Network Science, Homophily and Who Reviews Who in the Linux Kernel?
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Abstract

Peer review is a common quality control practice in both science and software development. In this research, we investigate peer review in the development of Linux by drawing on network theory and network analysis. We frame an analytical model which integrates the sociological principle of homophily (i.e., the relational tendency of individuals to establish relationships with similar others) with prior research on peer-review in general and open-source software in particular. We found a relatively strong homophily tendency for maintainers to review other maintainers, but a comparable tendency is surprisingly absent regarding developers’ organizational affiliation. Such results mirror the documented norms, beliefs, values, processes, policies, and social hierarchies that characterize the Linux kernel development. Our results underline the power of generative mechanisms from network theory to explain the evolution of peer review networks. Regarding practitioners’ concern over the Linux commercialization trend, no relational bias in peer review was found albeit the increasing involvement of firms.
Resumo

A revisão por pares é uma prática comum de controlo de qualidade tanto na ciência quanto no desenvolvimento de software. Nesta pesquisa, investigamos a revisão por pares no desenvolvimento do sistema operativo Linux usando teoria e métodos para a análise de redes sociais. Estruturamos um modelo analítico que integra o princípio sociológico da homofilia (ou seja, a tendência relacional de cada individual para estabelecer relações com outros semelhantes a si) no contexto de revisão por pares no desenvolvimento de software de código aberto em particular. Encontramos uma tendência relativamente forte de homofilia para os mantenedores de revisar outros mantenedores, mas uma tendência comparável está surpreendentemente ausente em relação à afiliação organizacional dos diferentes programadores. Tais resultados reflectem as normas, crenças, valores, processos, políticas e hierarquias sociais documentadas que caracterizam o desenvolvimento do kernel Linux. Os nossos resultados realçam o valor da teoria da análise de redes sociais para explicar a evolução da revisão por pares no desenvolvimento de software. Em relação à preocupação dos profissionais sobre a tendência de comercialização do Linux, nenhuma tendência de programadores para revisar programadores afiliados com a mesma organização (colegas profissionais) foi encontrada.
Network Science, Homophily and Who Reviews Who in the Linux Kernel?[1]

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Abstract

Peer review is a common quality control practice in both science and software development. In this research, we investigate peer review in the development of Linux by drawing on network theory and network analysis. We frame an analytical model which integrates the sociological principle of homophily (i.e., the relational tendency of individuals to establish relationships with similar others) with prior research on peer-review in general and open-source software in particular. We found a relatively strong homophily tendency for maintainers to review other maintainers, but a comparable tendency is surprisingly absent regarding developers’ organizational affiliation. Such results mirror the documented norms, beliefs, values, processes, policies, and social hierarchies that characterize the Linux kernel development. Our results underline the power of generative mechanisms from network theory to explain the evolution of peer review networks. Regarding practitioners’ concern over the Linux commercialization trend, no relational bias in peer review was found albeit the increasing involvement of firms.

Keywords: Peer Review; Open-source; Network Science; Homophily; Linux

I. Introduction

Many remark that “networks are everywhere!” (Latour, 2011; Mark Newman, A.-L. Barabasi, and Watts, 2006; Dorogovtsev and Mendes, 2002; Strogatz, 2001; Cohen, 2002). Examples of networks recurrently modeled by scholars are the Internet and other infrastructures, social, political and economic networks. Also neural, inter-organizational, scientometric, and text-representational networks among many others. As the network paradigm becomes scientifically relevant across disciplinary boundaries, scholars recurrently turn to network science – an emerging field, that like statistics, permeates a wide range of traditional disciplines (Brandes et al., 2013).

Network science, as the study of the collection, management, analysis, interpretation, and presentation of relational data, provides scholars across disciplines with both theory and methods to deal with the increasing availability of relational datasets (Brandes et al., 2013). Given the trans-disciplinary nature of our field (see Galliers, 2003) and as information systems become increasingly networked and interconnected (Henfridsson and Bygstad, 2013; Ciborra, Dahlbom, and Ljungberg, 2000) the network paradigm is gaining relevance in the discipline.

1[1] As presented at 2020 European Conference on Information Systems (ECIS 2020), held Online, June 15-17, 2020. The official conference proceedings are available at the AIS eLibrary (https://aisel.aisnet.org/ecis2020_rp/).
In this research, we explore one of the most important theoretical concepts in network science – homophily. The term homophily (etymologically from Greek; *homoios*: equal, similar; *philia*: friendship, love, affection) describes the relational tendency of individuals to associate and bond with similar others. We test such “love of the same” principle in peer-review networks by examining the evolution of the Linux kernel.[2]

The principle of homophily suggests that actors tend to establish ties with similar others. Homophily has been previously explored in information systems research within multiple settings (Gallivan and Ahuja, 2015). Among other examples, while investigating the adoption of a large-scale IT system across multiple sites in New York State, Hovorka and Larsen (2006) confirmed that organizational similarity influenced the willingness of organizations to establish and maintain communication ties. In a scientometric study examining the evolution of co-authorships in top IS journals, Gallivan and Ahuja (2015) found significant effects of homophily related to gender, proximity, and geography. IS scholars worldwide exhibit a stronger preference for collaborating with co-authors of the same sex and those who attended the same Ph.D. program. More recently, Chipidza (2016) found homophily related to gender, geography, and graduation year in the co-authorship network of the IS Senior Scholar Basket of 8. Among other circumstances, homophily was addressed by IS scholars within the context of multi-player on-line games (Putzke et al., 2010), virtual investment-related communities (Gu et al., 2014), online shopping (Gaskin and Oakley, 2010), and open-source communities Hu and Zhao (2009) and Hu, Zhao, and Cheng (2012).

