Democratizing Production through Open Source Knowledge: From Open Software to Open Hardware

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Introduction

The commercial success of open source software, along with a broader socio-cultural shift towards participation in media and cultural production, have inspired attempts to extend and expand open-source practices, for example into the realm of culture through 'Free Culture' movements (Lessig, 2004; Gautlett, 2010) and, more recently, an interest in 'open-sourcing' the designs of material objects, including communication hardware (van Abel et al, 2011). This paper provides a critical perspective on the democratic potential of "open" contribution structures by reviewing cases in which open-source contributions to production of communications resources (software and hardware) increase the opportunities for democratization of production, governance and knowledge exchange. By looking carefully at the case of open-sourcing hardware, it also notes the limitations of this democratization. The insights developed in the paper describe the complex and dialectical relationships between open-source cultures and commercial and market structures, identifying how the generative opportunities created by certain aspects of open-source contribution structures increase the potential for democratizing production of communication tools, but also how incongruities across different open source cultures and communities of practice limit the influence of these processes.

What is sometimes referred to as an open-source 'movement' grew out of norms and practices connected with several specific subcultures including the 'hacker culture' that developed at MIT in the 1960's and 1970's (Levy, 1985). From these somewhat marginal origins, open source practices have since contributed to transformations in software production paralleling current transformations in media use. The success of these interventions has raised questions about whether open-source production is connected with a greater democratization of software production

processes, in which a greater number of participants are able to contribute, and in which control of the production process is more broadly distributed, participatory and autonomous. The normative values of 'open' and 'free' associated with these changes in software production have also underscored the associated expectations about their democratic potential (Coleman and Golub, 2008).

These changes have raised tensions between the internal governance processes of open-source projects, and the external relationships between open-source projects and various markets, including the software production market, the markets for communication hardware, and the global labour market. In this paper I examine claims about the relationship between free software and open source software, and the influence of both of these movements on open hardware and the purported democratization of digital media production. How have specific cultures and associated legal codes become associated with democratization of media production? How do these forms of knowledge define and transcend the boundaries between technical subcultures and other participatory cultures?

Open-source software as an industrial process grew out of the culture of free software development, but departed from the latter's political focus on the value of sharing and the maintenance of a knowledge commons, and instead focused on the efficiency of open-source processes for software production. Within the software production industry, open source is broadly perceived as creating more democratic, “free” and “open” innovation structures. Following this, attempts are now being made to replicate the process in other fields of technology production, notably the production of designs for electronic hardware and other physical objects. To illustrate the challenges of an expanded notion of 'open' contribution I examine the case of the Open Hardware and Design Alliance (OHANDA), an initiative seeking to apply the norms of software freedom to hardware design by creating a licensing scheme. I investigate how open-source legal

tools act as 'boundary objects' (Star, 1989) unevenly delineating different communities of practice. These negotiations at the boundaries are increasingly important as knowledge – and media – production processes increasingly engage with open contribution structures.

I work from a constructivist perspective within communication studies where technological production (both materially and discursively) is considered as a site of knowledge transfer or exchange (Bowker and Star 1999) and as an element of controversies mobilizing opposing social or cultural perspectives (Callon 1981). Jasanoff (2004) describes how knowledge and practices are co-produced in these kinds of situations: "the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it " (p. 2). The expansion of open-source is marked by boundaries that are delimited not only by identifications with different communities of practice – groups of people who share common interests and who inspire learning by doing (see Lave and Wenger, 1999) - but also by the function of the legal tools which the communities choose. Although this paper broadly contributes to a political economy of 'openness', it departs from the primarily Marxist perspectives on labour sometimes employed to discuss free software and open-source (for example, Dyer-Witherford, 1999; Bauwens, 2009; Hunter, 2004; Karatzogianni and Michaelides, 2009) as well as from the liberal economic perspectives such as Benkler (2006), Lessig (2004) and Weber (2006). Instead, its constructivist perspective focuses on how knowledge-sharing and governing tools co-evolve along with communities of practice.

