Material-Discursive Practices in Technology Standards Development: A Topic-Modeling Approach to Technology Evolution

Full Paper

Takumi Shimizu

Desautels Faculty of Management, McGill University

takumi.shimizu@mail.mcgill.ca

Abstract

Social interactions play a vital role in shaping technology evolution, especially in technology standards development involving multiple actors across the industry. However, previous studies mostly focus on the interactions between technology designs and socio-cognitive factors and pay little attention to the intertwined nature of social and material aspects of technologies. From the sociomaterial perspective, a key is to focus on the process of discursive materialization and its performative consequences in practice. Drawing on Orlikowski and Scott's (2015) material-discursive perspective, this paper examines how the HTML5 (technology standard) evolves over time by investigating the processes of discursive materialization at the World Wide Web Consortium with the topic modeling techniques. The analysis shows that four fundamental mechanisms (process management, dialogical coordination, boundary work, and knowledge conversion) shape the evolution of HTML5. This study contributes to understanding processes of technology evolution from the sociomaterial perspective with a novel empirical approach.

Keywords

technology evolution, sociomateriality, material-discursive practice, technology standard, topic modeling

Introduction

Technology development is one key area of innovation research and practices. Especially after digital technologies and the Internet were introduced, the speed, complexity, and uncertainty of technology evolution have been increasing. For example, a Web browser is one of the key technologies of the Internet age, and its evolution is very rapid and unpredictable (Faraj et al. 2004). The development of Web browser technologies is a complex phenomenon not only because digital technologies change rapidly, but also technologies are collaboratively developed among multiple actors. Traditionally, entrepreneurs and organizations developed their technologies only by themselves. However, there are many organizations which have recently sought technology development through open innovation activities, such as strategic partnerships or consortia (Chesbrough 2003). Especially in the Internet industry, most technologies are developed not within an organization but through inter-organizational collaboration between firms, non-profit organizations, individual developers, and standardization organizations such as the Internet Engineering Task Force (IETF) or the World Wide Web Consortium (W3C) to achieve the interoperability of technologies. Recent open source software development and its communities also operate in the same way: multiple actors are involved in open collaboration and technology development (Germonprez et al. 2017). Social interactions and collaboration play a vital role in technology development, especially for technology standards development. Since technologies are socially constructed artifacts, we need to examine multiple actors' interactions to understand technology development (Kaplan and Tripsas 2008).

Technology development heavily relies on online communication tools such as Email or video chat system that can facilitate communications among geographically dispersed actors. Communication plays a fundamental role in organizations (Boje, Oswick, & Ford, 2004), and it can be more central in online contexts where language is the primary locus (Qureshi & Fayard, 2008). To develop technology standards collaboratively, participating individuals and organizations need an enormous amount of online communication to build a consensus on technical issues among them. It is critical for many organizations

whether they have a good sense of technological trajectories and whether they can control over technological trajectories and industry standards in their business domain. Understanding how technologies and technology standards are developed is an essential factor of conducting R&D activities effectively and efficiently that has significant influences on the survival and success of organizations. Scholars seek to advance our understandings of how technologies evolve from the material/design perspective (Abernathy and Utterback 1978; Anderson and Tushman 1990), the cognitive perspective (Orlikowski and Gash 1994), and the interplay between human and material aspects (Grodal et al. 2015; Kaplan and Tripsas 2008). All these studies, however, share an arguable assumption, which is that social and material aspects can be ontologically separable. There is little research on the intertwined nature of social and material aspects of technologies (Orlikowski 2007). To address this gap in the exsting research, this study adopts the concept of material-discursive practices from the perspective of sociomateriality. We examine how specific processes of discursive materialization enact performative consequences in technology standards development since social discourse needs to be materialized in some forms to exist in practice (Barad 2007; Orlikowski and Scott 2015). This sociomaterial focus is important because technology evolution cannot be understood without taking into account the mutual entanglement of social and material aspects and how it is enacted in everyday practices (Orlikowski and Scott 2008). With the sociomaterial approach, we investigate the case of Hyper Text Markup Language version 5 (HTML5) development at the W3C by analyzing eight years of emails in the working group with the novel research methods combining the automated topic modeling techniques with the manual, qualitative coding.

