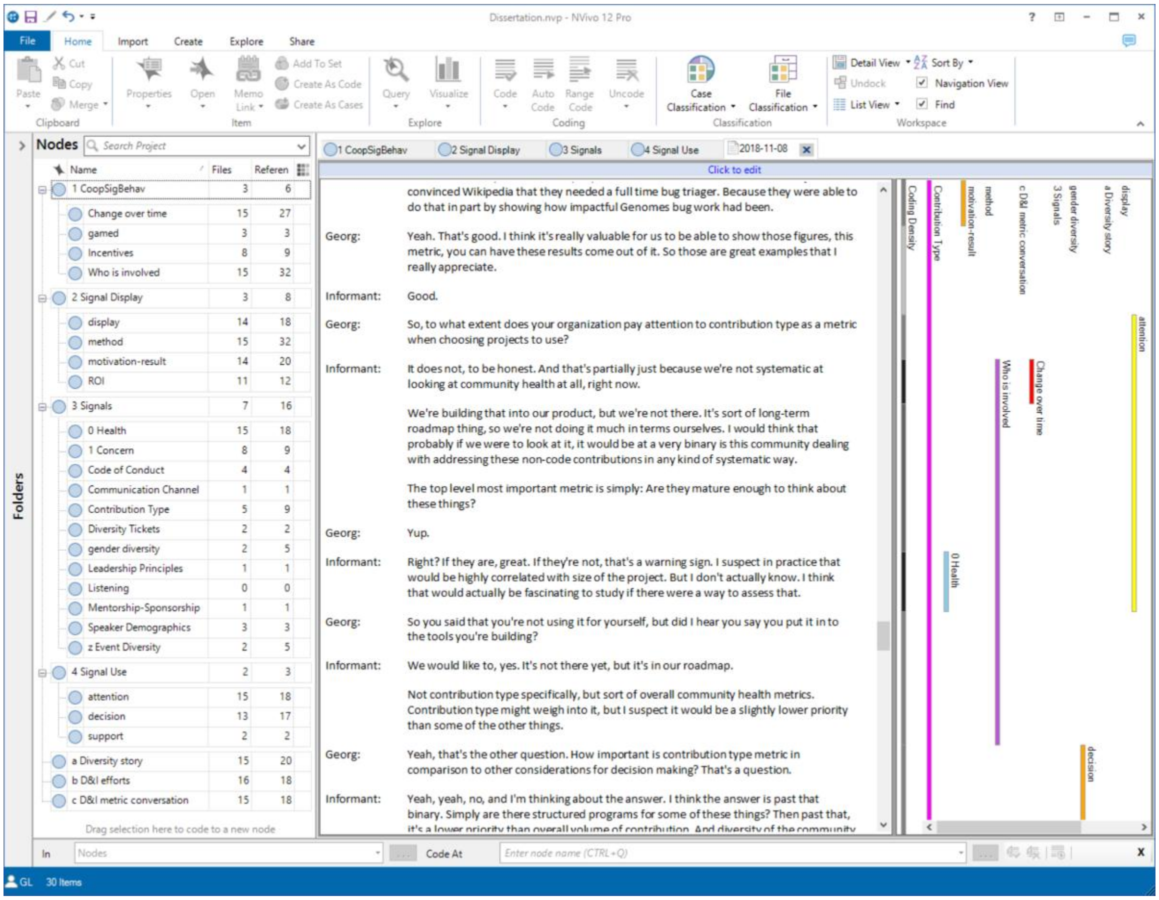

Figure 9. *Screenshot of NVivo software as it was used for coding interview transcripts. The left shows all nodes (i.e., codes), how many files (i.e., interview transcripts) a node was applied in and how many references a node was used for. The middle shows one interview transcript. The right shows which sections of the transcript are coded to which nodes.*

From the coded interview protocols in NVivo, matrix displays were created in a spreadsheet. A separate matrix display was created for each code, i.e., concept of the conceptual framework. The creative task of arranging data in the matrix required deep understanding of the data. Analysis of the matrix display allowed comparing and contrasting across interviews and spotting patterns by arranging the data in meaningful ways (Miles & Huberman, 1994). Direct quotes were sorted into three columns (Table 12): 1) evidence supporting the conceptual framework, 2) evidence that speaks to the conceptual framework but does not support it nor introduce doubt, and 3) evidence of anomalies and breakdowns that require changes to the conceptual framework to account for them. Rows grouped evidence by interview. The level of data was direct quotes from transcripts to avoid data condensation during this analysis step (Miles & Huberman, 1994). The layout ensured that all data from transcripts was represented in the matrix. Literature and field informed judgements decided which cell a direct quote was sorted into. Every direct quote in this paper bears a reference to its location in the effect matrix. For example, [1D7] points to cell D7 in the first worksheet of the effect matrix Excel file.

Table 12. Matrix display used for analyzing interview transcript data.

Concept	Interview	Support	Neutral	Anomaly or Breakdown
Cooperative Signaling Behavior	1			
	2			
	…			
Signal Display	1			
	…			
Signals	1			
	…			
Signal Use	1			
	…			

Each entry in the effect matrix was enriched with a formulated meaning to identify how a direct quote informed the conceptual framework (Creswell, 2013). Writing formulated meanings in square brackets in front of each direct quote in the effect matrix was an inductive task based strongly on literature and on a deep understanding of organizational engagement with open source projects resulting from field observations. Formulated meanings expanded on the sub-codes that had emerged during the interview coding. Formulated meanings were a way to take notes, summarize observations, and capture their meanings; thus, documenting a step in the analysis process. Formulated meanings served as abstractions from direct quotes that helped to reflect on the conceptual framework, to reflect on field observations, to find patterns, and to speed up subsequent reviews of the data. Direct quotes were bolded as a way to mark them for consideration in the final writeup, if the quote succinctly stated a relevant observation. Figure 10 shows a screenshot of the effect matrix.

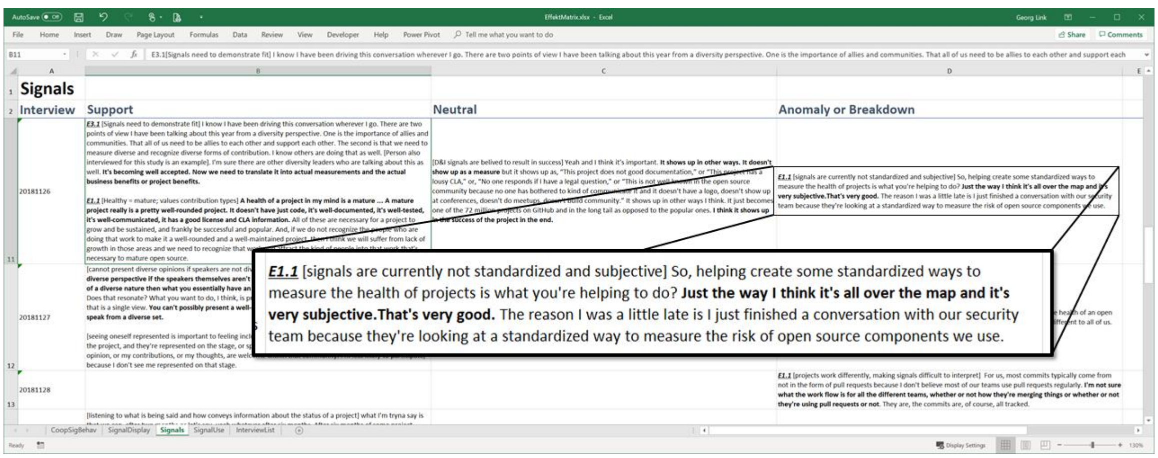

Figure 10. *Screenshot of effect matrix with one table cell zoomed in. A cell contains direct quotes from interview transcripts. Potential quotes for the final writeup are bolded. In square brackets, a formulated meaning was added before each direct quote. Quotes used in the assurance case oriented "Summary of Evidence" writeup were tagged with the evidence node of the assurance case (e.g., E1.1).*

Formulated meanings were written inside the matrix display. To get a better overview of anomalies and breakdowns, abbreviated versions of the formulated meanings were hand-written into the research journal (Figure 11). Recurring themes were marked with roman numerals to count their occurrences. The processing of formulated meanings facilitated reflection on the data. The resulting overview was instructive in determining what observations were important to highlight in the further analysis.

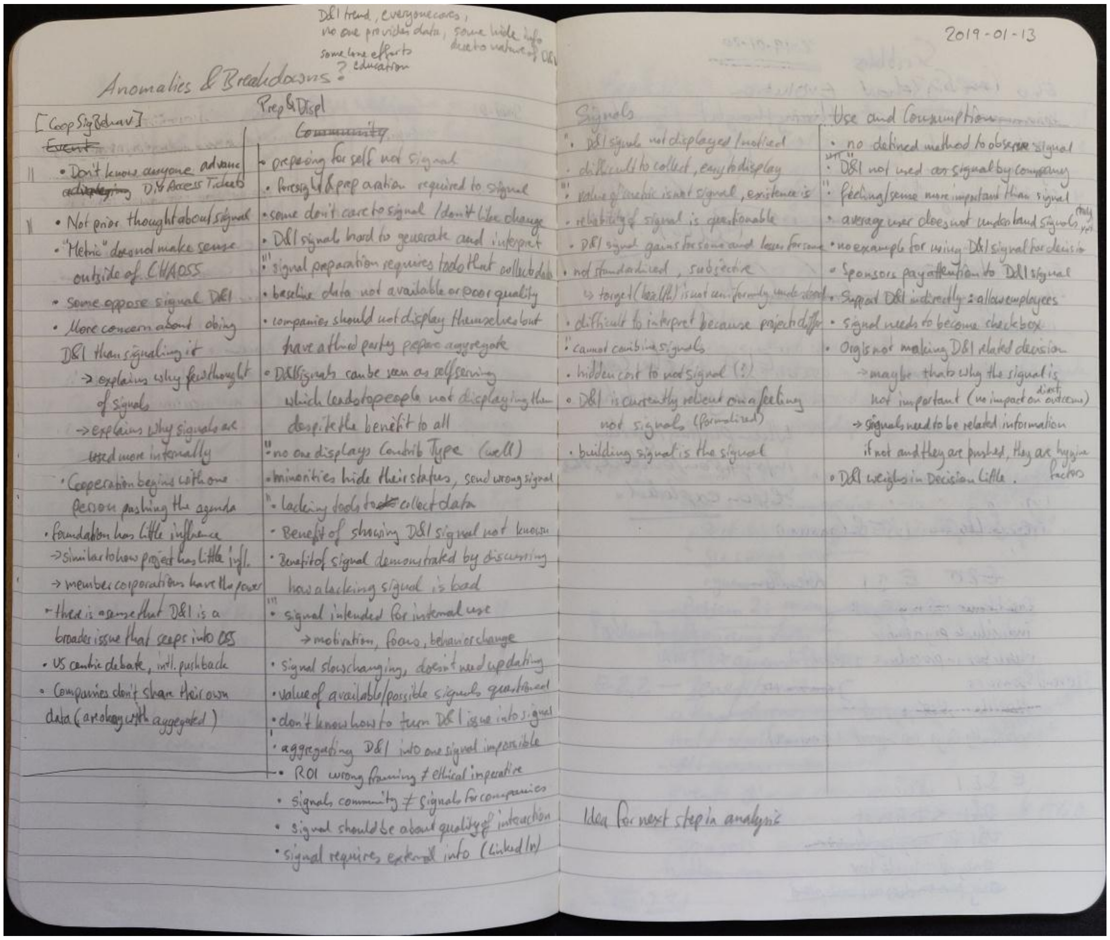

Figure 11. Picture of the research journal showing a hand-written overview of formulated meanings from the anomalies and breakdowns column.

In a next step, observations and relationships identified in the formulated meanings were collected in a “Summary of Evidence” document (Figure 12). The summary focused on the anomalies and breakdowns at first but was enriched with observations from the remaining matrix columns. The document was structured with one section for each evidence node from the assurance case. The goal was to see how much evidence was collected for areas that the assurance case had identified and to summarize what was learned.

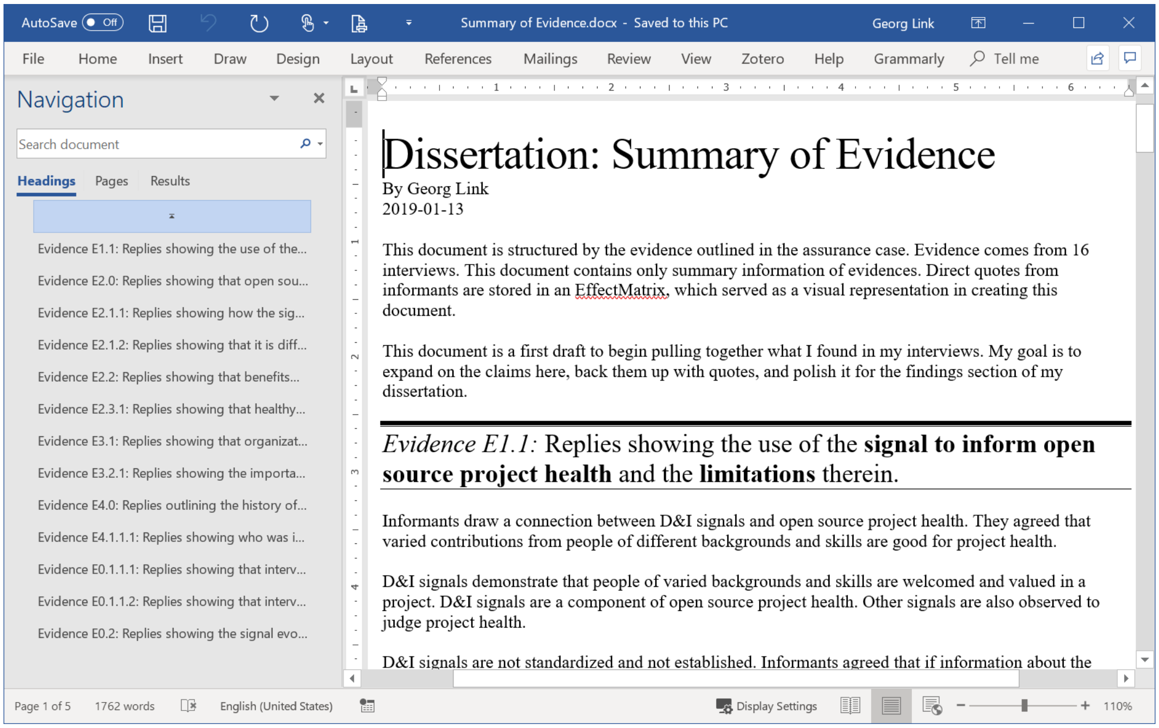

Figure 12. *Screenshot of the "Summary of Evidence" document.*

In parallel with creating the summary of evidence document, notes were made in the research journal to maintain an overview of evidence nodes and their formulated meanings (Figure 13). These notes contained bullet items of observations that were identified to belong together. This form of memoing was used to channel thinking through writing (Miles & Huberman, 1994). The notes in the research journal were hand-written to afford the flexibility necessary for a creative convergence task. As the analysis progressed, relationships between formulated meanings emerged. In sorting formulated meanings into evidence nodes from the assurance case, some formulated meanings could belong into multiple evidence nodes. These duplicate assignments were documented in the research journal and consequently fixed.

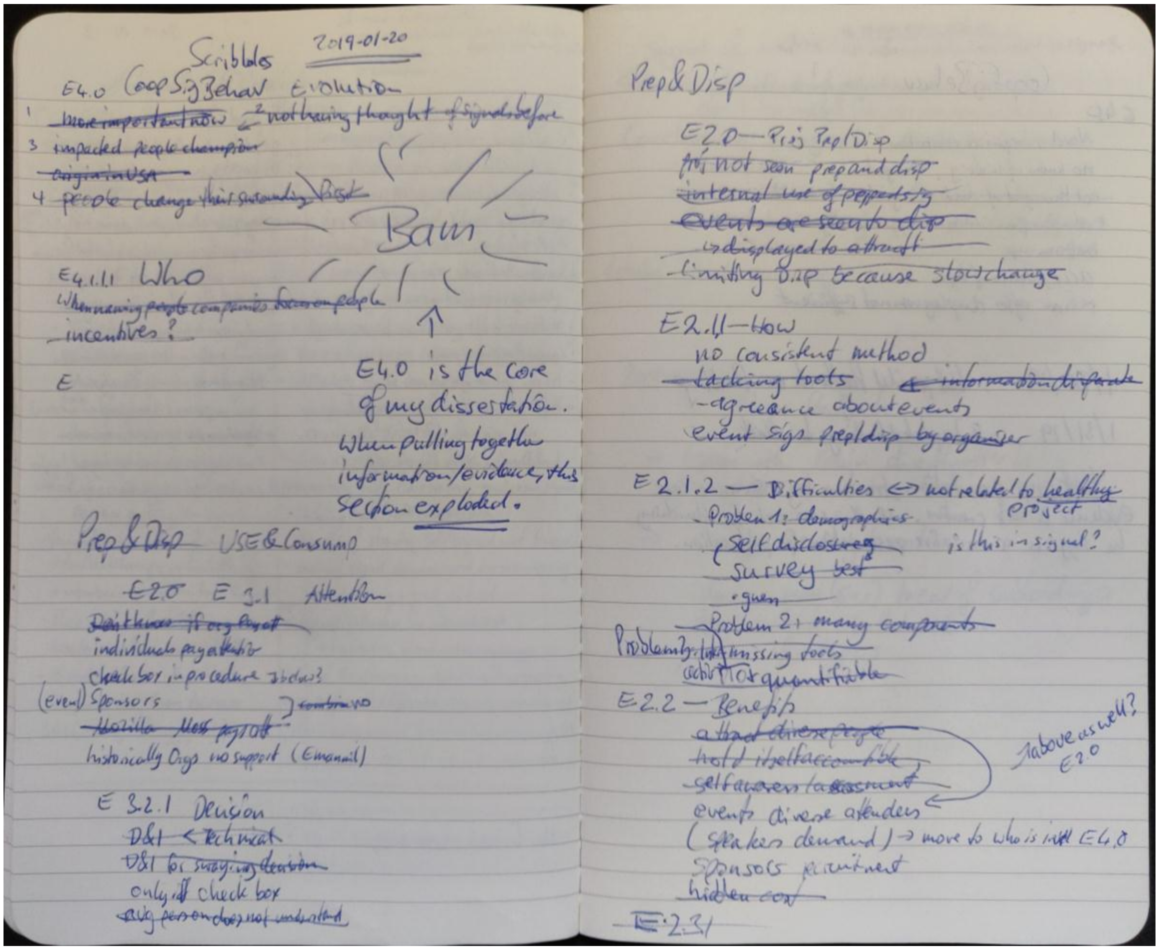

Figure 13. *Notes in research journal made during creation of the "Summary of Evidence" document.*

The summary of evidence was shared and discussed with research team members to discuss the emerging narrative and impact on the conceptual framework. The summary of evidence was developed further to contain full sentences and to group evidence that was similar. The first draft of findings was an extended version of the summary of evidence document with direct quotes added to support findings. While the assurance case and its evidence structure were organized around the conceptual framework, the structure of the findings was changed through several iterations as the focus of the narrative shifted towards answering the research question. The research question asked how signals were cooperatively created, and so the findings were organized around the steps that signals moved through as they were created. A thick description was added about how field observations from the context of the CHAOSS D&I Working Group informed cooperative signaling behavior. The thick description was based on field engagement and includes insights only available from participating since the working group was formed. The description was shared with community members for member checking. Community members accepted the description, found a blog[19] to publish the description, and planned an interview on a podcast to promote the blog post.[20]

4.4 Threats to Validity

While following these methods, the aim of the qualitative approach was to ensure the accuracy of findings (Creswell, 2013). Accuracy can be compromised through threats to validity during different stages of the research project. Following are validation strategies (Creswell, 2013) and how they were applied in this study to mitigate different threats to validity. Creswell (2013) suggested that a study should have at least two validation strategies; I highlight four validation strategies used for this study.

Threats to external validity were mitigated through *prolonged engagement and persistent observation.* Extended field observations were necessary to ensure a deep understanding of organizational engagement with open source projects as this area is deeply layered. In my four years of field engagement regarding organizational engagement with open source projects, I made field-informed decisions about what was

[19] https://thenewstack.io/how-chaoss-di-can-help-diversity-in-the-open-source-community/
[20] https://thenewstack.io/how-chaoss-measures-diversity-windows-gets-a-proper-terminal/

able to be studied – considering such things as time, access, and availability. I built trust relationships with open source community members and became an integral part of the CHAOSS project, giving me access to data critical for studying cooperative signaling behavior. Finally, this enabled identifying knowledgeable informants who were well suited to inform this research.

Threats to external validity were further mitigated through *member checking*. I solicited feedback from members of the CHAOSS D&I Working Group on conclusions I had drawn from the data. Member checking was not done on the raw data or theoretical claims but through contributions to signal definitions. Specifically, member checking was done on contributions to the CHAOSS D&I Working Group stemming from interpretations that came from this study. Contributions to signal definitions received positive feedback, verifying a good understanding of my data as it related to cooperative signaling behavior.

Threats to internal and construct validity were mitigated through *external audits* of the methods and conclusions. Auditors were research team members who were knowledgeable about the research context but were not involved in the signaling research specifically. The assurance case method provided a structure to audit the development of the interview protocol. The explicit chain of evidence from the research question to collected evidence allowed auditing the internal validity of the interview protocol (Gandhi & Lee, 2009). Claims within the assurance case were informed by literature and field observations, which was audited through in-depth discussions with research team members. During data analysis, a summary of evidence document containing evidence collected through interviews was presented to research team members. From there, regular reviews and conversations with team members about the writeup of findings validated that descriptions were logically rooted in the evidence.

Threats to internal validity were further mitigated through a *thick description* of method and findings. A thick description is important because knowledge from a qualitative study is contextual as it emerges from interpersonal interactions that are context sensitive (Brinkmann & Kvale, 2015). A thick description describes the research context, details observations, and explains how those observations translate into research findings (Creswell, 2013). Thereby, the thick description details supportive evidence, makes arguments explicit, and allows readers to judge the soundness of derived claims and to make new inferences (Brinkmann & Kvale, 2015; Creswell, 2013).

4.5 Ethics

Approval for this study was secured from the University of Nebraska at Omaha's Institutional Review Board (IRB #: 693-18-EX). Identities of informants were protected by reporting only anonymized results. An ethical approach to field engagement was followed because open source projects are neutral territory (Kozinets, 2015). An overt role approach was followed (Whyte & Whyte, 1988). Specifically, I displayed my role as a Ph.D. Candidate at the University of Nebraska at Omaha in all my online profiles and emails. In the field, I established relationships with open source project members. When scheduling one-on-one interviews, it was like asking a colleague or friend to chat about a specific topic of interest. After an interview ended, I was sometimes asked about my research and I explained what theory I am investigating, how it connected to my engagement in the CHAOSS D&I Working Group, and what outcomes I planned to produce. The research was mutually beneficial because relevant information was contributed back to the CHAOSS D&I Working Group.

5 Findings: Creating Signals Cooperatively

Field observations revealed how signals were created through cooperative signaling behavior. Cooperative signaling behavior was not visible in the creation of a single metric but could be observed across the entirety of activities by which a collection of signals was created. Therefore, understanding cooperative signaling behavior required looking at the creation of a collection of signals. These findings describe cooperative signaling behavior in the context of D&I signals as they were identified, evaluated, filtered, and then displayed and used. Figure 14 depicts a succession of processes that make up cooperative signaling behavior.

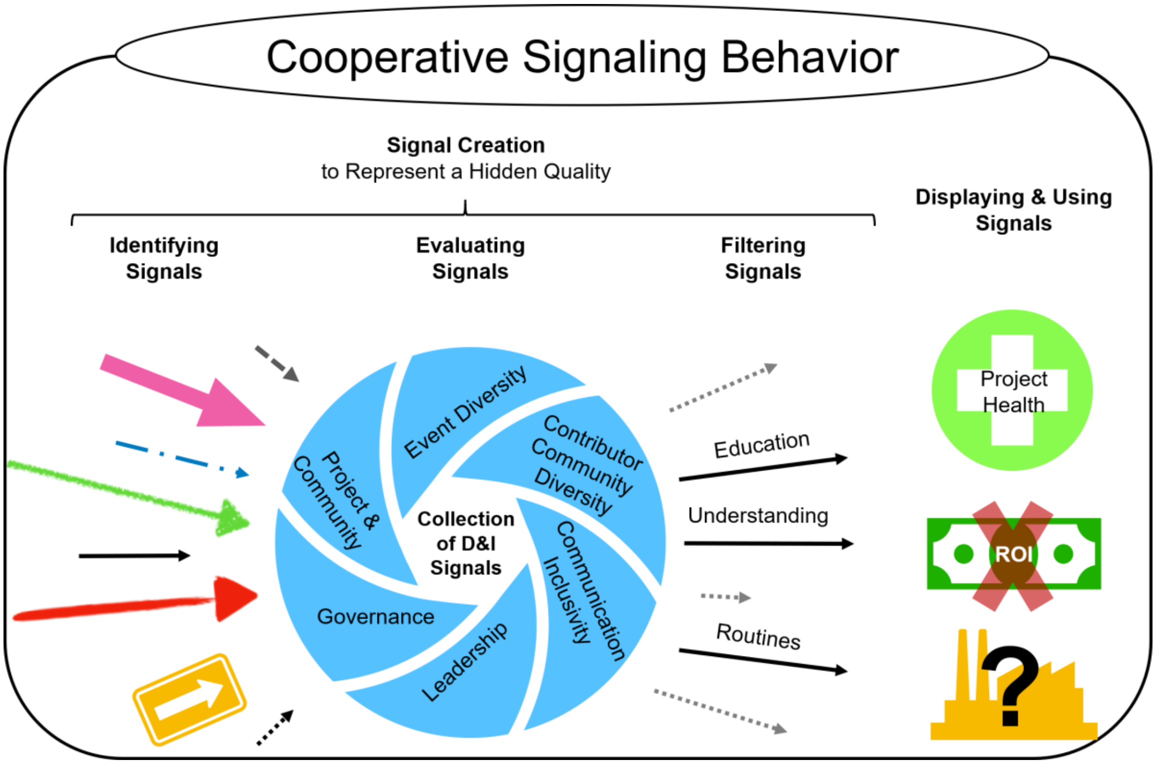

Figure 14. Cooperative signaling behavior is evident in how a collection of signals is created through identification, evaluation, and filtering, before they are displayed and used. The theoretical critique is in describing the processes used to create signals for representing a hidden quality.