This approach is supported by a methodological practice including the following elements: a long-term participatory observation of the OHANDA project, including depth interviews with founders and participants, observation of and participation in workshops and other public events from 2009 to 2011, and a review and analysis of OHANDA campaigns and public communications material. This approach permitted long-term observation of the articulations and tensions between communities of practice and the market. This primary strategy was supplemented by a review,

categorization and analysis of other online documents, including mailing list postings, produced by and about open hardware communities, and analysis of media material such as O'Reilly's *Make* magazine. Particular attention was given to discussions in which the potential of open source hardware is presented as a site of contest promising, variously, a transformation of labour and markets to parallel that of open-source software; a knowledge commons in keeping with the political goals of the free software movement; or a promulgation of social norms held by free software communities of practice.

Background: Free Software, Open Source and Democratic Knowledge

The culture of sharing software code began as a political project within the free software movement. As expressed by Stallmann (1999), it stressed the radical potential for knowledge exchange represented by software licenses stipulating that all products of free software should also remain free. Open-source software production, in contrast, adopted the idea of the commons of software code from the free software movement, but does not stipulate that all code must be subsequently available for free. The two processes are often conflated into an overall FLOSS (Free, Libre, and Open Source Software) group of processes, and associated with open and participatory production of new media systems. Previous research has suggested that collaboratively producing software code that is freely available for re-use creates more democratic production processes (Gristock, 2008) as well as more open cultures of participation and knowledge exchange (Lin, 2004). Downing (2002) argues that the open-source software used by Indymedia collectives was a part of the movement's critique of mass media. Similarly, Langlois and Dubois (2005) and Dunbar-Hester (2009) associate the alternative production of communications infrastructure like independent media and community radio contributes to broader and more democratic opportunities for civic participation, while operating as a critique of conventional mass media.

Despite these views of open participation structures as challenging to hegemonic forms of

media, tension remains between radical re-interpretations of how knowledge or culture should be produced, and the co-optation of this knowledge by institutions such as the market. This is particularly evident within technical cultures where new knowledge produced outside of hegemonic institutions such as the market can contribute to transformations in these same institutions. Turner (2005) draws a connection between computer technology, Californian culture and the emergence of cyberculture, while Bazzichelli traces a relationship between radical forms of net-art and the emergence of social networking sites and social media (2008) and Benkler (2006) considers 'peer produced' knowledge as contributing to a transformation in the structure of value creation in which the logic of scarcity is replaced with the logic of contribution. Thisraises questions about the extent to which characteristics of 'openness' especially the commons-based production characteristic of FLOSS have disrupted or reinvigorated capitalist modes of production.

Marxist theorists identify this process, whereby marginal knowledge is capable of disrupting or being recuperated by the superstructure, as being connected with a dialectic mode of social change. In a dialectic, change is brought about through the conflict between an immediate state and its potential mediation, resulting in a new concrete synthesis (1845). Marx himself used this dialectic, drawn from Hegel, to describe how the exploitation of labour under capitalism is negated by the return to workers of the mode of production (1909; cited in Cammaerts, 2011). Following, Žižek (2008) argues that a similar negation is presently occurring, as neo-liberal modes of experience, including the primacy of the free market and the dismantling of welfare state structures negate the socialist and communist ideals. In turn, neo-liberal ideologies are also allegedly being challenged by forms of bottom-up or rhizomatic organizations (Deleuze and Guattari 1987) and through both material and social forms (Feenberg, 1999). Cammaerts (2011) argues that sharing cultures including open-source cultures enact a negation of Žižek's negation, in which newly participatory modes restructure capitalist exchange, and transcend assumption of finite conflict between differing ideologies. These dialectic modes of analysis are helpful in understanding the

relationships between open-source practices and the market, but they are limited by an inherent assumption that the dialectic resolves into neo-liberal capitalism. The empirical work presented here suggests that resolution may well be more tenuous.

