A picture containing tool

Description automatically generatedKluskens Stef

Game Boy MBC1 Emulation

Supervisor: Tesch Tom

Coach: Defoort Stephanie

Graduation Work 2023-2024

Digital Arts and Entertainment

Howest.be

A close up of a card

Description automatically generated

Contents

[Abstract & Key words 2](#_Toc153482830)

[Preface 3](#_Toc153482831)

[List of Figures 4](#_Toc153482832)

[Introduction 5](#_Toc153482833)

[Literature Study / Theoretical Framework 6](#_Toc153482834)

[Research 7](#_Toc153482835)

[1. Topic 1 7](#_Toc153482836)

[1.1. Subtopic 1 7](#_Toc153482837)

[1.1.1. Subtopic 7](#_Toc153482838)

[2. Topic 2 8](#_Toc153482839)

[1.2. Subtopic 1 8](#_Toc153482840)

[1.2.1. Subtopic 8](#_Toc153482841)

[case study 10](#_Toc153482842)

[1. introduction 10](#_Toc153482843)

[2. Modelling 10](#_Toc153482844)

[2.1. Blockout 11](#_Toc153482845)

[2.2. Zbrush 12](#_Toc153482846)

[3. Texturing 12](#_Toc153482847)

[4. Shading 12](#_Toc153482848)

[5. Lighting 13](#_Toc153482849)

[Discussion 14](#_Toc153482850)

[Conclusion 15](#_Toc153482851)

[Future work 16](#_Toc153482852)

[Critical Reflection 17](#_Toc153482853)

[References 18](#_Toc153482854)

[Acknowledgements 19](#_Toc153482855)

[Appendices 20](#_Toc153482856)

# Abstract & Key words

In this paper, I’m discussing the implementation of the MBC1 in a Game Boy emulator. I discuss the relevant information about memory bank controllers as well as some implementation details. I also discuss the use of test ROMs and the results of the emulator before and after I added my implementation of the MBC1. I also go over the Game Boy’s opcodes, more specifically the ones that were missing. These were left out by the person who originally made the emulator, with good reasons. Lastly, I discuss the issue the graphics gave me. These issues were the biggest challenge of this entire thesis and project.

# Preface

***A preface is a statement of the author's reasons for undertaking the work and may include personal comments that are not directly relevant to other sections of the thesis or dissertation.* No word count limit.**

I chose this topic because I’ve been interested in emulating a retro console for a while. I chose the Game Boy for nostalgic reasons. The Game Boy is the console I used the most when I was a kid. It holds a special place in my heart and that’s why I wanted to delve deeper into its inner workings by working on an emulator.

At first, I wanted to create a full emulator with memory bank controllers included, but that wouldn’t have been possible in the given time frame. So, after some discussion, I landed on emulating just the memory bank controller inside of an existing Game Boy emulator.

# List of Figures

**The list of figures lists the figures in the order in which they appear throughout the thesis. They may be numbered sequentially, or be subdivided following the chapters in which they appear.**

Figure 1: A picture showing something

Figure 2: A graph showing another thing

Figure 3.1: A tabel showing yet another thing, that appears in chapter 3.

# Introduction

**In the introduction, you write the background of your topic and discuss the observation that spurred you on to do this research project. Explain the purpose of the paper and present your research question(s) and the hypothesis at the end of this section. This section is typically a couple of pages long.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# Literature Study / Theoretical Framework

For my literature review, I have to start with the thesis on Game Boy Emulation in C++ by Brecht Uytterschaut. This is the backbone of my work as I am continuing on his work by adding a memory bank controller to his emulator to allow it to run larger games.  
In his thesis, he explains how the Game Boy’s CPU works and how he implemented it. He talks about the opcodes, the instructions, that the CPU has. He mentions that he didn’t implement all of the instructions, only those that are needed to run Tetris, one of the few games that can run without an MBC.  
He then talks about the PPU, the Picture Processing Unit, which handles the graphics. He explains how the different layers work. These are the background, the window or UI, and the sprites.  
He finishes by shortly explaining how he implemented the input and how the memory bank controllers work. This part was really useful for me as a starting point on the MBC.

