

Conversational UI in browser extensions with agentic AI

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Conversational user interfaces have increased in popularity in the form of virtual assistants like Siri, and also chatbots in customer service settings. The emergence of large language models has improved the technology of natural language processing and enables the possibility of a conversational user interface capable of operating in the browser utilising LLMs with a browser extension. As there is no scientific research on such conversational browser-using agent browser extensions, the thesis gives an overview on the currently existing extensions and tests for their feasibility with an empirical study. A taxonomy for evaluating the extensions is created, and the empirical study uses different tasks to judge the capabilities of three extensions. The results of the study showcase that some of the existing extensions have very promising capabilities in operating in diverse web environments, and are able to operate based on vague natural language instructions with minimal oversight. The biggest challenge they face is their relatively slow execution speed, with multi-layered tasks and the correct choice of LLM and its instructions being among other challenges.

Keywords: conversational user interfaces, browser extensions, agentic AI, large language models

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1 Introduction

Despite the emergence of the smartphone, hundreds of millions of people are still using computers for browsing the web for work, education, hobbies, and entertainment purposes. The primary method of browsing is typing with the keyboard and navigating with the mouse. Conversational user interfaces (CUIs) such as Siri and Alexa have become popular for various purposes since the 2010s, but they are, for the most part, not capable of browsing the web as freely as a user on their own computer and own inputs. On top of being generally easy to use, conversational user interfaces can have accessibility benefits for many different groups of people, including the blind and visually impaired, the elderly [1], children [2], and people with disabilities [3].

With the emergence of large language models (LLMs), having a conversation with a computer using natural language has become possible and accessible for all. The significant advancement of LLMs has advanced the field of natural language processing and translation[4], which is useful for the development of CUIs. In theory, they could be utilised in making an all-purpose CUI capable of working in the browser using a browser extension developed for that purpose.

Discussing the browser extensions requires a new term, as "AI agent", "conversational user interface", or "Agentic browser extension" do not properly address the idea of what this study is looking for. Meng et al.[5] use the term *browser-using agents* (BUA), referring to agents capable of autonomously completing user-specified tasks. However, a

browser-using agent is not necessarily feasible as a conversational user interface. For this reason, the term *Conversational browser-using agent* (CBUA) will be used in this thesis.

The aim of this thesis is to find out what the current landscape of CBUA extensions is and how such extensions operate. The thesis also looks into the current quality of a few suitable extensions through an empirical study. By analysing the results of the empirical study, the thesis looks into the issues that these extensions have and what possible solutions could be found. Although using voice commands is a key part of a CUI, all experimentation in this thesis is done solely with text-based conversation for practicality purposes.

The following research questions will be used in this thesis.

- RQ1:** Are there any browser extensions feasible for working as a conversational user interface, and how do they operate?
- RQ2:** How can the feasibility of such extensions be measured and categorized?
- RQ3:** What kind of challenges are there in creating a browser extension-based conversational user interface?

Chapter 2 provides background into conversational user interfaces, browser extensions and web applications, and agentic AI. Chapter 3 takes a look at the AI-using browser extensions that are currently available online. Nanobrowser is identified as a fitting open source extension, and Chapter 4 takes a deeper dive into how exactly it is able to operate as a conversational user interface. The empirical study measuring CBUA suitability is explained in Chapter 5, and the results of the empirical study are shown in Chapter 6. Chapter 7 offers discussion based on the results and observations that were made during the study, aiming to answer RQ3. The thesis concludes with Chapter 8.

On the usage of generative AI

Generative AI was not used for any of the writing on the thesis. The only uses of generative AI in the thesis were ideation in the early phases and finding sources for the background sections.

2 Background

2.1 Browser extensions

Browsers are used as the interface for using services online in most cases. Browser extensions are software that can be added to a browser in order to customize the user experience in some way. Some of the most popular browser extensions on Google Chrome, the most popular browser, are extensions that modify the contents of any given website, such as ad blockers, translators, cursor changers or volume changers [6].

Browser extensions run alongside normal web pages. The extension is defined by a manifest file, which lists the structure and behaviour of the extension, including background scripts, content scripts, and resources [7]. Background scripts, or service workers, can work in the background to listen for events in the browser. Common events for a background script to monitor are navigating to different pages closing and opening tabs, and other browser events. [8] Content scripts run in the context of a web page and are able to read and modify the contents of the page. [9]

Content scripts modify the page content by modifying the Document Object Model (DOM) [10]. A DOM tree is a structure that represents the contents of an HTML document. The nodes of the tree correspond to the different parts of the document, such as text and other HTML elements. Websites themselves also modify the DOM dynamically to change and update page content. Modifying page content can mean almost anything: changing text, page structure, font size, highlighting elements, and remove advertise-

ments or other page content. In the context of CBUA extensions, content scripts can also simulate user actions such as clicking buttons and filling in forms.

2.2 Conversational user interfaces

A conversational user interface (CUI) refers to an interface that allows users to interact with computers using natural human language. The conversation can take place using either speech or text. Unlike with graphical user interfaces (GUI) and text-based or terminal user interfaces (TUI), the user may not need to use standard input devices like a mouse and keyboard to interact with a CUI. CUIs are beneficial accessibility tools for the blind and visually impaired and the elderly, but they are also beneficial for the development of children [1] [3] [2].

CUIs have been in development since the ELIZA chatbot at MIT in the 1960s. Massive improvements happened in the 2010s with the release of products such as Siri in Apple products and Alexa in smart home devices. CUIs are a part of daily life in many different industries, for example in the form of chatbots in healthcare or other customer service chatbots. [11]

2.3 Artificial intelligence

Artificial intelligence (AI) is an umbrella term that encompasses LLMs and many other things. LLMs are also conversational user interfaces, and the evolution in conversational user interfaces can be attributed to advancements in natural language processing, machine learning, and neural networks [11]. This thesis focuses on the use of LLMs, as the technology is what enables CBUA extensions.

Since the release of OpenAI's ChatGPT in 2022, new models are being released by a number of companies. The recent development of new AI models is enabled by the Recurrent neural network architecture based on an article by Vaswani et al. [12] in 2017[4].

Current popular models come from companies such as OpenAI, Meta, Google, Anthropic, Deepseek, xAI, and others.

Agentic AI

AI agents are applications of modern LLMs that can help with a variety of tasks. They are powered by LLMs that are usually extended with specific training in order to specialize the model to a specific domain. AI agents can help users within their domain in tasks such as programming with GitHub Copilot, or enhancing search like Google Gemini does automatically after a search has been made. [13]

System prompts are instructions meant to guide and provide context to AI models before they receive the user's actual prompts. They allow the LLM to give a much more structured, coherent and focused output without requiring the user to specify those parameters. The LLM can be given a role, and it would have to imitate being in that role while answering the user's queries. Having more rules in the system prompt can help with avoiding deviations from the user prompt. Especially useful in the context of CBUA extensions, system prompting allows the customization of very specific output formatting, so that it can be used by other software. [14]

3 Overview of available browser extensions

Overall there is very little scientific research on CBUA extensions or any agentic browser extensions. Because of this, the potential browser extensions have been found with Google searches and searches on the Chrome Web Store [15]. Google Chrome is the best browser to look for extensions, since it is by far the most popular browser [16]. In fact, hardly any of the selected browser extensions have a version available on Safari, Edge, or Firefox, which are the three next most popular browsers.

The searches were done with search terms such as "Conversational UI browser extensions", "Agentic AI browser extensions", and "AI web agent extensions". The extensions that were selected in Table 3.1 all advertised at least some degree of automation and autonomous capabilities. Some other notable extensions were rejected initially because of a clear lack of autonomous capabilities, as seen in Table 3.2.

The initial choice of extensions for Table 3.1 was done purely by browsing the website and Chrome Web Store page of each extension. Choosing the extensions for the study requires more careful consideration, as most of the extensions require payment for proper use beyond a free trial.

Further review into the properties of the extensions is required before the empirical study can be conducted, as a suitable CBUA extension will need to fulfill a number of technical requirements. At this stage, the meaningful properties that need to be found

Browser extensions	Developer	Downloads
Nanobrowser [17]	Nanobrowser Team	50 000
Claude [18]	Anthropic	900 000
Harpa AI [19]	HARPA AI	300 000
Do Browser [20]	Smooth Brain LLC	6000
rtrvr.ai [21]	rtrvr	10 000
Bardeen [22]	Bardeen	200 000
FillApp [23]	FillApp	1000

Table 3.1: List of browser extensions with agentic capabilities

include interface usage, understanding of natural language and autonomous task completion.

3.1 Nanobrowser

Nanobrowser [17] is a free open source browser extension developed by the Nanobrowser team. In addition to Chrome, it is also available on Edge. It runs locally in the browser, so no information is shared with the developers of the extension. The extension is able to complete tasks in the browser autonomously based on natural language prompts. Because Nanobrowser is open source, it can be analysed in much greater detail than other closed source extensions by looking at the source code directly [24].

Nanobrowser uses LLMs to plan and navigate given tasks. It supports a wide variety of different AI models from many LLM providers, such as OpenAI, Anthropic, DeepSeek and Ollama, given that an API Key is available. Local models may also be used, although they may require more specific prompting to maintain effectiveness. The extensions separates the LLM’s duties in two by differentiating between a planner and a navigator. The user is able to choose a different AI model for the planner and navigator, and it is recommended for optimizing performance or cost-effectiveness. The user also has a variety of settings to control LLM token consumption, including using a vision capability and limiting the number of steps a task can have. A Gemini model can be used for converting the

user's speech to text. There is no option for having the extension's output be converted to speech.

The Nanobrowser extension, once installed, can be opened by clicking on the small icon in the extension list on the top right corner of the browser, which opens the extension as a side panel on the right side of the browser. It can be given prompts by writing text on the text box or voice commands with a microphone. As the extension completes the tasks that it has been given, updates on the processes of the planner and navigator are given on the side panel.

The extension is able to read the contents of web pages. This is given to the planner and navigator models along with the user prompt and the system prompts of the respective models. When the user has given a prompt, the planner model analyses it and the current state of the browser and breaks down the prompt into smaller steps. In case the prompt is something that can be answered without any action, the planner model answers it without the navigator model getting involved. If action is required, the planner model answers with a description of the steps that must be taken next. All responses are given as a JSON object with specific fields so that the program can apply them correctly.

Based on the steps given by the planner model, the navigator model chooses actions specified in the system prompt. It can choose multiple actions at once. These actions include inputting text, clicking a button, navigating to a URL, scrolling to a different part of the page, and more. After the extension has completed the actions, the planner model re-evaluates the state of the task and gives the next steps to the navigator model. This loop is repeated until the planner model can determine the task as done. Once the task is done or terminated, the user can make a new prompt. The execution of a task can be terminated at any point using the "Stop" button.

3.1.1 Example task

A good and easy example task is searching for a trending song and playing it on YouTube. When the prompt is given, the planner begins planning the steps and gives tasks to the navigator. The user is immediately given the plan for the entire task, while the navigator executes only a small part of it at once. In the first part, it navigates to Youtube's Trending Music page. As seen from Figure 3.1, Nanobrowser detects the interactable HTML elements on the page and navigates using them. The elements are highlighted by having the "Display Highlights" setting enabled on Nanobrowser.

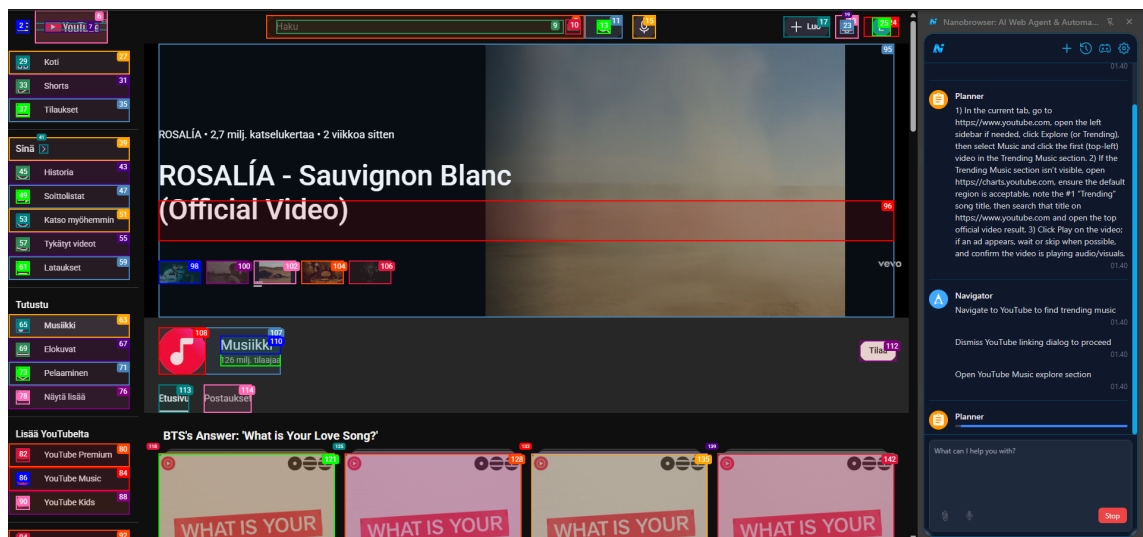


Figure 3.1: Nanobrowser highlighting HTML elements on the YouTube Music page after navigating to it.

Although it is not visible to the user on the actual page, Nanobrowser successfully determines what the requested song is, and moves on to search for it on YouTube, which it does by typing it into the search bar as seen in Figure 3.2. After making the search, Nanobrowser scans for the correct video from the search results as seen in Figure 3.3. Once the correct video has been found, the navigator navigates to it and the task is done. As seen from Figure 3.4, the planner determines the task successful and the extension stops working on the task.

Although Nanobrowser is not taking the most efficient route to the desired destination and in fact takes over a minute to do it, it is able to complete the task correctly. There is still more to be desired though, as it does not choose to skip the skippable advertisement in the event that YouTube plays one before the video can play. Regardless, this example showcases Nanobrowser’s ability to complete a basic web browsing task well. A deeper dive into how exactly Nanobrowser accomplishes the task is done in Chapter 4.