As an alternative, I draw on the ideas of circulating knowledge that Innis (1951) identifies and that Fuchs (2003) develops by way of Giddens (1984). This cyclical flow of knowledge from margins to the centre remains dialectical: some knowledge will always remain challenging to the dominant modes; yet this knowledge can also be recuperated by dominant institutions. Unlike Marx, Innis does not identify this process as either positive or negative in its nature. Nor does he perceive it as complete: in contrast, many other models of dialectical social change presume some final synthesis such as Cammaert's (2011) insistence, following Hegel, that open source's 'negation of the negation' finally resolves only into neo-liberalism. This is similar to the way that Fuchs (2003) engages with Giddens' (1984) structuration theory to identify human systems as re-creative systems in which knowledge is continually being reproduced. The complexity of these systems depends on the separation of time and space related to the storage of that knowledge. Within the context of changing modes of cultural and technical production, the circulation of knowledge, and thus challenges to and resistance of forms of hegemony are key, albeit unresolved, processes, as this paper explains. A dialectic remains central, but the examples developed below suggest that it is more unstable, since some elements of knowledge, culture and practice are re-created as oppositional and others influence institutional changes. As I explain in the next section, the movement of knowledge – and hence, of intellectual labour – from advocates of free software to open-source software production processes has significantly reconfigured the software production process,in part through an increased democratization, whereby contributions from a wider variety of actors destabilize neo-liberal market-based modes of assigning value, but also through entirely alternative ways of producing value.

From Free Software to Open-source: Challenge and Recuperation

The historical links between hacker culture, the free software movement, and the emergence of open-source modes of software production provide an example how circulating knowledge is suspended between challenge to hegemony and recuperation by it. As I explained above, the Free Software foundation, founded by Richard Stallman, argued for a radical democratization of software products. Free Software had its roots in a hacker culture linked with an ethic of individual liberty and technical prowess (Himamen, 2001; Levy, 1984; Söderberg, 2008). This culture promised a particular critique of hegemony by identifying flaws in computer systems and building alternatives to them.

This generative form of hacking, grounded in shared values and ethics, has produced shared norms. Foremost among these, according to Coleman and Golub (2008), have been the norms of software freedom that govern free software and supposedly contribute to the maintenance of commons-based knowledge including open-source. The freedoms are as follows:

Software Freedom 0.
The freedom to run the program for any purpose
Software Freedom 1.
The freedom to study how the program works, and change it to make it to do what you wish. Access to the source code is precondition to this
Software Freedom 2.
The freedom to redistribute copies to help your neighbours
Software Freedom 3.
The freedom to improve the program and, and release your improvements (and modified versions in general) to the public, so that the whole community benefits. Access to the source code is a precondition to this. (Stallman, 1999)

These freedoms are at the heart of one of the most significant attempts to codify the practices of free software development and hacker culture: the GNU Public License for free software, developed in 1989. This license challenged copyright law by reversing it - insisting that all code created under the license be freely distributed and made available for future free use (Stallman, 1999). The GPL codifies the re-use of software code, stipulating that the products of free software source code must maintain the terms of the license and themselves remain free, with the source code released to a publicly accessible repository. At least in theory, GPL licensing establishes

a process of governance that is self-propagating and outside of control by the national, international and self-regulatory bodies that have in the past controlled the design production and circulation of information infrastructures and knowledge (Mansell and Berdou, 2008) . This generative process is meant to democratize knowledge about software and software production itself, an assumption that has been extended from the radical free software process to open-source processes in general. Still, the governing framework that is established by the social norms of sharing software products and the maintenance of 'code repositories' as suggested by open-source has also made an enduring contributionto capitalism. This illustrates the unstable and unresolved dialectic between marginal forms of knowledge and governance, and hegemonic ones. The following section takes as an example the movement of the GPL, originally a free software license.

Generative Hacking Opens the Market

The GPL has contributed to the transformation of the software production field and, as Nissenbaum (2004) argues, is centrally embedded in the ascendence of digital capitalism. Access to the source code, a precondition for software freedom as defined by Stallman, also inspired the development of open-source software licenses. Like free software licenses these require a sharing of code, but they have fewer restrictions on commercial use. As Söderberg notes, open source often allows redistribution under GPL but may not require it, making these licenses attractive to software producers (2009). The results of this dialectic movement of knowledge includes the incredible success of open-source software within the market economy: two thirds of major websites use open-source Apache servers (Netcraft, cited in Cammaerts 2010). As Weber (2006) identifies, major software companies are now core contributors to open-source projects, recuperating the processes that hackers originally linked with radical politics – drawing on what Terranova (2000) calls 'free labour'. This restructuring of the labour process in turn restructures knowledge: open-source software developers maintain collective knowledge through code repositories outside of

individual institutional control. Their own knowledge about how to use and apply code from these repositories is becoming increasingly more significant, destabilizing the in-house software design processes that used to characterize software development (Weber, 2006) and inviting a more heterarchical organizational structure for software production (see Stark, 2006).

