National University of Ireland Galway

College of Science and Engineering, School of Computer Science

Web Platform for Computing Principles Education

Master Thesis

Jakub Duras

Advisor: Dr Frank Glavin

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Abstract

To be done.

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To be done.

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List of Acronyms

API	Application Programming Interface.
EU	European Union.
ICT	Information and Communication Technology.
ISO	International Organisation for Standardisation.
UX	User Experience.
WAI	Web Accessibility Initiative.
WCAG	Web Content Accessibility Guidelines.

Introduction

Taken from Thesis Proposal with only minor adjustments and notes.

Possible line of thought: High-level concepts have received more attention on the web - online IDEs. Introduction to low-level principles not as much. Example - the most popular course on this topic on Coursera - nand2tetris - desktop tools. Shift in the devices to mobile and chromebooks. Universal design - higher market share of mobile devices - especially in third world countries. Built-in accessibility with web tools, can be embedded into learning material. Outlines the process and considerations needed to migrate desktop educational tool to web and possible benefits (percentage of covered devices, improved UX indicators - primary research).

Understanding low-level computing principles can be beneficial for a wide variety of people - from the general public interested in computers, through practising software engineers, to Computer Science students. Rather popular material is the open-source licensed Nand2Tetris "taught at 400+ universities, high schools, and bootcamps" that explains how to build a computer from individual logic gates to high-level programming language (Shocken and Nisan 2017). The material is accompanied by a desktop software that is hard to access or completely inaccessible from a new class of devices unsuited for desktop Java applications: Chromebooks that are seeing massive growth and now account for the majority of the US K12 market (Boreham 2019) (IDC 2021), or mobile devices that account for 56% of web traffic, up from only

6% in 2011 (StatCounter 2021). The recently created web-based alternative, WepSIM, is showing promising results but takes a more complex look focusing on the CPU and instruction processing (García-Carballeira *et al.* 2019).

Common problems with Massive Open Online Courses (MOOCs) leading to a high rate of dropouts include lack of time, problems adopting new systems, and bad past experience with technical problems on MOOC platforms (Onah *et al.* 2014). The use of MOOCs for software engineering education within higher education is argued to broaden student knowledge and is integrated by some universities in their courses and programmes (Stikkolorum *et al.* 2014). However, MOOCs are also said to require significant time to both create and integrate (Stikkolorum *et al.* 2014).

This thesis will propose a new web platform for learning computing principles involving logic gates, machine code, and assembly via a basic set of individually usable tools integrated into example content. Can the new web platform for learning computing principles improve student task success rate compared to commonly used desktop software like that of Nand2Tetris?

Background

Outline of the covered topics should be added here.

2.1 Human-System Interaction Ergonomics

The following section concentrates on the selected topics of Human-System Interaction Ergonomics: Accessibility, Usability, and User Experience (UX). The selected topics are explored in relation to computer software and, where possible, web services specifically. After introducing the concepts, this section outlines non-obvious benefits and delves into the implementation and evaluation strategies.

2.1.1 Definition and Distinction

Keeping in mind there are incompatible definitions for Accessibility provided by International Organisation for Standardisation (ISO) (Wegge and Zimmermann 2007), the specific definition chosen for this thesis describes Accessibility as the "extent to which [a service] can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals [...]" (ISO 2018). ISO (2020) adds that Accessibility includes but does not apply exclusively to formally disabled people. That means Accessibility is concerned with the basic ability to utilise the software by the widest possible range of users, including disabled users (Wegge and Zimmermann 2007). Wegge and Zimmermann (2007) point to

existing confusion between the terms Accessibility and Usability. Although Wegge and Zimmermann (2007) admit these terms are related and have potential overlap, Wegge and Zimmermann (2007) stress the importance of their distinction. Importantly, Information and Communication Technology (ICT) is one of the fields where Accessibility, depending on the country and sector, is mandated by the law (Wegge and Zimmermann 2007; Sauer *et al.* 2020). For example, public sector services within European Union (EU) have to meet accessibility standards outlined in the Web Accessibility Directive, and there is an ongoing effort to extend this to the private sector (European Commission 2021).

Usability, on the other hand, is defined by ISO (2018) as the "extent to which [a service] can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction [...]". As Wegge and Zimmermann (2007) hint, compared to Accessibility, Usability deals with the success - "effectiveness, efficiency and satisfaction" (ISO 2018) - of software interactions which is hard to mandate the way Accessibility is. Therefore, there are few relevant laws and Usability is usually considered more as a competitive advantage that authors are trying to capitalise on (Wegge and Zimmermann 2007).

