Tomáš Karger

The Weight of the Intangible

Knowledge Networks in Free and Open Source Software Development

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Contents

List of Abbreviations

API (Application Programming Interface)
BSD (Berkeley Software Distribution)
CLA (Contributor License Agreement)
FOSS (Free and Open Source Software)
FSF (Free Software Foundation)
GDB (GNU Project Debugger)
GES (Gstreamer Editing Services)
GNU (GNU is not UNIX)
GPL (General Public License)
GTK (GIMP Toolkit)
GUADEC (Gnome User and Developer Conference)
HTML (Hyper-Text Markup Language)
IP (Internet Protocol)
IRC (Internet Relay Chat)
KVM (Kernel-based Virtual Machine)
LGPL (Lesser General Public License)
LOC (Line of Code)
OSI (Open Source Initiative)
POSIX (Portable Operating System Interface)
QEMU (Quick Emulator)

Preface

This book is a reworked and refined version of my dissertation thesis, which I was able to successfully defend in the fall of 2015. The text concludes with essentially the same points, although they are now better articulated thanks to the suggestions of two reviewers. The text is also structured differently to provide better orientation for the reader. In addition, many small modifications were made to the text as a result of re-reading and re-considering some of its parts.

The original topic of my dissertation research was quite a different one. It should have been a theoretical work about the concept of self-organization (or emergence, spontaneous order) and its use in the social sciences. Having a technological background in my education, I was fascinated by the language of Cybernetics and Systems Theory (Niklas Luhmann's theory in particular) and by the images of spontaneously emerging order. The reader can still trace these influences in several footnotes appearing throughout the work. It was only during the first year of my Ph.D. studies that I realized that I could put my education to use in a different way. I could do participant observation in a field where not many sociologists or anthropologists would feel at home. This went hand in hand with the fact that I found two fields to be repeatedly listed as empirical examples of self-organization: science and free and open source software development. The former has been researched for quite some time now with a substantial body of literature on record. But the latter has only about a decade and a half on its record with a significantly smaller body of literature. This was an area where I could make a good contribution. Moreover, since high school (where I studied electrotechnical engineering), I have been a user interested in the latest developments in free and open source software, which provided me with a rough picture of the field's most basic dividing lines.

All of this led to my decision to officially change the topic of my dissertation, leaving me with a lot to catch up on but also with the advantage of my prior everyday knowledge, which of course had to undergo a thorough reflection. Eventually, my findings led me to a rather critical position regarding the images associated with self-organization as I uncovered their limited relevance and the utopic valence they carry. There is some irony in the fact that one of the points of this work is to show the limitations of the images which initially fascinated me and drew me to the topic. But I take this as a sign that I did not succumb to my initial preconceptions. How much this work will transform knowledge in the relevant fields of study remains to be seen. However, a different transformation has already taken place, that of its author.

I would like to thank my colleagues and mentors for inspiration, advice and guidance. In particular, I would like to express my gratitude to Miroslav Dopita, Wolfgang Hofkirchner, Piotr Chomczyńksi, Jan Kalenda, Dagmar Lorenz-Meyer, Dušan Lužný, Albert Müller, Libora Oates-Indruchová and Gerlinda Šmausová. I am also grateful to my friends and members of my family for their support and patience.

Introduction

For some, software development is an activity obscure enough that it should nicely connect to the anthropological tradition of studying exotic cultures shrouded in mystery. Others may find it as boring as reading through telephone books – a different kind of information infrastructure. However, reading and writing source code (which is the primary activity behind software development) has been recently pronounced to be a new form of literacy by many influential individuals.[1] The atmosphere induced by this assumption has spread considerably. Some software developers criticize it[2] while many officials endorse it – to name the most prominent example, Barack Obama became the first US president to write a line of source code.[3] Without trying to position myself in the discussion about the legitimacy of the literacy status of programming, I want to point out that the spread and significance of activities associated with software development have risen considerably from the times when computers could be afforded by few and the knowledge necessary to operate them was held by even fewer, to the times when GitHub, a web service designed to share source code, is among the top 100 most visited sites on the Internet.[4]

This development went hand-in-hand with another process, a shift in which free and open source software (FOSS), as a movement or as a software development methodology, established itself against the traditional proprietary model. It suffices to reiterate the glaring difference between

[1] See the Code.org initiative which revolves precisely around this assumption and is supported by the likes of Bill Gates and Mark Zuckerberg.

[2] *Coding is not the new literacy*. Blog post of a well-known software developer relayed by Slashdot, a popular user curated news site. Published: 2015-01-26. Accessed: 2015-04-30. Available at: http://www.chris-granger.com/2015/01/26/coding-is-not-the-new-literacy/.

[3] *President Obama Is the First President to Write a Line of Code*. Article published by The White House Blog. Published: 2014-12-10. Accessed: 2015-04-22. Available at: https://www.whitehouse.gov/blog/2014/12/10/president-obama-first-president-write-line-code.

[4] *How Github Conquered Google, Microsoft, and Everyone Else*. An article in the Wired magazine. Published: 2015-03-12. Accessed: 2015-04-21. Available at: http://www.wired.com/2015/03/github-conquered-google-microsoft-everyone-else/.

the 1970s and the present day, pointing at the scale of involvement of significant players of the technological industry in open source software.[5] However, there is a more illustrative way of showing the gradual establishment of free and open source software.

In 2001, the Microsoft CEO Steve Ballmer famously stated that "Linux is a cancer that attaches itself in an intellectual property sense to everything it touches."[6] For a long time, Microsoft was seen as the arch enemy of free and open source software. This relationship occasionally culminated in statements like Ballmer's or, from the other side of the barricade, pokes by Linus Torvalds, the originator of the Linux kernel: "Really, I'm not out to destroy Microsoft. That will just be a completely unintentional side effect."[7] Such was the atmosphere in 2003. One decade later, in October 2014, a Microsoft CEO Satya Nadella says that "Microsoft loves Linux."[8] In February 2015, Microsoft releases its important .NET framework on GitHub under an open source license.[9] And in April 2015, Mark Russinovich, one of Microsoft's top engineers publicly states that open sourcing Windows, the company's core product, is "definitely possible."[10]

These statements mark a shift during which the open source approach to software development rose from a challenger to an established position. Microsoft, a company that has embodied the success of

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[5] Among top contributors to the development of Linux Kernel, the hallmark of open source software, there are companies such as Intel, Samsung, IBM, or Google (Corbet, Kroah-Hartman, & McPherson, 2015, p. 11).

[6] *Microsoft CEO takes lunch break with the Sun-Times*. Interview published by Chicago Sun Times. Published: 2001-06-01. Accessed: 2015-04-22. Available at: http://www.linuxtoday.com/infrastructure/2001060100920OPMS.

[7] *The Way We Live Now: Questions for Linus Torvalds*. Interview published by The New York Times Magazine. Published: 2003-09-28. Accessed: 2015-04-22. Available at: http://www.nytimes.com/2003/09/28/magazine/the-way-we-live-now-9-28-03-questions-for-linus-torvalds-the-sharer.html.

[8] *Why Microsoft CEO Satya Nadella Loves What Steve Ballmer Once Despised*. Article published by Wired magazine. Published: 2014-10-21. Accessed: 2015-04-22. Available at: http://www.wired.com/2014/10/microsoft-ceo-satya-nadella-loves-steve-ballmer-despised/.

[9] *.NET Core is Open Source*. Blog post on the Microsoft Developer Network website (msdn.com). Published: 2014-11-12. Accessed: 2015-04-22. Available at: http://blogs.msdn.com/b/dotnet/archive/2014/11/12/net-core-is-open-source.aspx.

[10] *Microsoft: An Open Source Windows Is 'Definitely Possible'*. Article published by Wired magazine. Published: 2015-04-03. Accessed: 2015-04-22. Available at: http://www.wired.com/2015/04/microsoft-open-source-windows-definitely-possible/.

the proprietary approach to software development, is the one who has to catch up, as Nadella openly admits.[11] Indeed, free and open source software became ubiquitous in the world of digital technology, in large part because other companies like Google learned to build their business models around this type of software development.[12] The shift was also recognized in the world of Linux distributions, where Ubuntu, one of the most popular distributions, had a longstanding bug in its issue tracking database (filed in 2004, it was actually the first bug in the database), which was labeled "Microsoft has a majority market share."[13] The bug served as a mission statement – that Ubuntu was intended to provide an alternative which could possibly end the dominance. Eventually, the role played by Ubuntu in the shift was not direct, but the shift took place nevertheless. Mark Shuttleworth, the founder of Ubuntu, closed the bug in May 2013, noting that Microsoft no longer had a dominant market share in computing platforms.

With this introduction, I do not intend to argue that free and open source software development is superior to other development models or that it is the future of computing. My intention was merely to show the relevance of this topic – that while the practices and cultural aspects of free and open source software may seem unusual, they do not involve just a few hobbyists at the periphery of the computing industry. It is now heavily involved in developing and maintaining the information infrastructure that became so important during the last decades. The subculture became heavily intertwined with current capitalist practices, changing the nature of both in the process. And it is the aim of this work to describe free and open source software development precisely in this context.

Another type of context this work is involved with is that of cyberspace. A predominant part of my research takes place online. This means that the information flows necessary to gather data and interact with

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[11] *Why Microsoft CEO Satya Nadella Loves What Steve Ballmer Once Despised*. Article published by Wired magazine. Published: 2014-10-21. Accessed: 2015-04-22. Available at: http://www.wired.com/2014/10/microsoft-ceo-satya-nadella-loves-steve-ballmer-despised/.

[12] For example, Google's Android, currently the most popular mobile operating system, is based on Linux.

[13] *Microsoft has a majority market share*. Bug in Ubuntu's issue tracker at launchpad.com. Published: 2004-08-20. Accessed: 2015-04-23. Available at: https://bugs.launchpad.net/ubuntu/+bug/1.

participants are carried through a technical infrastructure known as the Internet. I will attempt to follow the methodological implications briefly in the following paragraphs.

According to Bruno Latour, this digital environment greatly increases the materiality of networks, making them less virtual than before (Latour, 2010, p. 8). This claim seems to be at odds with how the online environment is typically characterized – as bringing virtuality into a world that has been up to that point material. Drawing upon Latour's work, I see the digital as a result of an actual network of ties that had to be put together.[14] In the end, digital information is nothing else than organized values of voltage differences. But one does not need to go that far. It is sufficient to consider the actual effort that goes into creating a digital artifact – the mobilization of actual people spending their actual time, connected through an actual infrastructure. Therefore, in this text, digital is seen not as virtual, it is seen as actual, that is, material, graspable and traceable.

The Internet infrastructure is often characterized as making time and space irrelevant, but such claims hold only in a certain sense and need to be carefully specified. The time dimension is displaced by the ability of digital information to persist. This can be illustrated by the opposition of synchronous and asynchronous communication, which is elaborated for example by Lorenzo Cantoni and Stefano Tardini (Cantoni & Tardini, 2006, p. 44). Tools belonging to the former type of communication are not designed for the later retrieval of information and because of that both parties have to be present at the same time.[15] On the other hand, tools belonging to the latter type of communication create a persistent trace that can be retrieved at a later time and in doing so enable both parties to sustain the communication even when they are not simultaneously present.[16]

Second, space is to some extent rendered irrelevant by the infrastructure's ability to transfer information in real time between nodes of the network. However, this does not mean that the space dimension of the

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[14] An alternative would be to look at the Internet as a distinct kind of space where interaction is made possible, as for example Anette Markham (2004, p. 99) notes. But that would correspond to a different kind of social topology (regions), than which is used through this text (networks). For a more detailed elaboration of the difference, see the work of Annemarie Mol and John Law (1994).

[15] A classic example of this type of communication tool is chat.

[16] A classic example of this type of communication tool is email.

world becomes wholly irrelevant. The problem known as the digital divide refers to the fact that infrastructure is far from being universally present throughout the world (Norris, 2001). If present, infrastructure provides varying levels of connectivity. As a result, there is a bandwidth limitation which often favors low bandwidth media (such as text) for transferring information (Cantoni & Tardini, 2006, p. 44). Although higher bandwidth media (such as pictures, sound, video) are ever more common, these play only a supplemental role in practices like software development as these practices predate the spread of digital high bandwidth media and thus are fully attuned to the nature of digital text.

With regard to spatiality, Cantoni and Tardini also speak about the "new syntax" related to the word 'here'. This word can now have several distinct meanings: it can mean the place where the body of the user is physically present; it can designate the online space the user is active in; and it can also denote the desktop space of a computer (Cantoni & Tardini, 2006, p. 59). As if this was not enough, Anette Markham notes that users are typically present in more than one online space at a time (Markham, 2004, p. 105), making the traditional notion of presence limited to only one place problematic.[17]

This issue shows its full extent once we realize that the data gathering techniques of ethnography are traditionally very closely related to presence in the field (i.e. at a certain place). The approach to data gathering must be adjusted appropriately and this is where the multi-sited version of ethnography comes into play. This approach has been developed since 1995, when the defining article by George Marcus was published. In it, Marcus defined multi-sited ethnography as a form of research that traces a certain phenomenon through various settings (Marcus, 1995, p. 669). According to Mark Falzon, this approach rests on the assumption that space is socially produced and on a subsequent realization that ethnographers could also produce a space of their own (Falzon, 2012, p. 4).

However, the conceptualization of space in this approach is far from unproblematic. Joanna Cook, James Laidlaw and Jonathan Mair suggest distinguishing between space (geographical area), place (cultural territory) and field (cultural territory in a geographical area appropriated for research) (Cook, Laidlaw, & Mair, 2009, p. 60). According to these authors, the turn to multi-sited ethnography implied an acknowledgment

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[17] The multiplicity of communication sites that are maintained by varying types of collaboration is also noted by Christine Hine (Hine, 2000, p. 115).

that cultural territories spanned multiple geographical areas or were part of networks that could not be examined from one geographical area only. In order for the field to correspond to a cultural territory, it has to involve multiple geographical areas (Cook et al., 2009, p. 63).

But Cook, Laidlaw and Mair went beyond what the first generation of researchers promoting multi-sited ethnography proposed and suggested an approach called "un-sited ethnography" (Cook et al., 2009, p. 69).[18] They made one more distinction by insisting that whereas spaces or places are two (or more) dimensional areas, ethnographic field is only a collection of one-dimensional lines connecting points of observation. These lines may intersect borders found in spaces or places and in doing so, provide useful data for making comparisons (Cook et al., 2009, pp. 63–64). The decisions on what to include in the network-shaped field should be made based on what the research is focused on and what the research questions are (Cook et al., 2009, p. 65). In this regard, it is possible to draw upon Marcus who laid out several options of what can be traced through the various settings. These options include following certain people, things, metaphors, narratives, biographies or conflicts (Marcus, 1995, pp. 106–110).

Within this research project, the un-sited approach is useful for drawing together various sites and platforms that are mobilized during the studied instance of software development. There is a chat channel for synchronous communication, a database for issue tracking, a repository for hosting source code, a website as a persistent reference point for information and there are also events at which developers from a broader community come together. What ties these sites together is the role they play in development of a particular piece of software and the fact that there are frequent references and links among them.

The interaction nodes present on online platforms provide the substrate for my points of observation. My field is quite literally constituted of links between these points. Within this field, I employed participant observation in order to have direct experience with tools, artifacts, platforms and infrastructures employed in knowledge building while also experiencing the whole process of establishing a work environment, learning how the tools behave and coordinating work on contributions.

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[18] Similarly, David Hakken proposes a non-site bound or trans-sited approach to grasp cyberspace research that takes advantage of the hypertext nature of the web (Hakken, 1999, p. 59).

Contributing to the project[19] also has an ethical dimension of giving back to the project, whose maintainers agreed with my fieldwork.

My entrance into the field happened in several stages. The first direct contact I made with the field was at the GNOME Users and Developers European Conference, which is an annual event (in 2013 it was hosted in Brno, Czech Republic) focused on development of the GNOME desktop environment. GNOME is a wide project aggregating many smaller projects underneath its label. Therefore, my presence at the event had a twofold purpose: to try to pre-select a smaller project where I could carry out participant observation and to familiarize myself with the environment by being present at the conference itself, as well as the hackfests (events dedicated to aggregating participants to work together on a selected problem) that took place after the conference officially ended.

In November 2013, through monitoring the GNOME blog aggregator Planet GNOME, I discovered that a project called Pitivi needed someone to write user documentation. It turned out that it was a rather small project aimed at developing video editing software and that it met all of the above listed criteria. I decided to contact the author of the blog post (who was one of the maintainers of the project) using the project's chat channel so that our conversation would happen somewhere that anyone associated with the project might be present, in the sense of being able to read it or participate in it. In this contact, I made it clear that I would be contributing to the project as part of my research and I spent some more time in the channel discussing the aims of my research project with several core developers who expressed interest.

From that point on, I became a curious newcomer who required help and explanations at times, and who also tried to learn and give back by doing something that would be of use to the project. Taken together, my participant observation was spread over a time frame of around half a year, starting on the first day of contact in the chat channel. However, my passive presence in the project – everyday monitoring of the chat channel where all of the non-private synchronous communication takes place and browsing through the sites holding records of asynchronous communication – spanned about a year, until the end of 2014. Part of the interaction with the software developers later on revolved around reading some of the material I wrote (an article discussing my prelimi-

[19] I assumed the role of documentation writer, which means that I edited and extended the user manual of the developed software.

nary results). To conclude this introduction, let me turn to the structure of the present work and its argument.

In the following paragraphs, I briefly summarize the content of individual chapters. In the first chapter (*From UNIX to Technological Utopia*), I give an overview of research on free and open source software relevant for this work. I start with a brief historical note to clarify the origins and cultural significance of the phenomenon. I then proceed to elaborate on the characteristics of the phenomenon, including common norms or values, demographics, status hierarchies, organizational structures, socialization processes, and its relationship to the capitalist mode of production. I note that in some works, the phenomenon is conceptualized as a new form of organizing production and is associated with positive anticipations, sometimes even utopian visions. I argue that these anticipations are part of a broader discourse centered around the potential of digital technologies and cyberspace. The claims made within the discourse rely on an assumption that knowledge has replaced capital, labor and natural resources as central productive forces. Informed by its critique, I formulate the general question of this work, which is, how is knowledge dynamized within the networks of FOSS projects?

In the second chapter (*Software and Knowledge*), I attempt to relate software and programming to knowledge conceptualized in accordance with some of the basic sociological works on the topic. Most importantly, I elaborate upon the role artifacts (tools or prototypes) play in software development, and introduce the distinction between information and knowledge. Then I proceed to formulate the problem of decontextualization – loss of knowledge or meaning during information transfer. A theoretical solution to this problem can be found in Alfred Schütz's work in the form of idealizations allowing for reciprocity of perspectives. The chapter concludes with an attempt to contextualize Schütz's idealizations in a digital environment by relating them to the role of artifacts and to the distinction between information and knowledge elaborated earlier in the chapter.

In the third chapter (*Network Shaped Knowledge Distribution*), I draw upon the theory of distributed cognition and the Actor-Network Theory to clarify the cognitive relevance of artifacts and to introduce the infra-language I use for further analysis. The section revolves around three topical areas: (1) the role of objects external to the human mind (or body) in creating cognitive accomplishments; (2) the concept of network; (3) the concept of mediation with its four meanings of translation, composition, delegation and black-boxing. After an elaboration of these topics, the research question is reformulated in terms of the infra-language introduced in the chapter.

The fourth chapter (*Practices of a FOSS project*) contains detailed descriptions of the four most significant practices I encountered during my fieldwork. Each of these practices is tied to a particular element of infrastructure that the studied project is using. (1) Code allocation is affected by an overall architecture of the developed software in which licensing plays a considerable role. (2) Knowledge channeling is tied to various means of communication used in the studied project such as chat channels, blogs, or wiki pages. Here, the self-documenting characteristic of FOSS projects is described. (3) Debugging consists of investigating and explicating issues in the developed software. It relies heavily on the use of programs that are able to observe the internals of running software and on databases that are used to keep records of issues. (4) Revision tracking is mainly concerned with producing and recording texts that capture differences which were introduced into source code with its modification. It is tied to version control systems, which function as a bridge between private and public spaces. All of these descriptions are supported and illustrated by my own experience, by observed communication among other participants and by excerpts of documents I analyzed.

In the fifth chapter (*Mediation and Resources Inside a FOSS Project*) I relate my descriptions to the infra-language elaborated in chapter two to take the first step toward their generalization. The specific focus is on relating the descriptions to the four meanings of mediation (translation, composition, delegation and black-boxing), which are also used to structure the text further into subsections. The second part of the chapter focuses on examination of resource flows within FOSS projects. It attempts to throw light on the puzzling problem of how FOSS projects are able to sustain themselves given that the costs associated with software development are notoriously high. The subsection describes various strategies the projects use to either avert the costs associated with software development or to gain resources of their own. The subsection concludes with an examination of the involvement of private companies in strategically positioned FOSS projects.

In the last chapter (*Conclusion*), I bring together all the important points I made throughout the text. I argue that the problem of decontextualization is diminished by using standard tools, licenses and commonly structured design artifacts (such as prototypes). These standard entities allow for conventionalization of information appropriation and control of situational circumstances to create conditions suitable for producing and applying knowledge. I also note that the amount of decontextualized information surrounding software development constitutes a barrier that is very difficult and costly to overcome. Therefore, I claim that even though the formal licensing terms under which the software is published purposefully suspend the rights traditionally associated with ownership and ascribe them to anyone, in practice these rights are exercised only by a small group of actors who are enabled to do so by holding specific types of knowledge. This clarification of the close relationship between knowledge and (practical) ownership is one of the two major points this work attempts to make. At face value, this point seems to confirm the assumption of a utopian vision, mentioned in the introductory chapter, that knowledge becomes the sole source of production. However, as the second major point of this work, I attempt to explicate limits to the images of free and frictionless association resulting from the visions formulated with regard to digital technologies and cyberspace. I attempt to do so by showing that knowledge does not immaterially operate upon itself, while drawing upon my descriptions to demonstrate that there is still a material production system surrounding the mind.

1

From UNIX to Technological Utopia

1.1 Free and Open Source Software

Free and open source software development began to be systematically researched at the turn of the millennium. According to Christopher Kelty, who was studying it consistently during the first decade after the turn, it can be defined as:

> *software whose source code (the code humans read and write) is made freely available (generally on the Internet, without restriction) through the use of a special copyright license. The software is copyrighted by its creator and then distributed under one of several standard licenses that allow the licensee to use the software, to distribute it, to copy it, and even to modify it for his/her own purposes. Some licenses require that if the software is re-distributed, any changes need to be released under the same license used to offer it in the first place (this is variously referred to as reciprocal, recursive, or viral). The most famous of these licenses is the GNU General Public License created by the Free Software Foundation. (Kelty, 2004, p. 501)*

Many of the characteristics that Kelty describes in his definition were inherited from the practices established around UNIX, a very successful operating system from the 1970s. Its success is attributed to the fact that it could run on affordable computers, that its source code was distributed together with its binaries and that its license permitted modifications to source code and even sharing of those modifications among licensees (Söderberg, 2008, p. 15). Retrospectively, we[20] can see that the main characteristics of the development model central to free and open source software was already present in practices related to the predecessor (direct or indirect) of many of today's widespread operating systems including a variation of BSDs (Berkley Software Distribution), Linux-based distributions or Mac OS X.

However, in the 1980s the AT&T company attempted to enforce ownership rights over UNIX which, according to Söderberg, resulted in the informal programmer community established around UNIX becoming skeptical of the existing intellectual property regime (Söderberg, 2008, p. 19). This led Richard Stallman to found the Free Software Foundation (FSF) in 1984, an organization dedicated to allowing computer users to operate without proprietary programs. The break with the privatized UNIX system is represented by the acronym GNU (GNU is Not UNIX), which is used to label all software and licenses (for example, the GNU Compiler Collection, or the GNU General Public License) that the FSF produces. The endeavors of FSF included development of an operating system kernel (called GNU Hurd) as a substitute for UNIX. However, the work had been significantly delayed due to licensing issues with the Mach microkernel, which was to be released by the Carnegie Mellon University under a suitable license and thus was proposed by Stallman to be used as a basis for development.[21]

Another reaction to the privatization of UNIX came from researchers at the University of California, Berkeley who participated heavily in UNIX development. They resorted to removing every line of code from UNIX that AT&T claimed and replaced them with their own code. The result is known as the Berkeley Software Distribution (BSD) and is still actively developed in several versions. However, in the early 1990s, AT&T sued UC Berkeley for infringement, which led to a trial that AT&T eventually lost, but which in the meantime drove developers away with the fear that their work could end up being claimed by the company (Söderberg, 2008, p. 24). Instead, the developers started contributing to another kernel project written from scratch by Linus Torvalds and licensed purely

[20] In this text I employ one rule concerning the use of personal pronouns consistently: I use "we" when I take into consideration the reader following my description or argumentation; "I" is used in every other case, often indicating that I take responsibility for particular decisions or the unfolding of the text in general.

[21] Source: https://www.gnu.org/software/hurd/history.html.

under the GNU General Public License (GPL). This project, today known as Linux, established a strong position during the rest of the 1990s and became (together with other successful projects such as the Apache web server) the hallmark of the new software development model (Kelty, 2004, p. 503). The conclusion that Johan Söderberg draws from this historical development is that Linux succeeded "not because it was backed by the highest concentration of capital, but to the contrary, because under the GPL it had the *purest absence of private property relations* [emphasis original]" (Söderberg, 2008, p. 24).

However, in spite of the success of several projects, free software was predominantly perceived as hostile to private businesses, a result of the value system developed by Stallman and the FSF, which considered free software a moral standard and was very critical of anyone using or developing proprietary software. To capitalize on the success of free software projects, Eric Raymond and Bruce Perens founded the Open Source Initiative in 1998 to redefine the existing development model with this new term. In doing so, they attempted to play down the moral and political associations that free software was bundled with and instead to emphasize the practical advantages of the development model (Kelty, 2004, p. 503).[22,23] Since then, there has been a spread of business models revolving around open source software.

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[22] At that time, this also meant going against a widely influential premise formulated by Fred Brooks. In his book, *The Mythical Man-Month*, Brooks argued that "Cost does indeed vary as the product of the number of men and the number of months. Progress does not. Hence the man-month as a unit for measuring the size of a job is a dangerous and deceptive myth. It implies that men and months are interchangeable. Men and months are interchangeable commodities only when a task can be partitioned among many workers with no communication among them (...). This is true of reaping wheat or picking cotton; it is not even approximately true of systems programming." (Brooks, 1995, p. 16) From this argument, Brooks deduced the famous Brooks's Law: "Adding manpower to a late software project makes it later." (Brooks, 1995, p. 25) After formulating the premise, Brooks argued that, for teams of software developers, the only organizational form which can assure efficiency and conceptual integrity is the one modeled after surgical teams, where problem solving is reserved for one person while everyone else provides necessary support (Brooks, 1995, p. 32). However, the FOSS software development model is based on an exactly opposite model of organization, involving volunteer association, work self-assignment and occasional contributions. Therefore, at that time, the FOSS model existed as an unexplained alternative.

[23] In this text I use the expression "free and open source software" (FOSS) to denote both branches of the movement represented by the Free Software Foundation and the Open Source Initiative respectively. I can allow myself to amalgamate the branches

But the significance of FOSS goes beyond successful software development projects. Broadly speaking, Kelty grasps free software as a movement with several defining characteristics: sharing source code, emphasizing and conceptualizing openness and using copyleft licenses and collaborative practices (Kelty, 2008, p. 14). Within those loose boundaries, there are varying practices that can be deemed conventional or experimental. This leads Kelty to postulate a system of thresholds discovered by collective experimentation within the movement. However, sometimes the experiments consist in attempts to apply conventional FOSS practices to other areas of production. In these cases, Kelty speaks of "modulations" of FOSS practices (Kelty, 2008, p. 16). As Kelty notes, FOSS values and practices have spread to or inspired other realms of life in recent years (Kelty, 2008, p. 2). These include hardware design and manufacture (Open Hardware[24]), science (Open Access[25]), media (Creative Commons[26]), knowledge management (Wikipedia[27]), visual arts (the Processing language[28]) and even ecological engineering (Open Source Ecology[29]). What all these initiatives have in common is, according to Kelty, that they use Internet as a key infrastructural element while attempting to reorient knowledge and power (Kelty, 2008, p. 16). Taken together, this historical development exemplifies the "cultural significance of free software" (which is the subtitle of Kelty's book).

Inside the FOSS movement, the predominant personal identity is that of a hacker.[30] The corresponding verb "hacking" designates work that, as Pekka Himanen claims, is tied to a specific ethic. Himanen describes the

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because most of the time I am not concerned with their value differences (and where I am, I differentiate between them), but with practices associated with them, which, as Kelty notes, are common: "for all the ideological distinctions at the level of discourse, they are doing exactly the same thing at the level of practice" (Kelty, 2008, p. 14).

[24] See http://www.ohwr.org.

[25] See http://www.doaj.org.

[26] See http://www.creativecommons.org.

[27] See http://www.wikipedia.org.

[28] See http://www.processing.org.

[29] See http://www.opensourceecology.org.

[30] In this context, the term "hacker" has a positive connotation and denotes someone who cleverly takes advantage of a formal or automated system. However, this does not necessarily involve criminal activities. To differentiate themselves, the free and open source software hackers use the term cracking or crackers to denote those who perform hacking with criminal intent.

hacker work ethic as being primarily based on passion and opposed to what has been, with reference to Max Weber's work, called the Protestant work ethic (Himanen, Castells, & Torvalds, 2001, p. 6). Work is seen by hackers as intrinsically interesting, inspiring, and joyous. On the other hand, the Protestant ethic perceives work as a calling – work is a duty which is an end in itself and must be done as well as possible.

This rendering of the hacker work ethic resonates with several later studies which emphasize the key role of intrinsic motivation for volunteer involvement. For example, one of the findings in a study by Sonali Shah is that while initial contributions to software development projects often serve to satisfy a need for improved functionality of the software, many of those who stay involved do so because they enjoy the work (Shah, 2006, p. 1010). Correspondingly, Stephanie Freeman claims that although the life situations of contributors vary widely, the commonality is that the boundary between work and hobby is blurred in their involvement (Freeman, 2007, p. 73). Furthermore, Margit Osterloh and Sandra Rota (Osterloh & Rota, 2004, pp. 291–292) identify two institutional preconditions for establishing intrinsic motivation within FOSS projects: enabled self-determination and conditional cooperation (contributing when others are too). Osterloh and Rota further claim that the intrinsic motivation of project members translates into the project's trustworthiness for those outside it of it (Osterloh & Rota, 2004, p. 296).[31]

Yet motivation is not the only determinant of participation in FOSS projects. The demographic characteristics of a typical contributor, as summarized by Söderberg, show that FOSS projects are populated mainly by "middle-class males living in the West" (Söderberg, 2008, p. 28).[32] According to the author, this situation has its origins in the early

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[31] However, it must also be noted that there are limitations associated with intrinsic motivation. While trying to explain the lack of a significant relationship between intrinsic motivation and participation levels, Roberts et al. point out that the enjoyment of work may sometimes come at the expense of its outcome, or that intrinsically motivated individuals tend to be more self-directed, which could potentially cause problems in aligning their goals to those of their collaborators (Roberts, Hann, & Slaughter, 2006, p. 996).

[32] A more detailed, though older, summary is offered by Holtgrewe, who draws on surveys by Ghosh et al. (2002) and Lakhani et al. (2002): "developers are youngish with an average age below 30 years. They are almost exclusively male (98–99%). 60–70% are university or college graduates, 20–30% are students. Around 80% are IT professionals, which leaves roughly a fifth of amateurs in the sense that they have nothing to do with the IT industry" (Holtgrewe, 2004, p. 10). These basic characteristics are consist-

days of computing when access to computers was highly restricted. However, these restrictions have been considerably lowered as the price of computers has declined. Currently, Söderberg sees the main cost in the amounts of leisure time that need to be spent in order to contribute to a project (Söderberg, 2008, p. 28); this resource is distributed along different lines than wealth and that, as a result, privileges aggregates such as students or the unemployed.

It is perhaps not surprising that there is a significant gender imbalance in FOSS projects. But this, according to Söderberg, cannot be explained by an active struggle for economic resources, as many of the projects are predominantly volunteer oriented.[33] On the other hand, there is not much preference, across FOSS projects, to actively seek and support underrepresented groups. The projects are declaratively and practically open, but the emphasis placed on meritocracy translates into a widespread opinion that it is up to the underrepresented groups to exert effort and join the activities (Söderberg, 2008, p. 29).[34]

This leads us back to the topic of values forming the hacker ethic. As such, the hacker ethic can be summarized as adhering to seven basic values (Himanen et al., 2001, pp. 139–141):

1. Passion – hackers work on tasks intrinsically interesting for them and enjoy their realization.
2. Freedom – hackers organize their life around creative work and other passions, they oppose routine and monotonous work.
3. Social worth – hackers aim to create something valuable and be recognized for that by their peers.

ent with the latest survey carried out in 2015 by the Stack Overflow web portal (Stack Overflow, 2015), which is focused on knowledge sharing among software developers or system administrators. Furthermore, the dominance of western countries in contributions to FOSS development is also supported by Yuri Takhteyev and Andrew Hilts (Takhteyev & Hilts, 2010, p. 6), who studied the geographical distribution of users of GitHub, the largest provider of services for sharing source code.

[33] Again, a more detailed description can be found in Holtgrewe (2004, p. 10): “Between half and 80% of FS/OS developers are volunteers. For the majority, involvement is limited to the extent of a more or less time-consuming hobby. Roughly two thirds of developers spend less than 10 hours per week on FS/OS development.”

[34] Although there are exceptions, such as the Outreachy program originating from the activities that took place already in 2006 under the patronage of the GNOME Foundation. The project’s website can be found at: https://www.gnome.org/outreachy/

4. Openness – hackers allow further usage, development or testing of their creations by anyone.
5. Activity – hackers prefer active pursuit of passion over passive receptiveness.
6. Caring – hackers perceive concern for others as an end in itself.
7. Creativity – hackers respect the imaginative use of abilities and providing new and original contributions.