As has been outlined here, in software, the circulating process of challenge and recuperation can be traced historically through the relationship between generative forms of hacker culture including free software, and open-source licenses as they are applied in industrial software production. This process has been less discussed, however, in other areas of open culture and open knowledge production. As the next sections of this paper explain, as software and hardware design converge, efforts are being made to develop norms for the production of open hardware design. These efforts reveal a different movement of knowledge and another set of expectations about democracy that are salient for considering the long-term socioeconomic impact of democratic production of media. The next section examines the points of connection and divergence between cultures of software and hardware hacking, as a means of identifying further instances of democratic participation through collaborative production.

Hardware Hacking and Open Hardware

Hardware hacking activities, where physical devices are broken and remade, are part of a broad range of cultural practices that also include crafting, tinkering, and other do-it-yourself (DIY) activities. Some cultural antecedents of these activities include the DIY and crafting cultures of mid-century America, where previously utilitarian practices became codified as leisure activities (see Haring, 2006) and the early techno-cultures of radio operation (see Douglas, 1987). Contemporary DIY can be divided into two broad types: utilitarian DIY, which is done out of scarcity of resources, and hedonized DIY, which is done for fun, often using commercially-available electronic parts (Hertz, 2011). Hedonized DIY is part of a broader 'Maker' movement that allows for

personal expression as well as exploration of how electronic media work. The availability of micro-controllers such as the Arduino and the ease with which they can be used has been part of an expansion of this hedonized production which in turn has helped to create a growing DIY electronics market, anchored by the O'Reilly company's *Make* magazine and the annual MakerFaire festivals which O'Reilly organizes in New York, San Franciso and Nairobi.

Within this broad set of cultural practices, modifications of electronic devices and other physical artifacts related to digital media range from primarily artistic endeavours like steampunk (Onion, 2008), where elements of digital hardware are replaced in order to generate a nostalgic, yet high tech DIY aesthetic, to projects that evoke a role for citizenship (Ratto, 2011), as well as re-engineering projects. This range of activities includes a variety of different relationships with the market: steampunk redesigns take place primarily outside of the market, civic projects might well be agnostic to the market, and some forms of re-engineering, for example the dismantling and reconstruction of high-tech devices in the Global South, create their own markets (see Wallis, 2009). Unlike modifying free or open-source software, re-engineering hardware is not governed by a legal framework. It results in violations of warranties and patents covering the intellectual property of hardware designs. The opportunities for articulating open-source forms of value creation with existing market structures creates tenuous relationships. Hardware hacking and open hardware are examples of generative practices and the peer oriented contribution base of the internet (Zittrain 2008) but they can also be deeply disruptive to existing forms of organization including markets, especially because of the complexity of the relationships between peer production and markets. This complexity highlights the contigent nature of efforts to democratize further the processes of technology development.

Small-scale production and the “long tail” of hardware

The major transformations of software markets promulgated by open-source software

licenses were as much a result of the non-material quality of software as they were of the actions of peer-production communities of practice. The creation of repositories of software code do indeed create commons of knowledge that can be accessed by anyone – but the fact that the digital information contained in these repositories can be duplicated perfectly at vanishingly low cost is also important. In this context, free and open-source software licenses that specify free access either to parts or to whole sets of source code create an abundance of free and open code. Using free or open source software software code neither consumes resources on the part of duplicators nor lessens the amount of code available for others to use. Because code is notated, records remain of previous modifications, and it is possible to identify which code is open-source.

In contrast, and posing significant problems for the promise of expansion of commons knowledge, hardware remains a material product with manufacturing costs. Open hardware advocates note that these costs are dropping as many forms of electronics hardware are becoming software-controlled (Rubow, 2008), as simple electronic switches can now be printed or etched on to various materials, and virtualization software allows some hardware to be controlled by software, but other constraints remain. Material constraints, for example, include the fact that modifying the circuit board of a digital device transforms the device and its function, but does not provide its original designer with any knowledge or information about the nature of that transformation. Open designs – in the form of circuitry diagrams and schema for designing chipsets – are available in repositories such as OpenCores (OpenCores.org, 2011). However, there are few means of identifying hardware objects as open-source, nor of making the labour of hardware hackers visible on the devices they modify. This is turn makes it difficult to find space to challenge the existing regimes of intellectual property. How then can hardware hackers gain access to the equivalent of software source code? Various modes of organization have emerged, but these are mostly ad-hoc and rarely develop shared norms of governance such as the free softwareand open-source licenses. As a result, there are a variety of ways that open hardware products engage the market.