This paper builds on the interdisciplinary tradition of network science – We overlap network theory, network analysis, open-source and information systems research. At the theoretical level, the principle of homophily is our principal theoretical interest. Even if this research is embedded in a larger project that aims at making sense of *who reviews who in the Linux kernel?*, the more workable initial research question provided the framing: "Does the code reviews in the Linux Kernel tend to be homophilous"? Or in other words “Does the contributions to the Linux kernel tend to be reviewed by people who are similar to the original contributors?”. Assessing homophily is important as innovative organizations should ideally disclose low levels of homophily as successful collaboration requires complementary over substituting actors (K. Desouza, 2011, pp. 125). In addition, low levels of homophily facilitate communication among very distinct actors (Rogers, 1976; Granovetter, 1973) and ease the recombination of ideas across diverse areas of the knowledge possessed in the team (Fleming, Mingo, and Chen, 2007; West, 2002).

At a more empirical level, the paper joins to the group of existing multidisciplinary case studies that have examined the Linux kernel and its development (e.g., Shaikh and Henfridsson, 2017; Homscheid, Schaarschmidt, and Staab, 2016; Ermann, Chepelianskii, and Shepelyansky, 2011; Hertel, Niedner, and Herrmann, 2003). The empirical longitudinal analysis concentrates on five kernel subsystems (i.e., arch, drivers, fs, kernel and net) and their evolution from 2006 to 2014. In total 45 directed and weighted peer review networks are analyzed. The distributed version control system used in the Linux kernel development provides the source of empirical data. The empirical analysis relies on descriptive statistics and different network indices, preserving the directed and weighed nature of peer review networks.

[2]To best of our knowledge, Linux is the most studied software development project.
II. Theoretical background

Network science and homophily

Network science provides theory and methods that are particularly suited to analyze and explain phenomena where dependence is observed both between and within variables (Brandes et al., 2013). Very often, IS scholars make strong assumptions about the independence of observations to access to standard theory in inferential statistics (Mingers, 2004; Lindberg et al., 2013). In network science, dependencies between and within variables, are not undesirable nuisances or defects to be left out by the study design, but they often constitute the actual research interest. As in spatial statistics, observations are not assumed to be independent of each other but are explicitly set up to have structure. Such dependence structure between observations is often what network scientists are after (Brandes et al., 2013). By taking such stance, the behavior of different information systems users can be influenced by ties among them (e.g., friendship, work-relationship); or the successful implementation of an IT system can be influenced by many relational factors (e.g., social networks, structure of value nets, systems interoperability).

One of the most fundamental characteristics of network theory in social sciences is the focus on relationships among actors as an explanation of actor and group outcomes (Borgatti and Halgin, 2011; Borgatti, Brass, and Halgin, 2014). The principle of homophily (i.e., that actors tend to establish ties with similar others in a group) is, therefore, central to network science. Such positive relationship between the similarity of two actors in a group and the probability of a tie between them was one of the first features early noted by network scientists (Freeman, 1996). As pointed out in the seminal homophily-review by M. McPherson, Smith-Lovin, and Cook (2001), structural sociologists have studied homophily in relationships that range from the closest ties of marriage (Kalmijn, 1998) and the strong relationships of "discussing important matters" (Marsden, 1987) and friendship (Verbrugge, 1977) to the more circumscribed relationships of career support at work (Ibarra, 1992) to mere contact (Wellman, 1996), "knowing about" someone (Hampton and Wellman, 2001) or appearing with them in a public place (Mayhew et al., 1995).