Theoretical Background

Technology Evolution and Sociomateriality

Technology evolution is one of the most fundamental research domains in the field of information systems and innovation research. Traditionally, the dominant research stream of this domain was the artifact/design-centric approach to technology evolution. Scholars investigate how technology designs evolve and the role of dominant designs in industries (Abernathy and Utterback 1978) and develop the model of technology lifecycles: a technological discontinuity initiates an era of ferment and periods of incremental progress after a dominant design, which might be disrupted by another technological breakthrough (Anderson and Tushman 1990). The literature in the early stage focuses on how the material aspects of technologies evolve over time. Then another research stream emerges with a particular emphasis on the socio-cognitive aspects of technology evolution. Studies suggest that individual and shared cognitions among technology developers shape technological trajectories (Garud and Rappa 1994), and people's frames of reference on technologies (technological frames) affect how we use and develop technologies (Orlikowski and Gash 1994). Taking into account these findings, recent studies examine the coevolution and interplay of material and socio-cognitive aspects of technologies (Kaplan and Tripsas 2008). For example, Grodal et al. (2015) investigate how technological designs and categories (and their associated labels) coevolve over time during industry emergence. All these research streams, however, share an arguable assumption: material and social aspects can be ontologically separable. These studies separate technological designs from socio-cognitive aspects and analyze the interactions between them. From the sociomaterial perspective, this assumption can be problematic.

Sociomateriality provides a novel perspective to understand technologies and organizations and provokes meaningful debates about both theoretical and empirical issues (Orlikowski 2007). Orlikowski and Scott (2008) point out two difficulties of traditional research on organizations and technology. First, previous studies pay most attention to particular technological processes or events and lack attention to how technology is always integrated to social phenomena. Second, the literature has an assumption that organizations and technology are separated as we described above. To address these issues, Orlikowski and Scott (2008) propose the concept of sociomateriality. Sociomateriality challenges "the deeply taken-for-granted assumption that technology, work, and organizations should be conceptualized separately, and advances the view that there is an inherent inseparability between the technical and the social (Orlikowski and Scott 2008, p.434)." One key aspect highlighted here is the relational ontology. It assumes that humans and technologies have no inherent properties. Humans and technologies exist only in a relationship between them. This ontological inseparability is a fundamental difference between the sociomateriality and traditional research streams. Orlikowski and Scott (2008) also emphasize the notion of performativity as a central concept in the sociomaterial approach. Performativity has its root in the

concept of performative utterances, which means that language executes actions such as "You are cheating" by a teacher in the classroom. Performativity directs attention to "how relations and boundaries between humans and technologies are not pre-given or fixed, but enacted in practice (Orlikowski and Scott 2008, p. 462)." By adopting this sociomaterial perspective, the study can address the inseparable nature of social and material aspects of technologies, which is under-investigated in the literature.

The concept of sociomateriality is clarified by Jones (2014). Jones identifies five key components of sociomateriality (materiality, inseparability, relationality, performativity, and practice), and proposes two types of sociomateriality: strong and weak sociomateriality. The strong materiality is what Orlikowski and Scott proposed, and the weak materiality relaxes the constraints of strong materiality. The weak materiality deals with humans and technologies as separate entities. The weak sociomaterial approach assumes that humans and technologies may have inherent properties, and materiality can be persistent across time and place. In line with the argument of weak sociomateriality, Leonardi (2012) conceptualizes the sociomateriality differently from Orlikowski and Scott. He defined the sociomaterial practice as "the space in which multiple human (social) agencies and material agencies are imbricated (Leonardi 2012, p. 42)." Leonardi also assumes that humans and technologies are separable, and both of them have their agency that is imbricated in practice (Leonardi 2011). Other scholars including Leonardi adopt the affordance perspective, which also assumes the separation between the social and material, to understand the materiality of technologies (Faraj and Azad 2012; Leonardi 2013). This weak sociomaterial view resonates with the recent coevolution studies on technology evolution.