Some of these values can be clustered into more general areas of conduct. According to Himanen (2001, p. 140), the values of passion and freedom constitute the hacker work ethic, the values of social worth and openness form the hacker money ethic and the values of activity and caring serve as a basis for the hacker network ethic, or "nethic", while creativity, the seventh value, permeates all of these areas. With reference to concrete activities, Katherine Stewart and Sanjay Gosain (K. Stewart & Gosain, 2006, p. 303) found four types of values present in FOSS communities: collaborative values (helping, sharing, cooperation), individual values (learning, technical knowledge, reputation), process values (bug fixing, code quality, status attainment) and freedom values (free information, free software). Based on their research, the authors claim that in most cases, these values have a positive impact on trust and communication quality (K. Stewart & Gosain, 2006, p. 303), which means that they are functional with regard to community building and technical performance.

Overall, the hacker ethic seems to imply the abolition of the distinction between work and leisure. Meaning cannot arise from duty bound work or unproductive leisure, it can be found only in the intrinsic value of a passionately performed activity (Himanen et al., 2001, p. 151). These values are, of course, not uniformly applicable to the movement as a whole so that the actions of every member would be generally determined by them. There are significant differences, most notably for example between the adherents of free software or open source software. But these values indicate the overall spirit the movement as such represents.

We can see that the norms are predominantly concerned with regulating the process of software development. This is indicative of what Kelty emphasizes by calling free software a recursive public, that is, a public "that is vitally concerned with the material and practical maintenance and modification of the technical, legal, practical, and conceptual means of its own existence as a public; it is … capable of speaking to existing forms of power through the production of actually existing alternatives" (Kelty, 2008, p. 3). In other words, this type of public is able to develop and deploy its own infrastructure, be it technical, legal, or conceptual. Because of this, it can enjoy a significant amount of independence.

In FOSS, technical recursivity is achieved primarily by the preference to use FOSS software as tools. Therefore, FOSS projects build on existing FOSS software to develop new programs. As Matt Ratto notes, in terms of FOSS development projects, there is a difference between software as a compiled tool and software as an object of work (Ratto, 2007, p. 96). Furthermore, considering the distinction between mutable and immutable mobiles, introduced to the FOSS studies by Mary Darking and Edgar Whitley (Darking & Whitley, 2007, p. 24), the developed software (object of work) and the used software (tools) differ in the nature of their presence in FOSS projects. While software tools could be characterized as immutable mobiles which maintain their shape despite the configuration of relations they enter, the developed software could be characterized as a mutable mobile – an unstable, situation dependent, or even "fluid" object. This is so because all the information and knowledge necessary to meddle with the developed software is actually and readily available in a given project, while for software used as a tool (and developed at another place) this is available only as a potentiality.

The distinction between the hacker and Protestant ethic also seems to be historically embedded in different spheres of life. Himanen (2001, p. 6) argues that the historical precursor of the hacker work ethic was the work ethic employed in the antique academia, with its intrinsic interest in knowledge, the search for inspiration and the joy of discovery. The Protestant work ethic is supposed to have its precursor in a work ethic present in medieval monasteries and its emphasis on the fulfillment of duties. The Protestant work ethic, as shown by Weber, was eventually embraced by capitalism, which stripped it off the religious context and preserved the emphasis on duty fulfillment (Weber, 2001). As the hacker work ethic is fundamentally different from the Protestant work ethic, Himanen (2001, p. 12) argues that its existence and spread poses a challenge for present-day capitalism.

This is why the hacker work ethic seems to be significant and worthwhile, but it still needs to be elaborated in more detail. First, it is a work ethic so it must be distinguished from utopian images of a life without doing anything. The hacker work ethic is characterized by a preference for tasks that are found to be interesting, inspiring and for the completion of which the hacker is even willing to go through less joyful stages (Himanen et al., 2001, p. 19). Furthermore, the hacker ethic involves the belief that the use and optimization of machines should lead to a less routine and machinelike human life. There is an implied emphasis on creativity, which cannot flourish under conditions of time pressure and monotonous tasks. Work is seen as part of a continuously ongoing life and workers are seen as multi-dimensional human beings. In this sense, the hacker ethic also constitutes an image of a worthy life (Himanen et al., 2001, p. 39).

As already noted, the hacker ethic emphasizes openness through information sharing (Himanen et al., 2001, p. 39). This goes together rather well with what is considered the prevalent motivational force – peer recognition. Only when the results of one's work are traceable and widely accessible can peer recognition work. This characteristic has the potential to collide in certain cases with the concept of ownership, which forms the basis of capitalism. This issue is further explored by Gabriella Coleman. She claims that hackers' emphasis on making the results of their work available not only to themselves, but also to anyone interested, is evocative of Karl Marx's critique of estranged labor (Coleman, 2013, p. 13). However, hackers do not follow the line of reasoning in a radically leftist critique of capitalism. As Coleman shows, they establish their critique by playing one aspect of liberalism against another, claiming that source code should be associated with freedoms related to speech, not with those related to private property (Coleman, 2013, p. 6). Hence, the central value expressed by Coleman as "code is speech" (Coleman, 2009, 2013, p. 147). This is also reflected in a saying hackers developed to distinguish between the two kinds of freedom: "free as in speech/free as in beer". This saying emphasizes the differences between freedom related to expression and freedom stemming from something being gratis (which is seen as inferior to the former type of freedom).

Johan Söderberg goes as far as claiming that the hacker movement is a part of a broader revolt against commodification of labor (Söderberg, 2008, p. 44) and a continuation of the labor struggle (Dafermos & Söderberg, 2009). In recent years, software development contributed significantly to de-skilling the workforce in many occupations. And the routinization is also paradoxically starting to affect the professions related to software development itself. However, Söderberg argues that knowledge workers have a specific position in the struggle (Söderberg, 2008, p. 46). They can either engage in hacking, that is, using their skills to build viable alternatives, or resort to cracking – using their skills to conduct actions of resistance that could be considered illegal. According to Söderberg, this resistance cannot be undermined by de-skilling the workforce – a strategy that could have been applied everywhere else. “At this point, however, Taylorism runs into its own limits. There is no easy way to deprive ‘knowledge workers’ of knowledge and still have them working” (Söderberg, 2008, p. 46).[35]

However, the hacker ethic cannot be considered wholly anti-capitalist. It does not oppose the idea of making profit; it opposes the idea of making profit by constraining specific kinds of information. In fact, there is significant involvement of private businesses in FOSS projects that are strategically positioned.[36] In this regard, Joel West and Siobhán O’Mahony distinguish between autonomous and sponsored communities. These authors claim that licensing and access to source code are provided in the same way by both types of communities. They differ, however, in that the governance is more pluralistic in autonomous communities, while in sponsored communities control exerted by the sponsor prevails. This is outweighed by the assurance of continued existence – autonomous communities that don’t attract any volunteers cease to exist. In sponsored communities, core developers are usually employed by the sponsor, which safeguards continuity (West & O’Mahony, 2008, pp. 14–15). On the other hand, companies may benefit from involvement with a community by extending their resource base, as Linus Dahlander and Mats Magnusson suggest in general terms (Dahlander & Magnusson, 2008, p. 638).

Moreover, by combining business and community involvement, sponsored communities are placed at the intersection of formal and informal economies. But in this case, informality is not associated with downgraded labor, breaching a link that Manuel Castells made in one of his older works (Castells & Portes, 1989, p. 26). Although it may share

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[35] A similar point is made by Kristi Sarheim Anthun, who notes that knowledge workers, as the “owners of the now most important resource (knowledge) acquire power and influence since knowledge cannot be replaced with capital” (Anthun, 2013, p. 17).

[36] This is also consistent with a claim that Manuel Castells makes about the elementary units of economic production. According to this author, individual companies as units of production are being replaced by projects, in which companies collaborate to create a product (Castells, 2000a, p. 11). It seems that FOSS projects, with their inhibition of some individual property rights, create appropriate conditions for this type of collaboration. This remark can be supported by the current state of large FOSS projects, such as the Linux kernel, which often receive sponsorship from multiple companies.

the status of being undeclared or invisible, which Bonnie Nardi and Yrjö Engeström (1999) show is the case with much of the work in postindustrial society. In this sense, autonomous FOSS projects may represent a specific kind of informal economy.

Correspondingly, some authors claim that FOSS projects are structured as a specific kind of symbolic economy. According to Magnus Bergquist and Jan Ljungberg, the economy is based on gift giving (Bergquist & Ljungberg, 2001, p. 312).[37] Here, software developers are seen as gift givers to those that accept the gifts – users. This constitutes a relationship where software developers gain power by systematically giving away the results of their work. The only way for users to even up their position is to give back by contributing. But this is not only a matter of decision. The presence of peer review for contributions means that the current developers assess and select contributions to be used and therefore, in a sense, select users who will be allowed to give back (Bergquist & Ljungberg, 2001, p. 314). However, as Bergquist and Ljungberrg point out (2001, p. 314), this relationship only works when the parties share a framework of meaning (e.g. the users know that the software they use was developed by volunteers and appreciate it).

Focusing on the developer side of the relationship, we can find more elaborate status hierarchies explored by Daniel Stewart. This author claims that status is based on references that other members give and that in FOSS communities, it is largely based on reciprocity and collaboration (D. Stewart, 2005, p. 834). In other words, developers tend to give references for those they work with and also give references back when they receive some. Furthermore, as Stewart argues, the references form a self-reinforcing cycle, which means that the more references of a sort a member receives, the smaller the probability of receiving references that counter the previous ones (D. Stewart, 2005, p. 835). However, the most interesting point made by Stewart is his identification of peer evaluation as predominantly endogenous (D. Stewart, 2005, p. 838). This means that status is derived mostly from the endorsement of work un-

[37] Alternatively, one could construct a similar explanation along the lines of spending attention. The conceptualization of attention as a resource was already proposed by Herbert Simon (Simon, 1971, p. 40) and the relation between attention economy and the Internet was later discussed by Michael Goldhaber (M. Goldhaber, 2006; M. H. Goldhaber, 1997) and Philippe Aigrain (Aigrain, 1997). However, the concept of attention is too general and underspecified in the sociological and anthropological traditions of thought and so it can't be readily used.

dertaken within the community, and external forces are not taken into account (at least not directly).[38] This makes the community embedded in its own rules but also provides the foundations for its compatibility with a broad range of organizations and worldviews.

Part of the hacker ethic is also its perception of authority. In this way, the hacker ethic once again resembles the academic, because one of its key components is that anyone can use, criticize or develop the objects produced by other hackers (Himanen et al., 2001, p. 68).[39] It is this model of open development and self-correction that is perceived as desirable in contrast with models that keep knowledge constrained and let authorities set goals. However, this does not mean that the hacker work ethic asserts the absence of any kind of structures (Himanen et al., 2001, p. 72). As we have seen, there are structures, at least in terms of status hierarchies, but browsing studies published during the last decade reveals more.

Siobhán O'Mahony and Fabrizio Ferraro studied the process of governance establishment in the Debian Linux distribution. These authors found out that in the long run, the community preferred leaders with organizational competence over the ones whose competence was purely technical (O'Mahony & Ferraro, 2007, p. 1100). This provides a correction for the description of the status building process – status does not have to be based only on an endorsement of technical work. Furthermore, even though the community initially placed many checks on the power of elected leaders, eventually, those that broadened their sphere of influence were preferred (O'Mahony & Ferraro, 2007, p. 1100).

With regard to power and influence, Didier Demaziére et al. distinguish between centralized control, which ensures consistent performance

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[38] This tendency can be observed also in other online constituted communities such as Wikipedia, where restrictions are placed on original research and where the status of its contributors (professional researchers, for example) is not taken into account (Luyt, 2011, p. 1063; Rosenzweig, 2006, p. 140).

[39] In this sense, Eric Raymond, the author of the highly influential essay *The Cathedral and the Bazaar* points out that the already mentioned Brooks's Law (a well-known premise among software developers implying that adding developers to a late software project makes it later) needs to be balanced with the concept of egoless programming. "Gerald Weinberg's classic The Psychology Of Computer Programming supplied what, in hindsight, we can see as a vital correction to Brooks. In his discussion of 'egoless programming', Weinberg observed that in shops where developers are not territorial about their code, and encourage other people to look for bugs and potential improvements in it, improvement happens dramatically faster than elsewhere" (Raymond, 1999, p. 39).

over time and serves as a guarantee that time invested by volunteers will not be lost, and distributed regulation, where influence is distributed according to the presence (number of contributions or amount of time invested) of individuals in the area (Demazière, Horn, & Zune, 2007, p. 51). These findings point to the fact that power and influence are dispersed among individuals with high levels of involvement – a fact that is used by the communities to label themselves as meritocratic.

However, as Nicolas Ducheneaut shows in his analysis inspired by Bruno Latour, FOSS projects recede from the ideals of openness and meritocracy in situations when newcomers are attempting to join and influence a project. Ducheneaut identified a series of stages that a newcomer goes through – from passive monitoring of development activities to making substantial modifications to developed software.[40] But as he notes, most newcomers stop at the initial stages and very few of them reach the advanced ones. Ducheneaut attributes this to several characteristics of FOSS projects. According to this author, FOSS projects represent black-boxes for newcomers – they need to uncover the relationships forming the project network in order to identify how they can interact with it and where they could start with their contribution. Furthermore, Ducheneaut claims that the network naturally resists change, which means that a newcomer has to mobilize human and non-human allies in order to insert himself into a position from which he can make a substantial modification (Ducheneaut, 2005, pp. 353–355).

Such situations typically lead newcomers to perform what could be called autonomous learning. In this process, newcomers make use of the available sources of information – which in FOSS projects are abundant and which, according to Andrea Hemetsberger and Christian Reinhardt, enable re-experiencing rationales and past events. These authors argue that the archived traces left after past interactions (for example in mailing lists) combined with information sources specifically aimed at newcomers (user or developer documentation) form a transactive memory that can be explored independently of the actors that created it (Hemetsberger & Reinhardt, 2006, pp. 195–199).[41] This phenomenon is further supported

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[40] Drawing on Ducheneaut's work, Israr Qureshi and Yulin Fang later developed a model of four classes of "joiners" differentiated according to the volume of interaction with core developers (Qureshi & Fang, 2010, p. 223).

[41] In 2003, Gwendolyn Lee and Robert Cole had already pointed out that the reuse of mailing list communication and peer review observation is at the heart of the knowl-

by the self-documenting tendencies in the FOSS culture. Hackers usually produce accounts (typically in the form of blog posts) of the learning processes that they undergo. These records are publicly available so that others can make use of them or develop them further. This leads to a continuous creation and re-creation of learning resources for any topic that is deemed to be interesting or worthwhile. In this sense, the learning of one individual can teach others.[42]

Similarly to learning, work in FOSS projects exhibits an emphasis on autonomy. Kevin Crowston et al. found that self-assignment is the most frequent type of work assignment in FOSS projects (Crowston, Li, Wei, Eseryel, & Howison, 2007, p. 6). This finding is further supported by Giampaolo Garzarelli and Ricardo Fontanella, who additionally clarify that self-assignment is made possible by the modular architecture of projects, allowing for individuals to work in parallel (Garzarelli & Fontanella, 2011, pp. 930–936). Keeping in mind that FOSS projects are often run by volunteers, so that there is little or no leverage to enforce work assignment, this should not come as a surprise. Overall, Crowston et al. characterize the FOSS projects as "self-organized" and compare the coordination mechanisms to those identified by Karin Knorr-Cetina in high energy physics (Crowston et al., 2007, p. 11).[43] Athina Karatzogianni and George Michaelides further characterize self-organized FOSS projects by noting that they typically exhibit a two-tier (core and periphery) structure differentiating maintainers from occasional contributors. The overall distribution of projects follows the power law (the frequency of an event

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edge generating processes in Linux kernel development (Lee & Cole, 2003, p. 644).

[42] Manuel Castells proposes to distinguish two types of workers in a network society – generic labor and self-programmable labor. The key difference between them is that unlike the former, the latter type of worker is able to process information in order to adapt their qualification when new kinds of tasks emerge (Castells, 2000a, p. 12). In other words, the difference between the worker types lies in the ability to learn, or even learn autonomously (Castells, 2010a, p. 377). Given the emphasis placed by FOSS developers on information sharing and autonomous learning, they seem to fit well into the second category.

[43] Knorr-Cetina herself characterizes self-organization in the following way. "Self-organization, in turn, keeps social relations liquid (and presupposes their liquidity): there is the fluidity of everyone's readiness to become drawn into temporary engagements with others in voluntaristic collaborations, a fluidity aided by the breakup of forces of individuation and the holistic competence of individuals trained in object circuits" (Knorr Cetina, 1999, p. 179). Here, self-organization consists in work self-assignment made possible by even distribution of knowledge.

is inversely proportional to its magnitude), which translates to the fact that there are few projects that attract large numbers of developers while there are many projects that attract only a small number of developers (Karatzogianni & Michaelides, 2009, pp. 148–149).

The two-tier structure observed by Karatzogianni and Michaelides points to the issue of participation inequality noted by several authors (Holtgrewe, 2004; Krishnamurthy, 2002; Kuk, 2006; McInerney, 2009). The study by George Kuk is of particular interest here, because it links participation inequality with knowledge sharing. This author claims that beside collaborative interactions, FOSS developers also perform epistemic interactions, that is, place inquiries on each other's knowledge. However, these inquiries can be demanding and so they may easily turn from exploration to exploitation. Kuk's point then is that participation inequality is functional in that it reduces the load of epistemic interaction by restricting it to a narrow group of core developers (Kuk, 2006, p. 1039). Taken to a more general level, this finding supports Ursula Holtgrewe's criticism of sweeping claims that characterize the Internet as an "undifferentiated mass of simultaneous and arbitrary information" (Holtgrewe, 2004, p. 14). Indeed, Holtgrewe points to FOSS development to demonstrate that meaningful action is not drowned in the abundance of digital information.

Moreover, Kuk's claim is consistent with the findings of Georg von Krogh et al., who claim that core developers usually avoid narrow specialization (Von Krogh, Spaeth, & Lakhani, 2003, p. 1230). Their activity spreads across a number of modules and requires exploration with epistemic interaction as one of its forms. We can expect higher levels of specialization in the activities of occasional contributors, as their motivations and actions are aligned with the project only in certain respects. However, occasional contributions do not cause disturbances in the development process. As Hemetsberger and Reinhardt point out, FOSS projects are able to integrate individual actions with their overall activities, regardless of their nature as general maintenance or specialized contribution. Therefore, these authors characterize FOSS projects as "coat-tailing work systems" (Hemetsberger & Reinhardt, 2009, p. 1003).

1.2 Utopian Virtualism

Developing software in the networked environment of the Internet introduces specific conditions that free and open source software development takes advantage of. These possibilities are based on two characteristics of digital texts as described by Lorenzo Cantoni and Stefano Tardini. The first characteristic, *persistence*, means that every communication that is mediated by a computer leaves a physical trace, making it possibly available for someone else for an unspecified amount of time (Cantoni & Tardini, 2006, p. 44). At first, this seems to apply to all communication, online or offline – even a voice makes a physical trace. However, when communicating outside cyberspace, additional effort needs to be exerted (writing or other forms of recording) in order to capture the communication and make it accessible for longer periods of time. Within cyberspace such effort is not needed because all communication takes place already in the form of text (or, less frequently, in other recorded forms).

Similarly, the second characteristic means that digital texts (and other recorded forms) are *reproducible* without the need to exert effort and resources that would be needed when reproducing non-digital media (Cantoni & Tardini, 2006, p. 55). Reproduction requires only computational resources which, once acquired, are abundant.[44] Going one step further, both characteristics (persistence and reproducibility) are tightly interconnected with the ability of *automated manipulation*. This ability implies that digital text can be manipulated (recorded, reproduced, searched or edited) in a way that does not require direct and permanent attendance by a human operator. Automation allows human operators to specify instructions before the manipulation process, which is then performed autonomously at the computer's own pace.

These characteristics of digital texts make possible what Yochai Benkler emphasizes as the transparency of online culture. As an example, this author takes the case of Wikipedia[45] articles. For any given article, all changes made to it are traceable in its history, while discussions leading

[44] The words "once acquired" are important here. One more important characteristic that Cantoni and Tardini list is that digital texts are inaccessible to human senses directly. This means that a computer (often with an Internet connection) is required in order to obtain and read digital texts. As the issue of the digital divide (see for example Norris, 2001) reminds us, the spread of this infrastructure is hardly universal.

[45] Wikipedia, launched in 2001 and explicitly stating an influence from the free software movement (see Wikipedia, 2015), can be considered what Christopher Kelty calls a modulation of free software practices, that is, an application of one or more characteristics of free and open source software development to areas other than programming (Kelty, 2008, p. 16). Roy Rosenzweig (2006), a historian examining the implica-

to those changes are also recorded on a separate page (Benkler, 2006, p. 289). Such an endeavor in offline archiving would require large investments in effort and resources, making it slow and cumbersome. But in cyberspace, the archiving procedures can be automated. Originating in the 1970s, free and open source software development seems to be the first organized effort to employ these possibilities systematically. As a result, the source code (and its documentation) is by far not the only set of information that is publicly available in FOSS projects. There are numerous other sources of information of which the main are: a detailed history of changes made to the source code, recorded communications among developers, lists of issues containing discussions on how to solve them and websites with further information. Such a wealth of information about the internal processes of software development projects lead Benkler to his characterization of such modes of organization as transparent.

On a more general level, Benkler includes free and open source software development under the umbrella of new forms of peer production. This author claims that the defining characteristics of these forms of production stem from reduced transaction costs.[46] Benkler argues that market transactions differ from non-market social exchange (such as gift-giving) in that the calculations or definitions (calculating prices or drafting agreements, for example) necessary for market transactions place a significant burden on all parties. According to this author, non-market social exchange is exempted from these costs because it does not involve explicit calculation or definition (Benkler, 2004, p. 307, 2006, p. 109). Non-market exchanges traditionally only reached a scope of locally and temporally restricted interactions, but the advancements in information technologies achieved in the past decades made possible the rise of what Benkler calls "effective, large-scale cooperative efforts – peer production of information, knowledge, and culture" (Benkler, 2006, p. 5). Given that this new form of production is based on non-market social exchange, Benkler claims that it not only has a systemic advantage in the form of reduced transaction costs and better allocation and motivation of the workforce, but that it also improves the practical capacities of individu-

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tions Wikipedia has for historiography, characterizes it in a similar way by posing the question "Can history be open source?".

[46] In this regard, Benkler bases his argumentation on the classic work of Ronald Coase (Coase, 1937, 1960).

als by opening them to a broader scope of production activities without the restrictions placed by traditional models involving price calculation or strict hierarchical organization (Benkler, 2002, p. 376, 2006, p. 8).

This is a rather optimistic grasp of the phenomenon. But Benkler is not alone in expressing it. One can find similar views in some of the work surrounding the concept of collective intelligence, which has been developed since at least the early 1970s (Wechsler, 1971). Collective intelligence can be defined as the "ability of virtual communities to leverage the combined expertise of their members" (Jenkins in Uspenski, 2013, p. 142). While Ivana Uspenski (Uspenski, 2013, p. 148) proceeds to a heuristically inspiring distinction between collective intelligence (based on mutual evaluation of meaning) and mass intelligence (based on aggregation of data), other works are often interwoven with utopian visions of the future. For example, Pierre Lévy foretells the coming of planet-wide civilization through collective intelligence based in cyberspace and proceeds further to claim that television will be replaced by omnivision, allowing all humans to watch any place at any time (Lévy, 2005, p. 189, 191). In his most popular work, Lévy claims that the historical development which the emergence of cyberspace has triggered implies "a new humanism", one that promotes individual intelligence to a collective level. From this, "new forms of democracy, better suited to the complexity of contemporary problems than conventional forms of representation, could [...] come into being" (Lévy & Bonomo, 1999, p. 18). Other authors associate the term collective intelligence with images of "harnessing crowds" (Malone, Laubacher, & Dellarocas, 2010) or "creating a prosperous world at peace" (Tovey, 2008) directly in the headings of their works.[47] This demonstrates the positive valence with which the terms "collective intelligence" or "cyberspace" are charged.

Furthermore, such claims can be also found in foundational texts of the FOSS movement. The essay *The Cathedral and the Bazaar* by Eric Raymond can serve as a good example.

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[47] Furthermore, Francis Heylighen, a former physicist who is attempting to formulate a general model of the Internet as a system of collective intelligence (Heylighen, 1999; Heylighen & Bollen, 1996; Heylighen, Heath, & Van, 2004), explicitly formulates his utopian vision such that the Internet has introduced a cognitive system on a planetary level, a global brain, and this super-organism can be conceived as a higher level in human evolution (Heylighen, 2002, p. 2).

That is, that while coding remains an essentially solitary activity, the really great hacks come from harnessing the attention and brainpower of entire communities. (Raymond, 1999, p. 39)

The Linux world behaves in many respects like a free market or an ecology, a collection of selfish agents attempting to maximize utility which in the process produces a self-correcting spontaneous order more elaborate and efficient than any amount of central planning could have achieved. (Raymond, 1999, p. 40)

The basic claim made by Raymond in the text is that taking advantage of Internet infrastructure and employing a certain set of cooperative customs leads to the establishment of spontaneous order, which is more efficient than central planning in that it allows the harnessing of entire communities' brainpower.[48] Additionally, for Jan Ljungberg, specific ways of knowledge sharing and work coordination signify the forms of organization of the future (Ljungberg, 2000). For Georg von Krogh and Eric von Hippel, free and open source software development represents a new model of innovation that should spread to other fields of production (Von Krogh & Von Hippel, 2006, p. 982). Finally, Cory Ondrejka stays within the boundaries of cyberspace and elaborates upon the possibilities for establishing a "metaverse", an alternative reality of unmatched complexity (Ondrejka, 2004, p. 81).

These visions are symptomatic of the enthusiastic anticipation[49] of what cyberspace can offer, and are placed under elaborate criticism by David Hakken.[50] Hakken argues that this anticipation is based on the assumption that knowledge has replaced capital, labor and natural re-

[48] The contraposition of "free market" and "spontaneous order" against "central planning" evidently hints at a certain positioning on a political spectrum. However, leading the analysis in this direction would diverge from the purpose of the current text.

[49] To be sure, there are also pessimistic expectations with regard to cyberspace, as, for example, Mark Davis (Davis, 2013, p. 162) shows. Yet it seems that these did not gain such a momentum with regard to claims about the discontinuity of knowledge-related processes introduced by cyberspace.

[50] The utopian tendencies in Lévy's work were also critically noted by László Fekete (Fekete, 2006, p. 742). A more systematic account of the discussion about the utopian tendencies surrounding digital technologies can be found in the works of Jakub Macek, who describes the techno-optimistic and techno-pessimistic views related to digital media (Macek, 2009, pp. 8–19, 2013, pp. 81–90).

sources as central productive forces (Hakken, 2003, p. 9). Indeed, Lévy starts his book on collective intelligence with a claim that the "prosperity of a nation, geographical region, business, or individual regions depends on their ability to navigate the knowledge space" while "power is now conferred through optimal management of knowledge" (Lévy & Bonomo, 1999, p. 1). Correspondingly, Hakken argues that there is a broader tendency to uncritically accept the "knowledge society" label.

> *Rather than carefully articulating their view of the proper way to conceptualize the knowledge revolution and then going on to make their case for it, most performers merely jump on a generally conceded "knowledge society" bandwagon. (Hakken, 2003, p. 9)*

As Hakken demonstrates, this tendency is also present in the works of prominent authors such as Karin Knorr-Cetina (Hakken, 2003, p. 9). Furthermore, if we look at the notable work of Manuel Castells, we can identify the tendency (provided we acknowledge the link between mind, cognitive processes and knowledge) in his more radical claims such as the one that: "for the first time in history, the human mind is a direct productive force, not just a decisive element of the production system" (Castells, 2010c, p. 31). While this claim was made in the first part of the first volume of Castells's trilogy (Castells, 2010c, 2010b, 2010a) on the information age, in the concluding part of the third volume, we can find the following statement:

> *The promise of the Information Age is the unleashing of unprecedented productive capacity by the power of the mind. I think, therefore I produce. In so doing, we will have the leisure to experiment with spirituality, and the opportunity of reconciliation with nature, without sacrificing the material well-being of our children. The dream of the Enlightenment, that reason and science would solve the problems of humankind, is within reach. Yet there is an extraordinary gap between our technological overdevelopment and our social underdevelopment. (Castells, 2010a, p. 395)*

A notable difference between the two statements is that the former constitutes a claim about the actual state of labor organization while the latter represents an expression of a potential state that could be reached. This ambiguity is further supplemented by claims of discontinuity: "I do believe that there is a new world emerging at this turn of millennium.

In the three volumes of this book I have tried to provide information and ideas in support of this statement" (Castells, 2010a, p. 372). These characteristics are typical for a speech mode that is closely related to the utopian visions I elaborated earlier.

Hakken identifies a speech mode, which he calls the "optative form", that is indicative of the sweeping claims emphasizing discontinuity in their images of cyberspace.[51] According to this author, the optative form's predominant characteristic is that it mixes statements about what is and what is hoped to be, it blurs the distinction between present and future (Hakken, 2003, p. 27). In other words, when using the optative form, authors see the future potential of things as their essence. This corresponds to the initial definition that Rob Shields uses in his elaborate work on the term "virtual" – "that which is so in essence but not actually so" (Shields, 2003, p. 2). However, Shields is also wary of uncritical acceptance of the expectations surrounding the virtual:

> *The hype around digital virtuality over the past decade has been more about myth and less about actual cyberspaces. As a fad and myth, virtualism is itself virtual. Symptoms of virtualism include exaggerated expectations of anything described as 'virtual', and unrealistic expectations that digital technologies will solve social problems. The boom in technology stocks and enthusiasm for virtual reality hinted at the ongoing expectations of the virtual. In line with its historical definitions, it carries a certain promise of positive potential or virtue. Portrayed as enabling a human virtuosity beyond the limits of the body or gravity, the legacy of the baroque echos through the claims of Silicon Valley entrepreneurs. (Shields, 2003, p. 15)*

In his older work, Hakken already claims that the images around the so-called computer revolution should be bracketed as a myth in the anthropological sense (Hakken, 1999, p. 18). The logical implication of this position is a call, made by Hakken, to examine in more detail the knowledge-related processes taking place in the cyberspace (Hakken, 2003, p. 29). This work aims to answer this call in a specific sense: informed by the critique elaborated above, the aim of this work is to explore closely

[51] Further critique of the positions emphasizing discontinuity can be found in the work of Steve Woolgar (2002, p. 17) or Marylin Strathern (2002, p. 311). Both authors claim that the dichotomy between the virtual and the actual (or "real") does not constitute a mutually exclusive binary opposition. On the contrary, they argue that the virtual and the actual are mutually co-extensive.

the knowledge dynamics in free and open source software development, an area of practice which Benkler deemed to typify the new form of cyberspace-enabled peer production.

The present work attempts to show how knowledge is dynamized by networks constituting FOSS projects and how these networks are interrelated with the practice of rights that were traditionally associated with ownership. Furthermore, I try to show the knowledge-related limitations of the images associated with utopian virtualism and frictionless interaction of individuals spontaneously emerging to solve problems. These claims are supported by an elaborate analysis of mediation and resource flows that take place inside a FOSS project. But before I immerse the reader in analysis, I need to flesh out several key concepts that will allow me to formulate more precise questions and to make my findings expressible.

2

Software and Knowledge

2.1 Tools and Design Artifacts in Software Development

Software is a general designation for the sum of all programs that can be run on a computer. It represents one side of the software/hardware distinction, where hardware designates tangible computer components on which software operates. It is common to say that software consists of ones and zeros, that is, of digital information. However, ones and zeros represent the end product that is readable only for machines. When developing software, programmers are not dealing with ones and zeros, they use one of many programming languages to produce a strictly formalized text – the source code. After the source code of a program is written, it is turned into a machine readable binary file consisting of ones and zeros through an act called compilation. Compilation represents an event in which readable and modifiable text is transformed into a solid thing that behaves according to its own logic. It is the act of materialization of an object.

What interests me, however, is what happens before compilation: the process in which humans and nonhumans are organized in a manner that results in an object that can be executed and purposefully utilized by its users. That is to say, I am interested in associational processes that take place during software development. As claimed by Jacob Nørbjerg and Philip Kraft, software production typically involves a "complex mix" of organizational structures, work practices or even politics (Nørbjerg

& Kraft, 2002, p. 218).[52] From this perspective, software is relevantly defined by Arne Raeithel:

> *Computer science or informatics appears in this perspective as one of the sciences of human self-regulation, mainly concerned with electronic and virtual machines used in this process. Software objects may consequently be seen as predefined constraining contexts ('forms') for sign processes (semioses) mediating between human actors, while at the same time presenting virtual objects and instruments ('means') for self-determined use by the cooperating persons. (Raeithel, 1992, p. 391).*

There are two important points in this definition. First, software is seen as a constraining context, a digital environment which determines the options its users have. Any action the user can take has to be pre-conceived by software developers and implemented in a given program. Second, software represents an instrument, a tool that can be used for purposes its developers have not envisioned and that can be combined with other tools to produce unexpected results.[53]

Software development is carried out by a practice called programming. According to Peter Naur, programming is "matching some significant part and aspect of an activity in the real world to the formal symbol manipulation that can be done by a program running on a computer" (Naur, 1985).[54] However, Naur further defines programming as knowledge building: a programmer must craft a theory of what is to be matched and

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[52] This is why ethnography is suggested by several authors for studying it (Dittrich, 2002; Klischewski, 2002; Rönkkö, 2002; Westrup, 2002).

[53] These two points can also be found in Christiane Floyd's work (Floyd, 1992, p. 15). The common point is that software, while it represents an instrumental means to achieve goals, constitutes some kind of constraining context for its users.

[54] According to Reinhard Keil-Slawik, a new quality emerges from this process. Sequences of activities that need to be performed to achieve a certain action can be condensed into a single object or operation. These objects and operations can then be further combined without the constraints of enforced sequentiality they previously had. As Keil-Slawik puts it: "prescriptive temporal structures are dissolved by creating physical objects and corresponding spatial structures" (Keil-Slawik, 1992, p. 182). Thus, matching real world activities does not mean mirroring them, it means distilling them into objects or operations that are not limited by the constraints their original models had.

in what way.[55] Theory, in this sense, represents a support for action not limited only to know-how, but also including explanations and justifications of what is to be done. The programmer has to be able to explain how the important characteristics of real world activities are mapped into the program and subsequently justify his decision and choices. In this way, the knowledge needed for software development transcends what is recorded in the final product. This knowledge is needed for every modification of a program in order for those modifications to form an integrated whole (Naur, 1985).

