When the Tab Comes Due:
Challenges in the Cost Structure of Tab Usage

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ABSTRACT

Tabs have become integral to browsing the web yet have changed little since their introduction nearly 20 years ago. In contrast, the internet has gone through dramatic changes, with tasks increasingly moving from the desktop to "*the cloud*". In this paper, we investigate how tabs support the diverse functionalities of the modern web. Based on interviews and surveys, we found that many users struggle to manage and switch between streams of complex tasks, resulting in significant breakdowns. We discover competing pressures pushing for the opening of tabs (such as revisitation costs, sunk costs, uncertainty around relevance, and mismatches between the aspirational vs. actual self) versus pushing for closing tabs (such as limited attention and resources). Our results indicate these pressures lead to issues ranging from tab overload, hoarding obsolete tabs, frustration, and even shamefulness. Based on our findings, we develop implications for designing better ways for users to interact with the modern web.

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Author Keywords

web browsers, tabbed browsing; information seeking; organization; management strategies; qualitative study

INTRODUCTION

Tabs have become an integral part of how people browse and navigate the web since they were introduced in the early 2000s, and they are now a ubiquitous feature in all major web browsers. However, since their introduction, the internet has gone through dramatic changes, with an increasing proportion of users' communication, productivity, and entertainment tasks moving from the desktop to "*the cloud*" [9]. Further, online information seeking has evolved from navigating web directories to finding websites (e.g. DMOZ [1]) for simple fact finding tasks to searching through dozens or even hundreds

of webpages to support complex sensemaking tasks [28, 25]. These changes reflect an increasing amount of dependence on the functionality and interfaces of modern web browsers in meeting these needs.

However, despite this expansion of functionality, there have been few changes to the way tab interfaces are designed today versus when they were introduced. Tabs are now simultaneously used to check email inboxes, view videos, control music players, stash articles to read later, chat with friends, plan trips, research products, write articles, and work on projects. Yet even with this diverse and multifaceted set of functions, tabs still remain instantiated as simple temporally-ordered lists with few contextual cues. Indeed, the fixation on tabs as a metaphor is so strong that the most popular changes to using tabs involve relatively small design adjustments such as making them a vertical instead of horizontal list [12] or creating tabs that contain more tabs [13]. There is increasing evidence that using tabs for this wide array of functions leads to breakdowns, overload, and missed opportunities [29, 30, 18, 17, 16]. To better understand and expand the potential design space for web browsing interfaces, we conducted an empirical study of the challenges people face when using tabs. Instead of examining the specific functions of tabs as they are currently used (e.g., as in Dubroy, 2010 [9]), we focus on developing a model of the way that tabs break down from their daily use. We performed both an online survey and in-person interviews to investigate and build this model.

We found that participants' behavior was governed by a variety of positive and negative drivers. Overall, these drivers could be classified as two opposing forces: pressures to close tabs, and pressures to keep tabs open. We found strong evidence that participants had numerous reasons to close their tabs, ranging from limited attention to limited browser resources to self presentation. At the same time, we found a diverse set of reasons why it was not so simple to close open tabs. These included previously reported drivers such as reminding users of unfinished tasks [9], but also new factors relating to cost structure of tabbed browsing, such as the cost of reaccessing pages, the sunk costs of finding and organizing information, the benefits of supporting an (unrealistic) aspirational self, and the uncertainty of the expected value of information in the future, especially for complex tasks. These pressures to close vs. keep open tabs interact to create feelings of stress, being overwhelmed, and even shamefulness in our participants. Our findings have implications for the design of new forms of web

browsing that can better support the underlying drivers behind the use of tabs.

RELATED WORK

Web Browsing Behavior

The way we use the Web has changed significantly throughout its history. Before tabbed browsing was introduced, researchers in the mid 1990s discovered that people frequently (up to 60%) revisited the same URLs, and characterized web in the 90s as a "recurrent system" [34]. Early research focused on lower-level navigation mechanisms that people used to load and switch between different webpages. Tabbed browsing gradually replaced the use of the back button as a main navigation mechanism, where its usage have seen a steady decrease from ~40% in the mid-90s [7, 34] to ~20% in the mid-2000s when tabbed browsing was introduced [37, 38] to 7.1% the early 2010s when tabbed browsing was supported by web browsers that had around 50% market share [9].

More recently, research has focused on exploring tabbed browsing behavior, with Dubroy et al. [9] discovering that Firefox users showed strong preferences towards tabbed browsing when compared to only using windows, and Huang et al. [20] finding that at least 60% of the tabs people created were related to other tabs of the same tasks. They also found that even though tabbed browsing encourages parallel browsing behaviors, it did not increase overall activity. These two studies were conducted around 2010, when 50% of internet users did not have access to tabbed browsing functionality in their browsers [36]. As of today (August 2017) all major web browsers support tabbed browsing [36].