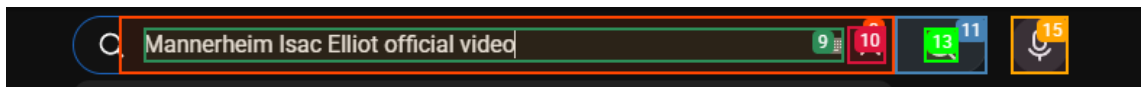


Figure 3.2: Nanobrowser typing the required song name into YouTube’s search bar

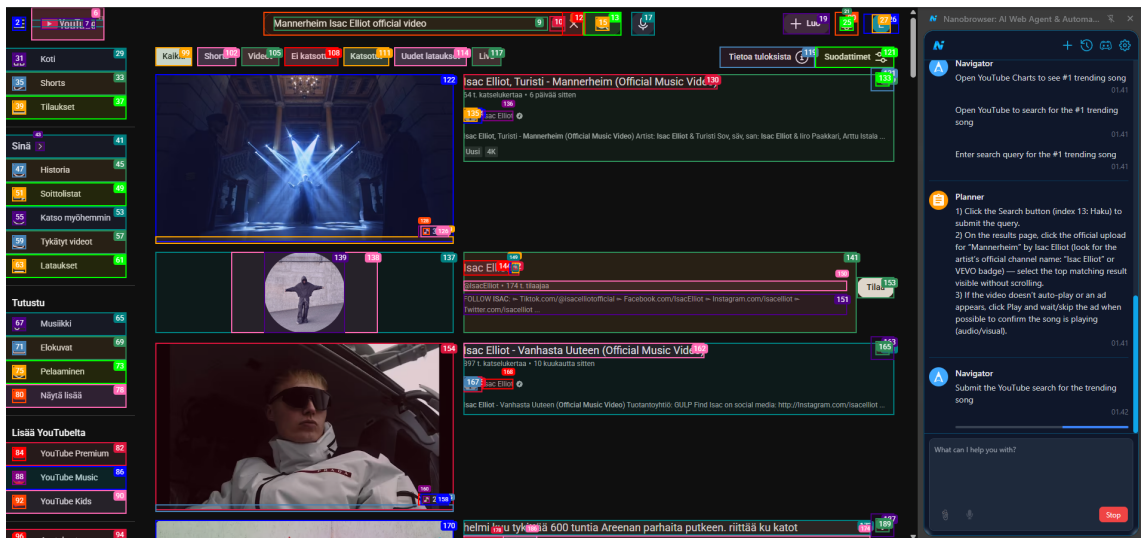


Figure 3.3: Nanobrowser scanning for the correct video

3.2 Do Browser

Do Browser [20] is an extension developed by Smooth Brain LLC. It is advertised as being able to control the browser with natural language. It is free to use with a Gemini API key or a paid Claude or ChatGPT subscription via sign-in. Do Browser also provides a \$25 monthly subscription where no additional AI provider is needed.

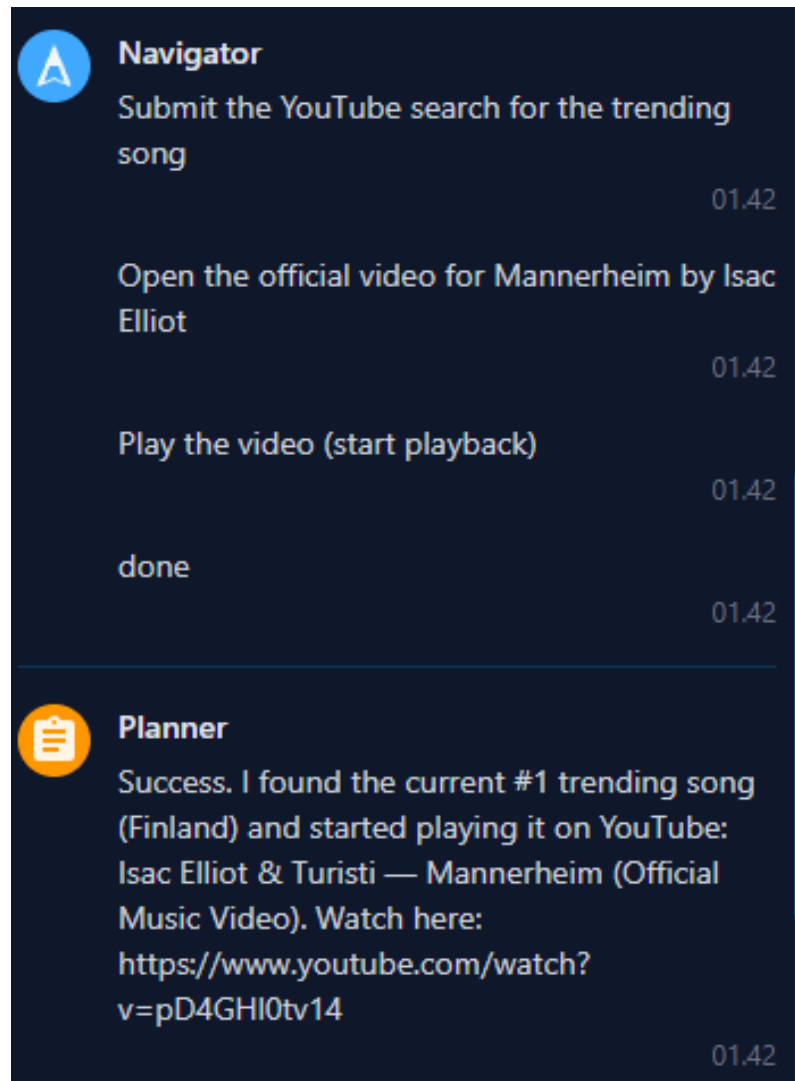
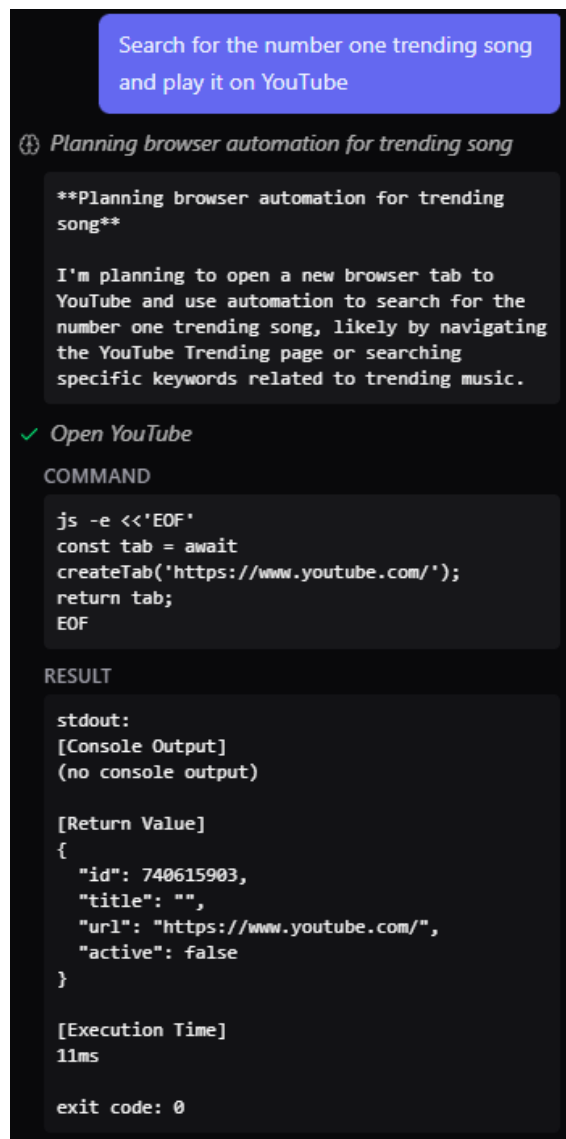


Figure 3.4: The last outputs from the navigator and planner for the Nanobrowser example task.

Similarly to Nanobrowser, the user can give prompts to Do Browser using the side panel. Prompts can also be given by typing "do" and hitting space bar into the address bar of the browser, which then allows the user to type the prompt directly into the address bar. After receiving the prompt, the extension is able to navigate the web to find the required page while explaining the steps to the user. The user is able to choose a level of "thinking", with the default being "High". The user can also attach files to the prompt. There is an icon for a microphone implying voice prompting, but it does not seem operational at the moment.

Although Do Browser is not open source like Nanobrowser, it can be deduced that it operates somewhat similarly to it. Once a prompt has been given, the extension alternates the outputs between "thinking" that the user can view by expanding the small explanation and concrete steps where the user can see the commands being used to complete the task and their results, as seen in Figure 3.5. This seems very similar to the planner and navigator of Nanobrowser.



The screenshot shows a dark-themed interface with a blue prompt box at the top containing the text: "Search for the number one trending song and play it on YouTube". Below this is a section titled "Planning browser automation for trending song" with a gear icon. Inside this section, there is a code block containing a planning comment: `**Planning browser automation for trending song**`, followed by a natural language explanation: "I'm planning to open a new browser tab to YouTube and use automation to search for the number one trending song, likely by navigating the YouTube Trending page or searching specific keywords related to trending music." Below the planning section is a green checkmark and the text "Open YouTube". Underneath, the "COMMAND" section shows a JavaScript snippet: `js -e <<'EOF'`, `const tab = await`, `createTab('https://www.youtube.com/');`, `return tab;`, `EOF`. The "RESULT" section displays the following output: `stdout:`, `[Console Output]`, `(no console output)`, `[Return Value]`, `{`, `"id": 740615903,`, `"title": "",`, `"url": "https://www.youtube.com/",`, `"active": false`, `}`, `[Execution Time]`, `11ms`, and `exit code: 0`.

Figure 3.5: Do Browser's reasoning and step completion.

Interestingly, Nanobrowser and Do Browser ended up on different songs when given the same example task, as Do Browser chose to look for the global number one song instead of the Finnish number one song. This is most likely due to not having knowledge of the location of the user, a difference in the reasoning model or even just a result of the inconsistency of LLMs. Just like Nanobrowser, Do Browser also takes quite long to complete its task. A noticeable difference between the two is that Do Browser opens a lot more new tabs on the browser instead of just navigating on the same tab.

3.3 FillApp

FillApp [23] is a browser extension that is advertised as a context-aware multi-tab AI browser agent for workflow automation and data entry. It is able to complete tasks given in natural language. It has a limited free tier and two paid subscription tiers which provide access to more advanced automation options.

FillApp can be used in a very similar way to Nanobrowser and Do Browser, with a prompt given on the side panel. The user can also add screenshots and files to the prompt. By typing the character @, the user can add a tab as context to the prompt. FillApp also allows integration with applications such as Google Sheets, HubSpot and Shopify.

As FillApp is not an open source extension, it is difficult to guess how it works. There is no back-and-forth responses from a planning and navigating model like in both Nanobrowser and Do Browser, only explanations of the steps taken, as seen in Figure 3.6. Interestingly, FillApp seems to complete the example task faster than both Nanobrowser and Do Browser.

3.4 Claude in Chrome

Claude by Anthropic is the only one of the major LLM's to have an official browser extension such as this, although OpenAI does offer an agentic browser for Mac, ChatGPT

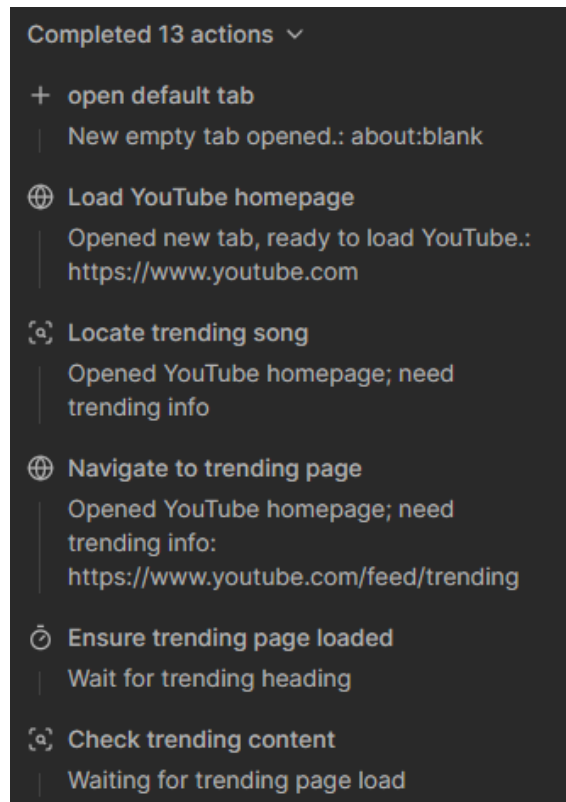


Figure 3.6: FillApp’s explanation of the steps taken in the example task.

Atlas [25]. Claude in Chrome [18] is especially advertised for web developers as a tool for live debugging when integrated with the terminal-based Claude Code. The extension is able to read the DOM state and console errors, which it can use to fix errors in the code. The browser extension is also able to act autonomously in the browser, and the store page uses editing in Google Docs and Google Slides as an example. The extension requires a paid subscription in order to be used.

3.5 Rtrvr

Rtrvr [21] (or Retriever), developed by Rtrvr.ai, is an AI web agent browser extension. It is able to complete tasks based on natural language prompts. The extension is targeted towards users who want to automate their workflows, as any tasks completed by the tool can be saved as execution workflows. Workflows can be automated and scheduled, and it

can be done by either letting the extension act on its own based on the prompt, or using the predefined custom tools to speed up the process. Separate files, Google Sheets and browser tabs can all be added as extra context for a prompt as well.

Rtrvr offers a limited amount of free credits outside of a number of paid subscriptions. It is also usable for free with a Gemini API key, which means that the extension most likely also uses Gemini when the user is paying for Rtrvr.

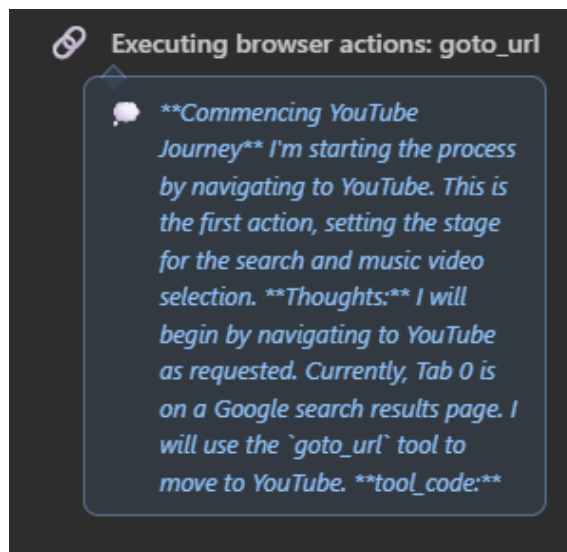


Figure 3.7: Rtrvr's thought process during navigation to YouTube.

The basic function of Rtrvr is similar to Nanobrowser and other extensions, as the prompt is given the same way and the extension gives updates on the process along the way. A difference is found in that Rtrvr explains its thought processes in more depth than the other extensions as seen in Figures 3.7 and 3.8. It refers to elements on the page with IDs and names the actions that it takes, such as *goto_url*, *type_into_element* and *click_element*.

3.6 Other extensions

HARPA AI [19] is an extension built by the Finnish Harpa Ai Technologies. It is advertised as an AI agent for web browsing and web automation. Unfortunately it does not

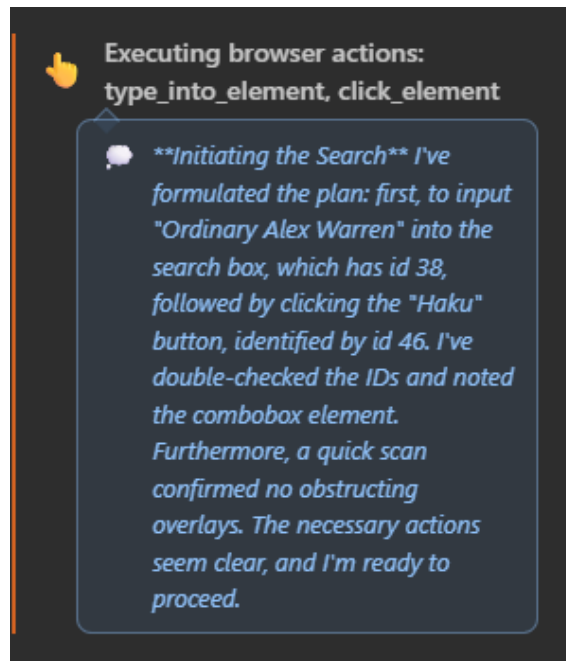


Figure 3.8: Rtrvr explaining the actions when making a search on YouTube’s home page.

seem to be able to complete tasks based on natural language alone. Completing tasks requires the use of commands, which can be created separately. There are many predefined commands, but they are mainly aimed towards extracting data from the web and creating text content based on the user’s prompt. HARPA really seems to excel at creating written content based on the user’s requests, which is how LLMs operate in the first place.

