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RESEARCH ARTICLE

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Tapestries of Innovation: Structures of Contemporary Open Source Project Engagements

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Abstract

Since the origins of the free-software movement, open source projects have fostered an environment for innovative ideas that has transformed much of our understanding of technology in everyday life. In our quest to learn more about the structures of large-scale contemporary open source engagements, we examine three open source networks as part of an ongoing field study (Van Maanen, 2011). We explore the innovation networks described by Lyytinen, Yoo, & Boland (2016) and resolve whether any of the open source innovative networks that we have been studying can be classified as Project, Clan, Federated, or Anarchic networks. We examine two collaborative open source projects (SPDX and OpenMAMA) housed at the Linux Foundation, and determine that they correspond to the Federated and Project innovation networks respectively. Further, we determined that the Linux Foundation itself, as an organization that houses numerous open source projects, did not fit any of the four types of networks. We therefore propose and authenticate a fifth type of network that we characterize as a Tapestry innovation network, which can illuminate the Linux Foundation's complexity of horizontal "weft threads" of participating organizations with the vertical, less visible "warp threads" of responsibilities and endeavors. Our study reveals important implications for research and practice by challenging the accepted view of open source projects, which still largely regards engagement around loosely structured groups of volunteers working on publicly available software. It also reveals that foundations are playing increasingly strategic roles in creating and stabilizing open source projects.

Keywords: Networks of Innovation, Project Innovation, Federated Innovation, Open Innovation, Open Source Projects, Tapestries Innovation Network, Field Study, Linux Foundation

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1 Introduction

Open source projects are software development projects with the following three characteristics: (1) the software being developed is communally constructed and redistributable to anyone; (2) the project's source code is freely available to be improved or modified; (3) the distribution of the project's software or source code is accompanied by a license that determines the rights and obligations associated with the software (O'Reilly, 2004; Crowston et al., 2007). Such projects have long functioned a test bed for innovative software products, as well as the innovative social practices around them (Tuomi, 2002). The prime example is Linux; born from Linus Torvalds' desire to produce a no-cost kernel that could utilize the functions of 80386 processors (Torvalds & Diamond, 2001), Linux gave rise to an informal, self-organizing network, that, for many years, was managed by Torvalds from a single email account. This method of management, however, changed drastically with the rise of the internet and the advent of internet-enabled software versioning repositories. These two innovations changed the way the Linux project was managed, as they changed Torvalds' ability to act as a single point of control, but they also fostered a greater diversity of project participants (Daniel, Agarwal, & Stewart, 2013; Benkler, 2002).

The aforementioned innovations led to Torvalds' second major technological contribution: The Git version control system. After nearly 15 years of observing how the network of an open source project functioned, Torvalds codeveloped Git, along with Junio Hamano and others, to better reflect the social practices of software developers in distributed open source environments. Prior to Git (roughly before 2005), version control systems were "linear." Issues were worked on by a single developer who checked out a code file and once the issue was purportedly fixed, the code was checked in, and tests were run to confirm the fix. In contrast, Git was developed to be nonlinear and distributed. It supports rapid branching and merging and provides each developer with a local copy of the repository with full development history, where changes are copied from one such repository to another. Today, Git has been adopted by many projects other than Linux. It is used to maintain over 100 million code repositories (GitHub, 2019) and the social coding practices enabled by Git have radically changed the way that open source software is developed (Dabbish et al., 2012).

Linux and Git are impressive examples of how innovation networks influence technologies and vice versa. We base our understanding of innovation networks and frame this paper according to the following definition: innovation networks are loosely coupled arrangements of interconnected individuals and firms, where loose coupling is a situation in which elements are responsive but retain evidence of separateness and identity while being linked and preserving some degree of determinacy (Rehm & Goel, 2017; Lyytinen, Yoo, & Boland, 2016; Weick, 1995). Again, the rise of Git provides a unifying example—an innovation network of open source software development that gave rise to a new type of organizing (Puranam et al., 2014). Thus, Git changed the way software developers in projects other than Linux perform their work (Mergel, 2015; Dabbish et al., 2012).

Researchers in information systems (IS) are just coming to understand this new type of organizing through innovation networks; in particular, the different structures of innovation networks that exist, and the technologies they generate (Rehm, Goel, & Junglas, 2017; Rehm & Goel, 2017). We contend that further exploration of innovation network structures is warranted so that we, as researchers in IS, can deepen our understanding of the innovation network structures that give rise to technologies in a diversity of social computing contexts. Accordingly, we apply the innovation networks frame to deepen our understanding of these contexts.

This article details our study of three different innovation networks. We explore two open source projects under the auspices of the Linux Foundation, the Software Package Data Exchange (SPDX), and the Open Messaging Agnostic Middleware API (OpenMAMA) and perform an exploration of the Linux Foundation itself. Moreover, we find that the Linux Foundation represents a new type of innovation network that, in response to the increasingly strategic nature of open source projects, brings together traditionally disparate projects under larger motivations to regularize the integration of open source projects (Linux Foundation, 2016).

In addition to identifying a new type of innovation network, our study sheds new light on the accepted view of open source. Open source projects are traditionally seen as consisting principally of volunteers that do not seek financial remuneration from their work (Chesbrough, 2003, Chesbrough, 2013), where the perception of individual rewards exceed those of process-related costs (von Hippel & von Krogh, 2003) and the projects consist of homogeneous "clans" of actors driven by a common interest using well-defined toolsets (Lyytinen et al., 2016). In contrast, our study details open source communities as developers of technology that support heterogeneous lines of business in which volunteers act as proxies for corporations that drive the strategic direction of the project. Based on this, our study was guided by the following research question: *How can open source projects be understood as more than volunteer-driven, clan communities through the lens of innovation networks?*

Section 2 delineates our innovation network analytical frame and theoretical structure. Section 3 describes the methods we used to explore the above research question. Section 4 tells the story of SPDX and OpenMAMA through our analytical frame. Section 5 explicates a new type of innovation network, a Tapestry innovation network, based on our exploration of the Linux Foundation. Section 6 discusses our collective findings and what this means for both innovation networks and open source in IS research. Section 7 concludes the article.

2 Theory on Innovation Networks

Innovation networks are rooted in network theory (Ahuja & Carley, 1999), which analyzes the relationships between nodes on a graph on which attributes can be assigned to both nodes and edges for analysis. As network theory made its way into the behavioral sciences to study innovation, it served to shift analysis from actor-centric to analysis centered on momentum, sequences, turning points, and path dependencies.

Research on innovation networks emphasizes how these networks expand, how knowledge transfers between nodes, how networks evolve over time relative to actors, and how an organization's location in a network is indicative of institutional status (Uzzi and Spiro, 2005; Powell et al., 2005). Powell et al. (2005) elucidate this relationship. In investigating the expansion of innovation networks in the field of biotechnology, they suggest four hypotheses that engender network expansion: (1) *accumulative advantage*, where the "rich get richer" because the most connected nodes receive a disproportionate share of new linkages; (2) *homophily*, where partners are chosen based on similarity to previous linkages; (3) *follow the trend*, where linkages are formed through "herd-like" behavior as choices are matched based on the dominant choices of others; and (4) *multiconnectivity*, where linkages are formed through multiple, independent paths to increase reachability and diversity. Interestingly, their study found the most support for multiconnectivity, highlighting the power of multiple linkage pathways—both directly and through chains of intermediaries—offering contrast to the "rich-get-richer" view. In another example, Uzzi and Spiro (2005) investigated the Small World network of the creative artists who made Broadway musicals from 1945 to 1989. They found that Small World network effects were parabolic—performance increased up to a threshold after which point the positive effects reversed. In yet another example, Hansen (1999) investigated innovation network linkages and found that strong linkages are needed to transfer complex knowledge (e.g., linkages that share many in-common attributes), and without them, network expansion can be challenging. Further, Powell, Koput, & Smith-Doerr (1996) found that development alliances, management experience, and portfolios of collaborative activities create a locus of innovation around organizational learning.

Innovation networks also inform IS research. IS research on innovation networks emerges from three key areas: (1) social network analysis at the individual and organizational levels on topics such as IS use, highlighting the conceptual and technological change in innovation networks (Oinas-Kukkonen, 2013); (2) new innovation processes, and the knowledge creation and knowledge transfer that occurs through the IT that engenders new ideas (Swanson & Ramiller, 1997); and (3) digitalization research that investigates topics such as digital transformation, digital business strategies, digital infrastructures, and digital innovation (Lee & Berente, 2012). Researchers in each of these areas have discussed innovation networks, but not until recently have innovation networks been given theoretical and empirical attention as mechanisms to understand the attributes and classes of networks that support the innovation across different contexts (Lyytinen et al., 2016).

Of note are recent theoretical and empirical advances in IS research that articulate networks of digital innovation (Goel et al., 2017; Lyytinen et al., 2016). These advances have been accomplished by bridging social networks (Oinas-Kukkonen, Lyytinen, & Yoo, 2010), innovation (Whelan et al., 2014; Berente et al., 2011), and digitalization (Yoo et al., 2012). In these advancements, research details the embedding of digital technologies in innovation networks to better understand generativity (Yoo et al., 2012), digital infrastructures (Tilson, Lyytinen, K., & Sørensen, 2010), product architectures (Yoo, Lyytinen, & Yang, 2005), and innovation ecosystems (Nambisan, 2013). Based on this work, we are coming to understand that digital technologies increase innovation network connectivity, which thereby increases reach and scope, and that these advances can increase the speed of digital convergence, the capacity for learning in the network, the resources in the network (e.g., people and technologies), and the integration of networks and the digital products they collectively produce.

Building on these advances, there is much to be learned about the structure of innovation networks (Lyytinen et al., 2016). In particular, there is still much to learn about the resources that give rise to innovation networks, the mechanisms of control that reinforce the linkages that occur within them, the shared innovations that are likely to coincide with different types of networks, and the way that resources are translated throughout a network. Moreover, there is much to learn about the "ideal types" of innovation networks that exist (Lyytinen et al., 2016, p. 57). Thus, to better articulate structures of innovation networks, and develop an understanding of new types of innovation networks, we base our analytic frame on the theoretically informed innovation network characteristics specified in Lyytinen et al. (2016, pg. 59)—*heterogeneity of resources and control via resources*. Accordingly, these characteristics are understood in relation to each other to characterize four types of innovation networks (Lyytinen et al., 2016, pg. 59): Project, Clan, Federated, and Anarchic (Figure 1).