These processes emerged from field observations and were further explored and informed through 16 focused interviews. In identifying signals, community members from diverse contexts and backgrounds proposed signals with different goals and embodying different perspectives (5.1). In evaluating signals, shared methods for displaying signals were advanced to improve signals and to overcome difficulties in preparing them (5.2). In filtering, signals were not displayed or used unless they were being explained to community members, understood well, and made part of organizational routines (5.3). Finally, cooperative signaling behavior not only created new signals but also shaped how signals were displayed and used. Findings suggest that signals were displayed and used to improve the health of open source projects, without consideration for the signal display effort, but organizations rarely used them in decision making (5.4).

5.1 Identifying Signals

Identifying signals is the first process for creating signals. The history of the Community Health Analytics Open Source Software (CHAOSS) project[21] reveals the identification of diversity and inclusion (D&I) signals.

5.1.1 D&I signals were proposed by community members from diverse contexts and backgrounds.

The CHAOSS project was founded in 2017 by academics and open source practitioners as a Linux Foundation project focused on creating signals to help define open source project health. Early in the project, diversity and inclusion (D&I) emerged as a category of signals when CHAOSS community members grouped signals by the kind of questions they had about project health. At the time, CHAOSS used a wiki to organize and document its work on signals. The D&I signal category was documented first on May 15, 2017 (Figure 15). D&I signals were further grouped to inform subcategories "organizational diversity" and "geographic diversity." Within each subcategory were the actual signals, called "activity metrics."

[21] https://chaoss.community

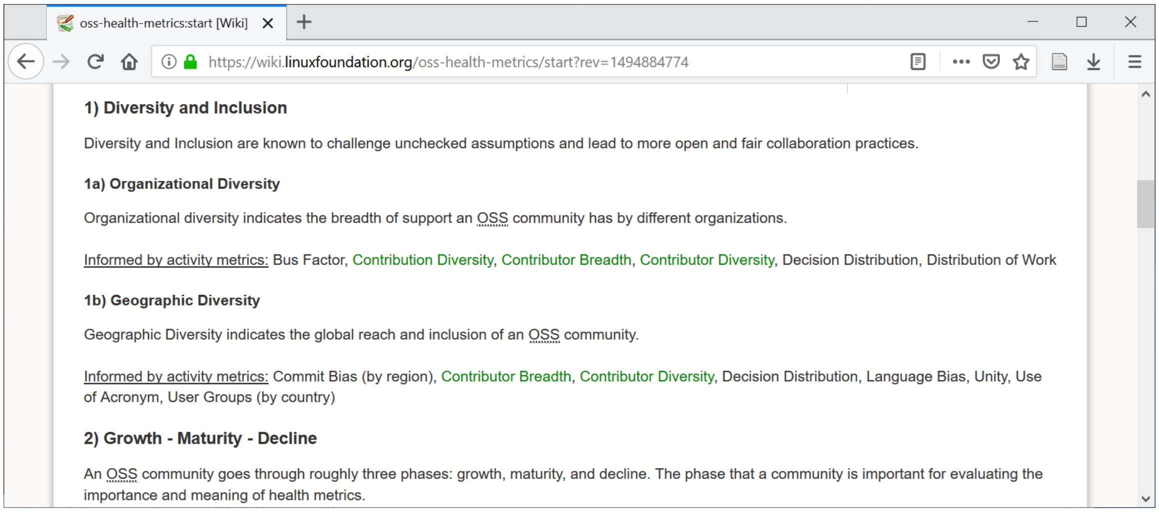

Figure 15. *Screenshot of CHAOSS wiki showing initial D&I signals (i.e., "activity metrics") as of May 15, 2017. Green signals link to detail pages that contain information about how to display the signals from data.*

Before the D&I category was created, members of the CHAOSS project had identified signals and documented them. Early D&I signals were suggested by community members on weekly conference calls and through mailing list discussions. Proposed signals were collected in the project wiki. Some signals were further specified in an associated signal detail page. A signal detail page contained more details about the signal, including how to implement the signal (Figure 16). Such an implementation was, for example, a SQL statement that could calculate a numeric value. The numeric value could then be displayed as the signal.

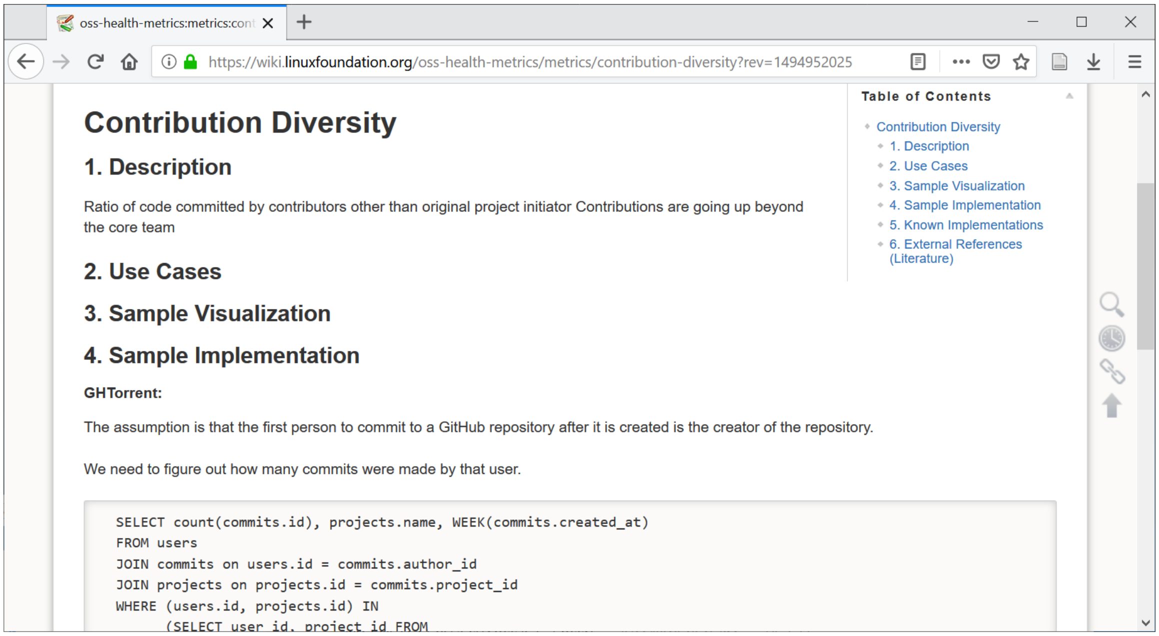

Figure 16. Screenshot of CHAOSS wiki showing the "contribution diversity" signal detail page that belonged in the D&I category. Page version from May 16, 2017.

During this time, the CHAOSS project was officially announced as a new Linux Foundation project on September 11, 2017, at the Open Source Summit North America (OSSNA) in Los Angeles.[22] In preparation for a large number of contributors that might join the project, the CHAOSS project changed its tooling. The wiki had restrictive edit permissions and thus did not allow everyone to make contributions. All wiki pages were copied into a GitHub repository.[23] The benefit was that GitHub, a widely used platform for open source projects, offered a well-understood method for contributing. This repository was still in use at time of writing and allowed anyone to propose a new signal.

[22] https://www.linux.com/news/if-you-cant-measure-it-you-cant-improve-it-chaoss-project-creates-tools-analyze-software
[23] https://github.com/chaoss/metrics

After the announcement at OSSNA, an increasing variety of people showed interest in the CHAOSS project, including members of many different open source projects and members of many different organizations. Interest came, for example, from the authors of the OpenStack Gender Report.[24] Their report was based on a survey of the OpenStack project community. The authors were interested in advancing the D&I signals they displayed in the report and joined the conversation in the CHAOSS project. Another connection made during OSSNA was with the diversity and inclusion efforts at the Mozilla Foundation. Mozilla had presented the results of a large-scale, world-wide survey of people in open source and developed an agenda to address diversity and inclusion issues in open source projects.[25] One of the issues Mozilla identified was the need to measure how well an open source project was doing with regards to diversity and inclusion. To work on this issue, Mozilla participated in the creation of D&I signals in the CHAOSS project. This leads to the first key finding related to identifying signals: *D&I signals were proposed by community members from diverse contexts and backgrounds.*

When asked to walk through the creation of D&I signals, the diverse set of informants connected signal origin and advancement with specific community members. Community members who were seen to propose D&I signals, were often affected by a lack of diversity and inclusion and felt excluded, unwelcomed, or disadvantaged. Some faced harassment and threats to their wellbeing. The specific context and problem that community members were addressing determined which D&I signals they proposed.

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[24] https://superuser.openstack.org/wp-content/uploads/2017/07/OpenStack-Gender-Diversity-Report_Apr2017.pdf
[25] https://medium.com/@sunnydeveloper/take-action-innovation-requires-diversity-ossummit-foss-opensource-de24d8bf853d

> D&I signals evolved starting from individuals, from people. Especially, people that were affected by the lack of diversity and inclusion. Because, if you are not affected you don't really understand it. That's why people that are affected are more involved, putting in a lot of effort, creating, and working on it because they really feel bad and understand it. It's not that other people don't care, but they don't really or fully understand, like the people that are affected by that. –[1B9]

Informants who could not name specific community members referred to projects and organizations. They perceived community members who proposed D&I signals to be speaking on behalf of their project or organization. Informants listed a variety of projects and organizations who propose D&I signals, further confirming that signals were proposed by a variety of sources.

> For this signal, in particular, I don't know who was involved. I would say that in general when it comes to diversity and inclusion, I do think companies like [company] have been leaders. The [open source project] with [diversity and inclusion effort] has been publicly visible. I'm probably just forgetting really obvious organizations. I know there are more because there are many organizations that are focused on getting more women into open source. I suspect a lot of those groups have had a lot of influence and I'm just not remembering any of them right now. –[1D4]

5.1.2 Proposed D&I signals had different goals and embodied different perspectives.

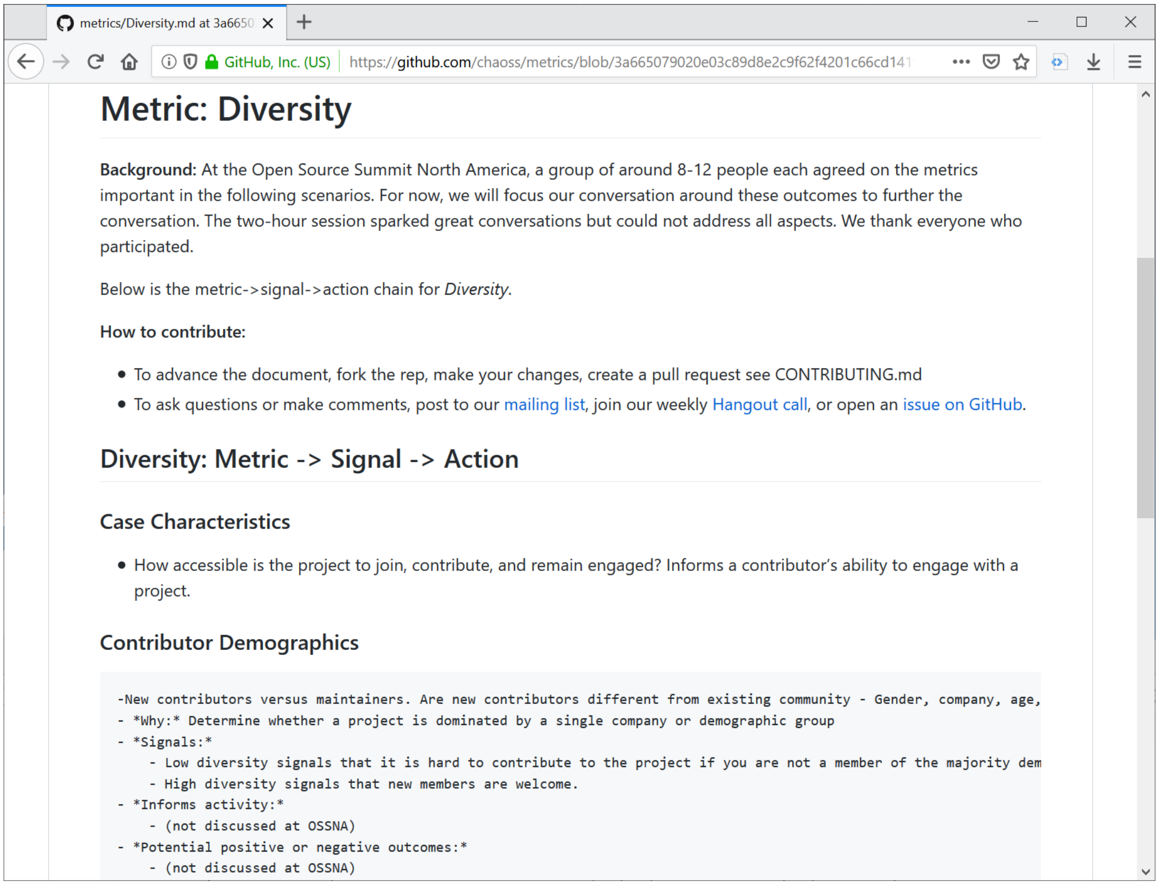
The next major event leading up to the formation of the CHAOSS D&I Working Group was a focus group at OSSNA 2017 (Figure 17). In planning the focus group, CHAOSS members advanced a new way of thinking about signals. Signals were discussed as being informed by one or more numeric value and to be only useful if they informed specific actions. For example, a signal "gender diversity" may have been informed by the numeric value "ratio of women to men in a project."[26] The signal could

[26] The CHAOSS project recognizes that gender is non-binary and exists on a spectrum. More complex signals were developed later.

then inform, for example, whether to launch an initiative with the aim of inviting more women to a project. During the focus group, participants were asked to self-select into smaller groups that talked about different categories of signals and one group decided on the D&I signals category.

Figure 17. Photo of participants in the Open Source Summit North America 2017 focus group for CHAOSS signals.

The focus group discussion was not bound by the signals previously identified and documented in the GitHub repository. Rather, participants were encouraged to propose new ideas for D&I signals. Three D&I signals emerged from the discussion: “contributor demographics,” “onboarding,” and “retention.” The first signal was about people in a project; the latter two were signals about interactions between community members. This shows that D&I signals were of different nature. Each group had a notetaker who captured the discussion. The notes were stored in the CHAOSS GitHub repository where anyone could review them and suggest improvements (Figure 18).


metrics/Diversity.md at 3a6650

GitHub, Inc. (US) https://github.com/chaoss/metrics/blob/3a665079020e03c89d8e2c9f62f4201c66cd141

Metric: Diversity

Background: At the Open Source Summit North America, a group of around 8-12 people each agreed on the metrics important in the following scenarios. For now, we will focus our conversation around these outcomes to further the conversation. The two-hour session sparked great conversations but could not address all aspects. We thank everyone who participated.

Below is the metric->signal->action chain for *Diversity*.

How to contribute:

- To advance the document, fork the rep, make your changes, create a pull request see CONTRIBUTING.md
- To ask questions or make comments, post to our mailing list, join our weekly Hangout call, or open an issue on GitHub.

Diversity: Metric -> Signal -> Action

Case Characteristics

- How accessible is the project to join, contribute, and remain engaged? Informs a contributor's ability to engage with a project.

Contributor Demographics

```
-New contributors versus maintainers. Are new contributors different from existing community - Gender, company, age,
- *Why:* Determine whether a project is dominated by a single company or demographic group
- *Signals:*
    - Low diversity signals that it is hard to contribute to the project if you are not a member of the majority dem
    - High diversity signals that new members are welcome.
- *Informs activity:*
    - (not discussed at OSSNA)
- *Potential positive or negative outcomes:*
    - (not discussed at OSSNA)
```

Figure 18. Screenshot of notes from the group discussing D&I signals at the Open Source Summit North America 2017 focus group. Document version from September 20, 2017.

Conversations and discussions in the months following OSSNA identified a need for the D&I signal conversations to be separated out from the general CHAOSS signal conversations. Up to this point, the CHAOSS community had one weekly conference call. Community members wanted to focus in-depth on the D&I signal category. The solution was the formation of the CHAOSS Diversity & Inclusion Working Group, or short CHAOSS D&I Working Group. Much time was spent in organizing the working group, setting up communication, aligning goals of community members, and building momentum of the working group. During the first half of 2018, the working group decided to work on D&I signals in its own GitHub repository, to set up its own mailing list, and to have its own weekly conference call.

During each conference call, community members took minutes collaboratively in a shared Google document and assigned “action items” to specific people who would report on the action item during subsequent meetings. These meeting minutes were shared with the mailing list to ensure community members could stay up-to-date without having to attend every conference call. When a discussion occurred during a call, for example, about designing a template for how to document a D&I signal, the discussion was continued on the mailing list, again, to include more community members. Conference calls were recorded and published on YouTube to allow revisiting discussions and including anyone who could not join (Figure 19).

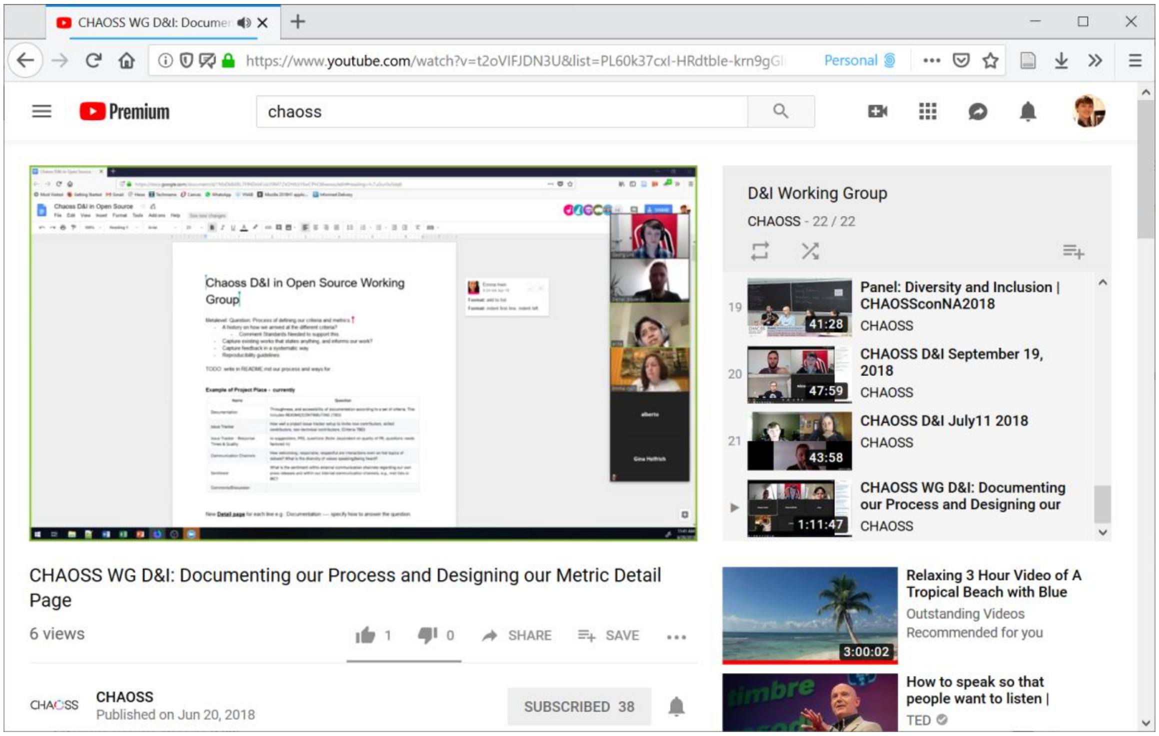


Figure 19. *Screenshot of a CHAOSS D&I Working Group conference call recording from June 20, 2018. The screenshot shows the collaborative process of working in a shared Google document to design a template for signal detail pages.*

New D&I signals were first created in a Google document, where everyone had edit rights. Everyone was encouraged to contribute ideas to the document and comment on the ideas of others. Community members were enabled to express, discuss, and resolve different goals and needs for a signal. Google documents were tracked at the project level in GitHub issues. Each document had its own issue which linked to the document (Figure 20). Community members converted the document to a markdown page for the GitHub repository when a D&I signal was well enough defined. Review and revision of the D&I signal continued in the GitHub workflow for adding a page to a repository. When the new D&I signal was accepted, the markdown page became part of the GitHub repository and the associated issue was closed. D&I signals were further revised when community members added or corrected something to better achieve their own goals for the signal.

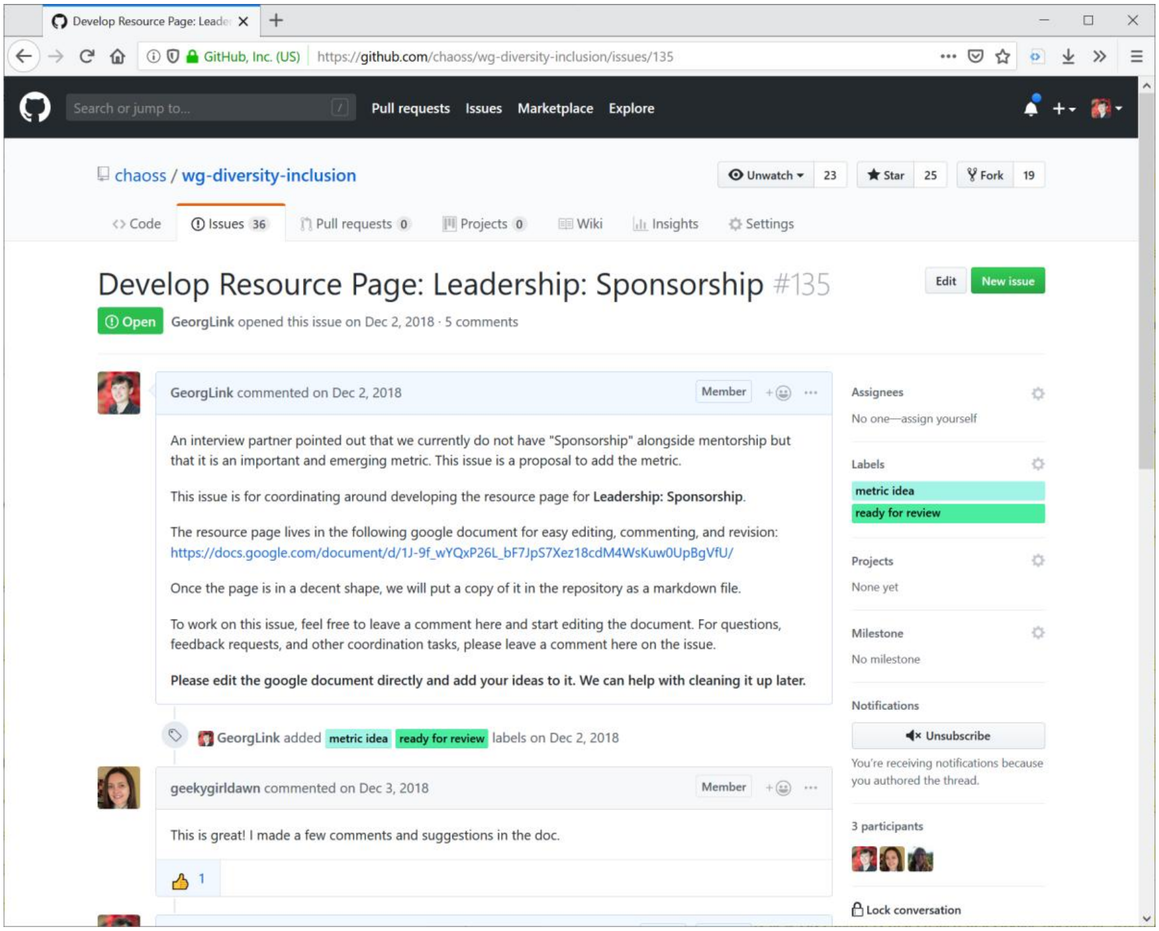


Figure 20. *Screenshot of a GitHub issue for tracking a proposed signal and the associated Google document. Community members work in the Google document to advance the signal.*

D&I signals were identified from a variety of community members who had different backgrounds and goals for these signals. Over time, more signals were identified to support these different perspectives, leading to the second key finding related to identifying signals: *Proposed D&I signals had different goals and embodied different perspectives.*

Informants had observed within their own projects that identified D&I signals were proposed and advanced by community members who worked with other community members such that a project could become more welcoming and inclusive if it started displaying D&I signals. With more community members joining a conversation, ideas on what D&I signals to display changed. These conversations resulted in a variety of proposed D&I signals which had different goals or embodied different perspectives.

> The QA community in a given bigger community would say, "Hey, we would like to promote this signal." Or the documentation team would say, "We would like to promote the documentation signal." It's been bottom-up, each of those communities that wanted to be measured, measured themselves, and propagated the signal up. – [1B5]

Cooperation within and across projects resulted in an increasing acceptance that diversity and inclusion was worth addressing. However, D&I signals were very diverse and community members lacked a shared method for displaying D&I signals. Without such shared methods, community members displayed D&I signals differently, which made it difficult to understand D&I signals across projects as D&I signals had different goals and embodied different perspectives.

> What I have seen over time is more awareness of [D&I signals]. The signals have not advanced as quickly as the understanding has. In part, I think, because projects are challenged to gather them a standardized way. – [1C5]

Field observations and interviews found that the first process in creating signals was identifying signals which is the collecting of ideas for new D&I signals. Table 13 provides a summary of the key findings related to identifying signals. Cooperative signaling behavior is evident in identifying D&I signals because community members work together in coming up with ideas for and proposing D&I signals. As many different D&I signals were proposed, community members engaged in the CHAOSS D&I Working Group to collect proposed D&I signals.

> We started the CHAOSS D&I Working Group and attracted a community. Then, we realized that we were missing many ideas and comments from people. – [1B3]

Table 13. Key findings regarding identifying signals.