Buechley and Mako Hill (2009) describe the Lilypad, an MIT project that developed a flexible electronic chip board adapted from the Arduino and intended for use in the manufacture of electronic textiles. After the end of the MIT project, the chipset becamecommercially available through the SparkFun manufacturer. This produced a "long tail" of personal consumption that created small but significant markets supported and expanded by online communities (2009). In licensing terms, the project designers initially applied a Creative Commons license to the Lilypad's design schematics and basic board designs and made them available to anyone who wished to use them, provided that the original designs were acknowledged and the results remained open-source. The personal and institutional networks of the MIT researchers were the primary means through which the designs were originally distributed. According to Buechly and Mako Hill, several open-source extensions of the chipset have been developed, one of which, a wireless radio connection, has now been integrated into the LilyPad kit and is also widely commercially available. Other extensions made using the open-source designs were purely for personal use of designers or artists, with the personal permission of the original designers. This example demonstrates how an academic project can be transformed into a commercial product primarily through the use of an open-source license (in this case, the Creative Commons license).

Another example of the articulation between open hardware production and the market illustrates the role of existing communication infrastructures and social relationships in effectively establishing frameworks for sharing knowledge about hardware. At the end of 2010, *Make* magazine sponsored a competition for "green" DIY projects. The winning project, the Global Village Construction Set, proposed "an open source, low-cost, high performance technological platform that allows for the easy, DIY fabrication of the 50 different Industrial Machines that it takes to build a sustainable civilization with modern comforts" (cited in Make magazine, 2010: Your Green). The project maintains the designs and schematics of these large machines on a wiki. The project's goal is neither mass-scale production of industrial machines nor a proliferation of

vastly different industrial machines, but instead a standardization of machine designs allowing a set of pre-determined modifications. Yet the knowledge of the design schematics is expanded primarily through *Make* magazine's readership. *Make* magazine also publishes instructions for how to create basic electronic devices using existing, commercially-available open hardware products such as the Arduino micro-controller. These instructions describe how to make an electronic product, but instead of being located in a central repository, they are primarily distributed as part of O'Reilly's magazine content. Publishing access to design schematics solidifies the importance of the magazine among its core subscription base. Access to open-source hardware schematics or designs thus generates value for the emerging DIY culture, without inciting major changes in hardware production processes beyond small scale DIY and art projects. Again, there is increased participation in hardware production, but ad-hoc forms of knowledge exchange are supported by the kinds of commercialized media that have helped to define markets within niche communities of practice.

Hardware Freedoms and Open-source hardware licenses

Some open-source hardware practitioners argue that it is important to develop standardized means of identifying and collecting open-source hardware designs and schematics. Underlying these efforts are expectations that better information about open hardware designs and transparency will lead to a more robust economy of innovation parallel to the one that occurred in open-source software. An organization called the Open Hardware and Design Alliance (OHANDA) has begun a project to extend the norms of open licenses, developing Hardware Freedoms from the Software Freedoms described above. The project attempts to create a parallel legal structure for hardware designs mimicking that of software code, and is an explicit attempt to apply the normative frames that characterize open-source software production to hardware design. The freedoms read as follows:

Hardware Freedom 0.
The freedom to use the device for any purpose
Hardware Freedom 1.
The freedom to study how the device works and change it to make it to do what you wish. Access to the complete design is precondition to this.
Hardware Freedom 2.
The freedom to redistribute the device and/or design (remanufacture)
Freedom 3.
The freedom to improve the device and/or design, and release your improvements (and modified versions in general) to the public, so that the whole community benefits. Access to the complete design is precondition to this. (Open Hardware and Design Alliance, 2009)

The efforts to define hardware freedoms in the same terms as software freedoms is evidence of an interest in democratizing hardware production on the model of software, particularly drawing on the 'viral' nature of free software licenses such as the GPL. As the hardware freedoms themselves suggest, many interlocking layers influence the extent to which hardware is or can be made open, both in terms of its potential design and redesign and in terms of its flexibility of use. The OHANDA project shares the goals of free software advocates in that it seeks to extend the principles of copyleft to hardware design. It also attempts to apply these principles to a formal process that will align the process of knowledge exchange about hardware designs with the process of sharing open-source software code.

