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Digital Preservation of Console Video Games

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Abstract

Video games are part of our cultural heritage, but with the rapid development of new computer systems the way games look and are played changes rapidly. The public interest in early video games is high, as exhibitions, regular magazines on the topic and newspaper articles show. Games considered to be classic are rereleased for new generations of gaming hardware as well.

As original systems cease to work because of hardware and media failures, methods to preserve obsolete video games for future generations have to be developed. This work evaluates strategies for digital preservation of console video games. First it presents an overview of the history of console video game systems. Next an introduction to digital preservation and related work in common strategies for digital preservation and preserving interactive art is given. Then emulation as a preservation strategy and the PLANETS preservation planning approach for documented decision-making processes are described.

When trying to preserve console video games one has to face the challenges of classified development documentation, legal aspects and extracting the contents from original media like cartridges with special hardware. Special controllers and non-digital items are used to extend the gaming experience making it difficult to preserve the look and feel of console video games.

The PLANETS preservation planning approach is then used to select digital preservation alternatives for an assumed library environment where console video games are to be archived as digital heritage. Games are selected as sample records for all presented video game consoles and a tree of requirements for preserving these records is developed. The various possible alternatives are described and it is discussed which preservation strategies will be included in the experiments. Experiments are then carried out to compare emulators first for a single console video game system, then for different console systems of the same era and finally for systems of all eras. The measured values are transformed to a unified scale and importance factors are set according to the defined basis. The values are then aggregated to a single value for each alternative and the results are compared.

From the experiments it can be seen that emulation is a viable solution for preserving obsolete console video games on current computer hardware. Most evaluated emulators are able to play the tested games well but do not meet the needs of digital preservation processes. Future work on using emulation for the digital preservation of console video games has to be done. Awareness for the topic has to be raised and responsibility for the preservation of games has to be set.

Zusammenfassung

Videospiele sind Teil unseres kulturellen Erbes. Durch die rasante Entwicklung von Computersystemen ändert sich die Art, wie Spiele aussehen und gespielt werden, ständig. Dass das öffentliche Interesse an der Videospielgeschichte groß ist, zeigen Ausstellungen, regelmäßig erscheinende Magazine und Berichte zu diesem Thema.

Da die Originalsysteme und -medien jedoch nicht auf Dauer funktionstüchtig bleiben und aufgrund properitärer Hardware nicht beliebig reparierbar sind, müssen Wege gefunden werden, diese Spiele für zuküntige Generationen zu erhalten. Diese Arbeit untersucht Strategien zum Erhalten von Spielen für Videospielkonsolen. Zuerst wird der Leser in die Geschichte der Videospielkonsolen sowie in das Forschungsgebiet der Erhaltung digitaler Objekte eingeführt. Gebräuchliche Strategien im Bereich der Digital Preservation sowie Projekte zur Erhaltung interaktiver Kunst werden präsentiert. Da Emulation eine bereits weit verbreitete Methode ist, nicht mehr erhältliche Videospiele auf modernen Computern wiederherzustellen, werden Arbeiten aus diesem Bereich untersucht.

Beim Archivieren von Spiele für Videospielkonsolen wird man mit unterschiedlichen Schwierigkeiten wie nicht zugänglicher Dokumentationen über die verwendete Hardware, das Sichern der Originalmedien auf besser archivierbare Speichermedien sowie gesetzlichen Rahmenbedingungen konfrontiert. Da bei Videospielen nicht nur die visuelle Präsentation, sondern auch das gefühlte Spielerlebnis wichtig ist, ist die originalgetreue Steuerung ein gewichtiger Faktor.

Der PLANETS Ansatz zum Planen von Digital Preservation Projekten wird verwendet, um für das fiktive Projekt einer digitalen Bibliothek eine Entscheidung für bestimmte Strategien zu evaluieren. Dazu werden für alle präsentierten Videospielkonsolen Anforderungen an die zu findende Lösung in Form eines hierarchischen Baums festgelegt. Die möglichen Alternativen werden ermittelt, einer Durchführbarkeitsentscheidung getroffen und die möglichen Experimente durchgeführt. Die gemessenen Werte werden auf eine einheitliche Skala transformiert und die aggregierten Gesamtwertungen verglichen.

Die Experimente zeigen, dass Emulation grundsätzlich eine geeignete Methode ist, um Videospiele von veralteten Konsolen auf modernen Computern auszuführen, allerdings erfüllen die getesteten Emulatoren nicht die Kriterien, die an ein Digital Preservation Projekt gestellt werden. Nicht nur müssen weiterführende Arbeiten in diesem Bereich durchgeführt werden, damit erfolgsversprechende Strategien umgesetzt werden können, auch das Problembewußtsein muß geweckt und Verantwortlichkeiten definiert werden.

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Chapter 1

Introduction

1.1 Motivation

The amount of content from digital origin permanently increases. The short lifespan of digital media makes it necessary to develop strategies to preserve its content for future use. Not only electronic documents, pictures and movies have to be preserved, also interactive content like digital art or video games have to be kept "alive" for future generations. Articles like [Stu07] and regular magazines like the German *Retro - Das Magazin für digitale Retrokultur*[1] and the British *RETRO Gamer*[2] (issue number 43 published in October 2007) which deal mainly with obsolete video game hardware and software indicate the public interest in "Retro Gaming". The exhibition *Electronic Kindergarten* in May 2001 in Vienna attracted nearly 1700 visitors [Pyr01]. The annual *Classic Gaming Expo (CGE)*[3] in Las Vegas draws more than 30.000 people within 3 days every year, which shows the public interest in video game history. Even companies releasing video games today have started to re-release old games which run on current video game hardware, for example *Activision Anthology* for the Sony Playstation 2 console system which includes 40 classic Atari 2600 games. Besides the public interest in classic video games, the Library of Congress in the United States established awards for preserving American art in 2007, which includes apart from films, sound recordings, photographs and cartoons also video games ([Lam07]). A two-year project called *Preserving Virtual Worlds* led by a team at the University of Illinois' Graduate School of Library and Information Science (GSLIS) will start in January 2008. ([Lyn07]. This project will explore methods how to

[1] http://www.retromagazin.eu/
[2] http://www.retrogamer.net/
[3] http://www.cgexpo.com/

preserve digital games and interactive fiction. Standards for metadata shall be developed and case studies on games like Spacewar!, Second Life, Star Raiders, Doom, Warcraft (selection of games is under discussion) will be conducted [ME07]).

Today it is still possible to show classic video game systems running original software in exhibitions and museums, however more and more machines fail beyond repair. Therefore it is necessary to find ways how to preserve the look and feel of the beginnings of video gaming as well as games that set milestones in the video game history for future generations.

Today emulators are developed mainly with gaming in mind. This comes closest to digital preservation of classic systems. This work evaluates if emulation is the best approach to digital preservation of console video games. It takes a look at existing emulators and evaluates how much they adhere to principles for digital preservation.

1.2 Scope of this Work

The term "video game" can refer to different kinds of electronic games where a person ("player") plays a game primarily produced by a computer and usually presented on some kind of display unit. These games are played on systems which have not been designed primarily for gaming (e.g. personal computers, mobile phones, digital cameras, classic home computers) as well as on systems made specifically for gaming (e.g. consoles connected to a TV, hand held consoles, arcade machines).

As the challenge to preservation of diverse types of video games varies in many aspects (for example used media for software, kinds of presentation, levels of known system architecture) this work concentrates on the preservation of console games as defined by Webopedia:
"Console games are more commonly referred to as video games. They are played on a device specially made for game play called a video game console. The player interacts with the game through a controller, a hand-held device with buttons and joysticks or pads. Video and sound are received by the gamer though a television. Examples of consoles include the Microsoft Xbox, Sony Playstation, and Nintendo GameCube." [Web06]

1.3 Document Structure

The remainder of this work is structured as follows.

First this work gives an overview of the history of console video games and related work in Chapter 2. The major systems of the different eras of console video games are listed along with games that represented the system best. Then related work in the research fields of digital preservation and emulation is presented.

In Chapter 3 the challenges for the digital preservation of console video game systems are investigated. Some of the general concepts and methods for digital preservation presented in the related work are discussed regarding console video games.

In Chapter 4 the PLANETS preservation planning approach is used to evaluate alternatives for preserving console video games. A requirements tree is developed to measure to what degree the required objectives are met and the results of the evaluation are analyzed.

Finally in Chapter 5 the conclusions that can be drawn from the experiments are presented and some suggestions for future work regarding console video games and video games in general are given.

Chapter 2

Related Work

This chapter will give an overview of the history of console video game systems and lists related work in the field of digital preservation research and emulation as a digital preservation strategy.

2.1 Console Video Game History

This section gives just a brief overview of the development of video games for home use and concentrates on console systems like defined in the introduction. This section covers only systems which had substantial market shares in the specified eras and which are considered as major systems.

Additional facts of the discussed systems can be found in Appendix A. Arcade games, home computers (and home computers marketed as consoles later in their lifespan like the Commodore Amiga CD32, the Atari XE Game System and the Commodore C64 Game System), personal computers and hand held console systems are not covered.

A lot of information in this section is taken from [For05] and [Her01].

2.1.1 The Road to Video Game Consoles

The first game which is acknowledged as video game was invented by Willy Higinbotham in 1958. He designed a simple tennis game which used an oscilloscope as display device. Its purpose was to have something with which the people could interact with on the open house day at the US Government's Brookhaven National Laboratory. Although the game was a success at the open house day, Higinbotham did not do any more research in the direction of video gaming.

The next step was done at the MIT in 1962. A team around Steve Russell developed the game "Space War" on a Digital Equipment Corporation PDP-1 mainframe computer. The game spread across universities in the 1960s. It was the predecessor for the first video arcade machine "Spacewar" which was an economic failure due to its complex game-play for people who were not used to playing video games.

At the same time Ralph H. Baer was thinking about different uses of television sets and came up with the idea to play tennis games on a TV. He was the first to file a patent for video gaming on TV in 1966. It took six more years until the first console system was commercially released.

2.1.2 The Pong Era

This era of console video games is named after the first generation of games which were variations of a simple tennis game with a ball and one or more bats on the screen. The first systems were built from discrete analogues components. Due to the price drop on microchips later systems of this era were built around a single chip. Lots of companies produced Pong-style video games which were usually based around the same microchip by General Instruments. None of these systems was as successful as the ones described below and are usually not considered as major systems of that time.

Magnavox Odyssey

The first video game for home use was released in 1972 by the American company Magnavox and was called *Odyssey* (Figure 2.1). It was sold with cartridges which actually did not contain any software but worked as a key to unlock games already built into the system. As the system was able to produce only simple black and white graphics, the games were sold with colored overlays for the TV screen as well as playing chips and cards to enhance the playing experience. All the built in games were variations of simple tennis (*ping-pong*) games and shooting games which were shipped with a light gun accessory. ([Bae98])

Video game sales were very low in the beginning, as Magnavox marketed the Odyssey as only being compatible with Magnavox TVs.

Atari Pong

As microchip prices dropped, the company Atari which was in the arcade business at that time started to produce their own version of the arcade video tennis game called *Pong* (Figure 2.2) in 1974. The system was superior to

Figure 2.1: Magnavox Odyssey [Sch07]

the Magnavox Odyssey, as it was able to produce color graphics and was cheaper.

Coleco Telstar

In 1976 Coleco produced their *Telstar* (Figure 2.3), a video tennis game console based on a microchip produced by General Instruments which cost only 5 USD in the production. The company was able to sell their system at the very cheap price of 50 USD which led to more than 1.000.000 sales of this system that year.

2.1.3 The First Cartridge Based Video Games

The Magnavox Odyssey already featured cartridges which unlocked games built into the system. In the second era of video gaming games were stored in microchips inside cartridges. This development gave manufacturers the possibility to develop games after their system has been released.

Fairchild Channel F/Saba Videoplay

The first system to feature programmable cartridges was the Fairchild *Channel F* (Figure 2.4) which was released in 1976. The system was sold as Saba

Figure 2.2: Atari Pong [Win07]

Figure 2.3: Coleco Telstar [Win07])

Figure 2.4: Fairchild Channel F ([oc])

Videoplay in Europe and featured two built in games. The sound was played using a speaker built into the system instead of using the TV sets speakers. The system featured complex controls which were not only simple dial controllers but handles allowing movement in four directions, pushing and pulling the handle and rotating the knob on top of the handle. The game graphics of this system were nearly as simple as the ones of advanced pong systems.

Atari 2600

When Atari released the *Atari 2600* (Figure 2.5) in 1977, it quickly outsold the Fairchild Channel F. The reason for its success was the conversion of popular games which people knew from Atari's popular arcade machines (e.g. *Space Invaders*). Its graphics were superior to the Fairchild Channel F and it was able to address more memory than its predecessors. Some of the other innovations with the Atari 2600 were controllers which were not fixed to the system but plug-able (so only the controllers had to be changed if they were broken) and the fact that for the first time third-party companies started to develop cartridges for a system. First this competition led to better games but later also to price dumping and the production of games of low quality.

Figure 2.5: Atari 2600

Ultimately this development destroyed the consumers' trust in video games and led to the "video game crash" in 1983, where many companies went bankrupt because of the high investments and low game sales.

The Atari 2600 in various different revisions and its games were sold until 1992.

Various accessories were released like keyboards, special joysticks and the *Supercharger* from Starpath which extended the system's video RAM and was able to run special games from audio tapes ([San02]).

Some of the most important games for this system were *Pitfall*, *Stampede*, *H.E.R.O.*, *Kaboom!* and *Keystone Kapers* by Activision, *Demon Attack* and Atlantis by Imagic, *Pac-Man*, *Space Invaders*, *Centipede* and *Asteroids* by Atari and *Frogger* by Parker Bros.

E.T. by Atari is an example of the poorly developed games which triggered the video game crash.

Magnavox Odyssey 2/Philips Videopac G7000

Originally planned to be sold with built-in games the Magnavox *Odyssey 2* was changed to a system with cartridges after the Atari 2600's release. It was released in the United States in 1978. In Europe Philips released the same system under the name *Videopac G7000* (Figure 2.6). The integrated keyboard set it apart from its competitors. Its key phrase for marketing was "The Keyboard is the Key". An updated system called the Philips *Videopac G7400* was released in Europe in 1984. It was backwards compatible to the G7000 and was able to play games with improved graphics. As Philips moved to the home computer business, the console video game division was closed shortly after.

Major games for the system were action games like *K.C.Munchkin*, *Stone*

Figure 2.6: Philips Videopac G7000

Slinger, *Killer Bees*. Educational games which made use of the integrated keyboard like *Mathematician* and *Computer Programmer* which taught the user how to program the system in Assembler were sold successfully as well. Philips also released a series of cartridges packaged with board games (*Quest for the Rings*, *Conquest of the World* and *Wall Street Fortune Hunt*). Most of the games were released by Magnavox/Philips, only six games were released by the third party developers Parker Bros. and Imagic. The lack in third party support was the main reason why the Odyssey 2 was not as successful as the Atari 2600.

Mattel Intellivision

In 1980 Mattel, which was one of the most successful companies to produce hand held electronic games at that time, released the *Intellivision* (Figure 2.7), short for "Intelligent Television". The system's technical specification was far superior to the one of the Atari 2600 and of the Magnavox Odyssey 2.

An updated version of the Intellivision was released as Intellivision II in 1983. Some of the accessories released for the system were a musical keyboard, a computer module with full keyboard, a speech synthesize unit (the *IntelliVoice*) and an adapter to play Atari 2600 games.

One of the strengths of the Intellivision were its sport games. Mattel licensed sport brands as Atari did with arcade games before. The system also used overlays for its controllers which showed real playing fields (e.g. of a baseball field). Some of the most successful games for the system were the sport games like *PBA Bowling*, *World Series Major League Baseball* and *Horse Racing* by Mattel. Also games like *Advanced Dungeons & Dragons*, *BurgerTime*, *Frog Bog* and *Sub Hunt* by Mattel, *Safecracker* and *Microsur-*

Figure 2.7: Mattel Intellivision

Figure 2.8: Coleco Colecovision

geon by Imagic and *Worm Whomper* and *Dreadnaught Factor* by Activision sold well.

Coleco Colecovision

The *Colecovision* (Figure 2.8) by Coleco was released in October 1982. It offered the same system specification as the home computers of that time, however it was cheaper. An expansion module which allowed users to play Atari 2600 games on the Colecovision was released to make sure that enough games were available when the system sale started.

Some of the other accessories released included a driving controller with gas pedal, the *Super Action Controller*, which was specifically designed for sport games, and a trackball controller.

Major games for the system included arcade hits like *Donkey Kong*, *Zaxxon*, *Ladybug*, *Frency*, *Carnival*, *Venture*, *Mouse Trap*, *Mr. Do!* by Coleco,

Figure 2.9: Atari 5200 ([Joh])

Galaxian and *Centipede* by Atarisoft, *Pitfall* and *River Raid* by Activison and *Q*Bert* by Parker Bros. *Super Action Baseball* and *Rocky Super Action Boxing* by Coleco were played using the Super Action Controller.

Atari 5200

The *Atari 5200* (Figure 2.9) was released in 1982 and featured nearly identical hardware as Atari's home computer series (the *Atari 400/800*) of that time. As the system's abilities were better than the ones the Colecovision had to offer, it was marketed as a direct competitor to that system. It introduced analogue joysticks which did not work precisely and were the biggest flaw of the system. The Atari 5200 was never released in Europe.

Some of the important games for this system were *Super Breakout*, *Missile Command*, *Joust*, *Quix* and *Space Dungeon* by Atari.

2.1.4 The 8-bit Era

In this era Japanese companies which have sold systems locally in Japan before (like Sega the SG-1000) started to manufacture consoles for the US and European market.

Most American companies did not survive the video game crash of 1983, so the number of new systems in this era is very low.

While most of the systems in the era before the video game crash were already systems built around 8-bit processors, systems of this era are usually referenced to as 8-bit systems to differentiate them from their 16-bit successors.

Figure 2.10: Nintendo Entertainment System (NES)

Nintendo Entertainment System (NES)/Famicom

The *Nintendo Entertainment System (NES)* (Figure 2.10) was released under the name *Famicom* (Family Computer) by Nintendo in Japan in 1983. After the video game crash in the US the system was sold on the world market. Its graphics were superior to the ones of the systems before the video game crash. The quality of games was ensured by Nintendo by controlling the release of every game through a special licensing model. Nintendo was able to sell more than 60 million systems worldwide ([oAI07a]).

Some of the accessories released for the Nintendo NES were a light gun, 3D glasses, a program-able robot, a fitness mat and the *Power Glove*, which was a virtual reality like controller.

The system is well known for games like *Super Mario Bros.*, *Tetris*, *Teenage Mutant Ninja Turtles*, *Excitebike*, and the start of game series like *The Legend Of Zelda*, *Dragon Warrior*, *Metal Gear* and *Final Fantasy*.

Sega Master System

The *Sega Master System* (Figure 2.11) was the first Sega system which was sold worldwide. It was based on a system developed in 1983. It used both ROM-cartridges as well as credit card sized *MyCards*. The system was released in Japan in 1986 and worldwide in 1987. It was shipped with a light gun and additional accessories like 3D-glasses were available.

Sega had a big pool of arcade games which were then converted to the Master System. Some of these games were *Hang-On*, *After Burner*, *Choplifter!*, *Double Dragon*, *Ghouls'n'Ghosts*, *Golden Axe*, *Out Run*, *Space*

Figure 2.11: Sega Master System ([oc])

Figure 2.12: Atari 7800 ([Klo])

Harrier and *Wonderboy*. The released 3D-games include *Zaxxon 3D*, *Missile Defense 3D* and *Space Harrier 3D*. Also the first game starring Sega's famous video game character *Sonic* was released as *Sonic the Hedgehog* for this system.

Atari 7800

In 1984 Atari test marketed its new console but due to the video game crash did not release it. After the success of the Nintendo NES Atari started to sell this system in 1986. It was backwards compatible to the Atari 2600, but only very few original titles were released. The system was more than 2 years old on its release, so it was not able to compete successfully to the systems by Nintendo or Sega.

Atari ported some successful arcade games to the *Atari 7800* (Figure

Figure 2.13: NEC PCEngine ([CNE])

2.12), for example *Asteroids*, *Ms Pac-Man*, *Joust* and *Dig Dug*.

2.1.5 The 16-bit Era

Systems of this era were marketed as 16-bit systems to differentiate them from the previous generation. Even if not all of them were systems with a 16-bit CPU, at least one component was a 16-bit chip, for example the graphical processing unit.

All of the major systems of this era were developed in Japan.

While all systems used cartridges as media the commercial break through of the CD led to the production of CD-ROM add-ons for or CD-based versions of nearly all the systems.

NEC PCEngine/TurboGrafx 16

The NEC *PCEngine* (Figure 2.13) was the first system of this era released in 1987. It had a 16-bit graphics processor and used small cartridges called *HuCards* as media. In 1989 the PCEngine was released as *TurboGrafx 16* in the US but could not compete with the Nintendo SNES and Sega Mega Drive. Later versions were the *PC-Engine SuperGrafx* with enhanced graphical capabilities and various systems which used CDs as media.

Figure 2.14: Sega Mega Drive (second revision)

The PCEngine is still well known for its excellent 2D shooting games like *R-Type*, *Galaga 88*, *Final Soldier* and *1941* and also for Japanese role playing games like *Far East of Eden* or the *Dragonslayer* cycle.