Research on the patterns of homophily is remarkably robust over various types of relations (M. McPherson, Smith-Lovin, and Cook, 2001; Kossinets and Watts, 2009). Studies that measured multiple forms of relationship have shown that the patterns of homophily tend to get stronger as more types of relationships exist between two actors – multiplex ties generate greater homophily than simple ties (Fischer, 1982a; Fischer, 1982b; Hristova, Musolesi, and Mascolo, 2014; Renoust, Melançon, and Viaud, 2014; Grossetti, 2007; Haythornthwaite and Wellman, 1998). Evidence of the homophily tendency crossed domains, in scientific fields (e.g., physics and biochemical networks) the same tendency is known as assortative mixing (Croft, James, and Krause, 2008; M. Newman, 2003; Peng, 2015). Particularly in social sciences, evidence was found that "similarity breed connection" with regard to many characteristics such as gender, ethnicity, age, religion, education, occupation, social class hierarchy, geography, family, organizational affiliation, network positions, attitudes, abilities, believes, and aspirations among others (see M. McPherson, Smith-Lovin, and Cook, 2001; Brass et al., 2004, chapter 6 in Croft, James, and Krause, 2008 and chapter 4 in Easley and Kleinberg, 2010 for exhaustive reviews).
Both classical and computational social science studies\cite{Lazer2009} recurrently confirmed that homophily bounds social networks \cite[Bakshy, Messing, and L. A. Adamic, 2015; Colleoni, Rozza, and Arvidsson, 2014; Aral, Muchnik, and Sundararajan, 2009]{Aral2009}. However, there are non-confirmatory studies as well. Three very recent studies on the open-source software domain did not confirm the expected pattern of homophily. In a recent exploratory case study, Teixeira, Robles, and González-Barahona \cite{Teixeira2015} investigated homophily in the joint-development of the OpenStack – an open-source infrastructure for big data co-developed by hundreds of organizations and thousands of developers (e.g., Rackspace, Canonical, IBM, HP, Vmware, Citrix, Intel and AMD among others). Contrary to expected, the analysis of a complex network on “who codes with who” revealed that developers did not tend to work with developers from the same firm in the ecosystem. There was a relational tendency among OpenStack developers to work with developers from other companies (often competitors). A similar study by Linåker et al. \cite{Linaker2016} investigated the Hadoop – open-source distributed storage and processing technologies for big data joint-developed by extensive network of participants (e.g, Cloudera, Yahoo!, Facebook, Twitter, LinkedIn, Jive, Microsoft, Intel and Hortonworks among others). The results pointed out that developers affiliated with competing firms collaborate as openly as the ones affiliated with non-rivaling firms do. In such dyad of recent studies, the theoretically expected homophily regarding company affiliation was not observed in open-source communities as in other social networks. Such a difference between the patterns of homophily in open-source communities and the patterns on homophily in other social networks motivates further examinations. After all, understanding of the dynamics of homophily, can lead to more effective reward structures and more creative collaboration structures \cite{Gallivan2015}.

**Peer review networks and open-source software**

Peer review is an essential element of modern science. Although the history of scientific peer review traces back to the classical antiquity, the roots of the contemporary institutional arrangements are located in the 18th century process that was first adopted by *Philosophical Transactions*, the first journal exclusively devoted only to science \cite{Bornmann2011; Spier2002}. While definitions, interpretations, and opinions tend to vary, quality control is usually still seen to be the main purpose of scientific peer review.

This fundamental trait is present also in different software development peer review practices. This trait becomes evident by considering the theoretical attempts to define the overall goal of reviewing or inspecting artifacts written by others. According to some authors, the explicit objective is to find errors \cite{Fagan1976}. While other definitions enlarge the theoretical scope, for instance by including the goal to find deviations from specifications \cite{Aurum2002}. Recent research explicitly addressing the benefits of code reviews pointed out that developers spend 10-15 percent of their time to find defects, share knowledge, build a sense of community, and maintaining quality \cite{Bosu2017}.

Many relational concepts from network theory have been observed within open-source software (OSS) collaboration and peer reviewing networks. On one hand, empirical network tendencies such as network centralization, and the associated theoretical concepts \cite{Lazer2009} for a discussion on the emergence of data-driven “computational social science” in general and Lindberg et al. \cite{Lindberg2013} on its application to open-source in particular
such as the core and periphery, have long been adopted to successfully describe relational socio-technical OSS collaboration (Bird, 2011; Crowston and Howison, 2006b; Toral, Martinez-Torres, and Barrero, 2010). On the other hand, actors’ attributes such as the activity, experience, and seniority, have been observed to have an impact upon OSS peer review networks and their efficiency (Baysal et al., 2013; Bosu and Carver, 2014; Rigby et al., 2014).

This paper contributes by exploring homophily as an important theoretical tendency in open-source peer review networks. As posited by Robins et al. (2007), understanding the theoretical reasons for a hypothetical network topology is important to ensure further research advances, and to allow the potential for further theorizing. To best of our knowledge, this is the first paper exploring homophily by longitudinally investigating peer-review along with the development of a high-networked information system (i.e., Linux).

III. Research design

This research was conducted as an empirical case study design informed both by methodological notes on case study research (Eisenhardt, 1989) and social network analysis (Wasserman and Faust, 1994; Howison, Wiggins, and Crowston, 2011; Contractor, Wasserman, and Faust, 2006). We assess the peer review practices of a large open-source software project driven by our interests in network theory (i.e. homophily). Our research design also reflects extant knowledge in peer review practices and processes of open-source communities in general and Linux in particular.

Case selection

From the empirical side, we motivate the case of Linux by pointing out that according to the empirical data, since the mid-2000s, the Linux kernel was developed by a network of with over eleven thousand distinct individuals. Many refer to Linux as the most successful, and the most important open-source project of all time. Also, in relation to existing literature, Linux is the most studied open-source project (Crowston, Wei, et al., 2012). As much research in Linux already exists, analyzing the peer review networks of Linux have a higher potential of integration with prior research. As pointed out in a recent critical review of research in open-source software, “investigating the phenomenon within a small and confined domain and gradually extending the validity of the results through replication is a much sounder approach rather than over-generalizing the results of a study to a broad domain without any theoretical justification or empirical evidence” (Carillo and Bernard, 2015).