In this study, we adopt the strong sociomaterial perspective to investigate technology evolution. If one takes the strong sociomaterial perspective, one cannot separate social and material aspects to analyze technologies. Drawing on Barad's (2007) agential realism, Orlikowski and Scott (2015) argue that researchers need to focus on the process of discursive materialization and its performative consequences in practice. Discourse and meaning can only exist when it is materialized in some formats, and materiality is not a static entity but a dynamic process in practice (Barad 2007). To capture the mutual entanglement of social and material, one needs to examine material-discursive practices: specific processes of discursive materialization in everyday practice (Orlikowski and Scott 2015). As an empirical study, Orlikowski and Scott (2014) draw on the strong sociomateriality and explore the inseparable nature of social and material aspects by focusing on material-discursive practices in the travel sector (offline and online evaluation practices). Their unit of analysis (i.e. focus on material-discursive practices) allows them to avoid just following interaction processes between human and technology. Instead, they develop formulaic and algorithmic apparatuses to understand entanglements of social and material aspects. The sociomaterial approach directs our attention to the relationality of humans and technologies, which is clearly distinct from traditional technology evolution studies. Following their lead, we specifically focus on the processes of discursive materialization to study technology evolution from the sociomaterial perspective.

Technology Standard Development

In the literature, there are several categorizations of standards. One dimension that relates to this study is technical and non-technical standards: technical standards refer to "codified specifications about components and their relational attributes (Garud and Kumaraswamy 1993, p. 353)." This standard is also called as interface or compatibility standards (David and Greenstein 1990). Technical standards specify interfaces of technical systems to clarify how each component should work and connect with each other, and provide common bases and infrastructures to develop products and services with a certain amount of quality assurance. Non-technical standards include many domains such as environmental management and financial disclosure other than technical specifications. One of the examples is a sustainability standard that refers to a set of rules and procedures to assess and communicate the environmental activity and performance of organizations (Reinecke et al. 2012). In this paper, we particularly focus on technical standards for the industry: technology standards for computer programming language. Another distinction of standards is de jure and de facto standards (Farrell and Saloner 1988). De jure standards can be understood as "the product of a deliberately steered process of decision-making (Brunsson et al. 2012, p. 617)." From the perspective of de jure standards, technology standards are the fruit of negotiation and discussion among multiple actors in the industry. De facto standards are developed through market competitions among industry players. After a given period of market competition, winning organizations can set industry standards and have control over technology

trajectories because they have a large market share in the industry. In this paper, we focus on de jure standards involving multiple actors in the industry: technology standards development in a consortium.

In addition to the categorization of standards, the literature has also examined the formal standard setting processes (Simcoe 2007) and the interplay between standard formation and diffusion (Botzem and Dobusch 2012). Also, past studies investigated the dynamics of competitions toward technology standards development such as battles between VHS and Betamax (Cusumano et al. 1992). Although these studies have addressed the process of standardization, they focused on the macro level processes and strategies of technology standards development. Simcoe (2007) studies the IETF to investigate the relationships between organizational characteristics and the time required for building a consensus among participants. However, little is known about the micro-foundations and discursive processes of technology standards development. In this study, we address this gap by investigating the processes of discursive materialization in technology standards development among multiple participants in a consortium.

Methods

Research Setting

In this section, we explain research methods to examine how processes of discursive materialization in technology standards development evolve over time. To explore this technology standards development process, we use a case of the Web browser industry as a research setting. In the Web browser industry, Web browser vendors, including IT firms such as Microsoft Corporation and non-profit organizations such as Mozilla Foundation, develop and distribute their products around the world through the Internet. The first Web browser was invented in 1990, and technologies of Web browsers continuously evolved until today. One of the most important institutional actors in the Web browser industry is the World Wide Web Consortium (W3C). W3C is an international standardization organization in the field of World Wide Web. W3C publishes the official guidelines and recommendations of Hyper Text Markup Language (HTML), a standard programming language to create Web pages. Although W3C is a standardization organization, it does not work in isolation to develop standards. The standards of Web technologies are developed through collaborations with participating organizations (major IT firms and non-profit organizations) and individual developers. We choose the Web browser industry because the Web browser is an essential and fundamental technology in the Internet age, and can be considered as one of the most widely used software applications in the world (Faraj et al. 2004). Moreover, as we describe below, the development of HTML specification heavily relies on social and online interactions between multiple actors. That is why we use this research setting to investigate the processes of discursive materialization in technology standards development.