Email Overload

These changes in tab usage behaviors are strikingly similar to the changes email has gone through. The seminal paper by Whittaker and Sidner in 1996 coined the term *email overload*, and pointed out the fact that email was being used for functions that were much more complex than what it was originally designed for, including task management and personal archiving. This observation spurred a series of research projects into designing better complex email sensemaking interfaces [39, 3, 4, 8], significantly influencing email is used today to manage complex streams of communication and diverse tasks [14, 15].

Similarly, browser tabs were introduced in the early 2000s for a much simpler internet. We can now not only conduct many productivity tasks in our browsers using web-based applications such as word processors and file storage, but also many entertainment tasks such as streaming films and music or playing web-based video games. Indeed, many of our participants accessed their email through web-based clients that could themselves support multiple browser tabs in their interfaces. In many cases, we found that tabs are also used for the same task management and short-term archiving functions as emails, but also served functions beyond what emails provided such as managing frequently accessed references or exploring unfamiliar fields [28, 25]. Conversely, browser tabs lack even the basic management features many email systems have supported for decades, such as prioritization and search. In this paper, we argue that tabbed browsing today seems to be in a similar state to email in the 90s: it has grown to encompass a wide array of functions with a simple mechanism. Thus we ask an analogous question as raised by Whittaker and Sidner [39]: how well do the simple tabbed browsing mechanisms available today support the wide range of tasks they are used for on the modern Web?

METHODOLOGY

In this section, we briefly describe a two part study involving an online survey and in-person interviews. In the next sections of the paper, we combine the results from both studies to give a holistic view about how people utilize tabbed browsing in modern browsers and discuss in-depth the problems they have encountered.

Study 1: Online Survey

An online survey was conducted with 64 participants recruited from the Amazon Mechanical Turk task market (age: M=33.7, SD=10.6, min=19, max=67; 57% male; 77% from the US). The survey consists of a demographic questionnaire, a 7 question Maximizer-Satisficer Questionnaire [27], and 24 questions we designed about users habits and opinions of using tabs. Each of the 31 questions were rated by the participants using a 7-point Likert scale with options ranging from Strongly Disagree (0) to Strongly Agree (6). The personality trait quiz was originally developed by Schwartz et. al 2002 for measuring how much a person tend to maximize (or optimize) in sensemaking and decision making scenarios [32]. In our survey, we used the short form version of the survey developed by Nenkov et. al in 2011 with 7 questions [27], which had been found useful in past work for identifying users with different types of online information seeking tendencies [23]. For each participant, we averaged their responses of the 7 personality trait questions to form a scale of 0 to 6, where a higher number indicates someone identifies as more of a maximizer. Participants agreed strongly on 13 of the tab questions, with 95% confidence interval above the neutral option (3.0 neither agree nor disagree). In addition, we found responses of multiple tab questions to be highly correlated with participants' personality traits. We will show these in the appropriate sections.

Study 2: In-Person Interviews

Ten participants were recruited from either a university or a research facility located in two states in the US for in-person interviews (age: M=23.0, SD=4.7, min=19, max=32, 40% male). Most participants were either graduate or undergraduate students conducting research during the summer. Pre-screening was used to recruit participants who self-reported often reaching 12 or more tabs open in their browsers and use a laptop as their main computer. Semi-structured interviews were conducted closely following a detailed interview scripts. Participants were asked to walk through each tab they had opened on their laptops with the interviewer, and explain the tasks, goals, or purposes of why each tab was opened in the first place. We then further probe our participants to discuss with us why each tab was still opened, using questions including "*Was this tab intentionally kept around for later usage?*" If answered "*yes*", we followed up with "*Did you came back to it recently, why or why not?*" And if answered "*no*", we

		Different Pressures for Closing versus Keeping Open Tabs
close	C1.Limited Attention	Keeping too many tabs makes it difficult to focus, overwhelming and causing stress
close	C2.Limited Screen Real-estate	Keeping too many tabs makes it difficult to navigate and have situational awareness
close	C3.Limited computing power	Drains processing power and memory, causing browser and other applications to slow
close	C4.Pressure to be Organized	Social and self pressure to avoid looking disorganized
keep	O1.Reminders and Resumption	Keeping tabs around as a reminder to work on them or keep track of progress
keep	O2.Revisiting References	Keeping frequently used tabs for quick access; has a diminishing return
keep	O3.Avoid Costly Re-finding	Avoid closing tabs in fear of missing out on valuable information
keep	O4.Sunk Costs and Aspirations	The hopes to process more information than capable; while aware of the situation
keep	O5.External Mental Model	Memory and mental model; Organize diverse tasks with windows, desktops, browsers
keep	O6.Uncertain Relevance	Difficulties in judging the current and potential relevance of tabs in the future

Table 1. An overview of our findings: Two sets of opposing pressures that drive tabbed browsing behavior.

followed up with "*Why was this tab kept around if you did not plan to use it again?*", and "*Do you struggle to close your tabs?*" We also asked about how and how effective are they managing their tabs with questions include "*How frequently do you evaluate your tabs to see if you can close them? How difficult is it?*", and "*Does the number of tabs you have opened affect how you feel?*" The interviews were recorded and transcribed. The authors then extracted and analyzed interested quotes using a grounded theory approach with four rounds of discussions and iterative coding [33].