Sega Genesis/Mega Drive

This new Sega console was released as *Genesis* in the US and as *Mega Drive* (Figure 2.14) in Japan and Europe in 1988. It was based on a 68000 CPU by Motorola. It was backwards compatible to the Sega Master System by using the *Master System Converter*. Later accessories for the system included a CD-ROM add-on which featured another 68000 CPU and the *32X* which enhanced the capabilities of the Mega Drive with 2 RISC processors and various sound and graphics components. The system was competing with the Nintendo SNES for market leadership and even had a market share of 66% in Europe in 1993 ([BJ93]).

Games for the system included *Sonic The Hedgehog*, *Sonic The Hedgehog 2*, *Populous*, *Revenge of Shinobi*, *Mortal Kombat 2*, *ToeJam & Earl*, *Phantasy Star 2* as well as the first games in the Electronic Arts sport series *NHL*, *NBA* and *NFL*.

Super Nintendo Entertainment System (SNES)/Super Famicom

Nintendo released its new system called *Super Famicom* in Japan in 1990. The system was called *Super Nintendo Entertainment System (SNES)* (Figure 2.15) in the United States and Europe and was technically comparable to the Sega Mega Drive. A CD-ROM accessory was in development for the

Figure 2.15: Super Nintendo Entertainment System (SNES)

SNES in corporation with Sony but was never released as Nintendo started to work on a CD-ROM add-on with Philips, which was also never released. Later games for the SNES were instead released through satellite by use of a device called *Satellaview*. (Sony consequently developed their PlayStation system out of the project with Nintendo.)

Some of the best sellers were games with characters from previous Nintendo games like *Super Mario World*, *Donkey Kong Country 1 - 3* and *The Legend of Zelda: A Link to the Past*. Some of the advanced games were equipped with special chips on the cartridge to enhance the capabilities of the Nintendo SNES like *F-Zero*, *Pilot Wings*, *Super Mario Kart* and *Street Fighter Alpha 2*.

SNK Neo Geo Advanced Entertainment System

In 1990 SNK entered the console market with a system that was a direct conversion of its arcade system which also used cartridges as media. The games were very high priced to not compete directly to SNK's games in the arcades. Later versions of the system (the *Neo Geo CD* and the *Neo Geo CDZ*) used much cheaper CD games.

Most of the games released for the *Neo Geo AES* (Figure 2.16) were 2D fighting games and shooters. Some of the most successful games were the *Metal Slug* series, the *King of Fighters* series and the *Samurai Shodown* series as well as *Pulstar*, *View Point*, *Blazing Star* and *Last Resort*.

Figure 2.16: SNK Neo Geo AES ([oc])

2.1.6 The 3D Era

With the rising need for storage on media and the dropping CD production prices most manufacturers started to use optical media as media for console video games.

But not only storage capacity was increasing, the new systems used much faster central processing units. Games with 3D graphics existed before this era, but because of the risen calculation power of the new systems games with real-time calculated realistic 3D animations shaped this era of console video games.

3DO Interactive Multiplayer

In 1993 the company 3DO developed the first console video game system which used CDs as only media. It was also the first system which was not only sold as a console video game system but as a home entertainment system playing CDs and movies. The high price compared to other consoles restricted the system's sales. The *3DO Interactive Multiplayer* (Figure 2.17) was licensed to the manufacturers Panasonic, Goldstar and Sanyo which named their systems *Panasonic FZ-1 3DO*, *Goldstar System 32* and *Sanyo Try 3DO*.

The system was well supported by Electronic Arts, which released games like *FIFA Soccer*, *The Need For Speed* and *Madden Football* for the 3DO. Some of the games which utilized the movie playing capabilities of the 3DO and consisted mostly of full motion video sequences were *Night Trap*, *Snow Job* and *Alone in the Dark 2*.

Figure 2.17: Panasonic FZ-1 3DO ([Bar])

Figure 2.18: Atari Jaguar

Atari Jaguar

Atari's last console video game system, the *Jaguar* (Figure 2.18), was released in 1993. The Jaguar's technical specification was superior to the ones of the market leaders Nintendo SNES and Sega Mega Drive. As these systems were still very strong on the market their games were just directly converted and did not utilize the capabilites of the Jaguar. While ROM-cartridges were used in the beginning, a CD-ROM accessory for the system was released in 1995.

Only about 60 games were released for the Atari Jaguar. Some of the more successful ones were *Alien vs. Predator*, *Tempest 2000*, *Rayman* and *Iron Soldier*.

Figure 2.19: Sega Saturn

Sega Saturn

The Sega *Saturn* (Figure 2.19) was released shortly after the hardware extensions for the Sega Mega Drive in 1994. While it still had a cartridge slot, CDs were used for storing the games. The cartridge slot was used for hardware extensions and memory cards. An MPEG1 card to play movie scenes in some games and a RAM-cartridge to extend the Saturn's main memory were released but only used by very few games.

While the system had good 3D games like the *Virtua Fighter* series, *Resident Evil*, *Nights Into Dreams*, *Daytona USA*,*Panzer Dragoon*, *Panzer Dragoon Zwei* and *Panzer Dragoon Saga*, it got famous for its 2D shooters. Most of those were released only in Japan like *Radiant Silvergun*, *DoDon Pachi*, *Layer Section II*, *Shienryu* and *Thunderforce V*.

Sony PlayStation

The Sony *PlayStation* (Figure 2.20) entered the market in late 1994 and was sold cheaper than the other new consoles on the market while still offering the same capabilities. Sony was able to sell more than 200.000 systems in the US in the first two months after its release. In Japan a special version of the PlayStation, the *Net Yaroze*, was released which offered the possibility to develop games and offer them online to other Net Yaroze users. Sony sold more than 100 million PlayStations up to date ([Inc07b]).

A lot of successful game series started on the Sony PlayStation, like *Ridge Racer*, *Gran Turismo*, *Tekken*, *Final Fantasy*, *Tomb Raider*, *Grand Theft Auto*, *Resident Evil*, *Metal Gear Solid* and *wipEout*.

Figure 2.20: Sony PlayStation ([oc])

Nintendo 64

While the other major console manufacturers used optical media for their systems, Nintendo still used ROM-cartridges for its *Nintendo 64* (Figure 2.21) released in 1996. The games on cartridges had virtually no loading time, but also very little memory space, so developers of complicated and big games did not produce games for the Nintendo 64. Nintendo released a memory expansion for the system in 1998, which was necessary to run some of the later games.

Most of the successful games released by Nintendo for this system were using well known characters from previous Nintendo games like the new games in the *Legend of Zelda* series, *Super Mario 64*, *Donkey Kong 64*, *Paper Mario*, *F-Zero X*, *Super Smash Bros.* Other game series debuted on the Nintendo 64 like *Conker's Bad Fur Day*, *Perfect Dark*, *Wave Race 64* and *Banjo-Kazooie*.

2.1.7 The 128-bit Era

Like in the 16-bit era the console video game systems of this era were advertised as being 128-bit consoles, even if only parts of them were true 128-bit components (for example only the graphical processing unit). The movement to home entertainment centers instead of pure video game consoles was started with some of the systems offering DVD and music playback. Consoles also were primary targeted not to appeal to kids but to adults for the first time (with the exception of the Nintendo GameCube).

Figure 2.21: Nintendo 64

Sega Dreamcast

Sega's last console released was the *Dreamcast* (Figure 2.22). It was released in Japan in 1998 and was far superior to the market leader Sony Playstation at that time. Unfortunately it used a proprietary media format called Gigabyte Disc (GD) and was not able to play DVDs. Sega was not able to sell enough Dreamcasts to get a good share of the market before the other new systems of this era hit the market. It was discontinued about one year after the PlayStation 2 was released.

The Dreamcast was the first video game console which was shipped with a modem for online play. It was popular for its innovative games with special controllers like *Samba De Amigo* that was shipped with maracas, *Sega Bass Fishing* and various other fishing games which were playable with a fishing controller and in the Japanese game *Densha De Go 2*, a train simulator which was released with a special controller. Some of the milestone games for the Dreamcast have been *Soul Calibur*, *Sonic Adventure*, *Shenmue*, *Space Channel 5*, *Crazy Taxi*, *The House Of The Dead 2* and it's 2D fighting games like the *King Of Fighters* series.

Sony PlayStation 2

The Sony *PlayStation 2* (Figure 2.23) was released in 2000. It supported DVD playback and was backwards compatible to the original Sony PlayStation. With the big library of games playable on startup and the possibility to reuse an existing software library it was starting to get the best selling console. Sony sold more than 115 million units up to date ([Inc07a]).

Figure 2.22: Sega Dreamcast

Figure 2.23: Sony PlayStation 2

Figure 2.24: Microsoft XBOX

Some of the best selling PlayStation 2 games were new releases in the series *Grand Theft Auto*, *Gran Turismo*, *Metal Gear Solid* and *Final Fantasy*. Other major innovations with special accessories included the *Sony EyeToy*, a series of games with motion detection through a camera, the *SingStar* series, a karaoke-like game type which was shipped with microphones and *Buzz!*, a game simulating a quiz show with special controllers.

Microsoft XBOX

Microsoft entered the console market with the *XBOX* (Figure 2.24) in 2001. The company was able to gather experience with video gaming previously with its game division for PC game development and its involvement in the WindowsCE support for the Sega Dreamcast. The XBOX was made from standard personal computer parts, so it was very easy to port software from PCs to the XBOX. Games could be played online against other players using the *XBOX Live* network.

Some of the most important XBOX-titles were *Halo* and *Halo 2*, *Project Gotham Racing*, the *Burnout*,*Call of Duty* and *FIFA* series and *Black*. Most games only used the standard XBOX controller, only very few utilized a light gun (e.g. *The House Of The Dead 3* by Sega).

Figure 2.25: Nintendo GameCube

Nintendo GameCube

The *GameCube* (Figure 2.25) was the first Nintendo console which did have an optical media (Mini-DVD) instead of ROM-cartridges. It did not have any backwards-compatibility due to the change on media, but a player for games from the hand held system Nintendo GameBoy was available as an accessory.

Nintendo released games starring its most successful characters for the GameCube like *Super Mario Sunshine*, *Wario World*, *Super Monkey Ball*, *Luigi's Mansion*, *Mario Kart* and new games in the *The Legend Of Zelda* series. A game shipped with a special Drum-Controller was *Donkey Konga*. Some games were also shipped with microphones to allow speech recognition for controlling parts of the game (e.g. *Mario Party 6*).

2.1.8 The Next Generation

Manufacturers of the current generation of console video game systems followed two different strategies. Microsoft and Sony produced high priced systems with high-end specifications and abilities to play new home cinema formats (HD-DVD and Blue-Ray). Nintendo invented a new controller and sold its system for far less than the competitors. All systems are aiming for multimedia application instead of video game console systems. All the systems feature online access to the manufacturers networks with content to download.

Figure 2.26: Microsoft XBOX 360 ([Mic07])

Microsoft XBOX 360

Microsoft was the first to release a console system of this generation in 2005. The *XBOX 360* (Figure 2.26) was initially sold in two different configurations with and without a hard drive. It is backwards compatible to the Microsoft XBOX by using software emulation ([Cor07]) and a HD-DVD Drive is available as an accessory.

Some of the best selling games released so far are *HALO 3*, *Gears of War*, *The Elder Scrolls IV: Oblivion*, *Lost Planet: Extreme Condition* and *Perfect Dark Zero*. Games can also be downloaded from the online platform *XBOX Live Arcade*, this includes classic arcade hits like *Dig Dug*, *Frogger* or *Gauntlet* but also newly developed games like *Geometry Wars: Retro Evolved*.

Nintendo Wii

With the *Wii* (Figure 2.27) Nintendo released a system with little improved system specifications over the Nintendo GameCube but with a radically different type of control. While most systems featured motion sensitive controllers for special games before, Nintendo made this type of control the default control for its new system. By just extending the hardware of the GameCube, Nintendo was able to sell the Wii for a much cheaper price than the other next generation systems. This similarities in hardware also make the Wii backwards compatible to the Nintendo GameCube by simply switching off all Wii-specific components. The system also offers a software

Figure 2.27: Nintendo Wii

emulator called *Virtual Console* to play classic games for various systems. At the moment this emulator supports games for Nintendo NES, Nintendo SNES, Nintendo 64 as well as the Sega Mega Drive and the NEC PCEngine. Virtual Console games have to be downloaded from the Wii's online shopping channel [oAI07c]).

Major games released so far are *Wii Sports* which is bundled with the system, *Wario Ware*, *The Legend of Zelda: Twilight Princess*, *Super Paper Mario* and *Red Steel*.

Sony PlayStation 3

The successor to Sony's PlayStation 2 was released in Japan and the US in 2006 and in Europe in 2007. It is able to play Blue-ray discs without an additional accessory and is backwards compatible to the PlayStation 2 and the original PlayStation. While this is done by hardware emulation in the first US and Japanese models it was switched to software emulation for cost reasons on the European model ([EDG07]). The very high price of the system leads to low market shares compared to the other next generation systems ([Kle07]).

Some of the best selling games for the *PlayStation 3* (Figure 2.28) are *Resistance: Fall of Man* and *MotorStorm*.

Figure 2.28: Sony PlayStation 3 ([Son07b])

2.2 Digital Preservation

After the introduction to the major console video game systems and games that have to be preserved, this section gives a short overview about digital preservation, the challenges and strategies involved as well as details about a well-documented preservation planning approach and an introduction to emulation.

The term *Digital Preservation* is used in this document like it is defined in the UNESCO Guidelines for the Preservation of the Digital Heritage [Web05]. Digital preservation is described as the process of preserving data of digital origin, not the process of digitizing non-digital data for preservation purposes (nevertheless this process can produce data that may have to be preserved digitally).

2.2.1 Introduction to Digital Preservation

The preservation of records from digital origin faces various different challenges. Digital records not only have to be archived in a proper way to keep them from decaying, they have to be accessible as well.

[Web05] lists four layers on which a digital object can be threatened:

Physical Object One of the challenges in preserving digital records is the decay of media. Books can be read even hundreds of years after they were printed, but data which has been written to floppy discs 10 years ago is in many cases already lost. But not only the decay of media is a problem, hardware to read the media can be a problem, too. While it may be fairly easy to get a disk drive to read a 3 1/2 inch floppy disc, it is probably much more difficult to find one that is able to read 8 inch floppy discs. As all digital objects have to be stored on a physical media, this is a crucial threat for digital data.

Logical Object Not only is it necessary to be able to access the data on a physical layer (bits that are either set or not set), but it is also important to know, how it is logically stored. A file which is stored on a hard-disc is referenced by some kind of table of contents and chunks of the file are distributed all over the physical media. If the information how data is stored on a physical media is lost, it is very difficult to reconstruct the original data even if the physical media can still be accessed.

Conceptual Object This is the data in human readable form. If the data on a logical level is a compressed image, the data in its conceptual form is the image that is presented to the user when it is opened with the appropriate software to view it. With hardware and software getting obsolete very fast, data formats are constantly changing. The format of digital records that have been created 20 years ago may not be supported by any software that can be executed on hardware used today.

Essential Elements The context in which a digital object has been created has to be preserved, too. For example it may be necessary to know when, where and by whom a digital image has been produced, which software or hardware was used and other information related to the actual digital object. This information describing a digital object is usually referred to as *Metadata*.

But not only technical problems are a challenge for digital preservation. National libraries have the responsibility to preserve published non-digital data like books or magazines whereas the responsibility for preserving data of digital origin is not determined yet.

Legal issues are a challenge as well. It is not only necessary to discuss copyright issues for the digital object that has to be preserved, it may also be necessary to keep the software to access this object, so copyright issues for the software have to be taken into account, too.

2.2.2 Digital Preservation Strategies

The UNESCO guidelines for the preservation of digital heritage [Web05] list the following common strategies for digital preservation projects:

- Maintaining the original software and hardware to display the data to be preserved (*Museum Approach*).
- Converting data to a non-digital format which is easier to maintain due to long experience on the subject (*Print to Paper*).
- Using open, widely available, supported or agreed standards and file formats instead of proprietary or undocumented formats (*Use of Standards*).
- Making software or hardware able to interpret older versions of data (*Backwards Compatibility*).
- Maintaining the original data and providing a viewer for each new technology (*Viewer*).
- Migrating data to a new format for every new technology (*Migration*).
- Using new software which emulates the original software or hardware (*Emulation*).
- Packing data with meta data and software (or link to software) to view it (*Encapsulation*).
- Providing data and software to interpret the data for a standardized platform (*UVC - Universal Virtual Computer*).

Usually a combination of some of these strategies is the most promising approach for successfully preserving digital documents.

2.2.3 Preserving Complex Multimedia Objects and Interactive Content

Most digital preservation projects in the past concentrated on the preservation of static documents. One approach to preserve complex multimedia art was done by the Guggenheim museum with the *Variable Media Initiative.* One outcome was the *Variable Media Questionnaire*, a questionnaire for artists and collectors of art which included descriptive elements needed for recreating the artwork. The research concluded in the *Variable Media*

Network[1]. The variable media paradigm lets the artists choose between different strategies for preserving their art. The available options are storage, emulation, migration and reinterpretation. Hunter et. al. describe in [HC03] an approach to use a combination of emulation or migration and the use of metadata for describing the digital object. With the PANIC[2] project a prototype of a web service based digital preservation tool for semi-automatic preservation of complex multimedia objects is presented in [HC06]. The PANIC project concentrates on objects composed from different content and does not focus on interactive objects.

A practical experiment on how to use emulation to recreate interactive art is presented in [Jon04]. The original piece of art called "The Erl King" (1982-85) by Grahame Weinbren and Roberta Friedman consisted of obsolete and generic hardware and software. It presented itself as an ideal candidate for an emulation project as the original software was written by the artist, so it was a very high priority to preserve the original code.

Becker et. al. present in [BKKR07] case studies on sample objects of interactive multimedia art from the collection of the Ars Electronica[3]. The PLANETS preservation planning approach (as described in Section 2.2.4) is used for evaluating applicable digital preservation strategies for interactive multimedia objects.

2.2.4 The PLANETS Preservation Planning Approach

It is necessary to evaluate different possible solutions with standardized, repeatable and objective methods when implementing digital preservation strategies. In [RR04] Rauch et. al. develop a preservation solution evaluation metric based on Utility Analysis. This approach is combined with the Dutch Digital Preservation Testbed ([SV04], [HVD+04]) to the DELOS Testbed for choosing a digital preservation strategy in [SRR+06]. In [SBNR07] Strodl et. al. present the PLANETS[4] Preservation Planning approach, which is based on the DELOS Testbed. The workflow used for the planning process was refined after practical experience.

The viability of the PLANETS preservation planning approach has been proven in various case studies such as for example [BKKR07] and [BSN+07].

The workflow as presented in [SBNR07] is divided in 3 phases with 11 steps (Figure 2.29). It provides a well-documented process for evaluating digital preservation strategies.

[1] http://variablemedia.net/
[2] http://www.metadata.net/panic/
[3] http://www.aec.at
[4] http://www.planets-project.eu

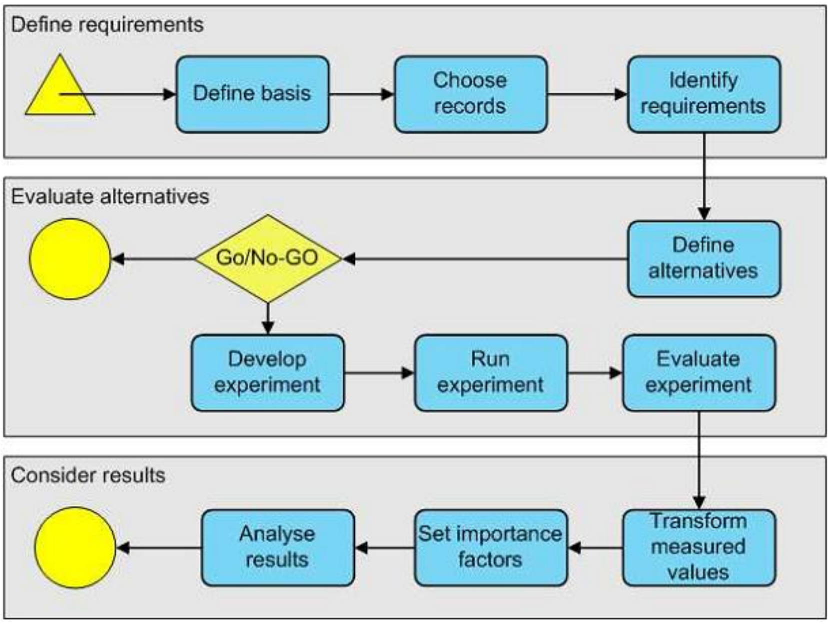

Figure 2.29: Overview of the workflow used in the PLANETS Preservation Planning approach ([SBNR07]).

Phase 1: Define requirements

The kind of data which has to be preserved and in the environment in which the preservation process has to be carried out is defined. Sample records are chosen and important characteristics of the data are collected.

Define Basis In this step the collection of data which has to be preserved is described as well as the environment, in which the preservation hast to take place along with the relevant legal and institutional boundaries.

Choose records Some sample records which represent are wide variety of the data are chosen out of the data collection to perform the evaluation.