In a similar way, Pelle Ehn describes software development as a process of designing a computer artifact. According to this author, design is an activity and a form of knowledge in which artifacts and their use are anticipated and which deals with the distinction between tradition and transcendence (Ehn, 1988, p. 161). This means that designing technological objects is a process which draws its resources from what is currently available and attempts to overcome it. It represents a situation in which human creativity is needed in order to produce something new using everything that is already there. However, human creativity, albeit important, is hardly the only thing that counts. The technological artifacts already there play a vital role in the process.[56,57]

According to Ehn, the importance of artifacts lies in the fact that they are able to augment or replace human activity and can do so with regard to both communicative and instrumental activities (Ehn, 1988, pp. 162–163). With this general characteristic, I hold that Ehn has one particular type of artifact in mind, one that is commonly grouped under the label "tools". But in software development, tools also take the form of software. Therefore, we must consider developers of certain software to be simul-

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[55] In this sense, Catharina Landström et al. write about "forming an understanding" with regard to software development (Landström, Whatmore, & Lane, 2011).

[56] This is consistent with how Bruno Latour connects his theory with that of Peter Sloterdijk. "Dasein ist design" says the quote in one of Latour's texts. And he further elaborates his position: "There is not the slightest chance of understanding Being once it has been cut out from the vast numbers of apparently trifling and superficial little beings that make it exist from moment to moment" (Latour, 2009, p. 139).

[57] The importance of things already there is highlighted by Reinhard Keil-Slawik's claim that preservation of tools (not their construction) is what differentiates humans from animals. As he states: "This is essential, because only then does it become possible to compare a previously built tool with a new one, to communicate about tools, and to use them as a means for education" (Keil-Slawik, 1992, p. 181).

taneously users of other software.[58] And as users, they are dependent on the interface of the software-used-as-tool, as it determines the options available for exploiting the provided functionality.

Furthermore, one other type of artifact is introduced by Ehn: "design artifacts". These can be defined as objects (for example descriptions, models or prototypes) which mediate the design process. Ehn's characterization of this type of artifact is worth quoting at length:

> *The role of design artifacts in the language game of design is as reminders and as paradigm cases for our reflections on existing and future computer artifacts and their use. The use of design artifacts brings earlier experiences to our mind and it bends our way of thinking about the future. I think it is in this sense we should understand them as re-presentations. … I see descriptions or models as design artifacts to objectify experiences, visions, and ideas relevant for communication in the design process. … These kind of artifacts support reflection. … Another category of design artifacts is prototypes, mock-ups, scenarios with role playing, etc. They differ from descriptions and models in the sense that they also allow for involved practical experience, not just detached reflections. (Ehn, 1988, p. 169)*

There are three important characteristics that Ehn attributes to design artifacts. First, he shows that representations do not necessarily have to be symbolic. In the design process, there are objects that are created specifically with the purpose of representing something, to prove a point. Second, these artifacts provide snapshots of experiences and make them intentionally reproducible so that more time can be allocated at reflection. Third, they also provide new experience through interaction with the latest version of the desired product. Overall, design artifacts play the role of inducing or mediating experience and reflection. This constitutes the relevance of design artifacts for knowledge dynamics in technology development.

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[58] In the terminology used by Susan Leigh Star, software tools are boundary objects, that is, objects that have a varying use or purpose depending on the location they appear in. Thus, their purpose is ambiguous in general, but clear in particular cases (Star, 2002). Specifically, the dual nature of software as a development target and as a tool is consistent with Star's claim (Star, 1999, p. 387) that we can read information infrastructure as a material artifact (tool) or a trace of activities (development target).

2.2 The Role of Knowledge in Software Development

To continue in establishing a model of knowledge dynamics, I draw upon the work of Mike Reay who considers conscious reflection and new experience as two main sources of learning, the activity which dynamizes knowledge. Furthermore, Reay distinguishes two types of knowledge distribution. Horizontal distribution of knowledge is based on distribution of experience in space and time. Vertical distribution, on the other hand, means distribution of knowledge into conscious and unconscious layers differentiated by the presence or absence of reflection. Differences in the distribution of experience and reflection can lead to stable patterns of ignorance or misperception. The barriers leading to this "knowledge insulation" can be overcome only by mobilization of new experience or further reflection (Reay, 2010, p. 100). These processes are key for social arrangements characterized by pooling knowledge because they are based on constantly overcoming knowledge insulation.

In the previous paragraph I suggest that by providing some sort of experience or reflection, design artifacts are able to transmit knowledge through the process of learning. But to grasp the problem in more detail, one must differentiate knowledge and information just like, for example, Nico Stehr does. According to Stehr and Ufer, knowledge inherently involves appropriation by a knowing subject, as they put it: "Knowledge always requires some kind of attendant interpretive skills and a command of situational circumstances. In other words, the acquisition, dissemination and realization of knowledge requires an active actor" (Stehr & Ufer, 2009, p. 9). Information, on the other hand, does not require appropriation and therefore can be likened to data, in the sense that it is something that actors simply have and can pass on. This makes information easily transferable (Stehr, 1994, p. 120, 2001, p. 44; Stehr & Ufer, 2009, p. 9).[59]

Overall, Stehr defines knowledge as a model of reality that gives actors the capacity for action. But the demanding nature of transferring

[59] Consider a map as an example. By itself, it is a piece of information that can be passed quickly from one actor to another (and even more so in a digital form). However, it takes an actor who can read all the signs, reference points and directions in order to turn the information into knowledge about locations and possible courses of action. Considering FOSS development, the same analogy should hold, for example, with regard to source code which can be shared in a matter of seconds, but which can take months to study in order to determine the course of its further development.

knowledge implied by the requirement of appropriation is not the only problem related to knowledge. To be able to translate knowledge into action, an actor must also control the circumstances of the situation (Stehr, 1994, p. 120, 2001, p. 44). In other words, an actor may prove to be knowledgeable only in conditions that support the utilization of the given type of knowledge.[60] Therefore, I hold the requirement of appropriation and the necessity of situational control to represent the most important problems when dealing with knowledge-intensive work practices.

In a similar manner, Loet Leydesdorff makes a distinction between information and meaning. According to this author, information by itself is in a state of "still-to-be-provided-with-meaning". Meaning arises in the process of relating information to itself in a context of individual (personal meaning) or supra-individual (discourse) systems of reference. Therefore, meaning is defined in use (Leydesdorff, 2011, pp. 393–394). This is consistent with how George Herbert Mead defined meaning, provided that we think of gestures as of transmitted information:

> *Meaning arises and lies within the field of the relation between the gesture of a given human organism and the subsequent behavior of this organism as indicated to another human organism by that gesture. If that gesture does so indicate to another organism the subsequent (or resultant) behavior of the given organism, then it has meaning. (Mead, 1972, p. 76)*

Therefore, meaning is derived from the ways in which information is used, from action.[61] In this sense, knowledge and meaning are very closely tied as ways of making sense from information. This relationship is further explored by Doyle McCarthy who claims that knowledge is best conceived and studied as culture. This is to claim that various bodies of

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[60] With regard to FOSS development, licensing arrangements or establishing development environments could be considered a concrete form of an effort to control the situation in such a way that knowledge related to a certain piece of software could be applied.

[61] It is also common to say that meaning is the result of interpretation. As Elizabeth Long shows, this process traditionally associated with reading in private can be made less opaque by explicating the "social infrastructure of reading", by which she means not only the socialization and learning processes that establish the competency of reading, but also the social base of reading groups or other associations devoted to reading, interpreting and discussing texts (Long, 1993, pp. 190–191). As a result, software development projects can be seen as a specific case of reading associations.

knowledge operate within culture, “that they contain and transmit and create cultural dispositions, meanings, and categories” (McCarthy, 1996, p. 118).[62]

Applied to the area of software development, the theoretical statements above mean that what is embedded in design artifacts is information which can be easily transmitted but which can also be easily stripped of its meaning.[63] Knowledge involves the ability to utilize information contained in objects and to give them meaning.[64] In other words, the source code of a program by itself represents only information. Knowledge arises from the ability to either use the compiled program as an end-user or read, understand and meaningfully alter the source code as a programmer. This means that knowledge does not reside either in programmer’s head or the source code, but can be found only in the interplay of the two. Knowledge is not the content, it is a quality of interaction.[65]

The problem of transferring knowledge through its embodiment in design artifacts essentially corresponds to the classical issue of reciprocity of perspectives explored by Alfred Schütz. According to Schütz, there is an inherent difference in perspectives among actors because they are located 1) at different spatial distances from the object while experiencing different aspects of it as typical, and 2) in different biographi-

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[62] Karin Korr-Cetina’s detailed study of epistemic cultures in natural sciences is a case in point (Knorr Cetina, 1999). Considering FOSS development, the overlap between knowledge and culture could be observed on a set of norms that are commonly called “the UNIX Philosophy”. For a long time, these norms have represented a model for software design within FOSS projects. This model will be elaborated further in this work, but for now it suffices to point out that it emphasizes principles such as simplicity, modularity or interoperability.

[63] Such decontextualization is documented in a study by Jessica Thurk and Gary Fine, who examine how importing pieces of architectural drawings causes errors when not accompanied with the original meaning. This happens despite the standardization with which tools are designed (Thurk & Fine, 2003, pp. 115–116).

[64] According to Hakken, the process of distilling knowledge from information is emphasized in the modernist knowledge discourse. In the other direction, production of information based on situated knowledge is emphasized in the postmodernist knowledge discourse (Hakken, 2003, pp. 37–39). Hakken further claims that these two points of emphasis form a useful dialectic, keeping the focus on both of the processes instead of just one (Hakken, 2003, p. 45). In software development projects, we can see this dialectic at work when a newcomer first appropriates information to gain knowledge and then use it to create more information for others to appropriate.

[65] This claim is also supported by Keil-Slawik (1992, p. 169).

cal situations, which are projected into different purposes at hand and systems of relevance (Schütz, 1953, p. 8). These two points also constitute the underlying basis for the distribution of knowledge. We can see that the knowledge with which software developers approach a program will necessarily differ from that of its users or newcomer programmers. Members of each of these three groups approach the object with a different purpose, different systems of relevance and different typifications. This is assuming, of course, that these three groups are homogeneous in those three regards, which does not have to be the case. But it seems reasonable to postulate that the differences will be bigger between those three groups rather than within them. After all, they are defined by a common experience (developing, using and learning to develop) with the object.

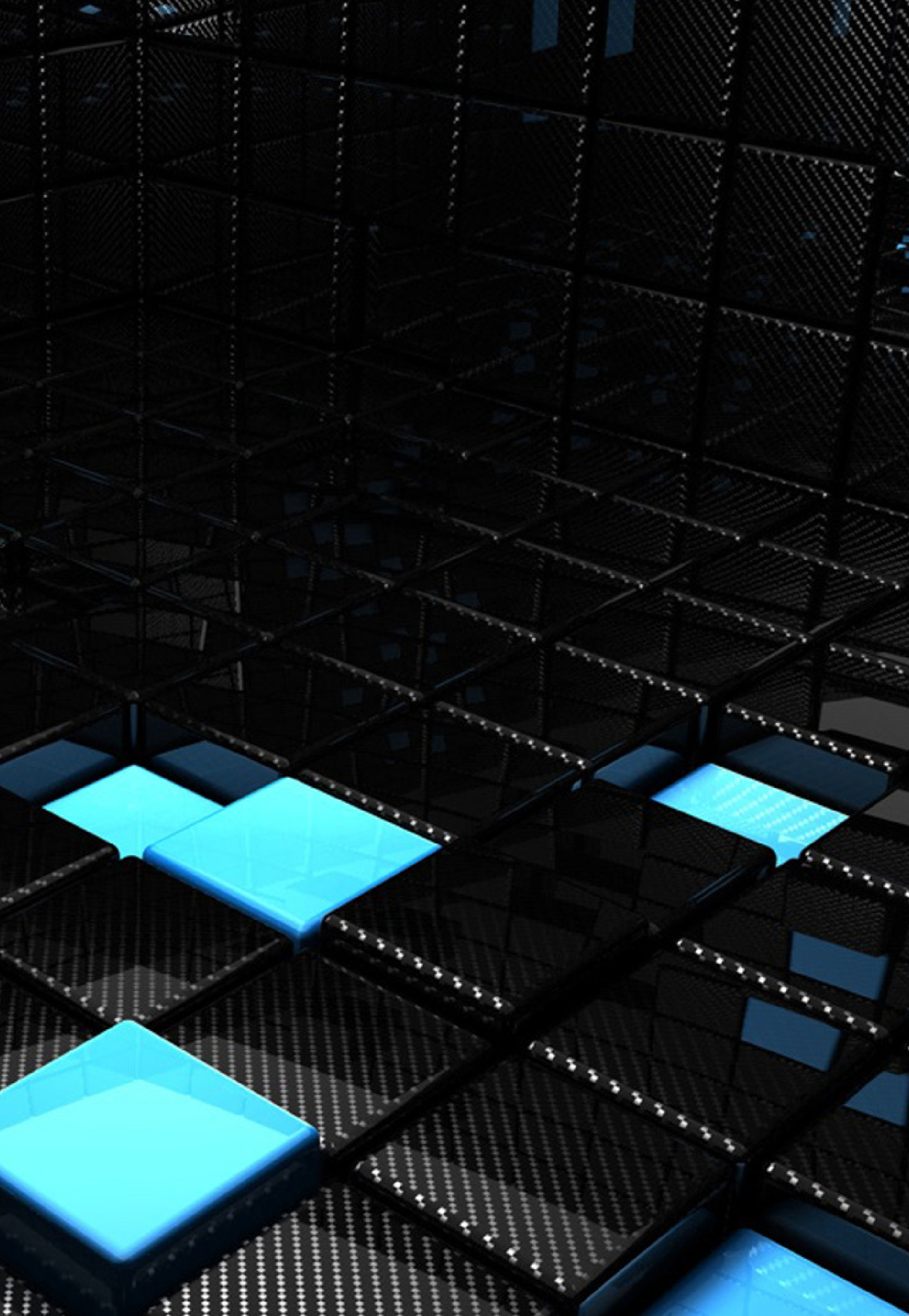
According to Schütz, the difference in perspectives can be overcome by two types of idealizations: the interchangeability of standpoints and the congruency of systems of relevance. According to the first, actors take for granted that when they change positions, they will be at the same distance from the object and see it in the same typicality as their counterparts (Schütz, 1953, p. 8). That is to say, actors presuppose a common *experience* should they find themselves in the same position relative to an object. In the light of the topic at hand, it is useful to specify this even more to state that actors presuppose that they will be provided with the same information. If not in the analogue environment, then at least in the digital environment, experience can be equated with providing information. But information does not take arbitrary forms; it is structured in the form of intentionally used design artifacts. These represent the externalized and formalized information that is used to distribute common experience.

The second idealization implies that actors assume the uniqueness of their and their counterpart's biographical situations can be set aside to establish the common purposes at hand and a common system of relevance (Schütz, 1953, p. 8). This means that actors presuppose they can *reflect* common experience in the same way, that is to say, draw upon similar knowledge to process the experience. Here, we arrive at a recursive statement, according to which pre-existing knowledge is used to produce new knowledge from experience. However, the pre-existing knowledge and the coming-into-existence knowledge need not have the same form. While the latter – at least initially – is bound to exist as a resulting state of mind, the former can take the form of an externalized tool that is used to process information and indicate its meaning in a common way. In this way, it is possible to conceptualize tools as externalized and stabilized forms of reflection, ready to be distributed.

Idealization	**Substrate**	**Process**	**Externalization**
Interchangeability of standpoints	Information	Experience	Design artifacts
Congruency of systems of relevance	Knowledge	Reflection	Tools

Table 1
Reciprocity of perspectives in digital environments

These two idealizations show us how the initial differences resulting from a heterogeneous distribution of knowledge can be overcome, that is, how a reciprocity of perspectives can be established in the digital environment. Both of them draw upon externalized and commonly used objects – design artifacts and tools – which by themselves represent ossified forms of experience and reflection, but which also allow for further distribution of common information and knowledge. In the following chapter, I will continue to explore the cognitive relevance of design artifacts and tools but I will do so in a way that will introduce the language with which it is possible to describe the organizational mode these objects appear in.



3

Network Shaped Knowledge Distribution

3.1 Cognitive Networks

If we try to sum up the role that tools and design artifacts play for a programmer's knowledge building, we could come up with a wording similar to "material means of thought", an expression used by Edwin Hutchins to describe the material dimension of symbol manipulation. Hutchins's line of argumentation starts with the claim that abstract manipulation of symbols is not a process that takes place inside an individual's mind. Instead, symbol manipulation should be considered to be mediated by cultural and physical objects (E. Hutchins, 1995, p. 363).[66] This is not to deny that humans process symbolic structures; Hutchins's aim is to counter the proposition that the cognitive process is *purely symbolic* (E. Hutchins, 1995, pp. 369–370).

Hutchins is not the only author proposing what could be called the central thesis in Theory of Distributed Cognition.[67] Andy Clark and David Chalmers also propose to award externalities with epistemic credit:

[66] The tendency to restrict cognition only to matters internal to the individual results, according to Hutchins, in attributing every cognitive characteristic to the individual mind while ignoring any role externalities could play (1995, p. 173, 356). This assumption has been rendered problematic by studies by Bruno Latour (1986), Karin Knorr-Cetina (1999) or Hutchins (1995) himself.

[67] Hutchins's work is a part of a broader line of thought represented also by authors such as Jean Lave (1988) or Lucy Suchman (1987, 2007) and applied in fields of study

> *If, as we confront some task, a part of the world functions as a process which, were it done in the head, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process. (Clark & Chalmers, 1998, p. 8)*

This seems to be the main criterion for determining whether an object is a part of a cognitive system.[68,69] To define what a cognitive system is, we can reach for Ronald Giere's grasp of the concept. In his view, cognitive systems are specified by what they produce: knowledge. Therefore, cognitive systems, even though they include material objects, are based on human agency (Giere, 2002, p. 642). We can also use Clark's and Chalmers's (1998, p. 8) distinction between pragmatic action (alteration of the world for its own sake) and epistemic action (alteration of the world in order to augment cognitive processes, for example search or recognition) to claim that cognitive systems engage predominantly in epistemic action.

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such as human-computer interaction (Wright, Fields, & Harrison, 2000), religion (Lawson, 1999; Reimer, 2005), morality (Magnani & Bardone, 2008) or work (Rogers & Ellis, 1994). Another approach that also refuses to attribute epistemic credit to the symbol manipulation performed only by the human mind can be found in the theory developed by Karen Barad, who claims that interaction (involving apparatuses used for measurement or observation) constitutes an inseparable part of phenomena (Barad, 1998, p. 95). In her more recent work, she brings this claim to its more radical implications, questioning the metaphysical belief that things have independent sets of determinate properties (Barad, 2007, p. 19). Finally, the central thesis of the Theory of Distributed Cognition is reminiscent of the cyborg image classically described by Donna Haraway: "Why should our bodies end at the skin, or include at best other beings encapsulated by skin? From the 17th century till now, machines could be animated – given ghostly souls to make them speak or move or to account for their orderly development and mental capacities. Or organisms could be mechanized – reduced to body understood as resource of mind. These machine/organism relationships are obsolete, unnecessary. For us, in imagination and in other practice, machines can be prosthetic devices, intimate components, friendly selves" (Haraway, 2006, p. 144).

[68] There is an ongoing discussion concerning the criterion as represented, for example, by Magnus, who considers whether double-blind studies are a case of distributed cognition, given that they in principle could not be carried out within a single mind (Magnus, 2007, p. 301). But these are discussions of rather peripheral cases that are not very relevant for the present text. Conceptualizing tools as parts of distributed cognition systems is well established (Clark, 2006; DiMaggio, 1997).

[69] Francis Heylighen further characterizes distributed cognition systems with self-organization, co-opting external media, network structure, selective propagation of information and production of novel knowledge (Heylighen et al., 2004).

According to Hutchins, the development of material means of thought results in different representations of given problems, so that problems once considered difficult can be turned into easily solvable ones (E. Hutchins, 1995, p. 367). This connects directly to Keil-Slawik's thesis about removing enforced sequentiality of tasks by condensing them into a single operation that can be easily performed by a program. A sequence of tasks can be mapped, represented as a formal function in a programming language, and implemented in a program by adding it to its source code. After compilation of the modified source code, the operation is available through the program's user interface. There, it represents not only the modification of text (source code), but also the modification of an object or tool (interface). Depending on the type of interface,[70] this modification can take the form of an added command in a command line interface or an added element in a graphical user interface, each representing the new operation. In cyberspace, each operation that can be performed has to be an operation of some program and therefore has to undergo this generally described process. As a result, an action can be defined as the coordination of condensed task sequences represented as operations in a software interface. This positions software (along with the underlying hardware of course) to be the material means of thought in programming.

Clark further specifies objects that meet the criterion for attribution of epistemic credit (what I have been calling "material means of thought" up to now) as "wideware" and defines them in a way that shows their direct relevance for this text as objects that "act so as to manipulate, store, or modify the knowledge and information that the organism uses to reach its goals" (Clark, 1998, p. 269). The sociological relevance of these claims, as Ronald Giere and Barton Moffat emphasize, lies in the fact that

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[70] In one of his early texts, Hutchins distinguishes between interfaces based on abstract formalism and direct manipulation interfaces based on graphical representation of tasks (E. L. Hutchins, Hollan, & Norman, 1985). The former are typically represented by command line interfaces that rely on a complex and precise syntax of textual commands, while the latter designate graphical user interfaces that rely on operations with graphical elements. To give an example, copying a file in a command line interface can by achieved a command like: `cp directory1/file_to_be_copied.txt directory2/`, while in a direct manipulation interface, one can simply drag and drop the file with a mouse. The latter interface seems to be faster and more convenient, however the benefit of using textual commands is that they can be combined with other commands, creating a new task sequentiality in a script file that can be executed as a whole, thus representing a new condensation of tasks.

the shape the distribution of actors and objects takes in particular cases originates in existing social structures (Giere & Moffatt, 2003). Furthermore, Hutchins, when dealing with the question of how the elements of distributed cognition systems are selected and included, relies heavily on the cultural context of cognition. Therefore, he proposes what he calls the "hypothesis of enculturated cognition", according to which "the ecological assemblies of human cognition make pervasive use of cultural products. They are always initially, and often subsequently, assembled on the spot in ongoing cultural practices" (E. Hutchins, 2011, p. 445). In other words, Hutchins claims that cultural practices play a key role in the organization of cognitive systems.[71]

3.2 Actor-Networks

In this work, I assume that social structures and *assemblies* of cultural practices take the form of networks. Besides the resemblance in terminology, this decision is also supported by the fact that Hutchins's work on distributed cognition is considered by Bruno Latour to be compatible with Actor-Network Theory (Latour, 2005, p. 60). For example, one of the central claims of Latour's theory, that connections among entities are constitutive for them (Latour, 1994, p. 35), can be seen as one of the more general assumptions behind the theory of distributed cognition, underpinning the effort to attribute epistemic credit to external entities.[72] Furthermore, Hakken introduces the concept of knowledge networking (broadly consistent with Actor-Network Theory) to avoid some of the controversies stemming from taking into consideration both modernist

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[71] There is also a topic within the theory of distributed cognition which roughly corresponds to the classical sociological dichotomy between actor and structure. Giere shows that there is a tendency to attribute agency to structures by speaking of "distributed minds" but claims that this is not necessary and argues for attribution of agency only to human actors (Giere, 2002, p. 642). In one of his early works, Hutchins (E. Hutchins, 1991, p. 38) draws a distinction between evolution and design to distinguish systems that emerged spontaneously (perhaps as a result of some underlying structure) from those that were results of conscious planning (attributable to human actors). More recently, Eviatar Zerubavel and Eliot Smith elaborated on the possibility of transcending methodological individualism by considering human actors to mutually constitute the entities of distributed cognition systems for each other (Zerubavel & Smith, 2010, p. 324).

[72] Considering this affinity, it is no surprise to find the two theories elaborated side by side in overview works such as that of Norton Wise (2011).

and postmodernist knowledge discourses and uses it to establish a dialectical perspective (Hakken, 2003, pp. 45–47).

An organized set of wideware (that is, tools and design artifacts) and its human operators hints at the main types of compositional elements that form the networks of FOSS development projects. At this point I draw from Latour's theory, which provides a useful infra-language that specifies how could these networks be mapped (Latour, 2005, p. 174). In other words, it is not a substantial theory of what is going on in any part of the social reality, but it is a perceptive grid used for observation (Latour, 1996b, p. 11). In Latour's approach, to interpret means to add something from the outside, something which has not yet been mapped to the network.[73] Subsequently, a good research account should be the one tracing a network through different locations.

According to Latour, a network is "not made of nylon thread, words or any durable substance but is the trace left behind by some moving agent" (Latour, 2005, p. 132). Networks are not simply "out there" in the sense of a material substance connecting their nodes all the time. Not all networks are like computer networks which need cables, routers and switches to be constantly present.[74] Usually networks need to be mapped

[73] This seems to contrast with more traditional approaches to interpretation based on subsuming or connecting particular observations with general concepts (see for example Reed, 2011, p. 92). As his criticism of theoretical frameworks demonstrates, Latour is strongly opposed to certain ways of interpretation. According to him, applying a theoretical framework in the initial stages of research results in making the phenomenon under study vanish. The rationale for this claim is that theoretical frameworks often contain assumptions about invisible social forces which, in the explanations of the studied phenomenon, tend to substitute other observable causes (Latour, 2000, p. 6, 2003, p. 3, 2005, p. 102, 2012, p. 138). In this sense, the invisible social forces are seen by Latour as something that Gregory Bateson called explanatory principles: "an explanatory principle – like 'gravity' or 'instinct' – really explains nothing. It's a sort of conventional agreement between scientists to stop trying to explain things at a certain point" (Bateson, 1972, p. 43). Considering Bateson's characterization of explanatory principles, I see Latour's approach to interpretation as an attempt to resist the tendency to close off the analytical process too early by assuming the operation of invisible forces implied by theoretical frameworks.

[74] Latour sees the Internet as increasing the material dimension of networks, he claims: "the more digital, the less virtual and the more material a given activity becomes" (Latour, 2010, p. 8).

and visualized to be graspable.[75] To further elaborate Latour's concept of networks, I note that networks have three basic features:

1. A point-to-point connection is established that is physically traceable and thus can be recorded empirically.
2. Such a connection leaves empty most of what is not connected.
3. This connection is not made for free. (Latour, 2005, p. 132)

First, we can see that the tracing is done on a material, not conceptual level. As Latour would put it, the world needs to be allowed to "put itself in order" (Latour, 2005, p. 184).[76] But this "putting into order" is nothing mysterious, it is traceable and accountable. As Latour claims, social formations hold together because of graspable entities that operate within them. And it is by tracing the connections that these entities are part of that we can understand the particular case of order that is established. In this research project, it means focusing on the tools and platforms used for version control, issue tracking, documentation or direct communica-

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[75] In this sense, Latour's conceptualization of networks seems to be rather analytical. According to Latour, networks can be observed in various forms of organization. Any actor can be decomposed into a set of network relationships and then recomposed (Latour, 2010, p. 5). On the other hand, Castells's conceptualization of networks is more substantial. Within it, networks represent a separate organizational form defined against centralized organizational forms (Castells, 2000b, p. 695, 2000a, p. 15) and empirically identified in structures that are commonly designated as networks (such as the Internet, hypertext, or financial networks).

[76] This strand of Latour's thinking is heavily influenced by Harold Garfinkel. According to Latour, both he and Garfinkel share the view that sociology should be a science examining how society holds together (Latour, 2005, p. 13). Although Latour does not use the concept, Garfinkel's definition of ethnomethodology explicitly rests on a presupposition that social settings are to be viewed as "self-organizing". Garfinkel further elaborates the concept as follows: "Any setting organizes its activities to make its properties as an organized environment of practical activities detectable, countable, recordable, reportable, tell-a-story-aboutable, analyzable – in short, accountable" (Garfinkel, 1967, p. 33). However, it seems that Garfinkel is not the only interactionist precursor of Latour's approach. If we compare Herbert Blumer's methodological approach (Blumer, 1986), described by Martin Hammersley as a program of naturalistic research (Hammersley, 1990, p. 156), it seems to be compatible in all points that Hammersley lists. In this context, the concept of self-organization is different from its other version rooted in the tradition of cybernetics (Ashby, 1962; Von Foerster, 2003b) and utilized most notably as the concept of autopoiesis (originally developed by Humberto Maturana (Maturana, 1980) and Francisco Varela (Maturana & Varela, 1987)) in the systems theory of Niklas Luhmann (Luhmann, 1995, 2014).

tion and tracing their origin, how they are used in the studied project and how they got there in the first place. It also means focusing on the elements within them, that is, individual contributions, issue reports, documentation pages or chat channels and the conversations within them. Tracing how these entities are put together will allow me to examine how this specific type of order is put together.

Second, networks are made of connections and so they differ from what is commonly called an area, a field, a sphere, or any surface in general. It is for this reason that networks have no borders (Latour, 2010, p. 5), they just leave everything that is not part of them unconnected (Latour, 2005, p. 242). As such, Latour claims that networks are "by no means comprehensive, global or systematic, even though they embrace surfaces without covering them, and extend a very long way" (Latour, 2012, p. 118). He then goes on to label everything that is unconnected with the word "plasma". It represents everything "which is not yet formatted, not yet measured, not yet socialized, not yet engaged in metrological chains, and not yet covered, surveyed, mobilized, or subjectified" (Latour, 2005, p. 244). This implies that the characteristics of a network could be arrived at by examining what is not connected just as well as what is. This is not a call to examine everything, but rather a call to include entities that as we understand could be connected though the connection is avoided, or are being connected at the time of observation. For this research project, it means closely studying the cases of newcomers who attempt to join the software development project. It also means examining the tools or platforms that the maintainers for some reason avoid using. Elaboration of such cases can offer key insights into the inner workings of the network.

Third, Latour repeatedly states that the connections made within networks are "not made for free" (Latour, 2005, p. 132) or that sites have to "levy the means" (Latour, 2005, p. 174) in order to influence other sites. Such statements point to the role resources play in building networks. Indeed, to connect something does not just mean attaching it. It means searching for something, appropriating it, learning how to use it, spending time with it and modifying it, or buying something, creating something and deserving something. In other words, resources are spent on making connections and making actor-networks more extensive. Without resources, networks will hardly flourish and so for explaining how a certain network operates, it is necessary to shed light on the resources it uses to do so. This also applies to this research project. Servers are necessary to run source code repositories, issue databases or chat channels. But servers need to be provided, powered and maintained, people need to be paid and legal entities must represent every attempt at gaining financial resources. Thus, to trace the tools and platforms means also finding out how they can operate, what resources make that possible.

Now I will attempt to describe the difference between the two basic types of units that form networks, that is, mediators and intermediaries. The latter are defined by Latour in the following way: “An intermediary, in my vocabulary, is what transports meaning or force without transformation: defining its inputs is enough to define its outputs” (Latour, 2005, p. 39). Thus, intermediaries are regular and predictable, just like machines that function reliably in accordance with expectations of their operators. Mediators are precisely the opposite; their output cannot be predicted from their inputs, so every time they must be considered with all their particular characteristics. Thus, mediators are anything but regular; they are like unreliable, broken or unfinished machines that seem to do whatever they want.[77]

Whether an entity is a mediator or an intermediary is not inscribed into its nature once and for all, but depends on its observed behavior. This means that an intermediary can turn into a mediator at a certain point in time (as when an error is discovered in a piece of software leading to unexpected behavior) or from a certain point of view (as when an unexperienced user is discovering unknown functions that certain piece of software can perform). This also applies to the transition from mediator to intermediary (as when a bug in a piece of software is fixed or a user learns what to expect).

In this perspective, mediation is a key concept that needs to be elaborated further. In one of his texts, Latour offers four meanings mediation has: translation, composition, black-boxing and delegation. According to this author, translation is “displacement, drift, invention, mediation, the creation of a link that did not exist before and that to some degree modi-

[77] These definitions appear to be analogous to the definitions of trivial (independent of their past states and therefore predictable) and nontrivial (dependent on their past states and therefore unpredictable) machines developed by Heinz von Foerster (Von Foerster, 2003a, pp. 309–313). This line of thought is further developed by Ranulph Glanville, who considers scientific knowledge to be a cumulative stabilization over examination of in principle unpredictable (because they are unopenable) black boxes (Glanville, 1982, 2007).

fies two elements or agents" (Latour, 1994, p. 32).[78] If we start with the premise that a relation between two elements modifies them, it seems logical to claim that connections are constitutive for those elements. Their "essence" is to be found in the links that connect them to others. Those connections allow them to act in ways they would not be able to just by themselves. This is the second meaning of mediation, namely composition (Latour, 1994, p. 35). Latour goes as far as equating embeddedness in various configurations of connections with different modes of existence (Latour, 2007a, p. 24). Therefore, interaction can be seen as action which is shared with actors that have different ontologies because they are made of connections from other spatio-temporal frameworks (Latour, 1996a).[79] Furthermore, this meaning of mediation can be related to the claim made by Hutchins and Clark, that actors widen their options for epistemic actions by interacting with wideware; by doing so they achieve augmented cognitive results. Programmers use software interfaces in order to perform task sequences that are condensed into easily performable operations. The way these operations are designed and implemented in an interface determines a programmer's options for action.

However, composition may not be visible at first sight. This is a result of the black-boxed nature of mediators or intermediaries (Latour, 1994, p. 36). Their composition is opaque unless an effort is made to make them more transparent. As I suggested earlier, compilation, the act of transforming human readable source code into machine readable binary files, represents the finest act of black-boxing. The contents of a binary file after compilation are not intelligible for human readers and thus an understandable text is turned into a black-boxed thing. Finally, delegation makes explicit what mediators or intermediaries do: they achieve a spatial and temporal shifting of action (Latour, 1994, p. 39). They make overcoming distances and durations possible to bring a certain kind of

[78] It seems that the concept of translation is roughly analogous to the concept of emergence used in the systems-oriented tradition of thought, see for example the work of Poe Yu-Ze Wan (Wan, 2011, pp. 69–82). However, while emergence is associated with the premise that the whole is always more than the sum of its parts, in Latour's approach, the whole is always smaller than its parts (Latour, 2011, p. 6). This is so because the whole black-boxes its composition by appearing as a single agent.

