Aliia Kodzhoshalieva

Reducing Cognitive Load for a Data-Intensive Web Application User

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Supervisor: Anssi Öörni
Faculty of Social Sciences, Business and Economics
Åbo Akademi University
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ABSTRACT

Users experience certain levels of cognitive load when interacting with data-intensive web applications. The overload of a user's cognitive workload leads to poor user experience (UX), inability to make timely and better decisions, poor productivity, and fatigue. This thesis focuses on understanding what is cognitive load in UX, its importance and ways of reducing that load through a better UX design. A literature review was conducted on cognitive load theories and 4 UX design principles to reduce the cognitive load. The qualitative data collection method was applied in the form of structured and semi-structured interviews. A total of 11 companies were interviewed for the qualitative data collection purpose. 11 companies' applications were reviewed during the interviews from the cognitive load reduction perspective. Finally, the thesis work evaluates in a discussion form the gaps identified between the research background and the data collection results. In conclusion, three suggestions for future research work are made.

Keywords: user interface (UI), user experience (UX), user cognitive load, user psychology, data-intensive web application, human-computer interaction.

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LIST OF ABBREVIATIONS

UX	user experience
UI	user interface
TTI	Time to Interactive
ID	Instructional design
ISD	Instructional systems design
CTA	Call-to-action elements
RQ	Research question

CHAPTER 1

Introduction

Cognitive psychology in user experience (UX) design is a trending topic today and is relevant to anyone who has ever used any website, web, or mobile application. Most humans interact with web applications on a daily basis as it is a reality of today's digital world we live in. It is also inevitable that applications are becoming more and more data-intensive requiring the user interface (UI) to match the user's expectations and behaviors within those applications. This thesis paper focuses on understanding how users interact with web applications, specifically focusing on the user's cognitive load. The research explores what is cognitive load in UX, how can it be reduced by good/better user interface (UI) design and where do real-life data-intensive web applications stand when it comes to tackling the ultimate goal of reducing the cognitive load.

1.1 Purpose of the thesis and research questions

Every web application is designed and developed following certain UX design principles keeping the human user in mind. This academic research explores the interesting relationship and interaction of that human user with the web application's user interface (UI). User interface (UI) is a very broad term that is an umbrella for many study domains that cover human-computer interaction and communication in a given device [33]. To narrow down the scope for this master's thesis, the topic of user cognitive load within data-intensive web applications was selected as the primary focus area. The end goal of this thesis conclusion is to answer the following 3 research questions and to provide meaningful insights in a form of discussion and suggestions for future work at the end.

The research questions placed for this thesis work are:
Research question (RQ) 1: What is cognitive load in the context of UX?
Research question (RQ) 2: Can the cognitive load be reduced with good/better design and in which ways?
Research question (RQ) 3: How well are modern web applications today tackling the mission of reducing cognitive load? What are the areas that today's web applications could improve?

To answer the stated research questions the author conducted a literature review on what cognitive load is, exploring briefly 3 types of cognitive load and focusing the entire thesis on extraneous cognitive load to be specific. Then the research work continued in the form of a qualitative data collection method which entailed structured and semi-structured interviews of 11 companies with existing data-intensive web applications.

1.2 Thesis structure

This thesis work answers the 3 research questions and provides insights on the topic of cognitive load in UX in the following structure:

Chapter 2: Research background based on the literature review on the topics of cognitive load in UX and 4 UX design principles that contribute to minimizing cognitive load.

Chapter 3: Research methodology. This chapter will cover data collection methods implemented for this research work. Structured and semi-structured interviews will be the methods applied.

Chapter 4: Results of the data collection methods chosen will be provided and analyzed.

Chapter 5: Discussion and conclusions chapter provides a discussion and conclusion about the research work conducted and the valuable insights observed.

CHAPTER 2

Research background, literature review

The purpose of this literature review was to explore available information on cognitive psychology in UX design with the focus on minimizing the cognitive load. First, the author provides a comprehensive overview of what is cognitive load in the context of user experience (UX), what types of cognitive load are known, and which type is selected as the focus point for the rest of this thesis work. Then the author continues the literature review by focusing on 4 UX design principles that contribute to minimizing cognitive load.

Information for this literature review was obtained using search phrases and keywords such as cognitive psychology, cognitive load, working memory, short-term memory, user experience (UX), user interface (UI), data-intensive application, user psychology.

2.1 What is cognitive load in UX?

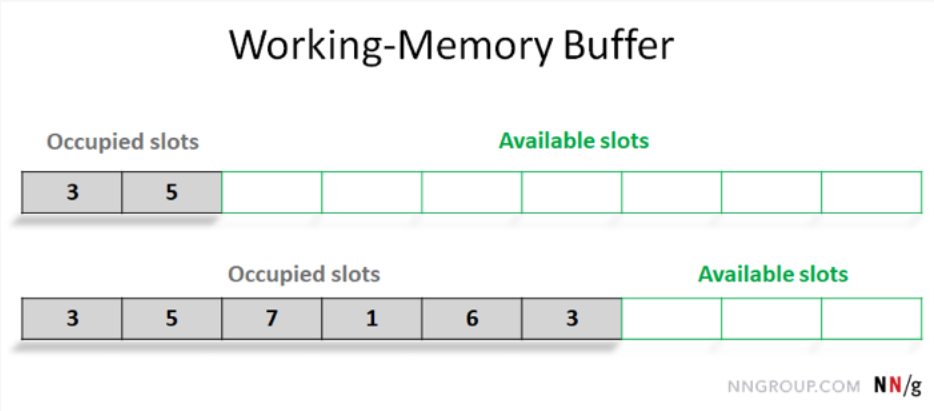
We as humans receive information through our senses (sight, hearing, smell, taste, and touch), which then trigger a call of action in our brain, and then the information is either used or not “digested". It takes some resources to actually process that information. The amount of resources our brain consumes to “decode” the received information depends on the cognitive load. Scientists have come to the conclusion that information carrying corresponding cognitive load enters our brain through the working memory [13]. Human working memory can only handle a certain amount of information and this is called the cognitive load.

Cognitive overload takes place when the user’s working memory is exposed to more information than it can process comfortably. Cognitive overload leads to fatigue, comprised decision making, and poor user experience in general. Before diving deeper into the topic of cognitive load, it is important to understand what human working memory is. Working memory is the human brain activity used to complete a task at hand in a given moment, it handles the processing of information [10].

As Danny Halarewich, Head of Commerce at Mailchimp said: “Think of working memory as computer RAM and long-term memory as the hard drive” [35]. Human working memory can be

compared to a scratchpad or a post-it note in which our mind stores information relevant to the current task. If that task requires too much information to be kept in that scratchpad (working memory) then there soon will be a need to free up some space for more information. The concept of working memory was first explained through a series of experiments by the psychologists Alan Baddeley and Graham Hitch where participants had to remember 1 to 6 digits while working on a second task [13]. When the number of digits the participant had to keep in memory was small (1-2), his/her performance on the second task was not affected. However, when the number of digits to be remembered became bigger, the participant's performance on the second task suffered. This is simply because there was less working memory (scratchpad space) left available for that task. This experiment is best illustrated in the following figure:

Figure 1: Working-memory buffer experiment [13]



Working memory is task-oriented in its essence, translating it to the UX language – working memory can be compared to the "interface" between different processes such as perception, attention, and memory while they all work together on a bigger task as the big picture.

For the purpose of this research paper, it is important to go one step further into the next sublayer or a component of the working memory which is the short-term memory. From the numerous literature available on cognitive psychology in UX it is clear that the two terms: working memory and short-term memory are used interchangeably. However, for this paper's agenda it is important to clarify that these two memories are not exactly the same. They are, however, both needed to be explained for the purpose of understanding what is cognitive load in UX. So short-term memory is simply the brain process that allows us to store information for a short amount of time, for about 20 to 30 seconds

according to George Miller, a cognitive psychologist, and linguist who was a big contributor in the cognitive psychology field [9]. Miller's information processing theories provided theoretical ideas that are underlying to cognitive psychology and the information processing framework and his work dates back to the 1950s [9]. Research on the limits of short-term memory conducted by Miller has established itself in digital design even today. For example, Miller's Law of 7±2 or "The magical number seven, plus or minus two: some limits on our capacity for processing information" which was first published in 1956 remains as the guiding principle to reducing cognitive load through better UX design [9]. This law argues that the human brain can hold in short-term memory 7±2 objects. In other words, human short-term memory can only hold about 7 pieces of information and these pieces will fade away from our brain in about 20-30 seconds. This should be considered when attempting to reduce cognitive load through better UX design.

Both working memory and short-term memory must be understood well before designing any web application's user interface (UI), as these two interconnected memory types are both directly related to the cognitive load concept. The higher the burden on the working and short-term memories, the more cognitive load is incurred by a user. Different tasks have different corresponding working-memory requirements. UX designers must first understand what type of information users of the web application need to reach their goal or complete a task, and UI features must be provided accordingly to help reduce the cognitive burden allowing the user to successfully perform the task.

Now that we understand how information enters our brain through working memory with the help of short-term memory, let's look closer at the cognitive load that that incoming information carries. Human cognitive as a notion has been around for centuries, however, the term of the cognitive load was first introduced by the Australian educational psychologist John Sweller in his renowned work: "Cognitive load theory, learning difficulty, and instructional design" in 1988 [8]. In this study of problem-solving, Sweller claimed that implementing instructional design can directly contribute to cognitive load minimizing. Instructional design (ID) or instructional systems design (ISD) refers to the approach of systematically designing, developing instructional material (in digital and physical forms) in a consistent practice to enable efficient and engaging attainment of knowledge [11].

In his work, Sweller distinguishes favorable conditions for any learner to return the information he or she was taught, outlining effective and ineffective teaching methods and presented key findings on the limitations of working memory. Although Sweller's work is within the educational domain,

instructional design to be specific, his work in many ways is still used by designers today when it comes to counting in the limitations of the working memory of a user.

In cognitive psychology, cognitive load theory characterizes three types of cognitive load: intrinsic, extraneous, and germane. The intrinsic cognitive load takes place when our brain is focused on a specific subject or task, extraneous cognitive load is associated with the way information is given to us and lastly, germane cognitive load handles the effort of creating a long-term store of information [12]. The part that can be easily tackled through good/better UX design is extraneous cognitive load. Extraneous cognitive load is a result of poor or bad UX design. In web application design, when we refer to extraneous cognitive load, we refer to anything that takes up user's mental resources to deal with problems that not exactly related to the real task or goal at hand. The extraneous cognitive load could happen, for example, when there are inconsistent font sizes used on the web page, this would distract the user from the core task. Extraneous cognitive load is the exact type of cognitive load that this entire research paper is focused on, however, for the sake of simplicity, the author will use the term cognitive load for the rest of the paper as this is the generally accepted term in the UX design field.