Identify Requirements Required objectives for the data which has to be preserved are defined. These are then categorized in different levels and put in relation to each other in a so-called *Objective Tree*. Typically between 30 and one hundred objectives are collected with experts from different domains in workshops.

The requirements are different for most preservation projects. The four top-level categories used to organize these objectives are usually: file characteristics, record characteristics, process characteristics and costs ([SBNR07]).

For every objective characteristic the results are measured in either a textual, numeric or boolean scale that represent the different values which can be assigned to this figure.

Phase 2: Evaluate alternatives

Different alternatives to digitally preserve the data defined in Phase 1 in the specified environment are outlined and the experiments are performed in this phase.

Define alternatives In this step various alternatives (different preservation strategies or different tools for the same strategy) are defined. The costs (time, work, money) for every alternative are calculated.

Go/No-Go Depending on the costs the decision has to be made if the evaluation of the defined alternatives is carried out, the alternatives are adjusted or the project is stopped.

Develop Experiment To make the experiment repeatable the used hardware, software, parameters and the process to carry out the experiment as well as the mechanism to retrieve the results have to be outlined and documented in a development plan for each experiment.

Run Experiment For the sample records the experiment is carried out like described in the development plan.

Evaluate Experiment The results of the experiments have to be recorded for the requirements defined in Phase 1.

Phase 3: Consider results

The results of the experiments are examined in this phase by aggregating the values in the objective tree into a single value and ranking the alternatives.

Transform measured values The values have to be converted to a uniform scale using transformation tables to be able to add up the results.

Set Importance Factors For every leaf and node of the objective tree an importance factor has to be specified. All leafs and nodes directly under each node have to add up to 100%.

Analyze Results For every experiment the results have to be aggregated to a single number which can then be used to rank the experiments.

This is usually done by summing up the results of the leaf-values multiplied with the importance factors, but other methods like weighted multiplication are also possible.

A sensitivity analysis should be performed to find out if the results are stable or if small changes in setting the importance factors heavily influence the ranking.

2.2.5 Emulation

The term *Emulation* refers to the capability of a device or software to replicate the behavior of a different device or software. It is possible to use hardware to emulate hardware or to use software to emulate software. The word *Emulator* for using software to emulate hardware in this document is used as defined in [Sla03]:

> "Definition (b): An emulator is a program that runs on one computer (the emulator's 'host' system) and thereby virtually recreates a different computer (the emulator's 'target' system)."

Emulation as a Digital Preservation Strategy

The concept of using emulation for digital preservation is to keep the data in its original, unaltered form and keep using the software originally used to display the data. This software has to be run on the operating system and the operating system on the hardware it was developed for. To keep this chain alive, an emulator for the original hardware is produced (Figure 2.30).

Methods for Establishing Emulation for Digital Preservation

Several methods to establish emulation as a long term strategy for digital preservation are discussed in [Sla03]:

Chaining : This approach is also described as "layered emulation", as an emulator is developed for a system once on a host system. When the host system gets obsolete an emulator for the host system is written and the emulator for the system to emulate is run on the emulator for the previous host system. Besides speed issues, which may occur through layered emulation, the compatibility can be also get worse when the emulator for the system to emulate and the emulator for the host system are both no perfect emulations of the original hardware.

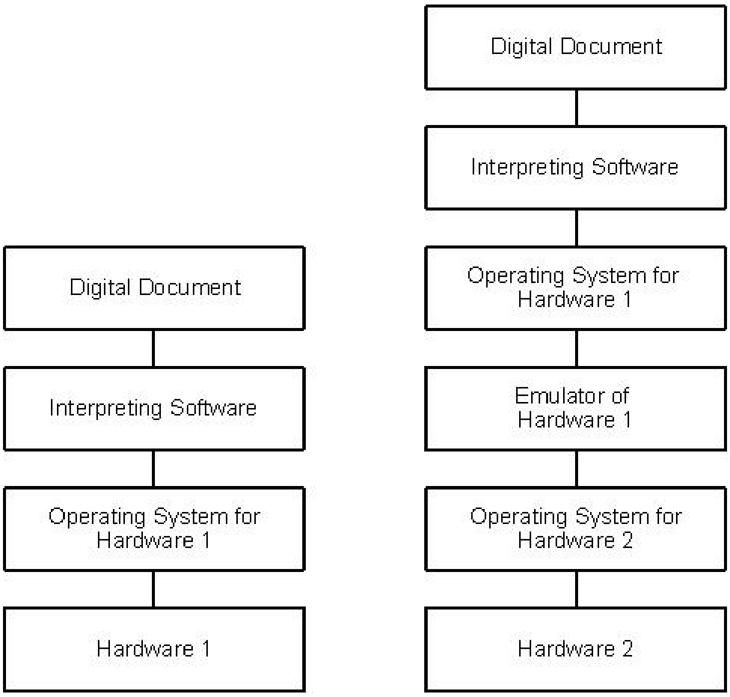

Figure 2.30: Emulation of hardware used as a digital preservation approach.

Rehosting : Other than the chaining approach an emulator runs always directly on the hardware of the host system. If the host system gets obsolete, the emulator is ported to the new host system. Speed is not an issue, as new systems are probably faster than previous systems, so the ported emulator will run even better. The costs for porting every emulator accrue on every technology change.

Virtual Machine (EVM) : The approach to use a virtual machine to run all emulators is a compromise of the two methods introduced before. Instead of running the emulator directly on the hardware of a host system a virtual machine is developed once for every system an emulator should run at. As soon as this system gets obsolete only the virtual machine has to be ported to the new host system. All emulators would in theory run like on the previous host system.

The Universal Virtual Computer (UVC)

An approach for a Universal Virtual Machine is the *Universal Virtual Computer (UVC)* by IBM ([HVDDVEM05]). With this approach a virtual machine is introduced, which is simple enough that it can be easily implemented but still sufficient for preserving digital data. The digital data is stored together with a program that can be run on the UVC but that is written when the data is archived. On a future system where the data will be restored an implementation of the UVC is hosted and the program which was stored with the data is used to extract the data from the record. A proof of concept for this approach has been done on the archiving of PDF-documents.

The Modular Emulation Approach

Emulation can take place on different levels (software, operating system or hardware) ([Rot00]). The most accurate approach to the emulation of console video games is most probably the emulation on a hardware level. Especially video games released later in the life cycle of a video game console are using system specific features on a very low hardware level to produce the best results with the then very well known system behavior. Video game consoles do not differ in the used hardware components like personal computers, so programmers can use very time restrained code and optimize the results to the specific system. Emulating a video game console on a different level than hardware would result in low compatibility for the game software. This approach uses software to reproduce the characteristics of hardware components and is not to be confused with emulating hardware using different hardware, which would not solve the digital preservation problems outlined before.

An approach to developing an emulator on a hardware level is discussed as a conceptual model in [vdHvW05] as *modular emulation*:

> "Emulation of a hardware environment by emulating the components of the hardware architecture as individual emulators and interconnecting them in order to create a full emulation process. In this, each distinct module is a small emulator that reproduces the functional behavior of its related hardware component, forming part of the total emulation process."

This approach suggests the use of a modular emulator which uses a component library and an emulator configuration document to bind the different components for a specific system to an emulated system. A component for which an emulator once has been written can be used for other systems using the same component. The ideal case is to write a new emulator by creating a configuration file and using all the existing components. The modular emulator is run on a Universal Virtual Machine (UVM) as suggested before. A controller program is used to start the UVM and loads the required components and the emulator.

An emulator which uses the modular emulation approach named *Dioscuri*[5] is currently under development. First versions that have been released are able to emulate a machine based on the Intel 8086 processor with basic input/output facilities. Dioscuri is written in Java and runs on the Java Virtual Machine. The goal of the project is a version of Dioscuri that is able to replace a reference workstation running Microsoft Windows 2000 ([KB 07]).

2.3 Chapter Summary

In this chapter a short introduction to the history of console video game systems was presented. The history was split in generations of systems that were competing on the market. The major systems of the different eras and some of the most important games were listed.

Then an introduction to digital preservation was given. The four threats for a digital object on a physical, logical and conceptual layer as well as for the context of the object were presented. The common strategies used for digital preservation were listed and related work in the field of preserving interactive objects was shown. Next the PLANETS preservation planning approach for documented decision making in digital preservation processes was outlined.

Emulation as a digital preservation strategy was presented. Methods to establish emulation as a long term strategy including chaining, rehosting and the use of an Emulation Virtual Machine were discussed. The Universal Virtual Computer by IBM was introduced. The modular emulation approach which uses component libraries and emulator configurations to create different virtual machines was presented as a method to develop an emulator.

[5] http://dioscuri.sourceforge.net/

Chapter 3

Digital Preservation for Console Video Games

3.1 Challenges for Digitally Preserving Console Video Games

When preserving video games one is faced with two different tasks: preserving the video game system and preserving the games themselves. The requirements and challenges for digitally preserving console video games are partially very different to those of digitally preserving static documents and even video games on other systems like personal computers, home computers and arcade machines. This chapter will list challenges of preserving systems, game code, look & feel and compare them to other system types.

3.1.1 Documentation of Console System Hardware

Unlike personal computers or early home computers the exact specifications of console video game systems and development documentation for game developers are usually confidential. The exact details about timing or accurate functionality of system components are often only known to the system manufacturer. They can get lost if a manufacturer goes out of business or decides not to keep this documentation any longer. Getting information about these systems usually means either to get restricted development documentation or to reverse engineer the system.

For digitally preserving games for console systems it is necessary to know details about how to get video game code off the original media and information about how this code was interpreted on the original machine. Without the manufacturer it can be difficult to preserve a video game of a particular system.

Maybe console video game systems are going to be better documented for the public in the near future. For some of the current generation of console video game systems possibilities for non-professional developers to create games are offered. These can be published for other users to download from the online platform of the systems manufacturer, for example Microsoft XNA Framework ([Cor06]) and Nintendo WiiWare ([oAI07b]).

3.1.2 Preservation of Game Code

Console video games have always been offered on various types of media which in most cases can not easily be read on standard computer hardware like floppy disc drives or CD/DVD-drives for PCs or home computers.

The most common media used for console video games are:

ROM-cartridges: Especially in the early years of video gaming ROM-cartridges were the most common used media. Microchips storing the game code were pinned out to a cartridge slot on the system and the code was read directly on the system's bus by enabling the microchip.

As ROM-cartridges were actually hardware that included software some contained additional circuits to increase storage capacity (e.g. Atari 2600, Philips Videopac). Other cartridges used additional hardware to implement copy protection mechanisms (e.g. Nintendo 64) or writeable memory to save game settings (e.g. Nintendo 64, Nintendo SNES). Some cartridges even contained complete processing units (e.g. various Nintendo SNES cartridges, Philips Videopac Chess Module).

With the rising demand for storage capacity and cost reduction for producing optical media ROM-cartridges were replaced by CDs. The last major system using ROM-cartridges was Nintendo 64 released in Japan in 1996. ([Wik07])

For digital preservation purposes it is not only necessary to save the content of the microchips on the ROM-cartridge but also to save information about how this content is accessed (e.g. how microchips inside a cartridge can be accessed by additional hardware). As different cartridges for the same system can use different kinds of circuits the original cartridge has to be opened (and in some cases even destroyed in this process) and be reverse engineered to get this kind of information.

Optical Media: With low production costs and high storage capacity optical media replaced ROM-cartridges as the norm for console video game media.

Most manufacturers use standard formats readable by standard optical drives for personal computers. This can be widely spread formats like CDs (e.g. Sega Saturn), DVDs (e.g. Microsoft XBOX360) and Blue-Ray discs (Sony Playstation 3). More scarce formats are used for some systems like the mini-DVDs for the Nintendo Gamecube. Some companies invented optical media just for the use in their console system (e.g. Gigabyte-Discs (GD) on Sega Dreamcast). To prevent users from copying discs most systems have some kind of copy protection which allows the system to detect original media.

The challenges for digital preservation are not only getting hardware that is able to read proprietary formats like the GD but also to read discs with copy protection and get documentation how to interpret the data on a disc. This information like the hardware documentation for the console system is usually confidential.

Online Content: With the use of memory cards with high capacities and hard discs in console video game systems manufacturers started to offer content also for download. This content is usually only accessible by using the original system directly and only for the time the system is supported by the manufacturer. Various games (e.g. *Planet Ring*) for the Sega Dreamcast are no longer playable because the necessary servers have been turned off in 2003 ([Dre03]). For these games the network protocols are not publicly available and only known by the manufacturer so the risk of loosing this information is very high.

Online content as well as game servers and online-platforms for different systems will have to be preserved in addition to console video game hardware and video games to replicate the system's behavior. Unlike video game software on media sold in stores this content is only in the manufacturers hand and can not be saved without their cooperation.

3.1.3 Look and Feel

While only the appearance has to be preserved for non-interactive content, it is necessary to preserve the user experience with interactive fiction like video games. Providing screenshots or movie captures of games will not provide the unique experience of playing a game like it was originally meant to be played to future generations.

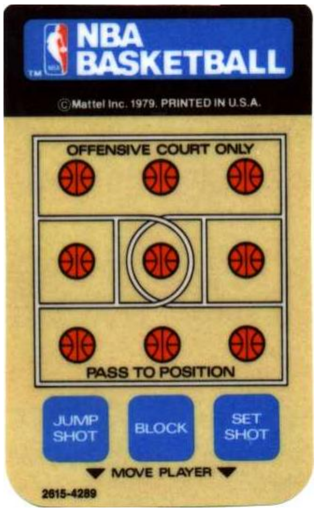

Figure 3.1: Mattel Intellivision *NBA Basketball* Controller Overlay

Overlays and Additional Game Items

In the beginning of video game history the technology was limited to very simple graphics and sound. Manufacturers tried to enhance the gaming experience by adding non-digital items to console video games. Screen overlays were used to give the impression of color-rich background graphics (Magnavox Odyssey). Some game controllers where designed to house overlays customized for the game (e.g. Mattel Intellivision, Coleco Colecovision). A good example is an overlay for the game *Basketball* by Intellivision Inc. which shows a basketball court with the corresponding buttons to press for offense or defense play (Figure 3.1). This concept was taken one step further by Philips by releasing combinations of traditional board games and video games (the *Master Strategy Series*) for the Magnavox Odyssey2/Philips Videopac. One of these games (*Quest For The Rings*) can be seen in Figure 3.2. It was shipped with a game board, playing pieces, an overlay for the keyboard and a cartridge. Playing the game without the added board game was all but impossible.

Special Controllers

Another way to enhance the gaming experience is to use special controllers designed for either a single game or a group of games. The earliest example are lightguns which have even been used for the first commercially published home console video system *Magnavox Odyssey*.

With recent PCs being able to play games as well as current video game

Figure 3.2: Magnavox Odyssey2 *Quest for the Rings* game board with playing pieces, keyboard overlay, box with cartridge

consoles manufacturers started to differentiate their systems by using special ways to control them like the Sony *EyeToy* or the Nintendo Wii motion sensitive controller. Games like Sega's *Samba DeAmigo* (Figure 3.3), Nintendo's *Donkey Konga* Figure 3.4) or Harmonix's *Guitar Hero* (Figure 3.5) use special controllers which are shaped like maracas, drums or guitars.

The experience with these games lies in the use of the special controllers. Therefore it is necessary to find a way to play the games like it was meant to be so that the feel of these games is preserved.

3.1.4 Legal Aspects

When it comes to legal issues, various parties are involved with the preservation of video games. The manufacturers of the original hardware usually keep information classified that might be necessary to get data off the original media. The producers of certain games which may be different from the hardware manufacturers own the rights on the video game code and limit its use to a certain console system. Games are usually also bound to a certain geographical region (Europe, US, Japan etc.).

To preserve video games in any other way than keeping the original hardware and media it is necessary to address the rights issues. For example for emulation of the original hardware the approval of the video game systems manufacturer is needed. To transfer the video game code to a different media

Figure 3.3: Sega Dreamcast *Samba DeAmigo* (Sega) maracas controller

Figure 3.4: Nintendo Gamecube *Donkey Konga* bongos controller

Figure 3.5: Sony PlayStation 2 *Guitar Heroes* (Activision) guitar controller ([Son07a])

the approval of the publisher of the game has to be obtained.

Slats points out some issues with emulation in [Sla03] and Nintendo of America, Inc. gives some information on their website about legal use of emulators and the involved copyrights ([oAI03]). It would be best to involve the original copyright holders when trying to preserve video games. This might not always be possible, as many companies may no longer exist if preservation has not been arranged at the time of a video game's release.

Ayre et. al. suggest in [AM04] some solutions to the rights issues with digital preservation which also apply to the digital preservation of console video games. It is necessary to constitute the responsibility for the preservation of digital data. Legal deposit laws should be extended to include digital data and the legal situation would have to be adjusted to enable legal deposits carry out the actions needed for digital preservation.

3.2 Choosing a Preservation Strategy

This section investigates which of the commonly used preservation strategies are applicable for the preservation of console video games.

3.2.1 Preservation Strategies Interpreted for Console Video Games

The principle common strategies for preserving digital data have to be translated into the preservation of console video games. They have to be interpreted with taking into account, that the look and feel has to be preserved and that the original media is prone to deterioration and can not be easily reproduced. With these things in mind, one can look at the various approaches in the following way:

Museum Approach

While this approach may be possible for machines built from standard components, console video game systems are usually built from custom manufactured parts. These are no longer available once the console system production stops, so they usually can not be replaced once broken. The same is true for video game software, as most modern systems do only allow to run originally manufactured media. This can only be an approach to digital preservation for the very near future.

Print to Paper/Video Approach

With this approach only screen shots (or non-digital videos) of video games could be preserved, this does in no way preserve the dynamic look and feel of interactive content and will in most cases not be a sufficient preservation strategy for video games.

A possible use of this strategy is to document the look of a game as a reference for newly developed alternatives when the original system is no longer working.

Use of Standards

Standards can be defined for data to be archived. In the sense of console video games the data are complex objects in games which interact with each other and with the player of the game by rules defined in the games code. As this game behavior is usually very complex and the original code which is executed in video games is very diverse, it seems very unlikely if not impossible to create a representing format which can be used as a standard for interactive games.

Backwards Compatibility

With games being recreated for new console video game systems and games offered for download for emulation on other systems, the following definition of backwards compatibility is used in this work:

Definition 1 *A console video game system is backwards compatible to another console video game system if it can use original media from that system* *either with or without additional hardware or software supplied by the systems manufacturer.*

The strategy to let consumers use games of earlier systems on newer generation models has been a successful commercial strategy since the third generation of video games (e.g. Coleco offered an adapter for their Colecovision console to use Atari 2600 games on it [Her01], Sony's Playstation 3 is able to play games both from Sony Playstation 2 as well as Sony Playstation). As this is a commercial strategy and not done with preservation in mind, usually only the previous generation of games is supported. Once a manufacturer goes out of business, the games are no longer supported by a future system. This strategy also works only with original media. As soon as the media is defective the contained video game is lost for preservation, too.

Backwards compatibility could be successfully used for digital preservation with chained emulation. Only the "last" system in a chain of backwards compatible systems would have to be emulated.

Viewer

For video games, the Viewer approach can only be accomplished with emulation, as viewing the behavior of video game code can only be done by executing this code on a representation of the system it originally ran at.

Migration

Migrating the contents of a video game (structure, graphics and sound data, behavior of the program) to a different universal structure faces the same problems as the *Use of Standards* approach. It may be possible to define universal structures for simple text-adventures or point-and-click games with linear game flow. Converting action games that rely on exact timing and intense graphical presentation as well as random gameplay seems not to be possible.

Emulation

For console video games this may be the most promising solution, as most systems have to be well documented for video game software developers to write games. The software itself is most probably not documented as well and can not be easily migrated. Further than that only one piece of software (the emulator) has to be written to run the library of all games for a console system instead of having to deal with every piece of software for a given system.

Encapsulation

Console video game software (in its unmodified original bit-stream) could be packed with the necessary emulator and metadata for preserving games in a library.

Virtual Machine Software

In the terms of console video games this could either mean to migrate games to a generic virtual machine (with all the problems outlined earlier but without the necessity to repeat it for every technology upgrade) but could also mean producing emulators running on a virtual machine which are then used to run unmodified video game software code.

The Documentation Approach

While migration from one format to another can be automated for static documents, video games would have to be reprogrammed for current systems to be reproduced properly. As this is not strictly a migration approach, but more of a re-interpretation of the original it is also called the *The Documentary Strategy* ([Dep01]). This could be a successful strategy for early console systems with only a few very simple built in games. For every system more complex than that, it would be very cost intensive and also not an easy task, as documentation for video games is usually not available and most games would have to be re-engineered to be able to reproduce it on a different platform. Most of the risks associated with migration for static documents like outlined in [LKR+00] and [Rot00] also apply to the re-interpretation of video game software.

3.2.2 A Promising Strategy For Preserving Console Video Games

As in most digital preservation projects, a combination of strategies promises to be the most successful approach. Lorie differs in [Lor01] between the archival of data and the archival of program behavior. While the first can be done without emulation, it can not be avoided for the latter. Video games are programs which have to be preserved, so emulation has to be one of those strategies.