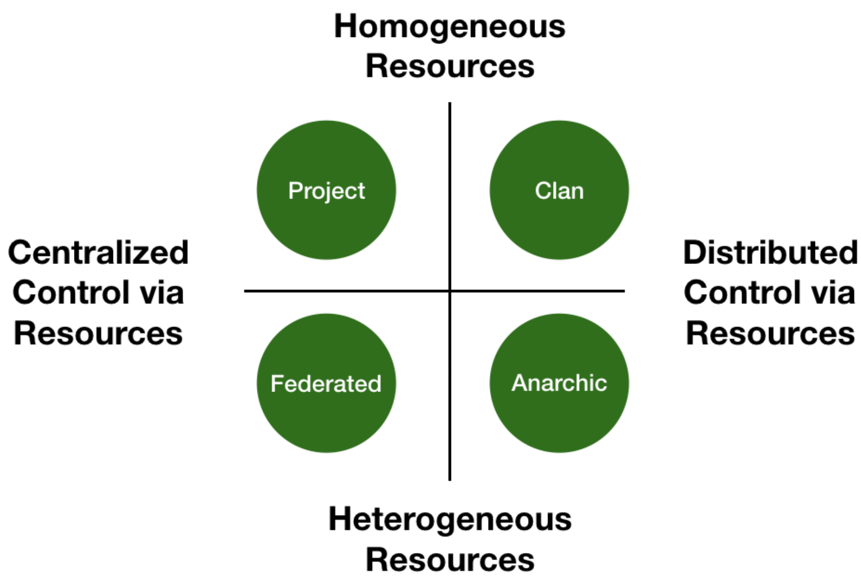

Figure 1. Four Innovation Types of Project, Clan, Federated, and Anarchic as identified by Lyytinen et al., 2016

2.1 Heterogeneity of Resources

With respect to innovation networks, heterogeneity is embodied by the variety in knowledge creation and resources shaping the community's existence and generative capacity (Lyytinen et al., 2016; Puranam et al., 2014). In innovation networks, the understanding of resource heterogeneity is based on how diverse resources are identified, shared, brokered, and assimilated to motivate innovation. According to Lyytinen et al. (2016), resources can be relatively homogeneous, comprised of sources with similar backgrounds and beliefs, or heterogeneous, where diverse sources of knowledge may be exchanged in "trading zones" (Lyytinen et al., 2016; Kellogg, Orlikowski, & Yates, 2006).

While there is no explicit set of scale dichotomies to define heterogeneity of resources (Lyytinen et al., 2016; Andersson et al., 2008), heterogeneity has come to represent the variety of IT components (e.g., embedded, mobile, stationary) (Andersson et al., 2008) and knowledge from diverse social settings (Galison, 1997; Lyytinen et al., 2016).

2.2 Control via Resources

Innovation networks are embodied by the people and digital structures that control the resources of the innovation network (Lyytinen et al., 2016). Control is inextricably linked to institutional facets, namely the prevalence to which regulative guidelines exist and are enforced, the strength of working norms, and the cognitive frames through which the innovation network is viewed (Scott, 2014; Barley & Tolbert, 1997). Further, these forms of control are what reify social constructions and manifest incompatibilities between structure and activity (Scott, 2014). It is in this sense that structure and activity come at a cost, resulting in tensions that reshape consciousness, void old social interactions, create new social interactions, and define new pathways aimed at evolving the control structure itself (Seo & Creed, 2002).

Similar to the heterogeneity of resources, control is not explicitly defined through a set of scales but represents who controls the resources and knowledge of the innovation network. At one end of the continuum, with innovations created in a vertically integrated firm, we see a centralized control over actors and resources. Here, the vertically integrated firm has sole ownership over the results through patents, trademarks or trade secrets. Typically, this is a top-down process that is envisioned and launched by managers using a dedicated research and development function. On the other extreme, we see minimal formal control over innovation actors and resources during the innovation process and little control over innovation processes and ownership rights. The innovation emerges as a decentralized community or "bazaar" without a formal hierarchy over its participants and outcomes (Lyytinen et al., 2016, pg. 58).

From heterogeneity and control, innovation networks come to house "generative process[es] whereby innovation knowledge is identified, produced, refined, integrated and evaluated partially through digital means in its movement towards an innovation 'closure' of being stabilized into a new product" (Lyytinen et al., 2016, pg. 55). As such, innovation networks accommodate variable social and cognitive *translations* in the ultimate production of *innovation* artifacts.

2.3 Translations and Innovations

Generativity in innovation networks is manifest in the translations that reify ideas (Carlo, Lyytinen, & Boland, 2012; Yoo, Boland, & Lyytinen, 2006). Translations can capture abstract knowledge through the production of artifacts or evolve artifacts through negotiation, sense-making, and sense-giving (Verganti, 2013; Gal and Berente, 2008). Translations are processes in which innovation knowledge is identified, produced, refined, integrated, and tested through digital means. Further, as digitization increases, so too does the range, accuracy, speed, and scope of translations (Lyytinen et al., 2016; Yoo et al., 2006). As a result, the complexities of translations are not performed in a linear progression but as iterative, fractal, and messy processes marked by ebbs and flows of knowledge, surprises, and disappointments (Boland et al., 2007).

In terms of generative processes, innovation outcomes represent the social and technological outcomes of innovation networks (Lyytinen et al., 2016; Kelty, 2013). Innovation outcomes are the artifacts that either describe a technology through code, an architectural blueprint for hardware or software, or descriptions of innovation network processes. Innovations can be resources as tools or components that act as enablers for innovation or triggering resources that lead to new innovations, innovative processes, or associated organizational routines and mechanisms (Nambisan, 2013). It is key to recognize that an innovation can further act as an enabler or a trigger through its generativity and ability to drive innovative organizational arrangements, processes, and products (Boland, Lyytinen, & Yoo, 2007; Faraj, Jarvenpaa, & Majchrzak, 2011). Table 1 summarizes the innovation network characteristics as understood in our study.

In using these characteristics as an analytic frame, particularly heterogeneity and control as identified by Lyytinen et al. (2016), our study revealed the capacity to understand newly emerging forms of corporate-communal open source projects, helping us answer the question of how engagements by diverse groups of participants (individual, firm, and foundation) in open source projects align with various innovation network types and even produce new structures of innovation networks. To do so, we will first discuss the methods we used to explore three different open source projects/settings, and following this, the findings from our investigation.

Table 1. Innovation Network Characteristics from Lyytinen et al., 2016

Key items	Characteristics	Studies that expand the idea of each network characteristic
Heterogeneity of resources	• Resources that motivate the network to develop innovations • Member interests and diversity of resources evolved throughout the innovation process	Cecez-Kecmanovic et al., 2014 Puranam et al., 2014 Uzzi & Spiro, 2005 Yoo et al., 2005 Carlile, 2002
Control via resources	• Organizational forms leading to centralized or distributed forms of control • Roles of people, prevalent social norms, cognitive framing of the community, and the culture of the community	Homscheid, Schaarschmidt, & Staab, 2016 Scott, 2014 Chesbrough & Appleyard, 2007 Fitzgerald, 2006 von Hippel & von Krogh, 2003
Translations	• Capture abstract knowledge through the production of artifacts via negotiation, sense-making, and sense-giving • Freedom of actors to generate, circulate, and proliferate ideas throughout a project	Kelty, 2013 Verganti, 2013 Gal & Berente, 2008 Kelty, 2008 Taylor, 2004
Innovation	• Form of the innovation outcomes that have modularity and architectural detail in design and related processes • Processes and outcomes as enablers or triggers for innovation	Kallinikos, Aaltonen, & Marton, 2013 Nambisan, 2013 Yoo et al., 2012 Faraj et al., 2011 Tuomi, 2002

3 Method: Determining Open Source Projects as Innovation Networks

Our investigation of innovation networks is based on a four-year participant-observation field study with the Linux Foundation as well as projects at the Linux Foundation, where direct engagement in open-source communities, interviews, and focus groups served as primary sources of data. Participant-observation was purposefully undertaken because it provided us with a ground-level view of contemporary open source projects (von Hippel, 2001). We used participant observation as a distinctly different research approach from other forms of field study where there is interaction between researcher and practitioner (Spradley, 2016; Van Maanen, 1979). Research approaches such as action research, participatory action research, and action design research put the research process at center stage, bringing together action and reflection, theory and practice, in participation with practitioners to develop practical solutions (Sein, et al., 2011; Brydon-Miller, Greenwood, & Maguire, 2003). As an alternative, participant-observation puts the culture at center stage to understand an organization, community, or project, where not enough is yet known about it to identify problems or form hypotheses, variables, artifacts, or other forms of solution-oriented abstractions (Gold, 1958). Participant-observation is useful in preceding these abstractions, requiring the researcher to "grasp the native's point of view" (Malinowski, 1922, p. 25). Participant-observation enabled us to engage in a disciplined study of what the world is like to people who see, hear, speak, think, and act so that we could learn from people in an effort to understand their setting (Kendall & Kendall, 1984; Spradley, 2016).

Grasping the native's point of view, in Malinowski's words, can sometimes require researchers to have or acquire skill sets necessary to gather data by participating in the daily life of the group or organization one seeks to understand (Becker, 1958). For example, Becker (1958) studied pedagogy at medical schools by attending a school's first two years of classes. In another example, Hayano (1982) became a professional card player to study the world of poker. In yet another example, Sudnow (1978) applied his skill set as a jazz pianist in order to study improvisational conduct.