PRESSURES TO CLOSE VS. KEEP OPEN TABS
Overall we found that people had mixed feelings about their tabs. Participants were positive about browser tabs when compared to only using application windows. These findings were consistent with a study on Firefox users in 2010 [9]. However, many participants experienced major issues when trying to manage tabs efficiently. Specifically, when too many tabs were opened, participants expressed feeling negative emotions and pressure. At the same time participants also expressed feeling an attachment to the information saved in tabs and an investment in the organization they built up. Table 1 shows an overview of our findings, and below we discuss these two opposing forces that govern users' tab behavior based on evidence from our interviews and survey.

Pressure to Close Tabs
When participants had too many tabs opened, they expressed a number of negative feelings and reasons behind them. Investigating this we found three common themes: tabs incurring pressure on attention; tabs taking up browser resources; and people feeling a desire to appear organized to themselves or others.

C1.Pressure on Attention
A fundamental problem is people's *limited attention*. In situations where users are presented with too many options, and faced with too many decisions to make, it becomes harder to focus on what is important [31, 40]. Similarly, having opened too many tabs can potentially cause users to lose track of all the information sources they have on hand, and lose focus on which tabs they should concentrate on. Many participants in our interview study expressed how they were sometimes overwhelmed by the large number of tabs they have opened, and how it made them unable to focus on important tasks.

"*I think probably, overwhelming is a good word. It's not like it's helping, it's not like I can suddenly find things better when I have that many tabs open because that's definitely not the case, so yeah I think the more tabs I have open then it's more an indication that I'm in some, some uh shit, like I'm like in the middle of a mix and like just don't have time for like basic human cleaning functions or something.*" - Participant J3

Conversely, participants also pointed to how closing and reducing the number of tabs can relieve pressure and stress caused by their browser tabs.

"*[on closing browser tabs and windows] Usually it's a relief, even if I'm missing things that I think would have been important. I can't usually remember specifically what they would have been.... Yes. When I close a window also. I feel like that's great.*" - Participant J2

C2&C3.Pressure on Computing and Screen Real-estate
Besides limited attention, many participants also mentioned *screen real-estate as another limited resource*. They expressed how having too many tabs leads to difficulties in navigating and finding previously opened tabs. More specifically, creating each additional tab reduces the width of existing tabs causing a smaller portion of the webpage titles to be rendered by the browser. Further, they pointed to a breaking point for tabbed browsing: When browser tabs became so narrow that the favicons were no longer rendered, tabbed browsing became unusable.

"*Sometimes, if it gets to so many that I can't even see the icons anymore, then I start closing them.*" - Participant H3

"*When I can't see the little icon. Then that's too many... I can definitely find what I want with like 3 clicks at most, generally 1 click. It's once I can't see the little icons...*" - Participant H4

"*As for like a mental burden...It's crazy. This doesn't happen very often, but if I have enough that the titles or icons don't show, I'll be like, "Wow, how did I get this bad?" And get really bothered by it*" - Participant H2

Echoing participants in the interview study, 28% of the participants in the survey study also agreed that they *often struggle*

with finding the tab they needed in their browser (M=2.17, 95% CI[1.74, 2.60]). Even though this issue was not reported by the majority of our participants, the responses were highly correlated with the maximization personality trait (t=3.38, df=62, p=0.001 based on Pearson's product-moment correlation), indicating that this might be an issue for a particular subset of the population or when conducting tasks that users care a lot about.

Participants who sometimes keep a large number of tabs around mentioned having too many tabs drains the *limited processing power and memory space* from their computers, causing their browsers to became too slow. Supporting evidence were found in both the interview study and the survey study. 25% of the participants in the survey study reported that they have experiences with *browser or computer crashing in the past due to having too many browser tabs opened* (M=1.89, 95% CI[1.40, 2.38]). Similarly, even though the average agreement were relatively low, the responses were highly correlated with the maximization personality trait (t=2.99, df=62, p=0.004 based on Pearson's product-moment correlation). One participant in the interview study, J4, even described how it inhibited him or her from using other desktop applications normally.

> *"I'll try to go into different browsers to see if there are tabs that I just don't need. so yeah usually the only time that I do that is if Chrome is starting to get really slow."* - Participant J2

> *"But right now, I can't, my battery drains so fast because I have all these tabs open, that it actually inhibits a lot of things I'm doing."* - Participant J3

Browser extensions such as [11] and [10] allow users to manually unload and reload webpages while keeping their tabs open to save memory usage has a combined of more than 1.2 million users (as of September, 2017). While they can ameliorate the pressure of using too much processing power, they also introduce another layer of caching that users have to manually manage, and does not help with pressures caused by depleting screen real-estate or user attention.