Similarly to confusion between Accessibility and Usability, researchers point to issues with the distinction between Usability and User Experience (Darin *et al.* 2019; Sauer *et al.* 2020). There are multiple views on the definition of UX and a great amount of disagreement on the topic (Sauer *et al.* 2020). ISO (2018) defines UX as "user's perceptions and responses that result from the use and/or anticipated use of [a service]". Compared to the sole satisfaction that was mentioned to be a part of Usability and Darin *et al.* (2019) argue is incorrectly used as, and often only, UX measurement, UX deals with "users' emotions, beliefs, preferences, perceptions, comfort, behaviours, and accomplishments" (ISO 2018). Additionally, UX is concerned with a broader timeline - the time spent performing the task *and* the time before and after that (Sauer *et al.* 2020; ISO 2018). Considering the definition by ISO (2018), we can look at UX as a more complex superset of Usability (Sauer *et al.*

2020).

In short, for the purposes of this thesis, Accessibility is the basic ability to use the software regardless of the user's various limitations, Usability is the extent to which it can be used to achieve delineated goals successfully, and UX is a more complex extension to Usability also concerned with impressions both during and outside of the use of software. The following subsections always refer to these ideas as Accessibility, Usability, and UX, even if cited literature refers to them differently.

2.1.2 Benefits

Sauer *et al.* (2020) point to their earlier research results that indicate implementing Accessibility on the web could provide benefits to users other than the usual primary target of Accessibility enhancements - disabled users. This notion is seconded by Vanderheiden (2000), who mentions that others in similar challenging situations can benefit from Accessibility as well. Edyburn (2010) provides terminology identifying these two groups of users: primary and secondary beneficiaries. Edyburn (2021) mentions that Accessibility can improve the ability to use the software for both primary beneficiaries - disabled students - and secondary beneficiaries - all other students - in the educational setting.

Examples of secondary beneficiaries in relation to the web are mentioned by WAI (2005):

- people using different devices with smaller screens or "different input modes" (WAI 2005),
- people challenged by limitations introduced by ageing,
- temporarily limited people - e.g. by a "broken arm or lost glasses [...or a] bright sunlight" (WAI 2005), or conditions that do not allow audio playback,
- and people limited by their internet connection - i.e. latency or bandwidth.

However, Sauer *et al.* (2020) also mention that benefits from concepts like "using easy language" (Sauer *et al.* 2020, p. 1210) may not be significant enough. Additionally, as far as Web Accessibility Initiative (WAI) is concerned, we need to point out the inherent bias.

2.1.3 Implementation

According to Wegge and Zimmermann (2007, p. 296), there are three main approaches to implement the Accessibility requirements:

- Universal Design - designing software to be usable without any modifications by the widest range of users.
- Adaptive Design - designing software to be adaptable to different types of users.
- Interoperability with Assistive Technology - designing software to work with existing assistive software.

Wegge and Zimmermann (2007) warn about the downsides of Universal Design: the ability to hinder the experience of the majority, stigmatisation, and implementation difficulties due to conflicting requirements. In contrast to that, implementation of Adaptive Design allows to opt-in to alternative, independent representations without influencing other groups of users (Wegge and Zimmermann 2007). Similarly, assuming the software follows the relevant standard Application Programming Interface (API), Interoperability with Assistive Technology allows selected users to use their existing tools, e.g. screen readers (Wegge and Zimmermann 2007). Edyburn (2021) mentions Assistive Technologies like speech-to-text and text-to-speech in relation to learning and argues they are already available on most platforms and can be targeted at both types of beneficiaries.

Sauer *et al.* (2020) mention that the web has received a significant amount of attention in regards to Accessibility thanks to its perceived importance. WAI is recognised as the relevant source of information used to develop and

verify the Accessibility of web services (WAI 2005). Web Content Accessibility Guidelines (WCAG) by WAI are adopted around the world, including in the law (WAI 2018), an example of which is the EU's Web Accessibility Directive (European Commission 2021).

The content below should be revised and finished and I have included it only for the context.

According to (WAI 2010) there are two kinds of Accessibility requirements: technical, which are mostly fulfilled by properly utilising available APIs; and interaction/visual.

2.1.4 Evaluation

Wegge and Zimmermann (2007) mention Usability, in contrast to Accessibility, is not typically tested by adherence to standards but by testing and analysing the impact on the end-users. Usability testing is done by focusing on specific roles and tasks (Wegge and Zimmermann 2007). Edyburn (2021) adds we can monitor subjective measures like decreased frustration or objective measures like increased productivity during the Ergonomics research and practice for the educational setting.

Summarise tools and methods mentioned by (Darin *et al.* 2019), strategies by (Wegge and Zimmermann 2007), and approaches by (Sauer *et al.* 2020). Mention comparative UX studies explicitly and guidelines on the size of the group.

Specifically for web - mention methods outlined by (**WAI˙Evaluate**).