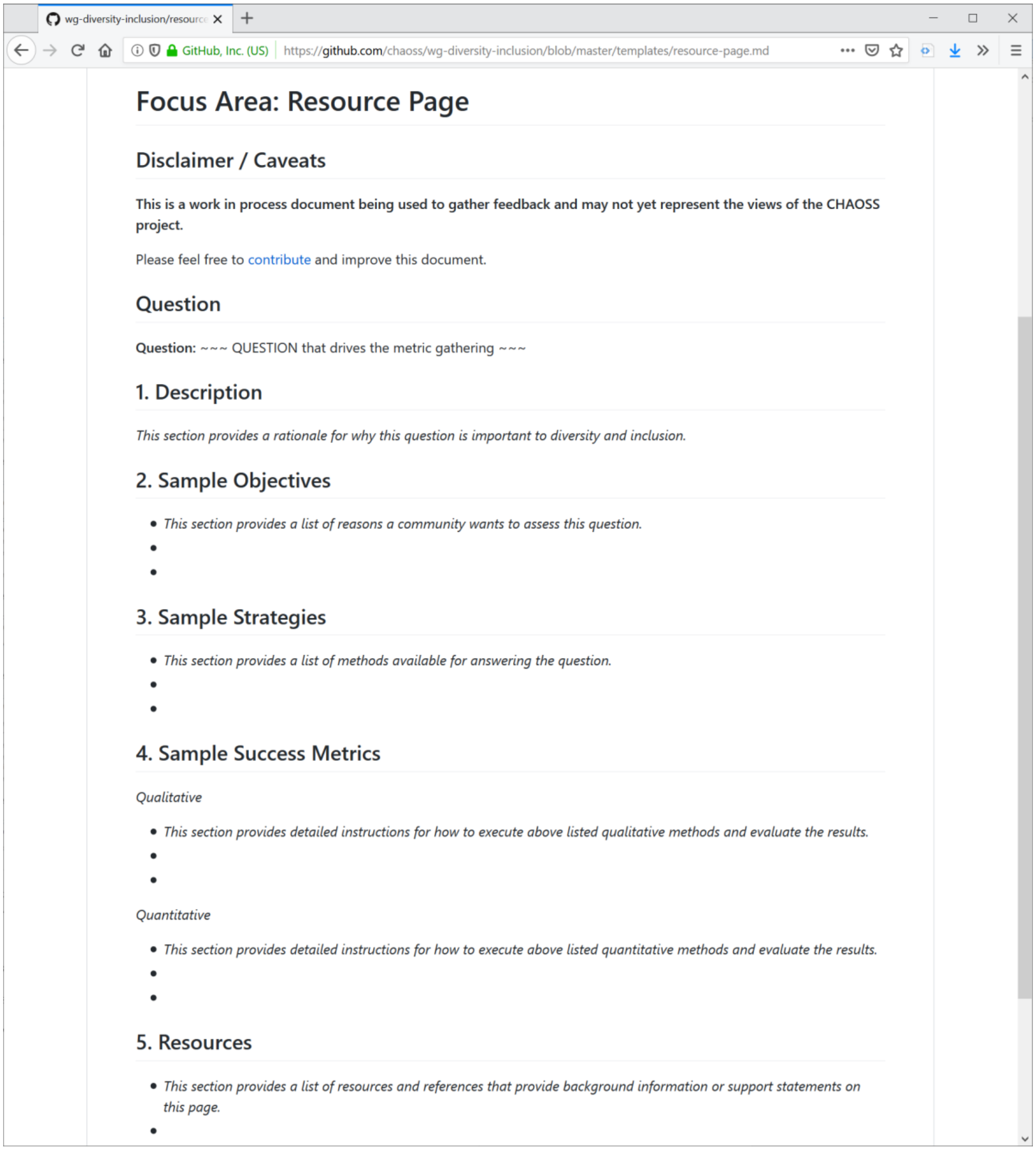
Key Concept	**Description**	**Supporting Evidence**
A hidden quality was represented by different signals	Many different signals were proposed to inform open source project health. Identifying signals involved collecting these diverse ideas for potential signals.	Field Observations Focus Group Interviews
Proposed signals were not clearly defined at first	Proposed signals were ideas that lacked clarity before they were documented and discussed. Identifying signals involved writing a definition of a signal so that it could be refined and improved cooperatively.	Field Observations Focus Group Interviews
Signals came from diverse contexts and backgrounds	Community members who proposed signals came from a variety of contexts and backgrounds. Identifying signals involved understanding these contexts and backgrounds and translating a proposed signal to be meaningful for community members from other contexts and backgrounds.	Field Observations Interviews
Signals were proposed by people and organizations who needed them	Both – people and organizations – proposed signals when they could benefit from improving how open source project health was understood. Identifying signals involved learning from these people and organizations how signals could serve their need.	Field Observations Interviews
Proposed signals had different goals and perspectives	Signals were proposed to serve specific goals and different signals had different goals. Identifying signals involved debating proposed signals with many community members to incorporate their goals so that a signal could serve more perspectives.	Field Observations Focus Group Interviews
Signals with similar goals were grouped together	It was easier to discuss signals when they were grouped together. Identifying signals involved comparing goals of signals and finding similar goals so that signals could be grouped together.	Field Observations Focus Group Interviews
Signals were about different things	Signals for open source project health could be about different aspects of a project, such as its people, their processes, their outputs, or what others said about a project. Identifying signals involved documenting what a signal was about and how it informed a hidden quality.	Field Observations Focus Group Interviews

5.2 Evaluating Signals

Evaluating signals is the second process for creating signals. Work in the CHAOSS D&I Working Group advances signals and reveals evaluation of signals.

5.2.1 Shared methods for displaying signals improved D&I signals.

Over time, the CHAOSS D&I Working Group evaluated proposed signals for example by advancing a standard way to document them. By standardizing how signals were documented, the CHAOSS D&I Working Group identified what information was important for displaying or using a signal. The template for a signal detail page (i.e., "Resource Page") included at the top the name of a signal and underneath a high-level question that a signal can answer (Figure 21). While a signal was under development, a disclaimer warned potential users of the unfinished state. The template specified five sections that described a signal in detail. First, "Description" provided a rationale why a signal may be important to display and use. Second, "Sample Objectives" were a list of reasons why someone might want to display or use a signal. Third, "Sample Strategies" listed methods for displaying a signal, leaving specific steps to the subsequent section. Fourth, "Sample Success Metrics" described instructions for how to execute a method for displaying a signal, from data collection, to display, to interpretation. Fifth, "Resources" listed references and related work that provided additional background information or supported claims about a signal. After creating the template, D&I signals were advanced by filling in the template for each signal, which required evaluating what information went into each section of the template. Filling in missing information improved the quality of signal descriptions.



wg-diversity-inclusion/resourc

GitHub, Inc. (US) https://github.com/chaoss/wg-diversity-inclusion/blob/master/templates/resource-page.md

Focus Area: Resource Page

Disclaimer / Caveats

This is a work in process document being used to gather feedback and may not yet represent the views of the CHAOSS project.

Please feel free to contribute and improve this document.

Question

Question: ~~~ QUESTION that drives the metric gathering ~~~

1. Description

This section provides a rationale for why this question is important to diversity and inclusion.

2. Sample Objectives

- *This section provides a list of reasons a community wants to assess this question.*
-
-

3. Sample Strategies

- *This section provides a list of methods available for answering the question.*
-
-

4. Sample Success Metrics

Qualitative

- *This section provides detailed instructions for how to execute above listed qualitative methods and evaluate the results.*
-
-

Quantitative

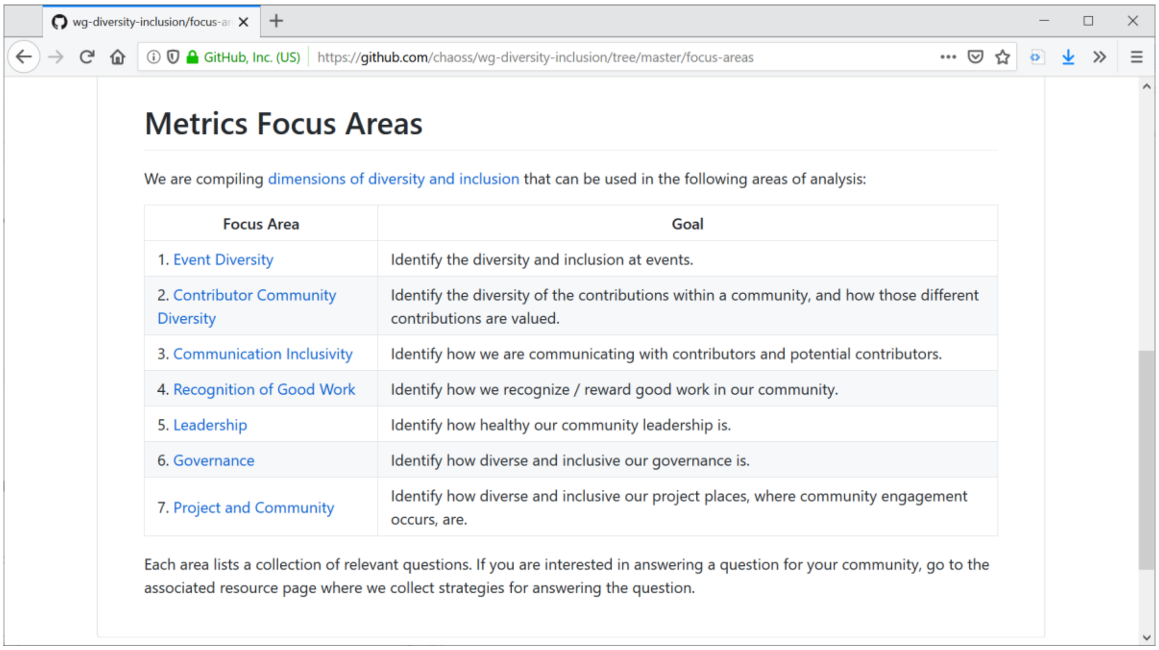
- *This section provides detailed instructions for how to execute above listed quantitative methods and evaluate the results.*
-
-

5. Resources

- *This section provides a list of resources and references that provide background information or support statements on this page.*
-

Figure 21. Screenshot of the template for a D&I signal detail page (Resource Page) containing a signal name and question, followed by five sections: 1. Description, 2. Sample Objectives, 3. Sample Strategies, 4. Sample Success Metrics, and 5. Resources. Document version from January 26, 2019.

As the number of proposals for signals grew, CHAOSS D&I Working Group members decided to organize signals in focus areas. The creation of seven focus areas was informed by Mozilla's 2017 research recommendations[27] which provided a stronger foundation for the organization of signals. Figure 22 shows the seven focus areas in the CHAOSS D&I Working Group repository.


wg-diversity-inclusion/focus-ar

GitHub, Inc. (US) https://github.com/chaoss/wg-diversity-inclusion/tree/master/focus-areas

Metrics Focus Areas

We are compiling dimensions of diversity and inclusion that can be used in the following areas of analysis:

Focus Area	Goal
1. Event Diversity	Identify the diversity and inclusion at events.
2. Contributor Community Diversity	Identify the diversity of the contributions within a community, and how those different contributions are valued.
3. Communication Inclusivity	Identify how we are communicating with contributors and potential contributors.
4. Recognition of Good Work	Identify how we recognize / reward good work in our community.
5. Leadership	Identify how healthy our community leadership is.
6. Governance	Identify how diverse and inclusive our governance is.
7. Project and Community	Identify how diverse and inclusive our project places, where community engagement occurs, are.

Each area lists a collection of relevant questions. If you are interested in answering a question for your community, go to the associated resource page where we collect strategies for answering the question.

Figure 22. Screenshot of focus areas in the README on the CHAOSS D&I Working Group GitHub repository. Document version from April 15, 2019.

The CHAOSS D&I Working Group, like the rest of the CHAOSS project, adopted a Goal-Question-Metric approach (Basili, 1992). The logic behind this approach was that signals were only useful if it was known how to use them in answering specific questions. The Goal-Question-Metric approach challenged the group to evaluate the utility of signals. Within the GitHub repository structure, the focus areas were connected

[27] https://opensource.com/article/17/9/diversity-and-inclusion-innovation

to a high-level goal that someone might have when looking for signals. Within each focus area were a set of questions that further narrowed down the choice of signals (Figure 23).

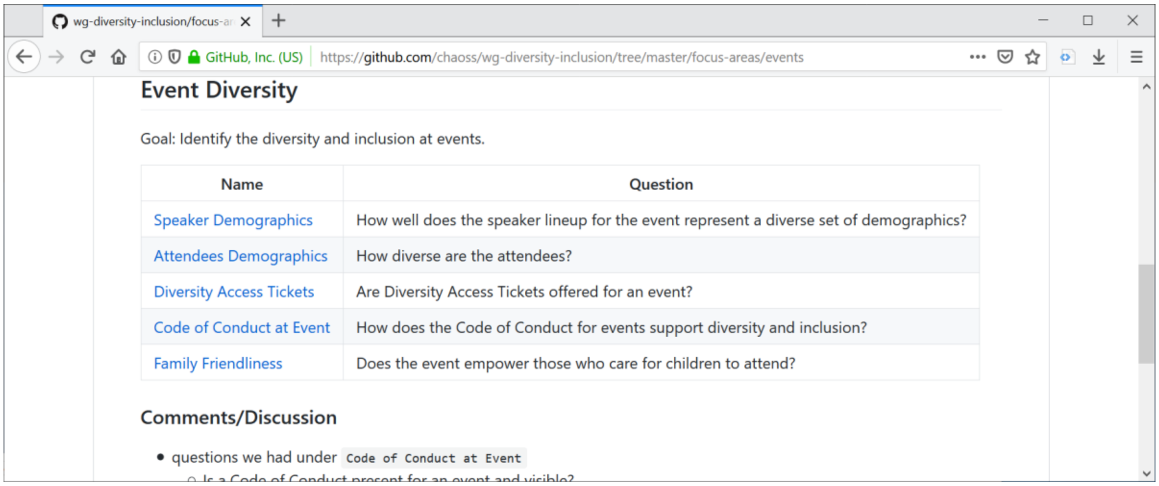


Figure 23. Screenshot of "Event Diversity" focus area, showing the goal, a list of questions, and subsequent signals (i.e., Name).

Each question had its own signal detail page (Figure 24), which provided qualitative and quantitative methods for capturing data that could be displayed as signals. Some community members shared methods and experiences from their own open source projects. Some community members were interested in applying a method in their open source project and asked for feedback and insights from others.

Stemming from the desire to share signals with others led to developing a standardized template for documenting signals and establishing a research-informed structure for organizing them. This improved coordination within the working group and communication with open source projects and organizations. Additional details were identified to improve methods for displaying signals. This leads to the first key finding related to evaluating signals: *Shared methods for displaying signals improved D&I signals.*

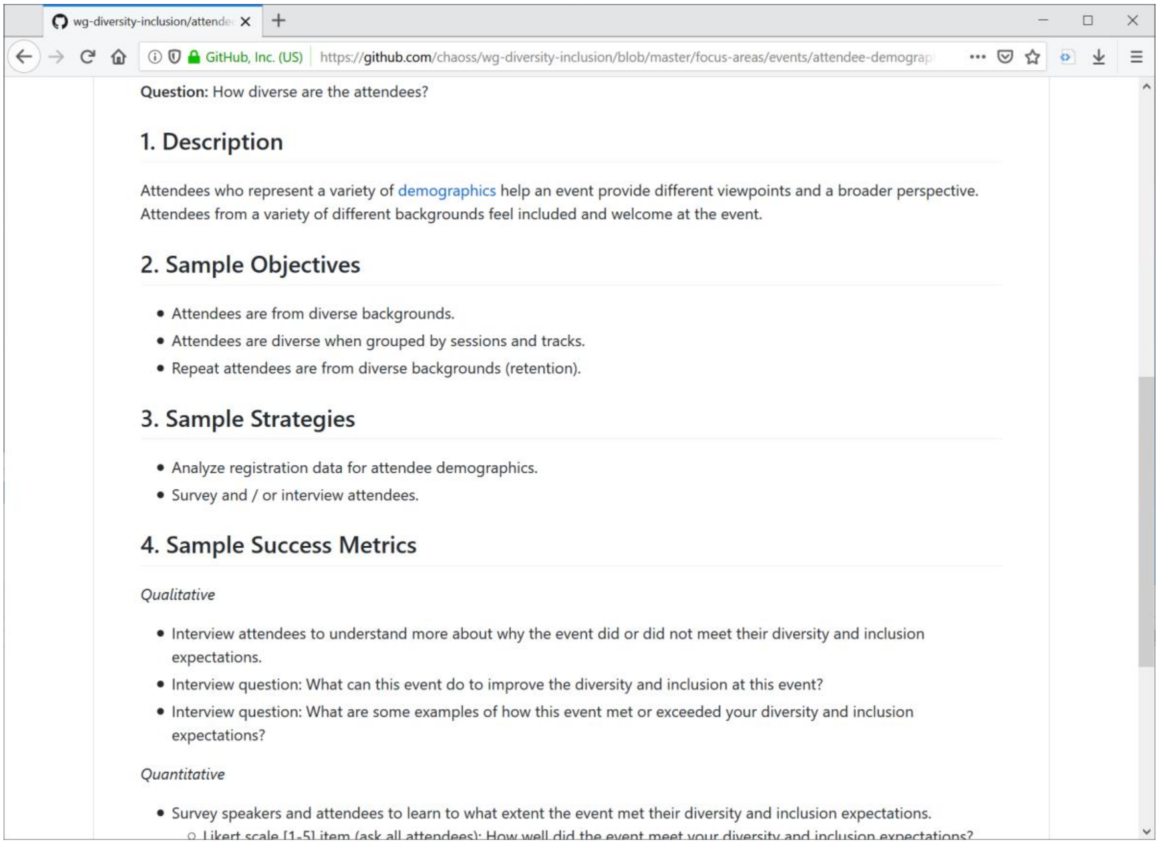


Figure 24. Screenshot of "Attendee Demographics" question detail page from the "Event Diversity" focus area, showing a selection of metrics that can be used as signals.

Informants described different methods for displaying D&I signals. Data collection varied by project and by tools used in a project. For several D&I signals, there was no automatic process for data collection, and signal display was done manually. Which methods for collecting data work was determined by community members who piloted different approaches.

> There are a couple of things we can do. Both are manual. It's time-intensive, and I'm not aware of software that exists that does this, but it would be fantastic if it existed. You can go to the foundation that hosts a particular project and ask them for those numbers. Or because, by virtue of open source, all of these things are public, you can go through and painstakingly actually manually do a count. The second one is more time-intensive than the first. We've done the first. — [2B12]

Some D&I signals were prepared to be displayed by using a tool that collected data and calculated numeric values. Tools for numeric values used data from collaboration tools that community members coordinated and executed their work with. This approach provided insight into who was doing which tasks, as long as interactions within a project were facilitated through a tool that captured such metadata.

> Our expertise is mostly related to a quantitative approach. The method would be running some specific tools, either [tool 1], [tool 2] or [tool 3] or any other kind of tool. The first step is to list all of the data sources that you have. For this first step, you really need to know and understand what's the infrastructure that you are using in your project. – [2B3]

For a proposed D&I signal, displaying it was sufficient at first regardless of the method because it demonstrated that community members were aware of and working on related issues. It was beneficial to piloting methods for signals because it created a viable signal and experience was gained with the signal. When more projects provided a similar D&I signal, more evaluation of the signal was necessary. Community members evaluated signals cooperatively by comparing how signals were prepared, displayed, and used. From these pilot tests, community members learned more about a D&I signal and established a better shared understanding. Such improved D&I signals more accurately demonstrated a commitment to diversity and inclusion.

> For a while, everyone was saying they had a code of conduct [i.e., the D&I signal], even if it was not really one. With the code of conduct assessment tool that [a foundation] built for its open source project support grant, I think we're starting to be able to help a project say: "We have a strong code of conduct according to this evaluation tool." – [1B7]

5.2.2 It was difficult to display correct D&I signals.

In the CHAOSS D&I Working Group, adding methods to a signal detail page was an integral part of evaluating signals and included discovering issues with methods and overcoming those issues. Several issues with displaying signals were discussed, including issues with data sources, data management, visual representation, and language. For example, when looking at diversity of contributions within commits in a repository, using the phrase "technical versus non-technical contributions" discounted the technical nature of many contributions, such as documentation writing. As a solution, CHAOSS D&I Working Group members concluded that "code versus non-code contributions" was a better way to signal diversity of contributions because it fit with the data the signal was created from and because it did not discount anyone's contributions.

CHAOSS D&I Working Group members did not resolve all issues. Some issues were documented as part of signal descriptions (Figure 25). By not resolving issues, CHAOSS D&I Working Group members acknowledged that D&I signals are context dependent and that making assumptions about specific contexts might resolve an issue only in theory but not for the contexts the signals may be used for. A preferred approach emerged in documenting known issues and waiting for feedback from community members who tried to deploy a D&I signal within their context. This leads to the second key finding related to evaluating signals: *It was difficult to display correct D&I signals.*

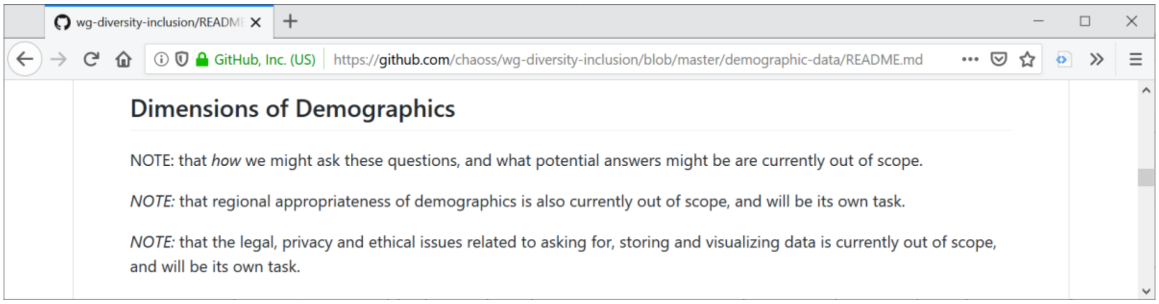


Figure 25. Screenshot of the CHAOSS D&I Working Group repository showing an example of unsolved issues. Document version from February 22, 2019.

Informants agreed that D&I signal display was fraught with issues and could not be fully reliable. Three difficulties emerged. *Difficulty 1:* Demographic information was not easy to observe from an appearance of a person or their public profiles, like LinkedIn or Twitter. This included inferring someone's age, gender, sexual orientation, religion, political affiliation, skill level, ethnic heritage, or other demographic information. Inferences based on name, photos, work history, or other available information were inaccurate.

> We started off with just looking at code contributions and then saying, "Which of the code contributions came from women with female names," and [company] struggled sometimes with the fact that Asian names or certain other names are harder to classify as female versus male. They needed some volunteer help to do that. The other challenge is that many women choose not to use a female name in their contributions because they feel that otherwise their contributions get blocked or don't get accepted. – [2D11]

A more reliable method for collecting demographic information was self-disclosure. Surveys were a popular method to ask for sensitive information. Surveys were work intensive because they required advance planning, infrastructure, advertising, data management, and analysis. This effort may not lead to desired information because community members did not always fill out surveys and results get skewed easily when only a few people from a minority demographic participated in a survey. Because of a survey's high-cost, limited return, and the potential of annoying people by asking them to take a survey, community members who prepared D&I signals tried to infer demographic information first. This approximation was less reliable but might have sufficed.

> We were curious about the diversity in our project. We wanted to just try to see where we stand. I sent out a voluntary survey to all full-time dedicated committers. I pinged people a few times and got maybe 50-60% response rate. I don't know how often we'll do that again because people get tired of answering surveys. The other thing I did, just for myself, I took all committers and was like: "I think I'll count this person as a woman," or "I think I'll count this person as a man." That probably came up with a more accurate number than the voluntary survey that got half the respondents. However, there's a problem with me doing that. I think it's fine to take that approximation, but there's certainly a problem that you obviously can't even begin to start with sexual orientation or things like that. I would never publish data in which I assigned people what I think they are. – [2C13]

Some projects maintained a collaboration tool that allowed community members to have a profile and disclose sensitive information there. This information could then be used to generate numeric values about community members' demographics to be displayed as D&I signals. However, surveys and other self-disclosure options were not used by all community members and especially members of minority demographics were cautious about providing information about themselves.

> A very emblematic method in the [project] community was for the signal that we had for gender participation. Our user interface gave you the option of specifying a gender in order to customize the user interface. You then got gendered pronouns correctly on the user interface. But that was optional. And, of course, many people did not set it. Therefore, the baseline data that we had was very poor, and we knew it from the beginning. – [2D5]

Difficulty 2: Diversity and inclusion impacted interactions between community members and should be measured as it was manifested in these interactions. When a project was welcoming and inclusive, it was so because community members felt they were welcomed and included as a result of how others interacted with them. D&I signals should be about the quality of interactions, which were difficult to measure, especially as channels for interaction varied. Additionally, diversity and inclusion were often understood less in terms of a specific numeric value but more as a sense of diversity and inclusion. Quality of interactions and a sense of diversity and inclusion were difficult to capture and express as a numeric value.

> I'm trying to see if there is a way to measure, but I can tell you that if people have a good first impression, it's more likely, that they will engage quicker with the community. They are excited when they send us the first email, and if they feel that the community was very welcoming, then they get a boost to start contributing and keep engaging with the community. – [3D17]

Difficulty 3: D&I signals consisted of many components that were difficult to be assessed separately and more difficult to be aggregated into a single signal. For example, the CHAOSS D&I Working Group identified “communication” in a project as important for its welcoming and inclusive nature. However, evaluating how to signal communication within a project revealed a variety of difficulties. Calculating a numeric value that could serve as a D&I signal from a communication perspective was challenging. The difficulty came from technical challenges of measuring diversity and inclusion within communication and was amplified when trying to aggregate across different communication technologies. Different communication technologies (e.g., code repository, issue tracker, chat, or email list) were used for different kinds of communication and elicit different behavior, thus requiring different ways of determining diversity and inclusion.

> In order to get the best technical solution for a D&I signal on communication, you need to work through several levels of depth. You get a unique breadth of communication, like many different views and backgrounds but also you need depth. You need details about the technology that's being worked on, the use cases, and the scenarios. You need many levels of details. – [3D14]

In addition to aggregating from diverse data sources, projects needed to collect such data. Some collaboration tools collected more metadata than others. This data included personal information about community members but also related to interactions and behaviors within a project. It is challenging to convince community members to change established collaboration tools and workflows around them, especially when it is only to collect more data. Therefore, available data was often limited for open source projects.

> Some of it is going to be the nature of the forum. I use forum very broadly here. For example, if you use [tool 1] for your mailing lists, getting information on non-code contributions through the mailing lists is going to be very difficult. Because you lack a lot of meta-data. Whereas, if you use [tool 2], you can do a lot to drill down. You can look at tags, you can look at who the top participants are, what the distribution of the participation is. You can do some of that with [tool 1], but it's much more difficult. – [2D5]

Field observations and interviews found that the second process in creating signals was evaluating signals. Evaluating signals took proposed D&I signals as inputs and produced better understood D&I signals. Table 14 provides a summary of the key findings related to evaluating signals. Cooperative signaling behavior is evident in evaluating D&I signals because it involved discussing D&I signals, coming to a shared understanding, overcoming issues for displaying D&I signals, and sharing experiences with D&I signals. Community members discussed in the CHAOSS D&I working group ideas on how to display D&I signals. They worked within the structure of the working group to advance D&I signals and developed signal detail pages for learning about D&I signals. Community members evaluated D&I signals based on what they learned from each other, from projects, and from organizations.