Now that the concept of cognitive load in UX is explained, the next natural question is why exactly it is important to reduce that cognitive load? To start this section of the thesis, the author suggests the reader to think of a very basic task most people do on a daily basis. Let's take opening a fridge door as an example. We know what to do to open a fridge door, we simply open it and we know that 99.9 percent of the time the fridge door will open because it always did before. We open the door without even thinking. Now imagine if there was an additional passcode to open that same fridge door every day: one must enter a 10-sentence password. Undoubtedly, eventually, this would lead to frustration, to say the least. This is exactly the strategy to consider when designing user interface (UI) for the data-intensive applications, the same basic principles of human psychology apply because it all comes down to the cognitive load that our working memory has to handle.

So why are we devoting an entire thesis work to understanding the cognitive load and triggers that could potentially minimize that load? Because reducing cognitive load leads to all-around better user experience (UX), less fatigue, better and faster decision-making possibility, improved productivity [36]. When the user is interacting with smart-designed, optimally implemented, and user-focused UI, the data is perceived and processed faster and decision making becomes easier. A well-designed UI

ensures that the user cognitive load is not overloaded, and the user has good chances to make a better and timely decision.

Users 'processing abilities are continuously overloaded with information and interaction opportunities within the multifaceted digital environment that we live in. Therefore, the optimal distribution of attention is one of the key factors that affect the success rate of human-computer systems interactions whether it is for learning, working, collaboration, or other tasks. Attention is such a vital human psychology phenomenon that it must play an important role in the design of any technology. In her book "Human Attention in Digital Environments" Claudia Roda presents research related to human attention in the digital environment and its implications for human-computer interaction [6]. The reason this particular book raised interest for this thesis is that it addresses the problem of how digital systems can be designed in such a manner that not only they would allow fast access to information and people, but they also would support human attentional processes (p.1 [6]. Essential theoretical findings about human attention are well explained in correlation to design systems in this book. When applying the cognitive load theory to web design we still need to remember a simple comparison of human limited attention to a speeding freight train as in the great quote from Luke Wroblewski, Product Director at Google:

> Getting in the way of a speeding freight train usually does not end well. It takes a lot of effort to shift the course of something with that much momentum. Rather than forcing people to divert their attention from their primary task, come to where they are (37, Wroblewski, L., 2018).

Minimizing the cognitive load is an integral goal to stay focused on while designing UX for any web application. The rest of the literature review develops into specific ways how user cognitive load can be reduced.

2.2 Principle 1: Provide working and short-term memory support

There are many various ways that user cognitive load can be reduced. As a reminder, this is referring to the extraneous cognitive load and UX design principles that can reduce that specific type of cognitive load. The author has grouped her entire UX principles findings into 4 predominant UX design principles that ultimately lead to cognitive load minimization. Now, it is important to note that

should have this research work been more extensive then there could be additional principles added or each principle could by itself stand as the research topic alone. However, for this research project this structure was more logical and provided a comprehensive overview of what UX design principles can directly reduce the user cognitive load.

The first principle described is providing memory support for working and short-term memories from the UX design perspective. As a short recap, according to Miller's law, the number of objects (information pieces) which a human brain can keep in short-term memory (post-it note) is 7±2, meaning seven items that will disappear from our memory in 20 – 30 seconds [9]. This law has to be kept as a golden rule when thinking of ways to reduce the cognitive load within this first principle.
The first and biggest limitation of our short-term memory is the time that the user can spare on focusing on a given set of objects, as Miller proved before, it is roughly 20 – 30 seconds. Therefore, the natural web design guideline would be to reduce the response times, because users can easily forget what they were in the middle of working on while waiting for the page view to load. We can lose our user's attention and focus by making him/her wait on slow page rendering. Users hate slow loading pages and it affects the overall user experience (UX) negatively. In his usability study conducted since 1994, Jakob Nielsen shares that users have been begging for the same thing over and over: for pages to download faster [43]. Moreover, Nielsen suggests already in 1997 that speed must become the overriding UX design criterion. One interesting metaphor to apply here is that the longer the user suffers waiting for the webpage to load, the faster the information stored in his/her short-term memory (post-it note) starts decaying. So, speed does matter. Usability studies continuously prove that even reducing the response time by 0.1 seconds directly leads to better user experience [43]. This is why the metric of Time to Interactive (TTI) was studied in this research process.

Time is a very simple yet complex multidimensional concept, it is perceived very subjectively from an individual to another. When it comes to user experience in data-intensive web applications, time is exceptionally important from the user's perspective. The time consumed on retrieving the relevant data is viewed as wasted time which in essence diminishes user's ability to make the timely decision or in the least detrimental case, it simply leads to poor user experience affecting productivity and again overloading the cognitive workload.

Time to Interactive (TTI) is a web performance metric that focuses on what users see and experience and was first coined as a key metric by Google [22]. Essentially, what TTI measures is the moment

when a user can start efficiently executing his/her task/goal at hand. The keyword to read in the TTI term is “interactive”, so what we are looking at is the moment when the user can interact with a given page/view within the application’s UI in a satisfactory manner by consulting the content he/she is exposed to. To elaborate further, TTI is a page load performance metric that evaluates the time it takes for a given page in the web application’s UI to become interactive. To define what does “interactive” imply, technical documentation on this metric provides the following definitions:

- Useful/comprehensible content is displayed on a given page
- Event handlers are registered for the most visible page elements
- User does not experience latency (at least what the user can perceive) as the page consistently respond within 50 ms. [23].

Time to Interactive (TTI) focuses on the “loading experience” providing web developers with useful insights. TTI is meant to be a better alternative for measuring page load time [23]. The reason TTI was selected to be added to this research work is because this is the latest and most sophisticated metric used by the web performance experts as of today. Google has integrated complex algorithms to measure TTI by pinpointing the time when the user’s seamless web experience begins [23]. Time to Interactive (TTI) is the most technical term of this thesis work and there is not a lot of scientific research done on this topic yet, therefore most of the reference points were mainly from the technical documentation available on GitHub. GitHub is a web-based version-control and collaboration platform for software developers, it hosts repositories for various web development projects [38]. The repository for hosting TTI specification and discussion around it was the author’s most reliable source [23].

So how is this TTI metric applicable to minimizing the user cognitive load? Examples optimizing web applications by reducing TTI indicate that cutting TTI even by a fraction of seconds can exponentially improve the user experience. The user does not experience delays and blocked UI elements that can have a negative effect on the user’s interaction in the web application. A case study of Pinterest’s web application observed a 60% higher user engagement after Time to Interactive was reduced from 23s to 5.6s, and to 3.9s on repeat visits [40].

Besides reducing the response time, there are other simpler ways within this first UX design principle that can directly contribute to reducing the cognitive load. This section will cover the topic of the

user's tasks within the web application. A user interacts with the given web application's user interface (UI) with the goal of completing a task or some other mission. So, what UX design guidelines can help with task performance as it is the main reason a user enters the web application? As we already identified, the human brain uses working and short-term memory to store small pieces of information on so-called mental "post-it" notes. That space is limited and when completing a task at hand the user has only that "post-it" to stack information onto plus add the limited time that working memory has to remember that information (20-30 seconds per 7 or so items). Quite often, users in data-intensive web applications have complex tasks to accomplish. One way to help users in task performance without overloading their cognitive load is to design large, complex tasks as a series of smaller operations rather than one large task involving significant cognitive load burden [46]. Users can easily get lost in the multiple tasks they must complete within the page even if those tasks would be hierarchically structured. Breaking complex tasks into smaller chunks or subtasks and breaking longer user workflow sequences into separate steps can help utilize the user's short-term memory capacity therefore minimizing the cognitive load. This process is usually referred to as "chunking" and chunking as a concept originated from the field of cognitive psychology. Breaking text, web content, and tasks into smaller chunks helps users process, understand, and remembers things better [44]. The end goal for the user is to complete the task at hand, and the UX design should provide all the favorable conditions for that to happen. Quite often there are also repetitive tasks that the user must do within the given application's user interface (UI). Repetitive tasks can be replaced by shortcuts. In UX, these shortcuts can be represented by "hotkey" equivalents of menu, icon, and button command choices, such as Ctrl-S for the Save command, for example [46]. Replacing repetitive tasks with shortcuts provides direct support that is needed for memory limitations in UX design.

2.3 Principle 2: Recognition rather than recall

There are two types of memory retrieval described by psychologists: recognition and recall. Recognition refers to our ability to "recognize" an event or piece of information as being familiar and recall is described as the retrieval of related details to the information from our memory [45]. Promoting recognition over recall in UX design is highly recommended by all UX principle guidelines. This part of the thesis work will explore why recognition is better than recall from the UX design perspective. Humans recognize things better than they memorize them. This fact becomes particularly crucial from the cognitive load motivations because recognition requires less processing

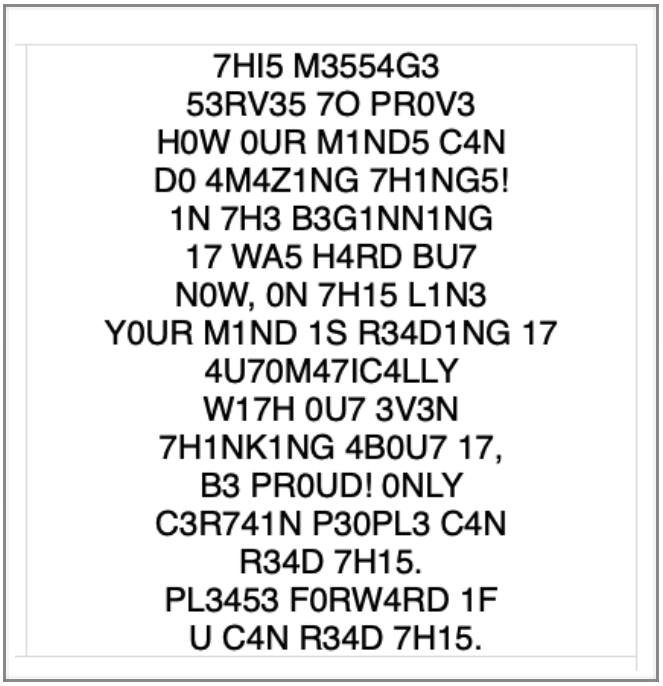
work for the human brain which leads to cognitive load reduction and fewer human errors [45]. Recognition differentiates from recall by the number of cues helping the memory retrieval process: recall requires less cues than recognition. To better understand how recognition works and can help reduce the cognitive load when working on the UX design, some well-known cognitive psychology principles will help. As James Montalbano said: “Your brain knows the shape of the world” (James Montalbano, the Gestalt perception principle is applied when we choose recognition over recall to simplify our users’ experience [47]. Gestalt memory theory describes how humans perceive visual elements based on the precognitive determination of what those elements mean or do based on the size, shape, position, and other applied conditions [18].