Bardeen [22] is an automation tool developed by Bardeen Inc. It is capable of creating automated workflows based on natural language prompts. The user is able to ask for a task to be automated, and Bardeen will create a workflow that aims to complete the task. Bardeen is able to integrate with many existing tools and platforms, and there is also many pre-built templates for professionals in different fields. Unfortunately, this automation is not really viable as a conversational user interface, as Bardeen will not directly start completing the tasks as they are given.

There are a lot more instances of browser extensions, such as Perplexity [26] and Merlin [27], that can only summarize web page content or help with understanding or writing, which are not sufficient functionalities on their own for the purpose of a conversational

Browser extensions	Developer	Downloads	Reason for rejection
Project Mariner [30]	Google Deepmind		Unavailable
Perplexity [26]	Perplexity AI	500 000	No agentic abilities
Merlin [27]	Foyer Tech	1 000 000	No agentic abilities
Taskade [28]	Taskade INC.	60 000	Requires manual setup
Agentic Workerrrs [29]	Agentic Workers	3000	Requires manual setup

Table 3.2: Rejected browser extensions

user interface. There are also many browser extensions that allow the user to automate tasks and workflows such as Taskade [28] and Agentic Workers [29], but do not have the ability to complete tasks autonomously based on natural language prompts. These kinds of extensions are not worth much further investigation for the purposes of this thesis.

Project Mariner is an experimental prototype by Google Deepmind capable of completing tasks automatically with the guidance of natural language. The demo videos show that it is able to complete tasks with multiple phases and different websites. Unfortunately, it is not currently available in Finland, as it is an experimental prototype only available in the US. [30]

3.7 Results of overview

Based on the overview on the existing browser extensions with agentic capabilities, Nanobrowser, Claude, Do Browser, FillApp and Rtrvr show promising signs of being able to operate as CBUAs. Table 3.3 shows that the aforementioned extensions are all able to operate based on natural language, use the browser's interface to complete tasks, and operate autonomously without the need for any user inputs other than the initial prompt. Because of this, they are prime candidates for the empirical study conducted in this thesis.

The other extensions that were looked into may have their own useful use cases, but are not feasible candidates for the empirical study. They mostly suffered from a lack of autonomy in their ability to complete tasks, and sometimes had a limited ability in

Browser extension	Natural language	Interface usage	Autonomous usage
Nanobrowser	X	X	X
Claude	X	X	X
Do Browser	X	X	X
FillApp	X	X	X
HARPA	X	X	
Bardeen	X	X	
Rtrvr	X	X	X
Project Mariner	X	X	X
Perplexity	X		
Merlin	X		
Taskade		X	

Table 3.3: Overview of extension capabilities

interacting with the browser interface. Still, a few of them are relatively popular in terms of downloads, as seen in Tables 3.1 and 3.2.

As is evident from the table, there are a great number of browser extensions that integrate LLMs into their software in some way. There are definitely even more than were found on this overview, although they are not relevant to this thesis in any way as they have very limited practical use. Low-effort applications that basically only act as wrapper software for asking LLM prompts are very common.

4 Deep dive into Nanobrowser

The purpose of this deep dive is to better understand exactly how Nanobrowser works and why it is able to complete tasks based on natural language prompts. By studying the way this open source extension works, it is possible to also make assumptions on how the closed source extensions might operate even though there may be large differences. The deep dive is done by taking a look at the overall architecture of the extension, a detailed look into how the planner and navigator models operate, and how the tasks actually get executed through the interaction between the LLM models, the extension and the browser.

4.1 Browser extension architecture

A simplified diagram of the flow of information within Nanobrowser can be seen in Figure 4.1. The extension does not do anything until the user gives a prompt. Nanobrowser runs with two LLMs: a planner model and a navigator model. As the names suggest, one makes an overarching plan while the other decides the specific actions taken at different times based on the plan.

When a prompt is made, Nanobrowser provides the context of the browser to the LLMs. This includes the current open tabs and URLs, but more importantly it builds a DOM tree and lists the interactive elements that it can find on the page [31]. It also has the ability to visually highlight them, if the setting is enabled as seen in Figure 4.2. The elements are indexed so that they can later be interacted with when the navigator model decides which element to interact with.

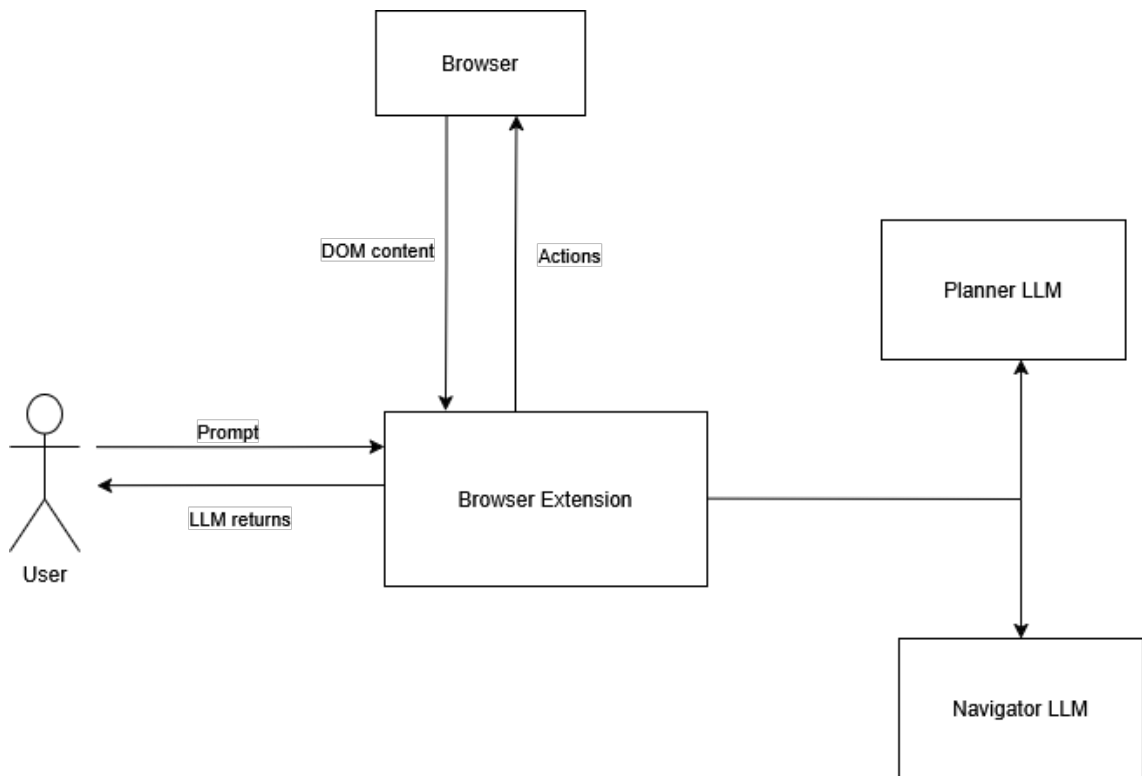


Figure 4.1: Diagram of Nanobrowser's operations

The DOM tree builder uses many different methods to try and find the interactive elements. It looks for interactive HTML elements such as *button*, *input* and *textarea*, but it also looks for interactive cursors, and any event listeners, such as *onClick*, that it can detect. It can also look for ARIA roles (Accessible Rich Internet Applications), which are used to allow for interaction with screen readers and other tools [32]. This means that Nanobrowser can find most interactive elements but it can still have blind spots if an interactive element is not a usually interactive element and has no detectable clues that would reveal it to be interactive. Nanobrowser also has the ability to take a screenshot that the LLMs can analyse.

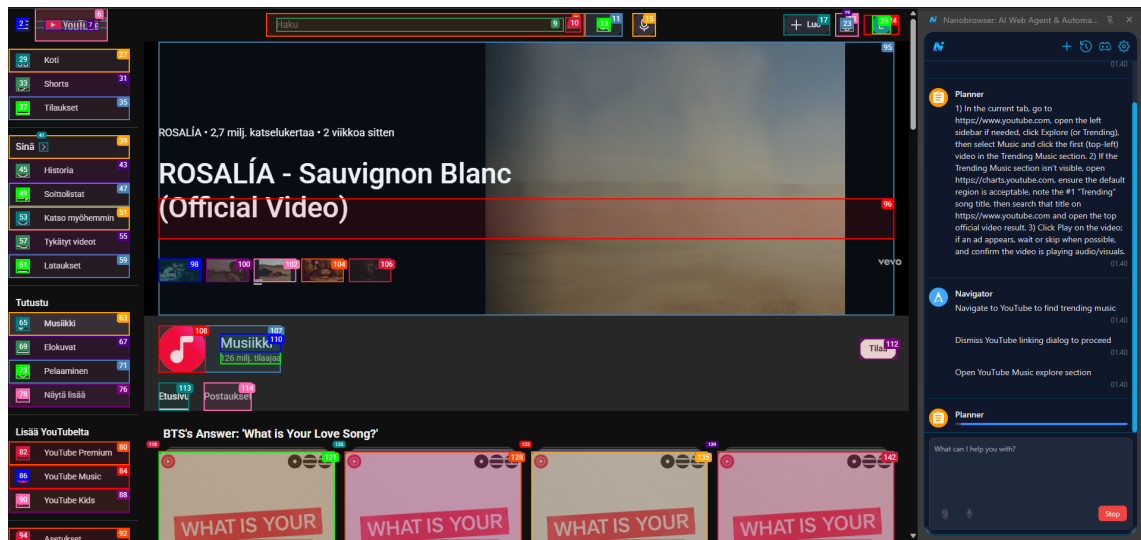


Figure 4.2: Nanobrowser highlighting interactive HTML elements.

4.2 Planner & Navigator

Nanobrowser’s Github page [24] has recommendations for LLM models based on preference over performance, cost-effectiveness and using a local model. For performance, the recommended model for the planner is Claude Sonnet 4, and for the navigator, Claude Haiku 3.5. These recommendations may be out of date though, as there is no mention of the newest and most powerful current models, such as Claude Haiku 4.5 or OpenAI’s GPT-5. The last update to the recommendations was in August 2025, so it is a reasonable assumption.

The operations of the both the planner and the navigator agent are defined in the system prompts for the respective agents [33] [34]. Both agents are first given common security rules, which includes vital instructions regarding the safety of the operation of the extension. The rules are in place to make sure that the models do not change their task from the user-given task, execute any content or use web page content as instructions, and never submit sensitive information, such as login information or payment information. Both the planner and navigator reiterate to follow the safety instructions. Repetition of

instructions is used in other instances as well, in order to make sure that the models do not forget them.

The planner is always executed before the navigator. When the planner model gets called, it goes through phases of thought. It is given the system prompt, the user-given task, the browser state, the previous planner outputs, navigator results, and possible errors. Based on all of the context, the planner model decides if the task it is given requires actions in the browser or can be answered without actions. When a task requires actions, the planner evaluates the current state of the progress to the ultimate goal, identifies potential challenges and suggests next steps to the navigator. It prioritizes working with visible content first, and only suggests scrolling when required content cannot be found.

The planner model gives its answer in a JSON format, which allows the browser extension to utilise the output in different ways. The JSON object includes the planner's analysis on the current state of the task, the potential challenges, the 2-3 next steps it suggests be taken, the reasoning behind the suggested steps, boolean fields pertaining to the done-ness of the task and whether or not the task requires navigation, and the final answer when the task is determined to be completed. The planner determines a task as done, when it decides that all of the aspects of the task have been completed, or the task is deemed too unclear to complete, or the completion of the task requires signing in to something using credentials.

Once the planner has given its output to an actionable task, the navigator model receives its prompt. It is given the planner's suggestions, the context of the task and most importantly a list of interactive elements available for actions. The elements are numbered so that the navigator can easily identify the correct element for completing a task. The navigator model will try alternative approaches if it gets stuck and no obvious path is found. The navigator may also receive image context to better understand the layout of the page.

The navigator model also gives its output as a JSON object, and the object includes an evaluation of the current state of the intended outcome, the memory of what has been done so far, the goal that should be targeted next, and the actions that the navigator decides on. The actions are based on a list of possible actions, which includes pressing buttons, inputting text, using keys or keyboard shortcuts, opening and selecting dropdown menus, scrolling up and down the page, opening, changing and closing tabs, navigating to a URL and going back and forth in the page. When the action requires it, the index of the element in question and text that is inputted are also included in the action object that is returned as a part of the JSON object.

4.3 Task execution

Nanobrowser makes use of Puppeteer[35], a JavaScript library that allows developers to create automation in the browser. When the navigator has chosen an action and an element, Nanobrowser locates the element and uses Puppeteer's functions to complete the action, for example when clicking a button, Nanobrowser uses Puppeteer's built-in click function. Puppeteer is not needed in every situation. For example when inputting text, it can be skipped completely as Nanobrowser can just set the element's value to the correct text string.

5 Empirical study of browser extensions

5.1 Taxonomy of AI agents and user interfaces

In order to accurately assess the different browser extensions, a categorization of their different attributes is needed. A taxonomy will be created with the help of a study on a taxonomy of the impacts of UI actions by Zhang et al. [36], and INSYTE, a classification framework for Agentic AI systems by Porter et al. [37]. Neither of them is sufficient for a taxonomy of conversational user interfaces, but they provide a helpful list of categories that can be modified for this purpose.

The article on the impacts of UI actions [36] presents a taxonomy of 10 general categories which are further divided to 35 specific categories. The 10 general categories for impacts of UI actions are:

User intent: Accomplishing the objectives of the user, such as information retrieval, navigation, or communication.

Impact on UI: Changes that occur on the user interface, such as visual changes, content updates, feedback and navigational changes.

Impact on Self: How the UI actions impact the user, for example knowledge acquisition, changes of assets or privacy of data.

Impact on Other Users: Similarly to Impact on Self, how the UI actions of the user may affect other users, such as changes in social perception, knowledge or assets.

Reversibility: The level of difficulty of reversing an action. Actions may be instantly reversible or require steps ranging in complexity, or not be reversible at all.

Roll Back Effects: The potential effects of reversing actions, in cases where the reversal does not return the system to its original state.

Idempotency: Whether or not repeated actions cause the same effect every time.

Statefulness: Whether or not the impact of an action may vary based on external states or contexts.

Execution Verification: The ease at which the execution of an action can be verified.

Impact Scope: The types of impact an action may have, such as immediate, enduring or subtle, or future impact.