> I see D&I signal development as the work that we're doing in the CHAOSS D&I Working Group. – [1D7]

Table 14. Key findings regarding evaluating signals.

Key Concept	Description	Supporting Evidence
A standard for signals was developed	A standard way to document signals provided a practical means for improving signals. Evaluating signals involved developing a standard that dictated what information about a signal needed to be provided.	Field Observations Interviews
Bottom-up and top-down approaches were used	Signals were defined bottom-up (i.e., available data was elevated as signals) and top-down (i.e., signals were created to answer specific questions). Evaluating signals involved both approaches— working from available data and working from questions—to ensure that signals could be displayed and were meaningful.	Field Observations Focus Group Interviews
Qualitative and quantitative methods were advanced	Signals could be prepared for display through qualitative and quantitative methods. Evaluating signals involved defining specific steps required for collecting data and displaying signals, which were more likely to be automatable for quantitative methods.	Field Observations Focus Group Interviews
Signals were piloted	Community members piloted methods for displaying signals to learn more about signals and to get benefits of signaling project health. Evaluating signals involved improving signals based on experience from piloting signals.	Field Observations Interviews
Signal quality was improved	The importance of signal quality increased with more projects displaying a signal. Evaluating signals involved improving signal quality based on feedback from projects and organizations that were displaying and using signals.	Field Observations Interviews
Data availability for signals was an issue	In the top-down approach, data for a signal that could answer specific questions might be difficult to obtain. Evaluating signals involved discovering ways to answer specific questions with data that could be obtained, thus overcoming issues related to data availability.	Field Observations Focus Group Interviews
Explaining how a signal related to a hidden quality was an issue	A signal had to inform about a hidden quality. Evaluating signals involved describing how a signal was related to a hidden quality so that community members could learn to interpret a signal similarly.	Field Observations Focus Group Interviews
Signals involved loss of information	Open source project health as a hidden quality was more complex than its signals, resulting in a loss of information. Evaluating signals involved identifying which aspects of a hidden quality could be captured in signals and expressing clearly the limits of what could be learned about a hidden quality from a signal.	Field Observations Focus Group Interviews

5.3 Filtering Signals

Filtering signals is the third process for creating signals. To understand how signals are filtered, we observe how the CHAOSS D&I Working Group promotes the use of D&I signals and helps establish their use.

5.3.1 Educating community members on D&I signals helps establish signals.

Not every signal that was identified and evaluated by the CHAOSS D&I Working Group would be displayed and used. Because open source projects individually decided whether to display a signal, the signals that failed to be displayed and used could be considered as having been filtered out. The CHAOSS D&I Working group employed several strategies to drive signal adoption and thereby to help signals "pass through the filter." To drive adoption, CHAOSS D&I Working Group members actively promoted D&I signals through writing blog posts and speaking at conferences. Conference sessions held by CHAOSS D&I Working Group community members included:

- August 28, 2018: "Establishing Metrics that Matter for Diversity & Inclusion" (CHAOSScon[28] North America 2018, Vancouver, CA)
- August 29, 2018: "D&I Metrics Hack-a-thon" (Open Source Summit North America 2018, Vancouver, CA)
- October 24, 2018: "Tutorial: How to Prepare a Diversity and Inclusion Report for your Community" (Open Source Summit Europe 2018, Edinburgh, UK)
- February 1, 2019: "Diversity & Inclusion WG Tutorial" (CHAOSScon Europe 2019, Brussels, BE)
- March 14, 2019: "Panel Discussion: Metrics that Matter: Forging a Path to More Diverse, Inclusive Communities" (Open Source Leadership Summit 2019, Half Moon Bay, CA, USA)

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[28] CHAOSScon is a conference series organized by CHAOSS project members to bring together anyone interested in displaying or using signals for open source project health. Every year, CHAOSScon North America is co-located with the Open Source Summit North America and CHAOSScon Europe is co-located with FOSDEM.

The first key finding related to filtering of signals is: *Educating community members on D&I signals helps establish signals.*

Informants identified education on D&I signals as critical for D&I signals to pass the filtering process. Education helped more community members to learn about displaying and using D&I signals, informing their decision to adopt those D&I signals. Community members may drive education because they wanted more projects to display D&I signals and more organizations to use D&I signals. Community members cooperatively educated each other to learn about D&I signals, to advance them, and to start using them. Education occurred, among other ways, through blog posts.

> We're going to put a blog post out on [a new tool for D&I signal preparation]. Hopefully, the signal gets on people's radars. I know that [project] is going to use that tool. People will want to use it when they know it's there. The thing is, a lot of D&I signals are cutting edge. – [4B7]

Education also occurred through conference presentations, meetings, and panel discussions. Community members who organized events could drive education because they decided on keynotes, sessions, and special topics that got attention. They set the tone for an event and thereby influenced what attendees talked about and cooperated on back in their projects and organizations.

> We started reporting on D&I signals for [a conference]. I remember, at [another conference], being involved in an unconference session to plan for the diversity track for [a third conference], and one person saying this D&I signal should be applied to all events: Women should receive a greater representation on keynote stages. – [1B12]

Signals are displayed and used by different community members. Education ensures that they understand each other and interpret signals in a similar way. With regards to who displayed signals, it was the community members from within a project because they have the necessary knowledge about their project. The following quote exemplifies that community members outside of a project can only use a displayed signal.

> You can't go do a survey of each open source project before deciding whether or not to add it to your software dependency chain. – [4C5]

Experiences and lessons learned from putting D&I signals into practice were valuable for educating community members. Additionally, D&I signals became more useful as more projects and organizations adopted them. As more projects displayed a D&I signal, organizations could start relying on using the signal. Through further display and use of D&I signals, community members had more opportunities to learn about them.

> I don't think that event organizers specifically mention D&I signals. Mostly, they just say: "The outcome of the event are these numeric values." D&I signals are something that needs to be mentioned more often in a sponsorship prospectus. Event organizers need to mention it more often because if you mention more often, companies will start to look at it when they try to make sponsoring decisions. – [1B9]

D&I signals became more widely displayed and used as an interplay of more projects displaying them so that more organizations started using them and, conversely, more organizations requesting to use them so that more projects started displaying them. The latter part is evident in an example where projects started displaying D&I signals when they applied for a grant program that included D&I signals as a funding requirement. Through such a requirement, projects were compelled to display D&I signals because organizations started using them.

> I was talking with [someone] about the notion that we would hold a project accountable for something like diversity and inclusion to have access to funding. I explained to them: "There's no one that can make someone display a D&I signal, but if they're going to apply for something like a grant, well, they might have to think about it." And that's where they were like: "Oh, right." They never thought about the fact that organizations can hold projects accountable through things like funding and grant awards. – [1B7]

5.3.2 Well-understood D&I signals were more successful in passing the filtering.

At time of writing, D&I signals from the CHAOSS D&I Working Group were piloted in some contexts. For example, the OpenStack Gender Diversity Report included new signals on mentorship programs.[29] The report authors had previously identified and evaluated the new signals in the CHAOSS D&I Working Group. Experience from implementing the new mentorship signals was shared with the CHAOSS D&I Working Group members. In another example, Mozilla had adopted D&I signals in their MOSS grant for open source projects.[30] Again, experiences from this pilot of D&I signals were shared within the CHAOSS D&I Working Group. Additionally, the CHAOSS D&I Working Group was talking with more open source projects that were interested in displaying D&I signals.

The CHAOSS D&I Working Group realized the importance of helping open source projects understand the value of and methods for displaying D&I signals. In this vein, the working group's goals[31] for the year 2019 (Figure 26) included documenting three high-quality and compelling use cases for D&I signals, partnering with projects to pilot display of D&I signals, establishing ethical guidelines around displaying D&I signals, and establishing a more sophisticated workflow for advancing methods for displaying D&I signals. This leads to the second key finding related to filtering signals: *Well-understood D&I signals were more successful in passing the filtering.*

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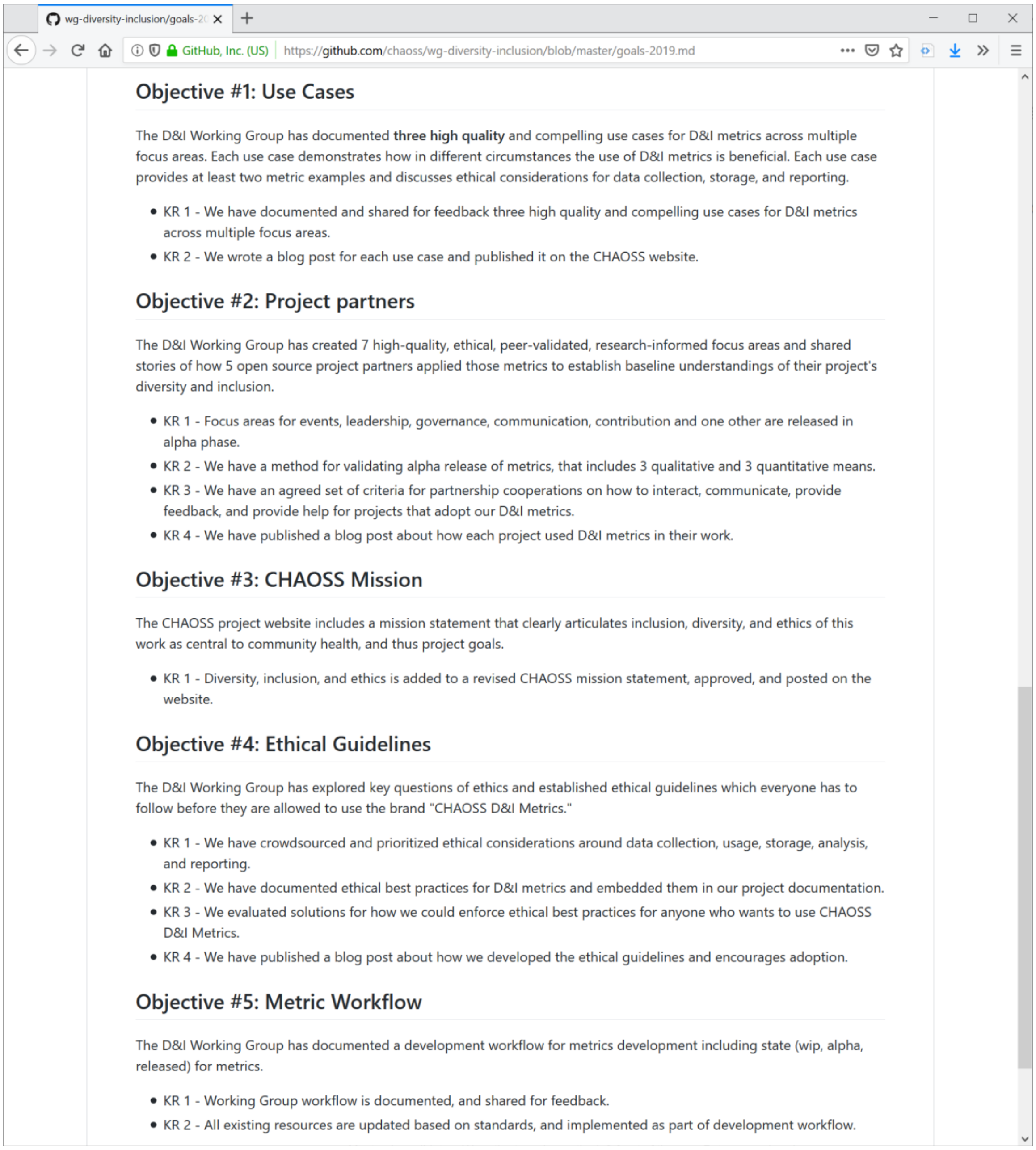
[29] https://superuser.openstack.org/articles/2018-gender-diversity-report/
[30] https://blog.mozilla.org/inclusion/2018/12/18/innovating-for-inclusion-in-the-mozilla-open-source-support-program/
[31] https://github.com/chaoss/wg-diversity-inclusion/blob/master/goals-2019.md



Objective #1: Use Cases

The D&I Working Group has documented **three high quality** and compelling use cases for D&I metrics across multiple focus areas. Each use case demonstrates how in different circumstances the use of D&I metrics is beneficial. Each use case provides at least two metric examples and discusses ethical considerations for data collection, storage, and reporting.

- KR 1 - We have documented and shared for feedback three high quality and compelling use cases for D&I metrics across multiple focus areas.
- KR 2 - We wrote a blog post for each use case and published it on the CHAOSS website.

Objective #2: Project partners

The D&I Working Group has created 7 high-quality, ethical, peer-validated, research-informed focus areas and shared stories of how 5 open source project partners applied those metrics to establish baseline understandings of their project's diversity and inclusion.

- KR 1 - Focus areas for events, leadership, governance, communication, contribution and one other are released in alpha phase.
- KR 2 - We have a method for validating alpha release of metrics, that includes 3 qualitative and 3 quantitative means.
- KR 3 - We have an agreed set of criteria for partnership cooperations on how to interact, communicate, provide feedback, and provide help for projects that adopt our D&I metrics.
- KR 4 - We have published a blog post about how each project used D&I metrics in their work.

Objective #3: CHAOSS Mission

The CHAOSS project website includes a mission statement that clearly articulates inclusion, diversity, and ethics of this work as central to community health, and thus project goals.

- KR 1 - Diversity, inclusion, and ethics is added to a revised CHAOSS mission statement, approved, and posted on the website.

Objective #4: Ethical Guidelines

The D&I Working Group has explored key questions of ethics and established ethical guidelines which everyone has to follow before they are allowed to use the brand "CHAOSS D&I Metrics."

- KR 1 - We have crowdsourced and prioritized ethical considerations around data collection, usage, storage, analysis, and reporting.
- KR 2 - We have documented ethical best practices for D&I metrics and embedded them in our project documentation.
- KR 3 - We evaluated solutions for how we could enforce ethical best practices for anyone who wants to use CHAOSS D&I Metrics.
- KR 4 - We have published a blog post about how we developed the ethical guidelines and encourages adoption.

Objective #5: Metric Workflow

The D&I Working Group has documented a development workflow for metrics development including state (wip, alpha, released) for metrics.

- KR 1 - Working Group workflow is documented, and shared for feedback.
- KR 2 - All existing resources are updated based on standards, and implemented as part of development workflow.

Figure 26. Screenshot of Goals for 2019 for the CHAOSS D&I Working Group. Document version from January 28, 2019.

Informants reported that well-understood D&I signals, like a code of conduct, were more successful in passing the filtering. A code of conduct is a way to outline accepted behavior within a project and establish consequences for violators. It serves as a signal because it could be observed to exist but did not reveal deeper issues, such as whether it was enforced and whether a project was welcoming and inclusive. Therefore, a project was displaying a D&I signal by having a code of conduct.

> I have seen many communities that have a code of conduct. They say, "We have the code of conduct," and they have it in a visible place where people can see it. – [2B9]

Another D&I signal that had successfully passed the filtering and was well-understood is “speaker demographics”, which indicated diversity of speakers at events. This D&I signal was inherent in an event schedule. Displaying photos of speakers provided an additional, visual aid for observers to get an idea of gender distribution. Many events displayed speaker demographics as its value had been demonstrated by event organizers. Attendees, sponsors, and speakers have come to expect the signal and use it when determining which events to patronize.

> If event organizers hope to get to full representation within their speaker or attendee lineup, if they hope to attract speakers or attendees to their event, then they need to display speaker demographics. They need to make sure that the composition of their speakers matches who they want to attract to their project. – [2B12]

Open source projects displayed D&I signals, if it was well-understood how they helped improve project health. Projects paid attention to which D&I signals were observed and used, thereby cooperatively determining which D&I signals to display.

> I think every project I've ever dealt with is very pragmatic about displaying D&I signals. You have to show how it's tied to community health overall. If you can explain that, people will display it. If you don't explain it, people won't display it. I think that's probably true in most of these signals. – [2B5]

Consequently, informants struggled to remember seeing lesser-known D&I signals passing the filtering. This was attributed to the fact that these D&I signals were too new, not standardized, and that projects had no guidelines for displaying them. Community members who wanted to spread adoption of a D&I signal put effort into piloting the D&I signal, gaining experience, and demonstrating that it was valuable so that they could educate others and increase understanding of the D&I signal.

> No, sadly I haven't seen a project display [a specific D&I signal]. I have not seen anyone do it yet. One of the projects in the [foundation] is trying very hard to have a system track the number of hours people are spending on different tasks in the project. That's the closest I've seen any project come to tracking the information needed to display this D&I signal. – [2D11]

5.3.3 Organizational members adopted signals by making them part of organizational routines.

In the CHAOSS project and its conference CHAOSScon, community members shared examples of how they incorporated cooperatively created signals in their organizations. An example of how using signals was not successful involved an organization that provided a dashboard with metrics to its community managers. The dashboard provided many signals about open source projects the organization was engaging with. For several months, the dashboard had not updated which no one had noticed, revealing that community managers were not using the signals from the dashboard. The takeaway from the example was that making signals available was not enough.

The benefit that organizations seek from signals require that they are observed and acted upon regularly. Examples show that organizations are working to integrate signals about open source project health into their routines. One such example is shown in Figure 27, a slide from a CHAOSScon Europe 2019 presentation that shows that signals are observed weekly. This leads to the third key finding related to filtering signals: *Organizational members adopted signals by making them part of organizational routines.*

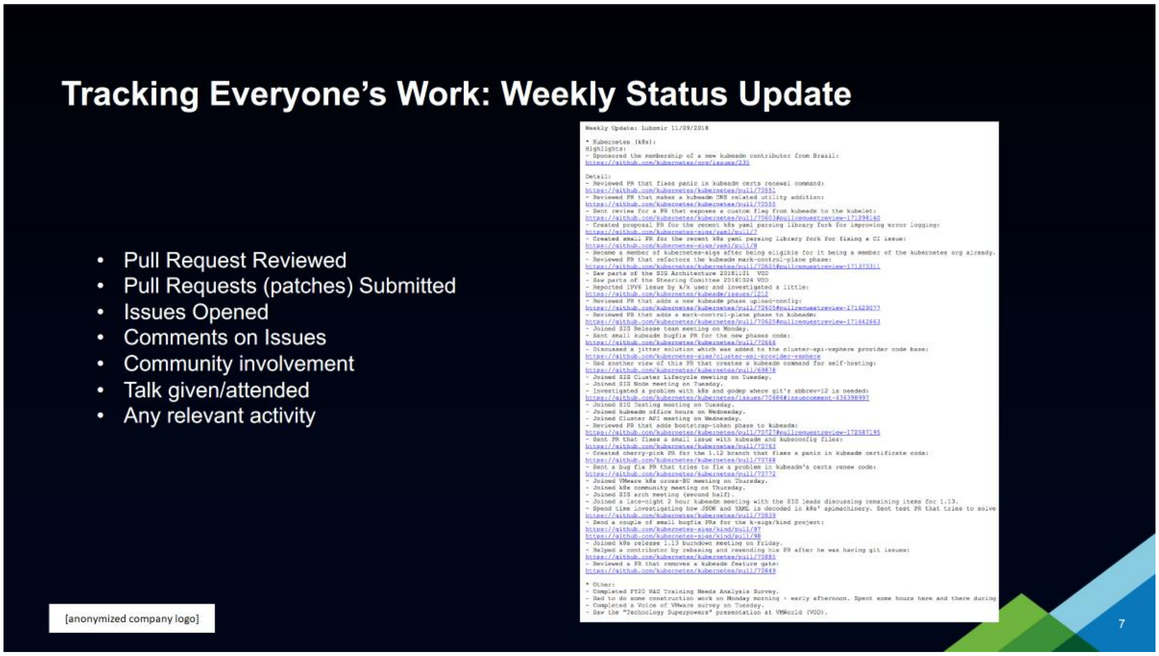


Figure 27. Slide from a CHAOSScon Europe 2019 presentation, showing that signals are made part of organizational routines.

However, organizations were seen as lagging in adopting the use of D&I signals. Most informants did not have an organizational directive to use D&I signals but reported doing it on their own volition. Organizations used D&I signals through individual members who used signals themselves. D&I signals were ignored until someone within an organization took the lead to establish their use. The following quote is from an informant who acknowledged that they used D&I signals at their organization only after someone from outside the organization made them aware of the need to use D&I signals.

> In the for-profit space especially, I see organizations getting involved only after they've received bad press. Like [company], while I was there and I was made aware of issues, problems, mistakes that we were making. While I broadly had support from everybody at the company to make the changes to make sure that we were doing the right thing, we only did that after people reported that we were doing the wrong thing. And I feel that's the industry in microcosm. I feel like companies are more reactive than they are proactive. It's unfortunate. – [1B15]

Organizations who supported organizational members to use D&I signals were supporting, by proxy, the adoption of D&I signals. Signal adoption may have been an initiative of individual organizational members and not organization-wide, but organizations had an option not to support their employees. Informants shared stories of either case, including, in one extreme, seeing organizational members get fired because they were pushing for more D&I signals and, in another extreme, seeing organizational members using their organization’s resources and reputation to spread adoption D&I signals. The support of organizations is therefore a factor in whether signals pass through the filtering. The following quote highlights how organizational members were cooperating in open source projects with support of their organization to spread adoption of D&I signals.

> Organizations are involved insofar as they supported the people that work for them. For example, [Person 1] is employed currently by [company 1], which tends to be pretty supportive of their work. One of my colleagues, [Person 2], who is working with the Python community, is supported by [our company]. These people know that if they say something, like challenging an event to adopt a D&I signal, they won't get fired, like [Person 3] had been. In that sense, organizations were involved in distributing D&I signals. Organizations are generally made of people. Individual people in those organizations have pushed for D&I signals, and then the organizations have been happy enough to adopt them. – [1B10]

For organizations to adopt using D&I signals, these needed to be concrete, had to deliver business value, and organizational members had to make changes within their organizations. Organizational members had an easier time convincing their organization to support the use of D&I signals, when they could demonstrate an impact of those signals on an organization's profitability. Experience and reports of others using D&I signals were facilitators in driving adoption.

> I have been driving this conversation wherever I go. I have been talking this year about that we need to measure diversity and recognize diverse forms of contribution. I know of other diversity leaders who are talking about this as well. It's becoming well accepted. Now we need to translate it into actual measurements and demonstrate the actual business or project benefits. – [1B11]

Field observations and interviews found that the third process in creating signals was to promote signals, to drive adoption, and to avoid filtering signals. Filtering signals results in some D&I signals to be displayed and used while others are not. Table 15 provides a summary of the key findings related to filtering signals. Cooperative signaling behavior is evident in filtering D&I signals because passing signals through filtering was facilitated by community members educating others on a D&I signal, working together to establish a good understanding of a D&I signal, and making a D&I signal part of organizational routines for others to use.

Table 15. Key findings regarding filtering signals.

Key Concept	**Description**	**Supporting Evidence**
Education drove signal adoption	Community members educated others to make them aware of a signal and teach them how to display or use a signal. Filtering signals involved educating different people to ensure that a signal was understood in the same way.	Field Observations Interviews
Experiences from piloting signals drove signal adoption	Practical experiences and lessons learned from trying to use and display signals were valuable for educating others about a signal. Filtering signals involved sharing experiences from piloting signals.	Field Observations Interviews
Understanding of signal drove signal adoption	Projects that understood the value of displaying a signal were seen more likely to adopt a signal. Likewise, organizations that understood the value of using a signal were seen more likely to adopt a signal. Filtering signals involved demonstrating the value that signals had.	Interviews
Routines for signals drove signal adoption	Community members started to use signals themselves before establishing checklists and other means of making signals a regular part of their work. Filtering signals involved making signals part of routines.	Field Observations Interviews

5.4 Displaying and Using Signals

Community members engaging in the CHAOSS D&I Working Group and CHAOSS project more broadly wanted to learn about signals so that they can improve their signal display and signal use. In engaging with the CHAOSS project, community members shared their goals for signals and what experiences they had. From this exchange, signals were identified, evaluated, and filtered. It stands to reason, that cooperative signaling behavior influenced community members’ signal display and use.

An indicator for the impact that the CHAOSS project had in industry was that industry professionals dedicated time and effort to participate in the CHAOSS project and CHAOSScon conferences to learn and discuss about open source project health signals.

The CHAOSS project was also regularly mentioned in blog posts and press releases (Figure 28).