In the terms of web applications, applying Gestalt principles translates to, for example, a case of designing a download button that must visually match what the user already has in his/her head as the perception of a download button. Since our human cognitive resources are scarce, we need to ensure that “digesting” these visual clues (i.e. download button) is as easy as it can be, meaning it should be effortless consumption. As David C. Evans said in the Gestalt Perception chapter in his book: “Psychologists have known for decades that we are cognitive misers, meaning that we will allocate the least possible processing power to determine your value to us” [18, page 37].

To better understand the origins of this theory, let’s look at the word “gestalt’, the literal translation from the German language of the word “gestalt” is” form, shape” [19]. According to the Gestalt principle, we judge the presented visual element (i.e. download button in the application) by its appearance and the conditions around it.

The following demonstration of the influence of context on our perception proves the notion of the Gestalt theory brilliantly: please try reading the following text.

Figure 2: If you can read this you have strong mind [2]



People can still read through the above text despite the gibberish letters because this is the power of the human precognitive determination according to Gestalt theory. The key takeaway from this theory to apply in web application design is:

> Before we read the textual labels on graphic elements, we precognitively examine their form (Gestalt) and nearby elements to guess their function, so as to expend the least attentional effort to reach our goals (Evans, D.C., 2017, p.38).

Gestalt principles applied in UX design could mean providing visuals as alternatives for reading the text while making contextual information required by a given task visible. One helpful UX strategy to apply here is simply using familiar, well recognizable, already known convention. The general advice is - don't reinvent the wheel, user psychology is human psychology (for now). Human psychology doesn't change that easily over a day or month or even a year. If we want our users to get things fast then the best strategy would be to follow existing conventions, meaning commonly used or standardized design patterns [1, page 29]. A good universally accepted example is a stop sign, it is more or so standardized worldwide with shape, color, and some text in the middle. The same principle

applies for the gas pedal. Imagine if rental cars had the pedal on a different side compared to the pedal location in your own car. This would make no sense and definitely overload our cognitive load.

However, it is necessary to note that many conventions in web applications have evolved and will continue doing so: for example, where links/tabs are located on each web page, how things work and look - all these set certain user expectations. When applied well, web conventions make life easier for users because users don't have to constantly figure out what things are and how they are supposed to work as they go from one-page view to another [1, page 31]. Last note to make here - innovation is good and should always be welcome, however, it should be a better solution to what is being replaced. The well-known example of this is a scroll bar in web pages, many designers try new trendy ways to design and implement the scroll bar in their pages, but it always ends up being the same scroll bar at the end of the day. Web navigation conventions should also be followed. Similarly, to physical spaces such as streets, buildings people rely on standardized navigation systems with conventions that have been there for a long time and have been evolving for years, some even for centuries. People know where to look and where to go when they see them. This standardization minimizes our thinking effort and makes it easy to distinguish them from everything else. Some most granted taken conventions are street signs, names of buildings being above or next to the front door, each aisle in a store having a name, page numbers in books or magazines. All these basic conventions are applicable in web navigation although with different appearances to fit the web.

2.4 Principle 3: Avoid visual clutter

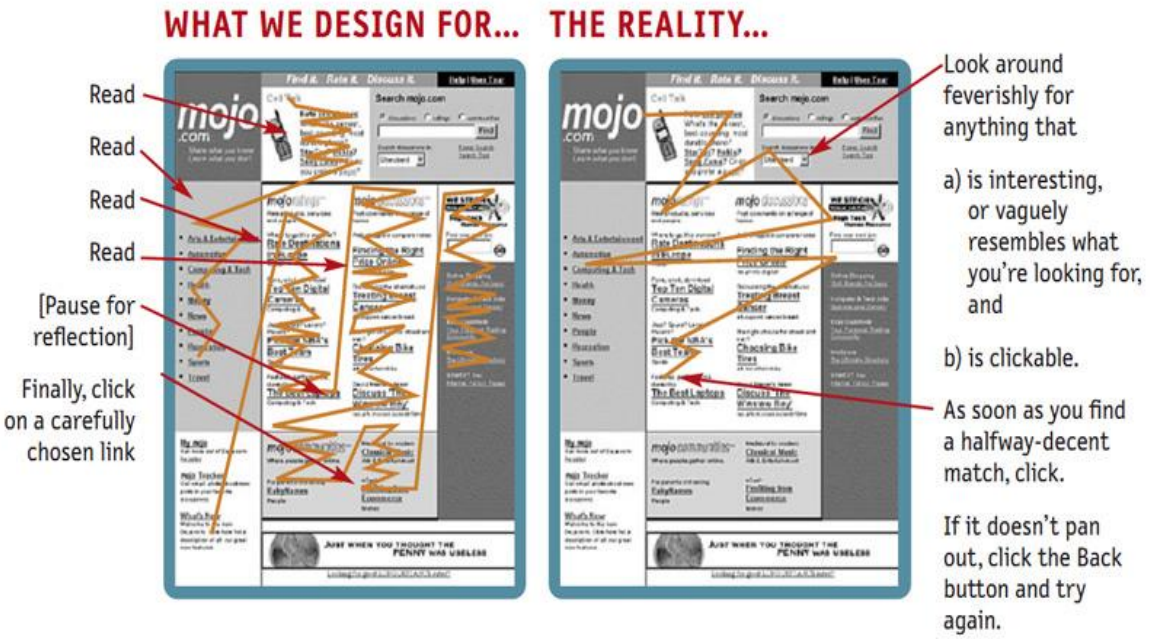
The ultimate goal when designing the user interface (UI) for a given web application should be to eliminate all the potential question marks in our users' heads, in other words, don't make the user think. Users should never devote even a millisecond of thought to whether something is clickable or not, for example. Every time a user has a question mark "hanging" over his/her head, it adds to the user's cognitive workload, distracting his/her limited attention from the important task or goal at hand. Even if these "slight" distractions last milliseconds, they can all add up and lead to decreased productivity, human errors, delayed decision making, and fatigue [1, page 17]. The goal should be for each page view or screen within the UI to be self-evident and self-explanatory so that just by looking at it a user will know what it is and how to use it [1, page 18].

This third UX design principle focuses on visual design decisions. To further recognize how this third principle contributes directly to minimizing user cognitive load, it is important to first understand how exactly users behave when they use web applications. The following quote from Steve Krug gives a good overview of how users behave online in real life:

> "When we're creating sites, we act as though people are going to pore over each page, reading all of our carefully crafted text, figuring out how we've organized things, and weighing their options before deciding which link to click. What they actually do most of the time is glance at each new page, scan some of the text and click on the first link that catches their interest or vaguely resembles the thing they are looking for." (Krug, S. 2014, p.21).

The reality is that users don't read pages, they scan them, looking for words or objects (buttons) that catch their eye [1, page 22]. The UI designed for a web application is often different from what the user needs in reality. Web application users have a mission when they enter the UI of the application, it could be a mission to retrieve information, to complete a task or some other assigned mission. Usually, users want to complete their mission quickly, therefore they don't want to waste any of their time on reading unnecessary texts on the web. Users are predominantly interested only in the fraction of what is displayed on most of the web applications. They swiftly scan for the parts that correspond to their ultimate goals, interests or the task at hand that they are trying to accomplish. The rest becomes irrelevant. Users want only relevant things. The word "instinct" was mentioned above when referring to the inherent habit of scanning. Indeed, scanning is a human habit and comes instinctively to us, it is a basic skill in human psychology that humans acquire as they learn to read. People scan newspapers, magazines, social media pages (scrolling) to find only the parts that are relevant to them or interesting to them. To design effective web applications, it is essential to acknowledge these facts of life that users are on a mission to get information or complete some task, preferably fast, and that users scan rather than read. The following figure was taken from the book by Steve Krug "Don't make me think", and it depicts quite well how our scanning habits work.

Figure 3: What we design for vs. The reality [1, page 21].



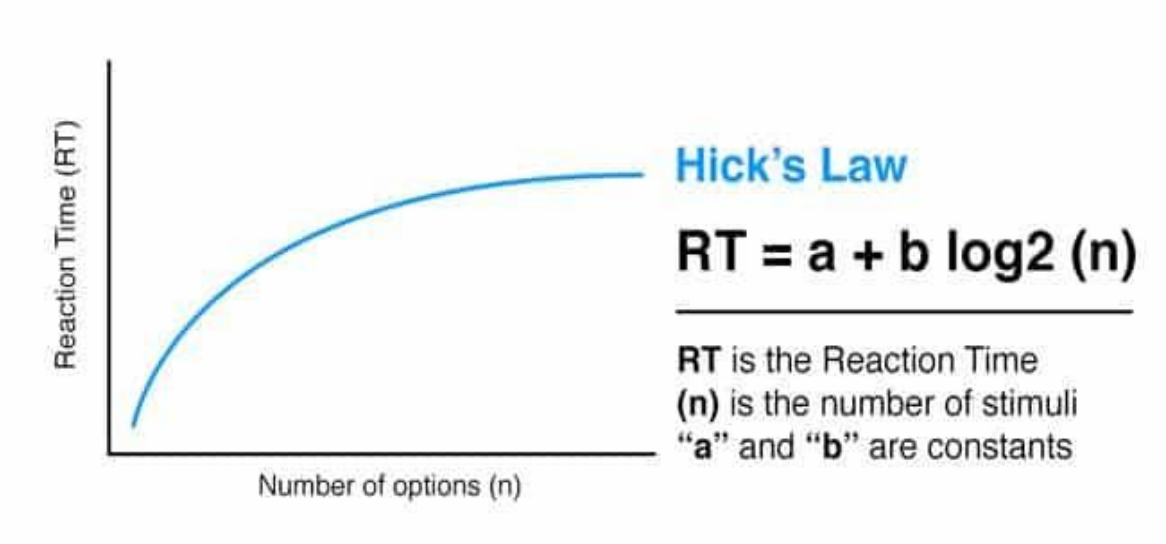
When users are scanning web pages in search of the needed information to complete the task at hand the way the text is formatted can affect greatly how easy or challenging the process of scanning is made for the user. So what can be done to make pages "scan-friendly"? The basic rule of thumb is to format the text within your application to support scanning. This translates to using plenty of headings, formatting those headings correctly, and for example, not letting the headings float (making sure they are close to the section they introduce than to the section they follow, since this can make a huge difference [1, page 40]. The author did not go more into detail on other text formatting techniques such as using bullet lists, keeping paragraphs short, highlighting key terms, etc., because those are not directly applicable for the web applications covered within this thesis work's scope. Another simple step to align the user interface (UI) design with the way the user "scans" the webpages is to present the information in chunks instead of concatenation.