From the theoretical side, the Linux kernel is a particularly relevant case to observe the important question of firm engagement in OSS development. First of all, the commercial aspects provide also one motivation for homophily theory – if the engaged affiliates from a company would be systematically reviewing each other, as has been suspected in some cases (Baysal et al., 2013), the normative ideals of OSS peer reviews would be arguably violated. Second, as Linux is a mature project with de facto hierarchies(cf. Crowston and Howison, 2006b; O’Mahony and Ferraro, 2007; Shaikh and Henfridsson, 2017) and such hierarchies apply to the maintenance and patch submission practices (Kleen, 2014; Love, 2005) and policies (Linux Kernel, 2015a), hierarchical roles are likely to impact homophilous behaviour (Dodds, Watts, and Sabel, 2003; Shen and Monge, 2011). In Benkler
(2006) terms, OSS communities often display a “meritocratic hierarchy”, which does not hinge on employment authority as in traditional firms. When common social attributes are largely absent or obscured (e.g., age, race, educational background) individuals could resort on project leadership, merits and reputation when deciding to “network” with other developers. Third, the Linux kernel provides an important case to reflect upon the software development peer review practices against the scientific counterparts (Lee and Cole, 2003). The question is important already because scientific peer reviewing has long provided empirical cornerstones for many of the high-level network theories (Merton, 1968; Mark Newman, 2001; Peng, 2015). These three reasons provide an ideal frame to follow the interdisciplinary network science domain. While the research observes socio-technical networks, the perspective is not attached to any specific discipline in the larger social or technical research domains.

Conjectures

The research question – does the code reviews in the Linux Kernel tend to be homophilous? – can be disaggregated into a few assertions. As the pursued methodology is based on descriptive statistics, these assertions should be understood as analytical research vehicles rather than strictly testable hypotheses. To make this difference explicit, the assertions are labeled as general conjectures of the underlying network theory. Besides attempting to gain some theoretical precision by reflecting prior expectations, these conjectures are also meant to control the common post hoc rationalization that has often been argued to be a typical element in case studies (Campbell, 1975; Bitektine, 2007).

When facing the empirical material, and to exploit homophily related to exogenous network elements (i.e., attributes of software developers modeled as network nodes), the following conjectures can be stated, given two exogenous node attributes of interests:

C1 Maintainers tend to review other maintainers.
C2 Developers affiliated with an organization (i.e., company, university) tend to review other developers affiliated with the same organization.

Maintainers are granted with a formal role within the Linux “meritocratic hierarchy” and they are expected to review contributions to the various parts of the Linux kernel that they maintain. Our second exogenous attribute of interest, affiliation, results from an employment or contractual relationship with an organization that commits resources to the development of the Linux kernel. While being a maintainer reflects meritocracy as a value of open-source communities, affiliation reflects the commitment of an individual to an organization. Such operationalization aligns with prior research relating homophily with hierarchy (see Shen and Monge, 2011; Škerlavaj, Dimovski, and K. C. Desouza, 2010) and homophily with organizational affiliation (see Teixeira, Robles, and González-Barahona, 2015; Kim and Higgins, 2007).

Finally, the research design allows to generalize these conjectures with the following two corollaries.

C3 The results are similar across the main subsystems.
C4 The results are similar across the annual subsamples.

Data collection and analysis

To extract the desired peer review data, we “borrowed” extensive knowledge from the Mining Software Repositories (MSR) field that provides many methods and tools to analyze
the rich trace data available in software repositories. After gaining insights on Linux and its development processes, we defined keywords and used pattern matching techniques with regular expressions[^4] to obtain the desired relational data provided by the software repository orchestrating the development of Linux.

Guided by cross-disciplinary methodological notes that overlap the knowledge on the Mining of Software Repositories with the analysis of networked digital trace data (e.g., Howison, Wiggins, and Crowston, 2011; Bird, Gourley, and Devanbu, 2007; Bettenburg et al., 2015), we modeled the patch’s delivery path (see Linux Kernel, 2015a) distinguishing between authors and reviewers (see Bettenburg et al., 2015). From naturally occurring traces of the Linux development history (signatures that credit the contributors of the Linux kernel) we could build networks of who reviewed who by analysing each code-contribution from the time it is submitted until the time it ‘lands’ and merges into the official Linux code base.

Authors and reviewers were identified by their names as they appear in the repository commit logs. Moreover, the common distance metric of Levenshtein (1966), which seems reasonable for the purpose (Zangerle, Gassler, and Specht, 2013), was used to account typing mistakes and other small inconsistencies in individuals’ names. Peer review relationships were modeled as weighted adjacency matrices, \( A_1, A_2, \ldots \), the dimensions of which are based on the approximately unique individuals who have either authored or reviewed commits in a given subsystem during a given year. A matrix \( A_i \) contains the conventional algebraic representation of a network in which individual elements represent the presence or absence of a link between two nodes according to whether an element \( a_{xy} \in A_i \) is positive. No truncation (Hong et al., 2011) or dichotomization (Crowston and Howison, 2006b; Conaldi and Lomi, 2013) was applied to the weights. The resulting networks are directed already by the nature of peer review, and, hence, the matrices are asymmetric by definition.