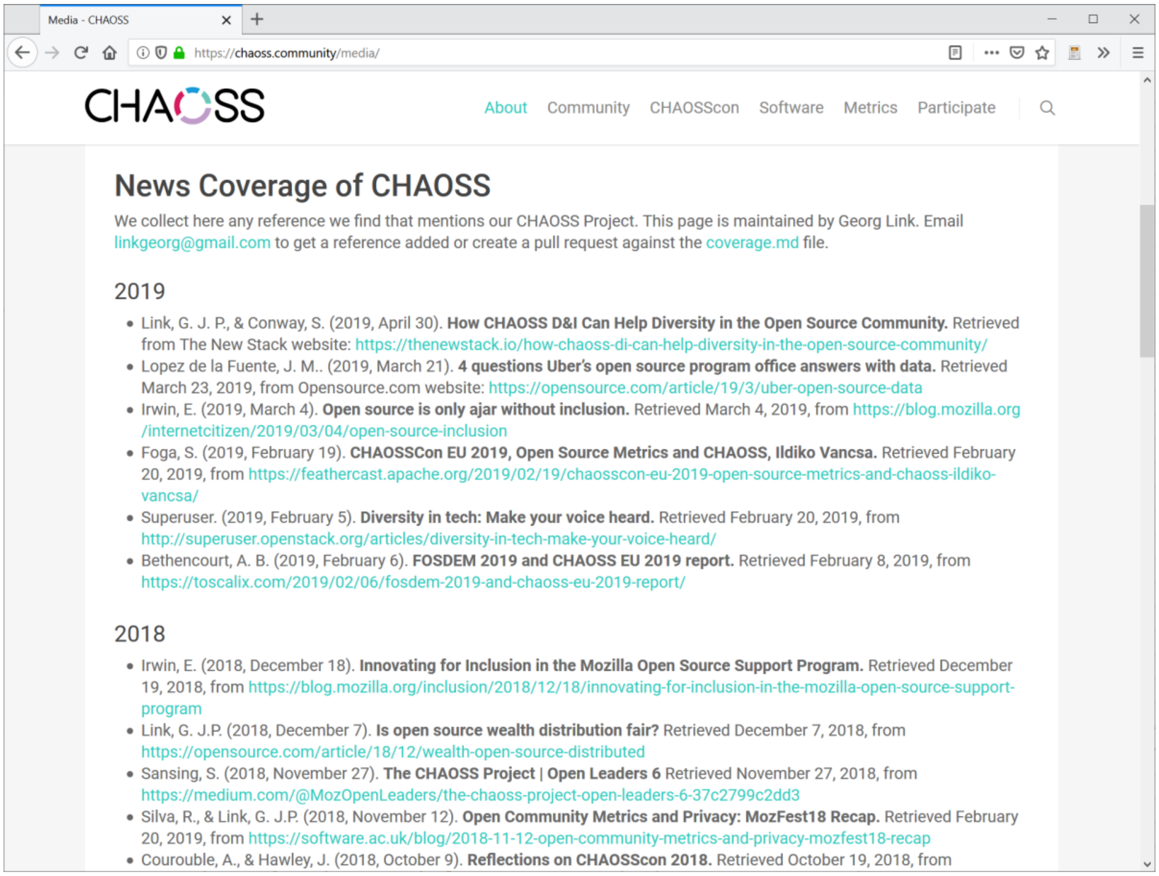
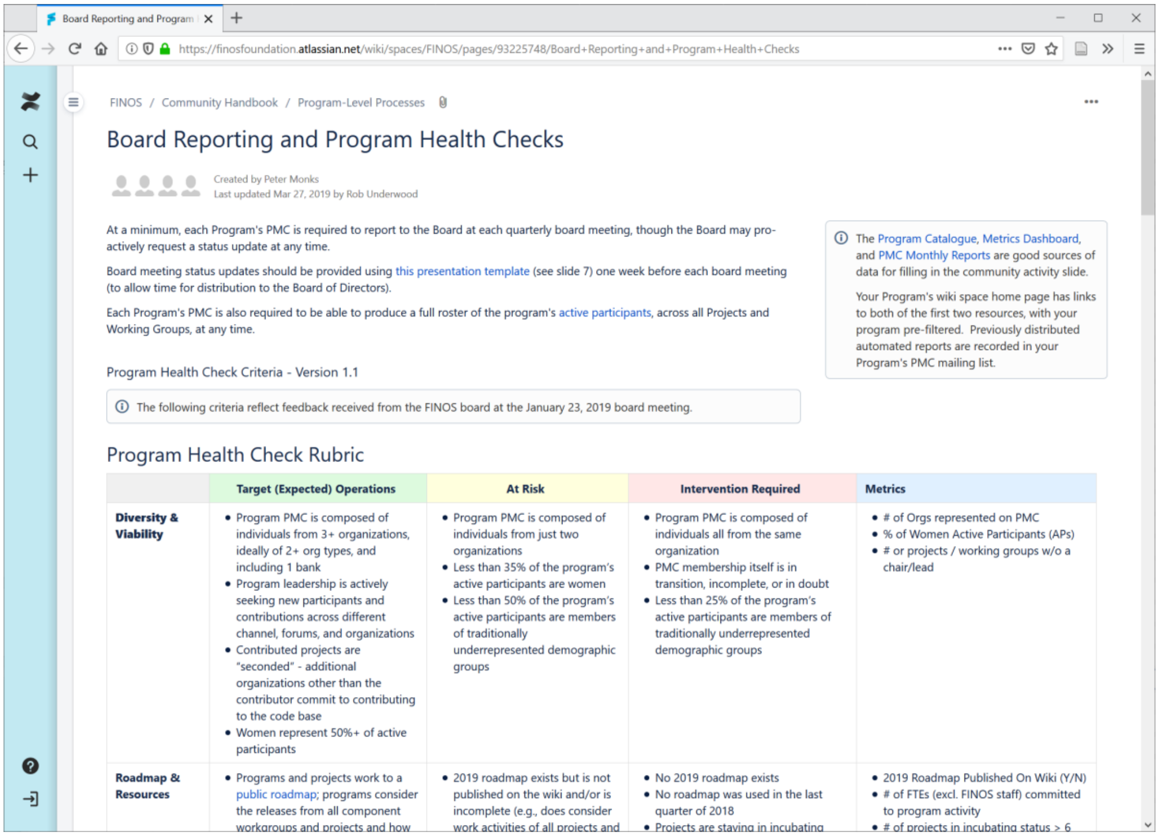


Figure 28. *Screenshot of CHAOSS website with media coverage, showing that a wide variety of community members were writing about the CHAOSS project. Page version from April 30, 2019.*

An observable example of how D&I signals were started to be used was FINOS' Program Health Check Rubric.[32] The rubric contains different signals, including D&I signals, that needed to be observed about open source projects. The rubric also provided guidance on how to interpret signals. Every quarter, signals identified in the rubric had to be shared with FINOS board members as part of FINOS' organizational processes.



Board Reporting and Program

https://finosfoundation.atlassian.net/wiki/spaces/FINOS/pages/93225748/Board+Reporting+and+Program+Health+Checks

FINOS / Community Handbook / Program-Level Processes

Board Reporting and Program Health Checks

Created by Peter Monks
Last updated Mar 27, 2019 by Rob Underwood

At a minimum, each Program's PMC is required to report to the Board at each quarterly board meeting, though the Board may pro-actively request a status update at any time.

Board meeting status updates should be provided using this presentation template (see slide 7) one week before each board meeting (to allow time for distribution to the Board of Directors).

Each Program's PMC is also required to be able to produce a full roster of the program's active participants, across all Projects and Working Groups, at any time.

The Program Catalogue, Metrics Dashboard, and PMC Monthly Reports are good sources of data for filling in the community activity slide.

Your Program's wiki space home page has links to both of the first two resources, with your program pre-filtered. Previously distributed automated reports are recorded in your Program's PMC mailing list.

Program Health Check Criteria - Version 1.1

The following criteria reflect feedback received from the FINOS board at the January 23, 2019 board meeting.

Program Health Check Rubric

	Target (Expected) Operations	At Risk	Intervention Required	Metrics
Diversity & Viability	• Program PMC is composed of individuals from 3+ organizations, ideally of 2+ org types, and including 1 bank • Program leadership is actively seeking new participants and contributions across different channel, forums, and organizations • Contributed projects are "seconded" - additional organizations other than the contributor commit to contributing to the code base • Women represent 50%+ of active participants	• Program PMC is composed of individuals from just two organizations • Less than 35% of the program's active participants are women • Less than 50% of the program's active participants are members of traditionally underrepresented demographic groups	• Program PMC is composed of individuals all from the same organization • PMC membership itself is in transition, incomplete, or in doubt • Less than 25% of the program's active participants are members of traditionally underrepresented demographic groups	• # of Orgs represented on PMC • % of Women Active Participants (APs) • # or projects / working groups w/o a chair/lead
Roadmap & Resources	• Programs and projects work to a public roadmap; programs consider the releases from all component workgroups and projects and how	• 2019 roadmap exists but is not published on the wiki and/or is incomplete (e.g., does consider work activities of all projects and	• No 2019 roadmap exists • No roadmap was used in the last quarter of 2018 • Projects are staying in incubating	• 2019 Roadmap Published On Wiki (Y/N) • # of FTEs (excl. FINOS staff) committed to program activity • # of projects in incubating status > 6

Figure 29. Screenshot of FINOS' Program Health Check Rubric. Page version from March 27, 2019.

Despite some evidence that signal display and use were impacted by cooperative signaling behavior, the evidence is not sufficient to make definite claims. Signal creation is still in an early stage as the CHAOSS project started less than two years before key components of the present research were performed. While field observations

[32] https://finosfoundation.atlassian.net/wiki/spaces/FINOS/pages/93225748/Board+Reporting+and+Program+Health+Checks

indicate that cooperative signaling behavior may impact signal display and use, informants provided interesting insights during interviews about D&I signals specifically.

D&I signals were believed to be connected to the health of an open source project. D&I signals informed that people of varied backgrounds and skills were welcomed and valued in a project. Contributions from people of different backgrounds and skills were positive indicators for project health because they improved the potential that a project will continue developing quality software. Because more diverse people were likely to join and continue to contribute when they were welcomed and included, displaying D&I signals had a positive impact on project health. Thus, D&I signals indicated and improved diversity and inclusivity of open source projects.

> The health of a project in my mind is a mature project; it is a well-rounded project. It doesn't have just code, it's well-documented, it's well-tested, it's well-communicated, it has a good license and CLA information. All of these are necessary for a project to grow and be sustained, and, frankly, be successful and popular. And, if we do not recognize the people who are doing that work to make it a well-rounded and a well-maintained project, then I think we will suffer from a lack of growth in those areas. We need to recognize that work and attract the kind of people into the work that's necessary to mature open source. – [3B11]

Looking at the display and use of D&I signals revealed that displaying D&I signals made projects appear healthier, that D&I signals were not evaluated by a return on investment, and that D&I signals had low importance in organizational decision making compared to other signals.

5.4.1 Displaying D&I signals made projects appear healthier.

Informants provided three main benefits for displaying D&I signals. *Benefit 1:* Projects benefited from displaying signals because it created an awareness among community members. Discussions for displaying D&I signals covered basic questions of whether a project should display D&I signals and what it hoped to gain from it. Discussions for displaying D&I signals identified what information would serve as a D&I signal and how community members could improve the D&I signal. A D&I signal might be a numeric value that demonstrated how well a project was doing and because it was public, bringing incentives to improve on it. By measuring and displaying such numeric values publicly, i.e., using them as signals, projects held themselves accountable for changes that they agreed on.

> There's nothing to encourage you to perform well on something like displaying it publicly. If you say that you're going to give away 20 diversity access tickets and you only end up giving away three, that's going to look really bad if all that's public. It's going to motivate you to actually perform on this numeric value. I'm actually a big fan of having numeric values in the public because I do think it encourages you to perform to those numeric values, even when there's a potential for being shamed later. – [3B4]

Benefit 2: Projects and events benefited from displaying D&I signals because it attracted more diverse people, which improved perception of project health. People were more likely to join and participate if they felt welcomed. To demonstrate the benefit of displaying D&I signals, one informant explained a negative impact that not displaying D&I signals could have for projects. This explanation built on a common assumption that a diverse and inclusive project community was better equipped to develop quality software.

> If projects and events don't publish D&I signals and if they don't try to have representative speaker line-ups, then they're supporting the status quo, and the existing out-of-balance power dynamics that we have, and that's a problem. That's a cost, whether or not they're realizing this is a cost to them. That's a cost because with a monoculture, we lack critical insights and perspective as we make technical or product decisions. You know, if we have a community that doesn't have many people with disabilities in it or people with limited connectivity, then we may very well go and build software that isn't accessible, and only works on broadband modems. So, there's a serious cost to supporting the status quo. – [3D15]

Benefit 3: Projects and events displayed D&I signals to secure funding and organizational engagement. Displaying D&I signals for an event was to demonstrate to sponsors that an event was "diverse enough." Sponsors might refrain from funding an event if it did not host a diverse set of well-known speakers. A project or event that was lacking D&I signals or had negative publicity might not be able to get organizations to support and participate. An organization might avoid associating with a project that could cause negative publicity for the organization.

> When event organizers contact sponsors or other people outside, they say, "These are the numbers of our conference that we had last year. We had X number of attendees and X speakers." Like different kind of statistic that they can show that the event was very diverse and having different kind of statistic that they can bring from the conference that was last year. Especially sponsors or people that care about the community, organizers show these kinds of signals to them. – [2B9]

5.4.2 D&I signals were not evaluated by return on investment.

Informants could not say whether healthy and unhealthy projects had a different return on investment. A reason was that D&I signals were not consistently displayed to provide a baseline within or across projects for comparison. Therefore, a cost-benefit-ratio could not be established.

> You have to have a baseline understanding of what your community health is. To have a return on investment, you need to know what needle you're moving and which way it's going. – [2D7]

With regards to D&I signals, informants rejected the "return on investment" framing. They argued that a project benefited from engaging more diverse people and that signal display efforts were not a consideration. Addressing diversity and inclusion issues was seen as the right thing to do, regardless of its effort. Displaying D&I signals was one way to satisfy the ethical imperative.

> I really dislike the return on investment framing. I don't enjoy putting forward the business case for accessibility or diversity and inclusion, because D&I is the right thing to do, period. – [2D15]

D&I signals were observed unchanging in the short-term. The demographic composition of a project community was seen as stable. Informants who conducted surveys found very little year-over-year difference, which was a concern for observing an impact of diversity and inclusion efforts because their impact was not easily observable in changes to D&I signals. With regards to return on investment, a concern was that any return would be measurable and observable only with a delay.

> We realized that communities don't change that fast. Every year, when we were collecting the data, the discussion was basically the same. That means that we were again finding similar numbers. They were perhaps a bit bigger or a bit smaller, but the population of women and so on were the same. – [3C3]

5.4.3 D&I signals had low importance in organizational decision making compared to other signals.

Diversity and inclusion, in general, and across the IT industry, was a topic that organizations were becoming more interested in. This nascent interest in diversity and inclusion by organizations was felt by projects, but evidence of organizations paying attention to individual D&I signals was scarce. Informants reported that their organizations valued diversity and inclusion but that it was not a focus.

> I don't know specifically about [D&I signal]. The organizations that I've been part of were looking at diversity and inclusion of events as something that's important. This being one element of it, I would think that it would be something we would look at. But it's such a small piece of the overall diversity and inclusion stuff that I'm not sure that this thing would tip the balance. – [4D4]

D&I signals were less important than technical requirements in decisions about organizational engagements. Organizations might use D&I signals to sway decisions that were borderline but influence of D&I signals was small. A D&I signal could serve as a knockout criterion but was not used to compare projects.

> I wonder if a company is thinking about using a technology like [project 1]. When they're weighing their options, and they're like: “Should we be all [project 2] or does [project 1] make sense, or what about [project 3].” I wonder, do any of those companies want to know how diverse and inclusive our community is? Probably to some extent, because if they're going to be going to conferences, they do care if we're terrible people because they have to actually see us and work with us. But as far as the technology goes, do they care what percentage of the programmers working on it were under-represented minorities in tech? I don't know. – [4D13]

Informants agreed that organizational decision making could not be made based on specific D&I signals because they were not reliably displayed by projects. When organizations looked at D&I signals, they would observe whether a project was displaying D&I signals.

> D&I signals do not influence decisions, to be honest. And that's partially because we're not systematic at looking at community health at all, right now. I would think that probably if we were to look at it, it would be binary: is this community addressing D&I signals in any systematic way. –[4D5]

One informant provided the following rationale, explaining that companies only used D&I signals in their decision making to avoid becoming affiliated with a project that could generate negative publicity.

> People are going to start becoming uncomfortable giving money or being seen to give money to projects that either mark or completely go against the intention of code of conducts. I think you'll see more projects or grant programs or whatever, start to say: “Hey, I can't be associated with you with that stuff going on.” It'll probably be blunt and subtle. – [4B7]

Established D&I signals became part of organizational routines that community members learned to execute. With the use of D&I signals becoming institutionalized, community members who newly learn about D&I signals did not know the background and history of how a D&I signal came to be. Nevertheless, these community members are a component in cooperative signaling behavior even if they are at the tail end of it and have limited insight to it.

> I really don't know why D&I signals have become important. But certainly, in the for-profit world, when you look at diversity and inclusion, this is becoming a category. There seems to be a checklist item for it. – [1B18]

Field observations and interviews indicated that signals were created to be displayed and used and that cooperative signaling behavior impacts the display and use of signals. Table 16 provides a summary of the key findings related to displaying and using signals. Cooperative signaling behavior is evident in displaying and using D&I signals because it directed the attention of community members as they interacted with each other.

Table 16. Key findings regarding displaying and using signals.

Key Concept	**Description**	**Supporting Evidence**
Cooperative signaling behavior influenced signal display and use	Community members who displayed or used signals could learn how to do it better through cooperative signaling behavior. Displaying and using signals involved learning about a signal from cooperative signaling behavior.	Field Observations Interviews
Signal display changed hidden quality	Community members reported displaying and using signals to make the health of their projects appear better. Displaying and using signals involved working towards changing a hidden quality.	Interviews
Signals worked internally	Signals were observed by community members who were members of the project that displayed signals. Displaying and using signals involved shaping the behavior of project members.	Interviews
Signals worked externally	Signals were observed by community members who were not project members. Displaying and using signals involved attracting more community members, organizations, and funding for a project.	Interviews
Signal display effort was irrelevant	The idea that effort to display a signal would determine which signals projects would display was rejected by informants. Displaying and using D&I signals was seen as an ethical imperative regardless of signal display effort.	Interviews
Signals were slow changing	Signals were reported to be stable and slow changing, which impeded their use for short-term decision making. Displaying and using signals involved observing signals as they changed over time.	Interviews
Some signals were used more than others	Organizations decided to engage with open source projects based more on technical signals and less on D&I signals. Displaying and using signals involved selecting which signals to pay attention to.	Field Observations Interviews
Prevalence of signal display was important for signal use	Users of signals did not rely on signals that were not widely displayed and could, thus, not be used for comparison. Displaying and using signals involved observing whether others were also displaying or using a signal.	Interviews
Signal were requested to be displayed	Users of signals incentivized projects to display signals, e.g., funders made signals part of their funding criteria. Displaying and using signals involved requesting signals to be displayed.	Interviews
Signals lived beyond cooperative signal creation	People learned to display or use signals without learning the history of how a signal was cooperatively created. Displaying and using signals in day-to-day work involved moving beyond cooperative signal creation.	Interviews

5.5 Summary of Findings

Field observations and interviews showed that cooperative signaling behavior is the combination of activities by which senders and observers create signals and shape how they are displayed and used (Table 17). Signal creation is about proposing ideas for new signals, debating them, and incorporating different goals and perspectives. It is about developing shared methods of displaying signals, identifying and overcoming difficulties in displaying signals, and piloting them to better understand them. It is about educating each other, sharing experiences with signals, and working together to include signals in routines. Cooperative signaling behavior for creating signals occurs through the processes of identifying, evaluating, and filtering signals. In this, community members from projects and organizations help each other and create signals. After signals are created, it is about making decisions based on signals, requesting that signals be displayed, and shaping behavior by displaying signals.

Table 17. An overview of activities involved in cooperative signaling behavior.

		Process	Activities
Cooperative Signaling Behavior	Creating Signals	Identifying Signals	- Proposing ideas for new signals - Debating proposed signals - Incorporating different goals and perspectives
		Evaluating Signals	- Developing shared methods for displaying signals - Overcoming difficulties in displaying signals - Piloting signals to better understand them
		Filtering Signals	- Educating others on signals - Sharing experiences - Including signals in routines
	Displaying and Using Signals		- Shaping behavior by displaying signals - Making decisions based on signals - Requesting signals to be displayed

6 Discussion

Open source projects are known to signal project health (Ho & Rai, 2017). Signaling theory research explains how signals are used to overcome information asymmetries (Connelly et al., 2011; Spence, 1974). However, the incentives in organizational engagement with open source projects to create signals match the incentives described for cooperative signaling behavior (Spence, 1974) providing a research context for critiquing signaling theory. As such, driving this research was the question of: *How do open source projects and organizations create signals for open source project health?* Below sections address the question, particularly in the context of open source project health and D&I signals.

6.1 D&I Signals are Cooperatively Built to Shape Engagement

Cooperative signaling behavior was supported by evidence. However, observations in the context of open source project health and D&I signals yielded interesting findings that were unexpected. Figure 30 shows the conceptual framework, identifying which parts of cooperative signaling behavior were supported, work differently, or were not supported with evidence. The discussion focuses on unexpected findings, highlighting that signals are cooperatively built to shape engagement and not to distinguish projects of high and low project health.

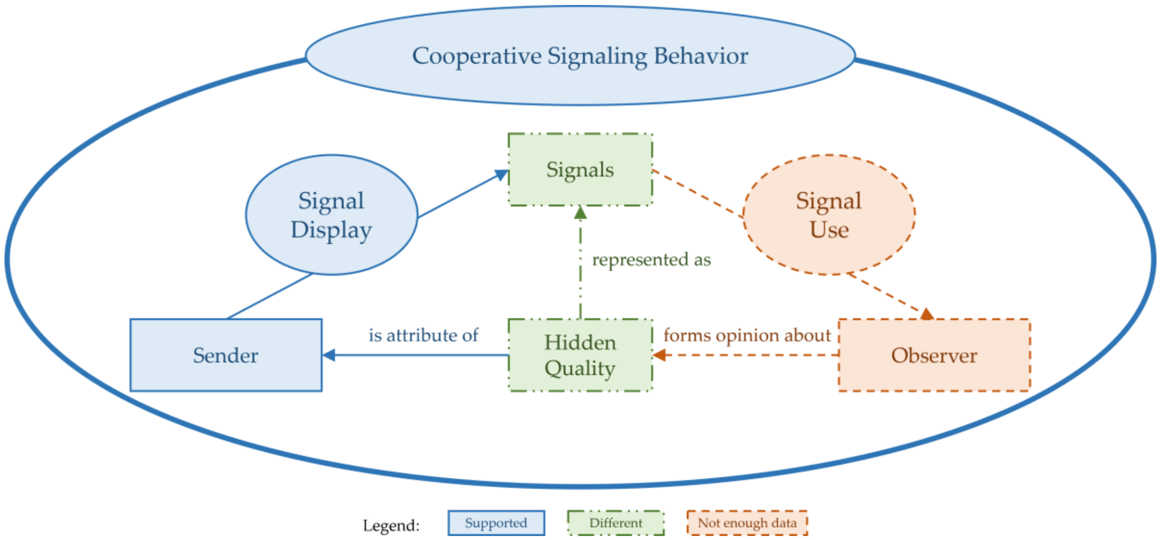


Figure 30. Color-coded conceptual framework: Blue (solid line) was supported by evidence as expected. Green (long dash dot line) was found to work different than expected: The D&I signal—health relationship is bi-directional. Red (dashed line) did not have enough evidence: Use of signals by organizations and use of project health in decision making.

6.1.1 Supported: Cooperative Signaling Behavior and Signal Display

As was expected, when signals are used to overcome an information asymmetry (Connelly et al., 2011), community members from within open source projects have to display signals because other community members would not have the necessary insight. However, they were not left alone with this responsibility but received help from community members from across other projects and organizations. The context of D&I signals was fruitful for exploring cooperative signaling behavior.

It was expected that community members have an incentive to shape an informational structure (Spence, 1974). This expectation was supported because community members from open source projects and organizations were found to propose signals and develop them for a variety of reasons. They balanced trade-offs between difficulties and benefits for displaying D&I signals, as was expected (Hasson, 1997). The creation of new signals was not the sole doing of either projects or organizations, but both worked together and benefitted from this cooperation.

6.1.2 Different: The D&I Signals—Health Relationship

The relationship between D&I signals and project health was different than expected. The expectation was that project health determines what signals are displayed because signaling theory often demonstrates signal credibility by demonstrating that a hidden quality is negatively correlated with signal display effort (Connelly et al., 2011). However, display effort for D&I signals was not determined by how welcoming and inclusive a project was (i.e., its hidden quality). Any effort to display D&I signals was seen as irrelevant, which supports that signals can be displayed for different motivations (Zerbini, 2017). Following an ethical imperative, projects expend the effort of displaying D&I signals, not to reflect their state of project health, but to improve their health. This indicates that D&I signals are a type of signal that derive credibility because they influence project health which corroborates that commitments to improve a hidden quality serve as credible signals (Hasson, 1997; Zerbini, 2017).

Literature found that the same signal is sometimes reused for conveying similar information to make communication more efficient by having fewer signals that need to be recognized (Santana, 2014). With regards to D&I signals, the opposite seems to be true where diverse signals are displayed for similar information. A reason is that D&I signals are displayed, not to inform about, but to improve project health. Diverse D&I signals developed by the CHAOSS D&I Working Group draw attention to different ways of improving project health. While specific signals focus community members on specific improvements, observers do not benefit from the level of detail and combine signals to use them. This indicates that signals displayed to change a hidden quality are not optimized for efficient communication.

Literature suggested that senders choose to display positive signals and avoid negative signals (Connelly et al., 2011). However, informants stated that they wanted honest D&I signals, even if they were negative. Displaying a negative D&I signal was seen as better than not having a signal. A negative signal is displayed by community members to be observed by community members, shaping their interaction within a project and towards others. A negative signal motivates to improve and demonstrates to observers that community members are attentive to an issue. It had been suggested that senders may use signals to inform their behavior (Hasson, 1997; Karanges et al., 2018). The findings suggest that positive and negative signals are useful in such a context.

6.1.3 Not Enough Evidence: Signal Use

It was expected that organizations use D&I signals, which was not supported with enough evidence. Organizations do observe D&I signals, but different types of signals bear different levels of importance (Hasson, 1997). Both, technical and D&I signals indicate project health (Link & Germonprez, 2018) and findings show that organizations choose to engage in projects based on technical signals, thus confirming that D&I signals are considered after technical signals (Linåker et al., 2019). Findings suggested that D&I signals are not used by organizations to compare projects. One reason is that D&I signals inform how welcoming and inclusive a project is, which is not quantified and does not lend itself to a comparison. However, organizations sometimes use D&I signals to avoid engaging with projects that may result in negative publicity.

Nevertheless, organizations engage in cooperative signaling behavior. They support their employees to work as community members on identifying, evaluating, and filtering D&I signals. However, use of D&I signals by organizations was little observed. Thus, there was insufficient evidence to determine differences between displaying fewer or more signals (Wang et al., 2018) and how corroborating or conflicting signals impact decision making (Miyazaki et al., 2005; Worsham & Gatrell, 2005). Future research could address these open questions as more organizations begin to use D&I signals. For example, D&I signals are starting to be used as a funding criterion by organizations for funding open source projects.

6.2 Creation of Signals by Identifying, Evaluating, and Filtering Signals

Prior signaling theory research explained how senders and observers overcome an information asymmetry but did not explain how signals were created (Connelly et al., 2011). The present research contributes to signaling theory by describing how signals are created through cooperative signaling behavior (Spence, 1974). When community members of open source projects and organizations engage in signaling activities, they advance signals. Community members who are seen to be most engaged were typically those who benefitted most from having signals, which supports that community members who gain from shaping an informational structure engage in cooperative signaling behavior (Spence, 1974). In cooperative signaling behavior, senders and observers engage together in identifying, evaluating, and filtering signals, which confirms that communication between senders and observers is essential to establishing new signals (Santana, 2014). Findings described three processes through which cooperative signaling behavior creates new signals, summarized in Table 18.

Table 18. Summary of cooperative signaling behavior processes that create signals.