This too was the case in our research. One of the researchers had a 12-year background as a software engineer using open source technologies, while another had over 10 years of experience as a researcher and member of open source projects. We believe this is essential to understanding the rather technocentric culture of open source projects (von Engelhardt, Freytag, & Schulz, 2013) in order to be a participant in open source projects and a participant in the culture. The sections below illustrate how we went about using our skill sets to specifically engage in two open source projects (SPDX and OpenMAMA) and to engage with the broker of those projects (The Linux Foundation).

3.1 Data Collection

We engaged with SPDX, OpenMAMA, and the Linux Foundation in different capacities. With SPDX, a project to create open source standards and tools that assist in tracking licenses and copyright in open source code, we were complete participants (Spradley, 2016). We were fully revealed as researchers and contributed actively to the project through standards development, tooling, and outreach, including writing a research paper with four of the members of the research team analyzing the governance of the project (Germonprez et al., 2014). However, to offset potential influence associated with our position, we eschewed greater influence in the community by not taking on managerial roles (i.e., technical leads or maintainers) and recused ourselves from conversations related to SPDX strategy. Regarding the OpenMAMA project, a project charged with creating an API to abstract the use of vendor-specific middleware for capital markets, we were participatory observers (Gold, 1958; Spradley, 2016). We were fully revealed as researchers but never directly contributed to the project. Instead, we were active participants through weekly meetings (e.g., participating in the conversations and offering insight) and paper writing with project members. Finally, regarding the Linux Foundation, a nonprofit organization that supports a variety of open source projects, we were complete observers (Spradley, 2016). We were fully revealed as researchers but recused ourselves from interactions that might have caused us to be unduly influenced by the strategic goals of the Linux Foundation. Within each of these projects, we relied on three main methods of engagement to better understand the behaviors, resources, and artifacts associated with them (Spradley, 2016): interviews, focus groups, and direct engagement.

Interviews: The interviews used for this project represent a subset of a larger interview sample aimed at understanding corporate engagement with open source projects in which we relied on 25 interviews. The larger sample includes over 125 interviews with people representing corporations engaged with open source projects—with the vast majority being Linux Foundation projects. The 125 interviews did not all rely on the same protocol, as, at times they were tailored to specific areas of interest. However, the large interview set collectively provided a broad set of data, capturing the large-scale landscape of corporate engagement with open source projects.

Table 2. Summary of Interview Engagement

Interviews	Number of interviews	Primary themes addressed
SPDX	10	Licensing, security, standards, community management
OpenMAMA	5	Intellectual property rights, licensing, messaging middleware, community management
Projects related to SPDX and OpenMAMA	8	Licensing, open source software distribution
Linux Foundation	2	Intellectual property rights, licensing, community management

In the larger sample, our 25 interviews were from 10 different organizations in which interviewees had direct involvement in SPDX and OpenMAMA. Each interview lasted approximately one hour and was transcribed with transcriptions deposited into the project team repository to which all team members had access. In all, the transcribed interviews generated over 250 pages of text. Interviews consisted of members from SPDX (10 interviews), OpenMAMA (5 interviews), members from projects related to SPDX and OpenMAMA (8 interviews), and full-time Linux Foundation employees (2 interviews). The interviews were presented to participants through themes immediately relevant to the interviewees such as licensing, intellectual property rights, and community management. Interviewees were users, developers, and steering committee members from the projects, as well as Linux Foundation members who managed related project areas. Table 2 summarizes our interview engagement.

Using themes relevant to the interviewees, we utilized the interviews to ultimately reveal routines, practices, and structures associated with the open source project in which the interviewee participated. Our questions addressed broad areas of: (1) open source software resources, (2) open source project control, (3) open source project innovation, and (4) open source project translations. The specific questions did not directly ask participants about innovation networks as described by Lyytinen et al. (2016) but addressed the characteristics of resources, control, innovation, and translations. Sample interview questions included:

1. *Resources:* Does participation with [open source projects] require new forms of organizational structure and process management?
2. *Control:* Is corporate participation with [open source projects] driven entirely by a need for the technology or are there other reasons to participate?
3. *Innovation:* What factors do you believe drive a company to utilize [open source artifacts] when building products?
4. *Translations:* What are the critical requirements for being successful as a participant [with an open source project]? What are the challenges?

Focus groups: We ran three separate focus groups at two different organizations. Both organizations, which were listed on the Fortune 1000, directly engaged with open source projects brokered by the Linux Foundation. The focus groups were built around the interview questions and were not specific to SPDX, or OpenMAMA, but were aimed at broadly understanding engagement with open source projects. This helped to build our understanding of contemporary open source projects and develop a broader collection of how open source projects are interrelated. This also developed the communicative capacity of our research team and established rapport with open source project participants. The focus groups ran for a half day and a full day at the organizations. The half-day focus group was performed in one sitting at a Fortune 100 organization with approximately eight participants. The all-day focus group was performed at a Fortune 1000 organization in a morning and afternoon block. In this group, there were approximately 20 participants, thus generating more discussion and justifying the full-day setting. Sample questions used to drive focus group discussions were the same in both cases and included:

1. What value does your organization receive from open source projects?
2. What value do you personally receive from open source projects?
3. What factors do you believe drive a company to utilize open source projects when building products?
4. Based on the model of high and low contributions to open source projects, do you believe that the community favors one of these contribution types from corporate participants?

Direct Engagement: One of the researchers was a participant in the SPDX and OpenMAMA projects. At SPDX, the researcher was involved in project weekly meetings and involved in developing software tools to create, merge, and store SPDX documents. In addition, this researcher served as a mentor for SPDX in the Google Summer of Code program, working with students to develop an online SPDX tool to upload and parse SPDX documents for validation, comparison, and conversion. At OpenMAMA, the researcher was a participant and observer in software development meetings and discussions and provided input and analyses on the details of open source project work. This led to writing a joint paper with two members of the OpenMAMA community and one Linux Foundation member (Germonprez, et al., 2013). Finally, members of the research team attended and presented at multiple large-scale conferences attended by SPDX and OpenMAMA members, such as multiple LinuxCon/OS Summits (2012, 2013, and 2017), multiple Linux Collaboration/Leadership Summit (2013, 2014, 2016, 2017), and the Linux Open Compliance Summit (2013).

Regarding direct engagement with the Linux Foundation, one of the researchers is a founding member and co-director of the board for the Linux Foundation's CHAOSS project. In this role, engagement has included the development of project governance documentation, project board management, community outreach and development, and integration with partner Linux Foundation projects. Engagement has included presentations of project work at MozFest (2018), OS Summit Europe (2018), OS Summit North America (2017, 2018), the Linux Open Compliance Summit (2018), and the Linux Foundation Leadership Summit (2017, 2018). Data in these efforts consisted of researcher field notes, source code, documentation, design artifacts, process artifacts, and meeting notes. Figure 2 summaries our data collection efforts.

As is the case in participant observation, our data collection efforts continually sought to maintain objectivity. In particular, the direct engagement component of the data collection was continually reflected on. All of our data collection efforts were meant to gain understanding of contemporary open source projects, sometimes taking advantage of opportunities to look deeply. We found corporate-communal open source projects can be difficult for non-corporately affiliated members to make strategically influential contributions to. As such, our direct engagement was naturally tempered by our fully disclosed academic standing. Beyond natural tempering, our contributions were aimed at fairly and equitably responding to communally defined needs, whether code contributions or conference presentations, paying particular attention so as not to unnaturally affect the project in the interest of any particular scholarly outcome.

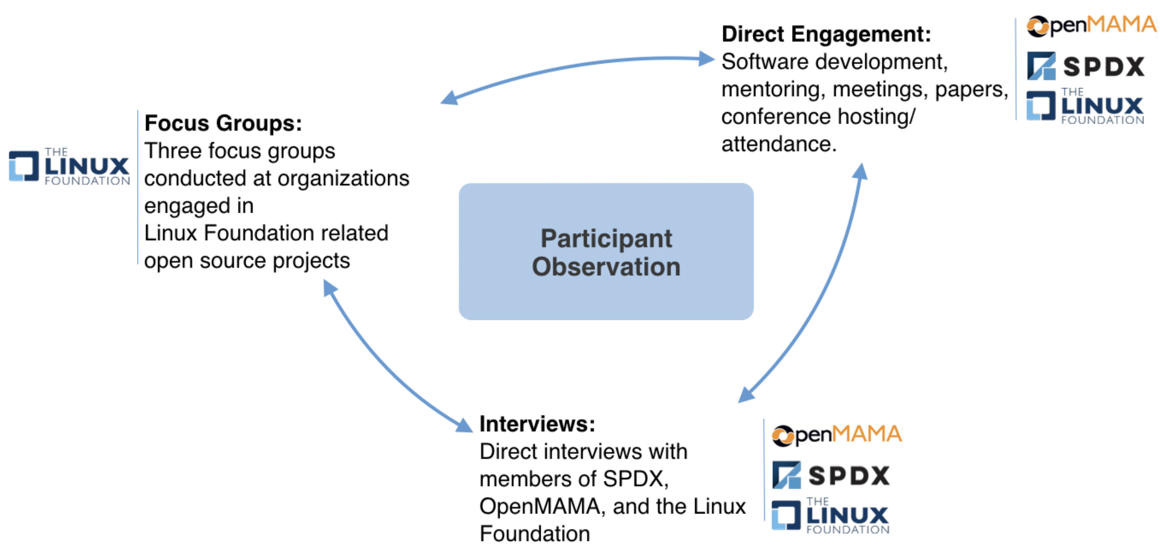

Figure 2. Participant Observation as Methodological Frame for Localized Methods (Chiasson, Germonprez, & Mathiassen, 2009).

3.2 Data Interpretation

To align our data collection and interpretation and maintain objectivity, we framed our approach around the interpretive implements of Kozinets (2015). Thus, our approach followed a process of "interpreting data, rather than analyzing it" such that we did not engage in a set of coding operations. Instead, interpretation of the data relied on invention, argumentation, and concession in parallel with the collection process so that we could "distance ourselves from the familiar, to find something alarming and new" (Kozinets, 2015, pg. 205).