The article on the INSYTE framework [37] presents an eight-dimensional framework categorizing the different abilities of a given agentic AI system. The dimensions are put into four categories: system design, system functionality, operating environment, and operational independence. The 8 different dimensions are:

System design: Underspecification and Adaptiveness. Underspecification refers to the system's ability to complete its objectives without explicit instructions. Adaptiveness measures a system's ability to operate in a given environment based on familiarity to the environment and changes made to the environment.

System functionality: Breadth and Depth. Breadth measures the diversity of tasks that the system is able to complete. Depth refers to the complexity and multi-layeredness of the tasks that the system is able to complete.

Operating environment: Environmental Diversity and Dynamism. Environmental Diversity refers to the elements that can be present in the environment that the system is operating in, and the interaction between the elements. Other elements may be humans or other agents. Environmental Dynamism refers to the frequency, rapidity and magnitude of change in the environment.

Operational independence: Independence from intervention and oversight. This measures how much the system can operate without human control or monitoring.

The taxonomy on the impacts of UI actions provides useful definitions and examples to all specific categories. The article on the INSYTE framework provides a few examples of the framework in practise, and it also comes with in-depth 0-5 ranking metrics for each dimension. Some of the categories and dimensions are not relevant in terms of the taxonomy of the browser extensions' conversational user interface feasibility, but many are, especially with some modification for the specific purposes of this study.

For the purposes of the empirical study, the taxonomy should focus mostly on the technical capabilities of the browser extensions. The main purpose of the taxonomy is to measure how well the browser extensions are able to follow the instructions of the user and utilise all of the elements of a given web page user interface.

Criteria	Explanation
User intent	How well the end result matches the original prompt
Underspecification	Ability to complete a task with vague instructions
Idempotency	Consistency of result in a repeated task
Statefulness	The impact of external context
Adaptiveness	Ability to operate in a foreign environment
Breadth	Diversity of tasks
Depth	Complexity and multi-layeredness of tasks
Environmental diversity	Number of different elements that can be interacted with
Environmental dynamism	Amount of change in the environment
Independence	Ability to operate without intervention

Table 5.1: Final criteria of the CBUA extension taxonomy

The extensions' capabilities can be measured using the taxonomy criteria in Table 5.1 by assigning different levels of values between 0 and 3. The meaning of the values is as seen in Table 5.2. This is a simplification of the level descriptions used in INSYTE, which used a range of values between 0 and 5. This simplification is done for the purpose of making the different levels easier to differentiate. The range between 0 and 5 caused some issues with properly differentiating between two contiguous levels during the evaluation of the usability of INSYTE [37].

Level	Explanation
0	The criteria is not fulfilled at all
1	The criteria is fulfilled poorly
2	The criteria is fulfilled well, but not perfectly
3	The criteria is fulfilled perfectly or almost perfectly

Table 5.2: Explanation of the levels of evaluation

5.2 Empirical study methods

A simple test of the basic functionality of the extensions chosen for this empirical study has already been done for each extension in the form of the example task in Section 3.1.1. The purpose of the empirical study is to get an understanding of the overall abilities of the different browser extensions. This is done through tasks given as a natural language prompt that the extensions have to complete. The tasks must be selected in such a way that each of the taxonomy criteria in Table 5.1 can be assessed. Some of the tasks will specifically target assessing certain criteria, while some of the criteria will be assessed in other ways. It is important that the tasks are designed in such a way that the capabilities of the extension are under assessment, but the capabilities of the LLM in charge of piloting the extension can also be examined. This is a necessary distinction, since some of the extensions may use different models by default.

5.2.1 Prompts and tasks

Each task will begin with a natural language prompt that should remain the same for each extension. Each extension will be evaluated using the following prompts and tasks. The tasks P1-P6 are executed by giving the prompts to the browser extension and observing the results. The tasks T1-T3 require the execution of the aforementioned prompts.

- P1.** "Cross-reference different sources for lasagne recipes and create a Google Doc with a list of ingredients needed for cooking the dish."
- P2.** "Find suitable products from K-Citymarket for the ingredients list found on the Google Doc and add them to a new shopping list on the K-ruoka website."
- P3.** "Look up the current number one Finnish artist. Find out if there are any upcoming concerts in Turku and put them on my Google Calendar."
- P4.** "Play an easy game of sudoku on sudoku.com."
- P5.** "Complete a 10x10 grid on liouh.com/picross."
- P6.** "By navigating the university intranet, find and open the degree certification application for the Faculty of Technology."
- T1.** Choose a task that the extension completed well and repeat it 5 times.
- T2.** Execute P2, but go to the home page of the K-ruoka website when the extension is adding an item to the shopping list.
- T3.** Execute P2, but close the current tab when the extension is adding an item to the shopping list.

Table 5.3 lists how the each evaluation criterion is evaluated based on the tasks. Tasks P1, P2 and P3 combine basic research using the web and the utilization of Google Docs, Google Calendar and other websites, which are commonly used tools for users in both

casual and professional settings. They are realistic use cases for a conversational user interface and thus useful for this study. In terms of taxonomy criteria, tasks P1, P2 and P3 can be used in assessing user intent, underspecification, depth and adaptiveness. Task P2 should be started with the Google Doc from task P1 open in the browser, so that the proper context is provided to the extension and statefulness can be assessed.

In order to test for idempotency, task T1 repeats a task 5 times in order to compare results between task executions. As the extensions may have different strengths and weaknesses, the choice of task will be done after tasks P1-P6 have been completed.

In order to test for environmental dynamism, tasks T2 and T3 aim to interfere with the extension's execution with user inputs. This way the extension's ability to adapt to change and interference in the environment can be assessed. It can be assumed by default that the extensions should be able to adapt to the changes that happen because of their own actions. P1 also tests for environmental dynamism a bit, as different websites can have sudden popups for cookies and other things unexpectedly.

Criteria	P1	P2	P3	P4	P5	P6	T1	T2	T3
User intent	X	X	X	X	X	X			
Underspecification	X	X	X	X	X	X			
Idempotency							X		
Statefulness		X							
Adaptiveness				X	X	X			
Breadth	X	X	X	X	X	X			
Depth	X	X	X	X	X	X			
Environmental diversity				X	X				
Environmental dynamism	X		X					X	X
Independence	X	X	X	X	X	X		X	X

Table 5.3: Relation of prompts and tasks to evaluation criteria

Tasks P4 and P5 are not necessarily realistic use cases for a CUI, but are a good way of gauging the extensions' capabilities for environmental diversity and adaptiveness. Figures 5.1 and 5.2 show what the games look like when the pages are first opened. They may be a bit more unusual in terms of the UI elements in web applications, as the sudoku game is presented as an HTML canvas element, and the Picross grid is an HTML table element

The image shows the PICROSS game interface. On the left, there is a settings panel with the following information:

- Progress:** 0.0%
- Mistakes:** 0
- Disable live validation (checkbox)
- Settings:**
 - Dark Mode (checkbox, unchecked)
 - Show Crossouts (checkbox, checked)
 - Grid Size: 10x10
- New Game »** (button)
- Current Seed: 1777549793827
- Custom Seed (input field)
- Custom Game (button)

The main area is a 10x10 grid. The clues are as follows:

	3	1	1		1				1	
	1	4	1	3	1	3	2	2	3	4
	3	1	2	3	1	1	1	1	1	3
2										
4 1 1										
1 1 1 3										
1 1 1 1 1										
1 1 2										
2 1 1 1										
4 2										
2 1 1 1										
1 1 1										
3 3 1										

At the bottom of the grid, there is a message: "Solve more of the puzzle to check for multiple solutions."

Figure 5.1: Unsolved Picross game board

where the clickable squares are HTML `<td>` cells. This may or may not cause problems for some of the extensions when it comes to their technical abilities in interacting with different elements. The sudoku game can be played on easy mode, since the goal is not to assess the AI model's sudoku abilities. The LLM's most likely know the rules and goal of both games, but they can also be explained if the LLM's struggle with that aspect. The goal of picross is to solve the grid by clicking in the correct squares based on the clues on the sides of the grid, and leaving the other squares empty. The empty squares can be right-clicked to mark them as non-filled. The goal of sudoku is to fill in numbers from 1-9 in the correct way so that each of the separate 3x3 squares has one of each number, and each row and column also has one of each number.

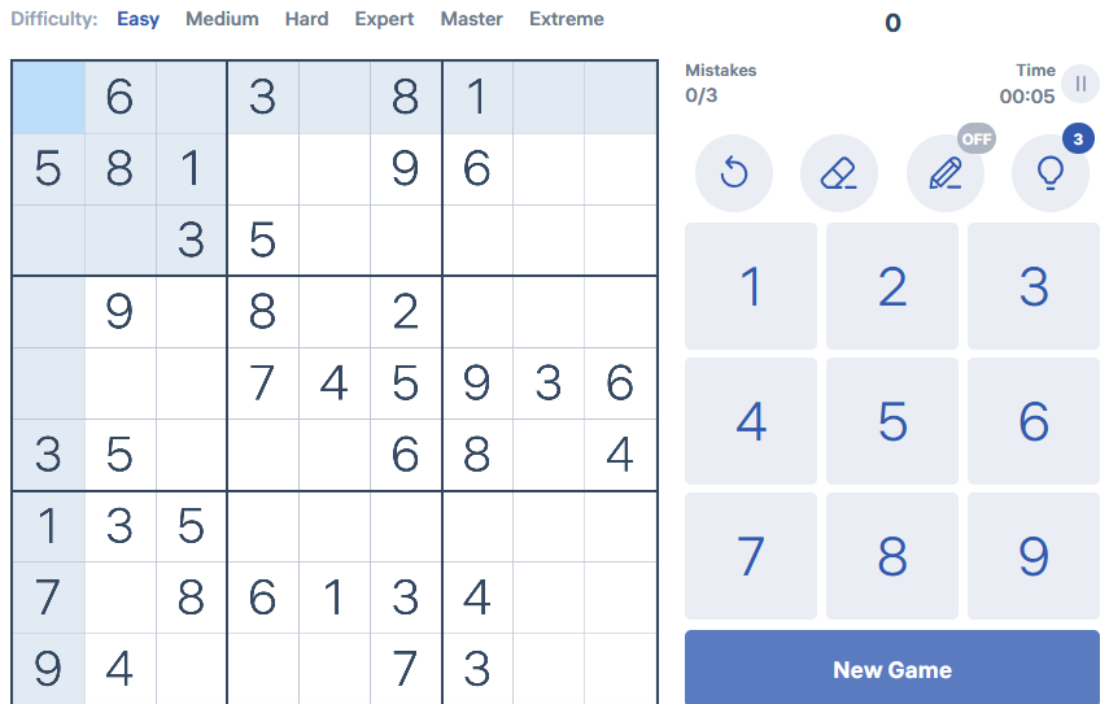


Figure 5.2: Unsolved sudoku grid

Task P6 is a relatively simple researching task, which has multiple reasons. While both P1 and P3 have researching elements, neither of them have definitive answers that the extensions should need to find. On top of that, P6 requires the extensions to answer the prompt by navigating the University of Turku’s intranet’s built-in search function or menus and clicking on links instead of making a simple Google search. The search function on the university intranet is quite bad in comparison to something like Google Search, as the search term needs to be much more accurate to yield useful results.

There was previously an idea involving completing an assignment on a Moodle page, but it was deemed both impractical and unnecessary. The inspiration for the task was having some kind of connection to the university and the internal tools that are in use, but the task had too many similarities to P1 and was replaced with P6.

Breadth, depth, independence, user intent, underspecification and environmental diversity are assessed during all of the prompts, as it is useful to have a variety of tasks to get a good understanding of them. The taxonomy criteria evaluation is ultimately subject-

tive, and every detail of the execution of the tasks should be taken into consideration. The scores are not an absolute truth about the capabilities of the extensions, but the overall results should give a good idea into the feasibility of the technology for the purposes of a CUI.

5.3 Study execution

The study is done with Nanobrowser, Do Browser, and Rtrvr. Nanobrowser allows the use of basically any LLM model, so GPT-5.4 will be used to keep parity with Do Browser, where it is also an option. It is also one of the most powerful current models, so it is a good choice. GPT-5 was used for the example tasks in Chapter 3, so it will also be used here as a comparison to GPT-5.4. Because Nanobrowser allows the use of any LLM, another lower performance LLM can be used to observe the difference between high and low performance LLMs.

In tasks where accounts on websites are required, the browser will already be logged in or at least remember the login details when possible. Allowing the browser extensions to use login information introduces an extra layer of security concerns that is outside the scope of this study, and usually the extensions refuse to fill in login credentials. In other scenarios the browser is always to be in the same state for each execution of the tasks, such as the "new tab" page with no other tabs open. Things such as cookies and other relevant history are also to be reset for every execution.

Whenever the browser extensions get stuck or do not manage to complete the task, they can be helped with additional prompts providing more context in order to nudge the browser extension in the right direction to complete the task. Doing this would naturally bring down the independence score among other criteria depending on the situation.

6 Results of the empirical study

The results of the empirical study are based on the chosen browser extensions' ability to complete the given tasks. Each extension is evaluated by their ability to complete each task, and the evaluation of the different criteria is done in Section 6.9. Generally, the tasks were manually terminated in cases where it looked like no progress was being made.

6.1 P1: Lasagne recipe

Table 6.1 shows how the different extensions managed to complete the first prompt. The evaluation value goes in line with Table 5.2's evaluations, where 0 means failure and 3 is perfect or almost perfect task completion. The time that the task takes to complete is also listed for additional context, as they ended up taking quite a lot of time.

Extension	Evaluation	Time (minutes)	Additional notes
Nanobrowser (GPT-5.4)	0	20	Terminated manually
Nanobrowser (GPT-5)	1	28	Did not write the document
Do Browser (GPT-5.4)	2	16	Figured out document writing in real time
Rtrvr (Gemini 3 Flash)	3	5	Successfully completed

Table 6.1: Evaluation of task P1

This prompt had two parts to it: searching for the lasagna recipes, and creating a list of ingredients onto a new document on Google Docs. Nanobrowser with GPT-5.4 as the planner and navigator models did not manage to complete even the first part of the task. It was able to navigate to two different recipe sites, but could not get past the cookie popup

on the second site. As seen in Figure 6.2, the navigator got into a repetitive cycle where it was trying to dismiss the popup, but the element index did not exist, even though it was visually highlighted as seen in Figure 6.1. Nanobrowser tries to dismiss the popup with both index 9 and index 11, which are for rejecting and accepting cookies respectively, but the response is that those elements are not available. Clicking the button manually did not help either, as the execution of the task got completely stuck at that point. As the task was not completed at all, the evaluation for this task is 0.

Nanobrowser with GPT-5 was able to navigate to the recipe sites better, although very slowly. The execution of the task seemed to slow down more when the extension had navigated to more sites. After 28 minutes, it finally navigated to Google Docs and created a new document. However, it was not able to actually write on the document, and it claimed to have completed the task without writing the final document. The final list of ingredients was obtainable by asking a follow-up prompt, but Nanobrowser could not recognize that it had not written the document. Because of this partial completion of the task, the evaluation is 1.

Do Browser was able to complete the task much faster than either Nanobrowser variant. It was able to navigate to multiple recipe sites and extract the data in a few minutes. Writing the document on Google Docs was more of a challenge, and it took many different approaches to do it while also explaining its thought process. At first it was not able to write at all, then it tried typing one character at a time, and finally it was able to find a "hidden editable box inside an internal frame", which allowed it to write the ingredients list very quickly. The whole task took 16 minutes, the majority of which was Do browser trying to write on the document. Because of the amount of time it took, the otherwise flawless execution of the task gets an evaluation of 2.