In the context of this paper, \( A_i \) represents more specifically an abstract composite in which columns denote authors and rows individuals who have peer reviewed commits. For example, a value two for an element \( a_{31} \) means that the third observed developer has peer reviewed two commits of an author whose commit records are given in the first column, irrespective whether the third column sum is zero, that is, regardless whether the third developer has been an author himself. It is worth noting that in the Linux kernel authors should always sign off their own commits. If the element \( a_{11} \) would, thus, take a value three, for instance, the first observed developer would have authored three commits, and correctly signed them off with the compulsory signature. By implication, the number of signed commits per developer can be extracted directly from the diagonal of \( A_i \). As is typical (Robins, 2013; Holland and Leinhardt, 1970), however, all diagonal elements are excluded in the actual network analysis already due to the theoretical absurdity of a single person peer review.

Regarding corporate affiliation, we adopted a strictly extrarelational approach: individuals are identified by their real names, while all affiliations are based on explicit data extraction from the domain names in individuals’ e-mail addresses.

[^4]: Due to lack of space, we opted to not detail the complex and fine-grained details of our pattern matching procedures that mined the Linux software repository (orchestrated with Git).
The actual identification was carried out semi-manually, to borrow a term used by Hamasaki et al. (2013). The frequent unique domain names were first examined manually in order to construct a suitable extraction scheme for each group. In general, the rightmost subdomain was considered as sufficient for the majority of cases (e.g., 't.jhun@samsung.com' identifies a developer’s affiliation with Samsung). If a recurrently occurring subdomain was not instantly recognized, a visit was attempted with a web browser (e.g., search engines as well as the LinkedIn social network). If this visit did not provide new information, a search engine was used for detective purposes. If also this search failed, the subdomain was finally tagged as unaffiliated.

Finally, all maintainers are identified from a file supplied in the root of the source code collection (Linux Kernel, 2015b). Since the file has been updated numerous times, the identification was done with a twofold matching procedure: for all individuals in each subsystem in each year, the corresponding real names were searched from the first annual revision of the file, and from all subsequent patches to the file until the last commit in the given year. While this procedure ensures that annual changes in the maintainership are accounted for, no attempts are made to match the distinct code sections that maintainers are responsible for. In terms of $C_1$ this choice means that a maintainer whose responsibilities are located in the $i$:th subsystem is still classified as a maintainer even when he or she reviews commits to the $j$:th subsystem, for instance.

IV. Results

In order to analyze homophily in the peer-review networks of the Linux Kernel, we looked at the endogenous elements of the network (i.e., without attaching additional extra-relational attributes to the associated nodes or links). The corresponding prior expectations (i.e., the conjectures) are tested by means of fundamental network measures and descriptive statistics that capture the evolution of five kernel subsystems from 2006 to 2014.

Trend analysis

The amount of individuals involved in peer review activities has indeed increased substantially in the Linux kernel during the past decade (Bettenburg et al., 2015). As can be seen from Fig. 1a, the number of nodes has increased steadily within drivers, arch, and net. The fs and kernel subsystems seem to exhibit a slower rate of growth, however. As generally suspected by Toral, Martínez-Torres, and Barrero (2010), the reason may relate to the strong company presence in the former three subsystems, which are all closely related to hardware. On the other hand, drivers presumably garners also a large amount of volunteers and hobbyists working with consumer hardware.

Maintenance as a foci of homophily

Guided by Blau’s (1977) established theoretical ideas, we employ a frequency-based analytic strategy (M. McPherson, Smith-Lovin, and Cook, 2001, pp. 418) as previously employed by IS scholars to assess homophily in social networks (e.g., Gallivan and Ahuja, 2015; Gu et al., 2014). In order to evaluate $C_1$, we developed a simple custom index which presumes a tendency for maintainers to review other maintainers[5]. For any maintainer, the group centrality index of Everett and Borgatti (2005) was considered as an alternative, but the custom index was seen preferable as the group centrality measure is restricted to undirected and unweighted networks.

[5] The group centrality index of Everett and Borgatti (2005) was considered as an alternative, but the custom index was seen preferable as the group centrality measure is restricted to undirected and unweighted networks.
the index is defined as the ratio of reviews that have targeted maintainers to all reviews carried out by the node. (A value zero is reserved for those maintainers who have not reviewed at all.) Using Fig. 2 as an illustrative example network: if A and B are maintainers and the remaining two nodes denote normal developers, the corresponding review ratios for the two maintainers are $4/5 = 0.8$ and zero, respectively. The index is undefined for C and D since these two nodes lack the attribute flag for maintainership. The higher the value, the higher the degree of homophily.