In this paper, we focus on the development process of HTML5 that is the latest version of the HTML. The development of specification of HTML5 in the W3C started in March 2007 by forming the HTML working group and making its mailing list (public-html@w3.org) as the primary tool to communicate with working group members. The first internal draft of HTML5 specification was proposed by the working group in May 2007, and the first official public draft was published online in January 2008. There has been a significant amount of interactions between different Web browser vendors, individual developers, and W3C members to develop the specification of HTML5. This development process ended in October 2014 by publishing the official recommendation of HTML5 specification. Developers in different Web browser vendors could have divergent views on Web browser technologies, and these differences might cause the debates about how the HTML5 specifications should be developed and how the HTML working group should work. Competition between browser vendors can also influence these discussions and the process of consensus building among them. Also, there are also interactions between Web browser vendors and the W3C members. In the consortium, the W3C members and developers of Web browser vendors discuss the future standards of Web browser technologies by using several online communication tools such as Emails and chat systems, and face-to-face communications such as workshops. The primary means of communication among the participants is an email (mailing list). Since the members of the W3C are geographically dispersed, they mostly communicate with each other and discuss many important issues via Emails. These discussions between Web browser vendors, individual developers, and the W3C members shape technological trajectories of HTML5 specifications and help us understand how people collectively develop technology standards over time.

Data Collection

The main data source of this research is the mailing list archives of the HTML5 working group in the W3C because the primary focus of this paper is the processes of discursive materialization among multiple actors. This mailing list archive is publicly available at the website of the W3C. The mailing list archive of the HTML5 working group contains 45,237 messages during the development period from March 2007 (the beginning of the mailing list) to October 2014 (the publication of the finalized official recommendation of HTML5.0). Developers including major Web browser vendors, individual developers, academic researchers, and W3C staffs participate in this working group and mailing list, and they continuously discuss future directions of the HTML5 specifications and Web browser technologies. Most discussions about the development of HTML5 specifications were conducted on this mailing list. This data source is especially appropriate to capture the processes of discursive materialization in technology standard development because the discussions on the mailing list naturally occurred and there was no intervention by the researcher. Therefore, we used the mailing list archives as the primary data source. In this research, we collect and analyze all 45,237 Emails sent during the development period.

In addition to the mailing list archive, we used multiple data sources as triangulation, which leads to the stronger substantiation of constructs and high internal validity (Eisenhardt 1989). We examined published documents such as official recommendations and guidelines issued by the W3C, and other public records including newspaper articles, trade journals, and books. These data could be served as supplemental evidence to obtain a detailed understanding of what we observed in archival records. Although findings of this paper mostly focus on the analysis of mailing list archives, these supporting data is used to check the facts and decisions in the conversations that were taken place on the mailing list.

Analytical Approach

Analytical approach conducted here involves inductive content analysis that follows the established principles and procedures of grounded theory approach (Glaser and Strauss 1967; Strauss and Corbin 1990). We chose this method because research and theories in this particular area are in early and formative stages (Langley 1999; Yin 2009). To analyze the large datasets (over 10 million words in 45,237 Emails), we combined topic modeling techniques with manual coding methods. We follow a novel analytical approach that combines automated topic modeling techniques with the inductive manual coding introduced by Croidieu and Kim (2017).