Rtrvr had a different approach to the information gathering part of the task. It first made a google search for the best lasagne recipes, then created a Google Sheet listing three different recipe websites. It filled in the information about the recipes on the Google

Arvostamme yksityisyyttäsi

Tällä verkkosivustolla käytämme evästeitä ja vastaavia toimintoja loppulaitteiden ja henkilöiden (kuten IP-osoitteiden tai selaintietojen) käsittelyä käytetään muun muassa sisällön, ulkoisten palvelujen ja kolmansien osapuolien elementtien integrointiin, tilastolliseen analyysiin/mittaukseen, personoituihin mainontaan ja sosiaalisen median integrointiin. Toiminnosta riippuen tiedot välitetään jopa kolmansille osapuolille ja ne käsittelevät niitä. Tämä suostumus on vapaaehtoinen, ei vaadi verkkosivustomme käyttöä, ja se voidaan peruuttaa milloin tahansa vasemmalla olevalla kuvakkeella.

- 1. Rajoitettujen tietojen käyttö mainosten valitsemisella
- 2. Rajoitettujen tietojen käyttö tunnistamista varten
- 3. Tarkkojen sijaintitietojen käyttäminen
- 4. Rajoitettujen tietojen käyttö sisällön valitsemiseksi
- 5. Palvelujen kehittäminen ja parantaminen
- 6. Yleisöjen ymmärtäminen eri lähteistä peräisin olevien tietojen, tilastojen tai yhdistelmien avulla
- 7. Sisällön tehokkuuden mittaaminen
- 8. Mainonnan tehokkuuden mittaaminen
- 9. Hylkää kaikki
- 10. Asetukset
- 11. Hyväksy kaikki

12

Figure 6.1: Nanobrowser highlighting the elements on the cookie popup

The screenshot displays a series of log entries from the Nanobrowser interface, organized into sections by icon and title. The entries describe a sequence of actions and subsequent failures related to closing a popup and navigating to a recipe page.

Planner (Clipboard icon):

1. Click the visible consent button at index 9 ('Hylkää kaikki') to close the cookie dialog.
2. Once the page is unobstructed, use the visible 'JUMP TO RECIPE' button to go directly to the recipe card.
3. Record the ingredient list from this source, then repeat with 2 additional recipe sources before returning to the Google Docs tab to create the document.

Yesterday, 23.10

Navigator (Letter 'A' icon):

Reject cookies to close the consent dialog and reveal the recipe content

Yesterday, 23.10

Element no longer available with index 9 - most likely the page changed

Yesterday, 23.10

Accept cookies to close the consent dialog and reveal the recipe content

Yesterday, 23.10

Element no longer available with index 11 - most likely the page changed

Yesterday, 23.10

Accept cookies to close the consent dialog and reveal the recipe content

Yesterday, 23.11

Element no longer available with index 11 - most likely the page changed

Yesterday, 23.11

Planner (Clipboard icon):

1. Click the visible cookie consent button at index 9 ('Hylkää kaikki'); if that still fails, use index 11 ('Hyväksy kaikki').
2. Once the modal closes, click the visible 'JUMP TO RECIPE' button on this same page to go straight to the recipe card.
3. Capture the ingredient list from this source, then repeat with two more recipe sources before switching to the Google Docs tab to compile the consolidated list.

Yesterday, 23.11

Navigator (Letter 'A' icon):

Accept cookies to close the consent dialog and access the lasagna recipe content

Yesterday, 23.11

Element no longer available with index 11 - most likely the page changed

Yesterday, 23.11

Figure 6.2: Nanobrowser getting in a loop of trying to close the popup

Sheet, and only after that created a Google Doc with the final list of ingredients. The consolidated list of ingredients was formatted nicely and the task only took a bit over 5 minutes. As the task was perfectly completed quite quickly, Rtrvr gets an evaluation of 3. The only slight negative aspect would be that Rtrvr used the imperial measuring system for the ingredients, when the metric system would be preferred. This could be caused by an American bias in Gemini or the fact that the recipe websites were also American. For comparison, Nanobrowser used both systems and Do browser gave no measurements, which is not good either.

6.2 P2: Shopping list

The ingredients that the extensions had to search for came from a slightly shortened version of the ingredient list that Do Browser made in P1. This was done mainly in order to speed up the process, as the original list was over 20 items long, and the list used in this task was 10 items long. Both the K-ruoka website and the Google Doc were open and logged into an account in the browser when the prompts were given. Table 6.2 shows how the different extensions managed with the task. Getting the list of ingredients from the Google Doc was a trivial task for all extensions, but there were differences in how they managed with the shopping list tool.

Extension	Evaluation	Time (minutes)	Additional notes
Nanobrowser (GPT-5.4)	2	22	Added 0 items
Nanobrowser (GPT-5)	2	22	Added only 1 item
Do Browser (GPT-5.4)	1	22 + 10	Added 5 items at first
Rtrvr (Gemini 3 Flash)	1	20+	Terminated manually

Table 6.2: Evaluation of task P2

In order to successfully complete the task, the extensions have to create a new shopping list first. The K-ruoka website allows the user to directly search for items, but the user can not add those items to a shopping list unless they are using the shopping list menu, which can only be accessed with a dropdown menu accessed in the top right corner of the page.

Nanobrowser made this mistake and first went to look for the items using the search bar on the front page, but was then able to navigate to the correct place. Figure 6.3 shows how Nanobrowser was able to use the shopping list search function and highlight the different options that show up following a search term. It also highlights the button responsible for adding the item to the shopping list, in the bottom right corner of each item.

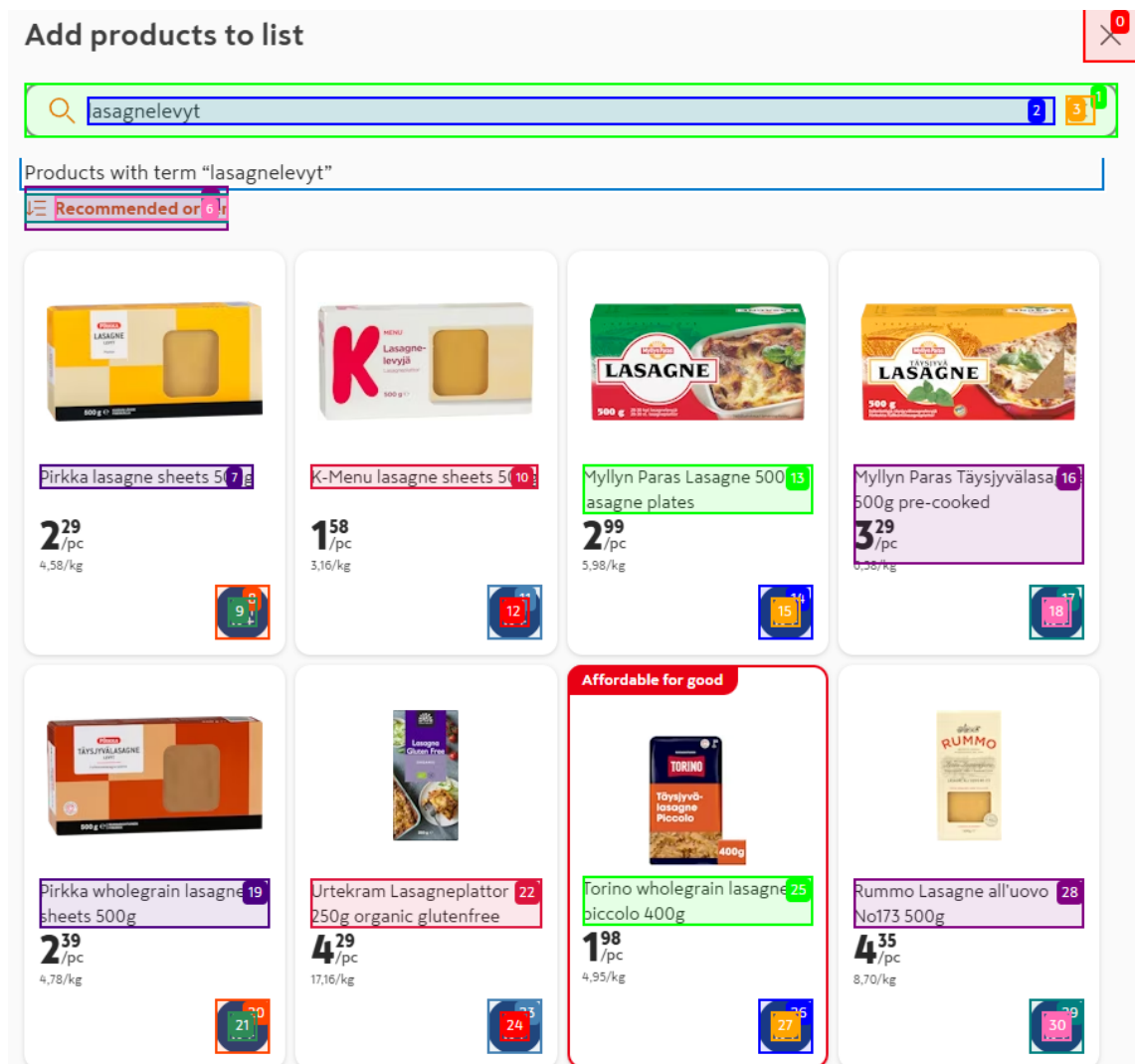


Figure 6.3: Nanobrowser searching for lasagne sheets using the K-ruoka shopping list search function.

Despite being able to use the search function and also having access to the buttons that add an item to the shopping list, Nanobrowser with GPT-5 only added a single item to the shopping list. It still searched for all the other items, but presumably hallucinated

clicking them, as the navigator’s output still included adding the items into the list. It is an interesting phenomenon, as it was clearly able to use the button, but still failed to do so. Nanobrowser took a long time to operate again, but as it demonstrated the ability to complete the task in some capacity, it gets an evaluation of 2.

GPT-5.4 had the same issue with not actually adding the items to the list, but it ended up not adding even a single item. Otherwise the execution was pretty much identical and the evaluation is the same. Both versions of Nanobrowser could be nudged to using the button with an additional button, so they both get the same evaluation.

Do Browser had a different problem. It was able to interact with the shopping list search function well, but forgot to erase the previous search result before entering another as seen in Figure 6.4. It ended up typing in a lengthy string of ingredients into one, and the search function obviously did not find the items that were wanted.

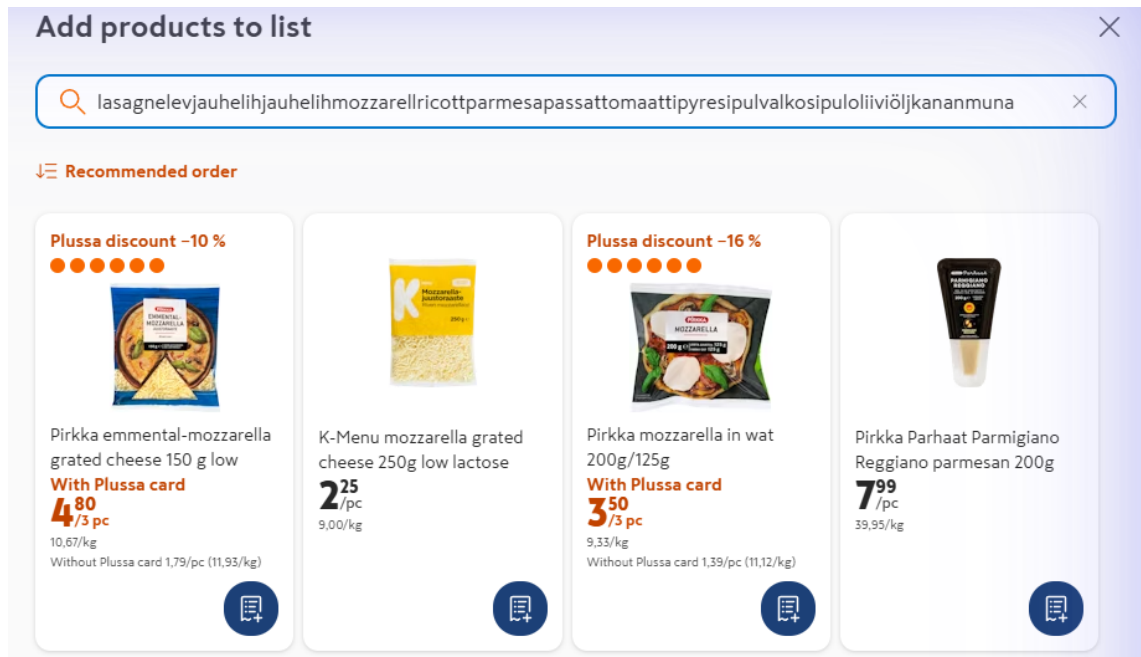


Figure 6.4: Do Browser typing in the ingredients into the shopping list search bar.

Once Do Browser recognized that its current approach was not working, it tried for several minutes to find another approach. After many different attempts, it gave up claiming that its workflow became unstable, as there was no other way to add items to the

shopping list. This entire process took 22 minutes, as Do Browser spent a long time thinking of approaches. It also took a long time to begin adding items in the first place, as it first looked up the items without adding them to the list.

After Do Browser had given up, it was given another prompt trying to nudge it towards erasing the search bar after each item. This did not instantly work, as Do Browser still spent a considerable amount of time thinking about different approaches, opening and closing more tabs, and going back to the beginning. After 10 minutes, it was finally able to add the remaining items. It also added extra items at this point. It may have stopped using the Google Doc as reference after the additional prompt. While it was eventually able to complete the full list of ingredients, it took a long time and an additional prompt, so the evaluation for Do Browser is also 1.

Rtrvr's process was more difficult to follow, as it operates in multiple tabs without any regard for the user's visual experience, as it is aimed towards working in the background. Regardless of that, Rtrvr was operating quite slowly. After 10 minutes, it looked like Rtrvr had created 4 shopping lists of the same name, with all of them having the same items: lasagne plates and 2 different kinds of minced beef. After another 10 minutes, 2 more shopping lists had been created, with the same items and yet another kind of minced beef. The list of shopping lists can be seen in Figure 6.5.

Rtrvr also added all of the items into the shopping basket, which is not intended, as it is a different feature to the shopping list. The task was manually terminated after 20 minutes of execution, because it was not progressing in the right direction. Rtrvr gets an evaluation of 1, as it was able to interact with the website, but was not able to follow the user's intent.

It is difficult to explain why all extensions struggled with the button so much, as the button is easily identifiable as a standard HTML `<button>` element, and it even has an ARIA label of *Add to shopping list*.