C4.Pressure to be Organized
When conducting tabbed browsing, depleting the different limited resources mentioned above created major issues for our participants. Indeed, many participants described how browser tabs can become a source of stress and frustration due to these limitations, especially when they try to navigate and manage many tabs in parallel.

> *"... but if it seems like I have a lot of tabs open, I try and go through and see which ones I can close. But sometimes, that's very frustrating because sometimes it's like, well, I can't exactly close any of these right now, but there are so many of them"* - Participant H1

More interestingly, some even noted feelings of *shamefulness* for having a large number of tabs opened, and their unwillingness to reveal their tabs to others.

> *"Because it's...shameful in a way. It makes, like I feel like I would have been giving, like a bad impression to these people that I, that had to look at my screen."* - Participant J3

> *"i'm going to do a presentation and I care about what people are going to think about me when I plug my computer in, then that's when I might clean it up"* - Participant J2

These results suggest that users are in fact motivated to maintain a clean and organized workspace, but were often failing to do so while conducting tabbed browsing. 56% of the participants from the survey study agreed that *it would be helpful if the browser somehow knew I was done using a tab* (M=3.4*, 95% CI[3.04, 3.93], highly correlated with the maximization personality trait t=2.08, df=62, p=0.042 based on Pearson's product-moment correlation). Participants also associated the pressure to be organized with social pressure and impression management, and how they would attempt to reduce the number of tabs they have opened before showing others their screens. This could potentially demotivate users to collaborate in-person with their co-workers in a office setting or even remotely using screen-casting tools [5].

Pressure to Keep Tabs Around
Given the above pressures caused by having too many tabs, and the seemingly low cost of closing tabs to relieve such pressure, why do participants still frequently find themselves in situations where they "*hoard*" many tabs? Close examination of the interview transcripts revealed 6 major causes for why people open and keep a large number of tabs, many of which were dependent on the usefulness and relevance of a tab over time, leading to issues such as keeping around obsolete tabs that could have been safely closed.

O1.Reminders and Unfinished Tasks
Most commonly, participants in the survey study reported that some of their tabs were intentionally kept around for reminding or to keep track of progress:

- *as reminders to go back to something*
  86% agreed, M=4.89*, 95% CI[4.59, 5.19]
- *to continue collect information from*
  91% agreed, M=4.73*, 95% CI[4.47, 4.99]
- *as reminders to explore further*
  89% agreed, M=4.70*, 95% CI[4.44, 4.97]
- *to resume where I left off*
  80% agreed, M=4.41*, 95% CI[4.08, 4.73]
- *each tab correspond to an unfinished task*
  77% agreed, M=4.11*, 95% CI[3.77, 4.45]

These results based on general tab usage are consistent with previous work that focused on browser tab usage during search sessions [19]. Similar responses were also collected from the interviews:

> *"And sometimes, when you're in a rush, you don't really have time to focus on which tabs you really need, so you'll put it off for later."* - Participant H2

> *"Yeah it sort serves it not in a ""Oh shit"" way but in more of a, sitting there nagging me like a mother sort*

of way. And I would say it's effective in doing that." - Participant J3

Since reminder tabs can be inactive for extended periods, one solution could be to save them as bookmarks so that tab resources can be released. However, participants expressed how bookmarks do not exhibit the same reminding functionality, citing the high cost of creating and accessing bookmarks and that once created they are "out of sight out of mind".

"Yeah, I would say bookmarks for me feel like deep archive or something so in Firefox when you bookmark something but you don't assign it to like you don't put it into a folder you just kind of puts it all in a pile" - Participant J5

"I would have to bookmark it and then put it into a category. Would have to save this bookmark and decide which category it would go into. If I bookmark everything, just a default bookmark, it would just get added to a long list of long-forgotten sites that I bookmarked randomly. Because I have bookmarked... I want to bookmark it and put it into a category but then that requires figuring out what category to put it in, which as you know, requires a lot of cognitive load." - Participant J1

While the task of categorizing and filing personal information requires high cognitive load [24], the structure it creates often bring benefits such as ease of access and a better understanding of the information landscape [33]. However, in this case, forcing users to create structure over their tabs does not seem to exhibit these benefits while still required the high cost of categorization. Additionally, this structure causes tabs to lose their ability to "nag" the users from time to time.