As can be seen from Fig. 3, the average number of reviews is much higher among maintainers compared to the group of normal developers, many of whom have no reviewed commits at all. Also the standard deviations are much higher in the maintainer group[6], which indicates that most of the noted extreme outliers refer to maintainers. The correspond-

[6]As early mentioned on section iii, even if maintainers hold formal responsibilities on specific code-sections of a specific subsystem, they can review as well code submitted to other subsystems.
ing average percentage shares are shown in Table 1. The relative ratios are particularly high in arch, drivers, and kernel, meaning that many maintainers in these subsystems have reviewed other maintainers. It is worth noting that the degree of homophily is rather high in drivers, although the subsystem contains the highest absolute amount of nodes (see Figure 1a and the lower ratio of maintainers vs. normal developers (see Figure 1b). In general, the subsystem differences are likely related to different peer review and patch submission practices that are customary to the daily development in the respective subsystems. A more theoretical interpretation can be left open, nevertheless. In terms of hierarchy, it could be, for instance, that particularly reviews in the development of device drivers pass through many nodes along paths that contain different layers of maintenance, sub-maintenance, and development (i.e., in a delegation hierarchy).

Table 1 Average maintainer review ratios (%)

| Year | arch | drivers | fs  | kernel | net  |
|------|------|---------|-----|--------|------|
| 2006 | 29.22| 32.55   | 29.00| 21.94  | 27.28|
| 2007 | 32.64| 39.14   | 22.48| 31.00  | 29.22|
| 2008 | 36.88| 36.15   | 34.81| 32.40  | 28.72|
| 2009 | 34.21| 33.83   | 30.59| 36.05  | 26.94|
| 2010 | 34.69| 36.98   | 30.54| 39.99  | 30.76|
| 2011 | 39.01| 35.21   | 29.70| 32.14  | 22.77|
| 2012 | 38.09| 34.51   | 27.56| 41.78  | 28.50|
| 2013 | 39.25| 37.15   | 28.76| 42.39  | 31.73|
| 2014 | 41.01| 39.29   | 25.18| 43.44  | 26.12|

Values larger than or equal the mean share are colored.

Although it remains debatable what suffices as an acceptable threshold in descriptive statistics, $C_1$ can be accepted already on the grounds that, on average, in all samples over one fifth of all maintainers have reviewed other maintainers. At this point the cumulative evidence can be also seen as sufficient to reject $C_3$ and $C_4$. There are empirically relevant differences between the sampled peer review networks.

**Affiliation as a foci of homophily**

The conjecture $C_2$ presumes a homophily tendency that developers from large companies tend to review other developers with the same affiliation. There are a couple of difficulties related to the assertion. First, the extraction of affiliations from e-mail addresses comes

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![Figure 2](image-url)
with the theoretical assumption that developers are affiliated with the organization that owns the corresponding e-mail domain. The second issue is more practical: the five subsystems differ considerably in terms of the largest reviewer groups; semiconductor companies do not commit extensively to net within which networking companies often operate; the fs subsystem is of special interest to companies working in the field of storage; and so forth [7]. Even for the largest reviewer groups, then, annual and cross-subsystem comparisons are difficult to make already because the resulting frequency distributions are small in some subsamples. While keeping this remark in mind, a descriptive evaluation can be carried out by first considering three well-known companies associated with the Linux kernel development: Intel (one of the world’s largest semiconductor companies), Red Hat (a well-known Linux vendor), and SUSE (a competitor for Red Hat’s products developed historically by Novell, and now owned by the Micro Focus International). The review ratio from the previous section suffices as a descriptive index. To briefly rephrase the meaning: the index gives the (percentage) share of reviews that, for instance, a Red Hat affiliate has done towards other Red Hat affiliates, scaled by the total number of peer reviews carried out by the affiliate.

The results are visualized with the six box-and-whisker plots in Fig. 4. The average review ratios (%) are shown on the left-hand side, whereas the three plots in the second column show the standard deviations of the percentage ratios. Since the plots are factored according to subsystems, in each plot the conveyed information (namely, central tendency, variance, and outliers) is read annually across the years. For instance, the top-left plot shows that there has been a rather large annual variation in the average review ratios of the Intel affiliates working in drivers. In general, however, the noteworthy detail relates to the scales: for all three affiliation groups, on average less than five percent of all groups’ reviews have targeted members with the same affiliations. When looking at the right-hand side plots, it becomes evident that variation is rather large among the individual developers affiliated with the three companies.

It is evident that the varying top-three affiliation groups exhibit only rather modest average degrees of homophily. These are accompanied by relatively large standard deviations, reflecting heterogeneity among the individual, affiliated, developers. Given that a

The article published by Cass (2014) in the IEEE Spectrum magazine and institutional reports from the Linux Foundation (see Corbet, Kroah-Hartman, and A. McPherson, 2015) provide aggregated figures on who contributes to Linux. Unfortunately, we are unaware documentation reporting on contributions by subsystem.
coarse threshold of 20% was interpreted as a sufficient acceptance criterion in the case of maintenance, the analogous homophily conjecture for affiliations, $C_2$, can be tentatively rejected\cite{8}. It seems that the affiliation attributes do not support a powerful homophily tendency – at least not when compared to the maintainership attribute.

V. Discussion

This paper approached one research question – does the code reviews in the Linux Kernel tend to be homophilous? – through network theory, network analysis, four conjectures, five Linux kernel subsystems, and nine years we provide further insights on ‘who reviews who in Linux’. The analytical evaluation model was based on the theory of homophily – actors are likely to structure their social network according to principles of similarity. The empirical findings support the theory for a limited extend.