[79] John Law articulates this perspective through the term empirical ontology, which he summarizes in the following way: "It washes away assumptions about pregiven realities and instead asks questions about how realities are done in practices" (Law & Lien, 2013, p. 3).

action to a situation. In cyberspace, delegation is carried out primarily by persistent digital text or the interface of a compiled program. They are able to overcome distance and endure time in order to carry information (digital texts) or carry out an operation (interfaces).

To sum up Latour's perspective, any interaction takes place in a situation which is full of elements that originated somewhere else, at a different time and perhaps were put into motion by some other agency. This means that an observer of an interaction should be led away from it and drawn towards different places, times and agencies that played a role in putting together elements of the examined situation. This perspective is based on the assumption that social phenomena are constructed of traceable elements, which are formed to provide stability. The title of one of Latour's studies simplifies this point: "technology is society made durable" (Latour, 1991).[80,81]

To sum up my theoretical approach, I will now go through the most important points I made in the last two chapters. I argued that programming, an activity central to software development, requires knowledge not only in the area of how to use programming languages and other tools, but also significant knowledge that consists of a theory, or an approach, with which a particular program is developed. An important role in the software development process is also played by artifacts. These may be used either as tools that augment or replace human activity, or as design artifacts, intermediary outcomes which allow for further reflection or new experience. Reflection and experience form the basis of vertical and horizontal distribution of knowledge, and so any change in the distribution of knowledge must come through these processes. However, it is necessary to differentiate knowledge that involves appropriation by an actor and information which denotes data that actors

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[80] It is also important to note that this is a recursive problem – a similar point is made by Dominique Vinck with regard to technology itself. According to her, a constant effort in both areas of production and use of technology is necessary in order to keep a technology existing. The material dimension of a technological object may create the basis for its performance, but it cannot be fully grasped without considering a number of actors and intermediary objects organized toward it. This creates the ground for the "objectivity of technology" (Vinck & Blanco, 2003, p. 212).

[81] In this sense, Latour proposes a specific kind of materialism. He tends to resist an idealized form of materialism that takes as a reference point the notions of what things in themselves should ideally be. Instead, Latour directs attention to actual processes that result in things as they are in practice (Latour, 2007b, p. 139).

possess. A similar distinction can be made with regard to information and meaning, where the latter arises from relating information to itself within a system of reference.

Therefore, within software development, design artifacts consist of information that can be easily stripped of its meaning, or in other words, decontextualized. To resist this, reciprocity of perspectives must be established among the parties exchanging design artifacts. I delimited three main aggregates according to their experience with developed software: developers, newcomers and users. I also assume that these groups are internally more consistent than among each other. I further attempted to contextualize the idealizations that, according to Schütz, lead to reciprocity of perspectives within the digital environment. Specifically, I related the interchangeability of standpoint idealization with the distribution of information as experience and also with the distribution of design artifacts as stabilized information structures. I also related the congruency of the system of relevance idealization with the distribution of knowledge stemming from reflection and also with the distribution of tools as stabilized reflection structures. As a result, the stabilized structures of experience and reflection – the design artifacts and tools – provide conventional ways to produce shared knowledge.

On this line of reasoning, tools and design artifacts play a central role. It is through them that cognitive processes leading to the establishment of knowledge take place. They constitute the so-called wideware, the parts of cognitive systems that are external to humans. At the same time, the distribution of wideware in particular cases originates in existing social structures. These structures, I assume, take the form of networks which can be assembled as conglomerates of physically traceable connections that are selective and require resources to be maintained or extended. The elements operating within a network can be of two types, reliably transporting intermediaries and unpredictably transforming mediators. What these elements perform can be grasped with the concept of mediation and its four meanings: translation, composition, black-boxing and delegation. By tracing the mediation of identified elements, a network can be assembled and described as a form of explanation of a phenomenon.

I will now use the implications of this section to reformulate the problem at hand. In the following chapters, I will assume that the networks which form free and open source software development projects contain elements (wideware) that are formative for the cognitive processes which lead to the induction of knowledge. The theoretical elaboration of idealizations as sources of reciprocity of perspectives represents my starting clue, but the strategy of network tracing leads me from theoretical premises to particular elements and resources that establish the studied knowledge networks. As a result, there are two specific questions to be asked about the knowledge networks of free and open source software. The first is how digital texts and software interfaces (as material means of thought) mediate actions of programmers. The second is how, or using what resources, the price to make connections is paid in cyberspace. Thus, the following analysis will not be limited only to the examination of the most immediate practices, but will also be aimed at exploring the less visible fringes of the network that make them possible. To provide the substrate for the analysis of these questions, I will first describe the four most significant practices I encountered during my fieldwork in a FOSS project.

4

Practices of a FOSS project

4.1 Code allocation

The development of the Pitivi video editor started in 2003 as Edward Hervey's end-of-studies project at the EPITECH engineering school in Paris. Initially, there were 10 students working on the project, aiming to have something usable before graduating. They decided to base their work on an existing FOSS multimedia framework known as GStreamer. This decision allowed for the functionality already present in GStreamer to be gradually implemented in Pitivi without re-inventing it. But this also meant that Pitivi relied heavily on GStreamer, which was at that time under heavy development and was not considered stable. Therefore, in the first years of development, the focus was aimed at GStreamer and Hervey transformed this activity into a full time job. After graduating, he was hired by a company called Fluendo in order to work on GStreamer. This lasted two years during which development of Pitivi itself was in a state of limbo. After that, Hervey co-founded the multimedia division at a company called Collabora, in order to develop Pitivi and the components it relied on. In late 2008, Collabora hired two new developers to work on Pitivi and related technologies. This boosted development that stalled during 2005–2007.

At that time the underlying framework for Pitivi consisted of GStreamer and its plugins. However, it turned out that in order to create a video editor on top of this framework, a lot of additional work had to be done. To solve this problem, and to make the solution re-usable, Hervey created a program called GStreamer Editing Services (GES) in 2009. In

2011, it was officially announced that Pitivi's next version will be based on GES. The subsequent release marked a large change in the architecture of the program, which brought with it a number of issues. The main focus of development at the time of writing is on stabilization that is necessary for releasing the 1.0 stable version of Pitivi.

The most recent component in the Pitivi architecture is a library[82] called GStreamer Editing Services (GES). This library filled the space between Gstreamer, which provides very general functionality through text commands, and Pitivi, which is designed to provide specific video editing functionality through its graphical interface. GStreamer is a library that is not intended only for video editing, but for media handling in general, and thus a lot of work must be put into condensing GStreamer functionality into operations that are conventionally used in video editing. To make this work re-usable, it was put into a separate library (GES), which can be used by other video editing programs. The ambition to create a common base for video editing programs can only be understood when we consider the number of projects that aimed at developing an open source video editor in recent years. An overview created by one of Pitivi maintainers lists 54 projects, 9 of which are still active.

The effort that aims to transform what has been initially at the core of Pitivi itself (and thus specific for only this program) into a library that is able to provide functionality to many other programs is indicative of an "upstream first" approach to software development, a convention that forms a cornerstone of the programming theory (in the sense of Naur's theory discussed above) with which Pitivi maintainers operate. This principle was described by one of the Pitivi maintainers at the GNOME User and Developer Conference (GUADEC) 2013:

[82] A library is a specific type of program that is in most cases invisible to the end-user but which is essential in that it provides general functionality that is used by programs that interact with users. The existence of libraries allows for modularity (libraries specialized in function may be combined) and reuse (the functions provided by a library may be used by a wide variety of programs) of components in software design.

> *It basically means: no hacks. You discuss with upstream[83] such as upstream GStreamer, upstream GTK[84] and everything and you work out solutions in cooperation with them and you don't put some stupid hacks in your application downstream instead of fixing the problem for everybody.*

What is interesting here is that in the world of free and open source software, the word "hacking" usually comes with positive connotation – in general, it denotes a creative and clever leverage of formal systems. But in this case, "hacks" are associated with stupidity. It denotes a way of solving problems that is faster and easier but that will eventually result in fragmentation and hindering of development in the wider community. On his blog, the same maintainer likens the difference between the "upstream first" approach and "stupid hacks" to the difference between "being a good citizen" and "doing your own thing in your corner". This is why many Pitivi developers do not actually work on Pitivi itself, but rather on some of the underlying libraries. This also illustrates how institutionalized this type of software development is today.

With institutionalization a set of formal rules usually appear to regulate an activity and free software development is no exception. In this context, the most prominent formal rules are expressed by licenses which define the possible uses of licensed source code. The variability of licensing use can be exposed by the categorization of plugins that GStreamer developers use and which result in a specific architecture of the library. GStreamer handles multimedia by sending streams of data through series of plugins. This means that the components which make GStreamer useful are packaged independently and may or may not be installed together with it. This seemingly odd design is enforced by licensing issues with various elements inside the plugins.

The GStreamer maintainers differentiate plugins into four categories based on source code quality and licensing: base, good, ugly and bad. The base and good plugins are unproblematic with regard to both licensing and code quality, as the maintainers put it:

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83 In software development, upstream and downstream specify the direction of functionality use among programs. The more general functionality usually lies in libraries (upstream) and is used for specific purposes in user-facing applications (downstream).

84 The GIMP Toolkit represents a set of libraries which provide functionality for programs developed within the GNOME framework. It was originally developed for the GIMP graphical editor (hence the name), but it later became a standard set of libraries for the whole GNOME desktop environment.

> *A collection of plug-ins you'd want to have right next to you on the battle-field. Shooting sharp and making no mistakes, these plug-ins have it all: good looks, good code, and good licensing. Documented and dressed up in tests. If you're looking for a role model to base your own plug-in on, here it is.*[85]

As indicated by their names, the "ugly" and the "bad" plugins are the problematic groups, each in their own way. Bad plugins simply have bad code quality and cannot be relied on. In this sense, they are technologically inferior to the rest of the plugins. By labeling them bad, GStreamer maintainers renounce their responsibility for their performance and support. They also renounce any commitments to fixing issues that are reported. Performance of these plugins has low priority so the only way that issues can be fixed in this area is when someone volunteers to do it:

> *Don't bug us about their quality – exercise your Free Software rights, patch up the offender and send us the patch*[86] *on the fastest steed you can steal from the Confederates. Because you see, in this world, there's two kinds of people, my friend: those with loaded guns and those who dig. You dig.*[87]

Here, the GStreamer maintainers emphasize the "Free Software rights" that are granted by the use of free software licenses and permit modification and redistribution of the code. However, the maintainers expect the contributors to exercise only the right to modify the code, not to redistribute it. The patch should be sent to them for review and redistribution. While this practice may seem as free-riding on the work of others, it is consistent with the "upstream first" principle by keeping development from fragmentation into a number of parallel versions. At the same time, the author retains his authorship and is provided with a distribution channel that reaches a wide audience. In other words, in exchange for providing the free software rights, the GStreamer maintainers expect contributors to be good citizens.

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85 *An explanation of the various plugin modules and how they were split up*. GStreamer documentation page. Accessed: 2014-07-23. Available at: http://gstreamer.freedesktop.org/documentation/splitup.html.

86 A patch is a term denoting a modification of source code that is made in order to fix a particular issue.

87 *An explanation of the various plugin modules and how they were split up*. GStreamer documentation page. Accessed: 2014-07-23. Available at: http://gstreamer.freedesktop.org/documentation/splitup.html.

However, the right to redistribute the code by other parties is still present and serves as a safety that counterbalances the maintainer's power stemming from the review and redistribution process. When contributors become unsatisfied with the way current maintainers operate, it is always possible to duplicate the whole source code of the developed program and start maintaining a parallel project. This practice is called forking.[88]

Ugly plugins, the fourth and final remaining category is characterized by licensing issues. GStreamer maintainers retain their responsibility for fixing issues that are reported against this group of plugins, but note there are difficulties in distributing them:

> *There are times when the world needs a color between black and white. Quality code to match the good's, but two-timing, backstabbing and ready to sell your freedom down the river. These plug-ins might have a patent noose around their neck, or a lock-up license, or any other problem that makes you think twice about shipping them.*[89]

To fully understand the extent of problems that licensing issues pose for the GStreamer project, it is necessary to note that key functionality is often accompanied by restrictive licenses or patents.[90] As a result, GStreamer distributors face a dilemma:

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[88] Although generally possible, forking is rather rare and is seen as a last resort in cases where every other option to resolve differences failed. Generally, forks are accompanied by argumentation that justifies the duplication of efforts, sometimes critically labeled as an instance of the 'not invented here' (NIH) syndrome that developing two parallel versions of a program implies. The argumentation also serves to draw contributors who must decide whether to stay with the original project or become part of the new one.

[89] *An explanation of the various plugin modules and how they were split up*. GStreamer documentation page. Accessed: 2014-07-23. Available at: http://gstreamer.freedesktop.org/documentation/splitup.html.

[90] For example, patented software is necessary in order to process files in the omnipresent MP3 format. The MP3 format has its free alternative in the free OGG Vorbis format, but the use of this format is far from standard. Contrary to licenses which affect precisely defined parts of source code, where an ex post change of their terms is very hard if not impossible in most cases, patents are problematic because they affect certain technology in a more general sense and allocate the power to decide into the hands of one formally defined party. Even though the party may permit a free use of the patented technology, there is no guarantee that this will not change in the future,

> *Due to this situation, many companies, including major GNU/Linux distributions, get trapped in a situation where they either get bad reviews due to lacking out-of-the-box media playback capabilities (and attempts to educate the reviewers have met with little success so far), or go against their own – and the free software movement's – wish to avoid proprietary software.*[91]

In attempting to help overcome this dilemma, GStreamer maintainers opt for a lesser evil – they choose to use the GNU Lesser General Public License (LGPL) which is a free software license that permits distribution together with proprietary software (as opposed to the classic GNU General Public License).[92] The proprietary or patented software is then packaged into a separate body of plugins so that the users may decide (according to their needs, local legislation, or their attitude toward using proprietary or patented software) whether they want to install and use it. As a result, the plugin architecture of GStreamer reflects this and moves the responsibility from GStreamer maintainers to users or local distributors, where the dilemma has to be negotiated over and over again.[93]

This problem also applies to all applications that use GStreamer to handle multimedia files. As a result, GStreamer maintainers recommend

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possibly as a result of transferring the patent to another party. In this light, a call made by Polk Wagner to supplement licenses as ways of organizing open source software development with patents (Wagner, 2003, p. 1031) seems inadequate.

91 *Licensing your applications and plugins for use with GStreamer*. GStreamer documentation page. Accessed: 2014-07-23. Available at: http://gstreamer.freedesktop.org/documentation/licensing.html.

92 The classical GNU General Public License introduces the necessity to license all derivative works with it, a characteristic that is often called a "viral feature".

93 The ambiguity regarding licensing and patents in this area is so deep that Fluendo, one of the companies involved in the GStreamer project has partly built its business model around it: "While Linux OS does provide multimedia functionality in terms of free media players, unlike major paid operating systems like Microsoft Windows and Apple OSX it does not come with licensed codecs pre-installed. Without these codecs, many Linux users and organizations unknowingly violate intellectual property laws, putting themselves and their organizations at risk. Patent infringement has serious consequences and, especially for larger organizations with many users, the cost can be substantial. [...] This is where we come in. From proprietary codecs to our robust DVD software, Fluendo legally protects organizations and empowers users to engage with multimedia like never before. Experience unmatched playback quality with the peace of mind that you're adhering to international audio and video patents." (*The Legal Risk that Linux Users Face*. Fluendo marketing materials. Accessed: 2015-04-09. Available at: http://www.fluendo.com/corporate-linux-users/.)

that all developers of applications utilizing their framework use the LGPL license as well, in order to be able to use the functionality contained in "ugly" plugins. But this is not the only option that developers of other applications have. They may also use the GPL license and supplement it with a clause stating that GStreamer plugins are exempted from the obligations of the license. However, GStreamer maintainers state that using a GPL license with a clause would result in hindrances to sharing source code among projects and therefore recommend the standard LGPL:

> *Our suggestion among these choices is to use the LGPL license, as it is what resembles the GPL most and it makes it a good licensing fit with the major GNU/Linux desktop projects like GNOME and KDE. It also allows you to share code more openly with projects that have compatible licenses. As you might deduce, pure GPL licensed code without the above-mentioned clause is not re-usable in your application under a GPL plus exception clause unless you get the author of the pure GPL code to allow a relicensing to GPL plus exception clause. By choosing the LGPL, there is no need for an exception clause and thus code can be shared freely between your application and other LGPL using projects.*[94]

The GPL and LGPL licenses are standard in free software development and their wide use allows for re-appropriation of source code between projects without the need to negotiate licensing conditions. On the other hand, the inclusion of a non-standard clause into one of the licenses introduces a requirement of negotiation and complicates "free sharing" of source code among projects. Thus, licensing may be seen as a part of the (legal) infrastructure of sharing in the sense that abiding to standards allows for frictionless distribution of source code.

4.2 Knowledge Channeling

The Internet relay chat (IRC) is designed to facilitate synchronous communication, that is, communication where both parties are present at the same time. Internet relay chat simulates the space for communication in a way that not being present means missing the communication – no

[94] *Licensing your applications and plugins for use with GStreamer*. GStreamer documentation page. Accessed: 2014-07-23. Available at: http://gstreamer.freedesktop.org/documentation/licensing.html.

history is recorded for those who join in to read. Pitivi maintainers circumvent this limitation by using "bouncers", programs that run constantly on a server and through which they connect to their chat accounts. This allows them to be connected to IRC channels even when they are asleep and their computers are shut down. When they connect again, they can read what happened when they were away and see if someone tried to talk to them. In this way, they are using IRC also as an asynchronous means of communication.

The basic organizational unit of IRC is a channel, which represents a chat room where those who are present see the communication taking place. Channels are differentiated by topics of interest: there is a Pitivi channel, a Gstreamer channel, a GNOME documentation team channel, etc. People are known to be present on certain channels so when I wanted to talk to them, I had to go where they were. Sometimes I went to a channel because of its overall specialization and sometimes I aimed for a particular person. In this way, the IRC channels represent reservoirs of knowledge. This is what I noted when I was beginning my work on the user manual:

> *I needed to make sure that the new page I created gets to the .pot file for translators to work on. No one at Pitivi knew for sure what was needed so I joined the channel #i18n [internationalization] and asked. I explained my problem and provided info on which module it is related to. Within an hour I got my answer and a place where to check that everything went ok. Went back to #pitivi and told others the result.*

Such trips to various channels in order to retrieve specific information are a common practice in this environment. Since one can be connected to multiple channels simultaneously, it is not even necessary to leave the current channel. All that is needed is the name of the channel and the network it belongs to.[95]

What takes place within a channel is similar to a screenplay text. The communication is sequentially structured, actors enter and leave, say

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[95] IRC channels are grouped into overarching networks which provide servers for their operation. During my fieldwork, I was present in two networks: Freenode and GimpNet. The former hosts the channels of FOSS projects in general while the latter hosts channels that belong specifically to the GNOME project.

something and do something[96] while they are present. All acts leave traces in the backlog. However, it is not necessary to communicate actively the whole time one is connected. It is common to be present in the channel just to monitor it for relevant discussions (a practice called "lurking") or to be available for others. For example, at the time of writing, there are around 30 people (not including bots) connected to the Pitivi channel even when no discussion is taking place. The lurking practice was jokingly referred to in one conversation:

> *Chris: sounds like it's probably doable, but i'll have to do some more poking and research*
> *Chris: it's not an 8am poke around before work task ;)*
> *Steve: Indeed :)*
> *Steve: Anyway, hope you're having fun with all this, always interesting to discover new techs :)*
> *Steve: (and fix stuff on the way)*
> *Chris: oh yeah i'm having fun diving back into gtk+ stuff*
> *Chris: did a little work on gimp aaaaages ago (in powerpc mac days)*
> *Steve: And jack is always very helpful, even when not giving out his code ahaha*
> *Chris: in the meantime, adding more irc channels to my defaults :D*
> ** chris idle ALL the channels!*
> *Steve: Yeah I think I remember you telling me this :)*
> *Steve: Ahaha that's the spirit*
> *Chris: :D*
> *Steve: 17 channels open here :)*
> *Steve: All these conversations I will never read :)*

In this conversation, Chris was returning after a long period of time to work on code that uses the GTK+ toolkit and investigated a task he wanted to accomplish. We can see that the return and investigation involve adding related IRC channels into a set of channels with which connection is automatically established (the "defaults") when his IRC client is opened. But this does not necessarily mean that he will read

[96] There is a way to write a message so that it refers to the author from the position of a third party. This is often used to let others know what one is doing or why one is not responding. Such messages begin with an asterisk and look like this: "* [nickname] is still reading the backlog".

all conversations that take place within the channels. He just wants to have those channels ready when he will need to make an inquiry. This is another example of using IRC channels as reservoirs of knowledge.

Communication inside a channel often oscillates between bursts of activity and pauses in conversation. This is obviously a result of developers being from different timezones and having differently structured work time. However, there also seem to be other mechanisms at work. First, an ongoing discussion draws attention to the channel. Second, when someone starts a discussion, it tends to sustain itself by provoking new inputs. Third, when participating in a discussion, others can see an actor's availability and often start a new conversation.

Thus, communication on IRC is often multi-threaded. There can be two or more simultaneous conversations taking place at the same time. Multi-threadedness means not only that there are several dyads communicating at the same time, but also that one can participate in more than one conversation. Such situations are demanding in response speed and responding slowly represents the risk of losing a counterpart's attention. Everyone is multitasking and so one is quickly driven away from the channel if nothing new happens in a while.

There is a mechanism though, that allows for making others pay attention. Writing someone's nickname in a message generates a notification in that user's desktop client. The notification system attempts to draw attention to the discussion. This can get annoying when over- or misused, and so I have witnessed maintainers having to calm down eager newcomers several times. On the other hand, some messages are not aimed directly at anyone; they just function as a way of letting others know what is on one's mind or what one is currently doing. Similarly, solutions to problems are posted even if no one requested them directly, to provide resources for future use and collect feedback on the solution. However, the texts flowing through IRC are not very persistent. The individual maintainers occasionally copy and paste parts of conversations into their private notes, but no systematic archiving takes place.[97]

There is a different kind of infrastructure in place exactly for this purpose – the project's wiki and individual blogs. This infrastructure provides means for self-documentation, which is an integral part of free and open source software. This means that problems and their solutions

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[97] This is, however, project specific. Some projects, like the Ubuntu Linux distribution, archive their IRC channels and keep the archives accessible from their website.

are recorded and elaborated upon, even when no one requested it directly. There is a conviction that the most effective way to deal with problems is to archive them and their solutions publicly. This allows others (and sometimes the writers themselves after a longer period of time) to quickly find information or solutions to problems they are facing. Blogs and wiki pages are better suited for this purpose as they offer more accessible archiving (through the standard Hyper-Text Transfer Protocol) where texts are persistent by default (contrary to IRC for example).

Furthermore, blogs and wikis differ in that the first represent simple web pages written in the standard HyperText Markup Language (HTML), while the second not only use their its own markup language (which is eventually translated to HTML), but adds functionality for collaborative writing and version tracking. Thus, blogs are usually used as a simple means of archiving and expression of individuals, while wiki serves as a more "official" source of information about a project. The project's wiki contains pages that serve as information resources dealing with common problems such as how to set up the development environment, how to use source code management or debugging tools effectively, what the general architectural model of the developed software is, or who the main contributors are. An aggregation of such pages creates a pool of knowledge that can be readily referenced in discussions.

However, a wiki does not work only as a convenient resource for referencing. This function would probably be served just as well by blogs, which are easier to establish and run than the whole MediaWiki platform.[98] There is more to its functionality that balances the effort. The differentiating feature is that Wiki pages allow multiple contributors to share work material while all modifications are systematically recorded and form a reversible history. This is a result of some of the design principles with which the platform has been built. These design principles were proposed by Ward Cunningham, the originator of the initial Wiki Wiki Web, which served as a model for later wiki packages including Medi-

[98] MediaWiki is a software package originally designed by Magnus Manske to run Wikipedia. However, today it is also widely used in other projects, not necessarily affiliated with Wikipedia. As it is licensed under the GNU GPL license, it is widely used in free and open source software development, where it is common for bigger projects to have their own wiki. Also, the MediaWiki is not the only software package with which a wiki can be established. There are numerous other packages, among which MediaWiki is probably the most known.

aWiki. Within the design principles, there is a set of claims that interlock in what could be called “the value of openness”:

> *Open – Should a page be found to be incomplete or poorly organized, any reader can edit it as they see fit.*
> *Organic – The structure and text content of the site are open to editing and evolution.*
> *Observable – Activity within the site can be watched and reviewed by any other visitor to the site.*[99]

Translated to the design of a software package, the first two principles mean that there must be a system for freely creating and managing user accounts. But by using the word “reader” with regard to editing, the implications seem to go further, to allow even those without a user account to edit pages. This is the case with the biggest project using the MediaWiki package – Wikipedia. Also, the word “evolution” used in the second principle hints at the expectation, that there will be a history behind every page and that pages will get better over time. Combined with the third principle, this leads to the design of an archiving function which records every set of edits, assigns them to a time and an author, and makes them comparable with every other version of a page. However to be observable to a full extent, not only must editing be recorded, but also the rationalizations behind it. Thus, for every page, there is a place where discussion is recorded and this represents another dimension of the page’s history.

However, it is interesting to see that Cunningham explicitly states that some principles, although followed by later designers of wiki packages, were not his primary concerns. These principles are explicitly formulated as follows:

> *Trust – This is the most important thing in a wiki. Trust the people, trust the process, enable trust-building. Everyone controls and checks the content. Wiki relies on the assumption that most readers have good intentions. But see: [link to a page called Assume Good Faith Limitations]*
> *Sharing – of information, knowledge, experience, ideas, views…*[100]

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99 *Wiki Design Principles*. Accessed: 2014-12-04. Available at: http://c2.com/cgi/wiki?WikiDesignPrinciples.

100 *Wiki Design Principles*. Accessed: 2014-12-04. Available at: http://c2.com/cgi/wiki?WikiDesignPrinciples.

Considering that Wikipedia is seen by many as the hallmark of the culture of sharing, it is ironic to see the originator of the design principles upon which it was built to state that sharing was not his primary concern. But the principle of trust seems to be the problematic point here. The underlying assumption that most readers have good intentions explains the design decision to make wiki pages open for editing by anyone and place the review process *after* the editing has been done and published. The fact that a link to a page discussing the limitations of this assumption is given right after its explanation is indicative of Cunningham's reservations about it. Nevertheless, this principle was followed by other developers and so the current wiki packages inherited this design decision.

However, the Pitivi wiki has different rules for contribution than what is standard in Wikipedia, where anonymous users (who do not have user accounts, but are identifiable by IP addresses) may edit pages. Their modifications are subject to review and revisions only after they have been made. This creates conditions in which vandalism and spamming are possible and may take hold in the time period between editing and review. Accordingly, vandalism and spamming are cited in the lockdown policy of the Pitivi wiki as main reasons for restricting the rights to edit pages:

> *Fighting spam and vandalism has always been a problem in our wiki, and it has been particularly tedious in 2010-2011 where a lot of spam consisted of "throwaway" user accounts made to create lonely pages.*
>
> *Those pages would typically not be seen by most visitors because they were not linked from any other pages (except the RecentChanges and LonelyPages special pages), and thus would fly under the radar.*
>
> *=== Some statistics === Before the new lockdown policy was enforced, in 2011 there were: * 831 registered users… but only ~10 were real/legitimate users! * 1156 pages… but only 108 were real content pages!*[101]

As a result, Pitivi developers reached the entirely opposite conclusion – that most users do not have intentions and they express it by saying: "managing accounts is perfectly acceptable and vastly more efficient than

[101] *Lockdown Policy*. Page in the Pitivi wiki. Last edit: 2014-02-22. Accessed: 2014-12-01. Available at: http://wiki.pitivi.org/wiki/Lockdown_policy.

managing spam". This means that because keeping spam under control is not possible, it is necessary to manage user accounts, which would otherwise be entirely up to users. As a result, only users that get in touch with the Pitivi developers and obtained a user account can edit pages.

Yet there is a reason for going through this trouble to keep the project wiki running. In most FOSS projects I have dealt with (and Pitivi is no exception) wiki pages are used extensively for documentation, be it for users or for developers. Having the MediaWiki platform in place allows for pooling information from various contributors that, ideally, form a manual. Furthermore, wiki pages can play a vital role in the prototyping process. Although I have not really witnessed a wiki being used for this purpose during my presence in the field, I found several older pages made specifically for the purpose of developing complex design concepts (like a plugin system, proxy editing or rendering profiles). These wiki pages contain a lot of rationalization, examples of how the problem is solved in other programs and relevant use cases. Often, they also contain a medium other than digital text as a visualization of how a problem's solution would appear in the user interface.

Using a wiki for prototyping is possible because of the implementation of the design principles of openness, organicness and observability. The implementation results in the key functionality of collaborative writing and version tracking, which are necessary for the prototyping process. It must be clear who made which set of changes, and with what rationalization. These changes must then be available for others to review, and make their own sets of changes that could be different from the original ones. Prototyping then takes place through this iterative process of modification (which in this case includes also publication) and review. In other words, wiki pages contain proposals that other contributors can review and further develop, retaining their individual authorship even though the pages are the result of collective effort.

However, all this functionality is necessary only when there are supposed to be more iterations of modification and review. If the aim is to simply show the design ideas once and collect feedback, developers often opt for the use of their blog. This allows them to reach a wider audience than with a wiki page, while presenting the content as their own work. In other words, blogs usually represent the efforts of individual developers.

Various content management systems (such as Wordpress) are used for writing and publishing blog content. While these systems support multiple users, they omit the functionality of revision tracking and are scarcely used for collaborative writing. Blogs simply have a different purpose. During my time in the field, the purpose of blogging was explicitly negotiated when a newcomer who wanted to apply for the Google Summer of Code[102] stipend to work on Pitivi brought that issue up:

Ben: It is necessary to post on a blog about the progress of the proposal for the GSoC? right?
Steve: Ben, I don't mind if you don't
Steve: And I think others agree
Steve: What we want is progress, not blogging about lack of progress :)
Ben: ;)
Ben: that's better
Steve: (not saying you would not progress, just that I preferred working to blogging for my GSoC and I don't think it ever hurt anyone :)
Eric: we're programmers, not writers haha
Steve: this :)
…
Ted: Ben, though I would like to strongly encourage you to blog
…
Ted: we can't force you though
…
Ted: I mean even one paragraph or two per week or two weeks, just to keep the pitivi and gnome communities informed, and to get feedback etc.
Ted: no need for a whole book
Steve: yeah Ben the thing is you would get a GSoC through GNOME, and they theoretically require your blogging
Ted: but then, I say that as the person who is pretty much the only one in the entire pitivi team to blog
Ted: (excluding the new fundraiser blog posts)
Steve: blogging is good for two purposes IMO : technical stuff (always

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[102] Google Summer of Code is a stipend program that annually supports students working on open source software. The general idea of the stipend program is to teach students practical skills through mentoring, while the students work to contribute to free software. But it has more far reaching consequences than this simple exchange. Many students continue to contribute to the projects even after the stipend is over. In the case of Pitivi, at least two of the maintainers initially got involved as participants in the stipend program. Therefore, by attracting students and developing successful strategies when asking for the stipend, some FOSS projects are able to gain new developers periodically.

happy to find a blog post about specific issues I'm also facing)
Steve: and marketing
… Ben: more "marketing" I think
Steve: what do you mean ?
Ben: because I don't know if I'm wrong, but I really think that there are many USERS who want tutorials, know about new features… I think blogging is more for marketing in the case of Pitivi.
Steve: Ben, I don't agree
Ted: being able to explain a technical implementation or problem is a valuable skill
Ted: blogging is a way to demonstrate that skill
Ted: and this helps your career
Ted: (I'm just saying :P)
Steve: Well it also helps other hackers, which is a key argument too
Ted: yes
Ted: and also, I'm sure there are semi-savy fans/users out there who love to read about progress on projects like pitivi, but don't have time (or skills) to sit around in our IRC channel and read everything that's going on
Ted: you gotta admit it's sometimes pretty crazy technical in here
Steve: Well I do hope so :)
Ben: I think marketing is powerful. That gives you users ;)
Steve: Ben, I said both were

From the first part of the conversation, it is clear what the priority is – it is more important to work than to blog about it. This position is summed up in the expression "we're programmers, not writers". However, as Ted (who declares himself to be the only one within the Pitivi team to blog consistently) joins the conversation, it shifts toward identifying the purposes of blogging. First, it is the "technical stuff" which may help others in finding solutions to problems they are facing – "it helps other hackers" (even Steve, who was initially skeptical admits he is "always happy" to find such blog posts). The value of this type of blog post to others facing the same problem is that it spares them the effort of investigating the problem and creating their own solution (while also demonstrating the technical skills of the post's author).

In such a self-documenting environment, solving problems often amounts to finding an appropriate blog post and implementing the solution described. In this way, blog posts create a reservoir of informative instruction materials which were written by knowledgeable authors and which can be picked up and utilized by others. Obviously, solving a problem and writing a blog post about it requires higher level of technical knowledge than finding the post and applying the prepared solution. In this way, actors can perform actions that are beyond their technical competence (for example, by copy-pasting commands from a blog to terminal without knowing precisely what the commands will do). This means that blog posts do not necessarily spread knowledge. Knowledge would be transferred if the recipient learned to understand the problem and its solution in such a way that would make it possible to re-apply it in different circumstances. Blog posts are often not detailed enough to allow this, but even if they are not, they may serve as initial impulses to investigate an issue further.

The second purpose, "marketing", is associated with blog posts that describe the progress of the project. New versions are announced, new features are demonstrated and work in progress is evaluated. Blogging about work in progress can be seen as one stage of the "release early, release often" imperative. It shows others what the aims are and what can be expected in the future, and it is also a form of collecting feedback on the work even when the source code is not yet released. This is aimed primarily at users (or developers in other projects) that do not tune in into the developer's communication channels to experience what is going on firsthand, but wait for what the "blogosphere" brings them.