O2.Revisiting Frequently Accessed Pages

People also keep tabs around to reduce the cost of repeated navigating to frequently revisited webpages. From the survey study, 78% of our participants agreed that they *keep frequently used tabs opened* (M=4.67*, 95% CI[4.33, 5.01]), and similar responses were also collected from the interview study:

" I do usually try to have one window more of my core stuff, so my window right now has my email, calendar, and capstone stuff that I can reference really quickly. " - Participant J2

However, immediately afterwards J2 noted that the benefit of keeping frequently accessed tabs around has a diminishing return: as the total number of tabs increases, users ability to efficiently access specific tabs decreases. This tension leaves users the heavy burden of carefully balancing between the number of frequently used tabs to keep around, and how efficiently those tabs can actually be accessed. J2 summarized this cost structure balance with an apt analogy to putting clothes away:

" ....think for me it feels like other things that I do that don't make a lot of sense but feel like the right things to do, so like I've often have in my room like a chair that I'll just drape clothes back over the chair instead of putting it away. Cuz if it's a sweater that I wear a few times a week, well it'll be easier if I just get that sweater that's

draped over this chair than if I put it in my closet, but then that becomes like 30 things draped over the chair, and I actually can't find anything draped over the chair, and I know it doesn't make sense but I still do it. Like in the moment it seems like the right thing to do, the easier thing to do." - Participant J2

O3.Avoiding Costly Re-finding

Besides keeping tabs open to reduce revisitation costs, participants also noted how *closing tabs* can potentially incur the high costs of re-finding and reopening them, and how they kept tabs around in order to avoid such scenarios.

"like if I close a window but I want those tabs back it's probably in history somewhere I just... it used to be really shaky so I never did it." - Participant H5

The cost of reopening tabs was often mentioned with online collaboration. Participants noted that when tabs were open from links shared by others, the costs of reopening are often higher, so they were less likely to close them.

"Because I'm not confident I know how I would get back to it. Especially if it was a link that I followed from Slack[1] that someone else created in our drive.... in some cases, the files that I've created, I know where they are and so I know where to find them. But in the case of other people's files, I don't know where they are so I am more likely to keep their tabs opens. I am more likely to keep tabs open for files that other people create because I don't know where they filed it." - Participant J1

Conversely, many participants expressed their fear of closing the wrong tabs, either by mistake or by misjudging their relevance, and pointed to cases where they had to pay the price of re-find and reopen valuable tabs. One participant even stated that he or she would go through history to find valuable tabs that were closed, while others were willing lose information they considered valuable just to avoid having too many tabs.

"But in all likelihood there's been a few tabs where I've saved and I've never come back to. Or it gets closed out accidentally. Which is a very scary... or a fear of mine where a tab will get closed out and I won't know what I'm missing.... It's the fear of missing something important, or something that will lead to enlightenment, or to more knowledge, or something that will help you get a job. Things like that. Just the fear of missing out." - Participant J1

"...I would actually go through my browsing history and go "I had this tab open, I had this tab open, I had this tab open" and then I would reopen a lot of those tabs." - Participant J4

As a result, one participant also noted how using external note taking application to record URLs before closing tabs can lower the potential cost of re-opening them.

"Right and if we were doing something like cancer research or something, I would paste a lot of links in so

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[1]Slack. An instant messaging application. http://www.slack.com

then I don't necessarily keep those tabs open. If I get it recorded then I can close things." - Participant J5

O4."Irrational" Pressures: Sunk Costs & the Aspirational Self
Participants also cited reasons for keeping tabs around that may not fit in a rational economic analysis view of the cost structures of tab usage. Two common patterns were the sunk cost of creating and managing tabs, and the disparity between a participant's actual and aspirational self.

Sunk Cost. When participants spent efforts to open, manage and organize their tabs, they feel invested and felt that those tabs had inherent value to them beyond just the costs and benefits of keeping them around for quick access or to avoid re-finding them. This reluctance to close tabs may be a form of loss aversion [35], in which simply the "ownership" of a tab may give it value:

> *"But it made me think about how it's weird that even when I'm not using those tabs, I don't want to close them. Maybe it's because it took effort to open those tabs and organize them in that way"* - Participant H2

Another form of "irrational" behavior reminiscent of loss aversion we found was the mismatch between a participant's goals for their aspirational self and what would be realistic for their actual self. For many tasks there are virtually an unlimited amount of relevant information given the scale of the modern Web. Users with a maximization tendencies may spent huge amounts of time collecting information to avoid the chance of missing valuable insights. Furthermore, users often encountered a variety of interesting articles or websites in their social media or news feeds that they would like to read someday. Indeed, participants reported that sometimes the amount of information they hoped to process exceeds their capability and resources.

> *"...it's not really worth it. But at the same time, I don't want to be like "Oh, okay, that's it. I'll never remember." So I just leave it there. And then I might not come back to it"* - Participant H4

> *"it kind of becomes this kind of mess that you see here, just a big list of tabs that I was supposed to get back to but never did."* - Participant J4

> *"I'm sure somewhere in that 100 there were some things that were really important for me to keep in my mind. But now they're gone. So "oh well" I guess."* - Participant J3

Interestingly, when asked if they would ever get to processing a certain resource some participants admitted that realistically they would never actually get to them.

> *"to be honest, it's more like I will collect a bunch of links and then never really ever go back to them. And when I figured this out I sort of stopped caring about bookmarks. sometimes I will throw things into this other bookmark that's more unorganized, but I don't think I ever look back on these."* - Participant J4

O5.External Mental Model
Participants expressed how browser tabs act as a manifestation of their mental models, using them as an external – yet transient – memory store in a similar fashion as an active working memory [2].