OHANDA's proposal is to develop a trademarking system, whereby the packaging of a product based on open-source hardware will carry a logo indicating that the the designs are available online. As a first step, this would require the designer of the hardware to agree to use a "copyleft" license based on the hardware freedoms outlined above. The designer would then have to register with OHANDA to receive a tracking number for their design. The tracking number would be included on the trademark logo, so that an erstwhile hardware hacker or hardware chip designer could enter it into a computer and find the design in an online repository. This repository would also include information on the designer, the product ,and the license. OHANDA provides this flowchart as a means of explaining their proposed process:

[Figure 1 about here]

The assumption behind this project is that open hardware production is empowering for producers. Its website reads: 'Empowered by the freedoms, users may develop the product further, register in as producer, share his/her design artifacts applied with copyleft license and be connected to the derivatives of the product' (OHANDA, 2009). More profoundly, the aims of the project are directed at establishing the virtuous cycle of sharing code and unlinking knowledge and labour from the market that encouraged the expansion of open-source software production. The main goal, according to one of the OHANDA founders interviewed for this paper, is to alter the hardware production ecosystem, lowering barriers to participation in the design of hardware, and potentially also lowering costs for hardware producers, who could use open hardware designs to lower the cost of producing more specialized or bespoke products (Neumann, 2009).

The actual hardware designs being identified with OHANDA, however, do not fit neatly within this virtuous cycle. For instance, one of the first products to apply for an OHANDA license mark was a line of portable, easy to use cook-stoves called “Good Stoves” designed by Dr. N. Sai Bhaskar Reddy and intended for use in a variety of contexts where resources are limited. The stove designs are available on the internet, but are also available as design schematics on paper. The easily modifiable designs specify easily-available materials such as scrap sheet metal. This is an example of open hardware licensing being employed to facilitate knowledge exchange within a development context. Another early licensee was a proposal from the C-base, a technology and cultural hub in Berlin, for open hardware to be used in a moon exploration project initially targeted at a competition run by Google. The C-Base, is an internationally-known hub of playful and provocative hacking. The Open Moon project is like many of the centre's projects, partially serious and partially frivoulous: proponents are intending on demonstrating that open-source hardware is

robust enough for a space voyage but they wish to produce this hardware within a collaborative, non-hierarchical organization. Tellingly, as of this writing the Open Moon project has withdrawn from the Google contest while continuing with open-sourcing hardware. Neither of these OHANDA licensees is primarily motivated by commercial efficiency and market success.

Along with the examples of *Make* magazines machines and MIT's Lilypad, these OHANDA licensees illustrate the variety of ways that open hardware articulates with the market: in some spheres it might might be completely outside the market, for example when hardware designs are shared by artists or scientists as the result of publicly-funded work. In others it might create markets like the niche markets for DIY electronics parts aggregated by *Make* magazine. In still other spheres existing markets could be disrupted, as Neumann implies above. Or perhaps open hardware could address the movement of monopolies of knowledge outside of existing markets: for example, repositories of designs for water filtration systems and other useful devices suggest the emergence of "Open Hardware for Development" (OH4D) practices which could parallel similar efforts to develop "ICT for development" (ICT4D).

Discussion

The attempts by some hardware hackers to mimic the institutional structures that emerged from generative software hacking cultures and that extended through their transformation into open source show the tensions inherent in attempts to democratize technology production. They also indicate the persistence with which freedom and openness are articulated as core values that are somehow promulgated through the design of digital media. The results of the transformations of knowledge and labour flows in software development have included new forms of labour relations , as well as expectations of contributions to source code used within software industries from those not working in those industries (see Weber, 2006). In the wake of these transformations, it is understandable that open hardware licensing is framed as empowering designers and potentially

restructuring design and manufacturing processes. Yet hardware production is characterized by a differently globalized flow of labour: often design schematics are produced in North America and Western Europe and implemented at a large scale in factories in Asia – a process parallel to the spatialization of other forms of industrial media production. Large-scale hardware production remains un-democratic, with a few market leaders competing based on proprietary designs and exclusive relationships with manufacturers. Although the examples in this paper indicate that knowledge about open hardware is emerging and circulating, the question remains as to whether this emergence and circulation of knowledge is in fact democratizing, and whether the kinds of norms and licenses being developed by OHANDA facilitate this democratization among the various communities of practice that are emerging.