In this regard, data interpretation was hermeneutic, much like Lee's (1994) hermeneutic examination of electronic mail and Boland's (1991) hermeneutic examination of management information. We continuously sought to make each source of data collection better understood in the context of a collective whole (Tesch, 1990), following Lee's (1994) approach of (1) distanciation, (2) autonomization, (3) social construction, (4) appropriation, and (5) enactment. In doing so, we distanced ourselves from the collected data, allowed the data to take a life of its own, derived meaning from the data, considered how the data fit in our knowledge of the world, and produced new meaning from the data. This was undertaken in adhering to the following cycle: data collection through participant-observation fieldwork, data interpretation of fieldwork data, continued fieldwork, continued data interpretation, and so on. This allowed us to progress toward an increasingly complete picture of innovation networks at SPDX, OpenMAMA, and the Linux Foundation. In addition, we continued to reflect on this increasingly complete picture through a constant revisiting of data collection sources, improving validity through data collection artifacts in their original forms (LeCompte & Goetz, 1982).

Hermeneutic interpretation strengthened our understanding of the communities with which we were engaged and allowed us to treat ourselves as an "instrument of knowing" (Dourish, 2004, pg. 3). As participant-observers, we were careful to allow conversations, observations, and engagement to emerge as naturally occurring encounters (Van Maanen, 2011). As events, practices, and routines emerged, we developed and updated field notes as an interpretational tool to revisit our concepts, strengthen our understanding, and establish ourselves as informed data interpreters (Lee, 1994; Neuendorf, 2017). This provided a hermeneutic interpretation of innovation networks that we encountered and allowed us to identify significantly more data than if we went through a more traditional interview-content inference process. Our approach allowed us to strengthen our capacity to build on our reflective experiences, and, as a sense-making experience, to understand the cognitive, social, and technological structures of the network, hence constructing a "system of meaning within which our experience is embedded" (Dourish, 2004, pg. 7).

In sum, data were interpreted along with data collection in a hermeneutic cycle to provide a view of innovation networks rooted in our field experiences, so that "rather than interpreting data as a gestalt shift, we represent it as a synthetic, holistic, and illuminating grasp of meaning" (Kozinets, 2015, pg. 204). Along with similar methodological frames like grounded theory and action research, our participant observation relied on a hermeneutic cycle for data collection and data interpretation as a core strategy for our qualitative inquiry (Denzin & Lincoln, 2008). As an alternative to other qualitative methods, we did not count the presence of any one particular term (Lee, 1994; Rihoux & Ragin, 2008), or rely on the heavy use of coding through tools like NVivo (Creswell & Poth, 2017). Instead, we relied on up-close and personal interactions to associate activities of data collection with concepts we interpreted as collective wholes (Boland, 1991; Lee, 1994; Kozinets, 2015). An overall timeline of our data collection and inference is provided in Figure 3.

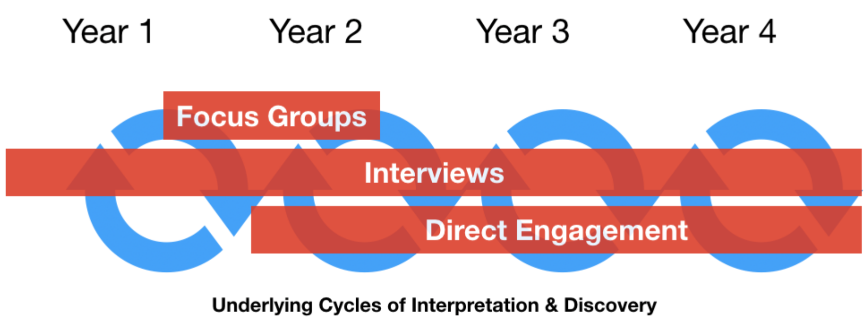

Figure 3. Timeline of Data Collection and Data Interpretation

4 Innovation Networks of Individual Open Source Projects

This section presents the SPDX and OpenMAMA open source projects as individual innovation networks. We expand upon prior work regarding open source projects and networks of innovation, in particular, providing empirical evidence that open source projects can take on a variety of innovation network archetypes (see Lyytinen et al., 2016). In Section 5, we develop the Tapestry innovation network to explain an overarching type of innovation network. Section 5 represents the core theoretical contribution of our research, demonstrating that innovation networks do not necessarily exist in isolation but can be part of a larger collective of innovation networks. In both sections, we present the innovation networks as described through the analytic frame of Lyytinen et al. (2016). We then explicate the *tapestry* as seen at the Linux Foundation—in weaving together individual networks for reasons of pooling shared needs, linking and closing the distance between communities, and creating a cohesive whole of projects within a vast system of open source projects.

4.1 SPDX as a Federated Innovation Network

In 2010, SPDX became a Linux Foundation project. The project aim was to enact a data standard to represent software copyright and license information and facilitate the regulation of licensing compliance analysis when exchanging open source software between organizations. To accomplish this, the community developed a standard for representing licensing information so that it could act as a shared manifest for anyone who downloads and uses a piece of open source software. In practice, the SPDX standard can be used to describe the exact terms under which a piece of software is licensed and the files from which those licenses are determined. SPDX reduces the human intervention in interpreting any potential license conflicts relating to the manner by which a firm distributes software or hardware, which invariably contains a multitude of open source software components.

4.1.1 Heterogeneity of Resources in the SPDX Federated Innovation Network

The SPDX project was started by the corporate counsel, software product release managers, and business managers from companies such as Canonical, Hewlett-Packard, Black Duck Software, Texas Instruments, Samsung, and Wind River (Lovejoy, Odence, & Lamons, 2013). Members envisaged the ability of any party in a software supply chain to communicate licensing information for any piece of copyrightable material used in innovation processes. Members collaborated with the Linux Foundation to create the SPDX open source project with the goal of eliciting knowledge from other areas of industry to develop standards that reduce the legal impediments endemic to software supply chains. As an SPDX community member explained: “So that’s the challenge. We deal with companies that have very, very different views about [licensing]; some are very specific and have very specific policies, and some have less clear policy.”

The knowledge that motivated the SPDX community stemmed from diverse sources with heterogeneous resources seeking to solve common problems—open source software license identification, representation, and exchange. Knowledge evolved through collaboration of legal, business, and technical groups—first within these groups, and then socialized between groups and the larger community to shape the innovation. The evolving SPDX standard was a central focus of the SPDX community, triggering resource exchanges among the legal, business, and technical groups, finding common ground in diverse knowledge and tooling to implement the standard as a peripheral activity through academic, communal, and corporate projects. In the words of an SPDX community member:

> *There’s a lot of open source projects out there that have done—that have documented their licenses in all sorts of different ways and if they're going to adopt the SPDX standard then they need to basically get the licensing in [an SPDX] format.*

4.1.2 Centralized Control in the SPDX Federated Innovation Network

> *Tech Team Report: Versions 2.2 v 3.0 discussion—Still open to input on burning use cases that aren’t covered. Legal Team Report: Uptick in activity on XML review; On the plate now: Lots of chatter on email list about implications of adding “+” operator. Outreach Team Report: We are still working on fleshing out and documenting the program tools that can scan licenses and generate/read SPDX documents.* (archive: SDPX team reports from the monthly general meeting)

Control within the SPDX project was governed by a culture of meritocracy but retained centralization as the legal, technical, and business teams were coordinated through a “core team.” While there was a balance between meritocracy and centralization, there were guidelines that established the responsibilities of team leads in steering the SPDX project and the roles of team leads in making centralized practices the norm for tasks such as agenda setting, project development, tracking and reporting progress, and updating the SPDX wiki. The following quote illustrates a centralized decision made by the SPDX business team. The other teams (legal and technical) also made decisions central to their specific teams. As an SPDX community member and founding member explained: “From an SPDX business team perspective, we might want to identify a few open source projects who might be interested in producing open source package IDs.”

Based on these team decisions, the team leads (legal, technical, and business) integrated their work through a core team that was responsible for reviewing the SPDX file specification, participating in strategic planning, making changes to the governance model, creating and restructuring teams, and responding to specific issues or concerns above and beyond the specific domain of the various teams. Within SPDX teams, there were clearly meritocratic ideals. Promotions to within-team leadership positions were given to those who exhibited qualities such as consistency and quality in maintaining contact with team leads, providing help where needed, playing an active role in online discussions, attending calls, submitting feedback, generating bug reports, resolving bug fixes, and documenting new use cases. Moreover, as many of the decisions within groups were made using lazy consensus (2018), those who expressed opinions were seen as active members of the project. Note that lazy consensus is common in open source projects where the desire is to speed up the pace of development and features are added without additional discussion based on an understanding that development will continue unless there are specific objections voiced. In all, guidelines were explicitly defined for those steering the project, but loosely defined for the decision-making processes within teams. Collectively, this contributed to a hybrid culture that rewarded SPDX project contributions but rejected the idea of fully “giving away” control to community members.

> *The Chairman [of SPDX] leads Core Team meetings and also coordinates and leads General Meetings. Once someone has been appointed Chairman, they remain in that role until they choose to retire, or the Core Team casts a two-thirds majority vote to remove them. The Chairman has no additional authority over other members of the Core Team: the role is one of coordinator and facilitator. The Chairman is expected to ensure that all governance processes are adhered to and has the casting vote when the project fails to reach consensus.* (archive: excerpt from SPDX governance model)

With respect to the SPDX open source project, resources were heterogeneous in contributing to and developing the SPDX specification and control was centralized to the SPDX teams. While these delineations are not perfect (i.e., some knowledge is shared and some control is distributed), investigation of the SPDX project begins to wrestle away the idea that *all* open source projects are built on homogenous resources with distributed control (Lyytinen et al., 2016). We can further represent the SPDX project as a Federated innovation network based on the innovation and translation outcomes.