> *"It's like a manifestation of everything that's on my mind right now I think. Or the things that I think need to be on my mind right now, I think that's the way I think about it. Like, so right now, in my browser window, I have like, a web project that I'm working on. I don't have time to work on it right now, but I know I need to work on it, so it's sitting there kind of reminding me that I need to work on it."* - Participant J3

Our participants typically conducted a wide range of different tasks in parallel, sometimes engaging in multiple productivity and leisure tasks at the same time. The simple linear structure of tabs were often insufficient for organizing multiple complex tasks at the same time, and participants had to resort to various strategies and tools to create more sophisticated structures to better represent their mental models. Participants in our interview reported strategies from using multiple windows to create two-level hierarchies of tabs (as in [9]) to using virtual desktops and even multiple browsers or computers to create more levels of hierarchies or to separate task contexts.

> *"...a lot of the times I have are for entertainment and reference and something that I need to get back to. whereas my Mac is for work. I'll just call it my home computer and my work computer. if I had my tabs on my home computer on my work computer I will probably get more distracted. this is more for fun and my work computer is for work."* - Participant J4

> *"I would usually try to keep either different windows or often I would have different browsers like Chrome at work and Firefox at home so that I wouldn't mix those things up."* - Participant J2

O6.Uncertain and Changing Relevance
The above pressures for keeping tabs around are driven by perceived value in opened tabs. However, in many instances participants reported the presence of tabs that were *obsolete* – tabs that could be safely closed yet were still open. 59% of the participants in the survey study agreed that *if they went through their tabs, there would be some that can be closed* (M=3.66*, 95% CI[3.24, 4.07]). One explanation for obsolete tabs is that participants were simply too lazy to close tabs that were no longer useful. However, only 18.8% of the participants agreed that *laziness contributes to not closing tabs* (M=2.64, 95% CI[2.19, 3.09]).

Our interviews shed light on alternative possible explanations centered around the difficulties of estimating the expected value of tabs. Specifically, it can be difficult to determine the relevance tabs for current and future tasks, especially when the task may not have one correct answer, the answers found do not perfectly suit the user's goals, or if one is too early in the process to be confident in an answer even when first seen.

> *"The next three tabs are all different response for that. Because none of them seem like completely wrong, but they also don't see like exactly what I'm looking for"* - Participant H1

As a result, users can be tempted to keep all potentially relevant tabs open until confident that they would no longer be needed. More than half of the participant agreed that they *feel like they can't let go of their tabs* (55%, M=3.5*, 95% CI[3.02, 4.0], highly correlated with maximization personality trait t=2.75, df=62, p=0.008 based on Pearson's product-moment correlation).

Participants also reported that the relevance of opened tabs may change over time as they learned new information, which potentially explains why relevance judgment can be difficult.

> "*I think sometimes I just forget to close out of tabs. A lot of these in the beginning, I forgot that I even had. This was a concept that I thought I would start using. But then I ended up using something else. But I just didn't close these*" - Participant H3

> "*Yeah, so I had a couple of different windows open and I opened back up that window that I feel was relevant to reopen I guess. And the others I felt, like I told you, like sometimes it feels like that moments' passed for whatever reason? So the others didn't really feel relevant anymore.*" - Participant J3

DISCUSSION

Our findings lead to many implications for future designs. We consider how to better support loading and managing multiple webpages in parallel to better support both simple and complex tasks.

Similar how emails today can be access as conversational threads, our participants' browser tabs often have implicit threaded structures as well. When conducting exploratory search, users often have multiple parallel threads of investigation in order to cross-reference and make holistic decisions. For example, in trip planning tasks users might have three separate but related threads about finding attractions, hotels, and restaurants. Within each thread, they might have sub-threads for investigating each of the competing options. Providing features for navigating information seeking sources that better fits users' mental model can potentially reduce their cognitive load, and enable efficient access to a large number of information sources without overly pressuring the users. Many readily available resources can potentially support creating these navigation structures, such as automatic search session structuring techniques [21] or recording users' search histories and webpages opened from different queries and allowing them to manually group searches into tasks [26].

Beyond threaded exploratory search sessions, participants were also conducting multiple general tasks in parallel, such as mixing productivity and leisure tasks. Users have to manually organize their tasks, and many were utilizing multi-tasking functionality of their operating systems such as multiple virtual desktops and multiple browser applications just to create hierarchical structures of more than two-levels. At the same time, some also noted the difficulty of organizing tabs, leading to mixing tabs of different tasks alongside each other in their browsers. On one hand, how to support organizing webpages beyond the two-level structure enabled from multiple windows remains a design challenge. On the other hand, many

simple mechanisms exist for organizing, triaging, and filtering files and emails could potentially provide ways of better manage opened webpages at the price of additional manual efforts. Further, many automatic machine learning approaches for identifying and classifying textual content into thematic classes that could also be explored for task identification of browser tabs. For example, topic modeling approaches such as Latent-Dirichlet Allocation [6] might help separate high level tasks, such as productivity tabs from leisure tabs. Other automatic techniques for classifying email beyond just spam and non-spam could also potentially help to identify finer-grained structures within opened tabs [8, 22].