Open Hardware Licenses as Boundary Objects

Open hardware licensing schemes have the potential to be enormously challenging to the structures of knowledge that characterize the software and hardware industry. At the same time, distilling cultural norms into licensing codes that are then applied as stand-ins for those complex social structures has some limitations. Partly, this is because licenses, as codified norms, have the potential act as what Star (1989; 2002) refers to as boundary objects. Boundary objects are texts or organizing conventions that are used for coordination and alignment between members different social worlds working in the same sphere but holding divergent goals. Star and Griesener's original (1989) notion of boundary objects refers to their coordinating activities in science, but subsequent work (notably Star, 2002) has explored how boundary objects – most often, standards – operate to coordinate and align other types of work including information systems design.

Locating and analyzing the appearance of boundary objects makes it possible to understand how communication occurs across communities, and thus, how knowledge moves and develops. Star (2002) writes, of boundary objects: 'hey have two important properties: they are loosely

structured in common use, and become more tightly bound in particular locations. They are thus both ambiguous and clear, at different moments, for different purposes.' (118). This kind of contingency of structure seems to characterize open hardware licenses. However, at present, the OHANDA process works weakly, at best, as a boundary object: the process of applying a free software-like license to a design placed in a repository does not address the way other communities of practice might share knowledge (the LilyPad designers making products for their own use or the *Make* magazine readers reading design schematics for fun). As a result, licenses related to open hardware now proliferate: the Open Hardware Roadmap, produced and maintained by American open hardware advocates, lists five different open hardware licenses, which do not include the OHANDA hardware freedoms (Open Hardware Roadmap, 2011). Many of the licenses mentioned adhere to an Open Source Hardware Definition agreed by the hardware design community in 2010, but the Roadmap's authors still express concern that small companies producing hardware (mostly for the amateur market) will 'theoretically not have much legal recourse if their designs get patented, made/sold, or used in a closed system' (Open Hardware Roadmap, 2011). Licenses are unevenly evoked as necessary for sharing common knowledge, but also for protecting individual innovation. Thus, the dialectics still hold: some knowledge is more easily recuperated, for example chipset designs were able to be manufactured by the company that commercialized the MIT project's Lilypad, but specific knowledge about the designs still had to be communicated by the researchers themselves, through individual social networks. Thus, powerful institutions as well as ad-hoc forms of knowledge exchange both configure the ways that knowledge about hardware are transferred.

The struggle to match open hardware's production process and cultural expansion to the parallel processes that occurred with open source software reveals that the creation of democratic communication spaces is contingent on the structures and cultures of capitalist production, as well as on the more resistant or emancipatory norms encoded in free and open software licenses. The

expansion of free software production has created its own structural dynamics that have resulted in codified licenses facilitating a democratic transformation in software production. To a certain extent this has depended on a culture that views software development not only as labour but also as expression. For members of this culture, open hardware licenses act as a way of ensuring the freedom of hardware designs and thus the freedom of the designer to express himself. Yet encoding these cultural norms into open hardware licenses also recapitulates the process by which the labour of software programmers has been recuperated by the software production market.

Some parts of the proposed OHANDA process reveal the challenges that opening hardware can pose both to markets and to proprietary and enclosed structures of knowledge. Increased openness based on licenses only democratizes certain aspects of the production process. The production of bespoke designs by a small factory is perhaps evidence of a shallow democratization of production in that it broadens the nature and type of participation in hardware design (see Gristock, 2008), but this is not democratic in the same way as the knowledge gained by an artist developing a new idea as the result of public support, and sharing it in her project documentation, or a DIY practitioner wanting to share a pattern if only to receive commentary from a community of practice. Indeed, the shallow democratization of industrial hardware production is already challenged: by re-engineering practices that are essentially piracy: the rise of "Shenzen" mobile phones, which are re-engineered copies of brand-name electronics, is evidence of this oppositional democratization.