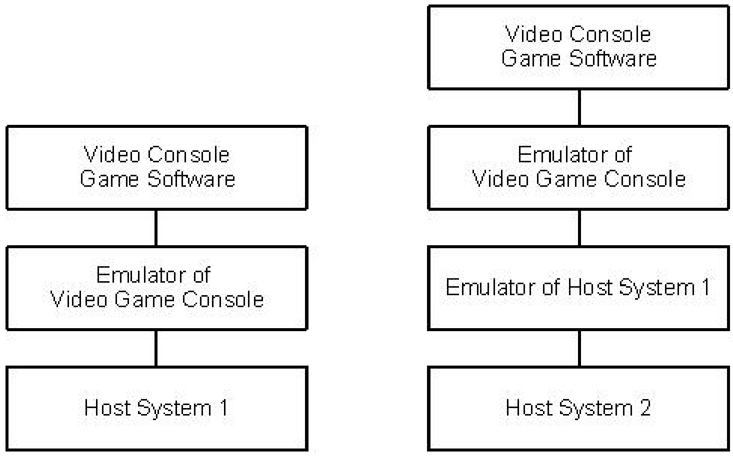

Figure 3.6: Chained emulation used for the preservation of console video games. An emulator for the obsolete Host System 1 is used on Host System 2.

The methods listed in Section 2.2.5 to establish digital preservation for console video game emulators can be described as:

Chaining

A certain console video game is running on an emulator of the games original system, which is running on a Host System 1. If Host System 1 gets obsolete an emulator for Host System 1 which can then run on the new Host System 2 is created. The emulator for the console video game system runs on top of the emulator of Host System 1. (Figure 3.6)

Rehosting

A certain console video game is running on an Emulator 1 of the games original system, which is running on a Host System 1. If Host System 1 gets obsolete a new Emulator 2 of the console video game system is created for the new Host System 2. The video game, which was running on top of Emulator 1 before rehosting to the new Host System 2, is then run on top of Emulator 2. (Figure 3.7)

Emulation Virtual Machine (EVM)

A certain console video game is running on an emulator of the games original system, which is running on top of an Emulation Virtual Machine 1 on Host System 1. If Host System 1 gets obsolete the Emulation Virtual Machine is

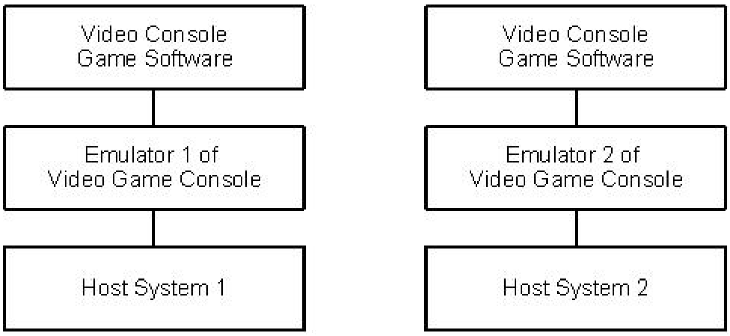

Figure 3.7: Rehosting approach for emulation used for the preservation of console video games. The emulator is ported to the new host system.

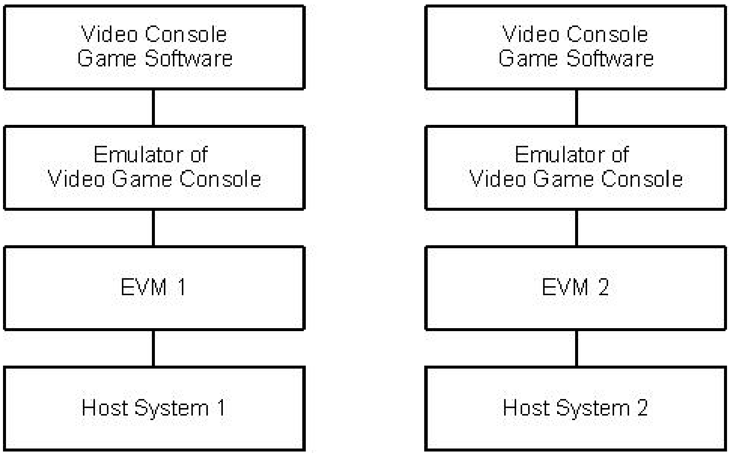

Figure 3.8: The emulator is run on an Emulation Virtual Machine (EVM) on Host System 1. Only the EVM is ported to Host System 2 when Host System 1 gets obsolete.

ported to the new Host System 2 as Emulation Virtual Machine 2. The same emulator that was running on top of Emulation Virtual Machine 1 is now running on top of Emulation Virtual Machine 2 on Host System 2. (Figure 3.8)

Given the complexity to develop an emulator for a console video game system, the EVM approach seems to be the best approach for running preserved console video games. The preserved games themselves should probably be encapsulated with appropriate metadata necessary to run the games.

3.3 Development Strategies for Emulators of Console Video Games

To evaluate existing emulators it is necessary to set criteria what can be considered as a good practice when developing a console video game emulator. First we will examine in what environment an emulator has to be developed in. Then we discuss the applicability of the modular emulation approach for console video game system emulation.

3.3.1 Choosing an EVM

An already existing and feature rich virtual machine is the Java Virtual Machine (JVM). Slats discusses in [Sla03] its use as an EVM. While it generally does not recommend it as the best solution, some of the disadvantages listed are not necessarily applicable to the emulation of video games:

- the rapid evolution of the JVM, which makes it relatively unstable, could possibly affect a specially developed EVM as well, as more modern video game console systems might require new features not implemented in previous EVM releases.
- the argument that the the JVM is language-specific bound to JAVA can as well be adopted to every other EVM which too has to use a language where existing emulators have to be ported to. Apart from that other languages able to compile to JVM byte code can be found in [Tol07].
- the difficulty to implement the JVM will effect an EVM usable for video game emulation as well, as it probably has to be as feature rich as a JVM to be able to emulate all facets of modern video game consoles.
- the *vernacular extraction* as described in [Rot02] is not used when presenting video games on some kind of screen and as such not a disadvantage of the JVM when it comes to video game emulation.

The Universal Virtual Computer (UVC) presented in Section 2.2.5 is in its presented form unusable for the emulation of video game consoles. It is kept very simple to make it easy to implement and was not specified for the rich input/output environment which is necessary for console video games.

As the JVM is an existing virtual machine, has the necessary rich input/output support and is implemented on a wide range of systems it can be seen as the best candidate for an EVM today. Like every other current technology the JVM will most probably not be used forever. At some point in time chained emulation probably has to emulate a system hosting a JVM or existing emulators have to be ported to a new virtual machine or a then existing dedicated EVM.

3.3.2 The Modular Emulation Approach

While the concept described in Section 2.2.5 should be used in an emulator to encapsulate the code for specific components, it is not as important for modern video game consoles as it was for early systems. Newer generation console video game systems no longer use standard components but specially developed parts to ensure technology advantages to the business competition at the time of a systems release. It is also necessary to prove that it is possible to configure system specific properties in an emulator document for console video games, as video game software depends on very exact timed interaction of hardware components.

3.4 Chapter Summary

In this chapter the challenges for digitally preserving console video games were discussed. The classified documentation for console video game systems presents a problem for recreating the behavior of a system on a different platform. The methods to offer game code on ROM-cartridges, optical media and online makes it difficult to transfer it to different physical media. The look and feel aspects of video games are especially hard to preserve when games use special controllers or additional items to enhance the gaming experience in non-digital ways. Legal Aspects have to be considered as well when trying to preserve console video games.

Next the choice of a preservation strategy for console video games was discussed. The common strategies for digital preservation were investigated for the preservation of console video games. As emulation is a promising approach, the different methods for using it as a long term strategy for console video game preservation were presented. The use of the Java Virtual Machine as an Emulation Virtual Machine as well as the modular emulation approach were discussed.

Chapter 4

Evaluating Strategies for Preserving Console Video Games

To evaluate strategies and alternatives for digitally preserving console video games, the PLANETS preservation planning approach (like described in Section 2.2.4) is used.

4.1 Defining the Basis

The data collections that have to be preserved are outlined in Section 2.1 along with the challenges and legal issues in Section 3.1. The types of media and approximate numbers of games which have to be preserved for each system can be found in the system fact tables in Appendix A.

No preservation environments are available as no responsibilities for preserving console video games have been defined, so no institutional policies have to be considered.

Based on the facts presented in the introduction of this work a digital preservation solution shall be chosen for a library approach where games can be archived and the look and feel of early video games can be reproduced for future generations. Early video games in this scenario are also the video games produced today, as video gaming for home use started 30 years ago and games for the systems currently on the market will probably be considered early video games in 100 years and more.

The following major goals have to be kept in mind when choosing a preservation strategy:

Authentic look & feel : As no one can predict how video games are controlled in the future and what they will look like, it is necessary to preserve the audible and visual characteristics of a game as well as the original game play and the feeling of playing a game like it was supposed to be. Using a paddle controller on Pong is a different experience than playing it with a mouse or the cursor keys on a keyboard.

Long term preservation : The applied strategy should ensure that games are still accessible for future generations, so an alternative has to be stable and maintainable for the curator.

Accessibility : Games should be archived with the information necessary to run them. While today people might know that a certain add-on to a console system is needed for a specific game, this knowledge will probably get lost. To use a preservation strategy in future exhibitions or museums it has to be easy to access the games.

Costs : It is assumed that costs are an issue but not as important as the authenticity of the preserved content.

Compatibility : As there is no authority to decide which games have to be preserved, a preservation solution should support all available games for a system.

4.2 Selecting Sample Records

For every video game system a maximum of three games will be selected as sample records. One game from each of these categories is chosen:

1. One of the best selling games for the system, as those are usually of the biggest public interest. This should be a standard game without special enhancements like overlays, special controllers or specially needed accessories.

2. A game with special overlays or special controllers, as it is more difficult to preserve the look & feel for these kind of games than for others.

3. A game using an accessory expanding the capabilities of the system. This additional hardware can either be applied to the system itself or on the media. If no hardware extensions are available, one of the last games for the system is selected. Those are usually the hardest to preserve as developers are able to utilize a system most at the end of its product cycle.

If no game for a system can be assigned to one of these categories, this sample record is not applicable for the system. Were available the European PAL release of a game is chosen unless otherwise noted. If no European release is available, the US NTSC release is used, if a game was not released in Europe or the US, the Japanese NTSC version is taken as a sample record.

As an example the selection for the Nintendo SNES system follows.

The popular game that was selected is *Super Mario World*. It was the first game for the system with Nintendo's famous character the plumber "Mario". It was one of the best sold games for the system. No games for this system used overlays, so a game with a special controller was selected. *Super Scope* is a game which was shipped with a light gun shaped like a rocket launcher. Various games for the Nintendo SNES used special hardware to support the system on cartridges. The third selected game, *Starfox*, uses a chip that assists the systems central processing unit with 3D calculations.

A complete list of the selected games used as sample records can be found in Table B.1 in Appendix B.

4.3 Identifying Requirements

The required objectives for the data which has to be preserved have been grouped at the top level into main categories as proposed in [SBNR07]. The complete tree can be seen in Figure C.1 in Appendix C and a complete list of requirements and units in Appendix F.

4.3.1 Object Characteristics

This main category describes the essential characteristics of the object that has to be preserved (Figure 4.1). In most preservation projects the requirements are collected on a file basis, but as complex multimedia objects usually consist of more files these attributes are evaluated on an object basis with a single video game being the object.

It is a knock-out criterion if an object is not interpretable by the preservation alternative. A sample record is considered interpretable, if any kind of output (audible or visible) is produced.

The speed factor describes how fast a preservation solution can recreate the original system. This value is measured in percent as deviation from the original speed. A value of zero (same speed as original) is the best value. Both a too fast and a too slow recreation of the original are considered as bad, as the speed and look of the original have to be preserved. While a game can

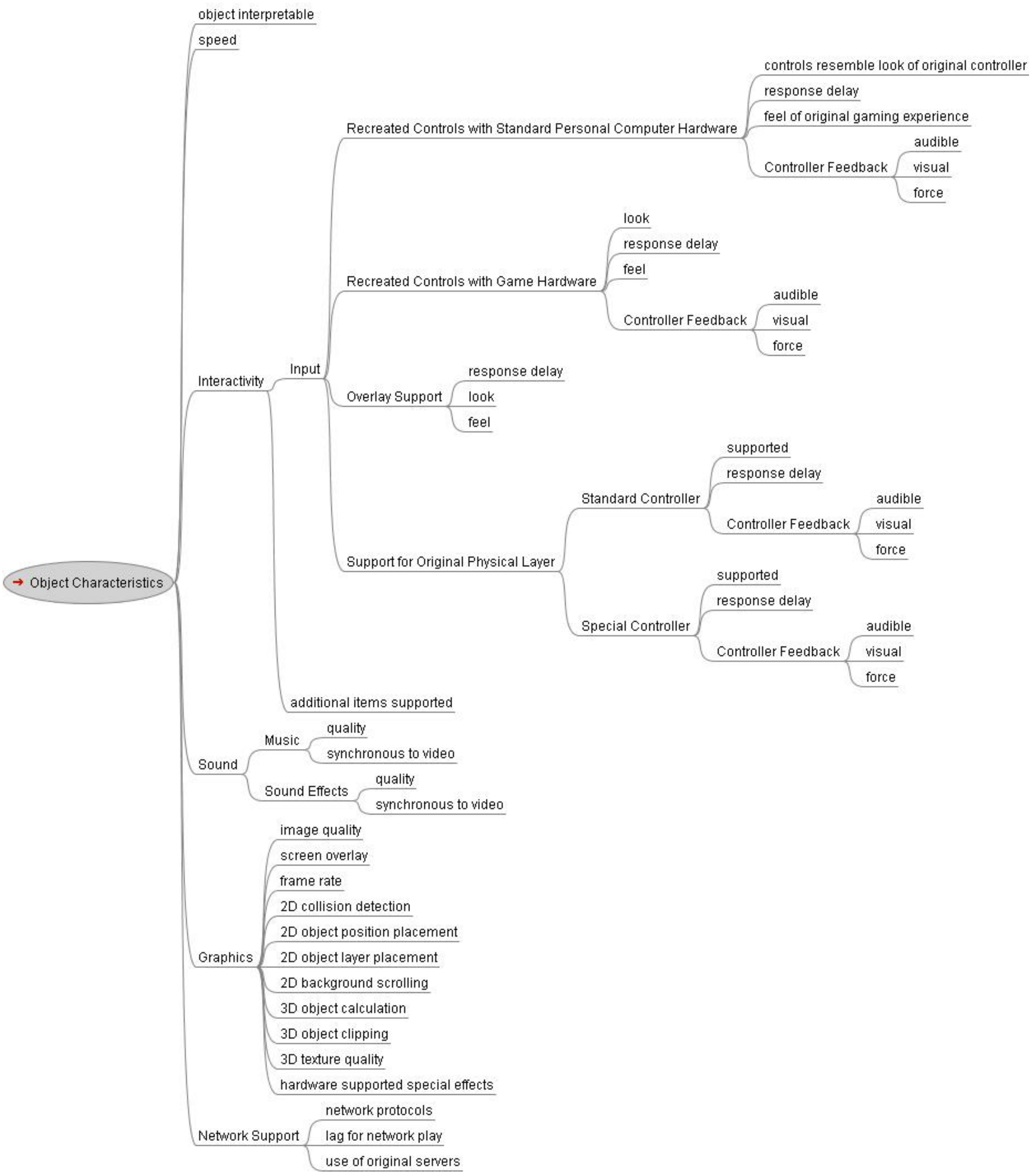

Figure 4.1: Object characteristics requirements sub tree.

run with the originally intended speed, the frame rate can be considerably lower than on the original system.

Sound

Sound can be divided into two different aspects: music being played and sound effects. The quality of the sound played can be either as high as the quality on the original system or lower. It is also recorded if errors are noticeable. A second figure measures if the sound is played synchronously to the visual content.

Graphics

This category describes the reproduced visual images. The factor for the image quality represents the overall subjective impression of the presented image in comparison to the original image side by side.

The frame rate measures the difference to the original frame rate. The value is calculated in percent as deviation from the original frame rate. A value of zero (same frame rate as original) is the best value. Both a higher and a lower frame rate than the original are considered as bad, as the original frame rate has to be recreated to preserve the original look and feel of the game.

The support for graphical features can be divided in 2 dimensional and 3 dimensional display characteristics. Some 2D characteristics are collision detection and errors in placement of objects like sprites, background objects and text. The layer calculation of these 2D objects (e.g. sprites have to be in front of the background) and how smooth the background scrolling is are other characteristics. For 3D objects the correct calculation, the clipping and the quality of textures are recorded. All graphical characteristics are measured with the following scale:

- not applicable: If for example no 3D objects are used in a game, this factor would not be applicable.
- no objects displayed: If the relevant objects can not be displayed by the alternative, this is a knock out factor.
- severe errors on whole image: If the objects are displayed but errors occur on the whole image and the gameplay is affected, this value would have to be assigned.

- errors noticeable but do not affect gameplay: This value is used when errors are noticeable for this factor but the gameplay is not affected and the overall image is still fine.

- no errors noticeable: If not difference to the originals behavior is noticeable for this factor, this value would have to be assigned.

Support for effects achieved by special abilities of the hardware are also noted.

For a system that uses screen overlays these can be supported either manually by loading an image, by auto-detection of the preservation solution or through encapsulation.

Network Support

This category describes to what degree network protocols are supported by a preservation solution. When network protocols are supported, the lag for online play is measured as well as if it is possible to use the recreated system with original network services provided by the console systems manufacturer (if those are still available).

Interactivity

This category describes the evaluation of the feel aspect of preserved console video games. The support for interactivity through controllers, overlays and additional items in different ways is described.

Input This category describes the various methods of recording input data for a preservation alternative. For every type of controller the response delay is measured with the following possible values:

- not applicable: This value is used, if this type of input us not applicable for the sample record.
- considerable delay: If a delay is noticeable that affects the gameplay, this value should be assigned.
- short delay: This is a delay that can be noticed but that does not affect the gameplay.
- delay not noticeable: If the input reacts just like on the original system, this value is used.

It is also measured, if feedback through the controller is supported. Feedback can occur as visual feedback (e.g. *Visual Memory Units* on the controllers of the Sega Dreamcast), audible feedback through a speaker on the controller (e.g. Nintendo Wii) or force feedback (e.g. controllers for the Microsoft XBOX).

Input can be supported through standard personal computer hardware (e.g. keyboard, mouse, microphone, web-camera) simulating controllers. It is measured if the feel of the recreated controller simulates the feel of playing with an original controller and how well the game is playable with it. It is also recorded if the controller resembles the original controllers look.

Another type of input is the use of game hardware. The availability and support of non-standard personal computer hardware as controllers (e.g. steering wheels, joysticks, light guns) is described in this section of the requirements tree. It is measured if controllers exist that resemble the original controller and if these are supported by the preservation solution.

If overlays are used for the original controllers and they are recreated by the preservation solution, the look & feel and the response delay are recorded as well.

A preservation alternative can also offer to support the controllers used on the original system. If supported the same figures as for recreated controls are measured separately for standard controllers for the system as well as for special controllers used by the specific game (e.g. steering wheel, guitar controller).

Support for additional items This figure measures if additional items of non-digital origin used by the game (like game boards and playing pieces) are supported by the preservation solution through recreation.

4.3.2 Context and Data Characteristics

This category describes the context needed for a certain preservation solution as well as data describing the object which is usually not encoded in the object itself (Figure 4.2).

The context includes references in the encapsulated data to have information on what original system the preserved data was to be used and what application can be used to interpret the data along with configuration options (e.g. command line parameters).

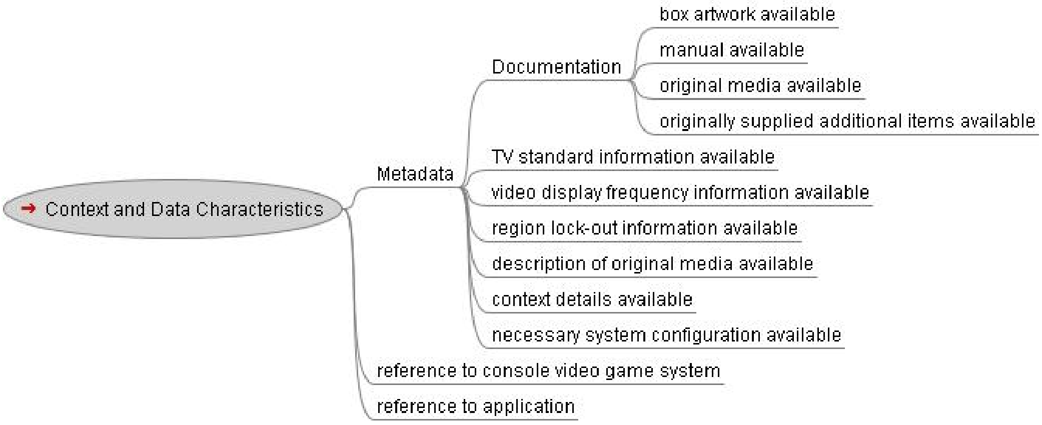

Figure 4.2: Context and data characteristics requirements sub tree.

The encapsulated metadata should contain the properties needed to recreate the systems original look. These should include information about the region the game was produced for, the intended TV standard and video display rate as well as information about the logical and physical architecture of the media. Information about needed add-ons and details about the context in which the game was originally released (developer, publisher, version, release date, country of release) can be inserted as well.

Encapsulated documentation can either be supplied as references to the non-digital data or as image scans or text representations. The data to be included consist of the instructions for playing the game, information about the non-digital items supplied with the media and pictures of the box art and the original media.