Many participants used external applications to support web browsing, such as note taking and instant messaging applications (both of which were sometimes accessed through tabs). One problem with using external application is that provenance can be lost while transferring sources and information between applications. Participants mentioned manually copying and pasting URLs into note taking applications, or how URLs shared through instant messengers can be harder to get back to once closed. One direction to relieve these gaps could be providing better integration between browsers and other applications through general APIs or browser extensions. For example, allowing users to backtrack from tabs to emails or instant messages that originally shared the URL for context, or automatically include provenance beyond URLs when clipping web content to a note taking application, such as the search query the user used to find the webpage or other webpages opened from the same query. This could allow users to build structures that better fit their mental model (such as tables or mind maps) with external applications that were deeply integrated with their web browsers, enabling them to fluently switch between foraging more information and structuring the collected information.

In their introduction to the special issue on revisiting and reinventing email, Whittaker et al. state about 15 years of research on email that "*there is a real absence of theorizing about what e-mail is and what it does*". We believe there is a similar problem for how people utilize browser tabs for the modern Web. We hope that the findings in this paper on what motivates people to retain and close tabs, the high costs of keeping organized, and the issues people faced today with tabbed browsing can be a first step towards a better understanding. Having a comprehensive model of people's behavior and needs when conducting tasks on the modern Web will lead to better interfaces that can properly support its multitude activities.

REFERENCES

1. 1998-2017. DMOZ: The Open Directory Project. https://www.dmoz.org/. (1998-2017). Accessed: 2017-09-10.

2. Alan D Baddeley and Graham Hitch. 1974. Working memory. *Psychology of learning and motivation* 8 (1974), 47–89.

3. Victoria Bellotti, Nicolas Ducheneaut, Mark Howard, and Ian Smith. 2003. Taking email to task: the design and

evaluation of a task management centered email tool. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 345–352.

4. Victoria Bellotti, Nicolas Ducheneaut, Mark Howard, Ian Smith, and Rebecca E Grinter. 2005. Quality versus quantity: E-mail-centric task management and its relation with overload. *Human-computer interaction* 20, 1 (2005), 89–138.

5. Jeremy Birnholtz, Graham Dixon, and Jeffrey Hancock. 2012. Distance, ambiguity and appropriation: Structures affording impression management in a collocated organization. *Computers in Human Behavior* 28, 3 (2012), 1028–1035.

6. David M Blei, Andrew Y Ng, and Michael I Jordan. 2003. Latent dirichlet allocation. *Journal of machine Learning research* 3, Jan (2003), 993–1022.

7. Lara D Catledge and James E Pitkow. 1995. Characterizing browsing strategies in the World-Wide Web. *Computer Networks and ISDN systems* 27, 6 (1995), 1065–1073.

8. Laura A Dabbish, Robert E Kraut, Susan Fussell, and Sara Kiesler. 2005. Understanding email use: predicting action on a message. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 691–700.

9. Patrick Dubroy and Ravin Balakrishnan. 2010. A Study of Tabbed Browsing Among Mozilla Firefox Users. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 673–682. DOI: http://dx.doi.org/10.1145/1753326.1753426

10. Chrome Extension. 2017a. Tab Suspender. https://chrome.google.com/webstore/detail/tab-suspender/ fiabciakcmgepblmdkmemdbbkilneeeh?hl=en. (2017). Accessed: 2017-09-10.

11. Chrome Extension. 2017b. The Great Suspender. https://chrome.google.com/webstore/detail/the-great-suspender/ klbibkeccnjlkjkiokjodocebajanakg?hl=en. (2017). Accessed: 2017-09-10.

12. Chrome Extension. 2017c. vTabs. https://chrome.google.com/webstore/detail/vtabs/ okpnlgbgcfchbicbhjmmhldhkbkfilce. (2017). Accessed: 2017-09-10.

13. Firefox Extension. 2017d. Firefox Extension: Tree Style Tabs. https://addons.mozilla.org/en-US/firefox/addon/tree-style-tab/?src=search. (2017). Accessed: 2017-09-10.

14. Danyel Fisher, AJ Brush, Eric Gleave, and Marc A Smith. 2006. Revisiting Whittaker & Sidner's email overload ten years later. In *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*. ACM, 309–312.

15. Catherine Grevet, David Choi, Debra Kumar, and Eric Gilbert. 2014. Overload is overloaded: email in the age of Gmail. In *Proceedings of the sigchi conference on human factors in computing systems*. ACM, 793–802.