Key findings

The empirical results are enumerated in Table 2.

\cite{8}With such results (i.e., low average degrees of homophily regarding affiliation), we can reject the conjecture without employing more complex relational methods addressing homophily in evolving social networks such as exponential random graph models (ERGMs) often employed to analyze longitudinal network data. (see Contractor, Wasserman, and Faust, 2006). While ERGMs have been widely used in social network research, they are not yet established in the IS discipline. Furthermore, they are also computationally intensive and require much computational power for handling large networks.
Table 2 Summary of results

| C | Support | Description |
|---|---------|-------------|
| C1 | Yes | Maintainers tend to review other maintainers. |
| C2 | No | Members affiliated with a large organization only infrequently review “colleagues” affiliated with the same organization. |
| C3 | No | The main subsystems differ. |
| C4 | No | Annual variation is large. |

If prior work along the lines of network science confirmed the presence of core-developers in open-source communities by tracing new code and bugs (Conaldi and Lomi, 2013; Crowston and Howison, 2006b; Mockus, Fielding, and J. D. Herbsleb, 2002), our analysis confirms the presence of core-reviewers. Such presence is in theoretical accordance with the ideological traits of meritocracy that characterize open-source communities (see O’Mahony and Ferraro, 2007; Stewart and Gosain, 2006; Raymond, 2001; Parameswaran and Whinston, 2007). By assuming that developers become maintainers by merit (i.e., by having a good track record of code-contributions), and that core-developers contribute most of the code (Mockus, Fielding, and J. Herbsleb, 2000; Crowston and Howison, 2006a), it is expectable that core-developers with maintenance responsibilities end up reviewing many contributions from other core-developers.

The open-source software development communities are also characterized by the co-existence of mechanisms that reinforce both bureaucratic and democratic values (O’Mahony and Ferraro, 2007; Shaikh and Henfridsson, 2017). As different software development roles exist (Conaldi and Lomi, 2013), the bureaucratic shared norms that empower maintainers can explain in terms of peer review, the relatively strong homophily, tendency for maintainers – who review frequently – to review other maintainers. On this point, as we found out that “maintainer-role” is a determinant of homophily, the peer review practices of Linux convey with the covered theory on social networks and open-source software.

However, contrary to what was theoretically expected (M. McPherson, Smith-Lovin, and Cook, 2001; Kossinets and Watts, 2009; Gallivan and Ahuja, 2015), we found out that the analogous homophily tendency is absent in terms of affiliations. Contrary to postulated by the principle of homophily, we found no evidence of a developers tendency to review other developers with the same organizational affiliation. In such aspect, the Linux peer-review processes remains “fair” – reviewers tend to not review the work of colleagues. This goes in line with the theoretical work of Cooper (2005) and (Morgan, Feller, and Finnegan, 2013) who previously suggested that open-source promotes anti-rivalry and inclusiveness. Contrary to expected from earlier research in social networks (M. McPherson, Smith-Lovin, and Cook, 2001; Kossinets and Watts, 2009; Gallivan and Ahuja, 2015), affiliation does not shape the relational patterns of who review who in Linux. The findings diverge from established research on homophily, but are in line with the few studies that explored so far homophily in the open-source context (cf. Teixeira, Robles, and González-Barahona, 2015; Linäker et al., 2016). If prior related research found that, developers affiliated with competing firms collaborate as openly as developers affiliated with non-rivaling firms do, regardless of their affiliation. Our analysis of peer-review in Linux added then corroborating evidence that in terms of relational patterning, it appears that organizational affiliation “does not matter” as much in open-source communities as in other social networks.
Since we found that "being a maintainer" shapes much more strongly the relational pattern of homophily than "being affiliated with a given organization", it seems appropriate to emphasize the different software development roles and processes in relation to the peer review practices across the Linux kernel subsystems. It is much more likely that the generative homophily mechanisms are driven by software engineering roles and practices rather than the commercialization trend that affected the Linux kernel development throughout the 2000s. In other words, the firm engagement in the Linux kernel development is unlikely to robustly influence the peer reviewing practice followed in the kernel development. From a peer review perspective, and besides the powerful social tendency for people to relate to others similar to them, the ideological values of meritocracy, inclusiveness and non-rivalry seem in good shape besides the Linux commercialization trend.

Contributions
Discussed our key findings, we position our contributions to theory and practice while arguing for the novelty and utility of our research.

The case study results largely reflect the prior expectations about peer reviewing in the Linux kernel. The maintainership aspects, in particular, mirror well the documented peer review practices and policies, social hierarchies, and patch submission procedures. Unlike what was presumed, however, in many respects the peer review networks show significant divergence both between the subsystems and annually across time. In analogy between science and open-source software, it is known that scientific peer-review has historically evolved over time (Benos et al., 2007) and its practices vary from discipline to discipline and journal to journal (Cicchetti, 1991; Weller, 2001). In the open-source arena, and in Linux in particular, our analysis suggests that peer-review practices also evolve over time and vary from subsystem to subsystem. These two aspects undermine the usefulness of the conjectures C3 and C4 for further theoretical hypothesizing.