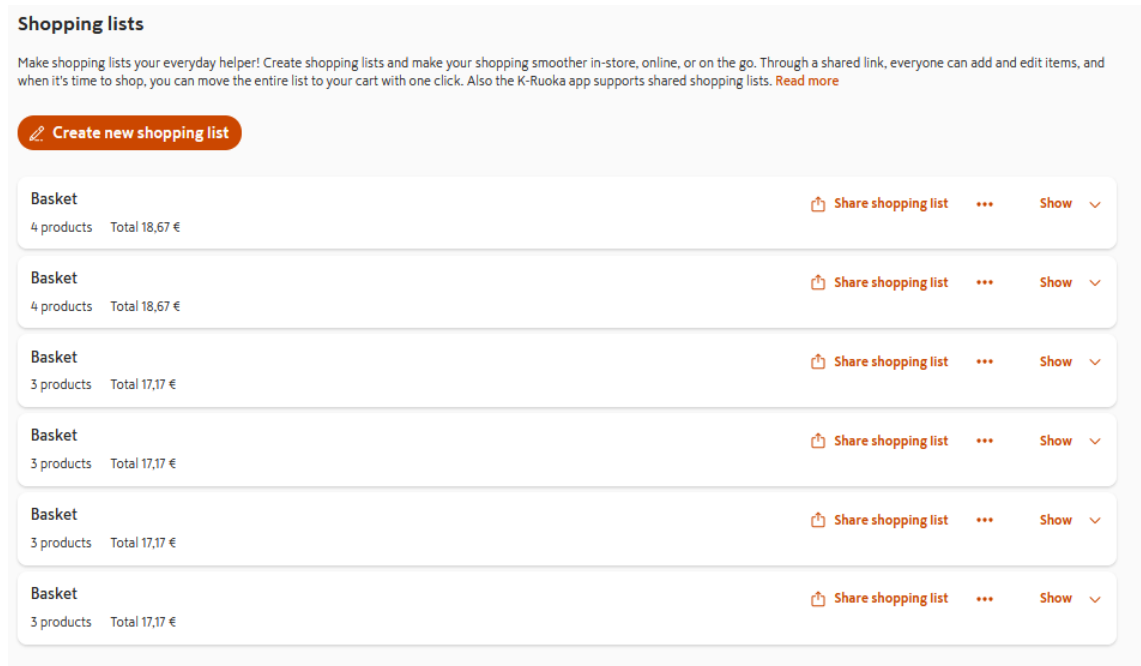


Figure 6.5: Do Browser typing in the ingredients into the shopping list search bar.

6.3 P3: Concerts

P3 involves a subjective decision, as the term "number one artist" is not clearly defined, which adds an interesting layer of variability to the task. The task is otherwise simple, and it has less steps than the previous tasks. Table 6.3 shows how the different extensions managed with this task.

Extension	Evaluation	Time (minutes)	Additional notes
Nanobrowser (GPT-5.4)	0	5	Execution failed
Nanobrowser (GPT-5)	1	15 + 20	Terminated manually
Do Browser (GPT-5.4)	3	4	Successfully completed
Rtrvr (Gemini 3 Flash)	2	15	Terminated manually

Table 6.3: Evaluation of task P3

Do Browser first found Nightwish as the current number one Finnish artist. As they are not currently touring, the task was completed. The prompt was then expanded with looking for artists performing in Finnish, so that a touring artist could be found. Do Browser chose both Isac Elliot and Samuella as high-charting artists, and looked for their upcoming concerts in Turku. It then added an event for both Isac Elliot and Samuella in

Ruisrock in July, and another event for Isac Elliot in Aura Fest in August. The events were successfully added to the calendar in a short amount of time, so Do Browser gets an evaluation of 3.

Rtrvr chose to use the top trending artist on Spotify as the number one artist. This ended up being LounaOnline, who performs at the Kesärauha festival in June. Rtrvr did not spend a lot of time researching, and moved straight back to the Google Calendar. For some reason, creating the event took a lot of time. After a few minutes, the event had been created. The event had no title at first, and Rtrvr actually went back and edited it. After the event was created, Rtrvr went to verify that LounaOnline was the number one artist, which took several minutes until it got into a loop of repeating the same output about verifying the number one artist. Because of this extra time lost at the end and the manual termination of the task, Rtrvr gets an evaluation of 2 for an otherwise well completed task.

Nanobrowser with GPT-5 struggled with the researching part of the task. The first 15 minutes was spent searching for the number one artist, which Nanobrowser chose to do by visiting websites using their URLs. Unfortunately those URLs were incorrect and led to pages that did not exist. After 15 minutes, the task was terminated and Isac Elliot was given as the artist whose concert had to be found. While the Nanobrowser took a long time to find the concert and to operate the Google Calendar UI, it was able to create an event for a valid concert. The event creation was not finalised however, as Nanobrowser kept trying to verify that the date of the event was correct and that the "All day" option was selected over and over again in a loop. Because GPT-5 had to be helped in the research and the task had to be manually terminated and was not properly finished, it gets an evaluation of 1.

Nanobrowser with GPT-5.4 failed because of an error as seen in Figure 6.6. This implies that the navigator model's response included more than just a JSON object, which made the further execution of the task impossible. Nanobrowser did not attempt anything else during the execution after this message, and the execution had to be terminated man-

ually. The task was attempted multiple times, but the same error happened in all attempts, so GPT-5.4 gets an evaluation of 0.

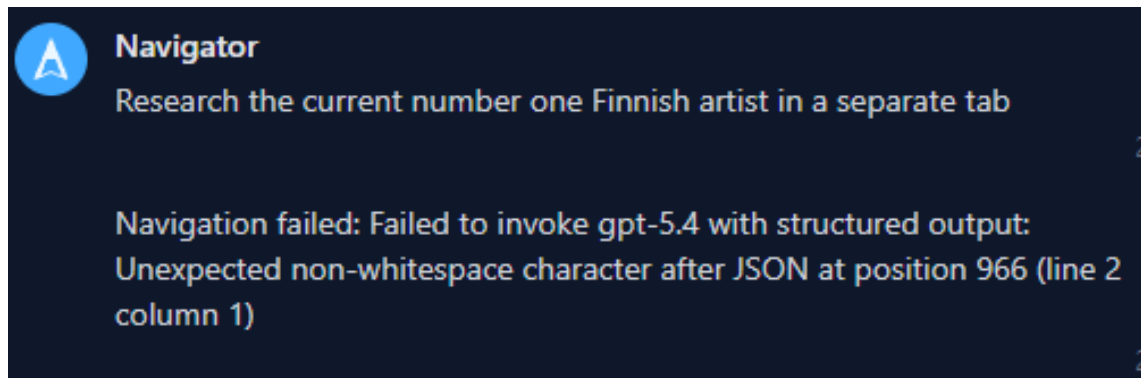


Figure 6.6: The error message from Nanobrowser's GPT-5.4 navigator

6.4 P4: Sudoku

Task P4 is relatively simple, the extension only needs to navigate to the given URL, and start and play a game of sudoku on the site by interacting with the sudoku game. Table 6.4 shows that this was impossible task for Nanobrowser and Rtrvr, but Do Browser was able to complete it after some time.

Extension	Evaluation	Time (minutes)	Additional notes
Nanobrowser (GPT-5.4)	0	5+	Terminated manually
Nanobrowser (GPT-5)	0	5+	Terminated manually
Do Browser (GPT-5.4)	3	6	Sudoku completed
Rtrvr (Gemini 3 Flash)	0	5+	Terminated manually

Table 6.4: Evaluation of task P4

Both variations of Nanobrowser operated the exact same way. Nanobrowser was able to navigate to the page easily and dismiss the popup at the beginning, but it was not able to interact with the actual game board. Figure 6.7 shows how Nanobrowser is not able to highlight anything on the sudoku game itself, but does highlight buttons around it. During the execution of the task, the navigator got stuck on a loop after opening the easy game, and nothing happened for several minutes until the task was terminated manually.



Figure 6.7: Nanobrowser highlighting the buttons around the sudoku board.

Rtrvr was also not able to interact with the sudoku game. It managed to navigate to the page, but after that it got stuck on a loop of trying to start the game. It constantly thought that a cookie popup was still visible when it was not, and it could not detect that a game had already been started. Because of this, it kept trying to close the cookie popup and start a new game repeatedly and never got to actually playing the game. It also kept scrolling to the bottom of the page, so the game board was not visible to the user.

Do Browser was able to complete the sudoku after 6 minutes of figuring out a way of doing it. It tried many different methods before it found a way to interact with the sudoku grid. These methods include inspecting the DOM, searching the HTML, inspecting the site's network resources to see where the game is loaded from, trying to query the puzzle API, and using shell tools to inspect the script. Eventually it found an action to solve the game, and was able to then instantly complete the game, which caused the win screen to display. Figures 6.8, 6.9 and 6.10 showcase some of Do Browser's unexpanded thinking

during the task and how it manages to find a way of completing the puzzle. Do Browser's evaluation is 3, as it managed to correctly solve a puzzle after a bit of time spent thinking about the right approach.

Do Browser does have the ability to enter the number on the grid one by one like a normal user would, and this method is used in Section 6.7. The method that was used here turns out to be the more difficult and rare one. What makes Do Browser's approach in this task interesting, is that it is not trying to use the interface that a normal user would. Instead, it is trying to find alternate methods in order to mutate the state of the sudoku canvas object. The *Considering game functions* part in Figure 6.10 explains Do Browser's thought process in choosing to find an action that allows for instant solving of the puzzle. The reasoning can be seen in Figure 6.12. Do Browser ends up finding a massive number of different actions, and ends up using one called *cheatFinishLevel*. A snippet of the actions found in the *Read store and actions* part of Figure 6.10 can be seen in Figure 6.11. Figure 6.12 showcases the use of the cheat action, which ends up solving the game.

```
🔍 Investigating grid data
I know it's an Easy classic puzzle. Now I'm locating the live board values.
✓ Search for puzzle state
🔍 Reasoned
I didn't find a simple global board array yet. I'm checking the page source for the puzzle data or level ID.
✓ Search page HTML for puzzle id
🔍 Exploring JS Bundle Data
I'm checking the site's network resources to see where the puzzle is loaded from.
✓ Inspect resource URLs
🔍 Investigating API endpoint responses
I found the puzzle start API. I'm querying it directly so I can read the board state cleanly.
✓ Fetch sudoku app_start
🔍 Troubleshooting API requests
The API is protected for direct calls. I'm inspecting the site's game script to see how the puzzle data is stored after load.
✓ Download game script info
🔍 Considering command options
I hit a tooling limit with Python here, so I'm switching to shell tools to inspect the script.
✓ Search game script text
🔍 Considering file download options
I'm saving the game script locally and searching it for the board/state logic.
✓ Save and grep game script
🔍 Reasoned
I'm fetching the script from inside the browser page context instead.
✓ Fetch script from page
```

Figure 6.8: First part of Do browser's reasoning trying to interact with the sudoku puzzle

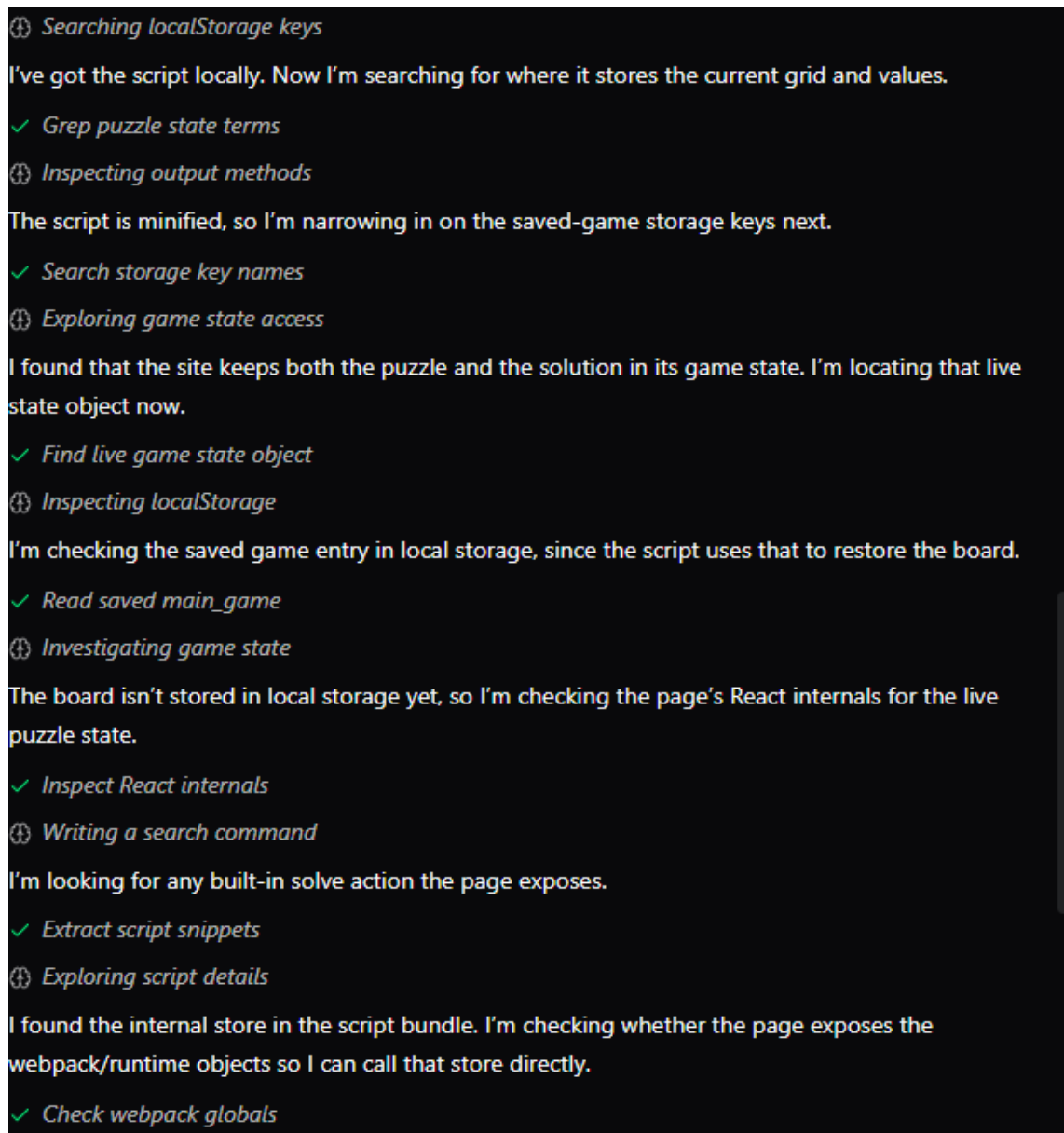


Figure 6.9: Second part of Do browser's reasoning interacting with the sudoku puzzle

The page does expose webpack. I'm using that to inspect the loaded modules and find the active game store.

- ✓ *Probe webpack modules*
- ⚙️ *Evaluating object keys error*

I hit a small webpack probing error. I'm retrying with stricter checks.

- ✓ *Probe webpack safely*
- ⚙️ *Inspecting request properties*

I got the runtime function; now I'm inspecting its properties to locate the module cache.

- ✓ *Inspect webpack require*
- ⚙️ *Exploring module caching*

I can require individual webpack modules. I'm scanning them for the active game store.

- ✓ *Scan required modules*
- ⚙️ *Considering game interaction*

I found the live game store. I'm reading the current puzzle and the available game actions so I can finish it cleanly.

- ✓ *Read store and actions*
- ⚙️ *Exploring cheat functions*

I found both a partial solve and a finish action. I'm checking which one actually completes the game properly.

- ✓ *Inspect cheat finish snippet*
- ⚙️ *Searching for validateBoard logic*

I'm checking the win logic to make sure this will count as a completed game.