4.1.3 Translations in the SPDX Federated Innovation Network

> *I just realized my earlier statement may have been ambiguous. When I say "you could reformulate..." what I mean is you could draft a *legally equivalent* statement having the conventional form of a GPLv2 exception. If anyone were to draft such an exception and start using it, it might then be useful to assign an SPDX identifier for it.* (interview: SPDX community member and legal counsel for a large open source company)

Within the SPDX project, translations stemmed from the abstract knowledge of corporate counsel, software product release managers, and business managers who helped originate the project. These members experienced impediments in dealing with their own software supply chains and it was not until the release manager from a major open source operating system began to openly negotiate these issues that ideas of open source compliance management were socialized among a group of industry experts. Soon-to-be SPDX members began to share stories of similar problems and thus began to delineate the details needed to create a viable compliance standard. As more translations were circulated, such as the issues faced when dealing with multiple types of licenses, more issues emerged and began to yield answers that could solve industry-wide problems. The following quote was generated from a discussion among SPDX members across six organizations about specific definitions in the SPDX standard. In this quote, one SPDX member engages in both sense-making and sense-giving in an effort to clarify this issue.

> *See below for a few attempts at some clarifications that are hopefully helpful. It's great you are looking at the SPDX [standard] so closely. I think you might also want to check out some of the documentation around the SPDX License List, as that may help clarify some of your questions (or be an opportunity to help us improve the documentation). I'm not sure*

> *what you are trying to achieve here, but it seems like you may be assuming that license authors are standardized in the way they version their licenses. I can assure you, they are not! We have no choice but to take and record the licenses as we find them - with or without version numbering (and sometimes with version numbering that is not necessarily sequential.)* (archive: SPDX founding member)

Translations were additionally made when SPDX standard drafts were committed to a shared repository that showed how licenses for software packages and package files were going to be codified. Members from different corporations participated and continue to participate in the translation process to evolve the standard for the well-being of open source broadly, as well as their own company's interests locally. Thus, translations originated cognitively from those who proposed ideas through the evolution of the standard and were shared broadly using cues from the community members to allow for the review of ideas.

4.1.4 Innovation in the SPDX Federated Innovation Network

> *[We're open] to anything that we think drives open source adoption in a way that is meaningful to the enterprise and also fits our business model. We have innovated from the beginning—open sourcing a [license] discovery tool.* (interview: SPDX community member and executive at open source license tooling vendor)

A key charge of the SPDX project was to produce a standard for describing open source software package licenses. The standard was articulated through XML or TAG formats so that tooling can handle SPDX documents to identify appropriate licensing, recognition, and product-use strategies. For example, in 2017, Samsung's mobile phone line transitioned to the open source Tizen operating system which uses the GNU Public License v2 (GPLv2). In the case of Samsung, it not only uses Tizen, but hundreds of other open source products with a multitude of licenses that require some reconciliation before distribution to avoid legal ramifications. SPDX provides clarity in this reconciliation process as it standardizes the time-consuming legal processes by digitizing human intervention and removing impediments with license identification. The SPDX standard was originally focused on software package and file license information. However, SPDX has expanded to allow for multidocument comparisons and heuristics generation to expedite decision-making for end-product licensing. What began as an enabler for innovation had since triggered a complementary software compliance program at the Linux Foundation and participating organizations that sought to shape software supply-chain decision-making and thereby become an indispensable guide to corporate counsel. A summary of SPDX as a Federated innovation network is provided in Table 3.

Table 3. SPDX as a Federated Innovation Network

Federated innovation network characteristics	Evidence in the SPDX project
Heterogeneous resources	• Heterogeneous as originating from corporate counsel, software product release managers, and business managers • Evolved through collaboration-driven standards development
Centralized control	• Hybrid centralized and meritocratic culture with emphasis on central teams • Rules for steering the project, loosely defined for within-group decision-making
Translations	• Dialectic translations in pursuing shared license complications • Emergent translations for SPDX standard feature review
Innovation	• Resources for removing supply chain impediments in software ecosystems • Resources triggering compliance initiatives across software ecosystems

4.2 OpenMAMA as a Project Innovation Network

OpenMAMA began as a Linux Foundation project in 2011. The goal of OpenMAMA is to act as an application programming interface (API) to abstract the use of vendor-specific middleware for the capital markets industry. The software was originally the proprietary MAMA middleware that was maintained by the IT division of the New York Stock Exchange-Euronext (NYSE Technologies). The technology was strategically moved by NYSE Technologies to an open source community, as it was envisaged that an open source community might accelerate innovation and open up new directions for those using the API. NYSE Technologies envisaged MAMA as an advanced platform for data analytics and even further, an open trading platform for use across multiple stock exchanges nationally and internationally. Today OpenMAMA is one of the key communities involved in “replumbing” market data systems, helping end users to innovate, reducing vendor lock-in, and mitigating rising costs for the average consumer (Chambers, 2016).

4.2.1 Homogeneity of Resources in the OpenMAMA Project Innovation Network

> *After suggestions from a steering committee action, I have been looking at various options available with respect to providing OpenMAMA forum functionality. The forum would operate alongside the existing mailing lists and should be accessible and searchable for anyone who wants to avail of its knowledge.* (interview: OpenMAMA community member)

Resources in the OpenMAMA project were influenced by a top-down steering committee. The steering committee consisted of representatives from NYSE Technologies that motivated the open-sourcing of the project, as well as financial firms who had a stake in what features were developed, resulting in largely homogenous resources among stakeholders. Beliefs of what OpenMAMA could provide as an innovation were largely agreed upon by members, as the technology had an active user base prior to becoming an open source project. As an open source project, the majority of resource sharing was with respect to technical implementation details: “Asynchronous Fails—I agree with you that mamaSubscription_processErr() is the correct function to use here. We have used this previously for in-house bridges for the same scenario” (archive: OpenMAMA community member).

From the homogeneity of resources stemming from the current technology, tasking was driven by a majority voting process at the steering committee level and was passed down from the steering committee by a project coordinator responsible for prioritization within the project, thus influencing the evolution of knowledge in the community. Decisions were then passed to a technical steering group that locally delivered prioritization to a set of working groups that form and re-form based on the issue and available expertise on hand. During our investigation, the steering committee was responsible for the following resources: strategy and leadership, composition of voting members, working groups, technical projects, and community funding. Notable was that all members of the technical working groups were working for the same companies as those on the steering committees and also receiving direct remuneration for their efforts in the OpenMAMA project. This made it difficult for nonremunerated volunteers to contribute resources to the project early on. However, since that time, an open source advisory group has been added to represent knowledge from users, nonvoting members, and advocates of the project to the larger open source community. While the OpenMAMA community remained predominately built from early homogeneous resources, the acceptance of more heterogeneous resources appeared to be a trend that may become more important as the project evolves, as indicated by the following archive excerpt:

> *As noted a few weeks ago, we have another OpenMAMA Roadmap discussion coming up later this week, on Thursday 24th in Central London. As before there's a few of the core team going to be floating around and leading the discussions, as well as representation from both the Steering Committee and Advisory Groups, so hopefully a few of you will be able to take the time to pop down and join the discussions.* (archive: OpenMAMA community member and community lead)

4.2.2 Centralized Control in the OpenMAMA Project Innovation Network

> *The OpenMAMA Steering Committee and Advisory Group have spent the past few weeks discussing the roadmap for the project, and have decided that the best thing to do would be to get together in person and have a bit of a face to face chat. The goal is to take a look at the items we think are top priority and start looking at how they can be designed and implemented, and really knock through some of the more challenging discussions up front.* (archive: OpenMAMA community member)

OpenMAMA began with evident forms of centralized control, since it began under the stewardship of NYSE Technologies and several major financial firms. At the time of our investigation, OpenMAMA maintained a critically important steering committee active in guidance, strategic input, and delineation of the project's roadmap (OpenMAMA Governance, 2017). Control acted as a regulative mechanism, flowing from the steering committee and through technical working groups: "We have a small community but a strong steering committee" (interview: OpenMAMA community member).

Moreover, centralized control was normative in how it influenced roles and values in the community. As mentioned, not only were all of the technical working group members we spoke with receiving remuneration for working on the project, but all also worked for firms represented on the steering committee, further inhibiting what we have come to understand as an egalitarian and volunteer culture in open source projects (Lyytinen et al., 2016). In the OpenMAMA project, new feature requests were handed down from a steering committee and a project coordinator and a software maintainer approved all code changes, drove direction of the codebase, scheduled work efforts, and managed criteria for what code would be accepted or rejected. In addition, the project coordinator was responsible for working closely with technical working groups and the quality assurance team in resolving bugs and other quality issues. As reported by one of the OpenMAMA community members and community founder:

> *One of the parts of our governance structure is that from the technical side around most of the endeavors, we form working groups, and these working groups will be tasked with actually exploring functionality and features and implementing them.*

4.2.3 Translations in the OpenMAMA Project Innovation Network

> *We will be discussing on a technical committee call tomorrow whether or not it's OK to break backwards compatibility. Depending on the outcome of that, we may be sending around a note to this list offering an opportunity for other members of the community to object before pulling the trigger on this.* (archive: OpenMAMA community member)

Translations traversed a path through the steering committee, the project coordinator, the software maintainer, technical committees, and technical working groups. Within the steering committee, there were processes that provided equal voting rights and forums to socialize ideas before they were passed along this path. One example was the need to support Apache Qpid-reliant messages. The motivation stemmed from members of the steering committee expressing the need for data from companies that were utilizing Qpid. Once they voted to implement this feature, the idea was standardized and passed through the OpenMAMA project hierarchy to a technical working group, which made the decision to both develop a solution for Qpid and also an architecture to easily add new middleware in the future. Translations took place among technical members and the software maintainer regarding how to best meet the requirement and easily add new middleware in the future. This consistently linear translation pathway was representative of a linear flow from the steering committee through technical working groups in realizing new directions for the project. However, once it left the technical working groups, the path was non-linear in how it enabled and triggered translations throughout the community.