4.3.3 Infrastructure

The infrastructure category (Figure 4.3) includes figures about how stable a method is and what kinds of media can be used.

Scalability

The scalability describes, if a solution can be ported to newer and different systems to provide a long term preservation strategy.

The source code of a preservation alternative can either be written in a platform independent programming language like Java or C or processor dependent code in machine language (assembler) can be used for speed reasons. The use of hardware dependent libraries like Microsoft DirectX can

Figure 4.3: Infrastructure characteristics requirements sub tree.

also influence the portability of a preservation software when switching to a different hardware or operating system.

The code is more maintainable with a modular approach. Modular approach in this context means that different system components are coded into separate code modules. If more systems are supported it is more likely that additional systems can easily be added to the software.

New hardware on systems like faster graphic cards can be supported by using plug-ins if this is offered by the preservation solution. If the specification for plug-ins is open, they can be developed by oneself if needed.

Stability

The stability describes to what degree the solution is stable against change in infrastructure and what kind of support can be expected for a solution.

While a commercial solution usually implies warranty, which is not given for non-commercial solutions, open source solutions tend to be more stable in terms of long term development. If a company goes out of business, development could continue. Both factors (commercial development and availability of source code) can be combined to give a factor for the stability of a solution.

Especially for open source solutions the time since the last release is an indication if the software is still in active development or not. If no new version has been released for more than a year, than development has most probably stopped.

Active user communities are also an indication for the stability of a project. If many people support or use a project, it is more likely to continue than if no forum or a forum with no active users exists. If a user community is active is measured on the following scale:

- official forum available with more than 200 active users
- unofficial forum available with more than 200 active users
- official forum available with less than 200 active users
- unofficial forum available with less than 200 active users
- no forum available or no active users

Legality

Various legal issues are involved when preserving console video games (see Section 3.1.4). The level on which a system is preserved is one of the factors that determine how legal a solution is. If a system is preserved on a high functional level, no re-engineering of the system may be necessary depending on the available documentation for developers. Depending on the level and the system preserved, the copyrighted original systems BIOS may be needed.

The approval of manufacturers is a key requirement for legally preserving console video games. No approval of digital preservation can be expected if a manufacturer is no longer in business. The commercial interests of a manufacturer that is still selling video games or video game console systems are probably contrarily to providing ways for playing games that are no longer sold.

Media

This category describes what type of media the preservation alternative supports. It is a knock-out criterion, if neither byte-stream nor the original media are supported and the preservation solution relies on media. If no media is used (e.g. simulation approach) this section is not applicable.

The support for byte-streams is important as original media either decays or hardware to access it is no longer supported by newer systems. Byte-streams can be supported either as stand-alone files which are raw dumps of the original media or encapsulated with metadata.

The use of original media with a preservation solution is an added feature and can be supported either with or without the use of special hardware.

Information about the logical layer of data on a media has also to be used by the solution. An example are ROM-cartridges with different mechanisms to address the data coded in ROM-ICs on the cartridge (e.g. Nintendo NES, Philips Videopac G7000, Atari 2600). This information can be hard-coded in a preservation solution, so new formats can be only be added by a change in the base-software. Adding new formats by writing plug-ins without the need

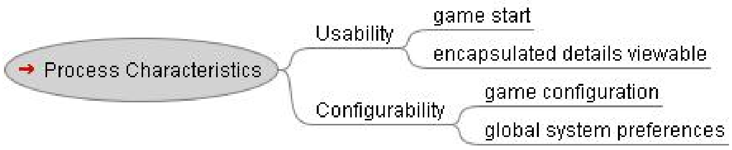

Figure 4.4: Process characteristics requirements sub tree.

of changing the base-software is a solution for software supporting plug-ins for media access. The information about how to access the data can also be encapsulated with the data and interpreted by the preservation solution. Additional formats could be added with new records.

Not only can data be stored differently on a media, additional hardware can also be present on a media. An example are ROM-cartridges with special graphic, sound or processing circuits supporting the systems hardware. The methods used for configuring logical layer information can also be applied to the support of special hardware.

Additional Accessories

This category describes the support for additional accessories which were not shipped with the system when it was first released. Examples include CD-add-ons, hard drives, memory cards, RAM-carts etc. Additional Accessories can either be supported by connecting the original accessory to the preservation alternative or by the preservation solution recreating the accessory.

4.3.4 Process Characteristics

This main category describes characteristics of the process to archive and access objects (Figure 4.4).

Usability

The usability describes, how easily preserved data and meta data can be accessed within a certain preservation solution.

Selecting games from a menu provides better accessibility then starting games only from a command line, with the latter being necessary for automating the process of selecting games in a universal application for selecting records and invoking applications.

Documentation encapsulated in the record should also be accessible by the preservation alternative. The instruction guide for a game for example could be displayed on the screen when requested by the player.

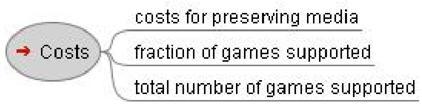

Figure 4.5: Costs requirements sub tree.

Configurability

This category describes how comfortable it is to configure a preservation solution and properties for single records.

Global system preferences like controller configuration and path to data records can either be only set in the user interface or handed over to the application on the command line or by using a configuration file.

Settings for single games can also be changed either in the menu of the used software or by handing them over in the command line. Other possibilities are the use of configuration files for the records, auto-detection by the software or the use of data encapsulated with the binary stream.

4.3.5 Costs

The costs main category depicted in Figure 4.5 describes the cost involved in a particular preservation alternative. They can be split into the costs for preserving a single record and the portion on the costs for creating a preservation alternative.

The costs (e.g. time, money) for preserving a single record that have to be raised for reading the byte-stream off the original media are different depending on the media. The costs are low for optical media which can be read using a industry standard optical drive and non-optical media like ROM chips that are directly connected to a console cartridge port and readable with a standard chip reader and adapter. They are higher if special hardware provided by the console system manufacturer has to be used. If additional hardware is applied on a media, the costs are a lot higher, as re-engineering has to be applied on a record basis.

The total number of games supported by a preservation alternative influence the portion of costs for a single record. A low number of supported games means high costs per record. The fraction of how many games from the available games for a system are supported by a preservation solution also influences the costs. The figure is calculated by dividing the number of games supported through the total number of games for a system. The value rises with more games for a system covered.

4.4 Defining Alternatives

Alternatives for the applicable digital preservation strategies are defined in this section for the console video game systems defined as basis.

4.4.1 Emulation

As described in Chapter 3.2 emulation is the most promising solution for the long-term preservation of console video game systems. Most of the alternatives are different emulators for a system. Only emulators that have seen at least one release in the last 6 month or that have been released in stable final versions are evaluated. If no emulator exists which meets this criterion, the latest released emulator is evaluated. Only emulators for personal computers running on a Microsoft Windows or Linux operating system or on a virtual machine on one of these operating systems are evaluated. For every system a maximum of 3 emulators are evaluated. If more than 3 emulators meet the criteria defined here, the ones which have been in development longest are considered. Alternatives are selected by using the publicly most popular and best rated emulators according to a world wide web research. Dedicated emulators as well as emulators supporting more than one system are chosen if available. Only emulators that are known to be able to launch commercial games are selected.

The chosen emulators are listed in Table D.3 in Appendix D. No emulators are available for current video game console systems (Microsoft XBOX 360, Nintendo Wii and Sony PlayStation 3) as well as for most early pong era console systems (Coleco Telstar and Atari Pong).

4.4.2 Simulation

As the simulation or re-interpretation approach is a potentially successful solution for pong-systems with only very few games, simulators of a system are considered as well if available. The same criteria for selection as for emulators will be applied.

Simulators are only available for the General Instruments chip AY-3-8500 used in the Coleco Telstar. The list of available simulators can be found in Table D.2 in Appendix D.

4.4.3 Backwards Compatibility

For the backwards compatibility approach only currently available video game hardware is considered (e.g. Sony PlayStation 3), as all other console systems already have to be preserved as well. The systems supported through backward-compatibility are listed in Table D.1 in Appendix D.

4.4.4 Print-to-Paper/Video Approach

The print-to-paper/video approach is an approach which documents either the visual (e.g. screenshots) or the audible and visual (e.g. videos) properties of a game and is applicable for all systems. The video approach is used as it supports the dynamic look of a video game. The gameplay is recorded and the video is digitally saved in a standard format.

The video is captured in the original resolution as used on a standard TV with the original frame rate that the system produces. As a container format *MPEG-4 Part 14* (or short *MP4*) is used as it allows the use of metadata tags and is a common standard. The open source VLC media player[1] release 0.8.6c is used to play-back the recorded videos.

4.4.5 Museum-Approach

The museum approach has to be considered as an alternative as well. It is applicable for all systems.

4.5 Go/No-Go

In this step it will be discussed, for which of the alternatives experiments will be carried out.

4.5.1 Emulation

No knock-out criterion is immediately apparent for systems where emulators are available. While it is very complex to develop an emulator, these costs arise only for the development of the emulator and not for every single video game for a system, so emulation is considered as an applicable approach and will be evaluated.

→ *Go*

4.5.2 Simulation

Simulators are only available for one system (Coleco Telstar) with only built in games. As developing a simulator for these games is much less complex

[1] http://www.videolan.org/

than developing an emulator, the costs will be lower, so simulation is considered as an applicable approach and will be evaluated.
→ *Go*

4.5.3 Print-To-Paper/Video Approach

The look of a console video game can perfectly be preserved by using the video approach. The cost factor for creating screen shots or videos of console video games is also very low compared to emulation. The complete loss of the feel aspect is a knock-out criteria for the chosen scenario, as this is probably the most important fact in understanding the user experience of console video games. To compare the results in all but the interactivity aspect an evaluation is carried out for one system with one sample record.
→ *No-Go*

4.5.4 Museum-Approach

As systems usually play only original media, systems as well as the console video game media have to be kept in a working state. Most console video game systems are not built from standard components but from specially manufactured parts which are only produced as long as the console system is produced. Once broken, these parts can not be replaced, so this can only be a short term solution. As one of the key requirements is the possibility of long term preservation, this is a knock-out criterion.
→ *No-Go*

4.5.5 Backwards Compatibility

Backwards compatibility gives very good results on emulated games. Most solutions are able to reach at least near 100% perfect emulation. Still some facets are knock-out criteria for this approach:

- Only original media can be used, so the console video game code can not be digitally preserved on a different physical media. Original media can not be preserved for a long term.
- As backward-compatibility is a marketing point for customers to have a large software library for a system available when it launches, usually only the last generation of a console video game is supported. With a typical generation life cycle of 4-6 years this does not qualify for preservation, as specimen of the original system are also still in working condition during this period.

- Only previous console video game systems from manufacturers of new systems are supported.
- While backwards compatibility sometimes offers improvement on the graphical representation of games (e.g. Sony PlayStation 2 improved Sony PlayStation games by using texture smoothing) the new system no longer creates the authentic images produced by the original machine. Usually this enhancement can be turned off to improve authenticity.

→ *No-Go*

4.6 Developing the Experiments

Each experiment is carried out on a *HP Compaq Business Notebook nc6120* personal computer for running the simulation or emulation programs. A system without dedicated graphic card was used to test the independence of special hardware.

The hardware specifications of the used personal computer are as follows:

- Intel Pentium M 750 1.86 GHZ Processor
- Mobile Intel 915GM Express chipset for graphic and sound system
- 1.5 GigaBytes main memory
- DVD-ROM drive
- serial, parallel, FireWire, USB2.0 and Ethernet network interfaces
- 15" TFT-active matrix display with a maximal resolution of 1024 x 768 and 24 bit color resolution (16.7 million colors)
- digital joystick connected to USB-port
- analog joystick connected to USB-port

The following software environment is installed on the computer:

- Windows XP Professional Service Pack 2 operating system
- Microsoft DirectX 9.0c
- Microsoft .NET Framework 2.0
- Sun Java Runtime 1.6.0_02

The Windows 32bit versions of alternatives are tested, if more than one version exist that would run on the system used for the experiments.

For every alternative menu options and configuration possibilities are reviewed for the usability aspects of the requirements. Next a short review of the source code (if available) is performed to evaluate the figures concerning the infrastructure aspects.

For every sample record the default settings of the tested preservation alternative are used to carry out the experiment. Game settings are set according to the region and video display frequency and necessary add-ons of the sample record (if necessary and possible).

Selection screens, 3D and 2D game sequences (if applicable) are tested for the audible and visible aspects. Every game is played at least 5 minutes to detect glitches along the playing progress.

The test is performed using the standard PC controls (mouse, keyboard) as well as the digital or analog PC Joystick (whichever resembles best the original controller of the system) to evaluate the interactivity aspects of the game.

The same tests will be performed on the original system to compare the gaming experience.

4.7 Running the Experiments

The experiments are split into three different categories for the various different aspects that have to be tested.

4.7.1 Comparison of alternatives for the same console system

This comparison is done to evaluate what differences between the alternatives occur and in what aspects shortcomings of current alternatives can be observed. For this experiments a system midway through the generations was chosen. The decision for the Nintendo SNES was taken as it used media with special hardware and special controllers that have to be reproduced to obtain the look and feel of the games. The selected alternatives include a dedicated alternative and an alternative supporting various different systems and are evaluated with the three sample records defined in Section 4.2.

For comparison the video approach using MP4 as container format and the VLC media player as displaying software is also tested as an alternative.

The experiments in Table 4.1 are carried out and evaluated.

preservation strategy	console video game system	evaluated alternative	sample record
emulation	Nintendo SNES	ZSNES 1.51	Super Mario World
			Super Scope 6
			Starfox
		SNES9X 1.51	Super Mario World
			Super Scope 6
			Starfox
		MESS 0.119	Super Mario World
			Super Scope 6
			Starfox
video	Nintendo SNES	VLC 0.8.6c/MP4	Super Mario World

Table 4.1: Experiments run for alternatives for Nintendo SNES.

preservation strategy	console video game system	evaluated alternative	sample record
emulation	NEC PCEngine	MagicEngine 1.0.0	Bonk's Revenge
			Gates Of Thunder
		MESS 0.119	Bonk's Revenge
			Gates Of Thunder
	Sega Mega Drive	Gens32 1.76	Sonic the Hedgehog 2
			Darxide
		Kega Fusion 3.51	Sonic the Hedgehog 2
			Darxide
	SNK Neo Geo	NeoCD 0.3.1	Metal Slug
			Crossed Swords 2
		Nebula 2.25b	Metal Slug
			Crossed Swords 2

Table 4.2: Experiments run for alternatives for console video game systems of 16-bit era.

4.7.2 Comparison of alternatives for different console systems of the same era

In addition to the comparison of alternatives for the Nintendo SNES two alternatives for every other system in the same era are evaluated to test if systems similar in hardware are recreated with similar results. For every system two of the three sample records described in Section 4.2 are evaluated. The selected alternatives and sample records are listed in Table 4.2.

4.7.3 Comparison of alternatives for console systems of different eras

The systems from the various eras differ both in system complexity and added capabilities like special controllers and online play. To compare preservation alternatives for console video games as systems evolve two alternatives for one system of every era are evaluated with two sample records if available. Additionally to the already selected alternatives for the Nintendo SNES the

preservation strategy	console video game system	evaluated alternative	sample record
simulation	Coleco Telstar	Pong 6.0	Tennis
		PEmu	Tennis
emulation	Philips G7000	O2EM 1.18	K.C. Munchkin
			Quest For The Rings
		MESS 0.119	K.C. Munchkin
			Quest For The Rings
	Sega Master System	Dega 1.12	Alex Kidd in Miracle World
			Space Harrier 3D
		Kega Fusion 3.51	Alex Kidd in Miracle World
			Space Harrier 3D
	Atari Jaguar	Project Tempest 0.95	Doom
			Highlander
		MESS 0.119	Doom
			Highlander
	Sony PlayStation 2	PCSX2 0.9.2	Gran Turismo 3
			EyeToy Play

Table 4.3: Experiments run for alternatives for console video game systems of all eras.

following systems are chosen for the following reasons:

The *Coleco Telstar* was selected as it is the only system where simulation exists as an alternative. To compare this approach to emulation, two simulators are evaluated. The *Philips G7000* is the only system with a keyboard which used overlays for its keyboard and that had games with additional items (board game).The *Sega Master System* was selected for its available 3D glasses which make this system a difficult one to preserve from its era. Controller overlays, cartridges as well as hardware extensions (e.g. CD-ROM add-on) where used by the *Atari Jaguar*. Finally the *Sony PlayStation 2* was selected as it offers lots of special features like online play with still active servers, accessories like microphones and cameras and controllers like the guitar controller. Games for this system are still in development and for sale and the sample games are applicable for most of the requirements in the objective tree.

As no alternatives exist for current generation console systems, no experiments are carried out for these. The selected alternatives and sample records are listed in Table 4.3.

4.8 Evaluating the Experiments

For every alternative that was defined in Section 4.7 the values have been measured and recorded on a spreadsheet. The scales for the various factors as defined in Section 4.3 have been used.

The complete list of measured values can be found in Appendix E.

4.9 Transforming Measured Values

As the measured values are not in the same scale, they are transformed to a scale of 1 to 5 with a knock-out criterion transformed to 0. If for the sample record no 2D or 3D objects in the game can be displayed by the alternative the requirements are defined as knock-out criteria.

Values that are not applicable for a sample record are set to the full value of 5. A sample record which is perfectly recreated with the best possible system (costs, process characteristics and infrastructure) will thus get the full value of 5 points regardless if the objectives defined in the requirements tree are applicable to the system.

The assigned transformation values for all requirement units are listed in Appendix F.

4.10 Setting Importance Factors

For every level in the requirements tree 100 percent are distributed over the nodes and leafs. The importance factors are shown in the requirements tree in Figure C.1 in Appendix C.

The overall factors have been set according to the basis defined in Section 4.1 with the following considerations:

Object Characteristics (40%) The displayed object properties are the most important requirements that have to be met. If the object is not displayed properly and the interactivity requirements are not met the preservation solution is not very useful.

Context and Data Characteristics (20%) Metadata about the object has to be connected to the representation of the media to be able to configure the system correctly. Data of non-digital origin such as instructions for playing the game and box art has to be connected to the media as well to preserve the video games for a long term. For the assumed preservation scenario this is an major criterion.

Infrastructure (20%): To meet the requirements for a long term preservation solution, a stable and scalable infrastructure is important.

Process Characteristics (10%) While it would be more comfortable to access the preserved games without having to configure the system manually for every record, the quick accessibility of the data is assumed not as important as the higher ratet categories for the library scenario.

Costs (10%) As defined in the basis the costs are not a critical factor in the assumed preservation scenario.

4.10.1 Object Characteristics

The visual and audible factors are set to the highest importance as those represent the look of the object. The feel aspect is taken into account with a high importance for the interactivity.

The quality of the sound is is rated higher than a perfect synchronous play to the video. The overall impression of the image is more important than individual factors or errors in the presentation.

For the interactivity it is more relevant that new controllers resemble the originals than that original controllers are supported, as those are prone to decay just as the original systems. The feel is more significant than the look for controllers and the support and response more than the controller feedback. For overlays the look is more important than the feel aspect.

4.10.2 Context and Data Characteristics

The categories in this main category are set to very similar factors, as the need for metadata is just as important as the reference to a target application for the record.

4.10.3 Infrastructure

The stability and scalability are the most relevant factors in this category as an active support for a product and the possibility to port the alternative to new target systems is necessary for a long term preservation. The support for media as a byte stream is rated higher than the use of original media, as those are just as prone to decay as the console systems.

4.10.4 Process Characteristics

The alternatives to configure the preservation solution automatically are set to a higher importance factor than the simplicity of starting a game, as that process was less time consuming when performing the experiments.

4.10.5 Costs

The portion of costs on the development of an alternative supporting the record is usually higher than the costs for archiving a single record, so the

Alternative	Sample record	Weighted Sum	Multiplication	WS Average	Mult. Average
ZSNES 1.51	Super Mario World Super Scope 6 Starfox	3,4511 3,3040 3,3751	2,7506 2,6952 2,7799	3,3767	2,7419
SNES9X 1.51	Super Mario World Super Scope 6 Starfox	3,4311 3,2840 3,3831	2,8212 2,6769 2,7777	3,3661	2,7586
MESS 0.119	Super Mario World Super Scope 6 Starfox	3,5531 3,4720 2,4745	2,8843 2,7882 0,0000	3,1666	1,8908
VLC 0.8.6c/MP4	Super Mario World	4,6934	0,0000	4,6934	0,0000

Table 4.4: Aggregated experiment results for preserving games for the Nintendo SNES.

importance factors have been set accordingly.

4.11 Analyzing Results

The results of the experiments have been aggregated to single values for every sample record as well as average values for the alternatives. For the first figure values have been aggregated as weighted sum by multiplying every transformed value with the leafs weight and then summing up the values for the node. For comparison a multiplication aggregation has been performed by raising the measured value to the power of the weight and multiplying the resulting values for every node. With the multiplication approach knock out criteria (measured values transformed to zero) lead to an aggregated zero value for the experiment.

4.11.1 Comparison of alternatives for the same console system

Three different emulators for preserving games for the Nintendo SNES video game console have been evaluated. The results can be seen in Table 4.4.