The blogosphere, in this case, is embodied in a blog aggregator called Planet Pitivi. It is the one place that displays blog posts from Pitivi developers and informs anyone interested about what is new and what is going on in the project. There is also an aggregator called Planet GNOME which displays blog posts from the wider GNOME community; to reach a broader audience, some of the Pitivi developers also feed their blogs to this aggregator. The "aggregation" is an arrangement in which texts are automatically redistributed from one place (the author's blog) to another (the aggregator). This arrangement is based on a mutual agreement between the administrators of a planet and the author of a blog and on the condition that the author meets certain requirements. Pitivi is a small project and acceptance to the aggregator is based on an individual agreement. However, GNOME, being a much bigger community, has the requirements spelled out explicitly:

> *We want readers of Planet GNOME to read and care about most of your posts.*

Some posts should be relevant to the GNOME community, either because they're related to GNOME, some underlying projects (like freedesktop.org projects), some technologies using GNOME, etc. or because it's a topic most people in our community care about, like freedom.[103]

The requirements are primarily related to the relevance of the blog posts for the audience. Blogging about projects related to GNOME (be it upstream or downstream) or about GNOME directly obviously meets the requirements, regardless of whether the posts are more about technical issues or "marketing". What is new here are the topics "most people in our community care about", of which only one example is given – "freedom". This common denominator has a historical background. It is part of common knowledge within the community that the GNOME desktop environment was founded at least in part because KDE (at the time, an established free and open source desktop environment) relied on the Qt toolkit, which, at that time, had a proprietary license. Therefore, GNOME filled the need for a desktop environment as independent of proprietary source code as possible by relying on the GTK+ toolkit, which has been using licenses by the Free Software Foundation from the very beginning. Therefore, it is no surprise to find such emphasis on the value of freedom permeating GNOME Foundation documents and being used for moderation of its blog aggregator. That GNOME operates with a certain vision can be seen, apart from licensing choices, in its Code of Conduct:

GNOME creates software for a better world. We achieve this by behaving well towards each other.

Therefore this document suggests what we consider ideal behavior, so you know what to expect when getting involved in GNOME. This is who we are and what we want to be. There is no official enforcement of these principles, and this should not be interpreted like a legal document.[104]

However, it is indicative that the "better world" which GNOME strives for is nowhere defined. There are several pieces of "advice" for individual

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103 *Planet GNOME Guidelines*. Last edit: 2014-04-20. Accessed: 2014-12-04. Available at: https://wiki.gnome.org/PlanetGnome.

104 *GNOME Code of Conduct*. Last edit: 2013-12-04. Accessed: 2014-12-04. Available at: https://wiki.gnome.org/Foundation/CodeOfConduct.

behavior in the Code of Conduct (e.g. be respectful and considerate, be patient and generous, assume people mean well, try to be concise, etc.) but no image of what the world should look like in any of the documents. The utopia is not explicitly elaborated upon. It is left to the individual contributors to fill the words with meaning.

However, the environment that GNOME constitutes does not allow for just any interpretation of the words "better world". What GNOME does is provide infrastructure (legal and technical) for all the smaller projects it overarches. This infrastructure is specifically suited for the free and open source model of software development. Thus, the combination of this type of infrastructure with the words "software for a better world" hints at a world view according to which the better world is not only achieved, but also constituted by free and open source software. This meaning is implicitly present because of the infrastructure and there is no need to explicitly specify it.

Apart from insisting on one development model (which gains a moral valence in this context), there is a remarkably wide maneuvering space for various political positions. This "political agnosticism" is rooted in the classical free software license – the GNU General Public License (GPL). Of the three basic rights – use, modification and redistribution – this license focuses solely on the third one, while leaving the first two completely unrestricted. Furthermore, redistribution is allowed just by meeting the requirements of applying the original license to the derivative work and marking clearly any modifications that have been made to the original work. A few more supplements can be made concerning the author's liability or identity, but all additional terms are considered to be "further restrictions" which are explicitly disregarded:

> *If the Program as you received it, or any part of it, contains a notice stating that it is governed by this License along with a term that is a further restriction, you may remove that term. … You may not impose any further restrictions on the exercise of the rights granted or affirmed under this License. For example, you may not impose a license fee, royalty, or other charge for exercise of rights granted under this License, and you may not initiate litigation (including a cross-claim or counterclaim in a lawsuit) alleging that any patent*

claim is infringed by making, using, selling, offering for sale, or importing the Program or any portion of it.[105]

Licensing fees and patent claims are stated as the most immediate examples of further restrictions, but this aspect of the license also covers for example use for commercial purposes. If the authors decide to license their work under the GPL, they may not further restrict the conditions for its use or redistribution. The software may be used by big corporations just as well as the unemployed or it may be used by activists just as well as the undemocratic regime they are fighting against. In this way, the license is "agnostic" – it explicitly denies the possibility of introducing any further restrictions than those stated. As a Linux kernel maintainer, Linus Torvalds elaborated upon this while he was discussing the differences between version 2 and version 3 of the GPL:

For example, the GPLv2 in no way limits your use of the software. If you're a mad scientist, you can use GPLv2'd software for your evil plans to take over the world ("Sharks with lasers on their heads!!"), and the GPLv2 just says that you have to give source code back. And that's OK by me. I like sharks with lasers. I just want the mad scientists of the world to pay me back in kind. I made source code available to them, they have to make their changes to it available to me. After that, they can fry me with their shark-mounted lasers all they want.[106]

Now it becomes clear why the expression "better world" from GNOME's Code of Conduct is nowhere specified. As the GNU licenses (GPL and LGPL) are used consistently across projects that GNOME associates, it is not surprising that it would apply a similar sort of agnosticism in its documents. Given the infrastructure GNOME provides, contributors are free to interpret what a better world is and translate this meaning into their willingness to spend hours of volunteer work, or invest in development as a company. Thus, we can observe a mix of specificity (to

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105 *GNU General Public License*. Text of the third version of the license published on the website of the GNU project. Published 2007-06-29. Accessed: 2014-11-16. Available at: http://www.gnu.org/copyleft/gpl.html.

106 *Linux Licensing*. Interview with Linus Torvalds published by Forbes.com. Published: 2006-05-03. Accessed: 2015-04-09. Available at: http://webcache.googleusercontent.com/search?q=cache:RaeC8J8_0isJ:www.forbes.com/2006/03/09/torvalds-linux-licensing-cz_dl_0309torvalds1.html+&cd=1&hl=cs&ct=clnk&gl=cz&client=ubuntu.

a point of implementation) with regard to infrastructure aimed at a particular software development model, and ambiguity concerning further values and motivations. Therefore, it is the term *infrastructure* (as a value and as a technological object) that differentiates the spaces where knowledge is channeled from their environment.

4.3 Debugging

Bugzilla is a database of issues (errors or feature requests) – commonly addressed as "bugs" – that were reported for a given program. Reports can be made by anyone who is willing to make an account in Bugzilla. This mostly involves dedicated users, testers of the given program or its developers. Because reports often come from actors who are unfamiliar with the project's development or they focus on other areas inside the project, the database has to be regularly cultivated and organized. The relevant practice is called bug triaging and it involves determining the bug's severity, checking if the bug is really related to the given program, checking for bug duplicates, and checking if the provided information is correct and sufficient. Once organized and prioritized by bug triagers, the database basically serves as a large scale to-do list for all contributors.

For newcomers, filing a bug is a rather lengthy process that requires submission of information that end users are normally not aware of, creating a barrier to feedback. However, without background information on the version of the program that exhibits the bug, on the environment the program runs in, or without a good description of the bug itself, the bug report has little value. Filling in the background information on program version and environment gets rather straightforward after reporting one or two bugs. The ability to generate a good description of a bug takes a longer time. This is so because when dealing with non-trivial bugs, it is often unclear what triggers them and which component is their source. Therefore, prior to filing a bug report, a good deal of effort needs to go into a practice called debugging.

Debugging is an investigative activity that gets harder with increasing code complexity and with a growing number of libraries that a program is dependent on, because a bug can be hiding in one of the dependencies, not the program itself. At the time of writing, Pitivi itself has around 20 000 lines of code (not counting blank lines and comments), but GStreamer, its main dependency, has almost 1.5 million lines of code. Therefore, identifying the source of an error is no straightforward procedure. In a discussion, one of the project members expressed it in the following way: "the trick is always to find a way to simplify the cause of the bug and steps to reproduce to the maximum, it's somewhat of an art ;)".

By using the word "art" the speaker points to the fact that there is no precise set of rules that, if followed, would guarantee successful debugging. Rather, it is a process that relies heavily on the experience and knowledge of the person doing the debugging. However, the knowledge and experience do not have to be individual. The IRC channel is often used to share the results of debugging efforts and to discuss what the possible culprit may be. This is possible due to debugging tools that are able to translate an error into a stream (often very long) of digital text expressing what is going on in the internals of the debugged program. In this way, the user description of errors is substituted with a text having common formal properties.

Furthermore, the simplification aims at identifying steps that are necessary to trigger the bug. These steps may involve performing specific operations or handling a specific file. In the latter case, it is important that the file is attached to the bug report or shared in some other way with the maintainers. Once the simplification is made, one can often guess which component is responsible for the error. But to get more information on what is wrong inside the component a special program is needed.

The standard tool for debugging is called GNU Debugger (GDB) which is used to pinpoint the part of source code responsible for an error. First, the debugger has to be pointed to the program or library that presumably causes the error. The ability to make an informed guess in this area assumes knowledge about the program's architecture and its internal workings. When pointed to a running process, GDB functions like an observer trying to record everything that is going on with it:

Ben: #~|@¿~~! Segmentation fault
Steve: gdb is your friend :)
Ben: Steve: how do I use gdb when I compile the source?
Steve: Ben, not sure I understand your question
Steve: How do you trigger the segfault?
Ben: I don't know how to debug something big as Gstreamer… I've only used gdb for some single files
Steve: Ben, what do you do to create the segfault?
Ben: I run the command
Ben: ges-launch-1.0 "multifile:///home/nick4/Pictures/Trash/numbers/%d.

png?start=100&end=230&framerate=1/1" 0 5
Steve: OK then run:
Steve: gdb –args sh ges-launch-1.0 "multifile:///home/nick4/Pictures/Trash/numbers/%d.png?start=100&end=230&framerate=1/1" 0 5
Steve: when the segfault kicks in, you will type bt
Steve: press Enter
Steve: and see the backtrace of the thread that segfaulted
Steve: Ben, ^
Ben: Steve: thanks
Steve: Do you have the backtrace?
Ben: yes
Steve: Cool
Steve: segfaults are usually pretty straightforward to fix, be happy it's not a race condition / deadlock ;)

Using GDB in this way generates a text file that is called backtrace or stack trace. At minimum, the stack trace identifies all functions (and libraries they are located in) that were called up to a point when an error occurs. At best, the stack trace lists exact line numbers inside concrete files, identifying precisely parts of source code that were running before the bug occurred. To render a detailed stack trace, a special debugging version of the tested program usually needs to be installed, one that allows for inspection of the running code (these versions are created by a different compilation process, thus pointing to the relationship between compilation/black-boxing, and debugging – its reversal). In this way the black-boxing done by compilation can be temporarily reversed and the internals of a running program exposed. To fully grasp the role debuggers play, consider the forms a program has before and after compilation:

```
def shutdown(self):
    if Pitivi.shutdown(self):
        self.gui.destroy()
        self.mainloop.quit()
        return True
    return False
```

The above is a part of the Pitivi source code written in the Python programming language; the snippet represents a definition of the shutdown procedure. What follows is what one sees when the compiled Pitivi package is opened with a text editor:

```
^?ELF^B^A^A^@^@^@^@^@^@^@^@^@^B^@>^@^A^@^@^@ø(@^@^@^
@^@^@@^@^@^@^@^@^@^@^Hw^@^@^@^@^@^@^@^@^@@^@8^
@^H^@@^@^]^@^\^@^F^@^@^@^E^@^@^@@^@^@^@^@^@^@@^@
@^@^@^@^@^@@^@@^@^@^@^@^@À^A^@^@^@^@^@^@À^A^
@^@^@^@^@^@^H^@^@^@^@^@^@^C^@^@^@^D^@^@^@^@
^B^@^@^@^@^@^@^@^B@^@^@^@^@^@^@^B@^@^@^@^@^@^
\^@^@^@^@^@^@^@^\^@^@^@^@^@^@^@^A^@^@^@^@^@^@^
@^A^@^@^@^E^@^@^@^@^@^@^@^@^@^@^@^@@^@^@^@^@^
@^@^@@^@^@^@^@^@ôl^@^@^@^@^@^@ôl^@^@^@^@^@^@^@^@
^@^@^@^@^@^A^@^@^@^F^@^@^@^@p^@^@^@^@^@^@^@p
```

This is, however, not what a computer operates with. This is a result of a text editor taking a binary code and translating it into signs. These seem to be random because it is no longer the binary code of a text, but of a program. To see what the computer operates with, one must access the contents of its memory:

```
009c000 0066 0138 0000 0000 3801 0800 0000 0000
009c010 0008 0b72 1003 001e 0200 0000 0001 0100
009c020 0001 5850 0124 41ed 0000 0000 ed41 0001
009c030 0000 0000 0100 0000 0000 0000 0000 03e8
009c040 0000 0000 e803 4654 011a 720e 030b 1810
009c050 0033 0b72 1003 1518 7200 030b 1a10 0004
009c060 4d4e 0105 0002 0066 011e 0000 0000 1e01
009c070 0800 0000 0000 0008 0b72 1003 001e 0200
009c080 0000 0001 0100 0101 5850 0124 41ed 0000
009c090 0000 ed41 0001 0000 0000 0100 0000 0000
009c0a0 0000 0000 03e8 0000 0000 e803 4654 011a
009c0b0 720e 030b 1810 0015 0b72 1003 0c18 7200
009c0c0 030b 1a10 0004 4d4e 0105 0004 0088 0d47
009c0d0 0000 0000 470d 0b64 0000 0000 640b 0b72
009c0e0 1003 001e 0000 0000 0001 0100 4713 4f4e
```

The memory contents take the form of a structured set of hexadecimal numbers.[107] The first column denotes a memory address, while the rest of the numbers in a row are representations of binary information. Each pair of hexadecimal numbers represents a binary byte.[108] This is the closest we get to see ones and zeros, the mythical building blocks of the digital. We can see that at this point (when inspecting the contents of a compiled program in a binary form), the logic according to which signs are organized is closer to the performance of voltage differences that hardware operates with than a language intelligible for humans. Hence the role of debuggers, which make it possible to inspect the contents of running binaries in a more intelligible form. Once an error is debugged in this way, a valuable bug report can be filled.

The central part of every bug report is a description of the issue. In the description, three things should be articulated: the expected behavior of the program, its actual behavior and steps to reproduce the bug. It is essential for others to be able to reproduce the bug for two reasons. First, newly added bug reports are automatically considered unconfirmed. A bug report has to be reproduced by at least one more contributor in order to be confirmed. Only then it is considered for further investigation and fixing. Second, in order to fix the bug, other contributors usually need to reproduce the bug in order to gain additional information and insight into the issue:

Eric: Why do I get this? [link to an error message]
Roy: Eric, That looks pretty wrong, how did that happen?
Eric: I click a clip with two Box Filter effects
Roy: Eric, Can you share the project so we can debug it?
Roy: (and possibly open a bug report)
Eric: which MTS did I send you last time?
Eric: found the video, but sorry, cannot reproduce with a new project
Roy: Eric, So you can't reproduce at all?
Eric: nope, I re-added the filters and it works fine now

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107 While the traditional decimal numeral system operates with a basic set of symbols 0 1 2 3 4 5 6 7 8 9, the basic set of hexadecimal symbols is 0 1 2 3 4 5 6 7 8 9 a b c d e f so instead of orders of ten, it operates with orders of sixteen.

108 This can be so because the number of states two combined hexadecimal digits can acquire (16^2=256) is equivalent to the number of states eight combined binary digits (one byte) can acquire (2^8=256). For example, 4d in hexadecimal (which is 77 in decimal) means 01001101 in binary.

Roy: Erg, that sounds like a bug in the effect priority management but I would need a way to reproduce to fix it

Bug reports provide public space for discussion of the problem, evaluation of alternative solutions, or assignment of severity and responsibility. Discussions often focus on identifying the problematic component, and evaluation often takes into consideration how similar problems are solved in other programs. Responsibility is divided among the maintainers depending on their specialization within the project. Severity represents a continuum with blocker bugs on one side and enhancements on the other. Blocker bugs represent the highest severity issues that need to be fixed before the next version is released. They are mostly regressions since previous versions or bugs that prevent testing of other issues. However, the decision on classifying a bug as blocker is never final. The bug can be reclassified to non-blocker or the version that it blocks can be raised so that it does not stand in the way of releasing the next version.

This pattern can be illustrated by bug 570118, which was filed in February 2009 and classified as blocker after a small discussion. Before the release of Pitivi version 0.13.1 in May 2009, its severity was demoted to normal so that the release would not be blocked by something that "would be a nice addition". After the May release, the bug's severity was promoted to blocker and again demoted to normal before the release of version 0.13.3 in September 2009. Eventually, the bug was labeled an enhancement and after more than three years of no activity (except for minor adjustments made by a bug triager) in the bug report, it was resolved as "won't fix" with the justification that the solution would "needlessly complicate things, and nobody else actually requested this feature".

This fate is shared by many low severity bugs that are largely ignored by the core developers. They expect either the reporter ("scratching his/her own itch") or some other occasional contributor to submit a patch. As lack of manpower seems to be a constant condition, core developers rarely find the time to pursue low severity bugs. However, they have the power to demote bugs that they see as low priority and that would stand in the way of the next release. In this way, bug severity can be the subject of a tug of war among developers and bug reporters or other interested contributors. This was the case with bug 570118 which was promoted twice by its bug reporter (who also happened to be a bug triager) and repeatedly demoted by a core developer. Eventually, the reporter agreed and labeled the bug report an enhancement request and after some time closed it.

In this context, submitting a bug report for a feature that is considered low severity from the start is considered futile effort. As one of the maintainers put it in a discussion: "the problem is we don't want to add more surface for bugs with new features unless we have a very good reason". Filing a bug report represents an impulse for maintainers to react and it simultaneously creates public space (a "surface") for anyone else to weigh in. In contrast to IRC, bug reports represent an asynchronous form of communication that persists. This means that bug reports can mobilize a broader audience than local and temporal chat discussions:

Brian: I'm working on sth that is not a bug, and it's not in Bugzilla as well. Should I create a new bug?
Ted: Brian, it would be nice yeah
Ted: it gives a public way to develop the idea
Ted: and something to refer to
Brian: Ok, I'll do it. Thanks again, Ted!

By providing a "public way to develop the idea", bug reports constitute a space for prototyping. This is more apparent in reports that are feature requests. Within them, comments often involve descriptions of how a given feature is handled in various other programs and argumentation on which option would be best to pursue. The interesting thing is that general agreement is seldom reached and an official decision seldom made. After some discussion, the prototyping process just moves to a new stage in which a self-assigned contributor attempts to implement the feature by creating a new branch in the source code history. The ultimate design decisions then lie in the hands of the contributor. It is the contributor who spends time and effort on the problem and this is compensated by the power to decide. However, this power is balanced by the existence of the review process. The contributors either have to align their work with the theory that the maintainers hold, or make an argument convincing enough to get them to go out of their way. In either case, the contributor is bound in his design decisions by negotiations with the project's maintainers.

Bug reports can also serve a purpose even when they do not result in a patch. They represent persistent traces that can be referenced (every bug report and comment has a unique HTML address) and that serve as a signal that the issue is known, that it is (or it is not) being worked on, and shows the progress that has been made on the issue. Thus repeated inquiries about the problem that keep the maintainers from other work and make them explain the problem multiple times are avoided. Also, by showing if anyone is working on a particular issue, bug reports help in avoiding parallel efforts that may result in sensitive situations where there are two fixes for one issue and the maintainers have to pick one over the other, preferably without offending either.

4.4 Revision Tracking

Git is a source code management system used to track revisions of source code. This means that it is able to track changes in a given text file and create diffs – detailed representations of changes comparing two versions of a text file. As such, Git and other source code management systems are able to track only plain text files. It is the standard form in which text is stored in software development.

Git differs from older version control systems in that it is distributed. This means that there is not one central repository created and operated by project maintainers from which source code is downloaded and its modified versions are uploaded back, as was the case with centralized version control systems. Creating repositories and modifying the source code they contain is an activity that is relegated to all users and so repositories can be "cloned" freely. However, there is usually one main repository which contains reviewed commits and represents the official state of the source code. Write access to the main repository is still restricted to project maintainers and any contribution must be reviewed by one of them before being included in the main repository. Therefore, write access represents[109] the main hierarchical distinction between maintainers and the rest of the developers.

However, the distributed source code management system was designed to mitigate the effects of this hierarchical break. Anyone with the abilities to do so can clone the main repository into their own personal

109 There are also other indicators of the maintainer position, like administrative access to the project's web page, having an account on the project's Wiki or having maintainer rights in Bugzilla. All have in common that they provide administrative access to a part of the project's infrastructure. However, commit access to the main repository is the key distinctive point as it gives access in an area central to software development: source code management.

repository and start modifying it without asking maintainers for permission. One can keep piling up commits in a personal repository as long as desired, and once satisfied with the outcome, the contributor can demonstrate that the modified version performs better in a certain respect. This provides an incentive for maintainers to review and appropriate the commits into the main repository. Thus, the distributed code management system is labeled as "truly open" and "meritocratic" in the Pitivi wiki. The wiki page also links to a video of Linus Torvalds (the originator of Git) describing the advantages of distributed source code management:

> *Because you have a central repository means that everybody that works on the project needs to write to the central repository. Which means that since you don't want everybody to write into the central repository, because most people are morons, you create this class of people who are ostensibly not morons. (...) So this whole commit access issue (...) is a huge psychological barrier and causes endless hours of politics in most open source projects. If you have a distributed model, it goes away. Everybody has commit access; you can do whatever you want to your project. You just get your own branch, you do great work, you do stupid work, nobody cares. It's your copy, it's your branch. And later on, if it turns out you did a great job, you can tell people: hey, here's my branch and by the way, it performs ten times faster than anybody else's branch so, how about pulling from me. And people do, and that's actually how it works and we never have any politics. That's not quite true, but we have other politics and we don't have to worry about the commit access thing. And I think this is a huge issue and that alone should mean that every single open source system should never use anything but a distributed model, you get rid of a lot of issues.*[110]

In his talk, Torvalds is hyperbolic: everybody has commit access. This is true with regard to the cloned personal repositories, but not for the official main repository of a project that is still managed only by maintainers. By using Git, the hierarchy is maintained but contributors gain a better position to demonstrate, argue and persuade maintainers to include their commits. This is so because the individual repositories represent

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110 *Tech Talk: Linus Torvalds on Git*. Video of a talk published by Google on Youtube.com. Published: 2007-05-14. Accessed: 2014-10-06. Available at: http://www.youtube.com/watch?v=4XpnKHJAok8#t=18m05s.

a means of publishing[III] work on an individual's behalf. The modified source code is publicly available through a personal repository. Thus, when arguing about its quality, the sides are able to point directly to particular expressions on particular lines in particular files. This makes possible discussing the modifications with precise references, which could be described as "talking the code" instead of "talking about the code". Moreover, the modified cloned source code could be compiled to an independent version of the program in order to be tested. Under these conditions, there is less space for what Torvalds calls "politics", that is, the challenging of power relations generating a large communication load.

During development, personal repositories serve as prototyping spaces. Suppose we have a contributor whose name is Paul, he writes some new code, pushes it to his individual repository, gets feedback during review and amends his code accordingly. Then, the code is appropriated to a personal repository of the reviewer, where further revisions can be applied. At this stage, every revision the reviewer makes is discussed with Paul. Finally, after reaching a satisfactory state, the code is pushed to the main repository. After that, Paul resets his development branch and synchronizes it with the master branch of the main repository. This creates a shared reference point from which further contributions can be made. Thus, development using a distributed source code management system is an iterative process balancing divergence (branching out with new modifications) and integration (review and appropriation into the main repository).

Using Git involves first and foremost dividing work into units called "commits". These units denote logical wholes so that when it is necessary to revert a certain modification, a corresponding commit can be identified and edited.[II2] See an example below (lines beginning with "-" are to be removed and lines starting with "+" are to be added):

[III] However it does not mean that anything the contributors do is necessarily public. All work initially takes place on a private local machine and only afterwards may be pushed into a server-hosted public repository. This allows contributors to control what stays private while making publication an option achieved by executing one command.

[II2] An example to explain what the expression "logical wholes" means in this context: suppose I use Git to keep a history of changes when writing this text and I make a commit that consists of adding two paragraphs to the theoretical section. However, to form a logical whole, the commit should not only consist of those two paragraphs, but also add any new references (to the appropriate section) they introduce. This way, if I later decide to remove the commit, no other editing is necessary.

```
commit 128461ff94c38c67d392d915b0d002e903379920
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Tue May 6 17:24:33 2014 +0200

    help: adjust see also links

diff --git a/help/C/cheatsheet.page b/help/C/cheatsheet.page
index 1084857..0a98e47 100644
--- a/help/C/cheatsheet.page
+++ b/help/C/cheatsheet.page
@@ -6,7 +6,6 @@
   <info>
     <link type="topic" xref="index"/>
     <link type="seealso" xref="movearoundtimeline"/>
-    <link type="seealso" xref="trimming"/>
     <revision pkgversion="0.16" version="0.1" date="2012-09-03"
status="complete"/>
     <credit type="author">
       <name></name>
diff --git a/help/C/keyframecurves.page b/help/C/keyframecurves.page
index fea14cf..4eeebb2 100644
--- a/help/C/keyframecurves.page
+++ b/help/C/keyframecurves.page
@@ -5,6 +5,8 @@

   <info>
     <link type="guide" xref="index#timeline"/>
+    <link type="seealso" xref="usingeffects"/>
+    <link type="seealso" xref="transitions"/>
     <revision pkgversion="0.92" version="0.2" date="2014-03-13"
status="complete"/>
     <credit type="author">
       <name></name>
diff --git a/help/C/presets.page b/help/C/presets.page
index ad61a69..6c937d8 100644
--- a/help/C/presets.page
+++ b/help/C/presets.page
```

In other words, commits should be conceived in such a way that the Git history is "atomic". This requires planning and discipline in work defining clearly what the current task is and what a commit will constitute, because Git monitors every modification that is made to the project files. The effort put into structuring Git history is then balanced by the fact that the history is fully reversible. Furthermore, it provides information on authorship, time stamps and a detailed comparison of files before and after every modification, which is essential for review. Still further, commits can be clustered into branches that provide isolated spaces for safe experimentation.[113] However, as my field notes indicate, grasping all the complex functions of this tool may not be a trivial matter for a newcomer:

> *Looked at my repository today and I realized that the Git history, if not performed properly, is useless. I think I will have to delete most of the commits and edit some through interactive rebase to get some sense out of it.*
>
> *Now that I know rebase and amend I feel more empowered because I can fix whatever mistake I make in the future. Until now, everything was stored in the history and it was beginning to look messy and unuseful. The history is not necessarily what exactly happened, it is revisable and it is revised to serve a purpose.*

However, for a seasoned developer, the impression may be very different:

> *Therefore, I'll say that Git is great because it provides version control in a very non-intrusive way, and because it provides version control very easily for individual projects, too. […] You don't have to be connected to the Internet, you don't have to setup a server, you don't even need a separate directory. You don't need to tell the world in advance what you're doing.*

[113] I discovered the full utility of branching once I realized that switching from one branch to another means that the working files change literally under my own hands as different commits get applied. This feature allows for having several versions of a file available in a repository without the need to have several distinct copies, and all the while detailed line-to-line comparisons of the branched versions can be summoned.

> *"git init" or "git checkout -b" are enough to start a project or a feature, and enjoy version control from the very beginning. I think that this leads to code that is better and more maintainable.*[114]

For this developer, the tool is "non-intrusive" by lowering the requirements for establishing version control for individual projects. All that is needed is to have Git installed and execute one command. Such lowering of requirements may lead to abandoning the practice of starting version control only when a project is sufficiently large or is being published. Instead, Git encourages the application of version control from the very beginning of the development process. As a result, the planning and discipline associated with committing modifications is also present from the beginning, avoiding the typically very large initial commit which aggregates (and thus obfuscates) all changes made before version control was applied. This should result in more maintainable code, in the sense that commit discipline is enforced at all stages of development and can be observed retrospectively.

As I point out in my field notes, Git functions more like a tool for work coordination than like an archive that records what exactly happened. However, some of its features can be considered to perform archiving functions. For example, if someone gets interested in a certain part of the code, Git can (through its *blame* command) provide information on who was the last one to edit that part. Furthermore, commits can be browsed as they were made to a branch; they can also be filtered by author or searched for a specific expression contained in the log messages attached to them. Every commit also has a unique identifier for referencing.

Now to the features that serve the purpose of work coordination. If two developers, working in parallel, edit the same line of code, Git will generate a conflict and guide one of them in its resolution. This means that after announcing a conflict, Git will open a text editor showing the modifications. The lines that were changed by both developers appear in three versions – the original one, the one modified by developer A and the one modified by developer B. It is then up to the human operator to

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114 *Git Success Stories and Tips from KVM Maintainer Paolo Bonzini*. Interview published by Linux.com. Published: 2015-04-07. Accessed: 2015-04-08. Available at: http://www.linux.com/news/featured-blogs/200-libby-clark/821899-git-success-stories-and-tips-from-kvm-maintainer-paolo-bonzini.

pick appropriate parts from the three versions and merge them into the correct result, a fourth version that is saved as the conflict resolution.

If a developer needs to edit a commit which has been in the meantime covered by several other commits, Git can temporarily revert those commits to get to the desired one. Through this operation, Git moves back in history to achieve a state when some commits are not yet applied. Then the developer is free to amend the current commit at will. When this is done, Git re-implements all reverted commits on top of the edited one as if it had been like that all along.

Such revisions of source code history are usually made only in the personal repositories of contributors, because a revision in the main repository would immediately change the reference point against which everyone else makes their modifications, leading to many conflicts, and making subsequent integration of contributions problematic. Because of that, changes in the main repository are made only by submitting more commits. Personal repositories, on the other hand, constitute a safe space for experimentation, as anything can be reverted or modified. This is probably the most important implication of the distributed nature of Git: with individual repositories, developers get their own self-sufficient space to develop and refine their modifications, that is, to branch out of the official version in the main repository and still enjoy the benefits of version control. As one project maintainer remarks:

> *Instead of having a single repository that everyone feeds from and into, everyone now has their own repository, their own branches. The meaning of branch changed. It's so cheap now.*[115]

The ability to version control a patch created outside of the main repository was not something that other version control tools could provide at the time Git was created. This meant that large contributions were difficult to review because they could not be dissected into smaller parts and the divergence between the patch and the development in the main repository that took place while the patch was being written was not systematically tracked, possibly leading to conflicts between the patch

[115] *Git Success Stories and Tips from Ceph Creator Sage Weil*. Interview published by Linux.com. Published: 2015-04-13. Accessed 2015-04-16. Available at: https://www.linux.com/news/featured-blogs/200-libby-clark/823164-git-success-stories-and-tips-from-ceph-creator-sage-weil.

and other parallel modifications. By now, the distributed approach has become standard as it brings significant refinement in creating patches. Patches are more refined because they consist of a number of smaller and well defined commits that simplify review and conflict resolution. Another project maintainer expressed his fondness for this approach:

> *As maintainer I love that I can review changes as series of small commits instead of one big patch. I'm constantly asking developers to split their changes even more....*[116]

It is clear that, through its command line interface, Git offers large functionality for source code management. However, in order to operate correctly, Git needs to be supplemented with other programs such as diff tools (programs that generate detailed comparisons between text files). It would also not be possible to resolve conflicts or revise history without pairing Git with a text editor. Furthermore, there are programs that serve as a graphical user interface for the command line tool that Git is. By not attempting to include all functionality, Git is in practice dependent on into Git itself. The developers of Git show their adherence to what is commonly referred to as "the Unix philosophy". This approach to software design has been summed up by Doug McIlroy (McIlroy in Raymond, 2003) in the following way:

> *This is the Unix philosophy: Write programs that do one thing and do it well. Write programs to work together. Write programs to handle text streams, because that is a universal interface.*

The approach encourages specialization on narrowly defined tasks that by themselves may seem trivial, but are general enough to be used in a wide variety of uses. The practical utility is then based on the ability to combine programs in such a way that the output from one constitutes an input for another. The universal medium which flows to and from programs is digital text. Searching for an expression in a log message, generating comparisons of files (diffs), resolving conflicts, and revis-

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[116] *Git Success Stories and Tips from Wine Maintainer Alexandre Julliard*. Interview published by Linux.com. Published: 2015-04-10. Accessed: 2015-04-16. Available at: https://www.linux.com/news/featured-blogs/200-libby-clark/822789-git-success-stories-and-tips-from-wine-maintainer-alexandre-julliard.

ing history – all those tasks are based on an interchange of digital text between Git and other programs. These are all built around the idea of automated manipulation of digital text.

Such a text interchange is also taking place when publishing new commits in a personal repository. This is necessary in order for the commits to be reviewed and included in the official version of the developed program. The review process is an opportunity, especially for a newcomer, when knowledge is passed on and norms are negotiated among maintainers and contributors. During the review of my first commits I learned many things, including how to make proper commits in the first place. But more importantly, I learned what the expected style of documentation writing is, pointing me in the direction I should proceed to in order to get my commits included. After a few iterations of writing new commits, receiving feedback and modifying them, I learned enough to make commits that got accepted without needing to be modified during review. It was the sandboxed space constituted by my personal repository that allowed me to publish, receive reviews and revise my work in order to develop the knowledge to contribute fluently to the project.