Some other concrete UX design decisions to support this third principle are making the design simple, keeping the visual clutter to a minimum, and striving for easily understandable visual elements that help the user have a seamless UI experience. When a user is bombarded by too many visual elements whether they are purely decorative or functional, he/she must continuously make choices what to focus on. Hick's Law or Hick-Hyman Law named after a team of psychologists, William Edmund

Hick and Ray Hyman states that the more choices the person is given the more time it takes that person to make a decision [14]. The more time the person has to think while choosing, the more cognitive overload takes place.

In 1952 Hick and Hyman started examining the connection between the number of stimuli presented and the person's reaction time to any given stimulus [15]. This research became the groundwork for understanding the so seemingly simple status quo we have today in human behavior: the more choices we give to a user, the longer it will take that user to make a decision and take a call of action. When exposed to too many options, users are overwhelmed with the abundance of information and it depletes the working memory bandwidth, therefore overloading the cognitive load and undoubtedly leading to slow decision making or even worse, no decision making at all.

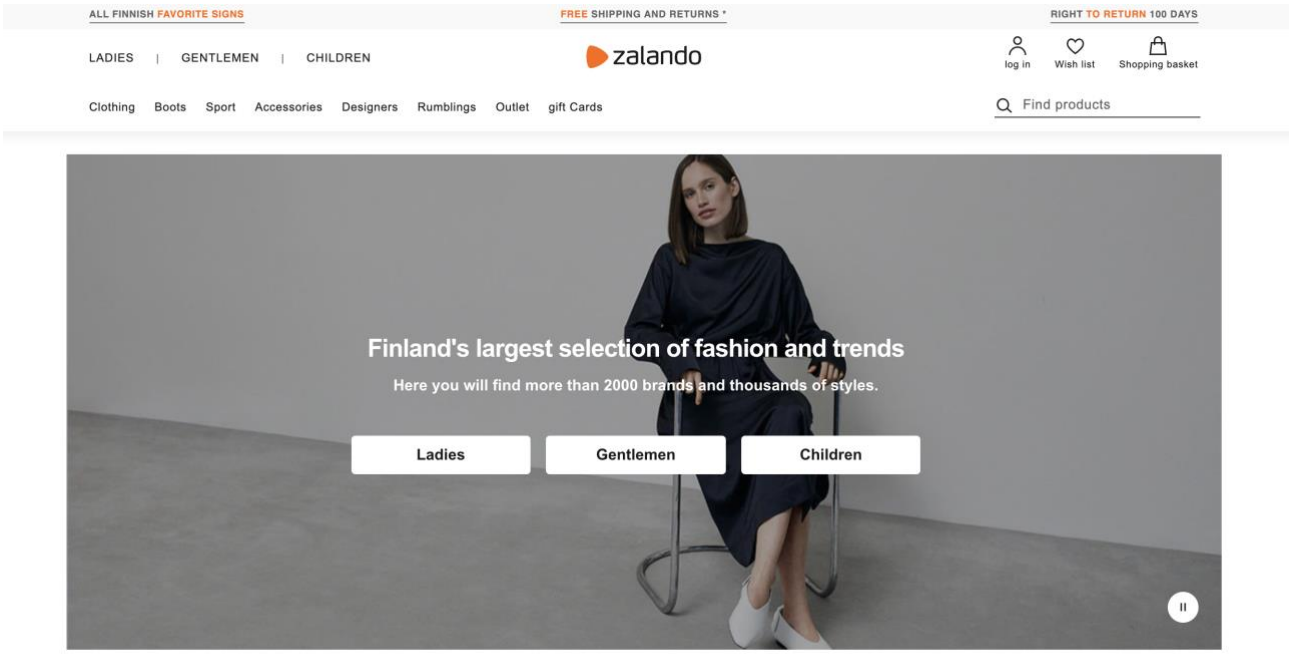
Figure 4: Hick's law graph [15]



This fundamentally important psychological principle must be absolutely considered when designing the user interface (UI) for a data-intensive application, for example, when prototyping functionalities of a page, navigation menus, etc. Always consider the burden is being placed on a user when giving a certain amount of options to choose from. Perhaps a simple question to continuously ask during the UX design process is "how is all the data being presented to the user?" since we can't completely eliminate choice making.

The example of Zalando, a European e-commerce company offering fashion shopping through a platform approach. Shoppers on Zalando have less decision-time to waste thanks to the platform's UI design. Imagine if a user would have to choose a clothing item from all the options available within the site, it would simply be impossible, therefore browse tabs, categories, and navigation menus are there to help the user walk through the UI to their end goal.

Figure 5: Landing page on Zalando, offering 3 options to choose from [screenshot from zalando.com]

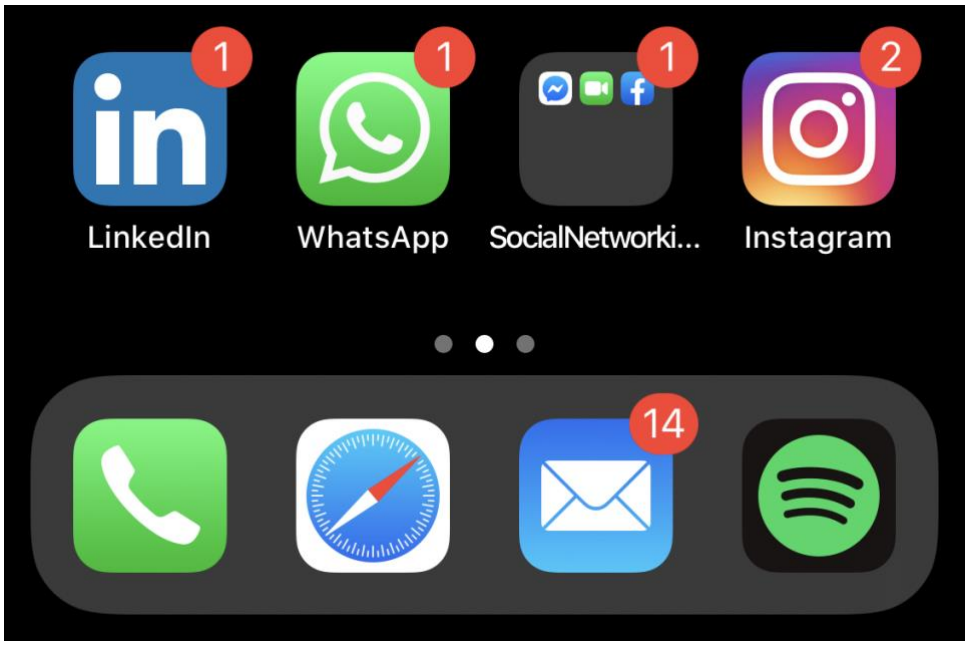


Once the user lands on the webpage of Zalando, he or she needs to make a simple choice between three tabs as shown in figure 5. The user experience continues with narrowing down the selection even further and shopping within the category that is relevant to the user. This is an example of a coherent and logical experience which reduces the time the user would take making a decision. Keeping the decision making simple and based on essentials is an optimal approach to presenting options to a user.

Another visual design rule worth mentioning is allowing the user to focus as much as possible on the most important visual cues, for example, crucial notifications or call-to-action elements (CTAs). It is important to make call-to-action elements (CTAs) easily distinguishable within the application's user interface (UI). This principle is explained by the Von Restorff effect, also known as the isolation effect, which is a psychology principle explaining when multiple related objects are present, the user

will remember the item that differs from the rest [16]. The theory was founded by the German psychiatrist and pediatrician Hedwig von Restorff (1906 - 1962) who in her studies examined how participants memorize much better the distinctive, isolated item among all the categorically similar items [17]. Some ways to use the Von Restorff effect are to make those CTA elements visually standout by color, shape, etc.

Figure 6: The Von Restorff effect in alerting users to incoming notifications [screenshot from the author's cell phone screen]



From the example given in figure 6, the user can clearly distinguish which applications in her phone currently require most immediate attention as the bright red bubble notification badges ensure attention is drawn at them. These visual design implementations ensure that the user's cognitive load is consumed for the necessary action or task at hand, and the attention is focused where it is needed.

This is especially important when talking about data-intensive applications for time-sensitive industry sectors such as autonomous driving, medical field, mining, and others. The cost of the user for example, not remembering or not understanding which button to click on can be not only financially detrimental but also could cost lives. So as basic as this Von Restorff effect sounds, it cannot be underestimated when designing UI for any web application. It all trickles down to minimizing user's cognitive load, everything within the application's user interface (UI) must be designed and

implemented in such a manner that it always lowers the cognitive load or at the minimum, it does not add more weight to it if not necessary.

Next, it is important to implement effective visual hierarchies by ensuring that all the visual cues within the application accurately represent the relationship between the items on the pages, which of those are the most important, which elements are similar, and which are part of other subjects. Basically, each page view should have a clear visual hierarchy [1].

The amusing fact is that users are so accustomed to good visual hierarchy standards in their everyday lives that it is taken as a status quo and they notice a difference only when the visual hierarchy is absent because then the user is forced to think. Many articles on visual hierarchy were reviewed for this thesis work and it is interesting to point out that there is nothing that innovative about visual hierarchy principles in general: every newspaper page, for example, does it well by using simple three principles: prominence, grouping, nesting [1, page 35].

Figure 7: Visual hierarchy example in newspapers [1, page 35]

A good visual hierarchy saves us work by processing the page for us, organizing, and prioritizing its contents in a way that we can grasp it almost instantly [1]. This is going to be a crucial factor when working with complex and large amounts of data being processed in real-time for a user to make a quick decision.

Lastly, breaking up pages into clearly defined areas is also a good rule to follow when a visual hierarchy is being planned. Eye-tracking experiments on web page scanning suggest that users decide very quickly in their initial glances which parts of the page are likely to have useful information and then rarely look at the other parts of the page - almost as though they weren't there [1, page 36]. No unnecessary data should be displayed to the user in order to minimize the cognitive load.

2.5 User's mental model

A mental model is a belief system that a user holds about any given system or interaction, in this case, a web application, for example. It is a user's own intuitive knowledge of how things are supposed to work in the given web application system based on his/her own experience [48]. Usually, a user's thinking is closely related to reality as they base their predictions about the system on their mental models. Understanding the user's mental model helps tremendously when designing the web application's user interface (UI) for that particular user type, as it helps to design a web application that communicates clearly to that user.

Translating mental model understanding into UX implementation could mean matching the user interface (UI) to the user's mental model and using real-world metaphors to convey the necessary information [39]. As Jakob Nielsen stated on the importance of matching the system and the real world, human beings find comfort in familiarity:

> The system should speak the user's language, with words, phrases, and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order (Nielsen, J. 1994).