The MBCs chapter on gbdev.io explains how every type of MBC works with the Game Boy. The part that is most interesting for this thesis, is the sub-chapter MBC1. It explains what the MBC1 is and how it works. It then gives a detailed overview of all the read and write functionality for the different memory addresses. This has been a vital reference in emulating the MBC1 myself.

This chapter in codeslinger’s version of a Game Boy emulator shows an implementation of the MBC1 and MBC2. It starts with detecting what kind of MBC a game uses, by reading the correct memory address. It goes on to detect if the game is using RAM banks and how to get the size of those. He then explains the reading and writing to the ROM and RAM banks. This is a simplified version, but a good continuation after the gbdev.io chapters.

Brendan Byers’s website has a post about the MBCs in Game Boys. In this post he talks about all the different kinds of MBCs. He then gives a short explanation on what happens at the different memory addresses. He also gives more info on how to access the MBC information from the cartridge header.

Brendan Byers’s website also has an interesting post about ROM and RAM bank switching. He takes the info from gbdev.io and expands on it. For every memory address in the reading and writing process, he gives a more detailed explanation on what is happening.  
After that, he goes into more detail on how bank switching works in practice, by taking a look at a disassembly of a Pokemon game.

The chapter on the CPU instruction set from gbdev.io gives an overview of all of the instructions the CPU can do. This overview made it easier to find what instructions were missing from the emulator I got.

The cartridge header chapter from gbdev.io gives a great overview on what all the memory addresses in the cartridge header hold. This is where I could find where in memory the ROM and RAM data was stored.

Game Boy: Complete Technical Reference gives an explanation of the full working of the original Game Boy. This reference is very useful, as understanding how the console works in real life, will help in understanding how to emulate it.  
Chapter 8 covers the MBC1 mapper chip. This gives a wealth of information about the MBC1’s inner working.

The Ultimate Game Boy Talk is a must see for anybody interested in the Game Boy. When I started on this project, that was the first piece of reference I saved. I’ve watched this video multiple times as it gives a thorough explanation in the inner working of the Game Boy.

# Research

**In the research section, you detail the elements of your experiment(s), the tests, objects you will test upon and subjects you will test with, the data gathering, data cleaning or feature extraction, measurements, … and you present the results obtained in an objective manner for each of the tests you conducted.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

## Topic 1

### Subtopic 1

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

### Subtopic

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

## Topic 2

### Subtopic 1

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

### Subtopic

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# case study

The test object of my grad work experiment will be a Game Boy emulator which I modified to have a memory bank controller. For the testing, I will use a test rom. These will run some test code in order to see how accurate the emulator is compared to the original Game Boy. I will test the emulator before and after implementing the memory bank controller. This will give me 2 sets of data to compare.

I will also both fully implement 1 memory bank controller and start on another. This way, I can test if the inheritance would work the way I envision it would.

## introduction

For this thesis, I always had it in my mind to do something with the Game Boy. This is something that I first thought of doing back when I had classes about the Game Boy and has stuck with me until now.

I first wanted to do a full emulator complete with memory bank controllers. This proved to be a bit optimistic given the time frame that I had. After talking with my supervisor, I landed on emulating just the memory bank controller and add that to an existing emulator. The reason why I wanted to do the memory bank controllers, is because the games that I wanted to emulate all required the same MBC, the MBC1.