4.2.4 Innovation in the OpenMAMA Project Innovation Network

> *In my mind, transport and payload are orthogonal. Seems to me the abstraction is incomplete without the separation. For the purpose of reuse of the OpenMAMA API and bridges, separation is very powerful. [It] enables the integration of commercial off-the-shelf and in-house bridges I suppose this hasn't been done already because of lacking business need. In my opinion, people should be able to reuse the bridges and be able to mix and match according to need.* (archive: OpenMAMA community member)

Innovation within the OpenMAMA project originated from the desire to increase modularity in a messaging stack that enabled banks and hedge funds to distribute market data through their ticker plants regardless of the underlying middleware. OpenMAMA is actually modular, composed of two technologies: (1) the OpenMAMA technology that acts as an abstraction layer to middleware technologies such as Informatica LBM, Tibco, Rendezvous, or IBM WebsphereMQ, and (2) OpenMAMDA, the Open Messaging Agnostic Market Data API that contains the information standards specific to financial data bridges for each data source. The capital markets industry needed innovation that would abstract the details of vendor-specific technology and serve their low-latency, high-throughput needs.

The OpenMAMA project provided a level of modularity by adding an abstraction layer to vendor-specific message-oriented middleware applications and enabled the ability to easily plug in new data feeds through bridges and facilitate the use of a common, easy-to-use protocol to access a multitude of these feeds. OpenMAMA technology combines these data feeds to glean new insight and even to serve as an open platform for trading across multiple exchanges. In the OpenMAMA project, innovation is manifest from the design of these complementary technologies—one of which is little more than an abstraction layer for the messaging protocols of vendor-specific middleware applications commonly used in the capital markets industry, and another that contains code specific to the information feeds of the capital markets industry. A summary of OpenMAMA as a Project innovation network is provided in Table 4.

The innovation networks we experienced in the SPDX and OpenMAMA projects serve to evolve our understanding of open source projects. Lyytinen et al. (2016) finds open source communities to most closely resemble a "clan innovation" in which resources are largely homogenous, control is distributed, innovation is highly modular, and translations take place on largely linear scales with a strong social ethos in the socialization of ideas that leads to creative solutions. However, the projects we researched did not fit that mold. SPDX closely resembled the attributes of a Federated innovation network, and OpenMAMA resembled the attributes of a Project innovation network. Moreover, both projects were part of a larger innovation network, the superstructure of the Linux Foundation, which we refer to as a *tapestry*. We next elucidate the Linux Foundation as a Tapestry innovation network and discuss how it can be a useful archetype for research on innovation networks.

Table 4. OpenMAMA as a Project Innovation Network

Project innovation network characteristics	• Evidence in the OpenMAMA Project
Homogeneous resources	• Predominately homogenous resources originating from prior, pre-open source work • Resources evolving through committees and technical working groups
Centralized control	• Centralized and hierarchical reliance on a steering committee • Central control over the innovation network
Translations	• Originating and standardized from a top-level committee • Executed linearly within steering committee and technical working groups but non-linearly once they are distributed to the larger OpenMAMA community
Innovation	• OpenMAMA: abstraction layer for the messaging protocols of vendor-specific middleware applications • OpenMAMDA: source code that contained code specific to financial applications

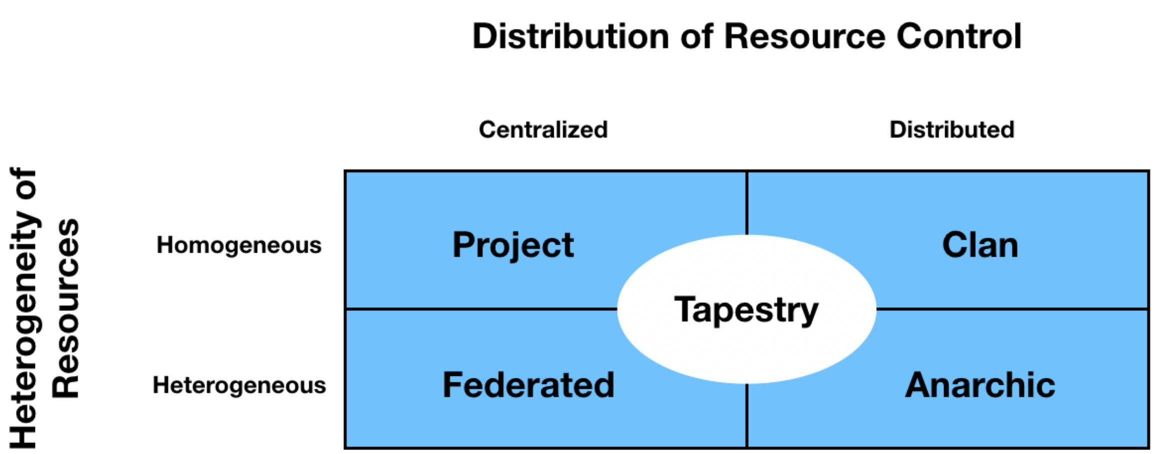

Figure 4. The Tapestry Innovation Network: A Hybrid of Innovation Network Types.

5 The Linux Foundation as a Tapestry Innovation Network

In this study, we observed that the Linux Foundation did not fit neatly into the four innovation network types described by Lyytinen et al. (2016). Our field study at the Linux Foundation thus revealed a new way to consider innovation networks. In our study, we recognize the Linux Foundation to be distinctly different from Project, Clan, Federated, and Anarchic innovation networks because it simultaneously contained heterogeneous resources and distributed control across brokered open source projects *while at the same time* containing homogeneous resources and centralized control over the development and management of open source best practices for all.

We found that the Linux Foundation, based on its brokering and management of distinctly different yet functionally related open source projects, can occupy all four quadrants of resource heterogeneity and control, as presented by Lyytinen et al. (2016). This describes what we refer to as a Tapestry innovation network, which we illustrate in Figure 4 and elucidate in the following sections.

As a new innovation network, we found that through coordinated projects, the Linux Foundation wove its supported open source projects into a “tapestry” to collectively serve an overarching need for numerous open source projects. We observed the Linux Foundation bringing together these projects: it was not members and their tools within project types that created complex networks, but rather people who brought multiple open source projects into a common fold. The following sections articulate the idea of a Tapestry innovation network as experienced from our exploration of the Linux Foundation, and again, illustrate *tapestry* as an innovation network type using the analytic frame from Table 1 to describe what an innovation network can be when simultaneously attending to disparate states of resource control and structure.

5.1 Tapestry Innovation Network

The tapestry metaphor is useful to describe an intricate and complex combination of things or a sequence of events, such as a tapestry of cultures, races, and customs. The original use of the word is to describe a form of “weft-facing” textile art, meaning that the warp threads, those strung across a loom, are hidden by the weft threads in creating the particular artwork. In tapestry weaving, both warp and weft yarns are discontinuous and it is the coordination of the loom and its artist that weave the threads into a single work of art. Much like the weaving of a tapestry, the Linux Foundation was representative of the artist and the operator of the loom, bringing together warp and weft threads to create an innovation network that weaves together technologies to serve overarching purposes. Byers (2013), in her examination of the tapestry metaphor to explain organizational control notes, writes: “tapestries are crafted to tell a story, to record history and to leave some physical evidence of a series of events deemed important” (p. 6).

As with any metaphor, the metaphor of a tapestry is somewhat paradoxical. We consider that it is often noted that tapestries when viewed from the “back” or reverse side of the pattern look like a jumble of incoherent threads and knots, and often do not present a coherent whole (ten Boom, Sherrill, & Sherrill, 1971) until they are completed and the creativity and the artisanship of the weaver are comprehended in full. Interestingly, when the completed tapestry is viewed from the back of the figurative design it is nearly identical and appears almost as neat as the front (Mallory, 2014). It is the seeming messiness of the reverse side as the weaving is in progress contrasted with the orderliness of the resultant picture that is remarkable in this metaphor.

In Figure 5, OpenMAMA is representative of an individual horizontal open source project (weft of the tapestry), [1] like other Linux Foundation-brokered projects including OPNFV or nodeJS. As with these other projects, the OpenMAMA project is distinctly aimed at advancing their particular technologies (e.g., the abstraction layer for the messaging protocols of vendor-specific middleware applications). In our metaphor, OpenMAMA represents a horizontal network within the Tapestry innovation network of the Linux Foundation.

In Figure 6, the SPDX project represents an individual vertical open source project (warp of the tapestry), like the Core Infrastructure Initiative, another Linux Foundation project, which is aimed at improving shared security concerns across all horizontal networks. In the case of SPDX, the Linux Foundation supports the project to discuss, share, and publish best practices in compliance programs to be distributed across the other Linux Foundation horizontal networks.

[1] Our use of the term horizontal is not meant to contrast with von Hippel’s use of horizontal (von Hippel, 2002). von Hipple uses horizontal to denote open source projects as consisting of members who are innovation contributors and users of that innovation. We use the term horizontal to describe the weave of multiple projects in the context of a tapestry metaphor.