Cooperative Signaling Behavior: Processes for Creating Signals	
Identifying Signals	Community members engage in conversations about how to best represent or influence a hidden quality, collecting proposed signals.
Evaluating Signals	Community members advance methods for displaying proposed signals, overcome challenges for displaying signals, and pilot them. Initial experimental implementations provide experiences for evaluating signals and learning what meaning people ascribe to them.
Filtering Signals	Senders and observers incorporate a signal in their processes or dismiss them, based on what was learned during the evaluation of signals.

Identifying signals is a process in which community members engage in conversations about how to best represent or influence project health through signals. Community members propose a variety of signals because they each represent a different way to understand project health. Many signals are in early development because it is challenging to precisely define what information to display and how it relates to project health. Only when community members give meaning to these potential signals (Santana, 2014) can they inform organizational engagements.

Evaluating signals is a process in which community members advance methods for displaying proposed signals, overcome challenges for displaying signals, and pilot them. Initial experimental implementations provide experiences for evaluating signals and learning what meaning people ascribe to them. Senders evaluate a signal based on how easy it is to display and what benefits to expect from displaying it. When community members convince project members to display untested D&I signals, they innovate and demonstrate how display is possible. Observers evaluate a signal based on what objectives it helps to achieve, which confirms that people pay attention to signals that they learn will help (Spence, 1974), for example to do the right thing or to avoid negative publicity.

Filtering signals is a process where senders and observers incorporate a signal in their practices or by which they may dismiss a signal (Gomulya & Mishina, 2017). Choosing to incorporate or to dismiss a signal is influenced by benefits of compared to difficulties to display a signal (Hasson, 1997). Conditions that help a community member filter a signal include positive experience with a signal, demonstrated benefits of a signal, and a communal understanding of a signal. Community members educate senders and observers of a potential signal by speaking about them at conferences, publishing blog posts, engaging projects, and discussing in organizations. For example, as a filtered signal “event speaker demographics” is used to attract more speakers, attendees, and funders to events. The event speaker signal is also routinely displayed by event organizers and used in organizational funding decisions. While signals are filtered to become part of communal and organizational practices, it remains individual community members who display and use signals. As signals are made integral parts of organizational processes, community members not involved in filtering signals may not know why they are expected to use a signal. Instead, they perceive it as a “check-box” to tick, explaining why people have been observed to engage in signaling behavior without perceiving it as such (Spence, 1974).

6.3 Displaying and Using Signals from Cooperative Signaling Behavior

Cooperative signaling behavior creates signals with the aim to display and use them. The research provided limited evidence about how cooperatively created signals are displayed and used. This is not surprising considering that the CHAOSS D&I Working Group had started educating others about D&I signals only three months before key components of the research were performed. One instance that did demonstrate the display and use of cooperative signals is the OpenStack Gender Diversity Report.[33] The authors of the report were active members of the CHAOSS D&I Working Group and discussed ideas for expanding the focus of their report before implementing them. An addition to the 2018 report was a section on mentorship programs with signals created in the CHAOSS D&I Working Group.

Field observations from the research inform where community members were starting to display and use signals. Within the CHAOSS project, a focus of work is on implementing signals in software (Figure 31). Two CHAOSS software projects – Augur[34] and GrimoireLab[35] – put pressure on methods for displaying signals because they translate proposed signals into software. Learnings from this translation are used to improve the signal definition. Implemented signals are then displayed by community members who use this software to understand the health of their projects. For example, Twitter[36] is experimenting signals with Augur. Cregit, the third CHAOSS software

[33] https://superuser.openstack.org/articles/2018-gender-diversity-report/
[34] https://github.com/chaoss/augur
[35] https://github.com/chaoss/grimoirelab
[36] http://twitter.augurlabs.io/

project, can be used to display signals that have not yet been the focus of discussions in the CHAOSS project.

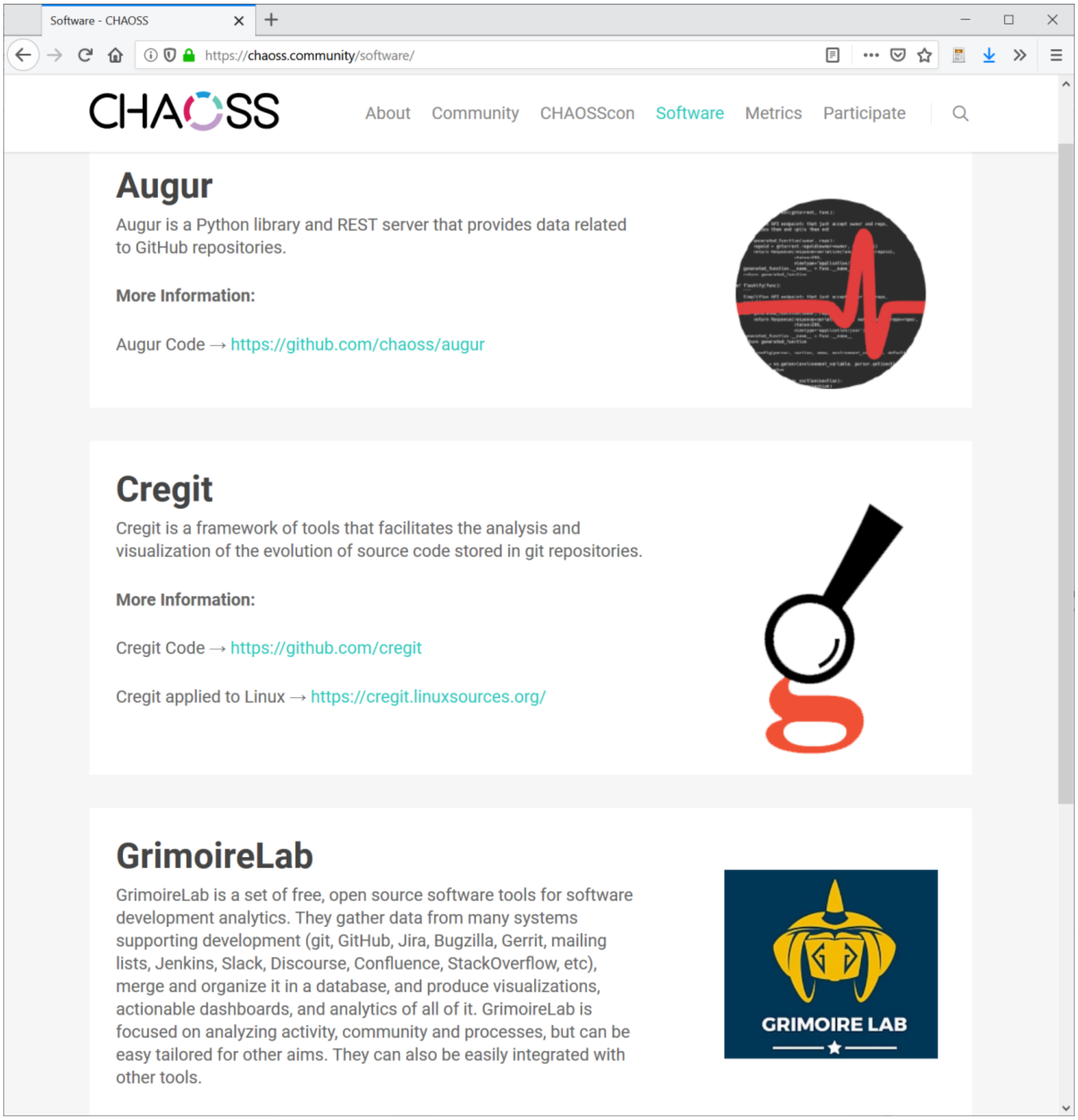


Figure 31. *Screenshot of CHAOSS website showing the three CHAOSS software projects: Augur, Cregit, and GrimoireLab.*

The findings suggest that signals are made part of organizational routines. With project health as a critical consideration for organizations, it can be expected that organizations learn from cooperative signaling behavior and advance their use of signals. This is evident from presentations that organizational members gave at CHAOSScon about their organizations' use of signals. A directly observable example is FINOS' Program Health Check Rubric.[37] The rubric contains different signals that need to be observed about open source projects and provides guidance on what actions the signals inform. The creator of the rubric made signals part of FINOS' organizational routines. It cannot be known to which extend such a rubric would have been created without cooperative signaling behavior in the CHAOSS project. However, available evidence suggests that cooperative signaling behavior influenced how signals are displayed and used.

[37] https://finosfoundation.atlassian.net/wiki/spaces/FINOS/pages/93225748/Board+Reporting+and+Program+Health+Checks

7 Reflection on Assurance Case Method

The assurance case method for qualitative research provides rigor in creating data collection strategies (Gandhi & Lee, 2009). Gandhi and Lee (2009) positioned the assurance case method as a structured way to document propositions of a case study and explicitly connect them to data. Gandhi et al. (2018) demonstrated that the assurance case can also be useful outside of a case study to develop an interview protocol. The present study used the assurance case to develop an interview protocol as an integral part of the overall method. My experience confirms the benefit of a rebuttal-claim-question-evidence logic that forces a researcher to develop a rationale for each interview question and anticipate evidence. The visual assurance case focuses conversations with research team members and facilitates critical reflection that can reveal overlooked rebuttals and new interview questions. However, these benefits come with pitfalls.

One pitfall is to expand the level of detail of an assurance case beyond what is needed to answer a research question (Goodenough, Weinstock, & Klein, 2015). It is tempting to unpack an inner logic of an assurance case through additional levels of sub-claims and rebuttals. However, additional levels of claims result in more interview questions. A downside is an increasing burden on an interviewer to manage more questions, even if only to skip them. Instead, it is beneficial to focus on developing open-ended questions. Throughout several interviews, an interviewer identifies new follow-up questions to ask (Seidman, 2006) even without a detailed assurance case.

Another pitfall is formulating leading interview questions by simply phrasing the connected claim from the assurance case as a question. For example, for a claim

"Informants believe that incentives for open source projects and organizations were balanced" an obvious question is "Do you believe that incentives for open source projects and organizations were balanced?" Leading questions have limited value for a qualitative study and should be replaced with open-ended questions that enable informants to explore an answer (Creswell, 2013; Seidman, 2006; Spradley, 2016). To conclude the example, I formulated the interview question as "How were incentives for open source projects and organizations balanced in the design of the metric?" Therefore, a good use of the assurance case informs an interviewer about evidence an open-ended question is expected to yield which guides formulating follow-up questions during an interview.

A third pitfall is to present an analysis informed by engineering practices (Goodenough et al., 2015) that summarizes findings to determine how well evidence supports claims in the assurance case. Such a rigid structure is a good intermediary step in qualitative data analysis (Miles & Huberman, 1994) but breaks with conventions for presenting results in narrative form (van Maanen, 1988). A possible solution was explored by including references to the assurance case from the finding's presentation. However, as theoretical contributions were developed, the link was difficult to maintain and removed at last. Having initially presented interview data by how it informed different branches in the assurance case, provided rigor in analyzing the data and provided insights into the evidence for the concepts of the conceptual framework.

8 Contributions and Implications

8.1 Critique of Signaling Theory: Creation of Signals Through Cooperative Signaling Behavior

This study provides a critique (Mathiassen et al., 2012) of signaling theory (Spence, 1974). Spence (1974) theorized that senders and observers have incentives to cooperate and create signals. However, signaling theory literature has focused on how signals impact decision making, not the creation of signals (Connelly et al., 2011). This study documents one instance in which senders and observers do engage in cooperative signaling behavior to create signals. We learned that cooperative signaling behavior works through identifying, evaluating, and filtering signals. This is a critique of signaling theory by demonstrating that signals are created. An implication for signaling theory research is that scholars should be mindful of where signals came from and why they were created. The findings from this study provide an expanded lens to investigate signaling behavior while considering where signals originate from.

8.2 Critique of Signaling Theory: The Signal–Hidden Quality Relationship

Signaling theory assumes that a signal is used to convey information about a hidden quality (Spence, 1974). A common argument for why a signal is credible refers to a correlation between the effort to display a signal and the hidden quality (Connelly et al., 2011; Spence, 1974). Such a cost-benefit-analysis was not supported by the findings.

Informants rejected a cost-benefit-analysis because they argued that displaying D&I signals was ethically the right thing to do, regardless of signal display effort. An implication for signaling theory is to revisit assumptions about what makes a credible signal. Hasson (1997) theorized in the context of biological signaling that signals are credible in collaborative engagements when senders and observes use signals to coordinate their cooperation and lack incentives to deceive. Signal credibility in cooperative engagements was not the focus of this study but emerged as an interesting observation. An implication for signaling theory research in social sciences is to investigate signal credibility in cooperative engagements.

Signaling theory literature describes signals to inform outside observers about a hidden quality. The findings suggest, however, that signals are used internally and work towards improving a hidden quality. Using signals not to signal to outside observers but to internal observers has been theorized (Karanges et al., 2018). Karanges et al. (2018) argued that executives in organizations signal to employees to influence their behavior. Findings of the present study support that members of an organization can display signals for internal use to improve a hidden quality. A related observation was the use of many similar signals for the same hidden quality. In contrast to displaying few signals to efficiently convey information about a hidden quality (Santana, 2014), many signals may be needed to efficiently influence a hidden quality. An implication is that more research is needed to uncover how signals influence a hidden quality.

8.3 Critique of the Assurance Case Method as a Tool for Developing an Interview Protocol

A critique of the assurance case method as a tool for developing an interview protocol is based on reflecting upon its application in this study. Use of the assurance case method for qualitative research had been proposed (Gandhi & Lee, 2009) and demonstrated (Gandhi et al., 2018). The present study appreciated the rigor that the assurance case method introduced into the development of an interview protocol. However, three pitfalls were identified, and solutions were developed. First, the assurance case should be limited to necessary elements when formulating interview questions. Second, extra effort is required to formulate open-ended questions and to avoid leading questions that speak too closely to an associated claim. Third, rigor in the analysis of data can stem from organizing data to match the structure of the assurance case, but the analysis needs to continue and move to a structure that informs beyond the assurance case.

8.4 Implications for Organizational Engagement with Open Source Projects

Open source projects are cooperative in nature where community members self-organize to solve problems (Kelty, 2008). Organizational engagements with open source projects are also cooperative in nature where otherwise competing organizations work together on non-differentiating problems (Germonprez, Allen, et al., 2013). One of the shared problems was signaling project health (Link & Germonprez, 2018) and cooperative signaling behavior was a cooperative approach to this problem. A common theme appears to be emerging across research on organizational engagement with open source projects: When problems arise, best practices are developed cooperatively with open source projects and organizations. Cooperative signaling behavior is the latest example for developing best practices for the shared signaling problem. Other examples include: the SPDX standard as a best practice to explicate license obligations for the shared problem of license compliance (Gandhi et al., 2018), the OpenChain project for best practices in organizations for the shared problem of compliance routines, and the CII Best Practices Badge for best practices for the shared problem of security. Enumeration of observations as an inductive approach is insufficient to make a determinate claim. However, a trend appears to emerge. Organizations that engage in an open source development model appear to be keen to also engage in similar cooperative settings for developing shared best practices. The implication is that research is needed to compare best practices development in organizational engagements with open source projects and other ways of best practices development.

8.5 Implications for Financing Open Source Work

Because signals influence decisions (Connelly et al., 2011), it can be expected that cooperatively created signals effect financing of work in open source projects. The findings suggested that some funders are making signals mandatory in their funding criteria. When funding of open source work is conceptualized as a marketplace, then attracting funds may require that projects display attractive signals. This is similar to how publicly traded companies send signals that influence their stock price (Zerbini, 2017). Open source projects that engaged in cooperative signaling behavior may have a better understanding of available signals that could attract funding. An implication is that signals need to be better understood, possibly through cooperative signaling behavior, with regards to how they influence funding opportunities for open source projects.

Conversely, signals about how much funds an open source project receives and pays out to contributors may also serve as signals about project health (Link et al., 2019). However, market places for funding open source work are fast changing and newly emerging. An implication is that open source projects and organizations may determine through cooperative signaling behavior how market signals apply to open source projects.

8.6 Implications for Compliance

Organizations are concerned with compliance to reduce risk (Ihara, 2014). Through cooperative signaling behavior, organizations can learn which signals can indicate risks. One signal that organizations may pay attention to is the Core Infrastructure Initiative Best Practices Badge.[38] Open source projects can self-certify and then display the badge as a signal of following best practices for reducing risk. The development of the badge could be likened to cooperative signaling behavior. In developing the badge, open source projects and organizations collected ideas for what best practices are, evaluated those ideas, and filtered them. The resulting check-list of best practices is what projects certify against. The badge itself serves as a signal. A more in-depth study would be needed to empirically verify whether the CII Best Practices Badge is another instance of cooperative signaling behavior. An implication is that organizations can engage in cooperative signaling behavior to create signals for understanding the risks associated with open source projects.

The CHAOSS project is starting a new CHAOSS Risk Working Group[39] in 2019 that focuses on signals concerning, for example, business risk, licensing risk, code quality risk, transparency risk, and security risk. The formation of the CHAOSS Risk Working Group on the one hand indicates that cooperative signaling behavior for compliance may be important and on the other hand provides a field site for studying this phenomenon.

8.7 Implications for Standards Setting

The way cooperative signaling behavior creates signals and facilitates implementation has similarities to how standards are created in open source projects, with signals as the standard. Like standard setting (Gandhi et al., 2018), routines for displaying and using signals are shaped through discussions and learnings that implementors and users provide. A common theme across standard setting and cooperative signaling behavior is that ideas come from a variety of contexts to solve a variety of problems. However, once a proposed idea enters into a standard, it increases the complexity of the standard (ibid.). Users of the standard have to cope with the complexity, even when using only a portion of the standard (ibid.). In contrast, in cooperative signaling behavior, a signal can be filtered out and thus not increase complexity in signaling a hidden quality because it is neither displayed nor used. Indeed, a wish for more modularity and optional

[38] https://bestpractices.coreinfrastructure.org/
[39] https://github.com/chaoss/wg-risk

aspects of a standard was expressed by users of a standard developed in open source (ibid.). An implication for standard setting is that modular standards may be better suited for open source development than fully integrated standards.

In the SPDX project, organizations and open source projects engaged in developing a standard for expressing license obligations and related best practices (Gandhi et al., 2018). Open source projects adopted these best practices and, for example, used SPDX-License-Shortidentifiers to express licenses at the file level. Organizations can observe the presence of license short identifiers as a signal and for example infer that evaluating licensing risks associated with such a project may require less effort because licenses are easier to identify. In the SPDX case, cooperative development of a standard has resulted in a signal. The implication is that cooperative standard development may entail cooperative signaling behavior.

8.8 Implications for Open Source Project Health

Open source project health is important to open source projects and organizations (Linåker et al., 2019). However, a shared method for assessing project health is missing (Link & Germonprez, 2018). The findings showed that shared methods for displaying signals about project health are created through cooperative signaling behavior. Someone who wants to know more about project health signals and learns about them from others is also engaging in cooperative signaling behavior. Shared methods for assessing open source project health therefore emerge from cooperative signaling behavior. The implication is that cooperative signaling behavior is a solution to improve identifying project health.

Project health can be assessed in the three dimensions: community, code, resources (Arantes & Freire, 2011). D&I signals are part of the community dimension (Linåker et al., 2019). D&I signals were found to be nuanced which supports that the community dimension is complex. The focus of this study was not on specific D&I signals but on how open source projects and organizations move past the complexity to create D&I signals that are meaningful. The findings showed that D&I signals emerged from cooperative signaling behavior. While D&I signals mentioned in this research give an idea of what D&I signals are, they only served to reveal the creation of signals. D&I signals are not well defined in this research nor intended to comprise a comprehensive list. The implication is that D&I signals were identified as important but that more research is needed to understand D&I signals, especially as they become more widely displayed and used.

9 Limitations

This research focused on organizational engagements with open source projects. Informants served organizational and communal interests. The role of signaling and specifically cooperative signaling behavior may be different in an open source context with little or no organizational engagement. Moreover, cooperative signaling behavior may work different in other contexts. It may be interesting to investigate cooperative signaling behavior in contexts that do not have cooperation as a core value like open source does.

Community members take on many different roles within open source projects and organizations. In explaining cooperative signaling behavior, these roles were not differentiated to avoid distracting readers with superfluous details. Future research can investigate how different roles in projects and organizations affect cooperative signaling behavior. For example, what do community managers, open source program officers, developers, or marketers contribute to cooperative signaling behavior and gain from it?

Additionally, the interview protocol for this research was built on a prevalent idea that signal display effort determines signal credibility. Signal display effort turned out to be irrelevant and signal credibility was derived from a project's commitment. However, the interview protocol was not adjusted because data collection had been completed when this discovery was made. Future research can investigate signaling that relies less on signal display effort and more on other signal credibility mechanisms.

Finally, D&I signals in open source are still emerging. The concept “signal use” could not be supported. Inferences were made throughout findings and discussion, but concrete evidence is missing. It may be interesting to investigate cooperative signaling behavior in a more advanced context where all concepts of the framework are observable.

10 Conclusions

This study critiqued signaling theory by advancing our understanding of cooperative signaling behavior and describing it in the context of open source project health in organizational engagements with open source projects. Signals were found to be created through cooperative signaling behavior, specifically through processes of identifying, evaluating, and filtering signals. Signaling was thereby shown to have cooperative elements previously only suspected (Spence, 1974). Signaling theory research should look beyond existing signals and understand how those signals came to be before they facilitated interactions between senders and observers.

Overall, value of the engaged scholarship approach cannot be overstated. This research project contributed to practice by collecting details about D&I signals and sharing them with the CHAOSS D&I Working Group. As such, the researcher engaged in cooperative signaling behavior and was able to report on it with an inside perspective. The thick description of the CHAOSS D&I Working Group was shared with community members who found a blog to publish it[40] and a podcast to promote it via an interview.[41] More broadly, the impact of cooperative signaling behavior is starting to show as projects and organizations report efforts to display and use signals. Future research will be needed to investigate how cooperative signaling behavior not only creates signals but influences signal display and signal use.

[40] https://thenewstack.io/how-chaoss-di-can-help-diversity-in-the-open-source-community/
[41] https://thenewstack.io/how-chaoss-measures-diversity-windows-gets-a-proper-terminal/

Open source projects are evolving and signaling plays an important role in shaping this evolution. Project members display signals that draw attention to issues and consequently change behavior of project members. Changing behavior of project members is different from signals attracting or retaining project members (Ho & Rai, 2017). An implication for open source projects is that establishing signals can focus their project members to improve project health and create visibility about it. Projects that innovate novel signals have an extra burden of trial and error but are first to benefit. Especially larger projects may benefit from this introspection and resulting change. Future research may investigate whether cooperative signaling behavior is more likely to occur in some types of projects. A need for cooperative signals appears to drive the CHAOSS project to start new working groups that focus now on: D&I, Growth-Maturity-Decline, Risk, Value, and Common Metrics. An implication for organizations is that if they want to use any kind of signals about open source project health, they may need to allow their employees to work with open source projects to create those signals and promote their display.

Cooperative signaling behavior may not be uniform. For example, D&I signals for events and projects were developed within the same timeframe but reached different levels of adoption. An open question is whether events and projects are different signaling contexts in which cooperative signaling behavior works differently. The context of events has a limited time frame for planning and organizing an event, resulting in a short learning cycle to observe whether displayed signals attract more diverse speakers, attendees, and sponsors. In contrast, the context of projects is an ongoing engagement where changes are slow to manifest, signals are hard to define, and learning cycles are longer. Length of a learning cycle may influence how fast signals mature. Within these different contexts, D&I signals for events have similarities with signals in transaction contexts where decisions are made once and D&I signals for events have similarities with signals in cooperative environments where coordination is a primary intention of senders and observers (Hasson, 1997). Institutional theory may provide an interesting lens to uncover specific actors, dynamics, and how D&I signals are shaped through institutional constraints.

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References

Aggarwal, N., Dai, Q., & Walden, E. A. (2011). The more, the merrier? How the number of partners in a standard-setting initiative affects shareholder's risk and return. *MIS Quarterly*, *35*(2), 447-A5.

Aksulu, A., & Wade, M. (2010). A comprehensive review and synthesis of open source research. *Journal of the Association for Information Systems, 11*(11).

Alspaugh, T., Scacchi, W., & Asuncion, H. (2010). Software licenses in context: the challenge of heterogeneously-licensed systems. *Journal of the Association for Information Systems, 11*(11). Retrieved from http://aisel.aisnet.org/jais/vol11/iss11/2

Arantes, F. L., & Freire, F. M. P. (2011). Aspects of an open source software sustainable life cycle. *IFIP International Conference on Open Source Systems*, 325–329. https://doi.org/10.1007/978-3-642-24418-6_26

Backhouse, J., Hsu, C. W., & Silva, L. (2006). Circuits of power in creating de jure standards: Shaping an international information systems security standard. *MIS Quarterly*, *30*, 413–438.

Bacon, J. (2012). *The art of community: building the new age of participation* (2nd edition). Sebastopol, CA: O'Reilly Media.

Basili, V. R. (1992). *Software modeling and measurement: the Goal/Question/Metric paradigm*. Retrieved from https://drum.lib.umd.edu/bitstream/handle/1903/7538/?sequence=1

Benkler, Y. (2002). Coase's penguin, or, Linux and "the nature of the firm." *The Yale Law Journal*, *112*(3), 369–446. Retrieved from http://www.jstor.org/stable/1562247

Benkler, Y. (2013). Commons and growth: the essential role of open commons in market economies. *The University of Chicago Law Review*, *80*(3), 1499–1555. Retrieved from http://www.jstor.org/stable/23594886

Black Duck Software. (2016, April). *2016 future of open source survey results*. Retrieved from https://www.blackducksoftware.com/2016-future-of-open-source

Bonaccorsi, A., Giannangeli, S., & Rossi, C. (2006). Entry strategies under competing standards: hybrid business models in the open source software industry. *Management Science*, *52*(7), 1085–1098. https://doi.org/10.1287/mnsc.1060.0547

Brinkmann, S., & Kvale, S. (2015). *InterViews: learning the craft of qualitative research interviewing* (Third edition). Los Angeles: Sage Publications.

Casile, M., & Davis-Blake, A. (2002). When accreditation standards change: factors affecting differential responsiveness of public and private organizations. *Academy of Management Journal*, *45*(1), 180–195. https://doi.org/10.2307/3069291

Chan, J. (2013). *Open source innovation in firms* (Thesis, ResearchSpace@Auckland). Retrieved from https://researchspace.auckland.ac.nz/handle/2292/22010

Connelly, B. L., Certo, S. T., Ireland, R. D., & Reutzel, C. R. (2011). Signaling theory: a review and assessment. *Journal of Management*, *37*(1), 39–67. https://doi.org/10.1177/0149206310388419

Creswell, J. W. (2013). *Qualitative inquiry and research design: choosing among five approaches* (3rd ed). Los Angeles: SAGE Publications.