That is how I landed on my research question: *What goes into emulating an MCB1B memory bank controller for an existing Gameboy emulator in order to play games that should be too large for the Gameboy?*

With the research question set, I started working on the hypothesis. This was a bit of a struggle for me, as I didn’t really know what was expected of a hypothesis. I ended up with 1 decent hypothesis, which was formed after thinking on how I would implement a functioning MBC into an emulator that was already reading in the ROM file. I landed on this hypothesis: *The implementation of dynamic switching mechanisms for different memory bank controllers through inheritance allows for easier integration of new controllers.*

For the emulator, I was given the grad work and thesis of Brecht Uytterschaut, who made a Game Boy emulator which runs Tetris. Once I familiarized myself with the codebase I was given, I started on my implementation of the memory bank controller.

## Memory bank controller

### Base class

To prove my hypothesis that using inheritance allows for easy switching of memory bank controller, it all started with a base class. This base class holds all of the common data that the different memory bank controllers have.

The main goal of this base class, was that it gave the opportunity to create every type of MBC, while trying to keep it as compact and simple as possible. Adding pure virtual functions makes sure that no instance of the base class can be created, while also exposing the common function definitions that all of the MBC’s need.

This base class itself only does a couple of things, it gets the ROM and RAM size.   
By getting the ROM size, I can figure out how many ROM banks are used by the loaded game.  
By getting the RAM size, I can figure out if the game has internal RAM and if it has, how much.

### MBC1

The main goal of the thesis was to create a functioning emulation of an MBC type 1. This was the first and most basic type of memory bank controller. This chip, which was added to the game cartridge instead of the Gameboy itself, could support games up to a whopping 2Mbyte. It also held up to 32Kbyte of internal RAM memory.

It worked by reading and writing into different ranges of memory.

For the reading:  
Range [0000 – 3FFF]. This range of memory held ROM bank 0, the first 16kb of the cartridge ROM.

Range [4000 – 7FFF]. This held any of the other 16kb ROM banks. There could be up to 7 extra ROM banks with this version of the MBC.

Range [A000 – BFFF]. This range of memory is used to address any of the external RAM that’s inside of the game cartridge. This RAM is only accessible if the RAM is enabled, otherwise read operations return open bus values and the write operations are ignored.

For the writing:  
Range [0000 – 1FFF]. In this address space, the external RAM can be enabled or disabled. If the value A is written in this space, the RAM gets enabled and is free to use. Any other value will disable the RAM again, closing it for use. This is something that is recommended to do after accessing it, in order to protect its contents.

Range [2000 – 3FFF]. In this range the current ROM bank number is selected. This is a 5 bit register, the higher bits of the values written into this range are discarded. If this register is set to 0, it is overwritten to a 1. This is to avoid having a duplicate ROM bank 0.

Range [4000 – 5FFF]. This range is used to select the current RAM bank number or to specify the upper 2 bits of the ROM bank number. If neither the ROM nor RAM bank are large enough, this range doesn’t do anything.

Range [6000 – 7FFF]. This 1-bit register selects between the 2 MBC1 banking modes. It can either be In simple mode, which locks the ranges [0000 – 3FFF] and [A000 - BFFF] to bank 0 of ROM and SRAM. Or, it can be in advanced mode in which ranges [0000 – 3FFF] and [A000 - BFFF] can be bank-switched via the [4000 – 5FFF] register.

## opcodes

The opcodes of a Game Boy are the instruction that the CPU can perform. It has 2 sets of instructions, the main instruction set and the extended instruction set.

The main instruction set has 245 instructions that the CPU can execute. The extended instruction set has another 256 instructions. This brings the total amount of instructions to 501.

All of the opcodes are fully explained in the CPU manual, and numerous websites have opcode tables for easy referencing. These tables allow you to see what address an opcode has and what the instruction behind it does.

When reading through the thesis of Brecht, I found that he didn’t implement all of the instructions. Not sure which instructions were missing, I took a table of opcodes and started going over all of them and fill in the missing instructions.

Completing this allowed me to actually run the test ROMs. Before this, the test ROMs wouldn’t start, they would get stuck. After implementing the missing opcodes, I got some testing results.