The sample records offered different challenges to the emulators. While *Super Mario World* is game without any special controllers or hardware on the cartridge, *Super Scope 6* uses a light gun as an input device and *Starfox* has a special chip applied to the cartridge that supports 3D graphics.

The differences and similarities that have been observed for the main categories:

Object Characteristics While all alternatives where able to emulate Super Mario World to a state where it was playable, only SNES9X and

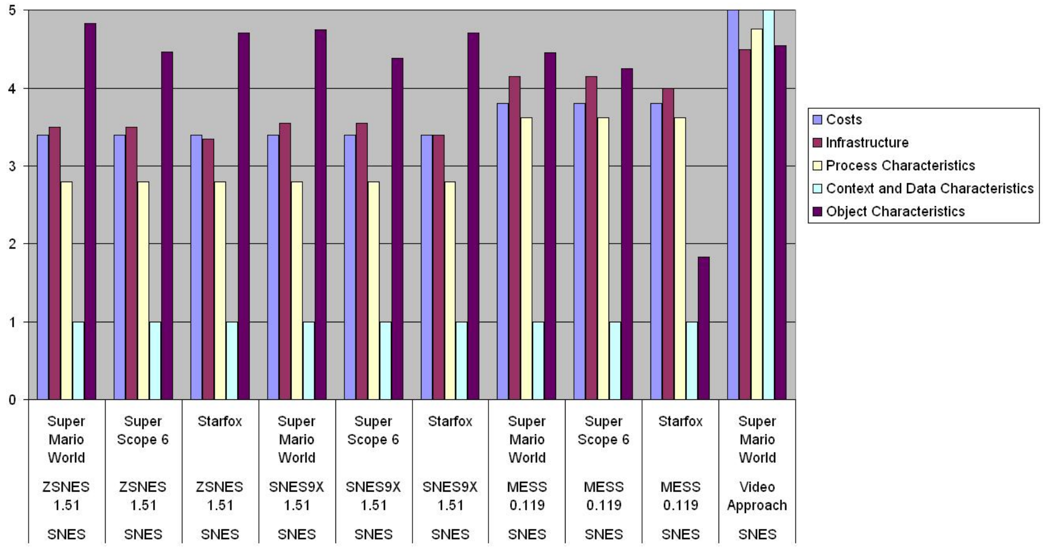

Figure 4.6: Aggregated results for the main categories in the requirements trees for Nintendo SNES preservation alternatives (weighted sum).

ZSNES where able to reproduce the game without major errors. With MESS the screen was garbled throughout the game. The gaming experience was rather good, as the the digital pad on PC joysticks resembles the pad found on SNES controllers.

The second game evaluated was a light gun shooter. SNES9X and ZSNES simulated a cross hair which could be moved with the mouse. The gaming experience is still lost as the game play is totally different to the original. On MESS the light gun input is not supported, which renders the game unplayable.

SNES9X and ZSNES both emulate the special chip found on the Starfox cartridge and emulate the game very well. The special micro chips on SNES cartridges are not emulated by MESS, so the game does not work on this emulator.

The video approach was able to produce the graphical and audible results perfectly. However the interactivity aspect is totally lost, so this alternative has to be excluded as the the support for controls is a knock-out criterion.

Context and Data Characteristics All evaluated emulators support only byte streams and no encapsulated data. MP4 supports tags, so it was possible to include metadata with the recorded video.

Process Characteristics In the current versions only MESS supports the use of command line parameters for starting specific games and setting options. Global settings for all emulators can be configured through configuration files.

In VLC it was possible to open the saved videos either through the command line or through the user interface.

Infrastructure Both SNES9X and ZSNES use x86 assembler to emulate all system components in the necessary speed on current PC hardware. ZNES is more hardware dependent than SNES9X while MESS is a modular multi-system emulator that uses no platform dependent code in its common code base. VLC does not use platform dependent code, but uses hardware dependent libraries.

All three emulators as well as VLC are not commercially developed and open source. New versions have been released for all of them in the last year with MESS being the one with the shortest release cycle. Active user communities do exist for all as well.

Emulation is done by recreating the original systems on a hardware-component level in every case and no original BIOS is used. Recreation of the original look is done on the highest possible level with the video approach.

Costs The cost factor is very similar for all emulators with advantages for MESS as it supports other systems games as well. The video approach has the best cost factor, as no media have to be reengineered.

While the total ranking gives very close results for all emulators for most sample records with slight advantages for MESS, the values are combined from different categories as can be seen in Figure 4.6. The differences in values on the separate leafs are minimal between ZSNES and SNES9X. MESS had much better results for infrastructure, process and costs but lacked on emulation compatibility. If it is required that all games for a system are supported, MESS has to be eliminated as an alternative as can be seen in the multiplied aggregated results.

The video approach using VLC and MP4 has the highest overall results for the weighted sum, as it is the only approach that supports metadata and has the highest cost factor. However as the use of controls and thus the ability to interact with the game is defined as a knock-out criterion, it has to be eliminated as an alternative for all records.

Alternative	Sample record	Weighted Sum	Multiplication	WS Average	Mult. Average
Nintendo SNES ZSNES 1.51	Super Mario World Starfox	3,4511 3,3751	2,7506 2,7799	3,4131	2,7652
Nintendo SNES MESS 0.119	Super Mario World Starfox	3,5531 2,4745	2,8843 0,0000	3,0138	1,4422
NEC PCEngine MagicEngine 1.0.0.	Bonks Revenge Gates of Thunder	3,5159 3,4699	2,7406 2,7455	3,4929	2,7430
NEC PCEngine MESS 0.119	Bonks Revenge Gates of Thunder	3,8769 2,6070	3,2977 0,0000	3,2420	1,6489
Sega Mega Drive Gens32 1.76	Sonic the Hedgehog 2 Darxide	3,5754 3,5194	2,9349 2,8593	3,5474	2,8971
Sega Mega Drive Kega Fusion 3.51	Sonic the Hedgehog 2 Darxide	3,4704 3,4594	2,7991 2,7842	3,4649	2,7917
SNK Neo Geo NeoCD 0.3.1	Metal Slug Crossed Swords 2	1,8350 3,0213	0,0000 2,3540	2,4282	1,1770
SNK Neo Geo Nebula 2.25b	Metal Slug Crossed Swords 2	3,4604 2,4315	2,8195 0,0000	2,9460	1,4097

Table 4.5: Aggregated experiment results for preserving games of the 16-bit generation of console video games.

4.11.2 Comparison of alternatives for different console systems of the same era

Based on the results of the comparison of emulators for the Nintendo SNES we evaluated more systems from the 16-bit era. For the experiments one dedicated and one multi-system emulator for every system where chosen with one game utilizing only the standard hardware of the system and a second sample that uses additional add-ons. The results are listed in Table 4.5.

The sample records chosen presented the following challenges to the preservation alternatives: two games used special 3D hardware on the cartridge (*Starfox*) or as an additional accessory for the system (Sega 32X needed by *Darxide*). *Gates of Thunder* and *Crossed Swords 2* were games using the CD enhancements of the respective system.

The differences and similarities that have been observed for the main categories:

Object Characteristics MagicEngine is able to emulate the tested sample records for the NEC PCEngine nearly perfectly. While the results for Bonks Revenge where very good with MESS as well, Gates of Thunder was not interpretable by the emulator due to lack of support for the CD add-on.

The results for emulating the Sega Mega Drive games with Gens32 and Kega Fusion where very well with slight errors on background scrolling for Sonic the Hedgehog 2. Both emulators also emulated the hardware add-on needed for Darxide and produced flawless 3D graphics.

Like discussed in the previous experiments ZSNES was able to emulate Super Mario World as well as Starfox almost perfectly. MESS does not emulate the special hardware used by Starfox and has severe errors on Super Mario World.

Metal Slug was emulated perfectly by Nebula but not supported by NeoCD. While the CD add-on was supported by Nebula the emulator crashed after the menu screen. NeoCD was able to emulate the game with severe errors in 2D layer calculation.

Context and Data Characteristics All evaluated emulators support only byte streams or original media and no encapsulated data.

Process Characteristics Starting games through the emulator is limited to the user interface by MagicEngine, NeoCD and ZSNES. All the other tested emulators can also be invoked with a game supplied on the command line. Apart from NeoCD all emulators offer configuration files to set global settings. All but MagicEngine and MESS use auto-detection for game settings.

Infrastructure Emulation is done by recreating the original systems on a hardware-component level in every case. The systems BIOS was needed for the emulators of the SNK Neo Geo as well as for most of the hardware add-ons (Neo Geo CD and 32X). The MagicEngine is able to start CDs without the BIOS probably through higher level emulation (source code not available).

MESS and Neo CD are the only emulators with source code publicly available and are both using a modular design with MESS also supporting different systems. Kega Fusion supports earlier generation Sega systems as well while Nebula supports arcade game hardware (Capcom CPS) besides the Neo Geo console games.

MagicEngine is the only commercial emulator tested and in steady development since 1997. All other emulators are non-commercial products with no new releases for NeoCD and Kega Fusion in the last years.

Games on original media (CDs) are supported by MagicEngine, Nebula and NeoCD.

Costs The costs per record are best for games for the PCEngine system, as its media can inexpensively be preserved. MESS has slightly better results as the dedicated emulators as games from other systems are supported as well. While Kega Fusion supports more systems than Gens32 the increase in supported games is not very large, so the costs

Alternative	Sample record	Weighted Sum	Multiplication	WS Average	Mult. Average
Coleco Telstar Pong 6.0	Tennis	2,9149	2,0933	2,9149	2,0933
Coleco Telstar PEmu	Tennis	2,8249	2,0737	2,8249	2,0737
Philips G7000 O2EM 1.18	K.C. Munchkin Quest for the Rings	3,4394 3,3843	2,8874 2,8241	3,4119	2,8558
Philips G7000 MESS 0.119	K.C. Munchkin Quest for the Rings	3,5959 3,5236	2,9717 2,8938	3,5597	2,9328
Sega MasterSystem Dega 1.12	Alex Kidd in Miracle World Space Harrier 3D	3,4599 3,3389	2,8311 2,7370	3,3994	2,7840
Sega MasterSystem Kega Fusion 3.51	Alex Kidd in Miracle World Space Harrier 3D	3,5354 3,3354	2,8611 2,6399	3,4354	2,7505
Nintendo SNES ZSNES 1.51	Super Mario World Starfox	3,4511 3,3751	2,7506 2,7799	3,4131	2,7652
Nintendo SNES MESS 0.119	Super Mario World Starfox	3,5531 2,4745	2,8843 0,0000	3,0138	1,4422
Atari Jaguar Project Tempest 0.95	Doom Highlander	2,9469 2,3386	2,1746 0,0000	2,6428	1,0873
Atari Jaguar MESS 0.119	Doom Highlander	3,1005 2,3441	2,5120 0,0000	2,7223	1,2560
Sony PS2 PCSX2 0.9.2	Gran Turismo 3 EyeToy Play	2,8535 2,7190	0,0000 0,0000	2,7862	0,0000

Table 4.6: Aggregated experiment results for preserving games for systems of all generations of console video games.

are similar. NeoCD has the lowest aggregated value for costs as only a fraction of the systems games are supported by limiting it to read only CDs.

Overall the results for the other systems in the 16-bit generation were comparably to the results for Nintendo SNES emulation. While the standard games were fully playable on all systems, the tested CD games of this era were not supported or not interpretable by the multi-system emulators. For the Neo Geo CD games a dedicated emulator was tested but failed to adequately emulate the tested game. Emulation quality of the games was high and controllers resembling the look and feel of the original controllers are available for personal computer systems. The results for costs were better for multi-system emulators and systems with media that can be read without reengineering on a record basis.

4.11.3 Comparison of alternatives for console systems of different eras

The evaluation of a dedicated and a multi-system emulator for one system of each generation resulted in the aggregated values in Table 4.6.

The Pong Era

Systems of this era are the only systems were simulators are available. Two simulators which try to recreate the behavior of the chip found inside the Coleco Telstar have been evaluated. Both where playable but only Pong 6.0 recreated the graphics found on the original system, while PEmu used much higher resolution for the game. While PEmu could be played without errors, the collision detection in Pong 6.0 had errors affecting the gameplay. Pong could be played with a mouse or the keyboard as controller, for PEmu only the keyboard could be used. Both input methods do in no way reflect the gaming experience with the original paddle controllers found on a Coleco Telstar.

None of the simulators is open source or commercially produced and development for both has been stopped.

The First Cartridge Based Video Games

As sample records for the Philips Videopac/Magnavox Odyssey2 *K.C. Munchkin* is a standard game for the system with no special items while *Quest for the Rings* was shipped with a keyboard overlay, a game board and various playing pieces.

Both the dedicated emulator O2EM and the multi-system emulator MESS where able to emulate both games. O2EM is able to emulate the games almost perfectly. The graphics and the sound on both games emulated by MESS have major errors, but the games are still playable.

While the controller is fine for playing K.C. Munchkin, no overlays for the keyboard of the system are supported by any of the emulators, so Quest for the Rings is unplayable without a knowledge of what part of the overlay originally mapped to which key. Also no support for the additional items is available in the two emulators.

Both alternatives are not commercially developed and are open source with little platform dependencies. Media are only supported as byte stream and the layer logic is hard coded into the emulation software. With O2EM having a very little user community and being less stable and scalable as MESS the total score for MESS is higher even if the emulation is much more accurate on O2EM.

The 8-bit Era

For the Sega Master System the game *Alex Kid in Miracle World* was chosen as a standard sample record and *Space Harrier 3D* to test possible realizations of the 3D glasses needed for this game.

While Alex Kidd in Miracle World is nearly perfectly emulated by both emulators evaluated, only Dega offers an option to convert the 3D image into a red/blue image for 2-colored 3D glasses. Other 3D glasses available for personal computers are not supported by the emulators making the game not very well playable.

While the cost factor is higher for Kega as other systems are supported as well, Dega is superior in stability and scalability as it is open source. No new versions have been released for both emulators in the last year.

The 16-bit Era

The results of the experiments for emulators for video game console systems of the 16-bit era are discussed earlier in this section.

The 3D Era

As sample records for the Atari Jaguar *Doom* was selected as it was shipped with overlays to show the use of the buttons on the controller. *Highlander* was a game for the Jaguar CD-add-on.

While Project Tempest is able to emulate Doom nearly perfectly, MESS is able to start it but does not produce a moving image. Highlander starts to load on Project Tempest but crashes the emulator. MESS does not support the CD-add-on for the Atari Jaguar. Overlays are supported by none of the two emulators but are needed for playing Doom.

As Project Tempest is closed source and no longer developed, MESS has higher values for stability and scalability and is also more configurable, which leads to better overall scores for MESS even if the chosen sample games are not playable yet.

The 128-bit Era

For the Sony PlayStation 2 only one emulator was evaluated, as only one is able to play commercial games. The selected games included *Gran Turismo 3* as a standard game and *Eye Toy Play* which uses a camera as an input device.

While the costs and infrastructure values are very high for PCSX 2, as a plug-in system and modular code are used, many games are supported and the original media can be read using standard personal computer hardware, the values for object characteristics are still very low, as the chosen games were not interpretable by the emulator (no in-game graphics were produced) and the emulation speed was very low on the system used for the experiments.

The camera is not supported yet as an input device, but the emulator has support for network protocols and it is already possible to use existing online services for the original console system with it.

4.11.4 Discussing Different Scenarios

In the assumed library approach high importance values were assigned to infrastructure and context characteristics. Even on games where an emulator was far worse than the others in recreating the original gaming experience, this system could be ranked as the best choice if it was not dropped out because single records were not interpretable at all.

Two different scenarios will be discussed in this section and how the change in priorities influences the ranking of alternatives.

Museum Scenario

One thinkable environment different to the evaluated library scenario would be a museum for video games. While the costs would probably play a more crucial role for this approach, only some specimen of games for a system would have to be supported and the ease of selecting and playing properly configured games by an interested public is more important. For this approach a perfect representation of selected games is necessary to go on display.

If the importance factors are set with this scenario in mind and an alternative is not eliminated if single games are not supported multi-system emulators can get better results than dedicated emulators because of their support for different systems and configurability even if compatibility for games is far worse.

For the preservation of the NEC PCEngine the multi-system emulator MESS is rated higher in this scenario than the MagicEngine. It is able to emulate one sample record nearly perfect and represents the original system well.

Game Playing Scenario

From the perspective of a private person who wants to play games now, the long term requirements like stability of an existing alternative are not relevant, so the infrastructure category would be rated very low. Context and data characteristics are not as important as in the library approach either. The games should play just like on the original system, so the object characteristics are of an even higher importance than in the museum scenario.

Multi-system-emulators that were only ranked as the best choice because of their stability and configurability will probably rank on the lower end of the scale in this scenario.

As an example for Nintendo SNES preservation MESS would not be chosen because of the low compatibility. ZSNES or SNES9X are workable alternatives as they present a nice user-interface for game selection and emulate all the sample records for the system very well.

4.12 Chapter Summary

In this chapter the PLANETS preservation planning approach was used to evaluate alternatives for the preservation of console video games. A fictional library scenario was defined as the basis and the necessary goals were outlined. Then games for every system were chosen as sample records. The characteristics of the objects were defined and arranged hierarchically in a tree. Next alternatives were selected for different preservation strategies and a decision was made, which of these alternatives would be considered for the experiments. The experimental set up and the process to measure the object characteristics were described.

The following experiments were carried out. Alternatives for the Nintendo SNES were evaluated to determine the differences between them for one system. Dedicated as well as multi-system alternatives were chosen. Next alternatives for other systems of the 16-bit era were tested, to find out if alternatives for comparable systems achieve similar results. To compare the alternatives for systems of every generation of console video games two options for one system of every era were evaluated.

The experiments were carried out and the results were then transformed to a uniform scale of 0 to 5. Importance factors have been set for all leafs in the requirements tree. The values were then aggregated to a single value for every alternative by using weighted sum and multiplication. Then the alternatives were ranked and the results for the different experiments were analyzed.

Chapter 5

Conclusions

5.1 Results of this Work

In this work an introduction into console video game history as well as work related to digital preservation in general and emulation as a digital preservation strategy was given. The challenges for preserving console video games were outlined and various different preservation strategies have been discussed. Emulation as the most promising strategy was explored in detail and different methods to establish it as a long term strategy were investigated. The use of the Java Virtual Machine as an Emulation Virtual Machine was discussed and the modular approach for developing emulators was examined.

The PLANETS preservation planning approach was used to select digital preservation alternatives for an assumed library environment where console video games were to be archived as digital heritage. Games were selected as sample records for all the video game consoles and a tree with requirements for preserving these records was developed. The various possible alternatives were described and it was discussed, which preservation strategies would be included in the experiments. Experiments were then carried out for comparing emulators for a single console video game system, for different console systems of the same era and for systems of all eras. The measured values were transformed to a unified scale and importance factors were set according to the defined basis. The values have then been aggregated to a single value for each alternative and the results were compared.

From these experiments the following conclusions can be drawn.

5.1.1 Emulation as a Preservation Strategy

The experiments showed that emulation is a successful strategy to interpret game software from obsolete console video game systems on modern computers. While early console video game systems can be emulated fast enough on personal computers of current standards if the software is written in platform independent code, most emulators for systems released after the third era use assembler language for time critical parts of the software to be able to achieve the speed of the original system. None of the emulators tested was using a virtual machine to ensure long term availability of the emulator.

Even popular systems of the first four generations are not 100% emulated today. With systems getting newer the accuracy drops. Of two tested games on two emulators for the Atari Jaguar only one game was playable. Two sample games for the Sony PlayStation 2 that were randomly selected were not playable at all.

The accuracy is also usually higher with dedicated emulators, as those are tweaked to the special features of one system and also support special hardware used on cartridges (e.g. Starfox for Nintendo SNES) or additional add-ons to the system (e.g. CD-add-on for NEC PCEngine). The most popular dedicated emulators for the same system are similar in their abilities to emulate the system and differ only in factors like costs, stability, scalability and process characteristics.

5.1.2 Costs Involved in Preserving Video Games

The media for early video games often were cartridges with special mircochips applied to them. This leads to high costs for preserving media for the systems, as those cartridges have to be re-engineered sometimes on a record basis. Costs for developing an emulator are low because of simple system designs. Todays systems mostly use optical discs that can be read either with standard personal computer hardware or special hardware supplied by the manufacturer. The costs for developing emulators are significantly higher as modern systems have more features that have to be emulated and a much more complex hardware design.

The costs for developing multi-system-emulators are less than for dedicated emulators as components can be shared between systems if the same hardware is used. Multi-system-emulators are more successful for early console games where similar hardware was used and the system design was less complex.

Simulation of games instead of systems was also tested as an alternative. The costs are only reasonable if very few games have to be recreated like on early Pong consoles. For these consoles this seems to be the right approach, as the effort for emulation on a low level would be much higher.

5.1.3 Commercial Development

Most emulators are not commercially developed. Especially dedicated emulators tend to receive little updates and get easily discontinued when the author gets distracted from development, so nearly no emulators in final versions that perfectly emulate all games for a system are available.

Only one of the tested emulators was developed commercially (MagicEngine for NEC PCEngine). The emulation of the system is nearly perfect, but the emulator lacks in the categories stability, scalability and costs. It is apparent that it was written with playing and not preservation in mind, so its use for long term preservation projects would be limited without modifications.