Typically in qualitative studies with the inductive coding approach (Gioia et al. 2013; Strauss and Corbin 1990), researchers interpret the data such as interview transcripts and field notes and conduct open coding with their particular research interests and research questions. In this first-order coding, researchers carefully look at the data and try to code them from the perspective of informants, which is called in-vivo codes (Strauss and Corbin 1990). In this analysis, researchers seek to develop detailed understandings of the data and identify what appeared to be significant practices and processes of interest. After they get a manageable number of concepts by using this first-order coding, they identify second-order themes and aggregated dimensions from the theoretical perspective. This theoretical coding phase includes back and forth switches between the data and theories (i.e. iterative processes including rereading the data and reviewing the related literature). Researchers pay much attention to nascent theoretical concepts that have been not well investigated in the existing research (Gioia et al. 2013). Finally, process models or theoretical mechanisms are identified based on theoretical themes and dimensions. However, there are several difficulties in this process. First of all, since researchers do this coding manually, they cannot deal with large datasets like this study (over 10 million words of text). More importantly, it is hard to separate in vivo codes (languages used by the informants) and theoretical themes (languages used by the researchers) because researchers conduct the first-order coding by their hands with their interpretations. Moreover, especially in the case of technology evolution research, there is a significant risk of researcher's retrospective bias when we interpret the dialogues and events in the past (Kaplan and Tripsas 2008).

To overcome these difficulties, this paper adopts a topic modeling approach to conducting the first-order coding. In this study, we use latent Dirichlet allocation (LDA) topic model that is developed in the field of natural language processing and machine learning (Blei et al. 2003). This method is used to analyze hidden meaning structures as topics and their probability distributions over time in the dataset

(documents) according to the co-occurrences of word pairs (Blei et al. 2003; Steyvers and Griffiths 2007). This method is recently adopted in the field of social science to analyze cultures (DiMaggio et al. 2013), novel ideas in patents (Kaplan and Vakili 2015) and legitimation processes (Croidieu and Kim 2017). LDA is particularly useful to analyze the processes of discursive materialization because it can capture the relationality of the meaning (a meaning emerges from relationships among other terms), the polysemy of words (LDA can capture different usage of a word based on its context), and the heteroglossia (LDA allows the co-presence of competing voices within a single document) based on its inductive machine learning algorithms (DiMaggio et al. 2013). To conduct the LDA topic modeling, this research follows established procedures in the literature (Croidieu and Kim 2017; Steyvers and Griffiths 2007). First, we prepare the raw text data and remove non-meaningful words based on standard natural language processing procedures including lemmatizing (i.e. grouping the inflected forms of a word together) and removing numbers, punctuations, pronouns, prepositions, conjunctions, articles, and adverbs. As a result, the final text corpus to analyze includes 4,697,633 words. Given this final dataset, we use a software application MineMyText to conduct the LDA topic modeling and generate 100 topics. This study follows a convention in the field to set the number of topics as 100, which provides semantically meaningful and interpretable topics (Croidieu and Kim 2017; Kaplan and Vakili 2015). We use these 100 topics as first-order codes in the analytical processes, and then follow basic content analysis procedures that follow the principles of grounded approach (Gioia et al. 2013). We label these 100 topics as first-order concepts and develop second-order themes and aggregated dimensions based on them. Table 1 shows the data structure of the first-order concepts with illustrative topic vocabularies, second-order themes, and aggregated dimensions. Table 2 presents the probability distributions of the themes over time.

Findings

The analysis shows that there are four fundamental mechanisms in the development of HTML5 at the W3C: process management, dialogical coordination, boundary work, and knowledge sharing and conversion. At the core of the HTML5 development, process management from design to implementation plays a key role in each development phase. Especially at the early stages, dialogical coordination and boundary work help members to navigate and manage the development processes. At the later stage, knowledge sharing and conversion including various technical discussions shapes and facilitates the development of HTML5 specifications.

Process management is a core mechanism that drives the development of HTML5 specifications at the W3C. At the beginning of the development phase, members mainly discuss design principles of HTML5. Members' main concerns revolve around how they should design the structures of HTML5 and its official recommendation as a published official document (see topic #23). After members had vibrant interactions about design principles, they focus on the bug fix and proposal development. Since the HTML5 specification is a large document including multiple elements and design guidelines, they need to validate various kinds of errors/bugs and make sure that the official recommendation document does not have critical bugs and inconsistencies (see topic #9). At the same time (during 2010-2012), W3C members need to develop and revise the proposals for the official recommendation. To gather feedback comments as much as possible from multiple participants, members propose the drafts of the recommendation, call for comments on them, and revise the documents (see topic #89). Once the proposal is approved, members implement and test features in the HTML5 specifications (see topic #78). Managing these core processes drives the HTML5 development.