After noting that the peer review practices of Linux are highly contextual, it is now worthwhile to summarize the general network tendencies that characterize the peer review networks in the Linux kernel:

- Visible but not uniform homophily across two exogenous node attributes (i.e., maintainership and organizational affiliation).
- Maintenance role induces more homophily than organizational affiliation.
- Homophily varies across different subsystems and time.

These observations have some research implications. As it is important to hypothesize about the generative mechanisms[9] that drive the evolution of network dynamics (see Contractor, Monge, and Leonardi, 2011, for a discussion regarding such theoretical generative mechanisms within socio-material systems), our research elucidates that the

[9] As warned by Eck, Uebernickel, and Brenner, 2015, there are different scholarly discourses regarding generativity in IS research. In our research, we refer to mechanisms through which relational structures emerge. We discuss then on the generative mechanisms underlying and producing observable phenomena as in Bhaskar’s foundations of critical realism (Collier, 1994; Bhaskar, 2013). We do not refer to Zittrain’s generativity as outcomes of digital technology (cf. Zittrain, 2006; Yoo, Henfridsson, and Lyytinen, 2010; Kallinikos, Aaltonen, and Marton, 2013).
homophily concept offers one high-level theoretical generative mechanism to interpret the evolution of open-source peer review networks. Given our results, it remains to be evaluated whether homophily is suitable to crystallize a typical OSS peer review network. On the other hand, also the network theories that emphasize self-organization, such as the preferential attachment theory and the onion metaphor (Crowston and Howison, 2006b), are unlikely to provide alone a sufficient empirical explanation for the theoretical generation tendencies (see Carillo and Bernard, 2015). The shape of a probability distribution of weighted network degrees is also unlikely to provide further ground for practical optimization models beyond simple hypotheses about correlation with peer review efficiency measures. On this point, we concur with the growing recognition among social networks researchers that the emergence of a network can rarely be adequately explained by a single theory (Contractor, Monge, and Leonardi, 2011; Monge and Contractor, 2003; Cederman, 2005; Poole and Contractor, 2012).

Our findings add Linux to OpenStack and Hadoop as muddling cases where organizational affiliation “does not matter” as recently reported (see Teixeira, Robles, and González-Barahona, 2015; Linäker et al., 2016). It is still unknown what is exceptional regarding homophily and organizational affiliation – the three cases executed so far, or the whole open-source community. Mining large datasets from software repository/hosting services (e.g., GitHub) should assess if firms within open-source ecosystems are able to work with possible competitors without rivalry homophilous tendencies. Future research is also required the explain such particular heterophily in open-source cases – What can explain such low levels of homophily? The norms, beliefs and values of the community? The virtualization of work practices as developers collaborate with reduced face-to-face interactions? The fact that developers identify themselves with the community and not with the organization that they are affiliated with? The fact that developers concentrate their attention in value-creation neglecting value-appropriation?

More generally, and in an attempt to illuminate the directions of IS research, we believe that the discipline can benefit by further overlap with network science. Not only by applying network analysis methods but also by embracing network theory. As information systems become increasingly networked and interconnected (Henfridsson and Bygstad, 2013; Ciborra, Dahlbom, and Ljungberg, 2000) further promising avenues for future research can benefit from both network theory and network analysis. This article attempted to demonstrate such potential by exploring the theoretical principle of homophily and peer-reviewing in the Linux kernel. Future research along these lines could look at peer review in other complex software development projects and explore other mechanisms of network evolution beyond homophily (e.g., clustering, preferential attachment, randomness, and small-world phenomena among others).

Regarding practical utility, we shed some lights on the Linux peer-review process that should be of practitioners’ interesting. After all, Linux remains a reference case – it is arguably the most studied software project of all time. Moreover, many practitioners are concerned with the commercialization trend in Linux. The so-called “open-source purists” consider that the tenets of OSS ideology (see Stewart and Gosain, 2006) are in danger due to the growing corporate involvement in the Linux kernel. (e.g., Fisher, 1999; Sliwa, 2004). Addressing such concerns, we do not further alarm the purists. When it comes to peer review, our analysis did not found any relational tendency undermining the norms, beliefs and values that characterized Linux since its inception.
Finally, by not looking at our outcomes, but rather to the employed research design. We believe that our method could be applied to investigate many peer-review facets of meritocracy, inclusiveness and rivalry for any given project orchestrated by a software repository - this could be of especial interest for open-source stakeholders wishing to conduct assessments from an ideological perspective. The assessment of community-practices regarding homophily, heterophily, inclusiveness and rivalry could be of governance concern, especially in large scale projects where knowing “who reviews who” is not as straightforward as in smaller projects.

VI. Conclusion

Based on our finding, we argue that besides the increasing involvement of commercial companies in the development of the Linux kernel, its peer review foundations have been preserved. On one hand, the commercialization trend and the arrival of paid development have not generated a forceful homophily tendency for affiliated developers to review other developers with the same affiliations. A contrary result would have been alarming for the OSS advocates and their ideologies. As Linus Torvalds emphasized already in the late 1990s, the point of OSS peer reviews is to find developers with different backgrounds to review each other (Lee and Cole, 2003).

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