The phrase "real-world metaphors" was mentioned here so it is important to note that there are widely spread metaphors that should be considered when designing user interfaces, however, each culture has its own established metaphors [39]. This has to be taken into account especially if designing web applications for the international user base.

Another important notion to make here is that when working on the design of the user interface (UI), it is wrong to assume that your own interpretations of the world, or as in cognitive psychology terms,

your mental model matches those of the users you are designing the web application for. The way the user interprets the world depends on a variety of circumstances and personal factors and experiences. Some simple concrete ways to handle this UX principle on the mental model of users are to use familiar language. As simple as it sounds, using terms that make sense or are familiar to the user will greatly alleviate the user's cognitive load as it will require less effort to process the UI elements. Using acronyms, abbreviations must be done with careful design thinking in mind because it should never be assumed that the user understands all the abbreviations and technical jargon [48].

The second practice of knowing your user's mental model is leveraging familiarity with real-world objects and experiences. The best way to achieve this could be through skeuomorphic web design which focuses on creating user interaction with the web application that imitates one from the physical world we live in [48]. This helps to utilize the users' existing knowledge and makes the process of getting to know the web application's user interface (UI) much easier and faster. Essentially, users transition to the digital environment from the real, physical world by carrying their learned interpretations of real-world objects along with them. Therefore, it is logical that user interface (UI) elements should at best reflect real-life objects similar to those that users have interacted with in the physical world. For example, a compass application on iPhones visually mimics the actual traditional compass that we know from the physical world.

Figure 8: UI elements in a compass app on iPhone (left) vs. the real-world (right) [screenshot from the author's cell phone and a free stock photo from unsplash.com of a compass]

Mental models are based on beliefs and not facts, so it is essentially a model of what users think they know about the web application based on their preexisting experiences. The users will base their predictions about the way the web application should work based on their mental models so from the UX design point of view it is important to match the web application's user interface (UI) to the user's mental models. So, what happens when there is a mismatch between the user's mental models and the web application's user interface (UI)? Will that increase the cognitive load in UX? The discrepancies between the user's mental model and the user interface (UI) can be detrimental from the UX standpoint. This could cause problems such as users not understanding what to do within the web applications, with basic mistakes as confusing commands, icons, mixing up various input fields. This would directly lead to cognitive overload.

CHAPTER 3

Research methodology

The original research plan for this thesis work scoped out a research methodology that included both qualitative and quantitative data collection approaches. However, that path had to be shifted due to the recent COVID-19 pandemic situation which has limited the data collection and analysis methods that would have been physically available at the author's disposal otherwise. Therefore, this research work has used a mixed, holistic qualitative research methodology with structured and semi-structured interviews as the selected approach. The reasoning for combining the two methods of interviewing was due to the nature of the interviews conducted.

The author used parts of the existing Vaadin UX Checkup interview methodology as it has been a proven, efficient, hands-on UX interviewing set already used in her work. Vaadin UX Checkup interviewing is a checklist-based assessment of a web application's user experience (UX) [39]. The entire interviewing set consists of a 100-item checklist and provides an overall and technical analysis on a given web application's UX. The author borrowed only 10 questions from this UX Checkup interviewing methodology to gather her empirical evidence to support her research.

There was a total of 11 companies interviewed and each interview meeting consisted of two parts: 1. structured interviews 2. semi-structured interviews.

3.1 Qualitative interviewing methodology

This chapter focuses on the methodology chosen for collecting empirical data. There were 3 research questions placed for this thesis research:

Research question (RQ) 1: What is cognitive load in the context of UX?
Research question (RQ) 2: Can the cognitive load be reduced with good/better design and in which ways?
Research question (RQ) 3: How well are modern web applications today tackling the mission of reducing cognitive load? What are the areas that today's web applications could improve?

To answer these stated research questions and to have a meaningful discussion at the end with concrete suggestions for future work the author has first conducted a literature review to answer the first research question: what is cognitive load in UX. Research question 2 was also answered from the theoretical perspective by exploring 4 concrete UX design principles for reducing cognitive load with better design. The author utilized the theoretical findings on the 4 UX design practices to lowering cognitive load in her qualitative research methodology. The interview questions were based on the theoretical findings to the second research question. The qualitative research methodology was applied to gather the empirical data to answer research question 3 and either to support the existing research findings so far or to provide new insights for the possible answers to the research questions.

As stated in the preface of this section, qualitative research methodology was applied within the scope of this thesis work. University of Southern California research guides define qualitative research as "a process of naturalistic inquiry that seeks an in-depth understanding of social phenomena within their natural setting." Qualitative research focuses on the reasoning behind the individual behavior, societies, and cultures through exploratory questioning [26]. This approach has several characteristics that are deemed to be integral to this methodology: it uses words, concerned with meanings, induces hypothesis from data, and case studies. Denzin and Lincoln (2005) explain further that qualitative research is built on the hypothesis of the social construction of the researched realities [24]. And this was one of the strongest reasons why the author selected qualitative research methodology, this research practice takes place in the natural environment, providing a focus on naturally occurring, habitual events in natural settings giving us a strong handle on what the usual flow of life is. In this approach, the data is collected in close proximity to a specific situation, rather than through the mail or over the phone [28]. So, by spending time talking to the inhabitants of data-intensive applications from the UI perspective, the author had an opportunity to derive the empirical data from the embedded context.

The richness and holistic approach of qualitative data methodology allow flexibility when revealing the complexity of the subject studied. Taking into consideration the personal features of the thesis writer the qualitative research method makes even more sense because this type of research gives a chance for the researcher to establish a direct relationship with the interviewees. This multifaceted relationship between the observer and observed is well explained by Mintzberg 1979 [29]. Qualitative approach methods are more interactive, personal; and give room for creativity.

Bryman and Bell outlined key research methods applied in the qualitative approach method, with the mixed-method approach being the most frequently used [25]. This is the approach chosen for this thesis work as well: employing qualitative interviews and analyzing texts and documents [25]. In this thesis work, the author organized and processed structured and semi-structured interviews as the chosen type of qualitative data collection method. This combination provided flexibility to explore social reality through the perspective of the interviewees. The social reality being explored was the state of today's web applications regarding tackling cognitive load reduction. The author aimed to gather empirical evidence on which of the 4 UX design principles researched in this thesis were being followed well by companies when designing today's web applications and which of the 4 UX design principles were least followed or applied. As we have identified all 4 UX design principles directly contribute to reducing cognitive load, therefore not following even one of the principles would directly lead to cognitive load increase. Therefore, the author used interviews questions and topics based on all 4 UX design principles studied in this thesis.

The structured and semi-structured interviews were administered on separate days. This was done for several reasons. First, for a better quality of the collected empirical data since it takes time to process the structured interview questions to prepare for a more elaborated open discussion in a form of semi-structured interviews. Secondly, the structured interviews lasted an hour which is already a long time to keep the interviewee's attention, thus scheduling the semi-structured interview part for a separate day was logical.

All interviews were organized and led by the author through her work role at Vaadin Oy. Each interview was also accompanied by a UX developer from Vaadin Oy. The UX developer's goal was to analyze each of the 11 customers' web applications from technical Vaadin checkpoints using the 100-item checklist that Vaadin UX Checkups are based on. The author was given permission by Vaadin Oy to utilize the overall results from those technical analyses.

3.2 Interviews

Structured interviews

The first part of the interview sets was completed using the structured interviewing method. The structured interview method asks interviewers a fixed set of questions in a standardized approach,

this method is useful for collecting demographics, understanding user knowledge, comparing results across various groups on a fixed set of responses, and gathering attitude and opinion data [41].

There was a fixed set of 10 questions asked from all the interviewees. All questions were focused on reducing the user cognitive load, specifically covering concrete UX design choices and decisions that minimize the cognitive load. These 10 questions were selected from the existing UX Checkup interviewing methodology that the author used at her daily work at Vaadin Oy. The list of questions is provided in the following screenshot from the original Vaadin UX Checkup interviewing template:

Figure 9: 10 questions on cognitive load asked in structure interviews

Principle	P#	Q#	Questions	Pass	Fail	Skip	Comment
Reduce cognitive load	1	1	Use of purely decorative elements is kept to minimum	x			
	1	2	Visuals are provided as an alternative for reading text		x		
	1	3	Contextual information required by a task is visible (no memory burden)	x			
	1	4	Information is presented in chunks instead of concatenation			x	
	1	5	Real-world, established metaphors are used to convey information	x			
	1	6	Complex tasks are broken down into subtasks		x		
	1	7	Long sequences are broken down into separate steps	x			
	1	8	Repetitive tasks can be avoided through shortcuts or other tools			x	
	1	9	Colors, font families and styles are used with restraint	x			
	1	10	Interface matches the user's mental model	x			

These 10 questions on cognitive load reduction illustrate the 4 UX design principles that were researched in the literature review part of this thesis. To better explain how each question is related to the 4 UX design principles studied and covered in the literature review part of this paper, the author has broken down these 10 questions into 4 sub-categories matching the 4 UX design principles covered so far in this work.

Principle #1:	**Provide working and short-term memory support**
Questions:	Repetitive tasks can be avoided through shortcuts or other tools Complex tasks are broken down into subtasks Long sequences are broken down into separate steps

Principle #2:	**Recognition rather than recall**
Questions	Visuals are provided as an alternative for reading text Contextual information required by a task is visible (no memory burden)

Principle #3:	**Avoid visual clutter**
Questions	Colors, font families and styles are used with restraint Use of purely decorative elements is kept to minimum Information is presented in chunks instead of concatenation

Principle #4:	**User's mental model**
Questions	Interface matches the user's mental model Real-world, established metaphors are used to convey information

To best support the theoretical research these exact 10 questions were systematically used during this data collection process on all interviewees.

Each question had 3 options for an answer: pass, fail and skip. Marking "pass" implied that the interviewee's web application met the requirements for reducing user cognitive load. The answer "fail" indicated that the web application being analyzed did not meet the criteria of being cognitive load "friendly". There were instances when the questions asked did not apply to the web application of the interviewee, in those cases the answer "skip" was recommended. A separate section for comments was added to allow a more elaborated explanation of why a certain answer was selected.