5.1.4 Feel Aspect of Video Games

Controllers are available for personal computers today that resemble most of the standard controllers used on original systems. USB adapters exist to use controllers of the original systems on personal computers. These controllers can be used in most emulators available. Special controllers (light gun, fishing controllers, maracas etc.) used especially in the last two generations of console video games are not supported so far. Controller feedback in any way is also not supported by the tested emulators, which influences the gaming experience for games that rely on force feedback to for example give the player information about getting hit.

Especially in the early generations of console video games overlays for controllers where used for specific games. Some of the games are not playable without the overlays, but as of yet no emulator supports their use in any form. Additional non-digital content like game boards, playing pieces or other items that were supplied with the original games are also not supported by the tested emulators.

5.1.5 Data Encapsulation

All tested emulators support media only as byte-streams or as original media (optical discs). Various private initiatives exist to label files with as much meta data as possible in the file name or create data files for byte-stream managing tools (e.g. TOSEC[1], No-Intro preservation society[2]). Information about the logical layout of the data inside the byte-stream as well as support

[1] http://tosec.org/

[2] http://www.gbadat.altervista.org/

for hardware on the physical media is also hard-coded in all emulators and not connected to the respective media.

To use emulation for digital preservation purposes metadata would have to be connected to the byte-streams supported by emulators. Currently none of the emulators supports metadata or encapsulated byte streams.

5.2 Future Work

This section is lining out some ideas for future work on the subject of console video games and video games in general that would have to be researched.

5.2.1 Encapsulation Schema

All emulators today support media only as a binary data stream. A schema should be developed which allows to encapsulate metadata and context information. The schema should be general enough to support not only console video games but also all other types of video games. At least the data defined in the requirements in Chapter 4 has to be included.

Different alternatives for using records with encapsulated data are possible:

- Adding support for encapsulated data to existing emulators.
- Developing a framework that is able to extract the encapsulated binary data stream and invoke the supposed target application (=emulator) with the appropriate system parameters.

5.2.2 Emulation of Special Controllers/Items

The recreation of special controllers is not solved satisfying in current emulators. This is getting a pressing issue with console video game systems of the last two generations as lots of games are using purpose-built controllers to separate the console video games from games on personal computers or resemble games known from arcades. With the success of the motion sensitive controls developed for the Nintendo Wii as standard controller, the trend away from ordinary joysticks could continue.

A strategy will have to be developed how to recreate the gaming experience of these special controllers.

5.2.3 Non-Console Video Games

While this work listed challenges and possible answers to the questions of digital preservation of console video games, all other types of video games have to be researched as well. Some of the challenges different to that of console video games are:

Hand Held Systems

Most of the aspects (e.g. media, closed specifications) for console video games also apply for hand held systems. The big difference is the use of controllers as the system itself is the controller. Recreating the gaming experience on a desktop system is even more difficult than for console video game systems. With systems like the *Nintendo DS* having two touch screens and motion detection on certain cartridges additional aspects are brought into effect.

Arcade Games

Especially early arcade games were using proprietary hardware for each game. The systems specifications were closed like with console video game systems and games were stored on ROM-chips applied to the printed circuit boards (PCBs). For recreation re-engineering would be necessary for every game, even if similar hardware is used on the boards, the costs per game are much higher than for console video games for arcade games of this era.

Later arcade games used console-like systems with media like cartridges, Gigabyte-Discs, hard-drives) and the same challenges as for the preservation of console video games apply.

Current arcade games are using special controls (e.g. sit-in controls with movement) which are difficult to recreate. The same challenges as with special controllers for console video game systems exist.

Home Computers

Most of the rules applied to early console video games also apply to home computers. Unlike for console systems the technical specifications for home computers were publicly available to encourage home development.

Games were often distributed on cartridges as well as on media like floppy discs or tapes (e.g. Atari 800XL, Commodore C64, Philips MSX). While the problems for preserving cartridges are the same as with console systems, floppy discs and tapes can be read without special hardware.

To use the requirements tree developed in this work also for preservation planning for home computer gaming some research of aspects concerning these systems would have to be done and the tree would have to be expanded or altered.

Personal Computers

While the hardware and operating system used for a console video game is fixed to a very specific system specification that does not change over time, the advancement in personal computer hardware is a continuous process. A certain video game has to support different kinds of hardware (e.g. amount of memory, graphics hardware, sound hardware, processing speed) and software (e.g. different releases of an operating system, other unknown programs running on the same machine, different drivers for hardware).

Other than with console video game systems the specifications for personal computer hardware is public knowledge. Media are also readable on standard drives instead of proprietary hardware.

One possible approach to the preservation of personal computer video games would be reference systems with a defined set of hardware and software which is specified to run a certain set of video games. A set like this could also be emulated. An approach into that direction is the Dioscuri project described in Section 2.2.5.

Mobile Games

Gaming on mobile devices (e.g. cell phones, digital cameras) can be compared to games on hand held systems concerning the controls. Depending on the device either a Java Virtual Machine or proprietary software for the specific device is used for games. The aspects concerning this devices would have to be researched.

Internet Based Games

Games based on online worlds (e.g. *Second Life* (Linden Research Inc.)) have to be preserved differently than other types of video games, as content can be created online by players. It would have to be researched to what extend this content has to be digitally preserved or if only the gaming environment has to be saved for future use.

5.2.4 Emulation Virtual Machine

As outlined in Section 3.3.1 the Java Virtual Machine is not a very stable virtual machine as it is constantly changing to new releases. A dedicated emulation virtual machine would have to be specified and developed to ensure long term preservation without having to port emulators to a new virtual machine constantly.

5.2.5 Responsibility and Awareness

Currently no official preservation projects for console video games are known. No government institutions are responsible for the preservation of console video games. Manufacturers are not responsible for making sure that their products are preserved either. As the video game business is very unstable, companies are going out of business all the time and material valuable for preservation gets lost.

With the legal situation concerning emulation it is not possible to digitally preserve video games using emulators and copying media to different physical layers without the manufacturers agreement. Awareness has to be raised at the manufacturers of console video game systems and console video games to reach agreements about how to preserve their work.

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Appendix A

Console Video Game System Overview

This appendix gives an overview of some of the facts for console video game systems. The number of units sold is not publicly available for all systems and are only approximate numbers. The number of released games is an approximated number of games released until September 2007. The information in this appendix was collected from [For05], [Her01] and system publishers official websites.

A timeline with the release years of the systems can be seen in Figure A.1.

Company	**System**	**released**	**media**	**compatibility to other console systems**	**approx. units sold (million)**	**approx. number of games**
Magnavox	Odyssey	1972	built-in ROM, unlocked with cartridges		0,3	28
Atari	Pong	1974	built-in ROM		unknown	1
Coleco	Telstar	1976	built-in ROM		1	3
Fairchild/Saba	Channel F/Videoplay	1976	ROM-Cartridge		unknown	30
Atari	Atari 2600	1977	ROM-Cartridge		30	500
Magnavox/Philips	Odyssey 2/Videopac G7000	1978	ROM-Cartridge		2	80
Mattel	Intellivision	1980	ROM-Cartridge	Atari 2600 (accessory)	3	150
Coleco	Colecovision	1982	ROM-Cartridge	Atari 2600 (accessory)	6	100
Atari	Atari 5200	1982	ROM-Cartridge	Atari 2600 (accessory)	unknown	70
Nintendo	Nintendo Entertainment System (NES)/Famicom	1983	ROM-Cartridge		62	1200
Sega	Master System	1983	ROM-Cartridge		13	300
Atari	Atari 7800	1986	ROM-Cartridge	Atari 2600 (hardware compatible)	unknown	60
NEC	PCEngine/TurboGrafx 16	1987	HuCard / CD		10	600
Sega	Genesis/Mega Drive	1988	ROM-Cartridge / CD	Sega Master System (accessory)	35	900
Nintendo	Super Nintendo Entertainment System (SNES)/Super Famicom	1990	ROM-Cartridge / Satellite		50	1400
SNK	Neo Geo	1990	ROM-Cartridge / CD		1	110

Table A.1: Overview of console video game system facts for systems of the 1st to 4th era.

Company	System	released	media	compatibility to other console systems	approx. units sold (million)	approx. number of games
3DO	3DO	1993	CD		6	170
Atari	Jaguar	1993	ROM-Cartridge / CD		2	60
Sega	Saturn	1994	CD / on-line		10	1200
Sony	PlayStation	1994	CD / on-line		100	3000
Nintendo	Nintendo 64	1996	ROM-Cartridge		33	400
Sega	Dreamcast	1998	GD / on-line		10	400
Sony	PlayStation 2	2000	DVD / on-line	Sony PlayStation 1 (software emulation)	120	8000
Microsoft	XBOX	2001	DVD / on-line		24	1000
Nintendo	Gamecube	2001	Mini-DVD		22	350
Microsoft	XBOX360	2005	DVD / on-line	Microsoft XBOX (software emulation)	10	100
Nintendo	Wii	2006	DVD / on-line	Nintendo Gamecube (hardware compatible)	10	60
Sony	Playstation 3	2006	DVD / Blue-ray / on-line	Sony PlayStation 1 and Sony PlayStation 2 (software and hardware emulation)	5	100

Table A.2: Overview of console video game system facts for systems of the 5th to 7th era.

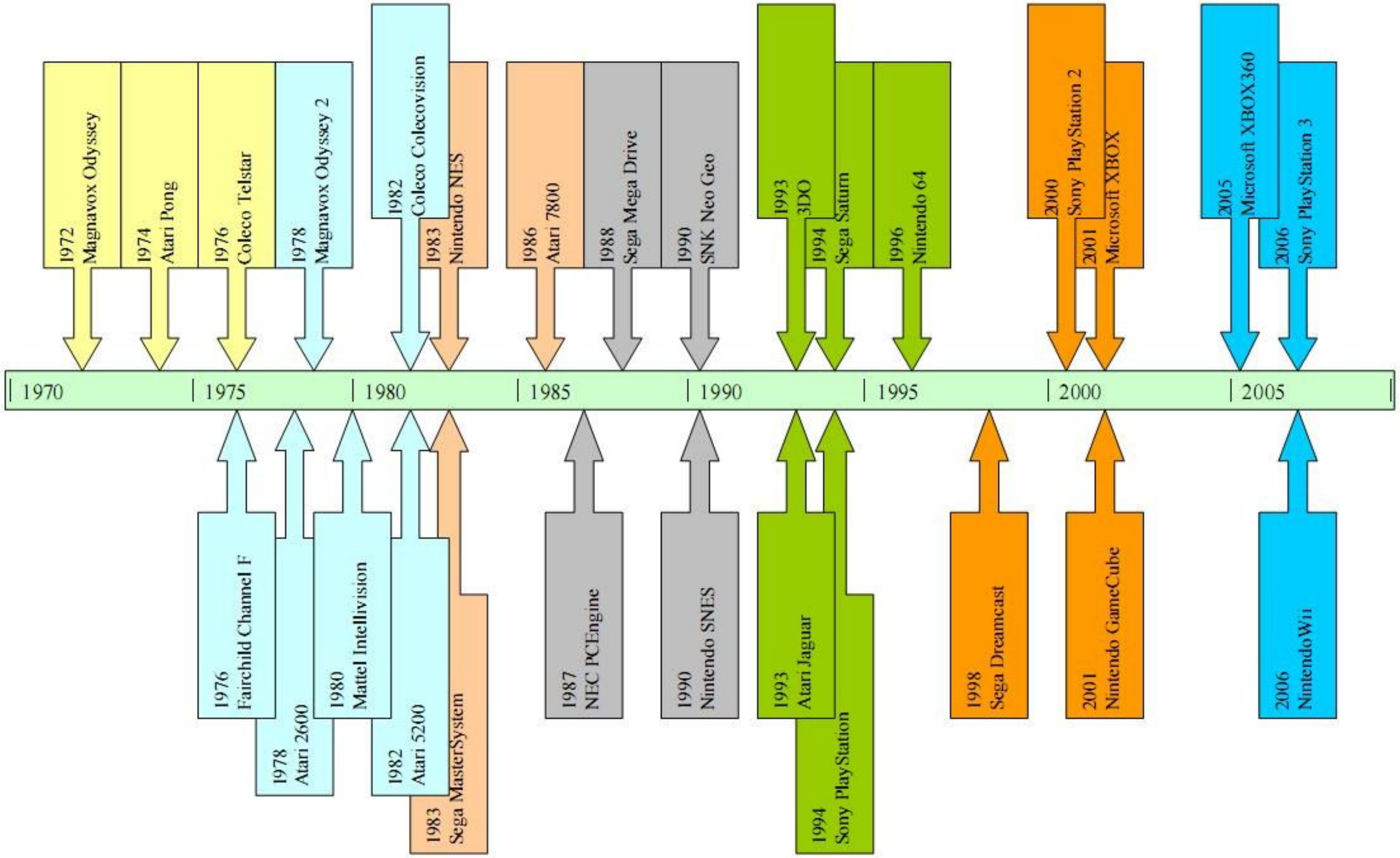

Figure A.1: Timeline of release years for console video game systems. Systems of the same era are shown in the same color.

Appendix B

Selected Sample Records

This appendix lists sample records for the systems described in Section 2.1. The games have been selected using the criteria defined in Section 4.2. Every game is listed with the company that originally published the game.

The first game listed for every system is the popular game without extras. The second is the one that uses a special controller or overlays. A game that uses special hardware extensions or that was released late in the life cycle of the system is listed as third game.

If a sample record is not applicable for a system it is listed as “n/a” (not applicable).

System	Game (Publisher)	comment/necessary accessory
	The Pong Era	
Magnavox Odyssey	Table Tennis	
	Baseball	screen overlays
	Shooting Gallery	light gun controller
Atari Pong	Pong	
	n/a	only one built-in game
	n/a	only one built-in game
Coleco Telstar	Tennis	
	n/a	only built-in games
	n/a	only built-in games
	The First Cartridge Based Video Games	
Fairchild Channel F/Saba Videoplay	Hockey (Fairchild)	built-in game
	n/a	no games with special controllers
	Chess (Saba)	additional processing hardware on the cartridge
Atari 2600	Pac-Man (Atari)	
	Indy 500 (Atari)	paddle controllers
	Communist Mutants from Space (Starpath)	*Supercharger* accessory
Magnavox Odyssey 2/Philips Videopac G7000	K.C. Munchkin (Magnavox)	
	Quest for the Rings (Magnavox)	game board, playing pieces, keyboard overlay
	Chess (Philips)	additional Z80 processing unit on cartridge

Mattel Intellivision	Q*Bert (Parker Bros.)	
	NBA Basketball (Mattel)	controller overlays
	TRON Solar Sailer (Mattel)	*Intellivoice* speech synthesizes accessory
Coleco Colecovision	Donkey Kong (CBS)	
	Turbo (CBS)	driving controller (*Expansion Module #2*)
	Alcazar the Forgotten Fortress (Telegames, Inc.)	one of the last games released 1986
Atari 5200	Montezuma's Revenge (Parker Brothers)	
	Centipede (Atari)	controller overlays
	Rescue on Fractalus (Atari/Lucasfilm Games)	one of the last released games
The 8-bit Era		
Nintendo Entertainment System (NES)/Famicom	Super Mario Bros. (Nintendo)	
	World Class Track Meet (Nintendo)	fitness mat (*Power Pad*) controller
	Castlevania III (Konami)	special sound and memory mapping chip on cartridge (Japanese version)
Sega Master System	Alex Kidd in Miracle World (Sega)	built into some console revisions
	Space Harrier 3D (Sega)	3D glasses
	Sonic Blast (TecToy)	The last game released for the Sega Master System released in Brazil in 1997
Atari 7800	Asteroids (Atari)	built into the European console system
	(n.a.)	no games used special controllers or overlays
	Ballblazer (Atari/Lucasfilm Games)	additional sound chip on the cartridge
The 16-bit Era		
NEC PCEngine/TurboGrafx 16	Bonk's Revenge (NEC)	
	(n.a.)	no games used special controllers or overlays
	Gates Of Thunder (Hudson)	CD-add-on accessory
Sega Genesis/Mega Drive	Sonic the Hedgehog 2 (Sega)	
	Lethal Enforcers (Konami)	light gun controller
	Darxide (Sega)	*Sega 32X* accessory for enhanced graphics capabilities
Super Nintendo Entertainment System (SNES)/Super Famicom	Super Mario World (Nintendo)	
	Super Scope 6 (Nintendo)	light gun controller shaped like a rocket launcher
	Starfox (Nintendo)	special co-processing chip (SuperFX-chip) on the cartridge
SNK Neo Geo	Metal Slug (SNK)	
	n/a	no games used special controllers or overlays
	Crossed Swords 2 (SNK)	game for the CD-version of the system
The 3D Era		
3DO Interactive Multiplayer	Need For Speed (Electronic Arts)	
	Mad Dog II - The Lost Gold (Amer Lasergames)	light gun controller
	Star Fighter (3DO)	one of the last games released in 1996
Atari Jaguar	Tempest 2000 (Atari)	
	Doom (Atari)	controller overlays
	Highlander (Atari)	CD-add-on accessory
Sega Saturn	Virtua Fighter 2 (Sega)	
	Densha de GO! EX (Taito)	Japanese train simulation with controller shaped like a train control system
	Metal Slug (SNK)	memory expansion cartridge

Sony PlayStation	Gran Turismo (Sony)	
	Dance Dance Revolution (Konami)	dance mat controller
	Rayman 2: The Great Escape (Ubisoft)	one of the more advanced games released in 2000
Nintendo 64	Super Mario 64 (Nintendo)	
	Hey You, Pikachu! (Nintendo)	*Microphone Pak* for communication with the game character
	Donkey Kong 64 (Rare)	*Expansion Pak* memory expansion unit
The 128-bit Era		
Sega Dreamcast	Sonic Adventure (Sega)	
	Samba De Amigo (Sega)	maracas controllers using ultrasonic senders and a receiver on the floor to determine the position of the maracas
	Phantasy Star Online Vers. 2 (Sega)	online based role playing game, does no longer work in online mode on the original system as the servers have been turned off
Sony PlayStation 2	Gran Turismo 3 A-Spec (Sony)	
	EyeToy (Sony)	motion detection through a camera is used to control the game, the players picture is projected into the game picture and the player has to "touch" game objects on the screen
	Kingdom Hearts 2 (Square Enix)	one of the last games released for the system
Microsoft XBOX	HALO 2 (Bungie Studios)	
	The House Of The Dead 3 (Sega)	light gun controller
	Black (Criterion Games)	one of the last games released for the system
Nintendo GameCube	Super Mario Sunshine (Nintendo)	
	Donkey Konga (Nintendo)	controller shaped like bongos to tap the rhythm given by the game
	The Legend of Zelda: Twilight Princess (Nintendo)	last game released for the system, released parallel to a version for Nintendo's next generation system Wii
The Next Generation		
Microsoft XBOX 360	Gears of War (Epic Games)	
	Project Gotham Racing 3 (Bizarre Creations)	steering wheel
	Geometry Wars: Retro Evolved (Bizarre Creations)	only available online through the XBOX Live Arcade service
Nintendo Wii	Wii Sports (Nintendo)	
	Boogie (Nintendo)	music/rhythm game which uses the standard Wii controller to record movements and additional Karaoke microphones for singing
	Virtual Console: Super Mario 64 (Nintendo)	online on the Virtual Console channel as a software emulation of the original Nintendo 64 game
Sony PlayStation 3	Resistance: Fall of Man (Insomniac Games)	
	Guitar Hero 3 - Legends of Rock (Activision)	guitar shaped controller
	Gran Turismo HD (Sony)	only available over the PlayStation 3 online network

Table B.1: Sample records that have been selected for every system.

Appendix C

Console Video Games Requirements Tree

The requirement tree of objectives for preserving console video games is shown in Figure C.1. Importance Factors are noted in brackets on the relevant leafs.