## Graphics

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

## Lighting

L Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# Discussion

**In this section, you offer an interpretation of the results you obtained and try to relate them to the theoretical framework you presented. This is typically not a very long section, but obviously one of the most important ones.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# Conclusion

**In this section, you ascertain the demonstrable outcomes of your study and outline the merits of the project for the academic field and the discourse community. This is typically not a very long section, but obviously also one of the more important ones.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# Future work

For future work on this emulator, there are a couple of things to improve the project.

More MBCs:  
I only implemented MBC1 completely, since that was the goal of this thesis. There are so many more MBCs, if they were to be added, this emulator would be able to play more games that were made for the Game Boy.  
Implementing the other MBCs would also increase the accuracy in which the original Game Boy is being emulated.

Sound:  
I did not have the time to implement sound on top of the MBC1. Adding sound would be interesting as it would be nice to hear those nice 8-bit sounds being played again.

Link connection:

The original Game Boy had the option of connecting 2 Game Boy’s with a link cable. This allowed for multiplayer between 2 consoles. It would be an interesting challenge to try and emulate that connection with 2 instances of the emulator.

# Critical Reflection

**This section is typically associated with a bachelor paper, not other forms of serious writing. It allows the student to reflect on the learning outcomes, both academically and in terms of personal growth.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis.

Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# References

1. gbdev. MBCs. Published May 29, 2021. <https://gbdev.io/pandocs/MBCs.html>

2. Uytterschaut B. Gameboy Emulation In C++. Howest; 2019.

3. codeslinger.co.uk. Gameboy - Rom and Ram Banking. Published March 27, 2010. <http://www.codeslinger.co.uk/pages/projects/gameboy/banking.html>

4. Byers B. Exploring the Gameboy Memory Bank Controller. Published January 12, 2020. <https://b13rg.github.io/Gameboy-MBC-Analysis/>

5. Byers B. Gameboy DMG ROM and RAM Bank Switching. Published July 22, 2019. <https://b13rg.github.io/Gameboy-Bank-Switching/>

6. gbdev. CPU Instruction Set. Published May 28, 2021. <https://gbdev.io/pandocs/CPU_Instruction_Set.html>

7. gbdev. The Cartridge Header. Published May 28, 2021. <https://gbdev.io/pandocs/The_Cartridge_Header.html>

8. The Ultimate Game Boy Talk.; 2016. <https://www.youtube.com/watch?v=HyzD8pNlpwI&ab_channel=media.ccc.de>

9. Javanainen J. Game Boy: Complete Technical Reference. Published online March 15, 2023. <https://gekkio.fi/files/gb-docs/gbctr.pdf>

# Acknowledgements

**In this section, you can thank people who contributed to your work in a meaningful way.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis. Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.

# Appendices

**In many cases, there are items that were developed for a research paper that can’t go into the actual paper in full. Things suc as code, art pieces, output of statistical analysis, questionnaires, … In this section, you can present these elements; use the first page to list and number the items, then paste them sequentially. If some items are too large, you can store them online, and link to them. Common practice is to keep those links active at least one year after the publication of the thesis.**

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vestibulum ac quam nec arcu semper dignissim. Nulla quam magna, varius sit amet pharetra et, dictum quis elit. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Proin ullamcorper, ipsum sit amet scelerisque rhoncus, leo quam rhoncus elit, sit amet ullamcorper tellus nisi eget sapien. Suspendisse potenti. Ut non justo viverra, tempus felis vitae, elementum mi. Morbi at dui sed lacus fringilla condimentum. Duis non odio ac arcu volutpat vehicula eu et turpis. Praesent vitae magna ante. Nulla in orci lacus. Donec quis vestibulum mi. Sed ipsum sapien, pretium maximus purus sed, bibendum consequat lectus. Aliquam porttitor dolor eu gravida vulputate. Vestibulum ut urna eget massa tincidunt ultricies. Morbi hendrerit sapien at diam tincidunt semper. Aliquam ut quam dictum quam maximus tempor sed at felis.