If licenses and other boundary objects codify norms from particular cultures while only superficially engaging withother cultures and institutional actors, aligning values and practices becomes difficult. The dialectics identified in the case of open-source software have motivated a codification of open-source hardware, even though the products and devices being licensed and marked are determinedly non-commercial. At the same time, the commercial open source hardware kits developed by Arduino and projects like LilyPad are used by artists and educators in several

"long tails" of individualized or small-scale production. The various kinds of knowledge being shared suggest that instead of one community of practice employing modes of sharing common to open-source practice as developed in software production, there are several different potential locations at which open-source hardware projects confront (or fail to confront) markets. In addition to industrial hardware design, which confronts open-knowledge as piracy and imitation, these include long-tail markets of amateurs, designs produced as the result of public investment in art or innovation, and open hardware for development.

The initial OHANDA efforts encode the values of a certain group of open-source software producers who hypothesize a parallel transformation of hardware production based on their experience and observation of software production. For other social worlds such as DIY practitioners, Global South innovators like the Good Stoves founder, or Shenzen phone manufacturers, the organizational structure and expectations of market success implied by the OHANDA effort could be less meaningful. In this broader conception, flows of knowledge begin to effectively operate in several different directions, breaking down even further the necessary – but suspended - dialectic between marginal or resistant knowledge and the hegemony of neo-liberalism and the market.

Conclusion

Hardware hacking is an open-source practice that opens up black boxes of consume electronics. Compared to free and open-source software software it presents more complex potential connections to the market, as well as a broader range of opportunities to share knowledge. Attempts to establish generative governance modes for the identification, reproduction and sharing of hardware designs are situated at the boundary of different communities of practice. While open-source software was able to 'democratize' labour contributions to the software industry, in part because of an historical shared set of norms and in part because of the immaterial quality of

software code, parallel attempts to codify open-source hardware production in a licensing scheme do not develop the potential of such codes to become boundary objects,. Instead, they fail to engage already-existing interpretations of how to share (or protect) hardware designs. The various attempts illustrate an unresolved dialectic between the knowledge and practices of hardware hackers and the productive application of that knowledge in a market. Hardware hackers belong to some of several social worlds - not all of which align with the social worlds that spawned the success of open source.

As this paper has discussed, pursuit of "openness" and thinly democratic participation in producing both software code and electronics hardware detract attention from the more fundamental shifts occurring elsewhere: in "long tails" of small-scale production of electronic devices for the educational market, in the black and grey markets for hacked or otherwise re-engineered electronics, and through nascent attempts at Open Hardware for Development. Thus, a process to distribute open hardware is a necessary, but not sufficient step towards developing new modes of knowledge sharing that might characterize an open design process. As Innis' theory of monopolies of knowledge and Fuch's concept of re-creation suggest, the dialectic between open knowledge such as open-source software, and the market's capture of knowledge and labour through open-source contribution does not neatly resolve. However, by focusing exclusively on codifying norms into licenses and licensing procedures, the varied ways in which hardware design and production are being democratized are overlooked in favour of a re-run of a cycle derived from a particular culture and community of practice. An obsession with creating legal codes and debating their relative "freedom" and "openness" may be distracting: Galloway and Thacker (2007) write that 'this opposition between closed and open is flawed. It unwittingly perpetuates one of today's most insidious political myths, that the state and capital are the two sole instigators of control.' (p. 125). Open source software's articulation with the market demonstrated that control could exist in the process of negotiation between emergent and hegemonic monopolies of knowledge. Attempts to

recapitulate the negotiation that is at the centre of this control underestimate and perhaps undermine the other ways in which design knowledge is being produced and shared.

In general, hardware hacking practices introduce opportunities to develop new forms of technological citizenship, based on better knowledge about how things work, and increased abilities to take apart, repair and reconstruct the devices that increasingly mediate and facilitate our communications. This establishes a new set of opportunities for democratization of knowledge, which are exemplified by the several different forms of open-source hardware. The licenses and branding schemes that are now being developed by advocates do not yet act as the boundary objects that might otherwise serve to negotiate between the various nascent and emerging open hardware communities of practice. The appearance and expansion of open-source efforts in the hardware and design field suggests that new forms of knowledge continue to emerge that can profoundly democratize the technological production that happens within industrial markets – as well as what happens outside them. This paper has charted the implications of these modes of knowledge sharing, but there is more to be done. The expansion of open-source cultures and processes presents philosophical and conceptual challenges that strike at the heart of questions about our contemporary social experience – and its future.

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Figure 1:

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