2.2 Learning Low-Level Computing Principles

Edybrun (2021) argues the industry now focuses on web-based curricula as the web already has essential accessibility tools, and frameworks like Depth of Knowledge (DOK) lend themselves better to the web environment. More specifically, Edybrun (2021) mentions developing more interactive ex-

periences than just "text on a screen" adapted from textbooks. Part of the web-based curricula can be interactive "embedded supports". Edybrun (2021) mentions these should be context-sensitive. However, the only kind of examples Edybrun (2021) provides are a tool that provides a breakdown and planning of subtasks and "virtual pedagogical agents" similar to virtual assistants like Alexa or Siri, but specific to the pedagogical environment.

2.3 Device Usage Trends

Work in progress.

Chromebooks are seeing massive growth and now account for the majority of the US K12 market (Boreham 2019; IDC 2021) Mobile devices account for 56% of web traffic, up from only 6% in 2011 (StatCounter 2021).

Overlap between Web Accessibility and Mobile Web.

2.4 Creating Open-Source Web Application

Methodology

Taken from Thesis Proposal with only minor adjustments and notes.

The main paradigm used for this thesis is Design Science Research (DSR), as currently outlined by Brocke *et al.* (2020). It uses existing theories, frameworks, and models to produce and evaluate a new artefact - instantiation, as categorised by Hevner *et al.* (2004).

The evaluation of the artifact consists of two parts:

- **Automated Tests** It is assumed it is possible to achieve feature parity with the selected three tools. To evaluate this and confirm the feasibility of porting to the client-side web, the author will prepare two classes of automated tests: end-to-end and unit tests. End-to-end tests will focus on the ability to perform equivalent actions (feature-parity) and unit tests, among else, to confirm various inputs, including the Nand2Tetris assignments from all six weeks, can be used and produce correct output (correctness).
- **Primary Quantitative Research** The central hypothesis is that the increased efficiency from using the web instead of the desktop will increase the student task success rate. This will be evaluated by conducting a comparative study. The participants will be tasked to perform a simple exercise of implementing chips like AND and NAND or XOR and XNOR in Nand2Tetris and the newly developed platform. The order of implemented gates and used programs will be randomised, and participants will be from different backgrounds corresponding to three

target demographics mentioned in the Introduction - Computer Science students, practitioners with/without formal education, and people interested, but not directly involved, in Computer Science. The tasks will be performed in their home environment corresponding to currently widespread distance learning or self-learning and will include the setup of the software. Collected data will include objectively measurable UX task metrics: completion rate, time on task, and the number of problems/frustrations.

Collected knowledge will be interpreted and described as part of the discussion. It is expected unstructured qualitative data could be generated in the process, e.g., the experience of participants using and integrating the system and their feedback. If that happens to be the case and the data will be significant enough, they will be documented as part of the discussion. However, this thesis will not delve into qualitative data.

Design and Implementation

Contains only brief notes in the form of free-flowing text.

Outlines considerations when migrating desktop education tool to accessible and usable, extendable, secure, and reproducible web application. Considers the mentioned hurdles with MOOC development.

4.1 Accessibility and Usability

Designed to be usable with built-in accessibility tools shown to be used by primary and secondary beneficiaries. Main points: semantics, ARIA.

Time to first interaction. Minimal build size - Svelte via SvelteKit and Tailwind with three shaking and chunking. Used bandwith and required internet connection. Compare size and time to download the Nand2Tetris desktop (with and without JRE) app and the highly-optimised web app. Contrary to expectations - web app does not have to be downloaded again - can be used offline as PWA.

Usable from all platforms - percentage? Compared to desktop Java - with and without preinstalled JRE.

Progressive enhancement. IDE - Monaco for accessibility and powerful capabilities. Simplified contenteditable with the same syntax highlighting for mobile phones.

4.2 Extensibility

Everything (including learning materials) control versioned on Github. Learning materials processed from Markdown files using MDsveX.

4.3 Acceleration of Development

Use of available third party libraries to accelerate development.

Nearley with Moo for simple parsers.

Use of freely available scalable services - Github, Cloudflare - CDN, CI/CD, key/value.

4.4 Security

Infrastructure and deployment: DNSSEC, HTTPS, automation - CI/CD with signed commits - open source considerations!, “Denial of Wallet”.

User: Passwordless login, Google Auth

Parsers and interpreters: No eval or access to arbitrary JS APIs in interpreter.

4.5 Reproducibility

Again - everything is versioned - infrastructure, documentation, content, code. Made for easy hosting by anybody even without the backend. Backend optional - can be swapped for other provider.

Evaluation

To be done.

5.1 Automated evaluation

Accessibility evaluation tools. Automated tests.

5.2 Comparative User Experience Study

UX KPI comparison results.

Discussion

To be done.

Conclusions

To be done.

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