Although the process management is one of the core mechanisms in the development of HTML5 specifications, dialogical coordination also plays a key role to facilitate communications and collaborations among members during the development processes. Core members in the W3C initiate discussions about how the HTML5 working group members should work together and how they can communicate each other (see topic #84). When the working group members face debates or inconsistencies in their understandings of HTML5 specifications, they bring up those issues and seek to build discursive consensus among them (see topic #38). Members of this working group coordinate their works and resolve issues related to the HTML5 development with these dialogical processes.

Moreover, to address internal issues in the working group, members need to deal with issues occurring at the boundaries around the HTML5. Since the HTML is a programming language for the development of

Illustrative topics vocabularies	First-order concepts	Second-order themes	Aggregated dimensions
Topic #23: principle design_principles exist content support software_standards charles_opera make design write html design_principle thing practice people good agree document work try_opera	Discussing the design principles	Design priniciple	Process management
Topic #9: validator error author make check valid validation validate warn tool invalid validators attribute conformance html5 developer write people page document	Validating the errors	Bug fix	
Topic #89: issue proposal html_weekly title due chair close paulc call week meet change_proposal update html ruby objection action work change_proposals janina	Organizing issues in the proposals	Proposal development and revision	
Topic #78: test implementation spec feature test_suite implement test_case rec browser write work version specification part require set cr run interoperability check	Testing and implementing the specifications	Implementation	
Topic #84: list email discussion issue comment people message mailing_list send feedback post group write mail thread read find reply work wiki	Disussing internal communications	Working group coordination	Dialogical coordination
Topic #38: make consensus write issue ian discussion proposal group draft people agree vote working_group time process work point decision editor change	Making a consensus and agreement	Coordination and discussion	
Topic #86: firefox browser test opera write change behavior work webkit spec safari match case gecko support bug treat result current find	Testing browser-specific behaviors	Browser and Web apps	Boundary work
Topic #62: user browser page content web ui provide access default control support device choose display application screen window set ua option	Discussing the user experiences	User experiences	
Topic #76: accessibility user accessible provide feature make content html people author web support requirement require access wcag issue design solution important	Ensuring the accessibility of the HTML	Compatibility and accessibility	
Topic #33: language document lang element meta author content html contentlanguage lang_attribute http attribute tag text change pragma set fallback process information	Managing multiple languages	Language and characters	Knowledge sharing and conversion
Topic #42: rdfa microdata rdf data vocabulary property prefix syntax attribute process htmlrdfa mechanism write curie map item add provide triple type	Discussing Resource Description Framework	Data formats	
Topic #5: svg html content texthtml element xml work support make syntax parse case handle proposal browser require parser document write author	Discussing the SVG elements	Audio and visual	
Topic #50: content proposal cdm browser drm support cdms make key require web service implement content_protection user work device w3c mark_watson write	Managing content protection mechanisms	License	
Topic #71: element section head content hgroup main outline article header heading document h1 footer level page div author structure subheading semantics	Developing the header and sections	Document structures	
Topic #40: input element label form control button select user focus command attribute area click key map text list type field accesskey	Developing the input form	Interface and input	

Table 1. Data Structure

Web contents, the HTML5 specifications have to test and resolve Web browser-specific behaviors (see topic #86). Established browser vendors such as Microsoft and Google play a significant role in discussing this issue. While the HTML5 specifications and its official recommendation are mainly for developers and Web engineers, W3C members need to care users to provide comfort user experiences when they are browsing the Web (see topic #62). Also, the working group pays particular attention to the compatibility and accessibility of HTML5 to ensure that Web developers have little confusion when they learn this new language (see topic #76).