- ✓ *Inspect validateBoard logic*
- ⚙️ *Planning game logic*

I've got the internal finish action. I'm using it now and then I'll verify the win screen.

Figure 6.10: Third part of Do browser's reasoning interacting with the sudoku puzzle

```
"changeCanShowInter": "changeCanShowInter",  
"changeCountSmartHints": "changeCountSmartHints",  
"changeShowGameOver": "changeShowGameOver",  
"changeSmartHint": "changeSmartHint",  
"cheatFinishLevel": "cheatFinishLevel",  
"cheatSolve": "cheatSolve",  
"checkSavedGame": "checkSavedGame",  
"clearAll": "clearAll",  
"hideMessage": "hideMessage",  
"hideMessageTip": "hideMessageTip",  
"increaseErases": "increaseErases",  
"increaseMistakes": "increaseMistakes",  
"increaseUndos": "increaseUndos",  
"makeHint": "makeHint",  
"makeHintToCell": "makeHintToCell",
```

Figure 6.11: A few of the many actions Do Browser was able to find in the sudoku page, including *cheatFinishLevel*, which ends up being used.



Figure 6.12: Do Browser's reasoning for finding cheats and then using the *cheatFinishLevel* action in a command, solving the puzzle.

6.5 P5: Picross

Similarly to the Sudoku task, the challenge in the Picross tasks is interacting with the grid. Table 6.5 shows that the performance of the extensions was similar to the performances in the Sudoku task, as Nanobrowser failed as it did in P4 and Do Browser succeeded. A difference can be found with Rtrvr, which was able to do more in this task than in task P4.

Extension	Evaluation	Time (minutes)	Additional notes
Nanobrowser (GPT-5.4)	0	5+	Terminated manually
Nanobrowser (GPT-5)	0	5+	Terminated manually
Do Browser (GPT-5.4)	3	3	Puzzle completed
Rtrvr (Gemini 3 Flash)	2	23	Many mistakes

Table 6.5: Evaluation of task P5

Nanobrowser was not able to interact with the cells of the grid, as it is not able to figure out that the cells of the grid are clickable, only being able to highlight and interact with the buttons and numbers on the side of the grid as seen in Figure 6.13. As usual, Nanobrowser does not recognize that it is unable to complete the task, and without interruption could go on for a much longer time.

Do Browser was able to complete the task easily and quickly. It was able to solve the grid correctly based on the clues. After solving the puzzle, it started filling in the grid by clicking the cells one by one. About half way through the puzzle it stopped, as it detected the page re-rendering. Because of the re-rendering, it went for a different approach in finishing the puzzle, as it updated the saved state of the puzzle into the solved grid and then reloaded the page to verify that the grid was completed.

Rtrvr was also able to interact with the grid quite easily. It spent more time and was much more careful during the actual solving of the puzzle. It started completing the grid from the seventh row at first, seemingly at random. It then moved on to the top row, where it made a mistake, clicking the fourth cell when it should not have been clicked. It made many more mistakes during the completion of the puzzle, without realizing that they were mistakes. It also kept going over the same cells that had already been filled, which con-

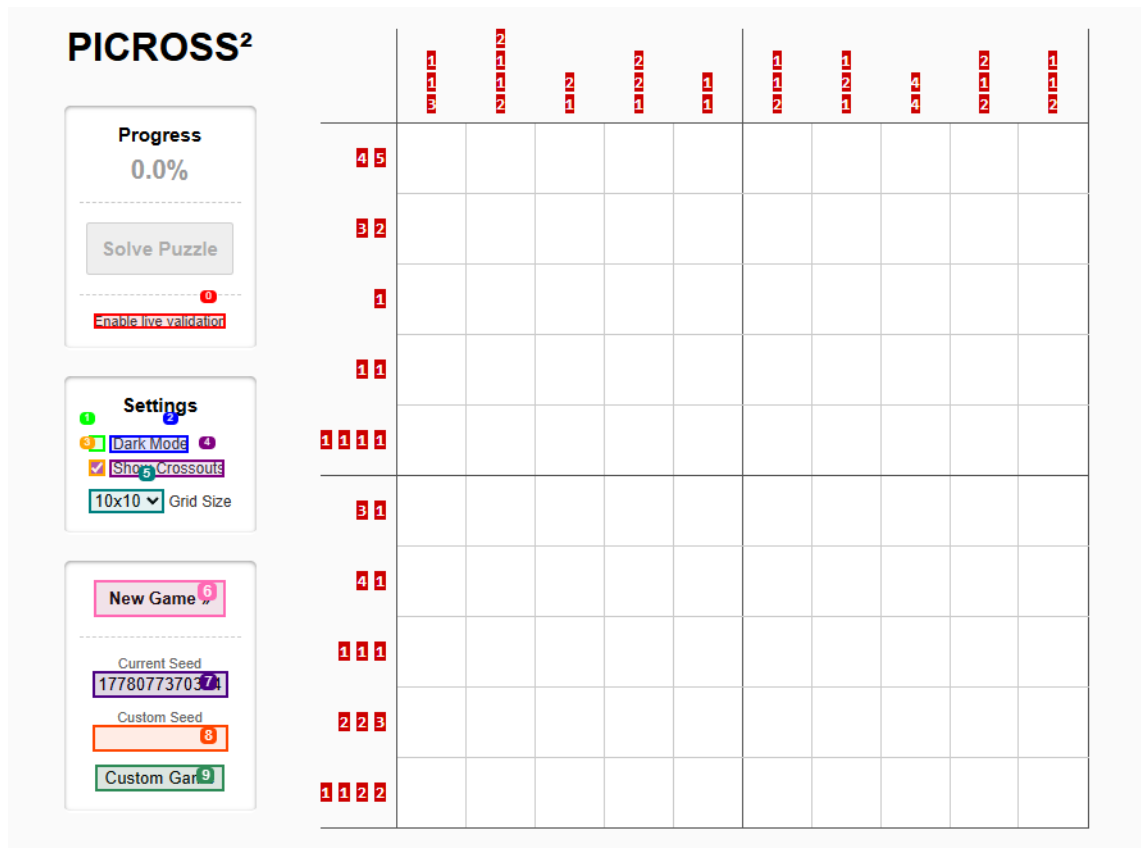


Figure 6.13: Nanobrowser highlighting the buttons on the side panel in Picross

tributed to the task taking so much more time. When more of the grid had been completed, it was also taking more time to go through again and again. As seen from Figure 6.14, it made quite many mistakes during the task. The blue cells are correctly filled in, the grey cells are correctly non-filled, the grey cells with a cross on them are incorrectly filled in and the blue cells with a cross on them are incorrectly non-filled. Despite the mistakes, the evaluation for Rtrvr on this task is 2, as it had no trouble interacting with the grid and it also understood the goal of the game. A point has to be deducted for both making mistakes and taking so much time in doing it.

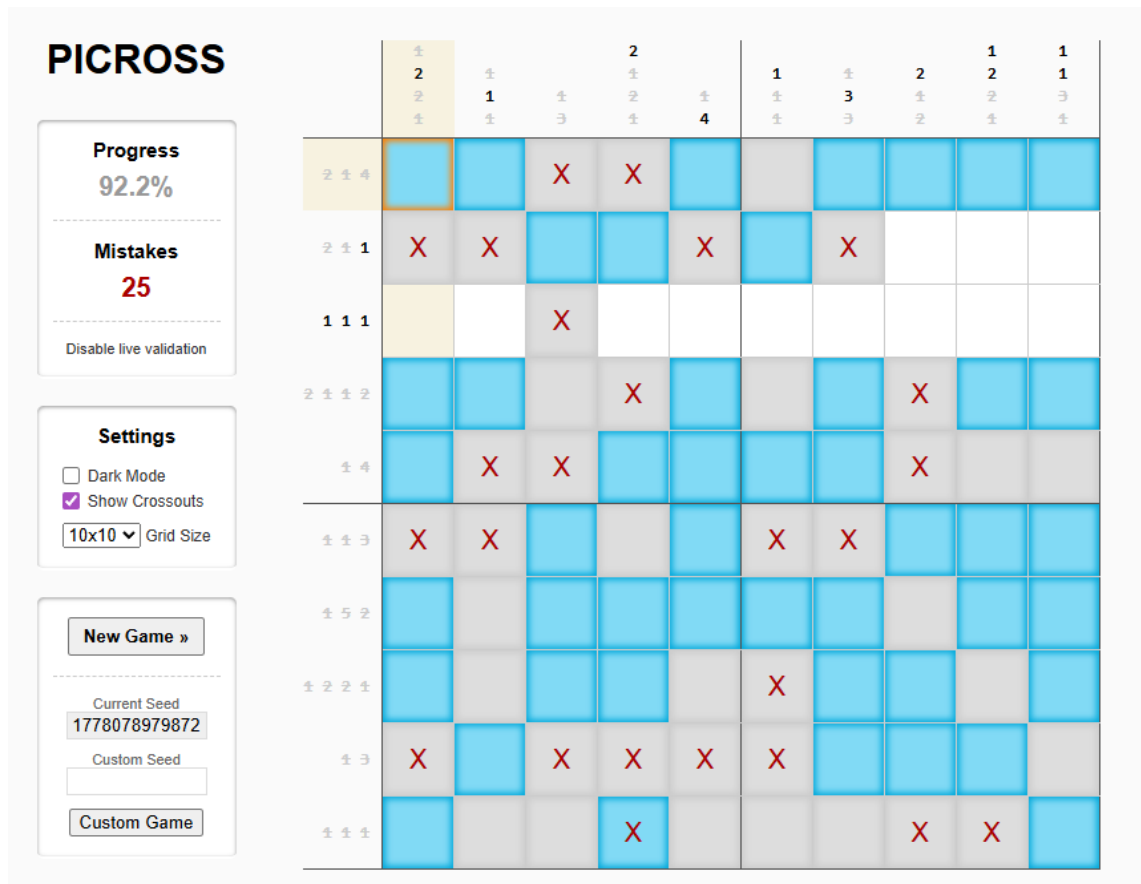


Figure 6.14: An almost finished Picross grid by Rtrvr

6.6 P6: Intranet

Task P6 is a relatively simple, but a useful task, as it is a realistic use case for a CBUA extension. There are two paths to finding the Degree certificate page: using the search function, or using the dropdown menu. It should be noted that the intranet search function is not perfect, and slightly different wording may have wildly different results. The evaluations for task P6 can be seen in Table 6.6.

Extension	Evaluation	Time (minutes)	Additional notes
Nanobrowser (GPT-5.4)	1	3	Execution failed
Nanobrowser (GPT-5)	3	4	Successfully completed
Do Browser (GPT-5.4)	3	3	Successfully completed
Rtrvr (Gemini 3 Flash)	3	4	Successfully completed

Table 6.6: Evaluation of task P6

Nanobrowser with GPT-5 used the search function, and managed to find the right page instantly with the search term "Degree certificate Faculty of Technology". The link for the degree certificate application can be found on that page, and Nanobrowser was able to open it quickly. The task was completed perfectly in only 3 minutes, and Nanobrowser with GPT-5 gets an evaluation of 3.

Execution of the task with GPT-5.4 was attempted multiple times, but the same error kept happening as the one in Section 6.3, the navigator's responses did not fit the structured output that Nanobrowser was expecting. However, Nanobrowser was able to navigate all the way to the degree certificate page using the search function before the error happened. For this reason, GPT-5.4 gets an evaluation of 1.

Rtrvr also chooses to use the search function first. However, it uses the search term "degree certification application Faculty of Technology", which does not bring up the correct page or anything related to it, showing that the search function is not very good. After verifying that the search results were not useful, Rtrvr uses the dropdown menus to navigate to the right page. It uses the optimal route to get there, which is *Organisation and decision-making/Faculties/Faculty of Technology/Studying at the Faculty/Graduation/Degree Certificate*. The entire process took about 4 minutes, and Rtrvr also gets an evaluation of 3. Using a search term that yields bad results can not be held against Rtrvr, as the wording in the original prompt matches the search term.

Do Browser started with the search term "degree certificate", which returned links to many pages for different faculties. Instead of trying to choose one of them, it went back to the beginning and tried to use the dropdown menu method instead. It navigated to the "Services for studying" page, which is not the right path. Once Do browser realised this, it decided query the intranet's search API directly in order to find the correct section, which worked. The task was then completed easily in under 3 minutes in total. Do Browser also gets an evaluation of 3.

6.7 T1: Repetition

Task T1 tests for the idempotency of the extensions by repeating one of the previous tasks 5 times. The results of the task can be seen in Table 6.7. The tasks were chosen for each extension specifically so that the extension would be able to complete the task, but also had a chance of doing something differently that could be observed.

Extension	Task	Evaluation	Additional notes
Nanobrowser (GPT-5.4)	P6	0	Execution can fail
Nanobrowser (GPT-5)	P2	1	Multiple inconsistencies
Do Browser (GPT-5.4)	P4	3	Consistent result
Rtrvr (Gemini 3 Flash)	P1	2	Consistent workflow

Table 6.7: Evaluation of task T1

Task P4 was chosen for Do Browser, because its execution of the sudoku board was very interesting. During the repeated executions, Do Browser actually did not repeat the original method of completing the puzzle in Section 6.4. All of the executions used a method of filling in the sudoku grid one by one. In 3 instances, Do Browser skipped over a few cells while filling in the grid, which increased the execution time by a bit. There was certainly some variance in how Do Browser arrived at the solution. There was a bit of variance in the time that the executions took, ranging between 4 and 8 minutes. The evaluation for Do Browser is 3, as the outcome was always the same and the method was also the same in the end outside of the original execution.

For Rtrvr, task P1 was chosen as Rtrvr succeeded in it the most and notably better than both Nanobrowser and Do Browser. The most meaningful differences that can be examined are the choices in the recipe sources and the contents of the final document. Rtrvr used 4 or 5 sources on each execution, and there was 6 different sources used in total. There was some differences in the formatting of the final document, mostly in terms of how the ingredients were categorized. In two instances, Rtrvr did not include the quantities that would be needed with each ingredient. Each instance of the execution was

fairly quick, around 4 minutes. While Rtrvr succeeded in the task well in every instance, the slight differences in the end result mean that the evaluation is 2.

Nanobrowser did not succeed especially well in any task outside of P6. P6 was chosen for GPT-5.4, as it failed a lot in the other tasks with the navigator's incorrect output. That was also the main point of interest during this task, as Nanobrowser succeeded in the task 3 times and failed due to the incorrect output twice. Some progress was still made in the failed instances, and the successful instances completed the task perfectly. Because the failure of execution is a detrimental issue that can happen quite often, the evaluation is 0.

For Nanobrowser with GPT-5, task P2 was chosen as it managed with the task relatively well. An interesting thing to observe was how often Nanobrowser would fail to add the item to the shopping list by not actually using the correct button. In all but one instance, no items were added to the list. However, in one instance, all of the items on the list were successfully added, and Nanobrowser succeeded in the task better than both Do Browser and Rtrvr did. Another point of interest was how the task was started as in whether or not Nanobrowser found the right way of adding items to a shopping list instantly or if it first tried to look for products without the shopping list function. The optimal route was taken in 2 of the 5 instances. A final observation is the variance in asking for additional information. Even though both the Google Doc and the K-ruoka website were already open and logged in, GPT-5 sometimes asked for clarification and sign-ins regardless. This happened in 3 of the 5 instances. Overall there was quite a lot of variance in the different executions, so the evaluation is 1.