Crowston, K., Howison, J., & Annabi, H. (2006). Information systems success in free and open source software development: theory and measures. *Software Process: Improvement and Practice*, *11*(2), 123–148. https://doi.org/10.1002/spip.259

Dahlander, L. (2005). Appropriation and appropriability in open source software. *International Journal of Innovation Management*, *9*(3), 259–285.

Dahlander, L., & Magnusson, M. G. (2005). Relationships between open source software companies and communities: observations from Nordic firms. *Research Policy*, *34*(4), 481–493. https://doi.org/10.1016/j.respol.2005.02.003

Dahlander, L., & Wallin, M. W. (2006). A man on the inside: unlocking communities as complementary assets. *Research Policy*, *35*(8), 1243–1259. https://doi.org/10.1016/j.respol.2006.09.011

Danes, R. (2017, September 12). In wake of Equifax breach, Linux Foundation unveils open source CHAOSS. Retrieved from SiliconANGLE website: https://siliconangle.com/blog/2017/09/12/wake-equifax-breach-linux-foundation-unveils-open-source-chaoss-ossummit/

Decan, A., Mens, T., & Constantinou, E. (2018). On the impact of security vulnerabilities in the npm package dependency network. *Proceedings of the 15th International Conference on Mining Software Repositories - MSR '18*, 181–191. https://doi.org/10.1145/3196398.3196401

Decan, A., Mens, T., & Grosjean, P. (2019). An empirical comparison of dependency network evolution in seven software packaging ecosystems. *Empirical Software Engineering*, *24*(1), 381–416. https://doi.org/10.1007/s10664-017-9589-y

Dedrick, J., & West, J. (2003). Why firms adopt open source platforms: a grounded theory of innovation and standards adoption. *Standard Making: A Critical Research Frontier for Information Systems - MISQ Special Issue Workshop*, 236–257.

Drover, W., Wood, M. S., & Corbett, A. C. (2017). Toward a cognitive view of signalling theory: individual attention and signal set interpretation. *Journal of Management Studies*, *55*(2), 209–231. https://doi.org/10.1111/joms.12282

Durumeric, Z., Kasten, J., Adrian, D., Halderman, J. A., Bailey, M., Li, F., … Paxson, V. (2014). The matter of Heartbleed. *Proceedings of the 2014 Conference on Internet Measurement Conference*, 475–488. https://doi.org/10.1145/2663716.2663755

Eghbal, N. (2016). *Roads and bridges: the unseen labor behind our digital infrastructure*. Retrieved from the Ford Foundation website: http://www.fordfoundation.org/library/reports-and-studies/roads-and-bridges-the-unseen-labor-behind-our-digital-infrastructure/

Egyedi, T. M., & Van Wendel de Joode, R. (2004). Standardization and other coordination mechanisms in open source software. *International Journal of IT Standards & Standardization Research*, *2*(2), 1–17.

Erdem, T. (1998). An empirical analysis of umbrella branding. *JMR, Journal of Marketing Research; Chicago*, *35*(3), 339–351.

European Commission. (n.d.). About EU-FOSSA 2. Retrieved from https://joinup.ec.europa.eu/collection/eu-fossa-2/about

European Commission. (2018, July 10). Study on the role of open source in standard setting. Retrieved from https://ec.europa.eu/digital-single-market/en/news/study-role-open-source-standard-setting

Feller, J., Finnegan, P., Fitzgerald, B., & Hayes, J. (2008). From peer production to productization: a study of socially enabled business exchanges in open source service networks. *Information Systems Research*, *19*(4), 475–493. https://doi.org/10.1287/isre.1080.0207

Fiorillo, D. (2011). Do monetary rewards crowd out the intrinsic motivation of volunteers? Some empirical evidence for Italian volunteers. *Annals of Public & Cooperative Economics*, *82*(2), 139–165. https://doi.org/10.1111/j.1467-8292.2011.00434.x

Fitzgerald, B. (2006). The transformation of open source software. *MIS Quarterly, 30*(3), 587–598. https://doi.org/10.2307/25148740

Fogel, K. (2015). *Producing open source software: how to run a successful free software project*. Retrieved from http://producingoss.com/

Gamalielsson, J., & Lundell, B. (2017). On licensing and other conditions for contributing to widely used open source projects: an exploratory analysis. *Proceedings of the 13th International Symposium on Open Collaboration (OpenSym '17)*. https://doi.org/10.1145/3125433.3125456

Gandhi, R., Germonprez, M., & Link, G. J. P. (2018). Open data standards for open source software risk management routines: an examination of SPDX. *Proceedings of ACM GROUP '18*, 219–229. https://doi.org/10.1145/3148330.3148333

Gandhi, R., & Lee, S.-W. (2009). Assurance case driven case study design for requirements engineering research. In M. Glinz & P. Heymans (Eds.), *Requirements Engineering: Foundation for Software Quality: 15th International Working Conference, REFSQ 2009 Amsterdam, The Netherlands, June 8-9, 2009 Proceedings* (pp. 190–196). https://doi.org/10.1007/978-3-642-02050-6_16

Gerlach, J. H., Wu, C.-G., Cunningham, L. F., & Young, C. E. (2016). An exploratory study of conflict over paying Debian developers: *International Journal of Open Source Software and Processes*, *7*(3), 20–38. https://doi.org/10.4018/IJOSSP.2016070102

Germonprez, M., Allen, J. P., Warner, B., Hill, J., & McClements, G. (2013). Open source communities of competitors. *ACM Interactions*, *20*(6), 54–59. https://doi.org/10.1145/2527191

Germonprez, M., Kendall, J. E., Kendall, K. E., Mathiassen, L., Young, B., & Warner, B. (2017). A theory of responsive design: a field study of corporate engagement with open source communities. *Information Systems Research*, *28*(1), 64–83. https://doi.org/10.1287/isre.2016.0662

Germonprez, M., Kendall, K., Kendall, J., Young, B., Warner, B., & Mathiassen, L. (2013). The domestication of open source. *DIGIT 2013 Proceedings*. Retrieved from http://aisel.aisnet.org/digit2013/8/

Germonprez, M., Link, G. J. P., Lumbard, K., & Goggins, S. (2018). Eight observations and 24 research questions about open source projects: illuminating new realities. *Proceedings of the ACM on Human-Computer Interaction*, *2*(CSCW), 57:1--57:22. https://doi.org/10.1145/3274326

Germonprez, M., Young, B., Mathiassen, L., Kendall, J. E., Kendall, K. E., & Warner, B. (2012). Risk mitigation in corporate participation with open source communities: protection and compliance in an open source supply chain. *Proceedings of the 7th International Research Workshop on IT Project Management (IRWITPM*. Presented at the International Research Workshop on IT Project Management 2012, Orlando, Florida, USA. Retrieved from http://aisel.aisnet.org/irwitpm2012/3

Goldman, R., & Gabriel, R. P. (2005). *Innovation happens elsewhere: open source as business strategy*. San Francisco, CA: Morgan Kaufmann Publishers.

Gomulya, D., & Mishina, Y. (2017). Signaler credibility, signal susceptibility, and relative reliance on signals: how stakeholders change their evaluative processes after violation of expectations and rehabilitative efforts. *Academy of Management Journal*, *60*(2), 554–583. https://doi.org/10.5465/amj.2014.1041

Goodenough, J. B., Weinstock, C. B., & Klein, A. Z. (2015). *Eliminative argumentation: a basis for arguing confidence in system properties* (TECHNICAL REPORT No. CMU/SEI/2015-TR-005; p. 71).

Grøtnes, E. (2009). The work of an international standardization consortia: paths towards its current structure. *International Journal of IT Standards & Standardization Research*, *7*(1), 48–65.

Hansson, D. H. (2013, November 12). The perils of mixing open source and money (DHH). Retrieved from http://david.heinemeierhansson.com/2013/the-perils-of-mixing-open-source-and-money.html

Hasson, O. (1997). Towards a general theory of biological signaling. *Journal of Theoretical Biology*, *185*(2), 139–156. https://doi.org/10.1006/jtbi.1996.0258

Heil, O., & Robertson, T. S. (1991). Toward a theory of competitive market signaling: a research agenda. *Strategic Management Journal*, *12*(6), 403--418.

Hicks, H. G., & Goronzy, F. (1966). Notes on the nature of standards. *Academy of Management Journal*, *9*(4), 281–293. https://doi.org/10.2307/254947

Ho, S. Y., & Rai, A. (2017). Continued voluntary participation intention in firm-participating open source software projects. *Information Systems Research*, *28*(3), 603–625. https://doi.org/10.1287/isre.2016.0687

Hurd, J., & Isaak, J. (2005). IT standardization: the billion dollar strategy. *International Journal of IT Standards & Standardization Research*, *3*(1), 68–74.

Ihara, A., Monden, A., & Matsumoto, K.-I. (2014, November). *Industry questions about open source software in business: research directions and potential answers*. 55–59. https://doi.org/10.1109/IWESEP.2014.12

Izquierdo, D. (2017, October 16). How to define a metrics strategy for your community. Retrieved May 31, 2018, from Opensource.com website: https://opensource.com/article/17/10/defining-metrics-strategy-your-community

Karanges, E., Johnston, K. A., Lings, I., & Beatson, A. T. (2018). Brand signalling: an antecedent of employee brand understanding. *Journal of Brand Management*, *25*(3), 235--249. https://doi.org/10.1057/s41262-018-0100-x

Kelty, C. M. (2008). *Two bits: the cultural significance of free software*. Durham: Duke University Press.

Kelty, C. M. (2013). There is no free software. *Journal of Peer Production*, *1*(3).

Kemp, R. (2010). Open source software (OSS) governance in the organisation. *Computer Law & Security Review*, *26*(3), 309–316. https://doi.org/10.1016/j.clsr.2010.01.008

Kirmani, A., & Rao, A. R. (2000). No pain, no gain: a critical review of the literature on signaling unobservable product quality. *Journal of Marketing*, *64*(2), 66–79. Retrieved from http://www.jstor.org/stable/3203443

Kozinets, R. V. (2015). *Netnography: redefined*. SAGE Publications.

Leiponen, A. E. (2008). Competing through cooperation: the organization of standard setting in wireless telecommunications. *Management Science*, *54*(11), 1904–1919. Retrieved from http://www.jstor.org/stable/30219581

Lerner, J., & Tirole, J. (2002). Some simple economics of open source. *The Journal of Industrial Economics*, *50*(2), 197–234. Retrieved from http://www.jstor.org/stable/3569837

Levy, M., & Germonprez, M. (2015). Is it egalitarianism or enterprise strategy? Exploring a new method of innovation in open source. *AMCIS 2015 Proceedings*. Presented at the Twenty-first AMCIS 2015, Puerto Rico. Retrieved from http://aisel.aisnet.org/amcis2015/StrategicUse/GeneralPresentations/18/

Linåker, J., Regnell, B., & Damian, D. (2019). A Community Strategy Framework – How to obtain influence on requirements in meritocratic open source software communities? *Information and Software Technology*. https://doi.org/10.1016/j.infsof.2019.04.010

Link, G. J.P., & Germonprez, M. (2016). Understanding open source communities as complex adaptive systems: a case of the R Project community. *AMCIS 2016 Proceedings*. Presented at AMCIS, San Diego, CA. Retrieved from http://aisel.aisnet.org/amcis2016/Open/Presentations/7/

Link, G. J.P., & Germonprez, M. (2018). Assessing open source project health. *Twenty-Fourth Americas Conference on Information Systems Proceedings*. Presented at the Twenty-fourth Americas Conference on Information Systems, New Orleans, LA. Retrieved from http://aisel.aisnet.org/amcis2018/Openness/Presentations/5

Link, G. J.P., Gill, J., & Khazanchi, D. (2017). Measuring adoption of open source software and practices in organizations: a pilot study. *Proceedings of the Twelfth Midwest Association for Information Systems Conference*. Presented at the Midwest Association for Information Systems Conference, Springfield, IL. Retrieved from http://aisel.aisnet.org/mwais2017/43/

Link, G. J.P., & Jeske, D. (2017). Understanding organization and open source community relations through the Attraction-Selection-Attrition Model. *OpenSym ’17 Companion*. Presented at the OpenSym 2017, Galway, Ireland. https://doi.org/10.1145/3125433.3125472

Link, G. J.P., Rao, M., Marti, D., Leak, A., & Bodo, R. (2019). Marktplatz zur Koordinierung und Finanzierung von Open Source Software. *HMD Praxis der Wirtschaftsinformatik*, *56*(2), 419--437. https://doi.org/10.1365/s40702-018-00474-6

Link, G. J.P., & Qureshi, S. (2017). The role of open source in new business formation: innovations for development. *Proceedings of the Twenty-Third Americas Conference on Information Systems.* Presented at the Twenty-third Americas Conference on Information Systems, Boston. Retrieved from http://aisel.aisnet.org/amcis2017/ICTs/Presentations/18/

Link, G. J.P., & Qureshi, S. (2018). The role of open source communities in development: policy implications for governments. *Hawaii International Conference on System Sciences 2018 (HICSS-51) Proceedings*, 2404–2413. Retrieved from http://hdl.handle.net/10125/50190

Lynn, M. (1996). Negotiating practice theory (or, I've got the theory, you've got the practice). In J. Fook (Ed.), *The Reflective Researcher: Social Workers' Theories of Practice Research* (pp. 140--150). St. Leonards, NSW, Australia: Allen & Unwin.

Marsan, J., Templier, M., Marois, P., Adams, B., Carillo, K., & Mopenza, G. L. (2019). Toward solving social and technical problems in open source software ecosystems: using cause-and-effect analysis to disentangle the causes of complex problems. *IEEE Software, 36*(1), 34–41. https://doi.org/10.1109/MS.2018.2874323

Mathiassen, L., Chiasson, M., & Germonprez, M. (2012). Style composition in action research publication. *MIS Quarterly*, *36*(2), 347–363.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: an expanded sourcebook* (2nd ed). Thousand Oaks: Sage Publications.

Miyazaki, A. D., Grewal, D., & Goodstein, R. C. (2005). The effect of multiple extrinsic cues on quality perceptions: a matter of consistency. *Journal of Consumer Research*, *32*(1), 146–153. https://doi.org/10.1086/429606

Mockus, A., Fielding, R. T., & Herbsleb, J. D. (2002). Two case studies of open source software development: Apache and Mozilla. *ACM Trans. Softw. Eng. Methodol.*, *11*(3), 309–346. https://doi.org/10.1145/567793.567795

Mulligan, C. (2008). Embracing open source methods for the standardization of NGN services and enablers. *2008 The Second International Conference on Next Generation Mobile Applications, Services, and Technologies*, 628–633. https://doi.org/10.1109/NGMAST.2008.90

Mulligan, C., Mortier, R., Houghton, R., Rahemtulla, H., Flintham, M., & Nord, C. (2011). Standardisation strategies for the android platform: the politics of the stack. *2011 15th International Conference on Intelligence in Next Generation Networks (ICIN)*, 265–270. https://doi.org/10.1109/ICIN.2011.6081087

Nagle, F. (2018). Learning by contributing: gaining competitive advantage through contribution to crowdsourced public goods. *Organization Science*, *29*(4), 569–587. https://doi.org/10.1287/orsc.2018.1202

Nagy, D., Yassin, A. M., & Bhattacherjee, A. (2010). Organizational adoption of open source software: barriers and remedies. *Communications of the ACM*, *53*(3), 148–151.

Naparat, D., Finnegan, P., & Cahalane, M. (2015). Healthy community and healthy commons: ‘opensourcing’ as a sustainable model of software production. *Australasian Journal of Information Systems*, *19*(0). https://doi.org/10.3127/ajis.v19i0.1221

Poba-Nzaou, P., Raymond, L., & Fabi, B. (2014). Risk of adopting mission-critical OSS applications: an interpretive case study. *International Journal of Operations & Production Management*, *34*(4), 477–512.

Ramsauer, R., Lohmann, D., & Mauerer, W. (2016). Observing custom software modifications: a quantitative approach of tracking the evolution of patch stacks. *Proceedings of the 12th International Symposium on Open Collaboration*, 4:1–4:4. https://doi.org/10.1145/2957792.2957810

Rao, M., Link, G. J. P., Marti, D., Leak, A., & Bodo, R. (2018). A trading market to incentivize secure software. *17th Annual Workshop on the Economics of Information Security (WEIS) Proceedings*. Presented at the 17th Annual Workshop on the Economics of Information Security (WEIS), Innsbruck, Austria. Retrieved from https://weis2018.econinfosec.org/wp-content/uploads/sites/5/2016/09/WEIS_2018_paper_27.pdf

Rao, M., Parkes, D. C., Seltzer, M. I., & Bacon, D. F. (2015). A framework for incentivizing deep fixes. *Proceedings of the AAAI 2014 Workshop on Incentives and Trust in E-Communities (WIT-EC 2014)*. Presented at the AAAI 2014 Workshop on Incentives and Trust in E-Communities (WIT-EC 2014), Quebec, Canada. Retrieved from http://nrs.harvard.edu/urn-3:HUL.InstRepos:33009631

Riehle, D. (2010). The economic case for open source foundations. *Computer*, *43*(1), 86–90. https://doi.org/10.1109/MC.2010.24

Riehle, D., Riemer, P., Kolassa, C., & Schmidt, M. (2014). Paid vs. volunteer work in open source. *System Sciences (HICSS), 2014 47th Hawaii International Conference On*, 3286–3295. https://doi.org/10.1109/HICSS.2014.407

Roberts, J. A., Hann, I.-H., & Slaughter, S. A. (2006). Understanding the motivations, participation, and performance of open source software developers: a longitudinal study of the Apache projects. *Management Science*, *52*(7), 984–999. https://doi.org/10.1287/mnsc.1060.0554

Sally. (2017, September 9). Apache Struts statement on Equifax security breach. Retrieved from The Apache Software Foundation Blog: https://blogs.apache.org/foundation/entry/apache-struts-statement-on-equifax

Santana, C. (2014). Ambiguity in cooperative signaling. *Philosophy of Science*, *81*(3), 398–422. https://doi.org/10.1086/676652

Schweik, C. M., & English, R. C. (2012). *Internet success: a study of open-source software commons*. Cambridge, Mass.: MIT Press.

Seidman, I. (2006). *Interviewing as qualitative research: a guide for researchers in education and the social sciences* (3rd ed). New York: Teachers College Press.

Sen, R., Subramaniam, C., & Nelson, M. L. (2011). Open source software licenses: strong-copyleft, non-copyleft, or somewhere in between? *Decision Support Systems*, *52*(1), 199–206. https://doi.org/10.1016/j.dss.2011.07.004

Shahrivar, S., Elahi, S., Hassanzadeh, A., & Montazer, G. (2018). A business model for commercial open source software: a systematic literature review. *Information and Software Technology*, *103*, 202–214. https://doi.org/10.1016/j.infsof.2018.06.018

Spence, M. (1974). *Market signaling: informational transfer in hiring and related screening processes*. In *Harvard Economic Studies*: *Vol. v. 143*. Cambridge: Harvard University Press.

Spradley, J. P. (2016). *The ethnographic interview*. Long Grove, IL, USA: Waveland Press, Inc.

Stallman, R. (1983, September 27). Initial announcement - GNU Project. Retrieved from https://www.gnu.org/gnu/initial-announcement.en.html

Stol, K. J., & Fitzgerald, B. (2015). Inner source–adopting open source development practices in organizations: a tutorial. *IEEE Software*, *32*(4), 60–67. https://doi.org/10.1109/MS.2014.77

Van de Ven, A. H. (2007). *Engaged scholarship: a guide for organizational and social research*. Oxford University Press.

Van Maanen, J. (1988). *Tales of the field: on writing ethnography*. Chicago, IL: The University of Chicago Press.

Vancsa, I. (2018, February 26). Community metrics: the challenge behind the numbers. Retrieved from Opensource.com website: https://opensource.com/article/18/2/community-metrics-challenge-behind-numbers

Von Hippel, E., & von Krogh, G. (2003). Open source software and the “private-collective” innovation model: issues for organization science. *Organization Science*, *14*(2), 209–223. https://doi.org/10.1287/orsc.14.2.209.14992

Von Krogh, G., Haefliger, S., Spaeth, S., & Wallin, M. W. (2012). Carrots and rainbows: motivation and social practice in open source software development. *MIS Quarterly, 36*(2), 649–676. Retrieved from http://misq.org/carrots-and-rainbows-motivation-and-social-practice-in-open-source-software-development.html

Von Krogh, G., & Von Hippel, E. (2006). The promise of research on open source software. *Management Science, 52*(7), 975–983. Retrieved from http://www.jstor.org/stable/20110574

Walden, G., & Harper, G. (2018, April 2). Letter to Mr. Zemlin from the One Hundred Fifteenth Congress of the United States Committee on Energy and Commerce. Retrieved November 30, 2018, from https://energycommerce.house.gov/wp-content/uploads/2018/04/040218-Linux-Evaluation-of-OSS-Ecosystem.pdf

Wang, Y., Qu, Z., & Tan, B. (2018). How do assurance mechanisms interact in online marketplaces? A signaling perspective. *IEEE Transactions on Engineering Management*, *65*(2), 239–251. https://doi.org/10.1109/TEM.2017.2786275

Weber, S. (2004). *The success of open source*. Cambridge, MA: Harvard University Press.

Wen, W., Forman, C., & Graham, S. J. H. (2013). Research note—the impact of intellectual property rights enforcement on open source software project success. *Information Systems Research, 24*(4), 1131–1146. https://doi.org/10.1287/isre.2013.0479

Whyte, W. F., & Whyte, K. K. (1988). *Learning from the field: a guide from experience* (2. paperback printing). Newbury Park, Calif.: Sage Publications.

Worsham, J., & Gatrell, J. (2005). Multiple principals, multiple signals: a signaling approach to principal-agent relations. *Policy Studies Journal*, *33*(3), 363–376. https://doi.org/10.1111/j.1541-0072.2005.00120.x

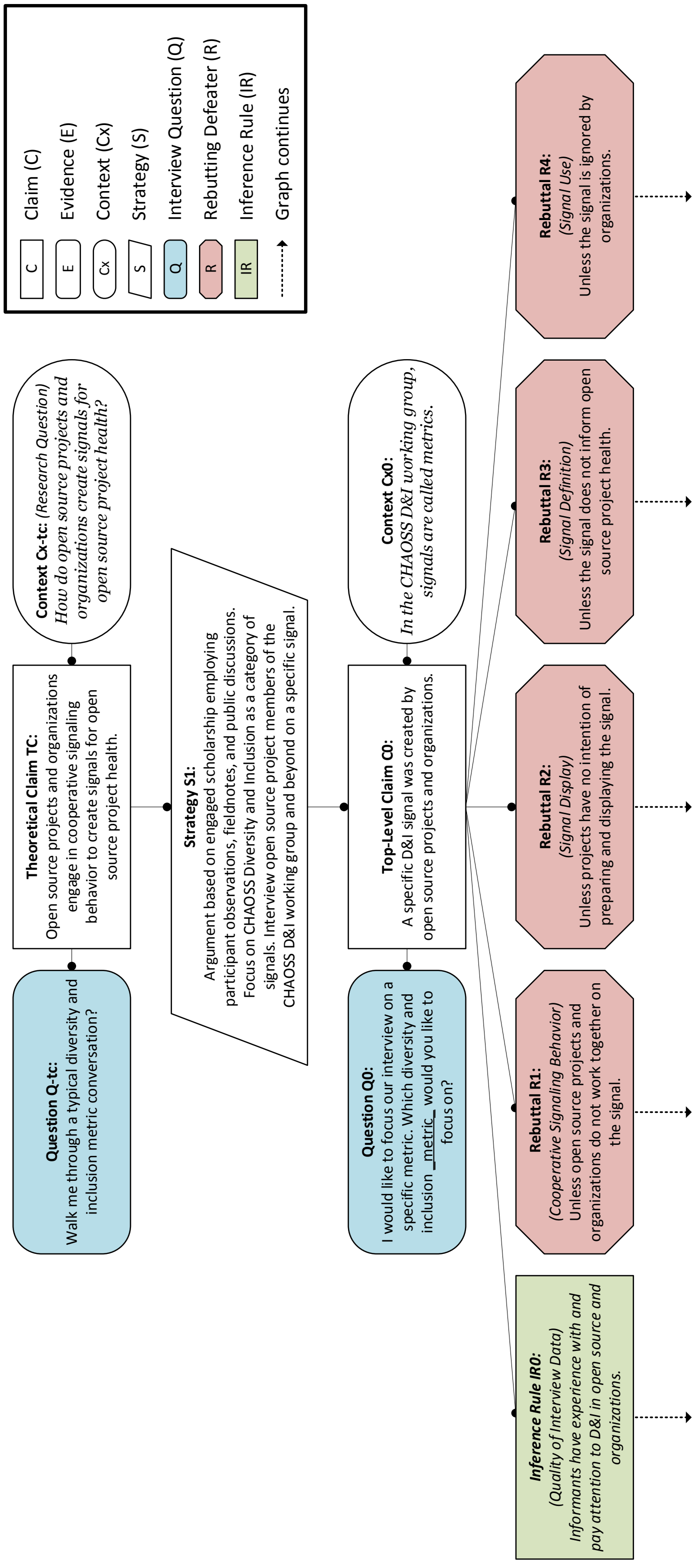
Wright, S. A., & Druta, D. (2014). Open source and standards: the role of open source in the dialogue between research and standardization. *2014 IEEE Globecom Workshops*, 650–655. https://doi.org/10.1109/GLOCOMW.2014.7063506

Zemlin, J. (2019). *Keynote: welcome & opening remarks - Jim Zemlin, Executive Director, The Linux Foundation* [At Open Source Leadership Summit 2019]. Retrieved from https://www.youtube.com/watch?v=NkhjcteL5L0