When the first batch of my commits was included in the main repository, I also came to understand why contributions appear in clusters. When a contributor makes a pull request, that is, asks for his commits to be included into the main repository, one of maintainers reviews the commits, appropriates them and pushes them to the main repository. This can happen immediately or take several weeks, depending on how extensive the commits are and how busy the maintainers are. Sometimes, the order in which commits from various contributors will be reviewed and pulled has to be negotiated. This was the case when Eric made a pull request for his branch A:

> *Eric: Steve, what's the status with the branch B?*
> *Steve: Eric, I'll need Keith to tell me what the "remaining bug" is*
> *Eric: I have the feeling the intention is to merge his branch first then mine*
> *Steve: No intentions here*
> *Steve: But I have the feeling reviewing his branch will be faster than reviewing yours :)*
> *Steve: I understand your concern, we should settle on a merge order*
> *Steve: If the remaining bug in Keith's branch is benign / can be fixed easily, I think we'll go the branch B first way*
> *Steve: if not then branch A*

Eric: I'm fine with everything, just want to make progress
Steve: so you should wait and see what Keith is saying before rebasing
Steve: Eric, I understand, but I'm pretty much the only one to review your branches so bear with me please :)
Eric: mine is invasive, I don't have any expectation
Eric: I keep amending the main commit.. :)
Steve: OK
Steve: The beginning of the release cycle is the good time to do such things
Steve: so I'll make sure to have a look at both Keith's and your branches soon

By the time Eric made his request, another contributor, Keith, finalized work on his branch B. Both branches had a common reference point in the main repository, but Eric's branch modified the source code in many places and the changes it made were pervasive. Pulling Eric's branch first would drastically change the source code in the main repository and that would result in generating many conflicts when pulling Keith's branch. From the maintainer's standpoint, it made sense to wait for solving the last issue on branch B and then pull it first. But there is one more angle to this situation: knowing that branch A will dramatically change the source code, Eric is blocked from working on anything else while he is waiting for review. Working on something new would introduce a new branch B that would generate many conflicts if not merged prior to the invasive one. The only option he is left with is to pile his work onto branch A ("I keep amending the main commit"). Thereby he risks only conflicts that would result from changes introduced by the review process.

Another strategy for avoiding conflicts when two developers work on the same part of code is to pass a modified branch from one of them to the other to let him implement his modifications on top of it before reviewing and merging the whole work into the main branch:

Ted: isn't that stuff going to conflict with whatever changes Steve was doing to the behavior of the timeline last month?
Roy: Ted, I will let him reimplement the right behaviour on that branch instead, right Steve ? xD

To this, Ted replies with a link to an image of a frightened cat that has a label "You make kitty scared", indicating the audacity of the procedure. But the procedure is illustrative of the degree to which Git makes it possible to make sets of modifications independent of their author and pass them around to others.

These examples of pull request coordination highlight the restrictions resulting from the use of source code management tools. In theory, these tools allow for almost any thinkable operation (from a purely technical standpoint, it does not matter which branch is pulled first, the final result will be the same). In practice, developers navigate by applying conventions to accomplishing the common tasks (in this case, opting for creating the smallest possible number of conflicts that require human assistance in their resolution). But these rules are always negotiated – if following the convention meant that a contributor would be blocked from working for a long time, it would probably not be followed. What is stable and cannot be negotiated, however, are the implications of using tools such as Git. In this sense, the infrastructure described above mediates the process of software development.

5

Mediation and Resources Inside a FOSS Project

5.1 Meanings of Mediation

Now is the time to explicitly formulate how the components described until now perform as mediators. The contents of this section (and its subsections) may seem repetitive at times, but this is only because I need to reiterate or elaborate upon some of the observations in order to relate them to the infra-language elaborated more thoroughly in chapter 3. In my analysis, I rely on the concept of technical mediation and its four meanings – composition, translation, black-boxing and delegation – which are used to structure this section.

5.1.1 Composition

The basic composition is expressed by the components already described in the previous sections. But to go one step beyond the most immediate tools, I will attempt to grasp more of the development environment that is presupposed in the Pitivi project. In the following, I will start from the position of a newcomer, who already has a computer with an appropriate operating system installed[117] and I will trace the elements of the development environment that reside on this basis.

[117] Naturally, the readily available computer presupposes a vast network of its own, going as far as mining raw minerals, as for example Jussi Parikka (2014) shows. How-

The environment consists mainly of the latest development version of the program (and the libraries it uses). The development version serves as a shared reference point, not in the form of source code, but in the form of a running interface. By running the development version, contributors are able to grasp and use the result of their work. This is necessary for testing work that has already been done and determining what should be done next. The following excerpt provides a relevant part of conversation a newcomer had with Pitivi developers while setting up his development environment:

Tim: hi I would like to contribute to pitivi, I am good at python and javascript, can somebody point me to the source code and small task to get started, thanks
Eric: Tim, /[link to instructions on building the development version/]
Eric: Tim, what Linux distro do you use?
Tim: fedora 19 x86 Eric 64bit
Steve: Tim, pitivi is a complicated project, with many moving dependencies
Steve: For that reason, we have a script that allows contributors to set up the environment automatically, which Eric linked to you
…
Steve: After the setup is done and you make sure you can run the dev version, what I would recommend is starting with writing simple tests with dogtail
…
Tim: so Eric : i ran the script here /[link to instructions on building the development version/] and have pitivi-git dir and [ptv] a virtualenv kind of a thing i guess?
Eric: good
Eric: cd pitivi-git/pitivi; bin/pitivi
Eric: works?
Eric: the [ptv] is just a bash with some environment variables set
Tim: well i have just glib and prefix dirs Eric
Eric: if you run bin/pitivi it should ..fail, can you confirm?
…
Tim: Eric, : i mean in pitivi-git/ i just have glib and prefix , and prefix is empty too after running the script is there anything else that needs to be

ever, since this work is focused on software, I will cut the network relations at the edge of the hardware/software distinction.

done ?
…
Eric: I really have to go, see you tomorrow
Steve: bye Eric o/
Tim: bye Eric : i will figure it out :-)
Steve: Tim, did you solve the dependencies as indicated on the website ?
Tim: yes that I need to I think I skipped some steps
Steve: Solve the Dependencies.
Steve: Get this script, save it, make it executable and run it: [link to the script]
Tim: cool! just doing
Steve: just two steps :P
Steve: on f19 it should work, we've been developing with f18 – 20
Steve: I skipped 19 but I believe Roy used it
…
Steve: Tim, no problem yet?
Steve: (aliasing make to "make -j4") makes the whole process faster
Tim: yeah downloading packages
Steve: Should have told you
Tim: Steve, i get [link to a copy-pasted output from Tim's command line] on running the script, it isn't able to clone pitvi for me i guess ?
Steve: Thats not the first run right Tim?
Steve: the previous one must have failed
Tim: Steve, yes
Steve: Can you paste the output of the previous one ?
Steve: The run that checked out the libs etc ?
…
Steve: Tim, the file you're showing me is a new run
Steve: You should just remove the newly created directory,
Steve: start the script once again, and paste me the output
Steve: ie remove "pitivi-git"
** Tim follows steps*
Tim: it takes too long, all CC CCLD and make on my screen, is it correct, or i have ended up firing something weird ?
Steve: It doesn't take too long
Steve: you're compiling gstreamer, which is a huge beast
Steve: Not the kernel by far but still
Steve: around ~1.5 millions LOC [lines of code]
…

Tim: yea finally something I got and it stopped, should I overwrite ? [link to a copy-pasted output from Tim's command line] ??
Tim: woah! cool I think I got the things right now :-)
Steve: yep, the duck pretty much means "good to go" ;)
Tim: would it take this much time always when i run the script ? Steve
Steve: Of course not
Steve: Once it's built it's built
Steve: you can ctrl + D and rerun the script to get back into the env
Tim: yea! my CPU would have died then :P
Steve: aha don't worry
Tim: Steve, yea so now I can get to do some work! what should I start with ?

Typically, to get the latest development version of a program running, one has to download its source code and compile it. But as Steve puts it, Pitivi is a complicated project – it depends on several underlying libraries, some of which can be used at latest packaged version (therefore no compilation is necessary) and some of which must be compiled from the source code. To simplify setting up of the development environment, Pitivi maintainers created a script that automates the process of checking for the required versions, downloading and compilation of the dependencies and Pitivi itself. However, the script does not take care of everything; there are several issues that the newcomer has to solve manually. It is necessary to install one of the Linux distributions that Pitivi developers typically operate with. The choice of distribution affects what software (and in which versions) is available for the contributor and therefore is crucial for solving dependencies. In this case, the standard distribution used for development is Fedora, because it provides the latest GNOME libraries upon which Pitivi is built.

As the quoted conversation indicates, running the script is also not a trivial matter. Tim went through several iterations before he figured out how to correctly run it. While doing so, he exchanged with others the output from his command line that he could not interpret properly himself. By doing so, he tapped into the knowledge that the maintainers pool in the Pitivi IRC channel. The knowledge present there allowed him to properly treat information that would otherwise remain cryptic for him. Tim is not even sure how the correct result of his action should look – this is demonstrated by him asking if he "ended up firing something weird?". He is assured by the developers that what he sees on his screen is normal and that in subsequent runs, it will not take this long. Finally, the running script on his screen stops and he is greeted with a picture of a duck made of text characters. This means that he is “good to go”.

```
===================================
     BATTLECRUISER OPERATIONAL
              >(º)__/
               (_~_/
           ~~~~~~~~~~~~~~
===================================
```

However, to contribute to Pitivi, Tim will need more than its running development version. He will need tools[118] to get the work underway. Text editors allow him to browse and edit the source code, Git allows him to manage source code and share it, compilers allow him to turn the source code into an interface, debuggers allow him to find errors, Bugzilla allows him to see the issues reported against Pitivi, Wiki allows him to make drafts and write developer documentation, an IRC client allows him to connect to the Pitivi channel and the list goes on. The common denominator is that the tools are typically developed consistently with the free and open source software model. The reasons for this differ but it seems they follow the reasoning typical for the two branches of the movement – either it is an issue of being self-sufficient with the tools abiding the same moral standards (free software), or it is a practical issue of being able to see the internals of the tools and being able to possibly influence the direction of their development (open source software).

Both of these reasons point to the recursivity involved in FOSS projects – the tools that are used in one software development project constitute development projects of their own, while also using a set of tools. A distinct way of demonstrating this recursivity is pointing to the project

[118] It should be noted that some tools are even needed to set up the development version. This applies to Git or compilers for example. As a result, the difference between some tools and dependencies may not be initially clear. The clarity comes with distinguishing the roles of developers and users. Dependencies are packaged programs that must be installed for a given program to run, regardless whether it is run by a developer or an end user. Tools, on the other hand, are not required from end users. Another way of saying this is that official versions of software require only dependencies while development versions require dependencies and tools.

that develops the version control tool called Git, where Git itself has been used for version control from the very beginning of its development. Linus Torvalds, the originator of Git, described the process in a following way:

> *You can actually see how it all took shape in the git source code repository, except for the very first day or so. It took about a day to get to be "self-hosting" so that I could start committing things into git using git itself, so the first day or so is hidden, but everything else is there. The work was clearly mostly during the day, but there's a few midnight entries and a couple of 2 a.m. ones. The most interesting part is how quickly it took shape; the very first commit in the git tree is not a lot of code, but it already did the basics – enough to commit itself. The trick wasn't really so much the coding but coming up with how it organizes the data.*[119]

In general, we can talk about FOSS projects being "self-hosting" in the sense that the production of one project is used by another. This is what Christopher Kelty is pointing at when he writes about recursive publics (Kelty, 2008, p. 3).

To describe how tools are used in the Pitivi project, let us first pick a very basic representative – text editors. There is a wide variety of text editors to choose from. There are command line editors and there are editors with a dedicated graphical user interface; there are editors supporting a number of modes or modeless editors, to name some categories according to which editors can be classified. Furthermore, text editors are usually customizable and extensible. For example, editors can be set up to use dark or light color schemes for their user interface, to highlight current lines, to display line numbers, to highlight the syntax of a certain programming language, to wrap lines longer than 80 characters, to display spaces, to use regular expressions for searching, to use various plugins, or to complement the editor with a terminal and debugger to create a so-called integrated development environment. Needless to say, this list only scratches the surface of possible customization. The width of customization possibilities is not surprising when we consider

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119 *Interview with Torvalds about Git on the occasion of 10 years of Git*. Interview published by Linux.com. Published: 2015-04-06. Accessed: 2015-04-08. Available at: http://www.linux.com/news/featured-blogs/185-jennifer-cloer/821541-10-years-of-git-an-interview-with-git-creator-linus-torvalds.

the fact that the interfaces of text editors are the ones in which developers spend most time and that software developers – their users – also often carry the knowledge and skills to modify them.

However, customizations are in most cases focused on the editor interfaces, not on the form of the resulting text files where standards are enforced, although customization can help following the standards. For example, when I submitted my first work, the maintainer doing the review told me that my files contained trailing whitespaces. This meant that I forgot blank space characters at the end of some lines. These characters are generally considered redundant and may cause problems in certain situations and so it is considered a good practice to remove them. After I got the review I had to set up my text editor so that it displayed trailing whitespaces (which were invisible until then) to avoid the issue.

Another instance emphasizing the existence of a standardized output was marked in a discussion among two of the maintainers I witnessed on the Pitivi IRC channel. The subject of the discussion was the "80 column rule", which states that any line in a text file should not be longer than 80 characters.[120] This rule is so common that many text editors assume it by default. But apparently, the rule makes more sense with regard to some programming languages (like C for example) than others (like Python, which is used in Pitivi). Also, wide computer screens are common and enforcing the rule leads to leaving much of the screen space unused. In the end, it is up to the project maintainers to make an agreement. There were two justifications for enforcing the rule for the Pitivi source code: (1) "I want to be able to dual screen on modest sized computers." (2) "Some hackers might have their editor setup with 80 chars assumption."

The first reason is practical – wide screens are common, but they are usually tied to a place because of their size. When traveling, for example, more modest screen sizes are still standard. Furthermore, the developer work-flow usually involves displaying two text files side by side on a screen ("dual screen") and this requires making the text limited in width. In this context, the old rule, with its roots in the 80 column IBM punch cards, still has some relevance.

[120] Unlike the mainstream text processing programs contained in various office suites, text editors used by developers do not employ the metaphor of a page, which restricts line width according to the specified paper format. The only limiting factor for editors designed for software development is the size of a computer screen, which is widely variable nowadays. Thus, limiting the width of the line has become more a matter of agreement than a matter of external constraints.

The second reason is explicitly concerned with standardization. Even though the maintainers are aware that the number 80 characters is arbitrary (stating that "[S]ocrates could troll like this: it could be 74"[121]) they still use it as a reference point because it seems to be the most commonly used option. By applying the 80 column rule, the project maintainers intend to comply with the expectations most experienced developers could have, therefore lowering the barrier (of setting up or adjusting the development environment) to entry for them. As we will see further, this pattern can also be found with regard to other tools.

Now, if we add to these components the tools and platforms elaborated upon in the previous sections of this text (Git, Bugzilla, Wiki, blogs, IRC channels, licenses, and the development versions of the software itself), we are starting to grasp the extent of the composition that goes into a single project of free and open source software development. However we get a more complete picture when we realize that each of these components is a development project with a composition of its own, thus widening the number of relations to an exponential degree. When we put this together with the fact that development decisions require knowledge of a broader development ecosystem, we see what is called the barrier to contribution. Thus, for a newcomer, the world of *open* source software development is anything but *transparent*. This is not because the key information is secret; it is indeed publicly available. But there is just so much information that it requires significant effort to process it.

This point has been expressed in a public video stream with developers from another project:

> *Nobody is allowed to push code directly to the trunk just because we believe in code reviews so there's not really a barrier like hey I need to be approved to such and such team before I can push code. That's not true.*
>
> *Once someone's been around for a little bit, then they start to find out where we keep certain information and things. I mean it's not like we intentionally keep people out, it's just like once you get into the flow of how things work then you figure it out and then one day you're like "oh, I'm an [project's name] developer" just because you know where the stuff's at.*

[121] To "troll" means to make controversial statements with the intention to spark heated discussion and conflict.

The only difference between us and a lot of other people is that we've been around longer and all that kind of stuff.

Here, the developers say that there is no higher authority that would select who can contribute. The selection happens on an entirely different front: the effort put into finding out where information is kept and learning how to use it. Obviously, the presupposition here is that newcomers already have the skills to contribute. If this is true, then the difference between a newcomer and a recognized developer is knowing "where the stuff's at". It is a problem of orientation, not accessibility. In other words, the word "open" designating this model of software development certainly means "accessible", but it does not mean that modification and redistribution are effortless. Quite the contrary.

As I have shown, there are many requirements new contributors have to meet. They need to know their tools, the standard platforms and also the project specifics. This goes directly against the advertised claims that "anyone"[122] can contribute. Certainly, there are roles in FOSS projects that are easier to pick up (like a translator or documentation writer), but these are rather supportive of the main activity and more often than not do not allow for employing the main incentive for development: scratching one's own itch. Therefore, there is a barrier to contribution that selects contributors according to their skills, motivation and free time. The other side of the coin is that overcoming the barrier means learning, which is empowering either on its own (actors are able to modify software to fit their needs) or in other institutional contexts (actors can demonstrate their skills in educational institutions or at the labor market).

But how can developers presuppose that newcomers already have the skills necessary to contribute when every development project relies on mastering so many other entities? The first part of the answer could be expressed by a single word: specialization. Developers choose the components they want to work on, and over time they become specialists in those areas. This is nothing uncommon. The second part of the answer rests on the fact that the relations are not attached to ever more new enti-

[122] Equating public access to source code with the claim that anyone can modify it and get the modifications through the review process is common. It is also the implication of what the first page of the Pitivi website states in the biggest font: "We believe in allowing everyone on the planet to express themselves through filmmaking, with tools that they can own and improve." There is a direct relationship between the words "everyone" and "improve" in that statement.

ties. The meaning of standards is that they are present through the field. For example, Bugzilla uses Git and wiki in its own development while MediaWiki uses Git for managing its source code. Almost all of the projects have an IRC channel. To be sure, projects have varying rules for using the components in development. For example, the commit messages will contain different information – in the MediaWiki project, the commit messages must contain the name of the reviewer, while in Pitivi they contain only a description of what the commit does. But the repetitive occurrence of these development components gives the landscape a sense of arrangement. Therefore, when a core developer on the Drupal project is asked what makes Git a great tool, she answers:

> *For me, it's Git's ubiquity. Particularly in the last couple of years, Git has become the clear winner in the version control wars, and having one common language to speak with and collaborate with other developers has solved SO many problems.*[123]

Given the same question, a maintainer of the Qt project remarks:

> *And since it's now so popular, it's not a barrier of entry for new contributors.*[124]

The advantage to using a standard tool is the lower entry barrier for newcomers. This is based on the assumption that most newcomers will already be familiar with the tool and do not have to learn it in the course of getting involved in the project. Furthermore, once the tool is used widely enough, one can assume that others know its commands. Therefore, it ceases to be necessary to describe at length various courses of action; rather, it suffices only to name the commands (which, in this sense, constitutes the "common language").

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[123] *Git Success Stories and Tips from Drupal Core Committer Angie Byron*. Interview published by Linux.com. Published: 2015-04-08. Accessed: 2015-04-10. Available at: http://www.linux.com/news/featured-blogs/200-libby-clark/822227-git-success-stories-and-tips-from-drupal-core-committer-angie-byron.

[124] *Git Success Stories and Tips from Qt Maintainer Thiago Macieira*. Interview published by Linux.com. Published: 2015-04-07. Accessed: 2015-04-10. Available at: http://www.linux.com/news/featured-blogs/200-libby-clark/821948-git-success-stories-and-tips-from-qt-maintainer-thiago-macieira.

These findings point to one claim – that knowledge of standard tools reaches very far. This claim draws on the conceptualization of knowledge as a relationship between an actor and information (for example information that constitutes an interface). And in a situation where a certain piece of information is standard, i.e. has an established presence in multiple locations, knowledge follows the actor wherever he goes. This relationship is symmetrical in the sense that both actor and information are needed to produce knowledge, but it is also asymmetrical in the sense that actors cannot be copied (and thus reach multiple locations simultaneously) – only information can. Thus, we are getting back to reproducibility and automated manipulation of digital text.

5.1.2 Translation and Delegation

This digital medium is crucial also for translation and delegation within free and open source software development. In this environment, translation occurs in a very literal sense when ordinary text is translated into one of the languages that are spoken by the major actants. For example, if a text is to be displayed on the project's wiki, it must contain markup signs consistent with the wiki markup language. This means that the formatting of such a text needs to be marked by additional characters. When saved in the wiki, these additional characters are translated into the desired formatting for the original text. As a result, there are two texts: first, the raw text with visible markup signs that is edited by the author, and second, the result translated into a formatted text without the markup signs that is accessible to the reader. Unless the reader decides to inspect the page by looking at the text "backstage" (in MediaWiki, this is achieved by clicking the "View source" button), he or she will not see the markup signs. They serve as instructions for the translating agency (in this case, a component inside the WikiMedia platform), but are invisible for the reader.

''text in italics'' gets translated as *text in italics*
'''bold text''' gets translated as **bold text**

The same applies, for example, to the Hyper Text Markup Language (HTML), which is used for publishing on the project's web pages or developer blogs. The syntax of the HTML markup signs is more complex than that of the wiki markup because the language is aimed at more general use. But it is still a markup language[125] – it is predominantly concerned with formatting of documents (websites) and their display. Adding to the complexity, there are a number of translating agencies for HTML – commonly known as web browsers, with minor differences in how the markup is interpreted in each one of them. However, the full complexity is uncovered by the fact that more than one language may be involved in the translation. For example, because wiki pages are accessed by web browsers, it is necessary to translate the content into HTML. Therefore, the wiki markup is translated first into HTML markup and only then into reader-ready formatted text.

Wiki: ''text in italics''
HTML: <i>text in italics</i>
formatted: *text in italics*

Wiki: '''bold text'''
HTML: bold text
formatted: **bold text**

Therefore, we have a chain of translations at the beginning of which stands the author, who decides which markup language to use and writes the first version of the text in it, thus augmenting plain natural language with markup. All subsequent translations are done by parsers which employ automated manipulation of text to translate it into different languages or reader-ready results. Each of these parsers consists of a set of rules for the substitution of markup signs from one language to functionally equivalent signs in another. This is only possible because of the existence of a set of conventions aimed at searching and replacing text patterns. These conventions may be part of a particular programming language, but in their raw form, they are formulated in what is called "regular expressions". Whatever their form, their general function is the same – instead of the limited options of searching and replacing literal strings of text, they introduce general concepts like a word, a number, a letter, or the beginning or end of a line, thus allowing for formulation of patterns that match entire classes of literal strings. I will use a few examples of regular expressions to demonstrate their functionality:

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[125] Or traditionally has been. The latest version, called HTML5, represents a departure from this category, but this fact is not relevant for the purposes of this text.

.*@example\.com matches any email address at the example.com provider
[0-9][0-9]?\.[0-9][0-9]?\.[0-9][0-9] matches any date in the dd–mm–yy, mm–dd–yy, d–m–yy, or m–d–yy formats
={2,6}.*={2,6} matches any second to sixth level heading in the wiki markup language
\w matches a word formatted to bold in the HTML markup language

The importance of regular expressions is also shown by the fact that they are regulated by the Portable Operating System Interface (POSIX) standard, a norm that regulates key components of operating systems to assure compatibility. However, despite standardization efforts, there are several versions or “flavors” of regular expressions, and so their exact formulation always depends on the parser that is used to process them. Now we arrive at the point where language translation is a nested problem. This is because parsers of markup languages require regular expressions (or programming languages) that require their own parsers (in the case of programming languages, a compiler) which may comply to different standards. Therefore, as we can see, even (literal) translation has its own composition.

The results of the described chain of translations are usually used for publishing. The contents of both blogs and wiki pages can be served to multiple readers at the same time as long as they are present on a server, thus creating a stable point for referencing. Essentially, the function of such pages is to delegate information to a number of places (the monitors of connected readers) for a given period of time. In this way, the delegation overcomes distance (the text was written somewhere else) and time (the text was written at another time) and is able to transport the same information into entirely different contexts.

In programming languages (as opposed to markup languages), the translation gets a whole new dimension. It is no longer the case that only markup signs are added to natural language; the whole statement needs to be reformulated according to the logical structure of the programming language and of the interface that is provided by libraries. This is so because, unlike markup languages that are focused on organizing text into a desired shape, programming languages are aimed at performing actions if certain conditions are met. Markup languages are full of markup signs while programming languages are full of conditionals. As an example, consider this part of a Bash script (which is not technically a programming language, but its use of conditionals is analogous) with every line annotated in natural language:

```
while read line                  # read every line of a given file
  do                             # at each line, do the following
    if [[ ${line} =~ $n ]]       # search for pattern specified in variable "n"
    then                         # if the pattern is found, do the following
      buff1="$buff1 $line"       # add the line to variable "buff1"
    else                         # if the pattern is not found, do the following
      buff1="$buff1\n\n"         # add two new lines to the variable "buff1"
    fi                           # no other options will follow
  done < $file                   # do all of above to file specified
                                   in the variable "file"
```

In the IRC channel, explanations of what parts of source code "do" are common. It allows for fast overview of the code and saves hours of browsing to discover its function – provided there is someone knowledgeable enough to explain it:

Ben: You have a media stream, imagine a video… you want to seek to the time 30s… how Gstreamer knows it has to stream the data at (the time) 30s and not 40s or 100s or whatever
Ben: Steve: ^
Steve: you're asking me to explain you the seeking mechanism in gstreamer?
Steve: Basically a seek event travels upstream until an element (such as yours, or a demuxer) answers "yep I'll handle that"
Steve: It then seeks itself in ways that are relevant to its job (for example your element finds the image that has to be output first, a demuxer might look up an index table to find out the byte offset in a file at which he'll be able to resume streaming, preferably a keyframe)
Steve: It then propagates a segment downstream, saying "the segment I'm going to play starts at the nth second in media time and ends at nth second in media time"
Steve: And starts to output buffers once again
Steve: In the case of a demuxer and accurate seeking, the demuxer might output data prior to the requested start, necessary for decoding of the first actual frame to be rendered, the decoder will clip these "decode-only" frames but that's irrelevant for your element

Steve: As it can be accurate at no cost even when the requested seek is not accurate
Steve: That means a demuxer usually needs to convert a time seek to a byte range when operating in pull mode
Steve: But imagesequence doesn't need that
Steve: Ben, does that answer your question?

The excerpt serves to demonstrate how formalized source code is translated back into natural language. There are events and elements which are personified so that they can travel, answer, need to do things, say things. The result of this complicated interconnection is that a video is played exactly from the point selected by a user – also an action. Here we can see that the compiled source code literally does things. It is designed to do so by its originators – its developers. They devise the actions to be taken and design the interlocking of elements and events. By writing, they populate the internals of a program with entities that delegate action and wait for the specified conditions to trigger it. The software entities that are closest to a literal expression of this principle are daemons.[126] These are programs on their own, designed to run in the background, monitor other tasks, and trigger an action if certain conditions occur. Thus, by formulating precise rules for triggering conditions and actions to be carried out, these entities allow for a very sophisticated delegation of action.

Such sophistication also leads to a high rate of errors, that is, delegated actions that are not intended by developers. The presence of errors is seen as inevitable and is considered unavoidable when writing source code. One of the maintainers expressed this point aptly when he substituted writing code for creating new bugs, saying "We all love creating new bugs :)". There is a distinction between the creative and fun activity of writing source code that gives a program new features and the often hard and frustrating maintenance that involves finding and fixing errors. Because the first activity usually means introducing new bugs to the existing code, it is common for development projects to have a "feature freeze" period before releasing a stable version. This period is

[126] The term daemon is probably used with reference to Maxwell's daemon, which represents a well-known image of an entity quietly and tirelessly working in the background and performing predictable actions depending on input. This image is not limited to science and technology, for example Pierre Bourdieu uses the metaphor to describe the function of an educational system (Bourdieu, 1998, p. 20).

dedicated to maintenance only, and the design and implementation of new features is put on hold. During my fieldwork in the Pitivi project, development efforts were stretched towards releasing the 1.0 stable version. As a result, there has been a feature freeze period for more than a year at the time of writing. This was indicated by the infrequent use of collaborative drafting tools like wiki pages on the one hand, and on the other, common instances when new bugs and debugging information filled the IRC channel.

I have described the basic principles of debugging in a previous section, but let us return to this activity and identify the translation and delegation that are performed in the course of it. Debugging starts with an error, an unexpected course of action performed by the program, which does not correspond to (or directly hinder) its functionality. Errors are usually discovered by using the program, which means that their natural form is contained in the user interface of the program. The whole practice of debugging is then focused on identifying the component and, if possible, the part of the source code within it that causes the error. A manifestation within an interface (which is usually expressed in natural language at first) is translated into an identified part of the source code. In this process, the debugging tool works like an interpreter that bridges the barrier made by compilation and translates the error from one form to another.

Usually, when an error is discovered, a bug report is created to account for it and to track its development. The report ideally contains both an expression of the error in natural language (which deals with the compiled interface) and the information produced by a debugging tool (which identifies parts of source code). This information is submitted to Bugzilla, which stores the data in a database and creates a dedicated web page for each bug. Thus the submitted information is embedded in HTML to be viewable in a web browser. The translation into the markup language goes hand in hand with publishing the information. During the process, the information is delegated from its origin at a user's local computer into a database run on a server and then into different local computers that belong to the developers, who access the report through web browsers.

If the bug is confirmed and no other information is necessary to identify its cause, the report serves as a space where public discussion takes place about the options for approaching it and how to design a patch that would fix it. In this phase, the error is transformed into a task that can be picked up and solved by a developer. Now it is halfway between problem and solution. Information about bugs is not posted solely to the IRC channel (even though the discussion is faster and more convenient there) because fixing a bug usually takes a longer period of time (when the debugging information must be handy) which can only be overcome with the asynchronous communication that Bugzilla provides. Furthermore, by also keeping track of all the errors that were fixed, Bugzilla delegates the information even further to the future, when the fixed bug can manifest itself as a regression. The small memory footprint of digital text and the efficiency of automated search functions allow for this luxury of archiving.

When a developer picks a task from Bugzilla, or decides to write a brand new feature, he or she needs to translate the feature into a complete design artifact first. A common vehicle in this process are artifacts called "mockups". In software development, mockups are essentially screenshots of how the future versions of a program will look. They take the form of pictures expressing the intended shape of the user interface and can be used to visualize adding buttons, resizing panes, moving menus, or simplifying the interface by removing any of the elements. Thus, the idea of a new design is translated from natural language to a non-text medium directly showing the result. After that, mockups are usually published on a blog or in the project wiki. Both of these publishing options serve to delegate the design idea to other developers, while collecting feedback. Thus, this type of delegation is aimed at provoking action, not propagating it.

The next step in the design process is to create a functioning prototype by modifying the existing program's source code. However, to ensure that the modifications remain distinguishable and reversible, they must be tracked by a source code management system. Hence, the translation at this point is double: first from a mockup and natural language to a programming language, and second from a continuous stream of developer's work to a set of self-sufficient work units. The first translation, as I already showed, leads to the delegation of intended actions from a private computer the source code is modified on, to all computers on which the code is running in the form of a compiled program. In the second type of translation, the work is planned in order to be dissected into a set of atomic commits. In Pitivi, commits are labeled in an imperative form, expressing what is achieved by applying them. Here is a log with labels of some of my commits that were included into the main repository:

```
commit 5b06c4686ffbe0eb76d08fd1b6f3b618384f5057
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Sun May 25 14:03:52 2014 +0200

    help: replace menu bar and main toolbar with header bar and app menu
everywhere

commit b103ce8947026d03c1f507200c7479fea38d6d4c
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Tue May 13 16:09:33 2014 +0200

    help: update sysreq.page

commit 90ac17a661a9a29686cf4a4f6f926e6f75f417d9
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Tue May 13 14:35:50 2014 +0200

    help: remove unnecessary note from mainwindow.page

commit ee93d664894b5253941d58f834f00d3bdd8f87f7
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Tue May 13 14:29:02 2014 +0200

    help: add tip on detaching the previewer to mainwindow.page

commit 6497108acf97c8c772e5dfea3d2824c68d5fb4b8
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Tue May 6 17:24:33 2014 +0200

    help: adjust see also links

commit bda833dfe0b1a5ad10341ce5c7fe68b44fbd2405
Author: Tomas Karger <tomkarger@gmail.com>
Date:   Tue May 6 16:51:04 2014 +0200

    help: move select unused files from a separate file to medialibrary.page
```

The labels are indicative of the delegation performed by commits. They too delegate actions, only not directly to user's computers, but to the source code. In this sense, the delegation of source code management systems (such as Git) is more enclosed in the development process – the commits usually don't reach the users, they remain a development aid – while the delegation performed by the programming languages goes practically end to end (from developers to users).

By creating a database of labeled, time stamped, uniquely identifiable and precisely recorded commits, source code management tools translate the work of an individual, so that it is self-sufficient and can be shared with other programs and programmers. It uses the "universal interface" proposed by the UNIX philosophy – digital text formed into predefined data structures – in order to pass information for processing to other entities. Commits can be pushed to a repository and pulled from it by someone else, conflicting modifications are highlighted and resolved, different versions of a file are sent to difftools to visualize differences and commit history can be sent to a search tool to find the work of a particular contributor. These are probably the most common instances of such use.

By translating work into standardized commits, Git performs an important function of delegation. Publishing commits in a repository makes possible independent cloning of the code by someone else. The source code is delegated to a public space so that it can be reviewed, modified and appropriated, can become the subject of discussions and can trigger learning. This delegation is key for free and open source software development, because it allows for the existence of one of its prime organizational features – work self-assignment.[127] This seems to be consistent with the fact that FOSS projects are often driven by volunteer effort, and so there is a lack of any leverage to enforce work assignment. This is often contrasted with the fact that FOSS projects sustain themselves for long periods of time and are able to produce stable and widely used software.

Seen from this perspective, a FOSS project represents a puzzling combination of stability and fluidity. However, such a configuration can be explained when we take into consideration the usual process of how new contributors get involved in a project. In this process, a minority of maintainers serve as bearers of the knowledge necessary for meaningful contribution. The heavy involvement of maintainers does not correspond

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[127] A study by Crowston et al. (2007, p. 6) indicates that self-assignment is the most frequent form of work assignment in free and open source software development.

to the image[128] of aggregates of unrestrained contributors that swarm around projects to contribute when the conditions are right. To be sure, there are occasional contributors who get involved from time to time, but cannot be relied upon for consistent input. In an interview for the Linux Voice magazine, Lennart Poettering, a well-known developer of the controversial Systemd init system, talks about such occasional contributions as “drive-by patches”:

> *LP: So anyway, long story short, we came to the conclusion that Upstart is conceptually wrong, and it moved at glacial speeds. It also had the problem that Canonical tried very hard to stay in control of it. They made sure, with copyright assignment, that they made it really hard to contribute, but that’s what Linux actually lives off. You get these drive-by patches, as I would call them, where people see that something is broken, or something could be improved. They do a Git checkout, do one change, send you it and forget about it.*
>
> *LV: And you never see them again!*
>
> *LP: Yeah, and this is great – these are the people you want to have, because the vast majority of patches are actually of that kind. It gives you this polishing that you want. The people invested in the project all the time do the big things, and don’t care so much about the polishing. So these kind of patches are what you want. But if you do these copyright assignment things, you will never get those people because they would have to sign a contract before they can send you something.*[129]

In the interview, Poettering compares Systemd with Upstart, a different init system developed at that time. He points out that the additional negotiation (Yochai Benkler would see this as an increase in transaction costs) involved in signing a contract before contributing discourages potential contributors (which, in turn, may be one of the reasons why,

[128] For example, the Fedora contributor conference is called Flock, drawing on the image of bird collective behavior as chaotic yet organized, and also on the popular expression “birds of feather flock together”.