6.8 T2 and T3: Interference

Tasks T2 and T3 are very similar, as they both involve interfering with the browser while the extensions are in the process of completing a task. The task in question was P2, and luckily all extensions were able to interact with the UI in the K-ruoka website in some

way. As both of the tasks are testing for a similar purpose, their evaluation is also shared in Table 6.8.

Extension	Evaluation	Additional notes
Nanobrowser (GPT-5.4)	3	Quick readjustment
Nanobrowser (GPT-5)	3	A bit slower
Do Browser (GPT-5.4)	3	Quick readjustment
Rtrvr (Gemini 3 Flash)	3	Quick readjustment

Table 6.8: Evaluation of task T2 and T3

For Do Browser, T2 was more tricky than T3. When the current view changed from the shopping list view to the home page, Do browser was still trying to add new items to the list. It was able to navigate back to the shopping list in a couple minutes, and continued to add the items. When the current tab of the K-ruoka website was closed for T3, Do browser reopened the tab almost instantly and kept operating normally.

Rtrvr was executing the task in a strange way, by opening many tabs and searching for the different items in the different tabs. Task T2 was done by navigating all the tabs to the K-ruoka home page. This did not slow down the process much, and Rtrvr got back to its process in less than a minute, working on the execution the same way it did in Section 6.2. Closing the tabs in T3 similarly had little to no effect, as the tabs were reopened quickly.

Somewhat surprisingly, Nanobrowser with GPT-5.4 was able to make it back to the shopping list view after the interference in T2 very quickly as well. When the current tab was closed in T3, the navigator noticed it quickly as it was in the process of adding an item to the list. Getting back to the page took a bit more time than with the other extensions, but no more than a minute. For T2, there was no real difference with GPT-5. A small difference could be found in T3, as GPT-5 used a Google search to return to the K-ruoka website, which the others did not do. GPT-5 was a bit slower than the others, but all extensions succeeded in these tests very well.

6.9 Final observations and reviews

Based on the results in the previous sections and the observations on how the extensions operated, each extension has been given final evaluations for each category on the taxonomy from Chapter 5. The evaluations can be seen in Table 6.9.

Criteria	Nanobrowser	Do Browser	Rtrvr
User intent	3	3	3
Underspecification	2	3	3
Idempotency	1	3	2
Statefulness	2	2	2
Adaptiveness	2	3	2
Breadth	1	2	2
Depth	1	2	2
Environmental diversity	1	3	2
Environmental dynamism	2	3	3
Independence	1	2	1
Total score	16	26	22

Table 6.9: The final reviews of the extensions based on the results and observations of the empirical study

User intent was met pretty well across all extensions. Even in cases where the extensions did not have the technical capability to complete the task, they tried to follow the original intent of the prompt, so the evaluations are high. Evaluations for underspecification are also high, as the extensions were mostly able to operate without explicit instructions. Nanobrowser gets a slightly lower score, as it often asked for clarification on the original prompts.

As for idempotency, it seems like the variance in results or execution comes from the LLMs operating inconsistently and sometimes unpredictably in the case of Nanobrowser with GPT-5.4. Because of this, none of the extensions can be expected to operate with 100 % consistency, but consistency in results is still quite high. For Nanobrowser, the choice of LLM makes a large difference, as GPT-5.4 can cause failures at any point of the execution process in any task.

All three extensions get a score of 2 for statefulness. This is because they are all able to receive additional context from the user and the pages that are open on the browser. None of them get a perfect score, because they all struggle to implement very specific instructions in cases where additional help from the user is needed.

In terms of adaptiveness, Do Browser was the strongest. All environments in the tasks were technically foreign environments, and Do Browser was usually the fastest in finding a way to interact with the environment. Do Browser also has a higher level of understanding of the environment that it is operating in compared to Nanobrowser and Rtrvr.

In terms of breadth, Do Browser is the strongest, as it is capable of completing all tasks in some way. Rtrvr excels in research-related tasks, but also has a decent capability of completing other tasks. Nanobrowser's strength was navigating menus and entering text into text fields in tasks P1, P2 and P6, which is only a small part of the necessary skillset.

Nanobrowser struggled with depth the most, as tasks with multiple steps such as P1, P2 and P3 took up a lot of time compared to a simple task in P6. Time is mostly the only way that the multi-layeredness of the tasks affected the extensions, and they were all affected by it to some degree. Do Browser and Rtrvr struggled with the shopping list tool in P2, which is reflected in the time spent on the task. Rtrvr also slowed down in the execution of P5 when more of the grid had been finished.

Environmental diversity is perhaps the most important criterion in differentiating the extensions. Do Browser is clearly the strongest, as it was the only one capable of interacting with the sudoku grid in P4 and was also very quick with the Picross grid in P5. It had some surprising struggles with the Google Doc in P1, but managed to use it after some time. Rtrvr is the second best, as it was very proficient with the Google Doc and also managed to complete the Picross grid. It was more difficult to follow from a user's perspective in some of the tasks where Rtrvr always scrolled to the bottom of the page.

Nanobrowser has the worst score in environmental diversity, as it has a limited amount of elements that it can interact with, as explained in Chapter 4.

As seen in Section 6.8, All three extensions were able to deal with interference well, and get a high score on environmental dynamism. While all were able to deal with user interference, Nanobrowser struggled with change in the form of unexpected cookie pop-ups in rare occasions. Because of this, its evaluation is a bit lower. Rtrvr and Do Browser never struggled with cookies or other popups, such as advertisements.

None of the extensions get a perfect score for independence. Both Nanobrowser and Rtrvr had to be terminated manually multiple times, because they got stuck in a loop or otherwise could not complete the task, and could not recognize that on their own. Nanobrowser especially does not seem very aware of its own capabilities and limitations, and would easily get stuck on a task. Do Browser could not figure out its own mistake in task P2, but outside of that it was able to operate independently, so its evaluation is higher.

Do Browser succeeds the best out of the extensions with a total score of 26 out of a possible 30. It was the most well-rounded of the three extensions as it managed to complete all of the tasks somewhat well and only struggled majorly with P2, still managing with it after additional user input. Rtrvr was second best with a total score of 22, and it was especially proficient in the tasks related to researching information. The gathering of information is not really shown to the user, as Rtrvr open multiple tabs at once and gathers the data on a Google Sheet without visually changing tabs. Nanobrowser's total score of 16 is the worst of the three due to multiple issues. In comparison to the other extensions, it was painfully slow in almost all cases. The choice of LLM changes the way that the outputs are written and how the execution of the tasks is done. Nanobrowser is also able to interact with the smallest number of different environments, which is an important factor.

7 Discussion

7.1 Successes, failures, and solutions

The empirical study showed that the extensions are capable of performing tasks for a CBUA extension, and can fulfill the taxonomy criteria very well. Table 7.1 shows where the extensions performed well and what kind of challenges the extensions still face. The biggest win in regards to conversational user interfaces is that all extensions were able to at least attempt to fulfill the user’s intent, and they did not really misunderstand the natural language prompts or hallucinate different goals for themselves.

Strengths
Fulfilling the user’s intent
Interacting with a variety of interfaces
Operating in foreign environments with vague instructions
Challenges
Execution speed
Choice of LLM and LLM instructions
Multi-layered tasks
Awareness of own capabilities
Awareness of current situation

Table 7.1: The strengths of the CBUA extensions and the challenges that prevent CBUA extensions from becoming

The best performing CBUA extension — Do Browser — got an evaluation of 2 or above in all tasks except for task P2. This means that it managed very well, which shows that the idea of a CBUA extension that works across the entire web is not out of the question. While it is not perfect, it could already be in daily use as a CBUA extension for

most purposes. An ideal extension would be mostly Do Browser, with Rtrvr’s efficient method of information gathering and Nanobrowser’s ability to complete P2 better than Do Browser. Do Browser’s ability to access methods outside of standard interface interaction is also a massive advantage that can be very useful in more difficult and unusual situations, but it may also complicate the process unnecessarily, if normal usage of the interface would be faster. Do Browser also utilises screenshots often, so that the LLM has a chance to take a look at the page and potentially learn something that is not visible in the DOM. A study by Zhang et al. [38] showed that LLM-driven mobile agents performed better when they had access to screenshot data in addition to text, although the cost of the LLM usage was much higher as well.

The biggest hurdle for these extensions is definitely execution speed. While Do Browser and Rtrvr managed to complete some tasks in only a few minutes, some tasks could take up to over 10 or even 20 minutes to complete. For simple tasks, even a couple of minutes could be too long if the alternative is using the mouse and keyboard and doing it in a few seconds, and over 10 minutes is too long in most cases regardless of task complexity. It is difficult to imagine what could be a solution to fixing this problem, as LLMs inherently do not give their responses instantly, but need a bit of time to output their reasoning. With good optimization of the browser extension and the system instructions of the LLM, the speed could be improved. It could also improve with time, as new models with better speed and efficiency keep getting released, but this is not a guarantee.

Some of the biggest causes for slow execution speeds were the complicated nature of some of the tasks and the number of different steps required to complete them. This was especially apparent with Nanobrowser, but Rtrvr and Do Browser also struggled with it a bit. On top of making the execution time longer by being a longer task, they also slowed down the execution speed the longer the process took. It could be that all of the additional context of the progress done on the task slows down the LLM processing. It can also be

argued that being able to try to plan execute the more in-depth tasks is a strength and a promising sign for the future.

An impressive and important factor for the future of CBUA extensions is that all of the different environments they were able to operate in were foreign, and the user mostly did not have to specify how the website UIs should be used. The fact that all websites are foreign environments as default is the thing that sets CBUA extensions apart from other conversational user interfaces the most. This of course also plays a part in slowing down the speed of the execution process, as the LLMs and the extensions need time to familiarise themselves with the environment first.

If the CBUA extension technology were to become popular enough, web developers could be incentivised to build their websites in a way that lets the extensions interact with the sites without any friction. This could be as simple as including guidelines to navigating and using the site in the DOM, hidden from the user, but visible to the CBUA extension. This way the LLM would not need to spend much time on figuring out the best way of completing a task, as the website would be able to provide that information. The K-ruoka shopping list task showed that the LLMs often first make the reasonable assumption that items could be added to the shopping list by simply searching for the items, which was not the case. It could be argued that this is poor UI design, and a better designed website would have been easier for the extensions to operate in.

Nanobrowser's failures with GPT-5.4 signal that giving the LLMs system instructions is a very delicate process, and different models need different things in order to make the LLM perform to its best abilities. The best solution would be a custom-made LLM specifically designed for the purpose, but as Do Browser proves, it is not necessary for achieving adequate results. Outside of only having a few options for the LLM, it is difficult to say what Do Browser does differently to Nanobrowser in this regard, as the former is not open-source. The one thing that is clear from the study is on top of having access to more actions and abilities, Do Browser is more aware of its own limitations when it

is failing to do something. It is able to change its approach to a problem, which leads to a longer execution time, but oftentimes also leads to a successful execution of the task. On the other hand, Nanobrowser never admits to not being able to do something, and will keep trying the same approach indefinitely, burning through LLM credits unless manually terminated. All extensions, even Do Browser, struggled to notice that they were doing something that was not working, so having better awareness of how the extensions' own actions change the situation is important.

7.2 Limitations

There are several points of view that are not really considered in this thesis or could be expanded upon further, the use of LLMs in the empirical study being one of them. Nanobrowser could be used with a wide range of LLMs, including open-source models. Nanobrowser was released before GPT-5 and GPT-5.4 came out, so older models could behave differently. It could also be interesting to look more into how models developed by different companies behave. The same LLM was used for both the planner and navigator during the empirical study, and the effects of having different LLMs for the planner and navigator are not discussed. The other extensions also allow the use of different models from the ones that were used.

The tasks used in the empirical study were chosen arbitrarily based on things that a user could realistically want to use a conversational user interface for, for research, work, and leisure purposes. Some tasks were also specifically selected to incorporate more variety in the types of interfaces that the extension had to interact with. A different number of tasks focused on different things could have produced different results and conclusions.

7.3 Further research suggestions

The execution speed of the tasks was recorded as a bit of an afterthought in the empirical study, but it proved to be an important metric for the extensions' success, as some tasks took up an unreasonable amount of time, especially with Nanobrowser. Looking more into the execution speed of CBUA extensions for different tasks and environments could be a useful topic of study.

The cost of execution was also outside the scope of this thesis. All of the different experiments cost around 25 € in total, and the likelihood of the CBUA technology becoming popular is low if basic tasks are too expensive. There could definitely be methods to optimising the LLM usage in such a way that minimises costs.

An alternative technology to CBUA extensions could be different solutions that do not involve extensions at all. AI-using browsers are also an emerging technology that is under development by a few actors, such as OpenAI. An even higher-level technology could be an operating system that incorporates AIs in creating a conversational user interface for the entire operating system including any browser that would be used on the operating system.

8 Conclusion

RQ1 was answered by giving an overview of existing suitable options for CBUA extensions in Chapter 3. Nanobrowser, Do Browser, FillApp, Claude in Chrome, and Rtrvr were all identified as feasible CBUA extensions. Chapter 4 took a closer look at the open-source codebase of Nanobrowser in order to find out how a CBUA extension could operate. It mainly relies on its planner and navigator LLM models, which use the current state of the browser and the user's natural language prompt to choose their next actions. The actions are predefined simple commands, which the LLMs choose by outputting them as part of their JSON-structured response. From that response, the extension is then able to choose an element on the web page on which it can then use the chosen action in question. Although there is no way of getting detailed information on how the other extensions operate, they seem to use a similar method of having a planner model feed instructions to a navigator model. How they interact with the user interfaces on websites can vary between extensions.

Out of the 5 extensions that were deemed feasible, Nanobrowser, Do Browser and Rtrvr were used in an empirical study where their capabilities were tested with a number of tasks. RQ2 was answered by creating a taxonomy of 10 categories in Chapter 5. The categories were based on two different studies, one on a classification framework for agentic AI systems and one on a taxonomy of the impacts of UI actions. The categories were selected based on the needs of a CBUA extension. The taxonomy was used to judge

the feasibility of the three extensions in the empirical study, and the tasks in the study were based on testing for each of the categories.

With the help of the results of the empirical study in Chapter 6, RQ3 was answered in Chapter 7. The biggest challenge in creating a usable CBUA extension is execution speed. While conversational user interfaces usually operate in a familiar environment, a CBUA extension is always in a foreign environment that the LLMs need time to understand before any decisions on actions can be made. Other important challenges for CBUA extensions are the choice in LLM and the efficient system instructions that the LLM requires, making sure that the extension is capable of interacting with all possible websites and interfaces that it might come across, and making sure that the LLMs are aware of the tools they have to find the best approach to a problem. Longer and more multi-layered tasks also hinder their execution speed and overall ability to complete the task. Despite the challenges, particularly Do Browser, but all of the extensions to a degree, are feasible CBUA extensions and capable of performing many of the common browser tasks in day-to-day life, although not without supervision. They follow the user's intentions from the natural language prompt well and are able to interact with most interfaces in common websites.

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