There were 11 companies participating in the interviews. All 11 participants were companies that are paying customers at Vaadin Oy and have web applications for their businesses. Interviewing existing Vaadin customers with the author's Customer Success Manager employee title made it easier for the author to overcome the barrier to getting detailed honest answers from companies as there is a certain level of trust and familiarity with the interviewees. Each interview started with a small intro and "small talk" on the interviewee's business domain background. Then each interviewee presented or did a demo of their existing web application that they are currently using in their company. The demo of the application started with the general presentation of what is the purpose of the application: is it for internal use or external customers, is it a database system, warehouse system or a customer-facing application, etc. After the author understood the main purpose of the application being reviewed, the interviewing continued with questions on the typical workflows that the interviewee's users have. A simple request from the author to the interviewee was made in each interview, asking the customer to describe or tell about the typical workflows of their web users. This helped to understand how the web application was used and what were the users' expectations from that web application. When the

interviewee was describing the typical user workflow and demoing it by clicking on different views within their web application (log-in page, reports page etc.), the author took notes on various UX design principles that were earlier described in this paper. The interviewees speaking about the typical user workflows and talking about their pain points that their users face gave structured answers to the 10 questions on reducing the cognitive load. The goal was to understand how the interviewee's web application's UX currently handles the user's cognitive load challenges. The author aimed to learn how each interviewee's web application's user cognitive load is being tackled through good design. And also, to understand where it is failing to respect the user's cognitive load.

The topics and questions for the interviews were sent beforehand via email to each interviewee to give the participants a chance to contemplate and have an overview of what will be discussed. Also, a request to kindly be prepared to demonstrate their web application via screen sharing during the interview was relayed in the same invitation email to set the participant's expectations right. The 10 questions on reducing the cognitive load were designed to allow comprehensive responses from the respondents and elaborate discussion from the interviewee's perspective and experience with using or designing data-intensive applications' user interface (UI).

Purposive sampling was applied when selecting the interviewees. The author aimed for specific expertise from the participants. The motivation and interest in the subject by these participants were also contributing factors when choosing them as it increases the probability for a more fruitful interview with meaningful insights. When a person is interested in the subject, we are more likely to get better results. The interviewees taking part in this research work had backgrounds directly related to the subject matter being studied here: user cognitive load and UI in data-intensive applications. The interviewees held professions such as UX expert, UX designer, lead developer, project manager, CTO of a company. Robson 2002 explains the definition of purposive sampling as a sampling technique frequently applied in qualitative research when a researcher relied on his or her own assessment when choosing a member of a population to participate in the study [31]. The sample size (n=11) was the realistic pool the author could fit within the scope of this thesis.

The duration of the structured interviews was one hour. All interviews took place online and in English. There were eleven companies interviewed in total.

Semi-structured interviews

The second half of the interviewing process was conducted in the form of semi-structured interviews. The semi-structured interviewing method combines some structured questions and some unstructured exploration. The semi-structured interviews were conducted on a separate day after the structured interviews have been processed. The semi-structured interviews are especially useful when working with complex issues as the interview can use probes and spontaneous questions to explore, enhance the author's understanding of the researched topic, and clarify answers to questions [41].

This was the second part of the interviewing method applied. The semi-structured interviews took place after the structured interviews. The reason for that order was to allow the author to first gain knowledge on the topic of cognitive load for each interviewee's web application and then to allow the interviewee to provide open answers on the questions. The semi-structured interviews lasted approximately an hour for each company that was interviewed. The interviews were conducted with the same people as in the structured interviews.

The author used this part of the interviewing process to gather more opinionated data and valuable insights from the domain experts. This was certainly a more exciting part of the data collection method as the respondents' reactions and comments were sometimes surprising. When faced with the reality that their web application did not quite tackle reducing cognitive load based on the 4 UX design principles depicted in this thesis, some interviewees were not happy to hear that or went in a defensive mode. It is understandable as nobody wants to admit that their users are suffering trying to use the web application that they so carefully designed.

CHAPTER 4

Results

This chapter analyzes the collected interview data extracting themes and patterns from the respondents' answers on reducing the cognitive load for the users of their web applications. The background information of the interviewees is anonymous data to protect interviewee's identities and their companies' intellectual property rights.

4.1 Analysis of the interview data, thematic analysis

Context is key when conducting qualitative data analysis. The insights captured from the collected data via qualitative research method are context-dependent and therefore it is important to explain them in reference to the context in which that data was collected. The author used thematic analysis which is one of the most commonly applied methods to analyze qualitative data. In thematic analysis recurring themes, patterns and correlations between the data are recognized and explicated to generate insights [25]. So, in a way, the frequency of certain themes that occur in the gathered data act as stimulus when emphasizing the key findings. The thematic analysis was applied to the free-form answers of the respondents from structured and semi-structured interviews and the comments that Vaadin UX developers provided in their detailed UX analysis of each participant's web application.

As mentioned in the methodology chapter, some interviews were screen recorded while most of the interviews were not recorded upon the interviewee's request. Each participant presented their web application via screen sharing online and therefore it is understandable when some of the companies choose not to have a screen recording of their internally used web applications or when sensitive data was displayed. Therefore, the author was taking detailed notes directly during the interview process of those interviews that were not screen recorded. However, some companies preferred to have a screen recording session and asked to provide them with a copy of the recording. These companies found the open form discussions valuable to be recorded as they wanted to understand how their web application is being perceived by a complete stranger.

To conduct the thematic analysis the author first transcribed all the screen recorded interviews and then read through each transcript, interview notes and UX developer's technical analysis reports to

make sense of the collected interview data. This was done right after each interview to log the ideas immediately. The data set then was searched across to identify patterns of meanings that reoccur. To do this the process had to be simplified by coding the data in order to decompose and find relationships within the recurring topics. Coding in this context means labeling the recurring themes. After the revision of the collected codes/labels of recurring themes, the author identified those themes and gave them names [30]. At first, all recurring sentences, phrases, topics were noted, then to optimize the results, the author grouped them into bigger themes.

Themes identified from thematic analysis:

- Visual hierarchy, visual consistency, visual noise
- Navigation
- Usability issues
- Application's UI responsiveness
- Reading data, data alignment to help the user read and compare the data easier
- User workflows
- The application is data-intensive by nature
- User experience could be improved
- UI consistency
- Accessibility (new theme)

These 10 themes were identified from discussions during both interview sets, from the participants' comments when replying to 10 interview questions, and from the professional feedback provided by Vaadin UX developers to the customers regarding their web applications. The 10 identified themes mostly corresponded to the 4 UX design principles reviewed in the theoretical part of this thesis. The theme "accessibility" emerged from the thematic analysis and it has not been mentioned as a separate topic throughout this thesis work since the topic of accessibility was not related to the scope of the research questions placed by the author. The reason this topic developed during the interviews is because the semi-structured interviews allowed quite free-form discussions between the participating customer and the author, hence there was no limiting range keeping the discussion purely focused on the topic of minimizing the cognitive load.

The identified 10 themes were further categorized by the author into the 4 UX design principles that were researched in this thesis:

Principle #1:	**Provide working and short-term memory support**
Questions	Repetitive tasks can be avoided through shortcuts or other tools Complex tasks are broken down into subtasks Long sequences are broken down into separate steps
Themes	Navigation, user workflows Application's UI responsiveness UI consistency

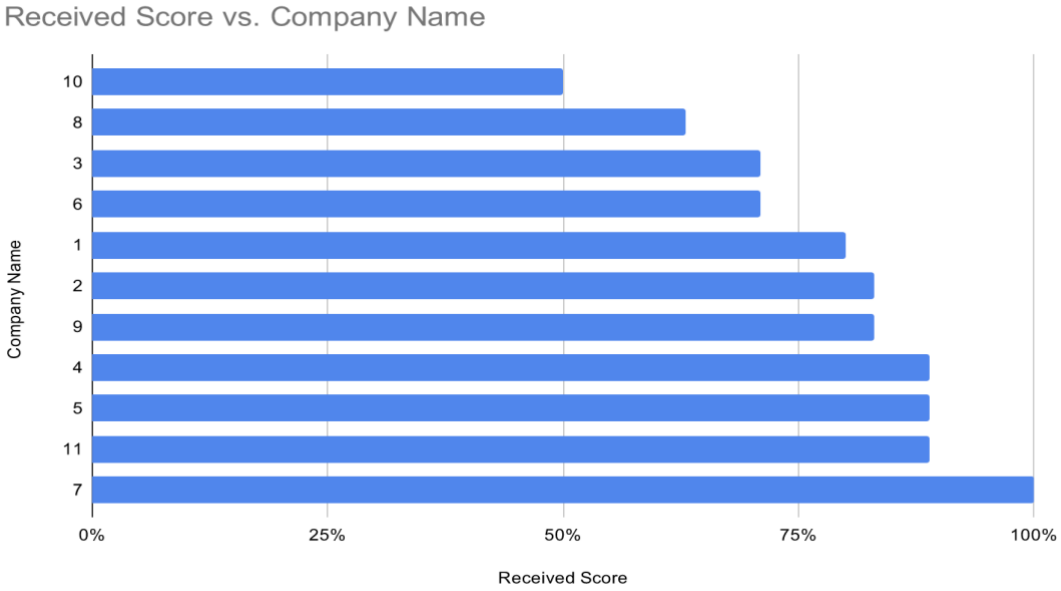
Principle #2:	**Recognition rather than recall**
Questions	Visuals are provided as an alternative for reading text Contextual information required by a task is visible (no memory burden)
Themes	User experience could be improved

Principle #3:	**Avoid visual clutter**
Questions	Colors, font families and styles are used with restraint Use of purely decorative elements is kept to minimum Information is presented in chunks instead of concatenation
Themes	Visual hierarchy, visual consistency, visual noise Reading data, data alignment to help the user read and compare the data easier

Principle #4:	**User's mental model**
Questions	Interface matches the user's mental model Real-world, established metaphors are used to convey information
Themes	Usability issues The application is data-intensive by nature

As explained before, the author conducted these 11 interviews with existing Vaadin customers that have web applications for businesses. Vaadin has a team of experienced UX experts who apply the 100-item UX checklist to technically assess customers' web applications against various UX principles. The author, however, used only 10 questions from this checklist to focus only on reducing cognitive load. The UX experts at Vaadin further analyzed how each of the 11 companies' web application measured on the cognitive load scale using their own metrics systems. The author was granted permission to share the outcome of the scores given to these eleven companies from the UX experts' perspective on cognitive load measurement. The names of the companies have been changed to numbers for confidentiality. The following table provides an overview of the scores:

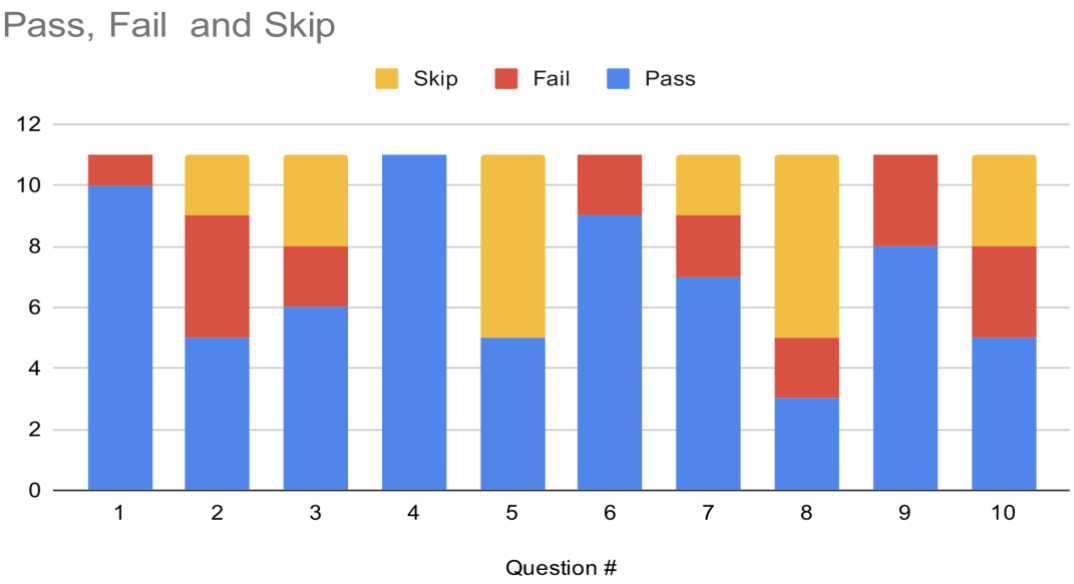
Table 1: Overall scores on cognitive load summarized



The result scores ranged from 50% to 100% on a 100% scale, with 100% being the best score to receive for your web application's cognitive load minimization. As seen from the results, company 10 received a score of 50% and company 7 received a score of 100%.

Furthermore, the author analyzed the total of answers given to each of the ten questions in the structured interview part of collecting the qualitative data. As mentioned in the methodology section of this thesis, there were three possible answers to 10 interview questions: pass, fail and skip. The following table provides an overall analysis of all the answers given to the 10 questions:

Table 2: Answers to the 10 interview questions graph



Positive replies/Pass:

Let's first review which questions had the most positive responses, meaning that the interviewee's web application met the cognitive load criteria asked within the question. Based on the 11 companies' web applications the third UX design principle on avoiding visual clutter is being well applied.

Principle #3:	**Avoid visual clutter**
Questions	Use of purely decorative elements is kept to minimum Information is presented in chunks instead of concatenation
Results	11 companies practice this UX design principle

Question 4 on how the information is being presented in chunks instead of concatenation had the highest number of positive replies (11 pass) responses. Based on this outcome it can be assumed that most companies find it important and easy to implement this simple UX design rule in order to minimize cognitive load.

The second runner up question was question 1 on keeping decorative elements in the application's UI to the minimum to not overload the user's cognitive load, which is also from the third UX design principle on avoiding visual clutter. 10 companies were practicing this third UX design principle based on this question.

Question 6 based on the first UX design principle of providing working and short-term memory support was the third most positively answered question in these interviews with 9 positive replies. Question 6 was on the way the complex tasks are presented to the user by being broken down into sperate steps:

Principle #1:	**Provide working and short-term memory support**
Question:	Complex tasks are broken down into subtasks
Results	9 companies practice this UX design principle

Negative replies/Fail:

The negative responses or in this case they were labeled as "fail" had lower numbers in general compared to the positive responses. This could be a piece of relieving news, as it could mean that companies take user cognitive load into serious consideration, however, this cannot be a sure statement with this limited data set.

Question number 2 based on the second UX design principle of recognition rather than recall had the highest number of negative responses. 4 companies' web applications failed to provide visuals that could be alternatives for reading text. 4 out of 11 is a 36% rate, but if we also consider that 2 companies were in the "skip" category, meaning that this question wasn't even applicable to them, this could also be a red signal and if being completely subjective then the author would have added those 2 replies to the basket of 4 negative replies, thus increasing the total number of "fail" responses to 6 out of 11 which would translate to 54%.

Principle #2:	**Recognition rather than recall**
Questions	Visuals are provided as an alternative for reading text
Results	4 companies fail to practice this UX design principle

Statements such as "visual hierarchy would help a user focus on which part of the app is the most important" and phrases as visual consistency, visual noise, visual style/appearance were very frequently occurring when coding the interview data.

This is an interesting observation of the correlation between the visual design themes and the most challenge that companies face when reducing the user cognitive load.

Questions 9 and 10 had similar outcomes with 3 companies facing problems for each question asked.

Principle #3:	**Avoid visual clutter**
Questions	Colors, font families and styles are used with restraint
Results	3 companies fail to practice this UX design principle

Question 9 was on colors, font families and styles while question 10 was on UI matching the user's mental mode.

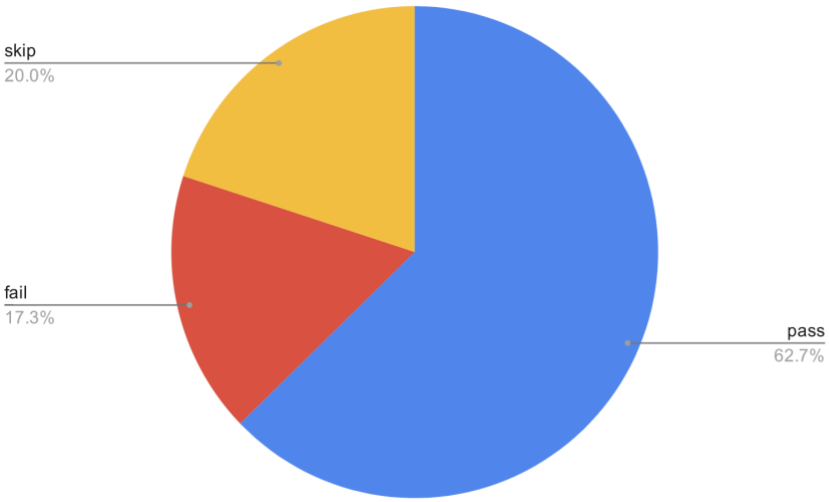
Principle #4:	**User's mental model**
Questions	Interface matches the user's mental model
Results	3 companies fail to practice this UX design principle

One factor to note here is that question 10 had also 3 companies that skipped it. The rest of the questions had similar outcomes with one or two companies failing in each section.

A total of six companies skipped questions 5 and 8. This is more than 50% of the respondents. Question 5 was on the way companies are conveying information to their users and whether real-world established metaphors were being used. Question 8 was on how users can avoid repetitive tasks in the given web application.

While most of the responses to all the questions were positive (62.7%), the outcome of "fail" and "skip" replies are much closer to each other in percentages (17.3% and 20% respectively). The following pie chart summarizes visually the overall response results:

Table 3: Overall responses pie chart



4.2 Comparison of findings to the literature review

When comparing the qualitative data analysis to the earlier literature review conducted there were both positive comparisons and negative. The author was of course relieved to find the common ground between the interview results and the literature review completed, however, there were also some surprising disparities identified as well. For simplicity purposes, the author will describe each comparison category separately.

Positives: The thematic analysis matched the 4 UX design principles researched in a literature review form. Out of 10 themes that emerged from the thematic analysis of the interviews, 9 themes corresponded to the already presented 4 UX design principles. This was additional supporting evidence for the theoretical research background that the author provided in chapter 2 of this thesis.

Negatives: The theme of accessibility elicited from the thematic analysis which was not covered by the author in the theoretical review part. The author did not have research questions on accessibility and therefore none of the interview questions were targeting to understand how accessibility is tackled in participants' web applications' design. The topic of accessibility emerged during the free-form discussions in the interviews despite the lack of its direct relevance to the original research questions.

However, after the thematic analysis, the author researched a bit more on the topic of accessibility and here are some key takeaways. Simply put, if people with disabilities cannot use your web application, then your web application is not usable, it must be accessible. According to the World Health organization's report on disability, about 15% of world's population lives with some form of disability, of whom 2-4% experience significant difficulties in functioning [34]. This is a very important factor to consider and respect when designing any web application. After a brief look at the topic of accessibility the author can conclude that it could be researched as its own separate UX principle topic as it requires complex design decision making processes and deeper understanding of various types of disabilities.

A wild card: The surprising factor for the author was the topic of latency in the user interface (UI), this topic did not elicit in the answers of interviewees as the author anticipated. The author has researched the effect of response delays in the user interface on the human working and short-term memory in chapter 2. This was deemed as an important criterion to measure when aiming to reduce the cognitive load. However, this topic did not get the spotlight during the 11 interviews. The speculations and thoughts on this matter will be shared in the next chapter.

CHAPTER 5

This concluding chapter first covers the discussion on the outcome results of the collected data and the author's personal and professional opinions. Lastly, some recommendations for future work will be presented.

5.1 Discussion and conclusions

This thesis research was completed through the literature review and qualitative data collection methodology. There were 3 research questions stated for this thesis work:

Research question (RQ) 1: What is cognitive load in the context of UX?
Research question (RQ) 2: Can the cognitive load be reduced with good/better design and in which ways?
Research question (RQ) 3: How well are modern web applications today tackling the mission of reducing cognitive load? What are the areas that today's web applications could improve?

The first research question was answered in the literature review part of the thesis providing the basis for the entire research work. The author explored answers to the second research question in a theoretical form and also applied the theoretical findings to this question in her data collection methodology. The third research question was answered by collecting qualitative data via structured and semi-strutted interviews.

The end goal of this thesis work was to answer the three research questions placed and to provide meaningful insights in a form of discussion and suggestions for future work at the end.

After answering what is cognitive load in UX (RQ1), the author researched the 4 UX design principles that contribute to reducing the cognitive load (RQ2). Then these 4 UX design principles were analyzed in-depth through qualitative data collection methodology in the forms of 11 interviews. This was done to find supporting empirical evidence on the 4 UX design principles and to see how companies today are tacking cognitive load reduction while applying these 4 UX design principles (RQ3). During comparison and review of the theoretical background to the empirical evidence, the author identified some gaps or discrepancies, however, this could be partially due to the scope of the

thesis work. The gap was in the topic of accessibility that the author did not include in the scope of this thesis. The topic of user interface (UI) design is quite vast covering everything from usability, learnability, accessibility, and understandability thus requiring a bigger project or even better covering each UX design principle into separate research projects. Cognitive load in UX as a topic itself is extensive too, as it is in the human psychology domain, and simply covering merely types of human memory, attention, etc. would not fit in the scope of this thesis. The second gap identified between the theoretical and empirical work was the topic of response time or user interface (UI) latency from the first UX design principle. While the author placed a heavy emphasis on the importance of page load time and the time the user has to wait to interact with the web application, the empirical part of the thesis did not provide supporting evidence on the importance of this topic. This was a surprising finding for the author. One speculation on this matter is that the interview questions did not cover this topic. After thinking more about it, the author concluded that it is challenging to assess how the user's cognitive load is affected by the page loading time and latencies in the user interface (UI) in general. One option could have been to conduct an eye-tracking experiment to explore the correlation between the user's attention and the delays in the user interface (UI). This would, however, require a more extensive quantitative analysis approach to the research, but it would be an interesting project to look into. The author remains of the opinion that this topic is very important as many usability studies have indicated how frustrated users get when waiting for the page to load. Also, the author herself is a user of that category of frustrated users.