[129] *Interview: Lennart Poettering*. An interview published by the LinuxVoice magazine. Published: 2015-01-16. Accessed: 2015-01-16. Available at: http://www.linuxvoice.com/interview-lennart-poettering/.

according to him, its development moved at "glacial speeds"). The group most affected by the contract requirement are the occasional contributors, whose work is highlighted by Poettering. He claims that Linux literally "lives off" drive-by patches, that the "vast majority" of patches are of this kind and that the occasional contributors are "the people you want to have". On the other hand, the maintainers ("the people invested in the project") are mentioned in only one sentence and their importance is diminished, even though Poettering acknowledges that they are doing "the big things". This tendency is described more precisely by Paolo Bonzini, a maintainer on a different project who, in an interview for Linux.com, talks about the "long tail" distribution:

> *Each release of QEMU [Quick Emulator] has contributions from roughly 170 people. The distribution has a very long tail: about 40 percent of those 170 people contribute only one patch, and about 60 percent contribute less than five.*
>
> *KVM [Kernel-based Virtual Machine] is smaller, with about 25 people contributing to each release. The same "long tail" effect is visible there, about half of the people only contribute one or two patches.*
>
> *The long tail is very important. A lot of those "drive-by" patches are bug fixes.*[130]

These remarks indicate that while the work of occasional contributors is emphasized, the work of maintainers is taken for granted and is, in a sense, invisible (as elaborated by Bonnie Nardi and Yrjö Engeström 1999). The work on the "big things", carried out by a few dedicated individuals,[131] goes largely unnoticed. However, core developers, by being available for communication most of the time (and maintaining their involvement for extended periods of time), holding necessary knowledge (with the willingness to share it) and performing (not so enjoyable) maintenance, form

130 *Git Success Stories and Tips from KVM Maintainer Paolo Bonzini*. Interview published by Linux.com. Published: 2015-04-07. Accessed: 2015-04-08. Available at: http://www.linux.com/news/featured-blogs/200-libby-clark/821899-git-success-stories-and-tips-from-kvm-maintainer-paolo-bonzini.

131 This is supported by studies which note the participation inequality issue (Holtgrewe, 2004; Krishnamurthy, 2002; Kuk, 2006; McInerney, 2009).

the backbone of a project without which the drive-by patches would not be reviewed and merged into the main branch. In other words, the continuity of a project relies on continuity of involvement for at least a narrow group of human operators.

But this claim shouldn't be read as a statement evaluating the importance of humans vis-à-vis non-humans. They still use delegators to transmit knowledge, even simply through chatting in the IRC channel. In fact, since this kind of software development is taking place online, they have no other choice. Some tool must be used to delegate the information through the Internet infrastructure. Furthermore, the whole organization of development projects relies on delegation of formalized chunks of information, whether commits within source code management systems or bug reports within issue databases. They allow for cloning, branching, prototyping, review, merging, testing, debugging, confirmation and fixing – all the key practices that there are in free and open source software development.

In this way, commits and bug reports resemble what Bruno Latour calls inscriptions (Latour, 1986, p. 20; Latour & Woolgar, 2013, p. 236). They are mobile, immutable, flat (just text), can be reproduced at little cost, recombined or superimposed. The mobility of digital text on the Internet is self-evident. Immutability is enhanced by the ability of Git to clone whole repositories. Thus, when developers make modifications to the source code, they can demonstrate their effect by compiling and running a self-sufficient version of the program. Similarly, reports in Bugzilla are public. Should there be a report about a critical bug that no one is paying attention to, it is always possible to link directly to the report in public discussions, be it in the project's IRC channel, in a blog post that is displayed by the project's blog aggregator, or anywhere outside the project. The pressure to address such instances comes from the fact that speed of development and fixing of critical bugs is a major indicator of the project's health for anyone outside, including other development projects that might consider using the software in question:

> *Steve: No,*
> *Steve: the errors are in the tests*
> *Steve: not in our software*
> *Steve: and maintaining tests is exactly what you don't want to do ;)*
> *Tim: i know! i was saying that, the point in writing tests is only if they pass!*
> *Steve: Look: [link to a bug report]*

Steve: That's my problem
** Tim looks*
Steve: And the lack of activity on the report makes me doubt the reactiveness of the team
Steve: I mean it's a fatal bug
Steve: [link to a git repository log]
Steve: I also look at that
Steve: 30 commits in 2013 is not really intensive dev
Tim: oh! I see, just 30 in complete yr!!
Tim: that's worse than my local repos lol ;)
Steve: We had like 600 in pitivi alone ahaha
Tim: quite obvious!
Steve: A stable project might of course have less commits
Steve: But I don't believe [project's name] is one
Steve: so …
Steve: I would give a good look at our other options ;)

In this conversation, a maintainer and a newcomer discussed the project's options with regard to automated testing. They were discussing what software to include into their infrastructure for testing. But there was a problem with the program they tried, it showed errors that the team found out to be caused not by the software being tested, but by the testing tool itself. As a result, members of the Pitivi project would have to contribute to the testing software first in order to fix it before using it. This is not a very pleasing outlook. Furthermore, the contribution would probably mean longer involvement to keep the tests functional because the project does not seem to be "healthy".

As evidence, Steve provides a link to a report about a critical bug, in which the response time from an assigned maintainer is rather long – weeks to reply to a comment and 10 months to fix the issue. As a further evidence, Steve provides a link to the project's stable repository, which shows that only 30 commits were made during a period of one year. This is a very low rate for a development project that has not yet reached maturity and stability. Even Tim, as a newcomer, recognizes that this is a problem and states that he has more commits in repositories that only he contributes to. The final point is made by comparing the development speed of Pitivi, which has twenty times more commits for the same time period (and this does not include the commits made to the underlying libraries). As a result, Steve encourages Tim to avoid using this testing software and look for alternatives.

This decision, based on indicators described above, will have unwanted consequences for the project which was evaluated. First, it will not advance in gaining new users, which will prevent it from becoming a widely supported standard in its area of utility. Standard software typically has the advantage that other tools are designed to work well with it, and so it often requires less effort to set it up in various environments. Its users will also be able to draw from a more extensive knowledge base as there will be more users who could provide information. Thus, becoming a standard is a process that could be characterized by bootstrapping – the more standard a software is, the easier it is to gain new users, which will result in it becoming even more standard.

Second, the evaluated project will lose potential future contributors, who are often recruited from users that need to fix an issue. It is not a good prospect for a newcomer to see that in order to use a program for contributing to one project (in this case Pitivi) they would have to become a maintainer on a different project (the testing software in this case). Alternatively, if the second project performed well and merely needed a limited contribution from time to time, it would probably be acceptable. In that situation, both sides could benefit – the first project for being able to draw on work that has already been done on the tool and by being able to influence the direction of its development, and the second project for gaining users and potential contributors to further enhance the speed of development. Here too, the bootstrapping process is at work once a project reaches the state of performing acceptably for others. And this state is indicated to others by immutable inscriptions described above.

The inscriptions are also flat. They usually consist of digital text organized by markup or programming languages. The use of pictures or geometry is not very common except for mockups or other design schemes. The result is a set of files that are rather easy to modify (in principle, it is much harder to make purposeful modifications as a part of the development process) and adapt to one's needs. However, the application of automated manipulation, which permeates the use of digital text, and to a lesser extent digital images, allows for reproduction only with the use of computational resources. This makes it possible for those files to be translated and delegated multiple times without representing a significant resource burden.

Furthermore, these inscriptions can be recombined and superimposed. The availability of self-sufficient commits in public repositories makes it possible to take them over and include them in other repositories, be it one owned by a reviewer or a repository containing the reviewed stable version of the software. In these repositories, the original commits are combined either with modifications made by the reviewer, or with subsequent commits pushed to the stable repository. Superimposition, on the other hand, manifests itself mainly in the review process. Here, the proposed commits are evaluated not only by the criterion working/not working, but also the overall design of the modification is assessed with regard to the theory that the core developers maintain. For example, Pitivi maintainers would not accept a patch that introduces video editing functionality to Pitivi itself, as they believe that the right place for this functionality is the underlying libraries. However, in the past, this functionality was part of Pitivi. It was only in 2009 that the design decision was made to separate the interface from the functionality into different modules. Thus, by superimposition of concrete modifications to the source code, the reviewers are able to assess whether they adhere to the basic development principles agreed upon within the project.

5.1.3 Black-boxing

The primary purpose of Bugzilla, Git and other tools is to organize work and make it connectable. They are neither intended nor used to work as archiving tools that record what exactly takes place during software development. Only reviewed and agreed upon commits are included in the main repository, and the prototyping space of personal repositories is periodically cleared when repositories are synchronized to share a reference point. All failed attempts, experimental branches or history revisions stay hidden when browsing the main repository. Furthermore, chat discussions, blog posts, issue database entries or conceptual prototyping on the project's wiki pages are not even part of the information that Git handles. Having available detailed records of all successful work that has gone into a piece of software is seductive but misleading. The full history of a project lies scattered over numerous wiki pages, blog posts, issue reports, chat discussions or mailing lists that need to be read against each other in order to reconstruct the theories that guide development.

The complicated composition of a FOSS project, involving a few platforms, several contributor roles, a number of tools, hundreds of bug reports and thousands of lines of code results in the project appearing as a thick black-box to a newcomer – but not only to a newcomer. Given that contributors have certain roles and specialize in certain areas, they too face smaller black-boxes that represent areas that are out of their scope. This can mean two things. Either they never spent enough effort to familiarize themselves with what constitutes the composition of that area, or their familiarity is not recent enough.

Software (i.e. the tools and platforms used) is constantly developed and new versions are released. This means that it is a moving target for anyone who wants to stay current. New versions always mean changes in interfaces or, more importantly, in behavior. These changes are documented in release notes, which are usually very extensive. In order to deal with the extent and complexity, developers often use the strategy of emphasizing several important innovations, and for the rest, provide links to all bug reports that were closed or commits that were made during development of the released version.

However, even this amount of raw information does not cover every change of the program's behavior. There will likely be unforeseen relations, unintended consequences or regressions to previously fixed errors. Every new version will have its own unexpected behavior. When we take this insight and multiply it by the number of software components used in one project, we may start to wonder how any software development is possible at all. The answer to this question lies in the constant effort to stabilize the components (debugging) in order to make them behave predictably. If a program is developed long enough, it might achieve what is called "maturity", which means that all major features are implemented and stabilized and that it now needs rather small modifications aimed at maintenance. And small modifications mean lower chances of introducing unexpected behavior. At this point, most of the unpredictability is eliminated and the unreliable mediators turn into mostly unproblematic intermediaries.

Of course, for any software development project, it is advantageous to mobilize programs that are generally considered mature and thus stable. It reduces the amount of friction, frustration and workarounds needed to run the project. However, old and mature programs will not provide all the cutting edge functionality which may be appealing for automating tasks that until now had to be done manually. As a result, development projects strive to balance the degrees of stability and innovation in the choice of their tools. Therefore, any project represents a blend of the agreed upon tools that introduce certain degrees of uncertainty together with their functionality.

The amount of information present in a project, together with an intricate network of interrelations and mutual dependencies, creates a barrier that is not easily overcome. There is certainly a considerable knowledge load assumed. I can illustrate this with my entering into the field and assuming the role that allowed me to be a participant observer. I had been using Linux and open source software for several years prior to my research and it was still a challenging process for me. In my memos, I made a brief list of things I had to do before I could make the first contribution:

discover a blog post on planet Gnome saying: documentation specialist wanted
set up an IRC client
connect to the IRC channel #pitivi on Freenode
negotiate my role in the project
install a Linux distribution as a second operating system on my computer
install the dependency packages
install development version of Pitivi by running an automated script
get familiar with the application (download sample video file and play with it)
get familiar with the user documentation
go through a documentation to-do list of one of the developers
go through documentation bugs filed against the project
set up a suitable text editor
get familiar with the Mallard markup language
get familiar with the Git version control system
create a Github account
download the Pitivi Git repository
create my own branch and set up a Git repository on Github
share link to the Github repository to others
learn the "commit etiquette"

Note that the points are very different in extent. Some of them (set up an IRC client, for example) took only minutes, while the others (like getting familiar with Git) required days of iterative effort. The self-documenting nature of activities associated with FOSS development plays an important role in the process. For most of the tasks, there were resources online that provided information on how to achieve them. There are manuals, troubleshooting posts on forums and blog posts on how to set up an IRC client and connect it to a channel. There are wiki pages dedicated to installing dependencies and the development version of Pitivi. There is a manual describing the Mallard language syntax. And there is a whole book online on how to use Git. One can follow the instructions, step by step, to get results with little knowledge about what is going on.

However, it is only when the bare information is related to itself during an intentional course of action that knowledge arises. It was only when I became familiar with the current state of the application, its user documentation and a list of issues that I was able to start contributing. The triangulation between information on how the application behaves, how this behavior is represented in documentation and what the known issues are allowed me to possess knowledge that oriented my actions. All other points from the list above could be labeled supportive. This is not to say that they are not important. I would not have been able to contribute one bit without a text editor for example. But a text editor does not specify the content of contribution, just as an IRC client does not specify the contents of discussions. And neither does Git or the other tools. It was the triangulation, which was aimed towards comparison of the current state of documentation and the state that could be reached, that provided guidance for content.

Applied to programming, this takes us back to Peter Naur's definition of the practice as matching a significant aspect of a real world activity to formal symbol manipulation (Naur, 1985), something that we could call modeling. The significance of modeling for software development is highlighted in a blog post of one of the main developers of Light Table, a text editor that was mentioned on Pitivi IRC channel as a new and possibly useful tool. In the post, its author is trying to argue against the new trend of considering programming a new literacy:

> *Reading and writing gave us external and distributable storage. Coding gives us external and distributable computation. It allows us to offload the thinking we have to do in order to execute some process. To achieve this, it seems like all we need is to show people how to give the computer instructions, but that's teaching people how to put words on the page. We need the equivalent of composition, the skill that allows us to think about how things are computed. This time, we're not recording our thoughts, but instead the models of the world that allow us to have thoughts in the first place.*

> *We build mental models of everything – from how to tie our shoes to the way macro-economic systems work. With these, we make decisions, predictions, and understand our experiences. If we want computers to be able to compute for us, then we have to accurately extract these models from our heads and record them. Writing Python isn't the fundamental skill we need to teach people. Modeling systems is.*

The author of the post argues that writing source code is not the key activity in software development. The most significant activity is to create models according to which source code is written. There is a large contingency in which activities can be modeled or mapped. As we have seen earlier, Keil-Slawik pointed this out with his claim that programs do not have to follow the sequential constraints of mapped activities (Keil-Slawik, 1992, p. 182). The author of the blog post expresses it in this way:

> *While properties of physical modeling are useful to us as guiding principles, the digital world offers us an opportunity to step out of their limitations.*

When facing such a contingency, it is commonplace that rules are formulated and taught and that experience is associated with increased performance. This is why the author claims that modeling is the "fundamental skill we need to teach people". However, modeling is not so independent from writing source code as the blog post seems to imply. The characteristics and possibilities afforded by programming languages and libraries interfere heavily with how the models are implemented in the end. Therefore, creating functional models requires the whole process.

Such a process is usually iterative and depends on surrounding entities for providing instructions and feedback. Although most interfaces in this environment provide rudimentary feedback by not working, giving an error message or performing an unintended operation if not handled properly, there certainly are sources of more elaborate instructions and feedback. As already noted in prior research (Hemetsberger & Reinhardt, 2006; Lee & Cole, 2003), browsing developer documentation, or more importantly re-experiencing communication from chat or mailing list archives, can be very instructive or even provide feedback (by responding to a particular search query). To be sure, hybrid cases of maintainers providing a link to documentation or archives in response to a newcomer query are common. But adaptive iterative feedback is the area where humans fit in. From guidance during setting up the development environment to reviewing the finalized commits, humans, in particular maintainers, are able to provide sophisticated feedback to a newcomer and guide his actions from the start. In this way, they are compensating the knowledge needed to take purposeful action in this complicated environment until the newcomer develops his or her own.

Naturally, this is a time consuming process for both sides and so one would think that there should be reciprocity, in that the possible contribution the newcomer could make is worth the time spent on guiding him or her. But most of the time (the students of GSoC being an important exception), there is no contract that would obligate either party to anything. Thus, the guiding relationship with a newcomer is based on a tacit sense of what seems to be worth it. And with the topic of worth, we are approaching the question of how resources are used in free and open source software development.

5.2 Resources Driving Development

Now that I have exposed what meanings mediation has in the context of free and open source software development, it is time to focus on the second part of the question that drives this endeavor, that is, the question of pooling resources. Software development is a costly activity, yet there are software development projects that offer their products for free (gratis). Up until this point, there were several clues in the text for how this is possible. Let me pursue them further.

5.2.1 Volunteer Effort

Most FOSS projects start as volunteer projects to which developers contribute in their spare time. Pitivi is no exception in this regard. It was started as a student project and although some of its developers eventually got full-time jobs working on some of the underlying technologies, Pitivi itself is still a volunteer project. Thus, the continuous existence of the project depends on the ability to attract new volunteers and keep them engaged. Someone has to spend time writing the source code, reviewing it, making design proposals, writing developer and user documentation and translating the interface and documentation. Software development is not simple, nor cheap. But still, there are many volunteer projects that manage to keep the inflow of resource high enough to survive. How is this possible?

To achieve this, the project needs to advertise itself as producing a well-designed tool to provide a useful functionality and doing things the right way. Or, in other words, it needs to present itself as worthy of contribution. There is a specific page on the Pitivi website which targets potential contributors. This page serves as an index of communication channels and development platforms, but also strives to provide rationales for contribution. The quality of the overall design is demonstrated with the modular architecture that allows for reusing of functionality worked into the underlying libraries. Being a well-designed software, Pitivi has many users, many developers and a long history proving the project's resilience. This implies several advantages for newcomers: they contributions will be distributed widely and so they will be able to affect the experience of many users and the number of developers and history length means that they will be joining a well-established project with maintainers who will be able to mentor they and review their contributions appropriately. Strategically, it also means that the newcomers will not be at the mercy of decisions made by a single person, as might be the case in one-man projects. At the end of the rationale, emphasis is placed on the single most important point: "when you contribute to Pitivi, your time is not lost".

Time is a valuable resource and even more so when spent by a highly qualified workforce. There is no one else who could contribute to a project because, as we have seen, high qualification is necessary to overcome the barrier to involvement. Therefore, it is no surprise that the demographic from which I have seen most of the contributors originate was the one that abounds with time and qualification – students. Considering that Pitivi was a student project in the first place, that its current maintainers got involved when they were students and that current newcomers are also students in most cases, this seems to be the most common background among contributors.

This is so for several reasons. The first is that there is institutional support for student involvement in open source projects. Once a year, Google launches its stipend program called Google Summer of Code. It allows organizations managing open source projects to select students who will be paid to contribute over a period of a few months. However, there are several limitations that reveal interconnectedness with areas outside software development. First, the organizations involved in the program must develop software under a license approved by the Open Source Initiative (OSI). Founded in 1998, this California based standards body serves as a maintainer of the *Open Source Definition*[132] and a reviewer of popular licenses. In this configuration, the rules that for some (traditionally in the free software movement) have ethical or moral significance translate into eligibility to gain resources.

Second, the students must be able to provide a certificate of their enrollment into an accredited institution. Furthermore, they must be eligible to work in the country in which they will reside during the program. Finally, students residing in countries with whom the U.S. law prohibits engaging in commerce are not eligible to participate. Here, we can see how the program is connected to the countries of residence of the respective parties. In the present context, the approval of a license by the OSI and a decision to use the license by an organization developing software, together with an approval from an educational institution, all while taking place in the right geopolitical area, creates an intersection at which the quality of applicants only begins to be assessed and through which the funds are potentially available.

The incentive of earning several thousand dollars in the period of a few months is the first at hand when we consider the motivation of new contributors (provided they are involved in the stipend program). But there are also other incentives. Starting with the most pragmatic ones, further learning and experience in the field of study is obvious. In this regard, active contribution to a FOSS project is similar to an internship. And considering that developers in some projects are paid by private companies for their work, it might also be an "internship" very close to a potential future employer. Furthermore, there is one important advantage for students contributing to FOSS projects. The combination of the project's transparency and emphasis on recording authorship allows students to demonstrate their skills by pointing to the work that they have already done, which is documented in publicly available records. Just as personal repositories create leverage for reviewing and including commits from a contributor, the commits included in the main repository create leverage for accepting an applicant.

Apart from the pragmatic ones, there are also other incentives to volunteer. One of them is based on the value of the developed software and was expressed most strongly at the start of a fund-raising campaign:

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[132] This is a rather short document defining the open source development method in ten points. The full text is available at http://opensource.org/docs/osd.

Free and Open Source video editing is something that can help make the world a better place, as it gives people all around the world one more tool to express themselves creatively, fight oppression, create happiness and spread love.

The expression does not go as far as changing the world, it is not revolutionary. It just aims to add one thing to the list of what is good in the world. The assets that the software offers permeate personal domains (happiness and love), possibly reach to professional relations (creative self-expression), but might also serve a political struggle (fighting oppression). This hints at the modes of existence[133] that the developers envision for their creation when it leaves the haven of the main repository.

Furthermore, one of the Pitivi maintainers shared his motivations in a presentation at the GNOME User and Developer Conference. According to him, there is a variety of subtle motives like fixing an annoying error, making friends with other contributors and thriving from the enthusiasm and trust that runs in the group. But one of the major motivations is a value which, according to his own words, resonates with most developers working on Pitivi. It is expressed on the main page of the Pitivi website as a text in the largest font:

We believe in allowing everyone on the planet to express themselves through filmmaking, with tools that they can own and improve.

The expression has two important dimensions. First, the words "everyone on the planet" means (as explained by one of the maintainers in a presentation given at the GUADEC conference) that the software is developed explicitly with no market segmentation in mind. The software should be suitable for anyone from students or activists to independent professional filmmakers. In this, the developers see one of the main differences between their program and software that is developed for commercial purposes and has to be tailored to a specific group of customers. In a way, the Pitivi maintainers claim that providing the software free of charge liberates them from the restrictions originating from classical business strategies.

For the second dimension of the expressed value, the words "own" and "improve" are key. According to this view, users truly own the

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[133] In the sense which Latour attaches to this expression (Latour, 2007a, p. 24).

program only when there is the possibility to see its internals, discover how it works, modify it or reuse some of the work that has been done. With proprietary software, this is not possible by definition. Its source code is not distributed publicly and any attempts at reverse engineering or modifications are forbidden by licenses. From this point of view, users of proprietary software only get the right to use the software with all other rights denied. Therefore, users are dependent on the decisions the provider of proprietary software makes and are left with no options to steer the direction of development or maintenance. In the open source model, a qualified user would be able to trade his right to participate in the decision-making process for spending time volunteering for the project. In this context, ownership is enabled by access to information (most importantly the source code).

This point is based on one of the basic ideas formed by the movement as a criticism of proprietary software. One can find it in popular interpretations of the GNU project such as the one provided by the British actor Stephen Fry:

> *If you have, I don't know, plumbing in your house, it may be that you don't understand it, but you may have a friend who does and they may suggest you move a pipe here or stack cowl there or valve somewhere else. And you're not breaking the law by doing that are you? Cause it's your house, you own the plumbing. You can't do that with your computing, you can't actually really fiddle with your operating system and you certainly can't share any ideas you have about your operating system with other people because Apple, Microsoft who run the two of most popular operating systems are very firm about the fact that they own that and no one else can have anything to do with it. Now this may seem natural to you, why shouldn't they? But actually, why can't you do with it what you like, why can't the community at large alter and improve and share, that's how science works after all. All knowledge is free and all knowledge is shared in good science. If it isn't, it's bad science and it's a kind of tyranny.*[134]

Fry uses the classic opposition between big companies that only provide a restrictive license for using software they own and free software that is unrestricted in this sense and therefore can be owned by anyone, while

[134] *Stephen Fry talks about free software (GNU 25th Birthday)*. Published: 2009-04-28. Accessed: 2015-03-25. Available at: https://www.youtube.com/watch?v=YGbMbFomdPU.

the latter alternative is further legitimized by the positive associations in the images of “community” and “good science”. However, ownership in this sense relies on the potential for engaging with the internals of a program (or an operating system) and therefore it is substitutable (if someone does not understand it, someone’s friend might). But my point is that the relationship between information access and ownership goes one step further, because one can have the source code available and still not own the software any more than if it were proprietary. One needs to engage with the information available, appropriate it and develop knowledge about it in order to really own the thing. As I will show at the end of this section, such a relationship between knowledge and ownership serves as a strong incentive for involvement of private companies in FOSS projects.

However, the trade-off between spending time and gaining rights is probably not the most important part of volunteer motivation, if only for the fact that contributing consumes large amounts of time and leaves the desired result uncertain (bugs may prove to be harder to fix than expected, commits might not pass review or other design choices may prevail). But there is an added value to this trade-off that takes it to a new level of attractiveness – the results of the volunteer work are made available to everyone who uses the software. The volunteers know they are giving a gift to the wider community and they are prepared to accept praise for it. What they give away in hours of skilled work for free, they gain in status. Apart from providing positive gratification, the status can also be translated into resources. Being employed for one’s individual merits is one way of doing so. Public fund-raising may be another one.

When Pitivi version 0.93 was released, one maintainer emphasized the volunteer nature of the project on his blog: “0.93 is the result of continued efforts in our spare time – occasional hacking during vacations, nights and week-ends”. The emphasis was not random, it was setting the stage for a fund-raising campaign that aimed to intensify the development by providing funds to the developers so that they could spend more than spare time on the project. “Just imagine what could be achieved if Gary and Randy could be funded to work full-time towards bringing us to 1.0!” reads the next sentence.

The fundraising campaign was no easy undertaking. It required preparations months in advance – an agreement with a legal entity representing the project was made, a video was shot, a separate website was established, a press release was published and payment and voting mechanisms were put into place. What the fundraiser meant for the developers (and why they invested so much effort into setting it up) was that they felt they spent a lot of time on it for free on their own and now they needed a push to finally leave the testing stage and reach the 1.0 stable version. It was a moment charged with emotional valence, even though the developers felt justified in asking for the funds. One of them wrote this into his blog post:

> *I'm writing this the day before launching the campaign, and I have the website in the background, taunting me with its "0 € raised, 0 backers" message. Fortunately I also have the spinning social widgets to cheer me up a bit, but it's not exactly enough to get me rid of my anxiousness. I know that what we do is right, and that requesting money for stabilization first is the correct and honest thing to do.*

At first the fund-raising campaign went well and received coverage from news sites that delivered it to audiences interested in free and open source software. The coverage was quickly translated into funds as the news got to potential donors. However, after the initial burst of enthusiasm, the campaign stagnated. It soon became clear that the fundraising campaign would not achieve the target amount. This sparked a discussion about a fallback plan:

> *Eric: Also, maybe you should set a date when you make a plan, considering there is a chance you won't get to 35.000?*
> *Steve: "make a plan" ?*
> *Steve: Eric, ?*
> *Steve: fall-back plan ?*
> *Steve: Gonna go sleep, if that was your question Eric the plan remains unchanged, we just do it with less money and more good will :)*
> *Steve: Not that good will was lacking, but it's an apt replacement for money, just means it will take more time for us to do the stabilization as we'll go on taking contracts on the side*

Even though Steve claims that money and will are interchangeable, they seem to have different characteristics. The will to work on the software is there, no matter how much money is present. Money just provides more time for the will to materialize. More money implies a smaller number of other contracts and more focus on Pitivi development. Thus, money seems to play a small role in deciding whether to work on the software or not. It plays a much bigger role with regard to how much time the volunteers are able to spend, which translates to the speed of development. This appears to be the opposite of how private businesses traditionally operate. There, the investment return is the biggest criterion in deciding whether to develop a piece of software or not. By this, I don't mean to imply that the open source method of development, being completely opposite to the proprietary, is incompatible with any form of business. As we will see in the following paragraphs, it is quite the contrary.

5.2.2 Formal Organizations

The economy of free and open source software development does not stop with the motivation for contribution. Besides humans, all other entities present in a project must have a reason to be there. The whole infrastructure described up to now is dependent on a continual inflow of resources. In other words, someone has to provide the server time for running Git repositories, Bugzilla, the IRC channel or the project's wiki. Without these elements, free and open source software development would not be possible in the way it is now commonly performed. The presence of these elements is possible due to the existence of non-profit organizations and the specific business models of some private companies.

First, there are non-profit organizations like the GNOME Foundation. Operating from a donation or sponsorship based funds, the foundation provides several key services for the individual projects while also maintaining libraries that form a low-level programming infrastructure. The foundation serves as a legal body that represents the projects in formal relationships with other organizations. This allows the projects to have fundraising campaigns or to participate on the GSoC stipend, even though the informal mode of organization of the projects themselves would disqualify them in such circumstances. Thus, the foundation shields the individual projects from the necessity of establishing formal organization. In a way, it provides them the opportunity to reap some of the benefits formal organizations enjoy while allowing them to stay informal.

Furthermore, the foundation also controls some server infrastructure, which is provided for individual projects. Therefore, the Pitivi main repository is hosted by GNOME. Also, Pitivi uses the Bugzilla instance provided by GNOME as its issue tracker. When I entered the project, I was made aware that it was not always like this. In the past, the main Pitivi repository was hosted elsewhere and there was a duplicate hosted by GNOME that was used to collect translation and documentation contributions. This points to another type of service that the foundation provides. It is able to attract contributors that translate and document the software developed by individual projects. It usually takes much less time to translate or document a program then to develop it, and therefore it makes sense to associate those activities under an overarching body so that the contributors may move from one project to another and still stay on the same infrastructure.

Second, there are services that are provided by some companies for free. A typical example of such a case are personal repositories of the individual developers. These are hosted by GitHub, a company which specializes in managing Git repositories. The company makes revenue by offering paid plans for individuals and organizations that require private repositories. However, there are free plans for both types of customers, which offer an unlimited number of public repositories. This configuration is tailored to be used as an intermediary in volunteer projects. A newcomer aiming to contribute to a FOSS project just needs to create an account and configure a repository to use the service. For the company, it serves a marketing function and creates a positive public image. But more importantly, by drawing a large number of developers to use its services for free, the service is becoming the de-facto standard in the market segment of providing source code management services.

The case of the main Pitivi repository is different. It is located in a space provided by the GNOME Foundation which in turn has its servers hosted by Red Hat. Red Hat is also a company with a business model revolving around the open source development method, but one which is quite different from that of GitHub. This constitutes the third option. Red Hat is sponsoring a number of free and open source projects, ranging from the Linux kernel to the Fedora Linux distribution or the GNOME desktop environment. The technologies derived from these projects form a portfolio of what the company is able to deploy and maintain for a customer. However, the software itself is not sold; it is the surrounding services (deployment and maintenance) that create revenue.

In this context, communities around the projects Red Hat sponsors serve as sources of innovative and tested technologies, while also providing a skilled workforce pool (which is already familiar with the products) to recruit from. On the other hand, the company keeps the inflow of resources to the projects by providing server time, sponsoring events and acting as a motivational force drawing in those who seek careers related to open source technologies. At the same time, the developed software is still publicly available, as it employs licenses approved either by the Free Software Foundation or the Open Source Initiative. The close relationship that a business might establish with a FOSS project can be illustrated precisely by the case of Red Hat:

> *But of course, all of that value that Red Hat is able to offer its customers is built on the contributions of the much larger open source community, both as a whole, and the specific communities that feed directly into Red Hat products.*
> *…*
> *Our most notable involvement is with The Fedora Project, the results of which feed directly into Red Hat Enterprise Linux.*
> *…*
> *Fedora releases come out every six months, showing the edge of innovation and new features. Red Hat engineers participate in that process from the beginning. (However, 65–70% of Fedora's code is maintained by volunteers.) Then, Red Hat dedicates its quality assurance resources to testing, hardening, and certifying those features to ensure that they meet the requirements for enterprise-level interoperability and performance. Code that started in the upstream community becomes the code that Red Hat customers … rely on to solve their daily business problems.*[135]

However, this is only half of the picture. After being used and modified by Red Hat, the source code is made publicly available again which makes it possible to be reused in a different community-run Linux distribution called CentOS. From the CentOS perspective, the process is described in the following way:

> *The upstream vendor is using open source (mostly GPL) software in their business model. They take software that other people write (Gnome.org, X.org, KDE.org, OpenOffice.org to name a few). They repackage the source files into RPM format for redistribution. Because they chose an open source*

[135] *Q&A. What Is the Secret of Red Hat's Success?* An article linked from the official Red Hat website. Published: January 2012. Accessed: 2015-04-09. Available at: http://timreview.ca/article/513.

> *model to obtain the software they distribute, they must provide their source code to others. That is how the GPL works. The upstream vendor provides much added value by creating the Source RPMS and distributing them. They also fix problems in software and provide feedback to the software developers … this is what makes open source software work.*
>
> *The CentOS Project takes the publicly available source packages (SRPMS) provided by the upstream vendor and creates binary (installable) packages for use by anyone who wishes to use them.*[136]

A similar type of relationship can be found between the GStreamer project and Collabora, a company sponsoring its development (with the difference that after modification, the source code is integrated back into its original community source instead of being reused by another project). Collabora employs several GStreamer developers (some of which contribute to Pitivi in their free time) and for Pitivi, it provides a server for building and testing daily versions of the program. The emphasis is put on developing GStreamer and other backend technologies, as these provide the functionality that Collabora can offer to its customers in turn. But in the past, there were also developers assigned by the company to work on Pitivi itself, as it represented the storefront demonstrating what the underlying technologies are capable of.

However, the relationships between sponsoring companies and communities often exhibit tensions.[137] Development decisions preferred

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[136] *Frequently Asked Questions about CentOS in general*. Last edited: 2015-03-20. Accessed: 2015-04-09. Available at: http://wiki.centos.org/FAQ/General#head-4b2dd1ea6dc-c1243d6e3886dc3e5d1ebb252c194.