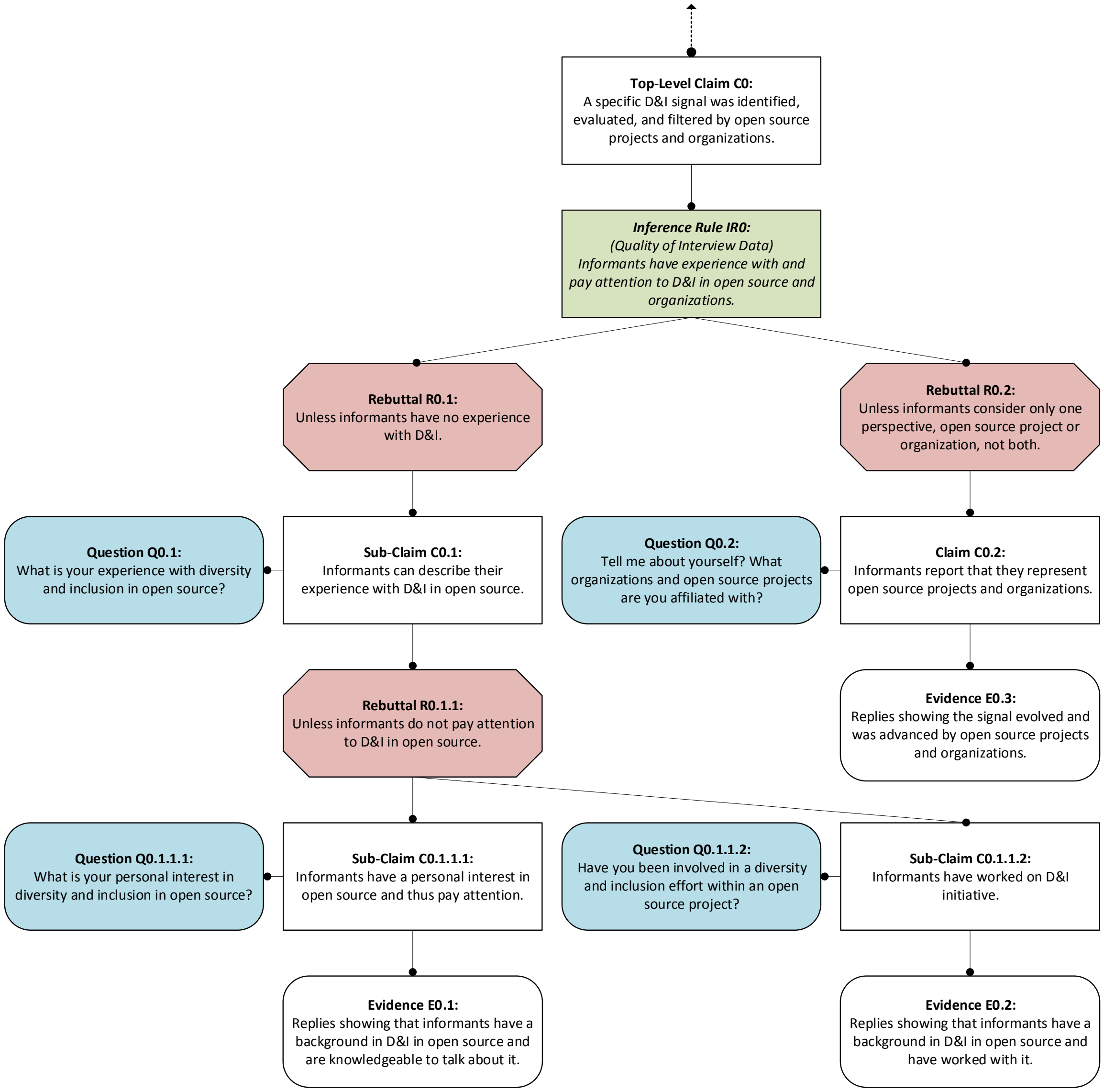
Zerbini, F. (2017). CSR initiatives as market signals: a review and research agenda. *Journal of Business Ethics*, *146*(1), 1–23. https://doi.org/10.1007/s10551-015-2922-8

Appendix

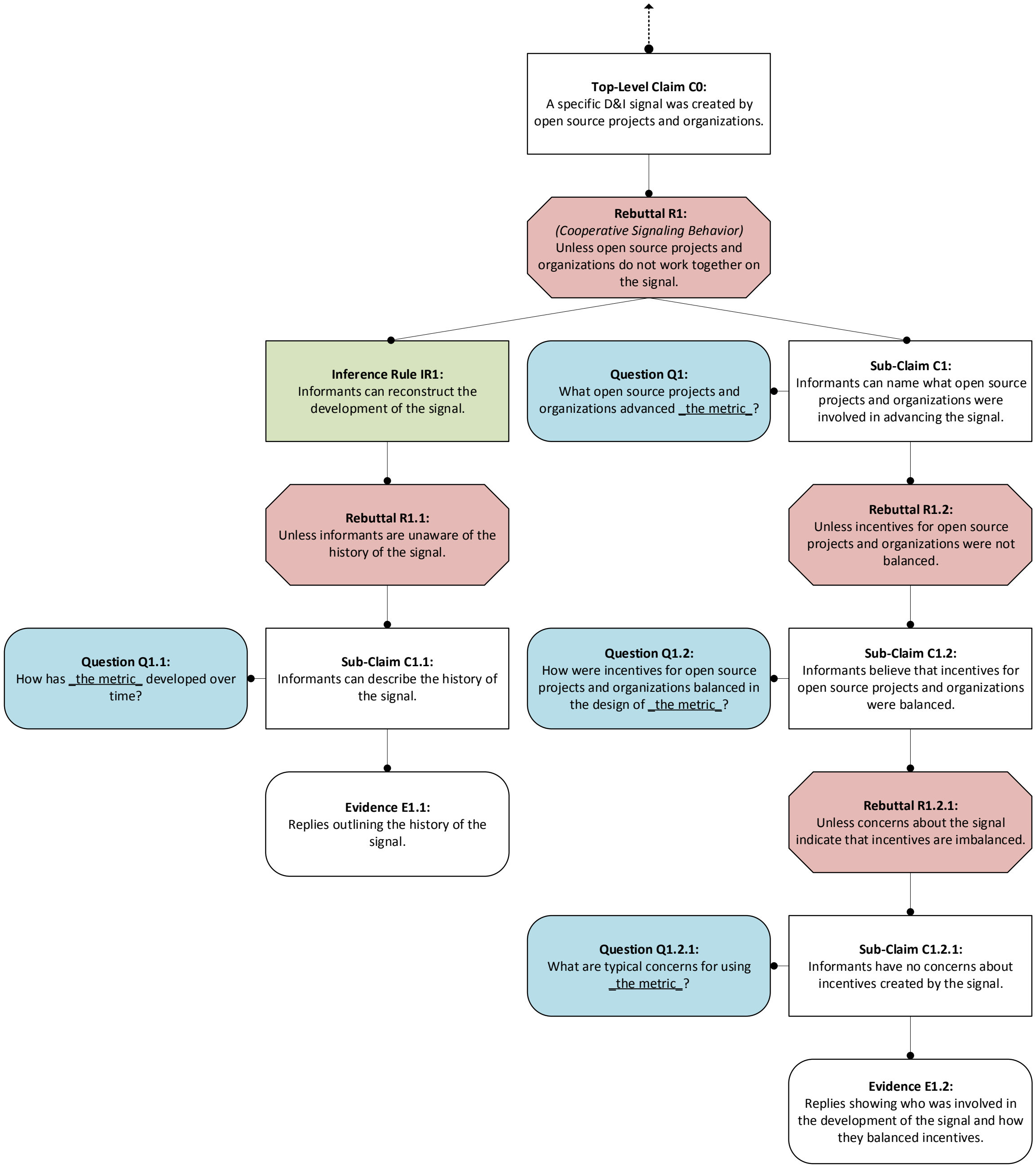
Appendix A: Visual Assurance Case



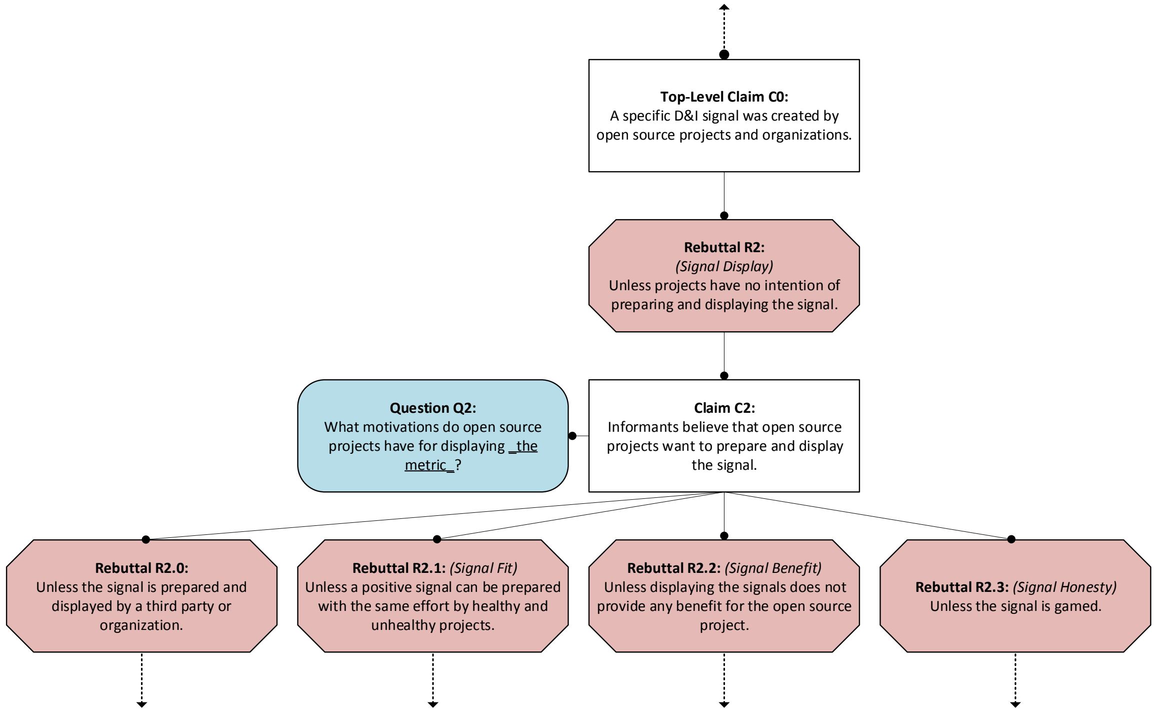
Appendix A: Visual Assurance Case (continued)



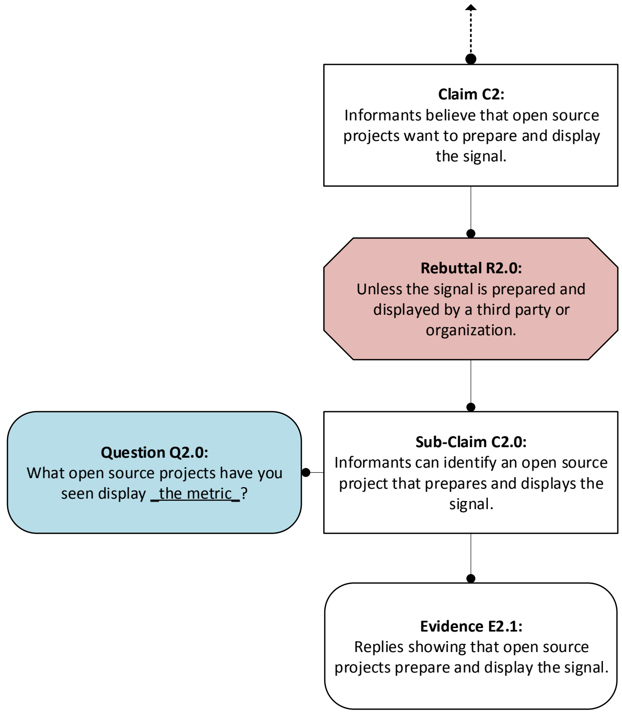
Appendix A: Visual Assurance Case (continued)



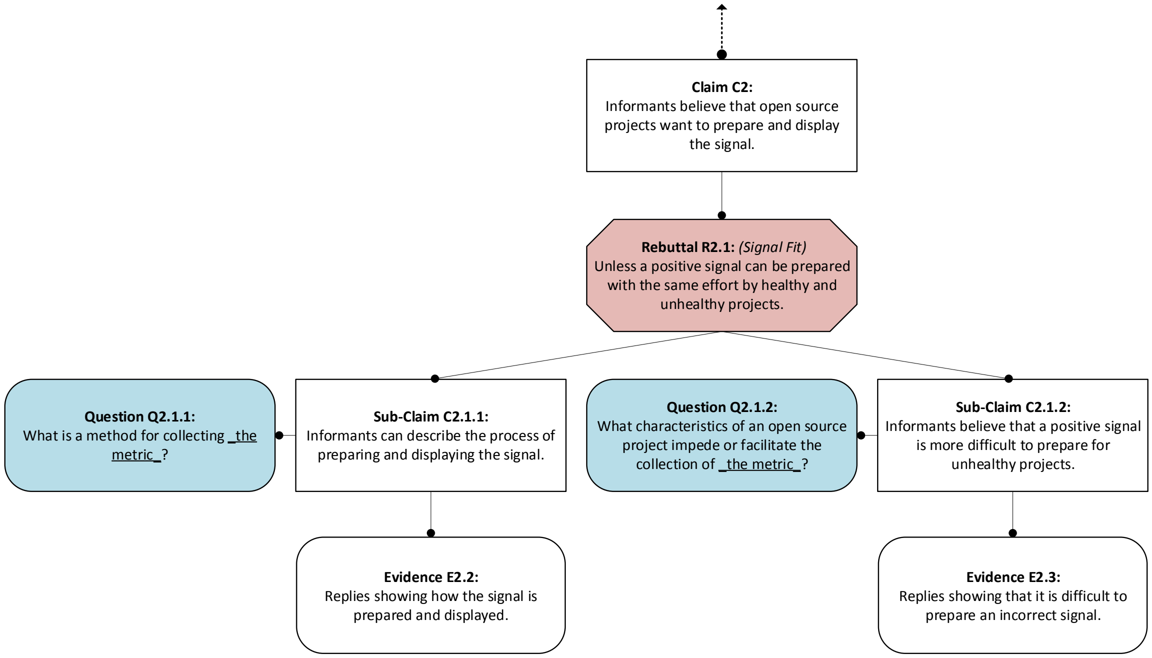
Appendix A: Visual Assurance Case (continued)



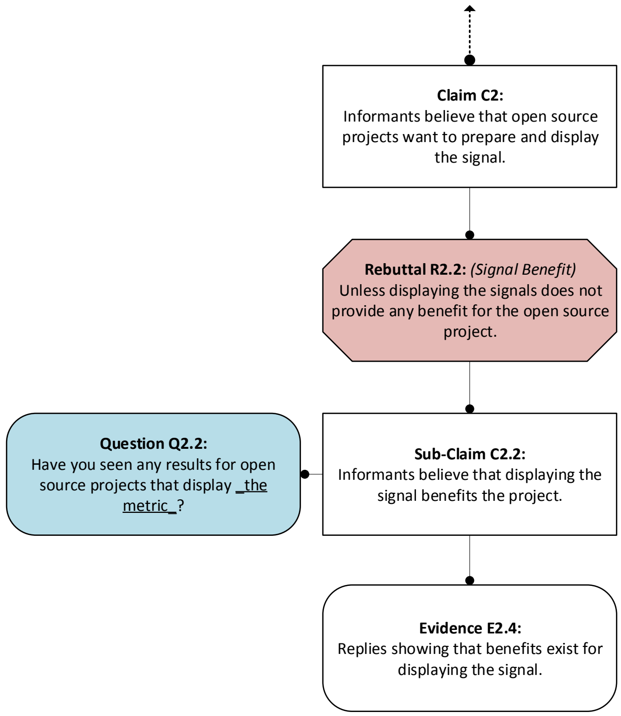
Appendix A: Visual Assurance Case (continued)



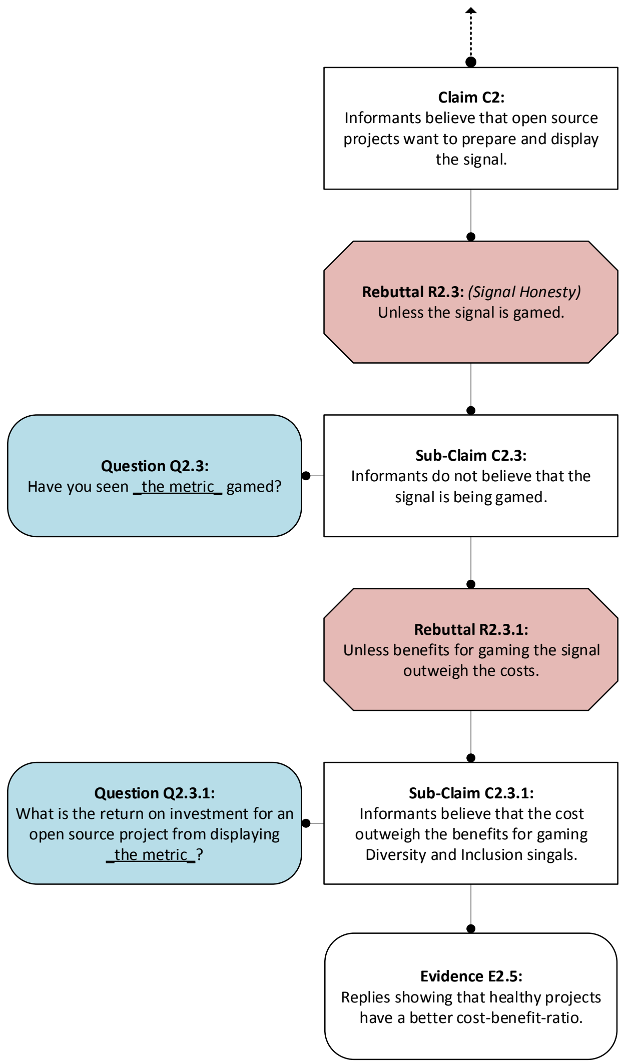
Appendix A: Visual Assurance Case (continued)



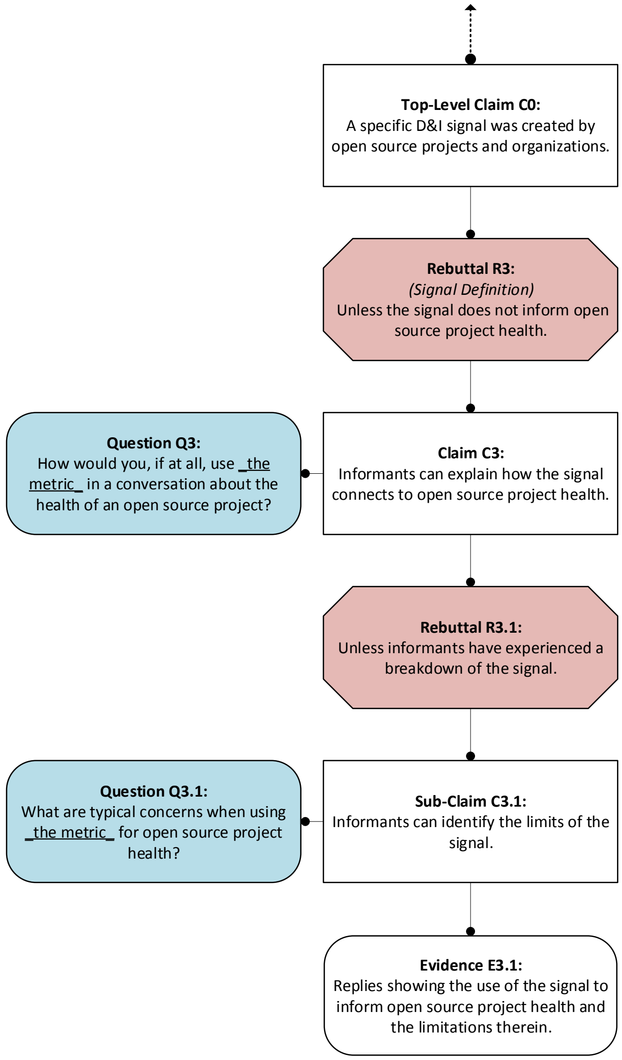
Appendix A: Visual Assurance Case (continued)



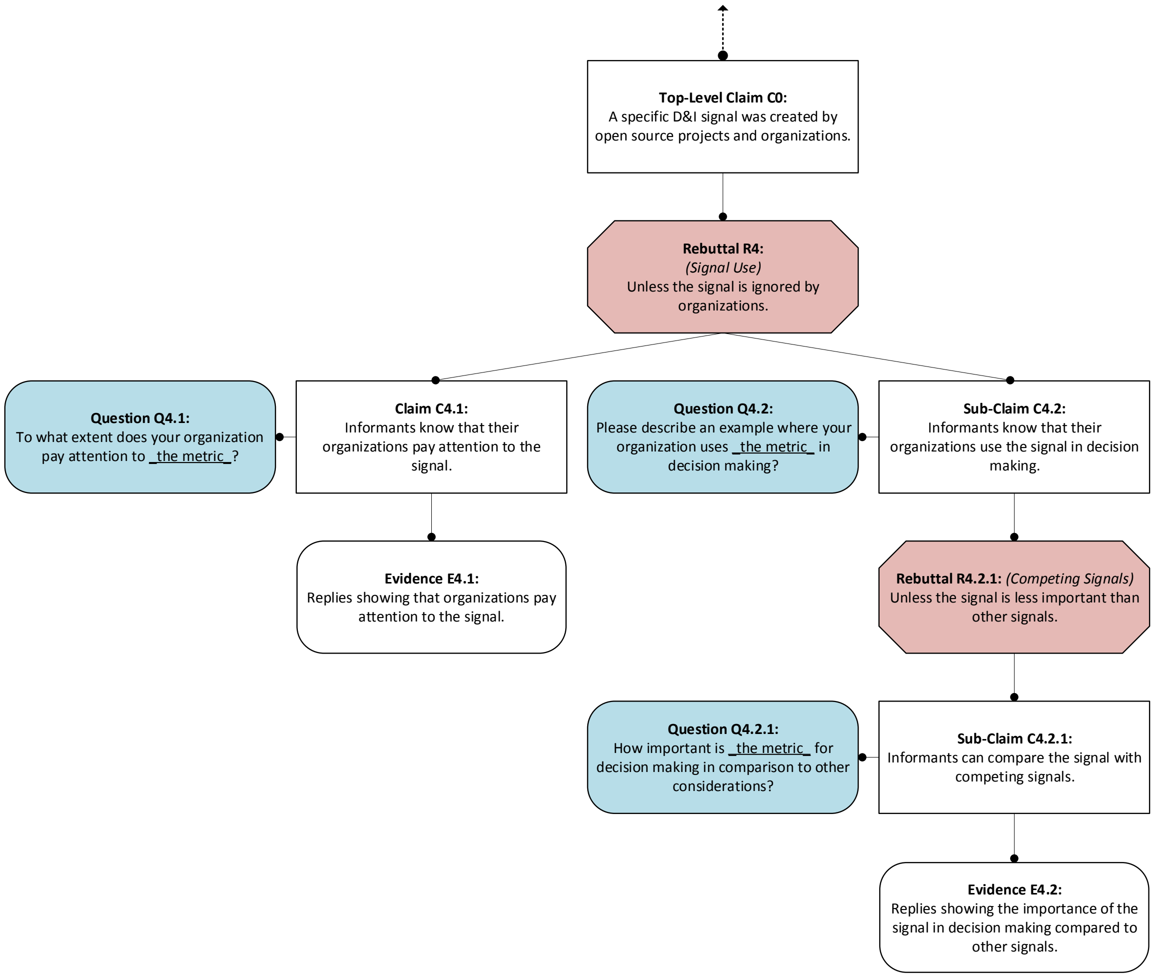
Appendix A: Visual Assurance Case (continued)



Appendix A: Visual Assurance Case (continued)



Appendix A: Visual Assurance Case (continued)



Appendix B: Interview Protocol

	Assurance Case Reference: Interview Question (IRB #: 693-18-EX)
Intro: Getting to know the informant – understanding the context.	
Context	**Q0.2:** Tell me about yourself? What organizations and open source projects are you affiliated with?
Experience	**Q0.1:** What is your experience with diversity and inclusion in open source?
Interest	**Q0.1.1.1:** What is your personal interest in diversity and inclusion in open source? (What are you paying attention to?)
Use	**Q0.1.1.2:** Have you been involved in a diversity and inclusion effort within an open source project? (If yes: How has this changed your perspective of D&I in OSS?)
Metrics	**Q-tc:** Walk me through a typical diversity and inclusion metric conversation? (Who is involved? What do they talk about? Why do they talk about it?)
Start Study: Focus on one signal [Share screen with the metric name on it to keep participant on track]	
Focus	**Q0:** I would like to focus our interview on a specific metric. Which diversity and inclusion _metric_ would you like to focus on? (Maybe one you are most familiar with?)
Signals: Metric as signal of open source project health	
Health indicator	**Q3:** How would you use _the metric_ in a conversation about the health of an open source project?
Limitation	**Q3.1:** What are typical concerns when using _the metric_ for open source project health?
Signal Display (more questions, because it may inform CHAOSS D&I Working Group resource pages)	
Who displays	**Q2.0:** What open source projects have you seen display _the metric_?
Gaming	**Q2.3:** Have you seen _the metric_ gamed?
Process	**Q2.1.1:** What is a method for collecting _the metric_?
Health correlation	**Q2.1.2:** What characteristics of an open source project impede or facilitate the collection of the metric? (Is it harder for an unhealthy project to prepare a good-looking metric?)
OSS motivations	**Q2:** What motivations do open source projects have for displaying _the metric_? What impact would a project have to expect when starting to display _the metric_?
OSS benefits	**Q2.2:** Have you seen any results for open source projects that display _the metric_? (Any benefits?)
Effort / benefit	**Q2.3.1:** What is the return on investment for an open source project from displaying _the metric_? (Long-term backlash if falsely displayed?)
Signal Use	
Attention	**Q4.1:** To what extent does your organization pay attention to _the metric_?
Use	**Q4.2:** Please describe an example where your organization uses _the metric_ in decision making?
Importance	**Q4.2.1:** How important is _the metric_ for decision making in comparison to other considerations? (What are those other influences or metrics?)
Cooperative Signaling Behavior (who all was involved in the creation of this metric, what was its evolution, who suggested it, who adopted it … ?)	
History	**Q1.1:** How has _the metric_ developed over time? Where did it start? How has it changed?
Who cooperated	**Q1:** What open source projects and organizations advanced _the metric_? (Can you describe how they helped shaped _the metric_? What was your involvement?)
Helping each other	**Q1.2:** How were incentives for open source projects and organizations balanced in the design of _the metric_?
Imbalance	**Q1.2.1:** What are typical concerns for using _the metric_? What misaligned incentives might _the metric_ create?

Was there a question you were waiting for that I didn't ask? Did I miss something? Any last thoughts?