As mentioned throughout the entire thesis work the less the users have to think about the user interface (UI) or design of it, the more they have chances to keep their attention on completing their task and meeting their goal within the given web application. As the results of the data analysis show, many web applications today still fail to respect the cognitive load of a user to the fullest extent. When interviewing 11 companies on their web applications, it was evident that not all companies utilize all 4 UX design principles to reduce the cognitive load of their users. Many might argue that companies have budget constraints and focusing on user cognitive load would take up a budget chuck from their overall UX budget. However, the author would like to challenge that notion as the entire chapter 2 of this thesis shows how simple steps following 4 UX design principles can greatly contribute to reducing the user cognitive load. Whether we like it or not, user cognitive load is here to stay, and we must continuously work on reducing it and designing the web applications' UI accordingly. If users can't use your web application successfully, then who are you designing the application for?

Jakob Nielsen's following quote used by Steve Krug in his book very well concludes the author's thoughts on why the basic UX design principles remain actual and applicable no matter how much the landscape and technology changes:

> The human brain's capacity doesn't change from one year to the next, so the insights from studying human behaviour have a very long shelf life. What was difficult for users twenty years ago, continues to be difficult today (Krug, S. 2014, p.xi).

As presented in chapter 2 of this thesis, there are basic human psychology principles to think about when making UX design decisions and these principles will remain relevant as long as the human brain remains in the same state, we know it today. Building good data-intensive applications remains to be work in progress and there is still room for improvement in many web applications when it comes to the subject of reducing cognitive load. Technology today changes rapidly, with new web application frameworks emerging and even new generations of networks developing continuously to match the demand for the abundant data transfer world we live in today. However, as said above, the human still remains as a constant variable in this equation. The human brain doesn't exactly change rapidly as technology changes. This must be a constant reminder during the UX design process.

5.2. Future work

The first suggestion for future work would be that future research in this field could be more agile to keep up with the fast-paced changes in the technology scene. Applying existing technologies such as eye-tracking machines, for example, should be considered as part of the future research work. One suggestion could be putting together quantitative research of a selected sample pool of the most well-known, specific data-intensive applications available in the market today. This could be a concrete analysis based on user testing on how applications work and how users interact with the user interface (UI) of those systems.

Moreover, there is room for in-depth research on each of the 4 UX design principles researched in this thesis. The topic of accessibility in UX design could emerge as the 5th UX design principle for future research.

The last suggestion for future work would be to study the connection between technology and the human brain: how UX is designed around human psychology versus when the human brain is being "trained" to adjust to the emerging technologies.

REFERENCES:

[1] Steve Krug (2014). *Don't make me think* (3rd ed.). USA: New Riders.

[2] Gary Klein (1998). *Sources of power: how people make decisions*. 20th Anniversary edition. Cambridge, Massachusetts: The MIT Press.

[3] Herbert A. Simon (1957). *Model of man: social and rational* (1st ed.). New York: Garland

[4] Donald A. Norman (2002). *The design of everything things*. New York: Basic Books

[5] William Strunk, Jr. (2006). *The elements of style.* Mineola, New York: Dover Publications, Inc.

[6] Claudia Roda (2011). *Human attention in digital environments*. United Kingdom: Cambridge University Press

[7] Hale, J. (2018). *Five Takeaways from the Visual Display of Quantitative Information.* Medium.com platform. Retrieved from https://medium.com/@jeffhale/five-takeaways-from-the-visual-display-of-quantitative-information-dd36dae35299

[8] Sweller, J., Kalyuuga, S. and Ayers, P. (2003). *Cognitive load theory*. New York, NY: Springer Science+Business Media, LLC.

[9] Miller, G.A. (1956). *The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychological Review*, 63, 81-97. Retrieved April 3, 2020, from http://www.musanim.com/miller1956]

[10] Baddeley, A.D., Eysenck, M.W. and Anderson, M.C. (2015). *Memory* (2nd ed.). New York, NY: Psychology Press.

[11] Merrill, M. D.; Drake, L.; Lacy, M. J.; Pratt, J. (1996). Reclaiming instructional design (PDF). *Educational Technology*. **36** (5): 5–7. Archived from the original (PDF) on 2012-04-26. Retrieved May 11, 2020.

[12] Bannert, M. *Managing cognitive load-recent trends in cognitive load theory*. Learning and Instruction 12.1 (2002): 139–46. Web.

[13] Baddeley, A. D. and Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

[14] Interaction Design Foundation. (2002).The basics of user experience design (ebook). Retrieved June 2, 2020 from https://www.interaction-design.org/literature/article/hick-s-law-making-the-choice-easier-for-users

[15] Rosati, L. (October 24–25, 2013). "How to design interfaces for choice: Hick-Hyman law and classification for information architecture". In Slavic, A.; Salah, A.; Davies, C. (eds.). *Classification and visualization: interfaces to knowledge: proceedings of the International UDC Seminar*. The Hague, The Netherlands. pp. 125–138.

[16] Parker, A., Wilding, E. amd Akerman, C. (1998*). The von Restorff Effect in Visual Object Recognition Memory in Humans and Monkeys: The Role of Frontal/Perirhinal Interaction"* (PDF). *Journal of Cognitive Neuroscience*. 10 (6): 691–703.

[17] Parker, A., Wilding, E. and Akerman, C (1998). *The von Restorff effect in visual object recognition memory in human and monkeys: the role of frontal/perirhinal interaction.* Journal of Cognitive Neuroscience. 10 (6):691-703.

[18] Evans, D.C. (2017). Bottlenecks: aligning UX design with user psychology. Kenmore, Washington: Apress.

[19] Gestalt. In oxforddictionaries.com. Retrieved from https://www.lexico.com/en/definition/gestalt

[20] Schimp, E, (2014). *Brain Study* (If you can read this you have a strong mind.) Project created by Khan Academy. Retrieved from https://www.khanacademy.org/computer-programming/brain-study-if-you-can-read-this-you-have-a-strong-mind/4681788649635840

[21] Gkogka, E. (2018). *Gestalt principles in UI design*. Medium.com platform. Retrieved from https://medium.muz.li/gestalt-principles-in-ui-design-6b75a41e9965

[22] *Time to Iinteractive* (2019). Web.dev. Retrieved from https://web.dev/interactive/

[23] Dresser, T., and Roy, D. (2018). *Time to Interactive explainer.* Retrieved from https://github.com/WICG/time-to-interactive#definition

[24] Denzin, N.K., and Lincoln, Y.S. (2005). *The Sage handbook of qualitative research* (3rd ed.). Thousand Oaks, CA: Sage Publications.

[25] Bryman, A. and Bell, E. (2011). Business research methods (3rd ed.). Oxford: Oxford University Press.

[26] *Research guides by the University of Southern California*. Retrieved from https://libguides.usc.edu/writingguide/quantitative

[27] Eyal, N. and Hoover, R. (2014). *Hooked: how to build habit-forming products.* New York, NY: Portfolio.

[28] Miles, M.B. and Huberman, A.M. (1994). *Qualitative data analysis: an expanded sourcebook.* Newbury Park, CA: Sage

[29] Mintzberg, H. (1979). An emerging strategy of "direct" research. *Administrative Science Quarterly*. 24 (4), 582-589.

[30] Liamputtong, P. (2013). *Qualitative research methods* (4th ed.). South Melbourne: Oxford University Press.

[31] Robson, C. (2002). *Real world research: A resource for social sientists and practioner-researchers.* (2nd ed.). Blackwell Publishing.

[32] Dean, J. (2018). *How 5G technologies can be implemented more efficiently.* Retrieved from https://www.techradar.com/news/how-5g-technologies-can-be-implemented-more-efficiently

[33] McKay, E.N. (2013). *UI is communication: how to design intuitive, user centered interfaces by focusing on effective communication.* Waltham, MA: Elsevier Inc.

[34] World Health Organization (2011). *World report on disability.* Retrieved from https://www.who.int/disabilities/world_report/2011/report/en/

[35] Halarewich, D. (2016). *Reducing cognitive overload for a better user experience.* Retrieved from https://www.smashingmagazine.com/2016/09/reducing-cognitive-overload-for-a-better-user-experience/

[36] Whitenton, K. (2013). *Minimize cognitive load to maximize usability.* Nielsen Normal Group. Retrieved from https://www.nngroup.com/articles/minimize-cognitive-load/

[37] Wroblewski, L. (2018). *Three facts about white space that all designers should know.* Retrieved from https://www.contentder.com/details/post/53/Three-Facts-About-White-Space-That-All-Designers-Should-Know/

[38] *What is GitHub?* Retrieved from github.com

[39] Lakoff, G., and Johnson, M. (2003). Metaphors we live by (1st ed.). London, UK: The University of Chicago Press. Ltd.

[40] Osmani, A. (2017). *A Pinterest progressive web app performance case study.* Medium.com platform. Retrieved from https://medium.com/dev-channel/a-pinterest-progressive-web-app-performance-case-study-3bd6ed2e6154

[41] Chauncey, W. (2014). *Interview techniques for UX practitioners: a user-centered design method.* Waltham, MA: Elsevier Inc.

[42] Edward Tufte (1992). *The visual display of quantitative information* (12th pr.). Chesire, CT: Graphics Press.

[43] Nielsen, J. (1997). *The need for speed.* Retrieved from https://www.nngroup.com/articles/the-need-for-speed-1997/ on June 7, 2020

[44] Moran, K. (2016). *How chunking helps content processing.* Retrieved from https://www.nngroup.com/articles/chunking/ on June 7, 2020.

[45] Budui, R. (2014). *Memory recognition and recall in user interfaces.* Retrieved from https://www.nngroup.com/articles/recognition-and-recall/

[46] Hartson, R., and Pyla, P.S. (2012). *The UX book: process and guidelines for ensuring a quality user experience.* Waltham, WA: Elsevier, Inc.

[47] James Montalbano: https://userexperiences.co/design-ui-for-recognition-more-than-for-reading-35ce510b0221

[48] Dodiya, J. (2016). *What is mental model in user interface design?* Retrieved from https://www.researchgate.net/post/What_is_a_mental_model_in_user_interface_design/56c32d976225ff40868b4575/citation/download