16. Life Hacker. 2012. Master Your Browsers Tabs with These Tricks and Extensions. http://lifehacker.com/5883299/master-your-browsers-tabs-with-these-tricks-and-extensions. (2012). Accessed: 2017-09-10.

17. Life Hacker. 2013a. It's Okay to Open More Than Nine Browser Tabs; Here's How to Easily Manage Them. http://lifehacker.com/5985462/its-okay-to-open-more-than-nine-browser-tabs-you-just-need-to-manage-them-properly. (2013). Accessed: 2017-09-10.

18. Life Hacker. 2013b. Why You Should Never Have More Than Nine Browser Tabs Open. http://lifehacker.com/5984149/why-you-should-never-have-more-than-nine-browser-tabs-open. (2013). Accessed: 2017-09-10.

19. Jeff Huang, Thomas Lin, and Ryen W White. 2012. No search result left behind: branching behavior with browser tabs. In *Proceedings of the fifth ACM international conference on Web search and data mining*. ACM, 203–212.

20. Jeff Huang and Ryen W White. 2010. Parallel browsing behavior on the web. In *Proceedings of the 21st ACM conference on Hypertext and hypermedia*. ACM, 13–18.

21. Rosie Jones and Kristina Lisa Klinkner. 2008. Beyond the session timeout: automatic hierarchical segmentation of search topics in query logs. In *Proceedings of the 17th ACM conference on Information and knowledge management*. ACM, 699–708.

22. Anjuli Kannan, Karol Kurach, Sujith Ravi, Tobias Kaufmann, Andrew Tomkins, Balint Miklos, Greg Corrado, László Lukács, Marina Ganea, Peter Young, and others. 2016. Smart reply: Automated response suggestion for email. *arXiv preprint arXiv:1606.04870* (2016).

23. Aniket Kittur, Andrew M Peters, Abdigani Diriye, Trupti Telang, and Michael R Bove. 2013. Costs and benefits of structured information foraging. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2989–2998.

24. Mark W Lansdale. 1988. The psychology of personal information management. *Applied ergonomics* 19, 1 (1988), 55–66.

25. Gary Marchionini. 2006. Exploratory search: from finding to understanding. *Commun. ACM* 49, 4 (2006), 41–46.

26. Dan Morris, Meredith Ringel Morris, and Gina Venolia. 2008. SearchBar: a search-centric web history for task resumption and information re-finding. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1207–1216.

27. Gergana Y Nenkov, Maureen Morrin, Barry Schwartz, Andrew Ward, and John Hulland. 2008. A short form of the Maximization Scale: Factor structure, reliability and validity studies. (2008).

28. Peter Pirolli and Stuart Card. 1999. Information foraging. *Psychological review* 106, 4 (1999), 643.

29. Reddit. 2013. I have a serious problem with browser tab hoarding. https://www.reddit.com/r/declutter/comments/1jpw13/i_have_a_serious_problem_with_browser_tab_hoarding/. (2013). Accessed: 2017-09-10.

30. Reddit. 2016. I'm a digital hoarder. I opened chrome to find all my tabs gone. I feel relieved. https://www.reddit.com/r/declutter/comments/4qkomc/im_a_digital_hoarder_i_opened_chrome_to_find_all/. (2016). Accessed: 2017-09-10.

31. Barry Schwartz. 2004. The paradox of choice. (2004).

32. Barry Schwartz, Andrew Ward, John Monterosso, Sonja Lyubomirsky, Katherine White, and Darrin R Lehman. 2002. Maximizing versus satisficing: happiness is a matter of choice. *Journal of personality and social psychology* 83, 5 (2002), 1178.

33. Anselm Strauss and Juliet Corbin. 1998. *Basics of qualitative research: Techniques and procedures for developing grounded theory* . Sage Publications, Inc.

34. Linda Tauscher and Saul Greenberg. 1997. How people revisit web pages: Empirical findings and implications for the design of history systems. *International Journal of Human-Computer Studies* 47, 1 (1997), 97–137.

35. Amos Tversky and Daniel Kahneman. 1991. Loss aversion in riskless choice: A reference-dependent model. *The quarterly journal of economics* 106, 4 (1991), 1039–1061.

36. W3C, W3Counter. 2017. Web Browser Usage Trends. https://www.w3counter.com/trends. (2017). Accessed: 2017-09-10.

37. Harald Weinreich, Hartmut Obendorf, Eelco Herder, and Matthias Mayer. 2006. Off the beaten tracks: exploring three aspects of web navigation. In *Proceedings of the 15th international conference on World Wide Web*. ACM, 133–142.

38. Harald Weinreich, Hartmut Obendorf, Eelco Herder, and Matthias Mayer. 2008. Not quite the average: An empirical study of Web use. *ACM Transactions on the Web (TWEB)* 2, 1 (2008), 5.

39. Steve Whittaker and Candace Sidner. 1996. Email overload: exploring personal information management of email. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 276–283.

40. Max L Wilson and others. 2008. Improving exploratory search interfaces: Adding value or information overload? (2008).