[137] A well-known example of such tensions was the relationship between the community around the Ubuntu Linux distribution and Canonical, its sponsoring company. Canonical was often criticized by members of the community for taking decisions behind closed doors and introducing them as fait accompli. The tensions culminated in 2013, when the website www.fixubuntu.com was established to instruct Ubuntu users on how to deactivate offending features introduced to Ubuntu by Canonical. At first, the company attempted to take down the website by using its ownership of the Ubuntu trademark, which resulted in an outburst of controversy. Eventually, Canonical founder Mark Shuttleworth apologized for this step and the website is accessible to this day. Such tensions are largely absent from my descriptions because I did not run into them during my fieldwork. This may be so because Pitivi is largely sponsored indirectly (for example through infrastructure provided by the GNOME Foundation) or the involvement of direct sponsors is limited and does not currently provide developer

by companies and those preferred by communities (or their parts) can diverge. In such a tug-of-war, companies have a more advantageous position, as they are usually able to mobilize developers that they employ to spend more hours of work than volunteers. Combined with the rule that decisions (rather the smaller ones, bigger decisions are left for governing bodies like councils in which, however, the companies also have their representation) are made by the ones carrying out the work (and review), companies can gain an upper hand just by employing the key actors. On the other hand, a community around a sponsored project is very valuable for any company and so their steering power is counter-checked by the possibility of the community abandoning or forking the project if a controversy reaches sufficient intensity. Volunteers are not assessing the project only before they start contributing, this is an ongoing process. Therefore, a perceived lack of good design decisions combined with the feeling that one does not get to be heard can lead to lowered willingness to contribute. As a result, the relationship between companies and communities involves careful balancing. Companies may lose a wealth of volunteers and risk competition if the project gets forked. Communities may lose resources from sponsorship and risk criticism for duplication of efforts if forking takes place.

But to return to the resources issue, one can ask: how can there exist a business model around software that is (together with its documentation) publicly available? The answer lies in the strategy I already mentioned with regard to Red Hat. It is not the software itself that is sold; the services around it are. The publicly available information is complex enough to require a significant amount of effort to be processed in order to be put to use. This can be demonstrated by a situation when a newcomer (Ben), after finishing his first bigger task, thought about taking on a much more demanding one:

> *Steve: As for the task you're thinking about, to be done correctly, it would certainly require changes in blender, and intimate knowledge of its code base, plus willingness from their upstream to expose an API*[138]
> *Steve: I am thus strongly hinting at you that it is *hard*, and will require*

time (as in the case of Collabora which provides developer time for GStreamer, but for Pitivi per se, it provides only a server).

[138] Application Programming Interface defines a set of commands that are used when one program uses functionality from another program.

changes in blender to do correctly
*Steve: I don't know if you already had a look at blender's code, but it's *huge**
Ben: I suppose.
Ben: I will need to read Blender code.
*Ted: I can concur on that, maybe I was not clear enough (but I thought I was) to Ben earlier today when I was hinting that you are *vastly* underestimating the complexity of something like integrating blender with pitivi*
Ted: I mean even if it was one of the gstreamer core devs doing it I would imagine a year of work
*Ted: Ben you realize that Pitivi is 18 thousand lines of code and Blender is *2 million* lines of code? you can't just go "read its source code" :)*
Ted: I mean you can… but we'll see you again in 10 years
Jim: reputedly the VSE (video sequence editor) in blender is a nightmare
Jim: terrible C code from the early 90s that nobody loves

In this conversation, the Pitivi maintainers (Steve and Ted) discourage Ben from taking on the task because of the difficulties it presents. To get an impression, it suffices to go through the emphasized points (marked with asterisks): the task is *hard*, the source code is *huge* (which is reiterated by stating that it has *2 million* lines of code), and Ben is *vastly* underestimating the complexity of the task. The maintainers point out that this is not a suitable task for someone who has just been around for several months, because even for someone as knowledgeable as a GStreamer core developer, the estimated time for completing the task would be a year. The conversation culminates in the statement that "you can't just go read its source code", pointing out that approaching such a task head on would require an amount of resources (illustrated by the expression "see you again in 10 years") that is out of the scope of any individual and that the codebase could perhaps be better appropriated by interacting with it (doing smaller tasks). To this, Jim adds a remark about the state of the source code ("terrible C code from the early 90s that nobody loves", it is a "nightmare"), which, together with its length, is also a significant indicator of the difficulty of dealing with it.

Such discouragement from experienced developers is indicative of how large barrier complexity is even when approaching documented and publicly available source code. For a more elaborate description of the problem, I can reach for the one provided by Brooks in his classical essay on programming:

Large-system programming has over the past decade been such a tar pit, and many great and powerful beasts have thrashed violently in it. Most have emerged with running systems – few have met goals, schedules, and budgets. Large and small, massive or wiry, team after team has become entangled in the tar. No one thing seems to cause the difficulty – any particular paw can be pulled away. But the accumulation of simultaneous and interacting factors brings slower and slower motion. Everyone seems to have been surprised by the stickiness of the problem, and it is hard to discern the nature of it. But we must try to understand it if we are to solve it. (Brooks, 1995, p. 4)

Although this characterization of the difficulties associated with software development is dated, it still retains its point. Even though it is normal today to make documented source code publicly available, it does not mean that the complexity barrier will disappear.

Returning to the question of business models, the answer seems to lie in the fact that employing developers who are already familiar with source code represents a considerable advantage for any company, as it is able to put the information to use without the need to spend large amounts of resources on overcoming the barrier. In other words, the company's competitive advantage is possessing knowledge (through employing developers). And it seems that possessing knowledge provides an advantage to such an extent that giving away the information is not threatening the business strategy.[139] This highlights the value (and the difference) of possessing knowledge compared to just holding information.

Indeed, when we look at what the companies involved advertise as their competitive advantage, we can see that it is the employment of experienced contributors who carry significant expertise. Collabora is particularly explicit about this on their website:

Whether you are getting ready for a new product development or upgrading a current one, adopting Open Source can seem challenging. Collabora will save you time and money by helping you leverage existing Open Source

[139] Moreover, as Josh Lerner and Jean Tirole note, making source code publicly available requires it to be adjusted to make orientation and contribution easier (Lerner & Tirole, 2002, p. 226). Therefore, even though the barrier is being actively lowered, it is still so high that knowledge of the codebase is very valuable.

> *software so that you can focus on the truly differentiated value of your product.*[140]

> *Collabora employees are not just professional Open Source developers. They are also longtime contributors and form an integral part of the Open Source community. And the years they have spent exploring projects and distributions and forming relationships with members of the Open Source community have resulted in expertise they can pass along to you.*[141]

Browsing through Collabora's portfolio, it offers the following services around GStreamer: consulting assistance, training, custom development, architecture (design review and creation). Note that three of the four offered services do not involve writing new (or modifying current) software and selling it as a product. The one service that does (custom development) could potentially involve writing source code that is not made public. This is also explicitly indicated on the website:

> *We believe that developing the vast majority of software publicly in a collaborative fashion must become the standard. Of course there will always be room for differentiated value; we don't suggest that every line of code must be made public (although that would be nice). Assisting customers maximize their use and contributions to Open Source is our raison d'être.*[142]

This excerpt suggests that extensions of the publicly available source code that are kept private are one of the ways to add a differentiated value to the customers' product. However, the text hints at a preference to make even the extensions public ("that would be nice") by integrating it back into the publicly available source code.[143] This process is elaborated elsewhere on the website:

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140 *Services: Planning*. Collabora marketing materials. Accessed: 2015-04-09. Available at: https://www.collabora.com/services/planning.html.

141 *Services: Guiding*. Collabora marketing materials. Accessed: 2015-04-09. Available at: https://www.collabora.com/services/guiding.html.

142 *Paving the Way*. Collabora marketing materials. Accessed: 2015-04-08. Available at: https://www.collabora.com/open-first/open-source.html.

143 To protect the extensions from the necessity of being published, which would normally be required by the GNU GPL, some companies resort to strategies like dual licensing or requiring contributors to sign contribution license agreements (CLA), which state that the code they write may be relicensed in the future. We can see that

> *Collabora has helped many customers to upstream their software contributions to existing Open Source projects. Compliance with the terms of Open Source licenses governing the software our customers use is of paramount importance to Collabora. Whether the code is originally developed by Collabora or our customers, we help our customers lower their maintenance burdens by ensuring that all relevant code is merged upstream. Collabora is committed to maintaining the code as part of our involvement in the Open Source community.*[144]

This excerpt shows that integrating extensions back into the open source codebase is not only a potentiality, but an ongoing practice. The incentive for Collabora customers to do this is expressed here as the possibility to "lower their maintenance burdens". The reason for this is that creating modifications of software that is held privately constitutes a parallel (privately forked) version of the software that has to be maintained separately. Such maintenance consists of monitoring the development that takes place in public and manually including all modifications that result from public development (which may also mean resolving conflicts that arise between public and private modifications). It follows that over time such an approach requires significantly more resources than integrating private modifications into the public source code, in which case every subsequent modification is built upon them and consistent with them, thus doing away with the costs of separate maintenance. As we can see, resharing of modified source code is not only a condition introduced by the "viral feature" of the GPL licenses, but it is also backed up by incentives based on cost and effectiveness.

We can see how practiced knowledge empowers volunteers and businesses alike, in the sense that it allows them to steer the direction of development in FOSS projects. For volunteers, this represents an op-

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the GPL requirement to distribute derivative works under the same conditions as the original work is problematic for some parties and requires further procedures to be dealt with. This may be one of the reasons why so-called permissive licenses (such as the MIT or Apache licenses) that lack this requirement have been gaining momentum over the past several years. (*What are the Most Popular Open Source Licenses Today?* A report based on data from Black Duck, a company specializing in monitoring FOSS projects. Published: 2014-11-14. Accessed: 2015-05-13. Available at: http://redmonk.com/sogrady/2014/11/14/open-source-licenses/)

[144] *Services: Integrating*. Collabora marketing materials. Accessed: 2015-04-09. Available at: https://www.collabora.com/services/integrating.html.

portunity for raising status, which can eventually be translated into resources through donations, fundraisers or employment. For businesses this represents a competitive advantage in overcoming the barrier of technical complexity. This advantage is often monetized in specific types of business models aimed at providing services around publicly available technologies.

In sum, we are now able to see the rough outline of the network that allows many FOSS projects to sustain themselves. The project must be able to draw volunteers and motivate them to stay. It may use some of the services provided by non-profit organizations or by companies whose business model involves free services. Finally, if strategically placed, the project may enjoy the benefits of direct sponsorship from a private company. Most of these sources are affected by design decisions and the quality of implementation within the project, as companies and volunteers alike will evaluate the worth of the project before contributing. Therefore, software is often initially developed privately and it is made public only after reaching a certain level of completeness, because it is at this point that developers are able to demonstrate their skills and motivation. From the point of view of potential contributors, this serves as a guarantee that the initial developers have the ability to reach their goals and are willing to do so, as they already invested a significant amount of effort before reaching out to public.

6

Conclusion

We are now in a position to see the overall shape of a FOSS development project. The projects are architected to facilitate and encourage autonomous retrieval of information and there are several structures that are particularly significant in this regard.

On the most basic level, there is the upstream first principle, which implies that the maintenance of functionality inherited from other programs should be done in the original programs, not in the one using the functionality. This is the difference between "being a good citizen" and "doing your own thing in your corner."[145] This approach helps to keep generalized functionality allocated in reusable libraries. Therefore, the functionality does not have to be recreated for each new program, but also (and perhaps more importantly) it allows for concentration of expertise around a technology that is considered standard.

Furthermore, licensing is key in establishing conditions for unconstrained information flows. But, as we have seen in the case of the GStreamer library, using just about any license permitting free reuse of information does not lead to frictionless sharing. Using non-standard licenses (with a clause, for example) introduces the necessity of negotiating the terms of reuse with some parties and therefore, as Yochai Benkler

[145] It also indicates that free and open source software development assumes a collective form of authorship, similarly to, for example, users of Creative Commons licenses who see the accessibility of their work as an acknowledgment of the intellectual debt they have toward their influences. Minjeong Kim contrasts this position with what he calls a "private property vision", in which authorship is seen as an exclusively individual achievement (Kim, 2007, p. 195).

would point out, raises transaction costs (Benkler, 2006, p. 109). As a result, the use of standard licenses, recommended by significant parties (such as GStreamer developers), or vetted by definition-maintaining organizations (such as the Free Software Foundation or the Open Source Initiative) is imperative for autonomous retrieval of information.

Apart from being part of the sharing infrastructure, licenses can carry a significant moral load, while at the same time be otherwise politically agnostic. This is the case with the GNU licenses created by the Free Software Foundation, which considers hoarding software under different licenses a moral fallacy. On the other hand, the GNU licenses explicitly preclude restrictions on reuse based on any further terms. This ambiguity is also reflected in the images of a "better world" put forward by organizations such as the GNOME Foundation. What exactly this better world will look like is nowhere specified, but it certainly involves the use of the FOSS development model. As a result, the identity of the observed organizations is based primarily upon the use of infrastructure defined as standard.

Correspondingly, the primary activity is not waging a political fight and trying to achieve a state of utopia. The primary concern here is branching out and establishing self-sufficient alternatives. Everything revolves around translating ideas expressed in natural language into formal languages (either markup, or, more importantly, programming languages). Once translated and compiled, the actions devised by software developers are fully automated and delegated to the computers of their users. This translation is achieved by writing (or making modifications to) the source code. The modifications are tracked by version control tools, translated into standardized form and delegated to a public repository in order to be appropriated by others. Personal repositories then represent sandboxes for experimentation, prototyping and learning. Once contributors are confident in their work, they make a pull request to indicate to others an intention to merge the work into the main development branch.

What follows is peer review, which is the center of gravity for power relations. Compared to the collaborative practices implied by Mediawiki, the review process utilizing Git has specific spatial and temporal characteristics. Here, peer review takes place in a distinct place (personal repositories) before the work is incorporated into the main repository. On the Mediawiki platform, there are no personal repositories; there is one central repository which is by default open to modifications. Peer review takes place only afterwards, as other users browse the content. While this model seems to produce acceptable results for the Wikipedia community, the maintainers of the Pitivi project decided to make further restrictions in order to avoid spam and vandalism. Considering that the Pitivi project is orders of magnitude smaller than Wikipedia and that maintaining wiki pages is not the main concern here, it seems reasonable to suggest that the wiki collaboration model provides the intended performance when a certain threshold of number of active users is exceeded, while the model utilizing Git performs even when the numbers of contributors are low.

Proceeding exactly in the opposite direction, debugging represents a temporal and local reversal of the black-boxing introduced by source code compilation. Debugging is a procedure which translates defects initially formulated in natural language into formalized descriptions known as stack traces. These are part of bug reports which delegate the defect and its description into a publicly available issue database and provide space for negotiation, initial prototyping and also a reference point. The contents of either the Bugzilla database or Git repositories can be seen as inscriptions, establishing non-human allies to be mobilized in demonstrating a claim and persuading others inside or outside a project. Inside a development project, this may be used to alter design decisions or allocation of time by individual contributors. Outside of a project, the information is used for assessing the project, its health and future prospects. This, in turn, affects the rate of adoption, which is also the rate of reaching possible contributors, in a bootstrapping process of becoming a standard (or not).

There are conventions that structure the procedures, such as writing the source code (the 80 column rule), making commits (the commit etiquette) or merging reviewed work (opting for the lowest number of conflicts in revision tracking). But it turns out that in some cases, the conventions are negotiable. If we look for something more stable, we would have to focus on the behavior enforced by the tools used. These are not negotiable, and are hard to alter. Granted that tools developed in accordance with the FOSS model are preferred, it is in theory possible to modify their behavior. But doing so requires effort going beyond the modification itself. Either one can opt for modification in cooperation with the developers of the tool. In this case, the developers will have to be persuaded that the modification is necessary and it will also have to go through the standard review process. One can opt for making the modification without cooperating with the developers of the tool, but this will establish an alternative version of the tool that will require maintenance (including updates from the official version) in the future. As a result, such situations are often dealt with by searching for a different tool that fits the requirements.

A similar dilemma can be found with regard to dependencies. However, from what I have experienced, there is a stronger tendency to contribute to dependencies than to tools. Some of Pitivi's core developers contributed more to GStreamer (its main dependency) than to Pitivi itself. This preference seems logical given that dependencies are presupposed in many parts of the source code and without them the developed program would simply not run. Therefore, switching a dependency always means modification to the source code, while switching a tool means that the change is contained within the project's infrastructure.

But even though the individual tools may vary, we can always find certain types of tools put to use in a project. Together with programming languages, tools like text editors, compilers, debuggers or version tracking systems establish the necessary minimum for a FOSS project. These tools make it possible to perform not only pragmatic action (text editors allow for writing, compilers for compiling, version tracking systems for pushing and pulling source code around), but also epistemic action – programming languages allow developers to *think* in a way that is designed to be automated; text editors allow developers to *see* the source code, or to perform searches; debuggers allow for *seeing* the internals of a program while it is running in order to identify which part is responsible for an error; version tracking systems allow for *seeing* differences in the source code so that the work of an individual can be *known*. In this sense, the tools serve as the wideware of software development.

At this point, I am closing in on the first question formulated at the end of chapter 3 – how do digital texts and software interfaces mediate the actions of programmers? The epistemic action performed with tools leads to establishing knowledge necessary for contribution. While this kind of knowledge is specific for every project, the knowledge needed to operate tools is not. In the area of tool use, the knowledge problem can be circumvented by resorting to standards, which will not only decrease the barrier to entry for contributors, but also make the output of their use standard. On the other hand, the problem of decontextualization is most pressing in the area of design artifacts. These intermediary results of work need to be examined thoroughly each time they appear. As I have already pointed out, their examination requires the use of tools to be possible at all, but a consistent use of tools also yields consistent output. As a result, deployment of standard wideware facilitates the emergence of knowledge in different places; it allows knowledge to "travel".

This is consistent with the premises developed in chapter 2, which describe how the idealizations proposed by Alfred Schütz (1953) work to establish reciprocity of perspectives in the digital environment. Information is externalized in the conventional form of design artifacts and reflection is externalized in the form of standardized tools. Processing design artifacts with the help of tools creates situations suitable for establishing interchangeability of standpoints and congruency in the system of relevance. Seen from the perspective of Nico Stehr's (1994, 2001) theory, the appropriation that is needed to transform information into knowledge is conventionalized with the use of the two types of objects. In a sense, tools and design artifacts also help actors to gain the command of situational circumstances, which is required for producing and applying knowledge. However, as we have seen, developing such control over situations is not the sole achievement of an actor, but of an actor using standardized objects. By populating the environment with familiar objects, standardization extends the number of situations an actor is able to control. As a result, this finding describes one of the ways in which situational control may be established – through dissemination of standards.

In his work, Bruno Latour conceptualizes metrology as the practice of developing and implementing standards in science (Latour, 1986, p. 30), a practice which makes it possible for inscriptions to play the role of immutable mobiles. Here, the subject of inquiry is software development, but we can see that in this field standards are no less significant. They allow for knowledge to travel together with actors and make large scale coordination possible, which is also consistent with the role Latour gives to standards (Latour, 2005, p. 229, 244). It follows that what is outside the network consisting of distributed standardized objects is not interacted with because it is difficult to control the conditions in which the interaction would take place. From this perspective, it is possible to grasp the recursivity of free and open source software – the fact that it mobilizes existing free and open source software as means to develop new software – as an issue of standards dissemination. Be it standard licenses, standard tools or standard design artifacts, their presence make interaction acceptable, or even desirable. From this perspective, the two branches – free software and open source software – differ in the emphasis they put on which standardized components they expect in software development projects. While the former tends to emphasize licensing and its moral implications, the latter puts more emphasis on the practical implications of using open source tools. Proprietary software is then off the table for both branches because it does not contain either of the components considered standard by free and open source software developers.

Now let me turn to the second question, which is focused on resources that are necessary to make connections in this environment. The process described above is very valuable because, as we have seen, knowledge is closely related to practicing rights traditionally associated with ownership in this context. Users do not own proprietary software; they are only licensed to use it. This is a common claim in the FOSS world, which, as Coleman (2013, p. 6) shows, leads to the prevailing opinion that source code should not be subject to property rights. Indeed, by using FOSS licensing, the authors of source code voluntarily abandon most rights associated with ownership. Formally, this prevents ownership from being exercisable (unless, of course, the licensing conditions are violated). FOSS licensing disposes of ownership by ascribing the most fundamental rights associated with it to anyone. But practically, if we consider ownership to be defined exactly by those activities the licenses are explicitly permissive about (that is, source code access, modification and redistribution) we can see that they are not practiced by just about anyone. The most significant prerequisite for doing so is holding specific kinds of knowledge. Hence my claim about the close relationship between ownership (at the level of practice) and knowledge. However, this claim has one important caveat – it uses ownership in a sense in which it is no longer an exclusive right. In this context, ownership is redefined to a form in which it can be exercised by multiple parties simultaneously.[146]

[146] The extent of the redefinition becomes visible when we compare this case with a classic model of ownership such as, for example, the one that Bruce Carruthers and Laura Ariovich use as a starting point for their overview work on the sociology of property rights (Carruthers & Ariovich, 2004, p. 24). In the model, ownership is defined by the simultaneous validity of three points: (1) A has the right to use P; (2) A may exclude others from using P; (3) A may transfer rights defined by rules 1 and 2 to others by consent. The mismatch between the model and the empirical case at hand would be worth examining in detail and, as such, represents a venue for following up on this research. But within the scope of this work, I must limit myself to pointing out that the

The distribution of source code and provision of free software rights introduces ownership only potentially, or we could say (with reference to Rob Shields 2003) virtually. It is only by exercising the rights to study, modify and redistribute the source code that ownership is actually performed. These knowledge intensive activities (performed through pragmatic and epistemic actions enabled by tools) allow for knowledge accumulation, which in turn supports further activities. In its course, this bootstrapping process renders ownership actual. This claim is further supported by observations of business models that do not rely on (formal) ownership of information. Instead, these business models are based on employing actors knowledgeable of publicly available information and through them, providing paid support for their customers. Therefore, even though a product (software) is publicly available, it is owned (to the extent that profit can be made) only by those holding knowledge of it.

Reintroducing the concept of ownership (although highly modified) to FOSS development can help explain the interrelatedness of significant FOSS projects with private companies, even though prominent authors in this area consider the movement incompatible with capitalism (Coleman, 2013; Himanen et al., 2001; Söderberg, 2008). Indeed, the FOSS movement is at odds with classic capitalist values like the duty based work ethic or the legal form of private property rights. However, this does not seem to matter all that much, as long as there is some source of differentiating value that can be utilized to build business models around. The barrier of information complexity and the necessary investments to appropriate the information represent such a source.[147] Its existence allows

sources of this problematic relationship seem to lie in an ambiguity of the word "use", in this case stemming from the difference between use by users and a more knowledge intensive use by software developers; in the assumed exclusivity in use of property, which is problematic for the whole domain where digital data are concerned, as I can illustrate with the work of Majid Yar on piracy, particularly the part where he stresses the difference between tangibles and intangibles (Yar, 2008, pp. 612–613); and in the unforeseen possibility that rights (1) and (2) could be systematically suspended through consistent use of a specific type of licensing.

[147] I believe that this line of argumentation is consistent with the implications of Stehr's concept of incremental knowledge. According to this author, incremental knowledge represents a "marginal unit" of knowledge in the process of its ageing or decay (Stehr, 2001, p. 39). Seen from this perspective, such a marginal unit can have a strategic value, especially if it is not yet widely spread. Therefore, as Stehr deduces, the faster the process of knowledge ageing, the greater the significance of those producing knowledge. Simultaneously, the position of knowledge producers is also se-

for the establishment of contexts where decoupling of differentiating values from dutiful work or private property rights is possible. It is not very important whether we view this as the result of an adaptive capacity of capitalism or a transformative capacity of the FOSS movement. What matters is the existence of a symbiotic (although fragile at times) balance between two entities that were initially considered inconsistent. This represents the underlying logic which allows for a considerable amount of resources to be allocated to FOSS projects.

At face value, the claim about the central role of knowledge in this environment seems to support the assumption of utopian virtualism, that knowledge is currently the most important production force. However, as we have seen, knowledge does not stand on its own even in the digital realm and so there are too many caveats to the claim. In FOSS projects, knowledge transmission is made possible by free access to information granted by a specific type of licensing. Furthermore, knowledge is dynamized through involvement in an intricate network of tools and platforms, with investment of significant amounts of time, allowing for epistemic action to be conducted continuously in order for a newcomer to become part of a software development project. The tools and platforms are conditioned, in turn, by hardware such as servers, personal computers and their connection to the Internet.[148] The amounts of available time are dependent on the life situations of the respective actors. Combined with appropriate motivational impulses (such as intrinsic interest, status, moral or ideological positions) only this configuration results in accumulation of significant amounts of knowledge. It should become clear now that for all its significance, knowledge is not self-sufficient; knowledge does not immaterially operate upon knowledge.

Furthermore, in utopian virtualism the implicit concept of immaterial action is an assumption enabling the image of free and flexible as-

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cured by the fact that if sold (or provided as a service) knowledge still remains within the domain of the producer. As Stehr puts it: “the transfer of knowledge does not necessarily include the transfer of the cognitive ability to generate such knowledge” (Stehr, 2001, pp. 39–40). From this perspective, the barrier to producing knowledge from information seems to be a plausible source of differentiating value for FOSS projects.

[148] The tables or basements filled with digital equipment that were recorded on video in the series on Linux kernel developer workspaces by Linux.com are cases in point. See, for example: https://www.youtube.com/watch?v=HSgUPqygAww or https://www.youtube.com/watch?v=NomqUIC_Uzs.

sociation.[149] It is based on the image of self-organizing masses, flocking, swarming around problems to solve them and push the advance further. However, the idea held by utopian virtualism that taking advantage of the functionality that digital technologies bring is only a matter of having these technologies available omits significant contingencies. As we can see in how FOSS projects, the avant-garde of digital culture, operate, the interlocking of various conditions cannot be assumed to be unproblematic. The dropout rate of newcomers demonstrates this very well. As my findings indicate, even in the supposedly frictionless digital environment, the center/periphery structure emerges, signifying the central role of a few heavily involved individuals. This is also supported by other research uncovering participation inequality (Holtgrewe, 2004; Krishnamurthy, 2002; Kuk, 2006; McInerney, 2009). This phenomenon may be explained by taking into consideration the combination of specific interests an individual has and the heavy knowledge investment one has to make in order to be able to contribute to a project. The core maintainers are the bearers of the deepest knowledge about a project, and their association with it is anything but loose. Switching to another project would deprive them of their status and place them under the pressure of learning how to deal with a new codebase.[150] Thus, paradoxically enough, knowledge can be a limiting condition with regard to the images of utopian virtualism just as it seems to be enabling.

As represented by the claim that "for the first time in history, the human mind is a direct productive force, not just a decisive element of the production system" (Castells, 2010c, p. 31), the tendency to invoke the images of frictionless association seems to be implied by Castells's work.[151] But how can the mind be a direct productive force? All the "knowledge workers" who are entrenched with computing technology through their working hours always interact with a software inter-

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[149] This could also be related to Castells' claim about mind being a direct productive force – nothing is more flexible than a mind with unrestricted access to reality.

[150] However, it is not uncommon for such switching to take place. This seems to indicate that involvement in FOSS projects, in a sense, constitutes the kind of education that Castells envisions to produce "self-programmable labor" (Castells, 2010a, p. 377).

[151] This premise seems to represent an assumption also found in Castells's later works, such as the book *Communication Power* (2009) where this author dedicates a whole chapter (*Networks of Mind and Power*) to a description of a direct relationship between the mind (located exclusively in the brain) and culture, not considering any kind of mediation between the two.

face. And when it gets to users, an interface is no longer a fluid thing that can be meddled with by modifying text (source code) as was the case while it was developed. In interaction with users, an interface is part of a compiled program, having a binary form and operating closer to the logic of voltage differences transmitted by hardware, than to the logic of (programming) language and text (source code). Therefore, when software reaches its users, we can see that the culturally contingent construct has materialized (literally) into a solid thing that (together with hardware input/output devices) forms the interface for the mind.

It is said that a good interface should be invisible (in the sense that it does not get in the way of user's actions) but that does not mean it is not there. As we have seen, interfaces are there to display data (because digital information is not directly accessible to the senses, by definition, it needs an intermediary to be accessed) and to offer to the user a set of possible actions. Anything that is not part of an interface, is impossible to perform for a user.[152] This dependency on interfaces is not consistent with the claim of mind being a *direct* productive force. Castells ascribes epistemic credit only to the human mind,[153] but as we can see, there is still a production system revolving around a mind, mediating its input and output.[154]

To avoid this criticism, one could argue that Castells's statement should not be considered with relation to an individual worker, but with regard to the minds of all concerned workers. That is to say, one mind is operating with something that is a product of another mind, but it is still the product of a mind. Therefore, with regard to the *type* of production

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[152] In this regard, Lawrence Lessig famously claims that source code is the law of cyberspace (Lessig, 2006, p. 5) while Richard Spinello builds upon this analogy to argue that software developers should aspire to a similar moral competence to that of lawmakers in a democratic establishment (Spinello, 2001, p. 149).

[153] According to Edwin Hutchins, the image of the human mind as the sole origin of cognitive accomplishment is the result of a reified analogy between the human mind and the computer: "The computer was not made in the image of the person. The computer was made in the image of the formal manipulations of abstract symbols. And the last 30 years of cognitive science can be seen as attempts to remake the person in the image of the computer" (E. Hutchins, 1995, p. 363).

[154] This tendency in Castells' work can also be seen as an omission of Stehr's claim that actors need to maintain control of the situational circumstances in order to be able to translate knowledge into action (Stehr, 2001, p. 44, 2007, p. 143). In other words, it seems that Castells presupposes that the introduction of digital technologies automatically creates conditions suitable for utilization of knowledge.

(production by mind) the statement could be formally correct. But when we consider the argument formulated in this way, that in production one mind builds upon what other minds created, it loses its claim to discontinuity. Was production, with its use of tools designed by a narrow group of people and utilized by a larger one, not organized in this way before the 1970s? It certainly was.

I do not aim to disprove, or argue against Castells's work as a whole. A proper analysis of his comprehensive work is beyond the scope of this text. My argument is centered around just one of his claims that I see as being symptomatic of utopian virtualism. In the light of my findings, Castells's premise about the mind being a direct productive force seems to be untenable. This is so because, in the sense elaborated above, he omits the mediating role of at least some of the technologies he writes about and because he ascribes cognitive accomplishments solely to a universalistic model of a human mind. What my findings, connecting to previous developments in Actor-Network Theory and the theory of distributed cognition, demonstrate is that the human mind (if we can talk about such a singularity at all) can achieve very little by itself. How could knowledge exist without the elements that together form a (digital) interface? This is not to argue that the impulses of the mind have to be embodied in a material form. I point to the thesis that material objects (including the digital ones) are constitutive of cognitive processes. Therefore, the mind is surely a part of the production process, but it is not the sole nor direct productive force.

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Summary

The roots of free and open source software (FOSS) reach to practices established around the UNIX operating system in the 1970s. During the few decades of its existence the movement inspired a number of similar initiatives in other areas of production (e.g. Creative Commons, Wikipedia or Open Hardware) and its approach to software development, once considered marginal, has become mainstream.

The FOSS movement can be characterized as revolving around the central value associating source code with freedoms related to speech rather than property. Combined with work ethics opposed to that of traditional Protestantism, the movement is seemingly at odds with the current modes of capitalist production. FOSS exemplifies a form of peer production that is based on reduction of transaction costs achieved by informal mode of organization and utilization of the Internet infrastructure. There are enthusiastic anticipations or even utopian visions associated with this type of phenomena. The anticipations are based on an unconfirmed assumption that knowledge alone determines the results of organized forms of production and are therefore strongly criticized by some authors. Informed by this discussion, the work aims to explore the knowledge related processes in FOSS projects to describe the role knowledge plays in this particular form of peer production.

Methodologically, the work takes into account the specifics of cyberspace as a research field and is informed by George Marcus's multi-sited ethnography (with its later developments such as multi-sited or un-sited ethnography). Data were gathered during fieldwork (including participant observation and document analysis) in a FOSS project – I assumed the role of software documentation writer.

My theoretical approach to FOSS is based on conceptualization of programming, an activity central to software development, as a knowledge intensive practice. I proceed to differentiate knowledge and information which allows me to formulate the problem of decontextualization: Given that only information is exchanged, how is knowledge transmitted? One of the possible answers that I explore

further is that tools used in software development serve not only for instrumental but also for epistemic purposes. I further assume that the configuration of participants and artefacts that shape cognitive processes take the form of networks. To analyze them I use the infra-language provided by Actor-Network Theory, particularly the concept of mediation specified with its four meanings of composition, translation, delegation and black-boxing.

In the analytical sections, I use thick description to elaborate the components forming the project network, such as: licenses, software distributions, package management systems, command line interface, programming or mark-up languages, text editors, developers in various roles, IRC chat channels, wiki pages, a user manual, blogs and their aggregators, a Bugzilla database, Git and its repositories, non-profit organizations or private companies.

Using my observation, I describe programming as a practice that assembles and delegates (through compiled programs) action in a durable form to multiple places (user's computers). In this process, software tools serve to translate unpredictable flows of work into standardized units, delegate them to public places and make them connectable (easily includable into other compositions). This, in turn, greatly reduces the transaction costs of peer production.

However, a significant amount of knowledge is assumed for meaningful participation. And turning large amounts information from several sources into knowledge is very costly even though the information is freely available. Thus, although the licensing typical for FOSS projects intentionally and systematically suspends the rights (to access, modify and redistribute) traditionally associated with ownership by ascribing them to anyone, the rights are actually practiced only by a narrow group of participants who hold specific types of knowledge. As a result, there seems to be a close relationship between ownership (on the level of practice) and knowledge.

This point seems to validate the assumption of the enthusiastic anticipations related to the potential of cyberspace and digital technologies in general that knowledge in itself became the dominant factor of production. I, however, attempt to show that knowledge is still embedded in broader systems of production which are of material nature and that knowledge requirements these systems place on participants limit their supposedly frictionless interaction.

The Weight of the Intangible
Knowledge Networks in Free and Open Source Software Development

Tomáš Karger

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