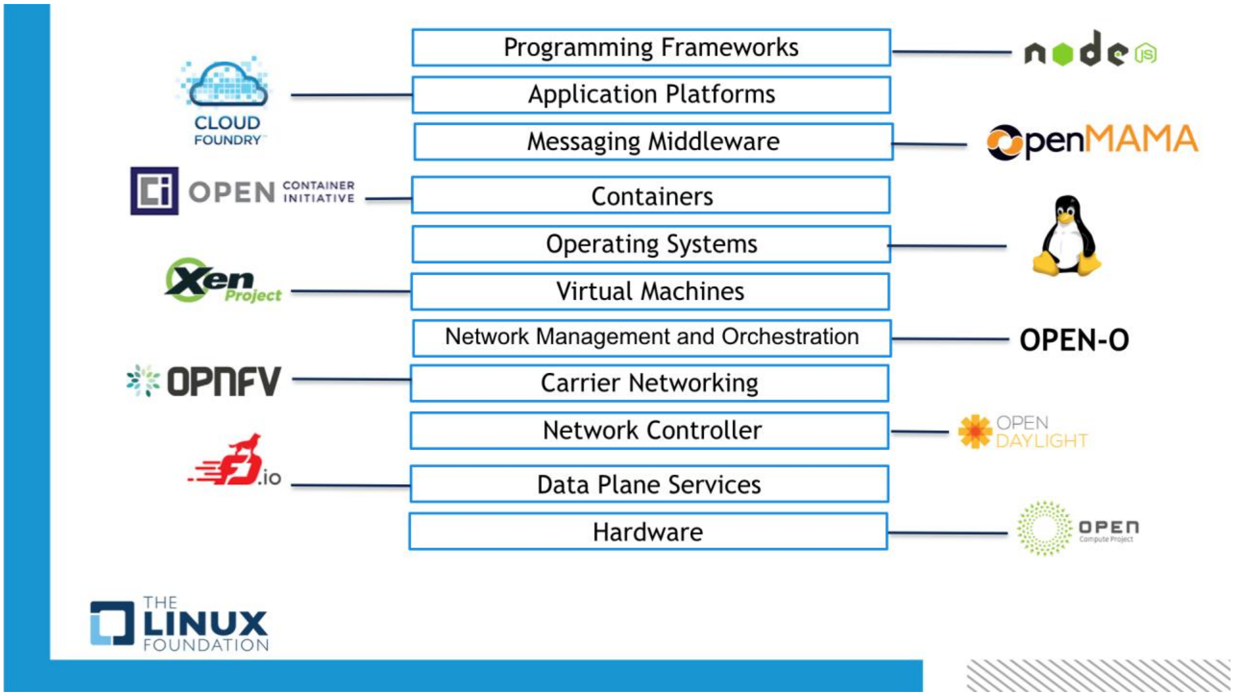

Figure 5. "Horizontal" Networks as Brokered by the Linux Foundation (Reprinted with Permission from the Linux Foundation)

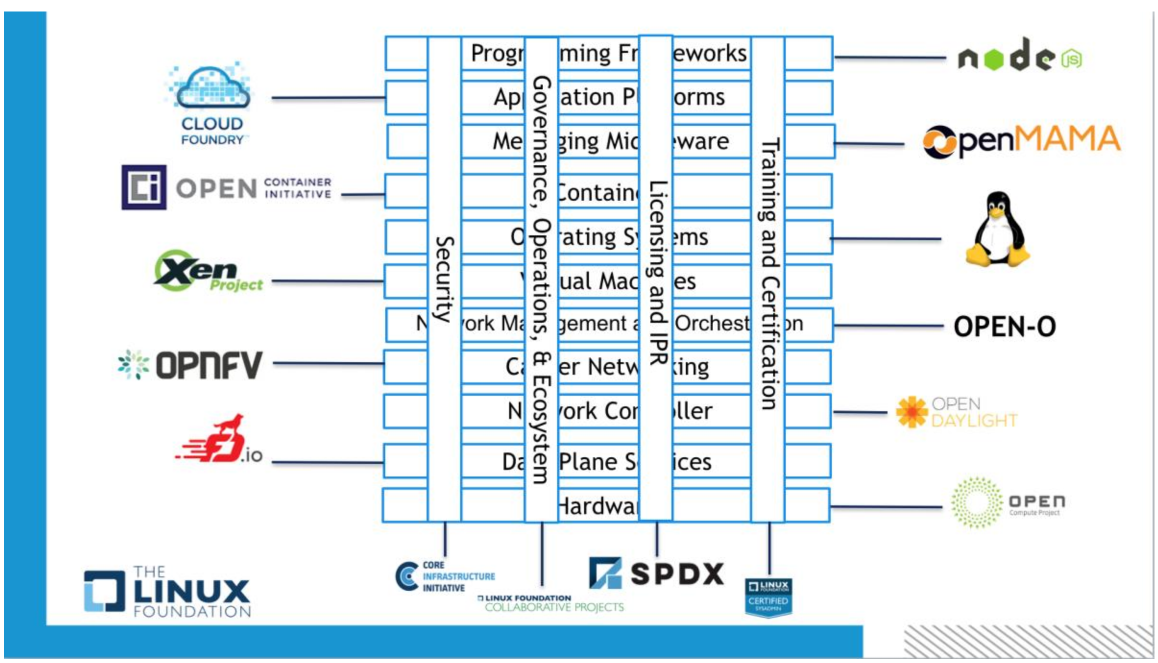

Figure 6. "Horizontal" and "Vertical" Networks as Brokered by the Linux Foundation (Reprinted with Permission from the Linux Foundation)

The “Licensing and Intellectual Property Rights” vertical network was architected by the Linux Foundation to strengthen licensing and intellectual property rights technologies and best practices for all horizontal networks, and SPDX is the core of this vertical network for open source communities seeking to improve compliance practices.

Through positions of shared interest, innovation networks representative of the ideal types from Lyytinen et al. (2016) can be identified, becoming connected through interactions arranged within tapestries. In our research, we found that vertical networks can strengthen the purpose and use of the horizontal networks and collectively form a more highly coordinated and integrated tapestry. Thus, Tapestry innovation networks exist at a more abstract level than any single innovation network, possess differing origins of resources, control, translations, and innovation that foster their overall generativity.

5.1.1 Resources in the Linux Foundation as a Tapestry Innovation Network: Collaborating on Shared Needs

In Tapestry innovation networks, homogeneous resources originate from shared interests among open source projects seeking to bring together independent innovation networks and heterogeneous resources under a common fold. The key to this in a Tapestry innovation network is that the individual horizontal networks do not naturally interact but rather generally preserve high levels of autonomy and knowledge, naturally creating a large pool of heterogeneous resources under the brokerage of the Linux Foundation. However, the Linux Foundation provides an opportunity for horizontal networks to innovate around shared needs and homogenous resources related to security, governance, licensing, and training (i.e., the vertical networks). SPDX is a prime example of innovation around shared needs.

SPDX has become core to the Licensing and Intellectual Property Rights vertical network (Rooney, 2010), along with other communities including the TODO Group, OpenChain, FOSSology, and Code Janitor to stress the responsibility of open source risk-related concerns. In creating the Licensing and Intellectual Property Rights vertical network, the Linux Foundation coordinated homogenous resources for all horizontal networks to educate and help users, developers, and corporate counsel in understanding open source risks and how to build efficient, frictionless, and often automated processes to support compliance (Open Compliance, 2016). Moreover, the Licensing and Intellectual Property Rights vertical network utilizes best practices espoused by the horizontal networks regarding open source licensing and risk-oriented initiatives to serve and sustain the viability of their own community while working to reciprocally support and sustain Linux Foundation horizontal networks. In the Tapestry innovation network, heterogeneous and homogeneous resources are overlaid and attended to concurrently.

5.1.2 Control in the Linux Foundation as a Tapestry Innovation Network: Linking Horizontal and Vertical Networks

Tapestry innovation networks are intersecting affairs: the vertical networks stem from issues that are manifest from and span horizontal networks. As individual horizontal networks go about the task of specialized innovation, they often do so with an overarching goal in mind. Within this focus, problems arise that may inhibit others from engaging with a horizontal network, require additional stabilizing efforts within the community, or require additional work to solve noncore but critical issues in the project. Thus, in Tapestry innovation networks, control is simultaneously distributed and centralized because the Linux Foundation does little to influence the horizontal networks but brings them together to address shared issues that form the vertical networks. The roles, norms, and culture within the horizontal networks remain stable. However, a new set of roles and norms emerge among the vertical networks that address key open source issues for all.

Both the SPDX project and the OpenMAMA project are projects in the Linux Foundation with specific goals in mind. With SPDX, it is to provide compliance artifacts for all open source projects. With OpenMAMA, it is to provide vendor-agnostic messaging middleware that can serve the needs of the capital markets industry. In each of these projects, there is nothing that overtly links either SPDX or OpenMAMA to each other; however, shared issues can be found where the vertical network interweaves with the horizontal network, and the Linux Foundation helps coordinate and control these intersections. In this, control in each of the individual innovation networks is unaffected regarding their specific goals but new, consolidated controls emerge as part of the weaving of the tapestry in addressing the issues that manifest at the intersection between projects. In the Tapestry innovation network, control is distributed to the individual open source projects but is centralized to advance connections and both types of controls are attended to concurrently.

5.1.3 Translations in the Linux Foundation as a Tapestry Innovation Network: Revealing a Cohesive Picture

The respective translations with independent horizontal and vertical networks remain consistent within those networks, focused on the core technological issues within those projects. However, Tapestry innovation networks represent an overarching structure for new translations. Tapestries reveal the translations encountered when connecting independent innovation networks into a larger whole, whether through collaborating around shared needs or closing the distance between projects. With millions of open source projects across GitHub, Sourceforge, and other locations, the Linux Foundation is focused on helping translate a subset of the enormous open source environment into a clear, concise, and cohesive whole that is meaningful for all their members. Translations are necessary at this level to (1) make sense of the tremendous noise within open source generally, and (2) create a Tapestry innovation network that can effectively share and combine resources in ways beneficial to all.

5.1.4 Innovation in the Linux Foundation as a Tapestry Innovation Network: Closing the Gaps

Innovation takes place through the people who identify complementary assets between individual innovation networks and articulate how individual networks can be brought closer together to pair these assets. In relation to Figure 6, the horizontal and vertical networks retain autonomy but can also find overlap. Similarly, the Linux Foundation also supports the ability of projects to close the gap with complementary projects. The Xen Project (a horizontal network) is supported in the Linux kernel (also a horizontal network). FD.io and Open Daylight (both horizontal networks) pair complementary resources that originate from both communities. Even Licensing and IPR is paired with Training and Certification (both vertical networks) to provide courses dedicated to OSS compliance and risk mitigation.

A Tapestry innovation network manifests itself when the Linux Foundation actuates the use of complementary practices and technologies that increase points of connection between horizontal and/or vertical networks. As such, innovation represents "closing the distance" between communities where complementary resources are brought together in an effort to extend the reach and impact of any one project. Innovation can be about finding the shared points of intersection between horizontal and vertical networks, but innovation is also about getting the right tension on the threads (or pushing the thread down close to the one placed immediately before it as you would in weaving a tapestry so that there is no gap). As such, the horizontal or vertical networks become more closely related through the innovative pairing of complementary resources. Table 5 summarizes the Linux Foundation as a Tapestry innovation network.