Dimensions and themes	# of topics	2007	2008	2009	2010	2011	2012	2013	2014
Process management									
Design principle	13	22%	17%	14%	11%	7%	8%	12%	12%
Bug fix	5	2%	3%	5%	15%	24%	8%	2%	2%
Proposal development and revision	9	3%	4%	9%	15%	15%	20%	3%	6%
Implementation	6	4%	3%	4%	3%	6%	11%	13%	18%
Dialogical coordination									
Working group coordination	6	14%	8%	9%	7%	5%	8%	7%	11%
Coordination and discussion	6	7%	10%	13%	9%	5%	4%	3%	4%
Boundary work									
Browser and Web apps	4	8%	6%	5%	4%	3%	3%	4%	6%
User experiences	8	9%	9%	6%	6%	7%	6%	5%	6%
Compatibility and accessibility	5	5%	4%	6%	6%	2%	3%	2%	3%
Knowledge sharing and conversion									
Language and characters	5	3%	6%	5%	5%	3%	2%	2%	3%
Data formats	7	6%	6%	8%	3%	3%	2%	2%	4%
Audio and visual	8	5%	11%	6%	6%	10%	12%	5%	5%
License	3	1%	1%	2%	1%	2%	8%	2%	1%
Document structures	11	7%	8%	6%	7%	6%	4%	35%	14%
Interface and input	4	4%	4%	4%	4%	4%	2%	3%	6%

Table 2. Temporal Distribution of Theoretical Themes

Lastly, knowledge sharing and conversion in various technical areas become significant practices, especially at the later stage of the HTML5 development. The main technical domains include language and characters (topic #33), data formats (topic #42), audio and visual (topic #5), license (topic #50), document structures (topic #71), and interface and input (topic #40). For example, the developers in the working group share their technical knowledge to discuss how to design and implement certain types of data formats such as resource description framework (RDF) or how to develop the interface of each object in the HTML5 (i.e. how each object can relate to each other in the HTML). Since these conversations purely focus on particular technical details, knowledge sharing and conversion practice are different from the process management, which focuses on organizing and managing the whole processes of collaborative technology standard development. The working group requires new insights and knowledge to resolve various technical problems. According to organizational knowledge creation theory, new knowledge is created through a spiral of knowledge conversion: a continuous interaction between tacit and explicit knowledge (Nonaka and von Krogh 2009). Members of the working group accelerate knowledge sharing and conversion toward the publication of official recommendation of HTML5 specifications.

Discussion and Conclusion

In this study, we examine the processes of discursive materialization in technology standards development in the case of HTML5 at the W3C and identify four fundamental mechanisms: process management, dialogical coordination, boundary work, and knowledge sharing and conversion. Process management serves as a core mechanism when the HTML5 working group collectively develops the HTML5 specifications from the design to the implementation phase. Dialogical coordination and boundary work are performed by the working group members to facilitate this core mechanism. Toward the end of the development processes, members intensively involve in knowledge sharing and conversion to solve technical issues. The findings, especially temporal distribution of topics, suggest the dynamic

nature of technology standards development: 1) coordination of the working group with boundary work is emphasized at the beginning, 2) process management plays a central role in the middle of the standards development, and 3) intensive knowledge sharing about technical details follows. These findings contribute to understanding processes of technology evolution from the sociomaterial perspective by addressing the lack of empirical research that pays attention to the dynamics of sociocognitive aspects in technology evolution (Grodal et al. 2015; Kaplan and Tripsas 2008) and the mutual entanglement of social and material aspects of technologies (Orlikowski and Scott 2008). As a practical implication, this study offers insight on how technologies dynamically evolve with the specific processes of discursive materialization, which is a key to having a good sense of technological trajectories. Since this study focuses on technology evolution and technology standards, high-tech companies and industries such as the field of IT and Web will likely to benefit from the findings. We, however, argue that recent information technologies transform many other industries (e.g. Uber changes a traditional taxi industry, and Airbnb reforms a traditional hotel industry). Therefore, managing technological trajectories can be an opportunity (and a challenge) for many business domains beyond IT and Web industry, which can fundamentally transform how organizations and industries operate and innovate.

Like all empirical qualitative research, this study also has limitations. This study focuses on the single technology standard in one research context. Although it employs an inductive and explorative approach and does not aim to achieve the statistical generalizability, the analytical transferability of the findings is limited. Future studies should include multiple cases and conduct across-case analysis to get more credible and transferable findings. In conclusion, this paper sheds light on under-investigated material-discursive mechanisms in the context of technology standards development and opens up fruitful future research directions by employing a novel analytical approach.

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