Table 5. The Linux Foundation as a Tapestry Innovation Network

Tapestry innovation network characteristics	Evidence in the Linux Foundation
Resources: Collaborating on shared needs	• Representing heterogeneous resources of individual projects as seen in the horizontal networks • Representing homogeneous resources around shared needs of individual projects as seen in the vertical networks
Control: Linking horizontal and vertical networks	• Managing the tapestry so as not to control any one innovation network • Managing the tapestry to link innovation networks to address the issues that form the vertical networks as platforms in solving shared issues
Translations: Revealing a cohesive picture	• Creating an overarching structure for horizontal and vertical networks • Identifying open source projects that provide complementary services that benefit all members woven into the Linux Foundation as a Tapestry innovation network
Innovation: Closing the gap	• Driving the use of complementary practices and technologies among individual projects • Closing the gap between horizontal and vertical networks by fostering places of connection on complementary technologies and practices, effectively tightening the overall structure of the tapestry

6 Discussion

We identified new ways that diverse groups of participants are brought together when using open source projects as a platform for innovation. In particular, we explored how engagements by participants in open source projects can be understood through a variety of types of innovation networks. As corporations leverage open source projects to innovate around for-profit initiatives and open source foundations interweave the projects, the forces of innovation alter how we understand the composition of these projects (Kelty, 2013; von Hippel, 2002). Traditionally, open source projects were seen as egalitarian in nature, aimed at producing innovations that would act as checks against external powers (Kelty, 2008; Kelty, 2005). In this regard, open source innovation was a pursuit of private, nonmonetary rewards gained through collective action (von Hippel & von Krogh, 2003; Lerner & Tirole, 2002) and considered to be part of a larger moral obligation (von Krogh et al., 2012; Stallman, 1999). While these ideals still exist across numerous open source projects, corporate and foundation presence within projects represent new and powerful forces that influence the ways that innovation networks are enacted (Kendall, Kendall, & Germonprez, 2016). Corporate-communal-foundational engagements have altered how we consider the resources that participants contribute, the control within networks, the ways that translations are manifested, and the innovations developed by members.

As corporations directly compensate employees to act as open source project participants and steer the direction of these projects, new arrangements form as engagements change from participation architectures (West & O'Mahony, 2008) to strategic engagements (Fitzgerald, 2006). This inexorably changes the structure of innovation from loosely structured publics of volunteer developers with no remuneration (Crowston, Howison, & Wiggins, 2012; Wayner, 2000; Raymond 2001) to employees acting on behalf of commercial interests to produce publicly available yet corporate-backed artifacts where projects become considerably more deterministic and considerably less "libre" (Crowston et al., 2007). The structures by which participation occur change accordingly, to now include overarching services that distribute shared and complementary solutions to all with an interest. As such, open source projects are becoming woven together, because the alignment of internal and external sources of innovation must remain commensurate in the development of corporate goods (Kelty, 2013). These open source project engagements are reliant on new and variable structures for innovation with members aligning and distributing corporate intellectual property and communal strategy throughout highly specialized open source projects and Tapestry innovation networks.

Our research contributes to the accepted view of open source projects and innovation networks, respectively. First, in contrast to Lyytinen et al. (2016), we demonstrated that open source projects are not restricted to a single innovation network type. More precisely, we found evidence for both Federated and Project innovation networks within open source projects. This tells us that corporate-communal engagement types may be conditional on the rationale of engagement rather than simply a one-size-fits all consideration. Perhaps horizontal networks (OpenMAMA) are more disposed to particular network innovation types than would be vertical projects (SPDX). While this conclusion cannot be drawn from our research, it warrants a deeper consideration of the types of innovation networks that open source projects can comprise.

Second, and more importantly, we contribute to the accepted view of innovation networks by illustrating that innovation networks do not necessarily exist as ideal types in isolation (Lyytinen et al., 2016) but can be part of a larger tapestry. In our research, we identified and named the Tapestry innovation network. Our research revealed that this type of network was intentionally constructed by the Linux Foundation in order to link and connect innovation networks with shared and complementary resources. Through the Tapestry innovation network, we demonstrated that innovation networks can occur at a higher order than any one singular network and that innovation network archetypes can accommodate changing perspectives of how resources, control, translations, and innovations are handled (e.g., see Greenwood & Hinings, 1993) for a helpful exploration of the contribution of archetypes to organizational change).

Under a Tapestry innovation network, it is observable that one horizontal network can share resources and innovation through the common interests available within vertical networks. Tapestry innovation networks bring to bear more than just a new archetype; they illustrate a new system to support the distribution of labor among members with shared and complementary interests. While Tapestry innovation networks are built on an extensive division of labor across the member communities, the division of labor is not haphazard but instead developed with intentional places of connection between members. As such, the managed and regulated conventions brought forward by the Linux Foundation in this labor network can work to "regulate the relations" between those who are woven into the tapestry, "specifying the rights and obligations of both" (Becker, 2008, pg. 29).

Further, Tapestry innovation networks help projects understand what is "in bounds" and what is "out of bounds" with respect to their own open source project technology and practice (Becker, 2008). Tapestry innovation networks convey boundaries such that any singular community can know its position within the larger tapestry, the practices or technologies it services, and the partner communities with whom shared and complementary resources may be paired. The Tapestry innovation network of the Linux Foundation is built to help communities manage their discrete but sharable technologies and practices by providing "the knowledge acquisition, services, and infrastructure needed to develop professional open source software … in creating the largest shared technology investment in history" (Linux Foundation, n.d.).

Lastly, given our inquiry and all that we have described about it, evident in our investigation of innovation networks and their interconnectedness was a distinction between "open source" and "community." While contributions to any open source project are not explicitly restricted, the contributors we interviewed were largely representatives of sponsoring corporations and were unaware of any members who were not compensated by representative corporations for their participation. In our research, open source became best understood as a method for innovation and community was a group of members who shared an interest in the same, nondifferentiating technology or practice. An open source project resembled a method for shared work by an alliance of corporations partnering to advance shared interests—whether as Federated or Project innovation networks. As such, when open source is separated from community, it is possible to elucidate two separate ideas, two separate structures, that allow research and practice to better understand platforms that foster innovation networks in complex settings.

6.1 Limitations and Future Work

As with any study, ours carries several limitations. First, our field study was exclusively focused on arrangements within the Linux Foundation. While the Linux Foundation represents a powerful and important force in the world of open source projects, their technologies and practices are inherently different from those at the Apache Software Foundation or the Software Freedom Conservancy. However, our goal was to provide a clear understanding of a complex system and we do not seek one-to-one parallels with other open source foundations.

Second, we spent extensive time with only two projects at the Linux Foundation. It is quite possible that a deeper examination of projects such as OpenDaylight or nodeJS would have yielded findings that impacted our field interpretations. In response to this concern, we are founding members of a new Linux Foundation project (CHAOSS). Our membership in this newly forming project will give us access to continue to apply tenets of networks of innovation generally (Lyytinen et al., 2016) and tapestries more specifically through such questions as: What does this mean for understanding open source projects and the genres of innovation that can occur within them? Will open source projects still be able to produce the broadly available technologies they have become recognized for if the rationalistic means for their own existence are changing? Can it still be called open source if the ability to contribute to open source projects has different or higher barriers such that volunteers are, in fact, compelled by their company to work in a community?

Both research and practice must consider these questions to further understand open source projects and their place both as and within innovation networks. Our discovery and characterization of Tapestry innovation networks elucidate how open source projects are changing with respect to strategic advantage, who participates, and the role of central actors in creating larger innovation networks from projects with shared and complementary interests. We invite researchers to give further theoretical and practical attention to the level, knowledge, control structures, forms, and translations of innovation networks that can occur in open source projects and, more abstractly, open innovation spaces. Further investigation could reveal not only the types of technologies and practices best suited for Tapestry innovation networks, but also open the door to understanding the plentitude of shared structures by which innovation can occur.

7 Conclusion

Through a four-year participant-observation field study that included interviews, focus groups, and direct engagement, our research revealed that open source projects do not always live in isolation. Freely structured groups of volunteers have been replaced by foundations that create, coordinate, and help stabilize open source projects. Open source brokers, like the Linux Foundation, bring complementary open source projects together to improve efficiencies for all—creating vertical networks that solve shared problems for horizontal networks (i.e., open source licensing as a shared problem for all). As a result, those in open source projects need not only be aware of their own project outcomes (i.e., source code, documentation, and test suites) but also need to be aware of their position relative to partner open source projects. The vertical networks are aimed at reducing inefficiencies or gaps in the overall tapestry by creating standards, reproducible practices, and shared resources to benefit all.

Our experiences interacting with the Linux Foundation called for an elucidation and authentication of a fifth type of innovation network, that we refer to as a Tapestry innovation network. By definition, a tapestry is created by weaving weft (horizontal thread) over and under warp threads, which are typically hidden from view. Mallory (2014) states that

> *although you cannot see them in a finished tapestry, the vertical warp threads are vital components of each piece—they are the backbone of every tapestry, and provide the support for the weft threads. Think of the warps like a blank canvas and the wefts like strokes of paint on that canvas. In other words, the weft threads are the colors which gradually build up to form a tapestry's picture.*

We determined that the Linux Foundation was made up of both horizontal threads and the less visible, but invaluable vertical threads.

Open source projects are now being deliberately formed with the goal of explicitly supporting other open source projects. In doing so, it is quite likely that both the height and the width of the Tapestry innovation network as observed at the Linux Foundation will expand as new technology-specific open source projects (horizontal networks) and new supportive, open source projects (vertical networks) become the backbone of the structure. Our research also discovered that, like open source projects, innovation is not bound within singular projects. Innovation is an interwoven engagement across projects and exists across structures created to support its distribution. Similar to issues of design (Germonprez et al., 2017) and control (Kirsch, 1997), innovation is a broad and shared activity, not easily reduced to local groups solving local problems. We believe that this research contributes not only new structures of innovation but also highlights the need to accommodate Tapestry innovation networks, as we continue to explore and shape such complex phenomena as innovation in ever-changing contexts like open source project engagement.

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