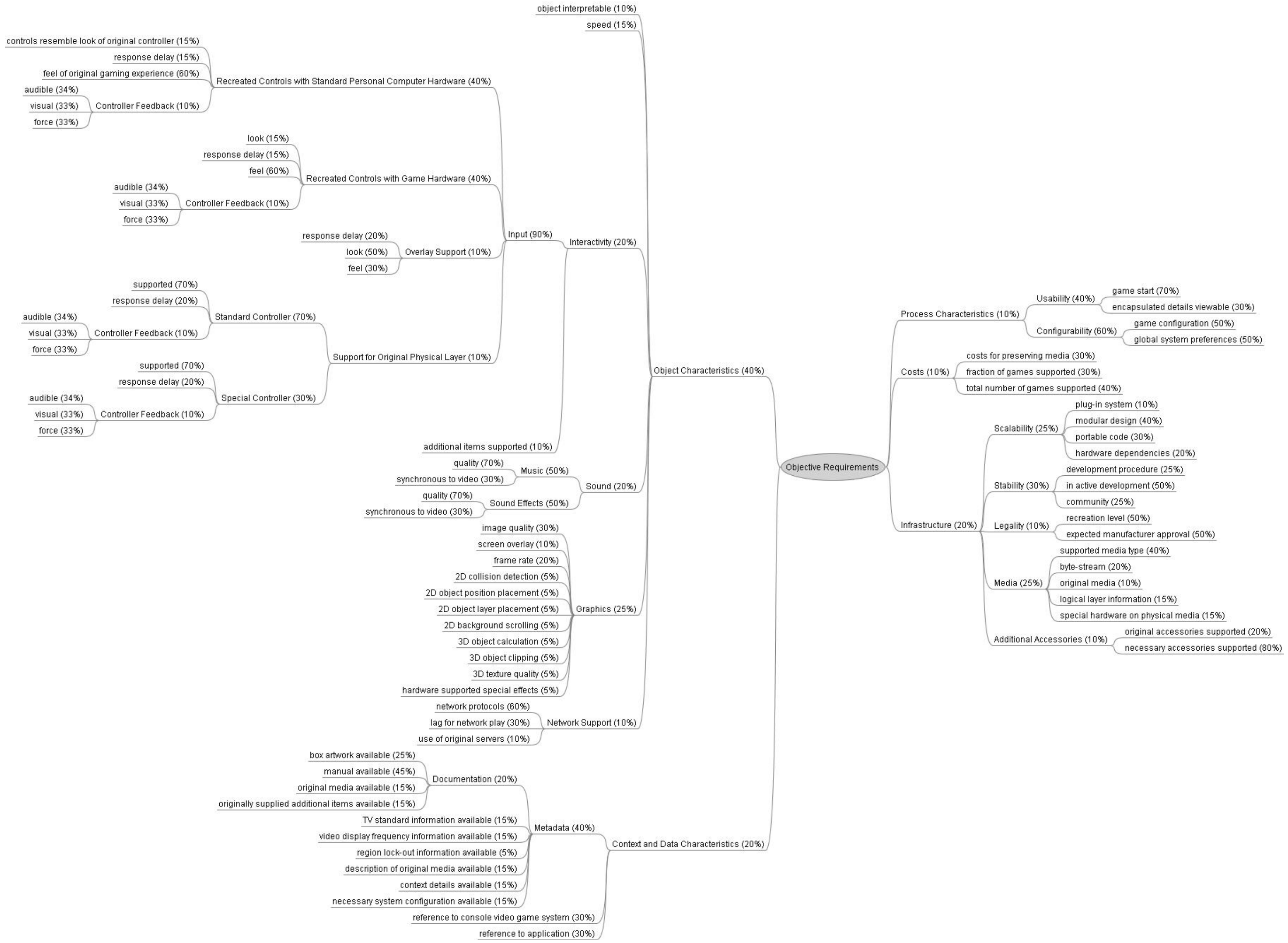

Figure C.1: Requirements tree of console video games with importance factors on leafs and nodes.

Appendix D

Selected Alternatives for Preservation Planning

This appendix includes the various different alternatives selected for the preservation planning process outlined in Chapter 4.

Company	**System**	**backwards compatible system**
Sony	PlayStation	Sony PlayStation 3
Sony	PlayStation 2	Sony PlayStation 3
Microsoft	XBOX	XBOX360
Nintendo	Gamecube	Wii

Table D.1: Console video game systems supported by backwards compatibility.

Company	**System**	**Name**	**Version**	**Release Date**	**Homepage**	**Platform**	**Commercial**	**Open Source**
Coleco	Telstar	Pong	6.0	1997	not available	Windows 32bit	No	No
Coleco	Telstar	Pemu	not available	not available	not available	Windows 32bit	No	No

Table D.2: Simulators for console video game systems.

Company	System	Name	Version	Release Date	Homepage	Platform	Com-mercial	Open Source
Magnavox	Odyssey	Odyemu	RC5	1999-11-29	http://www.pong-story.com/odyemu.htm	Win32	No	No
Fairchild/Saba	Channel F/Videoplay	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Atari	Atari 2600	Stella	0.4.1	2007-08-27	http://stella.sourceforge.net/	multi	No	Yes
Atari	Atari 2600	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Magnavox/Philips	Odyssey 2/Videopac G7000	O2EM	1.18	2007-01-15	http://o2em.sourceforge.net/	multi	No	Yes
Magnavox/Philips	Odyssey 2/Videopac G7000	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Mattel	Intellivision	Bliss	2.0.5	2005-05-25	http://bliss.kylesblog.com/	Win32	No	No
Mattel	Intellivision	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Coleco	Colecovision	Koleko	1.33	2002-10-26	unavailable	Win32	No	No
Coleco	Colecovision	Meka	0.72	2007-05-17	http://www.smspower.org/meka/	multi	No	Yes
Atari	Atari 5200	kat5200	0.4.1	2006-08-23	http://home.cfl.rr.com/jberlin/kat5200/	Win32, Linux i386	No	No
Atari	Atari 5200	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Nintendo	Nintendo Entertainment System (NES)/Famicom	Nestopia	1.37	2007-05-20	http://sourceforge.net/projects/nestopia/	multi	No	Yes
Nintendo	Nintendo Entertainment System (NES)/Famicom	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Sega	Master System	Dega	1.12	2004-04-14	http://www.finalburn.com/dega/index.html	multi	No	Yes
Sega	Master System	Kega Fusion	3.51	2006-01-06	http://www.eidolons-inn.net/tiki-index.php?page=Kega	Win32	No	No
Atari	Atari 7800	EMU7800	0.81	2007-02-28	http://emu7800.sourceforge.net/	Win32	No	Yes
Atari	Atari 7800	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes

Table D.3: Emulators for console video game systems 1st to 3rd era.

Company	**System**	**Name**	**Version**	**Release Date**	**Homepage**	**Platform**	**Commercial**	**Open Source**
NEC	PCEngine/TurboGrafx 16	MagicEngine	1.0.0 PR10	2005-04-01	http://www.magicengine.com/	Win32/Mac	Yes	No
NEC	PCEngine/TurboGrafx 16	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Sega	Genesis/Mega Drive	Gens32	1.76	2007-09-02	http://gens32.emubase.de/		No	No
Sega	Genesis/Mega Drive	Kega Fusion	3.51	2006-01-06	http://www.eidolons-inn.net/tiki-index.php?page=Kega	Win32	No	No
Nintendo	Super Nintendo Entertainment System (SNES)/Super Famicom	ZSNES	1.51	2007-01-24	http://www.zsnes.com/	multi	No	Yes
Nintendo	Super Nintendo Entertainment System (SNES)/Super Famicom	SNES9X	1.51	2007-05-01	http://www.snes9x.com/	multi	No	Yes
Nintendo	Super Nintendo Entertainment System (SNES)/Super Famicom	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
SNK	Neo Geo	NeoCD	0.3.1	2004-05-14	http://pacifi3d.retrogames.com/neocdsdl/	multi	No	Yes
SNK	Neo Geo	Nebula	2.25b	2007-02-18	http://nebula.emulatronia.com/	Windows	No	No
3DO	3DO	FreeDO	1.9	2007-01-03	http://www.freedo.org/	multi	No	No
3DO	3DO	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Atari	Jaguar	Project Tempest	0.95	2004-02-13	http://pt.emuunlim.com/	Win32	No	No
Atari	Jaguar	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Sega	Saturn	SSF	0.09	2007-09-17	http://www7a.biglobe.ne.jp/phantasy/ssf/index.html		No	No
Sega	Saturn	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Sony	PlayStation	ePSXe	1.6.0	2003-08-05	http://www.epsxe.com/	Win32, Linux i386	No	No
Sony	PlayStation	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Nintendo	Nintendo 64	Project64	1.7	2007-04-28	http://www.pj64-emu.com/	Win32	No	No
Nintendo	Nintendo 64	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes

Table D.4: Emulators for console video game systems 4th and 5th era.

Company	**System**	**Name**	**Version**	**Release Date**	**Homepage**	**Platform**	**Com-mercial**	**Open Source**
Sega	Dreamcast	Chankast	0.25	2004-07-07	http://chanka.emulatronia.com/	Win32	No	No
Sega	Dreamcast	MESS	0.119	2007-09-16	http://www.mess.org/	multi	No	Yes
Sony	PlayStation 2	PCSX2	0.9.2	2007-09-05	http://www.pcsx2.net/	multi	No	Yes
Microsoft	XBOX	cxbx	0.8.0-pre2	2004-09-06	http://sourceforge.net/projects/cxbx/	Win32	No	Yes
Nintendo	Gamecube	Dolphin	1.0.3.2	2006-04-23	http://www.dolphin-emu.com/	WIn32	No	No

Table D.5: Emulators for console video game systems of 6th era.

Appendix E

Evaluation Results

This appendix includes the results of the experiments conducted and described in Chapter 4. Separate tables for the experiments for systems of the 16-bit era and systems of all other eras and for the main categories in the requirements tree are listed. The different experiments are consecutively numbered like described in Table E.1

Number	System	Alternative	Sample record
1	Nintendo SNES	ZSNES 1.51	Super Mario World
2	Nintendo SNES	ZSNES 1.51	Super Scope 6
3	Nintendo SNES	ZSNES 1.51	Starfox
4	Nintendo SNES	SNES9X 1.51	Super Mario World
5	Nintendo SNES	SNES9X 1.51	Super Scope 6
6	Nintendo SNES	SNES9X 1.51	Starfox
7	Nintendo SNES	MESS 0.119	Super Mario World
8	Nintendo SNES	MESS 0.119	Super Scope 6
9	Nintendo SNES	MESS 0.119	Starfox
10	Nintendo SNES	video approach	Super Mario World
11	NEC PCEngine	MagicEngine 1.0.0.	Bonks Revenge
12	NEC PCEngine	MagicEngine 1.0.0.	Gates of Thunder
13	NEC PCEngine	MESS 0.119	Bonks Revenge
14	NEC PCEngine	MESS 0.119	Gates of Thunder
15	Sega Mega Drive	Gens32 1.76	Sonic the Hedgehog 2
16	Sega Mega Drive	Gens32 1.76	Darxide
17	Sega Mega Drive	Kega Fusion 3.51	Sonic the Hedgehog 2
18	Sega Mega Drive	Kega Fusion 3.51	Darxide
19	SNK Neo Geo	NeoCD 0.3.1	Metal Slug
20	SNK Neo Geo	NeoCD 0.3.1	Crossed Swords 2
21	SNK Neo Geo	Nebula 2.25b	Metal Slug
22	SNK Neo Geo	Nebula 2.25b	Crossed Swords 2
23	Coleco Telstar	Pong 6.0	Tennis
24	Coleco Telstar	PEmu	Tennis
25	Philips G7000	O2EM 1.18	K.C. Munchkin
26	Philips G7000	O2EM 1.18	Quest for the Rings
27	Philips G7000	MESS 0.119	K.C. Munchkin
28	Philips G7000	MESS 0.119	Quest for the Rings
29	Sega MasterSystem	Dega 1.12	Alex Kidd in Miracle World
30	Sega MasterSystem	Dega 1.12	Space Harrier 3D
31	Sega MasterSystem	Kega Fusion 3.51	Alex Kidd in Miracle World
32	Sega MasterSystem	Kega Fusion 3.51	Space Harrier 3D
33	Atari Jaguar	Project Tempest 0.95	Doom
34	Atari Jaguar	Project Tempest 0.95	Highlander
35	Atari Jaguar	MESS 0.119	Doom
36	Atari Jaguar	MESS 0.119	Highlander
37	Sony PS2	PCSX2 0.9.2	Gran Turismo 3
38	Sony PS2	PCSX2 0.9.2	EyeToy Play

Table E.1: Numbering of experiments for evaluation results.

Alternative		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Requirement	Unit																						
Object Characteristics																							
object interpretable																							
	Y	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		X	X	
	N									X					X					X			X
speed																							
	deviation in percent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interactivity																							
Input																							
Recreated Controls with Standard Personal Computer Hardware																							
controls resemble look of original controller																							
	no controls supported										X												
	Y																						
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
response delay																							
	not applicable									X	X				X					1			1
	considerable delay																						
	short delay	X	X	X	X	X	X	X	X														
	delay not noticeable											X	X	X		X	X	X	X		X	X	
feel of original gaming experience																							
	unplayable									X	X				X					X			X
	fairly playable																				X		
	well playable	X	X	X	X	X	X	X	X			X	X	X		X	X	X	X			X	
	perfectly recreated																						
Controller Feedback																							
audible																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
visual																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
force																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
Recreated Controls with Game Hardware																							
look																							
	controllers resembling original controller not available		X			X			X		X												
	controllers resembling original controller not supported																						
	controllers resembling original controller supported	X		X	X		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
response delay																							

	not applicable									X	X				X					X			X
	considerable delay		X			X			X														
	short delay	X		X	X		X	X															
	delay not noticeable											X	X	X		X	X	X	X		X	X	
feel																							
	controllers resembling original controller not available		X			X			X		X												
	controllers resembling original controller not supported																						
	controllers resembling original controller supported	X		X	X		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
Controller Feedback																							
audible																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
visual																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
force																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
Overlay Support																							
response delay																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	considerable delay																						
	short delay																						
	delay not noticeable																						
look																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported but necessary for game play																						
	not supported and not necessary for game play																						
	supported but not necessary for game play																						
	supported and necessary for game play																						
feel																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	not usable																						
	usable																						
Support for Original Physical Layer																							
Standard Controller																							
supported																							
	not supported										X												
	supported with special hardware	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
	supported without special hardware																						
response delay																							
	not applicable									X	X				X					X			X
	considerable delay																						
	short delay																						
	delay not noticeable	X	X	X	X	X	X	X	X			X	X	X		X	X	X	X		X	X	

Controller Feedback																							
audible																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
visual																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
force																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
Special Controller																							
supported																							
	not applicable	X		X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported		X			X			X														
	supported with special hardware																						
	supported without special hardware																						
response delay																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	considerable delay																						
	short delay																						
	delay not noticeable																						
Controller Feedback																							
audible																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
visual																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
force																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
additional items supported																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
Sound																							
Music																							
quality																							
	no music supported									X					X					X			X
	severe errors apparent																						
	errors noticeable																						
	near perfect			X										X									
	like original	X	X		X	X	X	X	X		X	X	X			X	X	X	X		X	X	
synchronous to video																							
	not applicable									X					X					X			X

	severe errors noticeable																						
	small errors noticeable																						
	no errors noticeable	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		X	X	
Sound Effects																							
quality																							
	no sound effects									X					X					X			X
	severe errors apparent																						
	errors noticeable		X			X																	
	near perfect			X			X							X									
	like original	X			X			X	X		X	X	X			X	X	X	X		X	X	
synchronous to video																							
	not applicable									X					X					X			X
	severe errors noticeable																						
	small errors noticeable																						
	no errors noticeable	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		X	X	
Graphics																							
screen overlay																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported manually by loading image																						
	supported by auto-detection																						
	supported through encapsulation																						
frame rate																							
	deviation in percent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
image quality																							
	nothing displayed									X					X					X			X
	severe errors on whole image							X	X												X		
	errors noticeable but do not affect gameplay																						
	near perfect				X	X	X																
	no difference to original noticeable	X	X	X							X	X	X	X		X	X	X	X			X	
2D collision detection																							
	not applicable			X			X			X							X		X				
	no 2D objects displayed														X					X			X
	severe errors																						
	errors noticeable but do not affect gameplay																						
	no errors noticeable	X	X		X	X		X	X		X	X	X	X		X		X			X	X	
2D object position placement																							
	not applicable									X													
	no 2D objects displayed														X					X			X
	severe errors on whole image							X															
	errors noticeable but do not affect gameplay																						
	no errors noticeable	X	X	X	X	X	X		X		X	X	X	X		X	X	X	X		X	X	
2D object layer placement																							
	not applicable																						
	no 2D objects displayed									X					X					X	X		X
	severe errors on whole image							X															
	errors noticeable but do not affect gameplay																						
	no errors noticeable	X	X	X	X	X	X		X		X	X	X	X		X	X	X	X			X	
2D background scrolling																							
	not applicable			X			X										X		X				

	no 2D objects displayed									X					X					X			X
	severe errors on whole image								X							X		X					
	errors noticeable but do not affect gameplay	X			X							X	X	X							X	X	
	no errors noticeable		X			X		X			X												
3D object calculation																							
	not applicable	X	X		X	X		X	X		X	X	X	X	X	X		X		X	X	X	X
	no 3D objects displayed									X													
	severe errors on whole image																						
	errors noticeable but do not affect gameplay																						
	no errors noticeable			X			X										X		X				
3D object clipping																							
	not applicable	X	X		X	X		X	X		X	X	X	X	X	X		X		X	X	X	X
	no 3D objects displayed									X													
	severe errors on whole image																						
	errors noticeable but do not affect gameplay																						
	no errors noticeable			X			X										X		X				
3D texture quality																							
	not applicable	X	X		X	X		X	X		X	X	X	X		X		X		X	X	X	X
	no 3D objects displayed									X					X								
	severe errors on whole image																						
	errors noticeable but do not affect gameplay																						
	no errors noticeable			X			X										X		X				
hardware supported special effects																							
	not applicable											X	X	X		X		X			X	X	
	no objects displayed									X					X					X			X
	severe errors on whole image																						
	errors noticeable but do not affect gameplay																						
	no errors noticeable	X	X	X	X	X	X	X	X		X						X		X				
Network Support																							
network protocols																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						
lag for network play																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not acceptable																						
	acceptable																						
	no differences to original noticeable																						
use of original servers																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																						
	supported																						

Table E.2: Evaluation results for object characteristics for 16-bit systems.

Alternative		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Requirement	Unit																						
Context and Data Characteristics																							
Metadata																							
Documentation																							
box artwork available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
manual available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
original media available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
originally supplied additional items available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
TV standard information available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
video display frequency information available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
region lock-out information available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
description of original media available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
context details available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
necessary system configuration available																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
reference to console video game system																							
	Y										X												
	N	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X

reference to application																							
	not available	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	without system configuration																						
	with system configuration																						

Table E.3: Evaluation results for context and data characteristics for 16-bit systems.

Alternative		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Requirement	Unit																						
Infrastructure																							
Scaleability																							
plug-in system																							
	not available	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
	available, closed specification																						
	available, open specifications										X												
modular design																							
	code not available											X	X			X	X	X	X			X	X
	code not modular				X	X	X																
	code modular and one system supported	X	X	X								X	X							X	X		
	code modular and different systems supported							X	X	X	X			X	X								
portable code																							
	code not available											X	X			X	X	X	X			X	X
	platform dependent code	X	X	X	X	X	X													X	X		
	platform independent code							X	X	X	X			X	X								
	Virtual Machine used																						
hardware dependencies																							
	code not available											X	X			X	X	X	X			X	X
	platform dependent libraries are used	X	X	X							X												
	platform dependent libraries are not used				X	X	X	X	X	X				X	X					X	X		
Stability																							
development procedure																							
	commercial and open source																						
	not commercial but open source	X	X	X	X	X	X	X	X	X	X			X	X					X	X		
	commercial but closed source											X	X										
	not commercial and closed source															X	X	X	X			X	X
in active development																							
	new version in last 3 month							X	X	X		X	X	X	X	X	X						
	new version in last 6 month				X	X	X				X												
	new version in last year	X	X	X																		X	X
	no release in last year																	X	X	X	X		
community																							
	official forum available with more than 200 active users	X	X	X	X	X	X	X	X	X	X			X	X			X	X			X	X
	unofficial forum available with more than 200 active users																						
	official forum available with less than 200 active users											X	X			X	X						
	unofficial forum available with less than 200 active users																						

	no forum available or no active users																			X	X		
Legality																							
recreation level																							
	high level and no BIOS is needed										X												
	low level and no BIOS is needed	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X				
	high level and BIOS is needed																						
	low level and BIOS is needed																X			X	X	X	X
expected manufacturer approval																							
	manufacturer out of business																						
	manufacturer in video game business	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X
	manufacturer no longer in video game business											X	X	X	X								
Media																							
supported media type																							
	not applicable										X												
	neither byte-stream nor original media supported														X					X			
	original media but no byte stream supported												X								X		
	byte stream but no original media supported	X	X	X	X	X	X	X	X	X		X		X		X	X	X	X			X	
	byte stream and original media supported																						X
byte-stream																							
	not applicable										X												
	not supported												X		X					X	X		
	supported as stand-alone file	X	X	X	X	X	X	X	X	X		X		X		X	X	X	X			X	X
	supported encapsulated in file																						
original media																							
	not applicable										X												
	not supported	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	
	supported with special hardware																						
	supported without special hardware												X										X
logical layer information																							
	not applicable	X	X	X	X	X	X	X	X	X	X												
	hard-coded in preservation solution											X	X	X	X	X	X	X	X	X	X	X	X
	plug-in system																						
	encapsulation supported																						
special hardware on physical media																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	hard-coded in preservation solution																						
	plug-in system																						
	encapsulation supported																						

Additional Accessories																							
original accessories supported																							
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X	X	
	not supported																X		X	X			
	supported with special hardware																						X
	supported without special hardware																						
necessary accessories supported																							
	not applicable	X	X	X	X	X	X	X	X	X	X					X		X				X	
	Y												X	X			X		X		X		X
	N														X					X			

Table E.4: Evaluation results for infrastructure for 16-bit systems.

Alternative		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Requirement	Unit																						
Process Characteristics																							
Usability																							
game start																							
	only through user interface	X	X	X	X	X	X					X	X							X	X		
	only through command line																						
	through command line or user interface							X	X	X	X			X	X	X	X	X	X			X	X
encapsulated details viewable																							
	encapsulation not supported	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
	no										X												
	yes																						
Configurability																							
game configuration																							
	menu only											X	X										
	command line	X	X	X	X	X	X	X	X	X				X	X								
	auto-detection by preservation solution															X	X	X	X	X	X	X	X
	configuration file for record																						
	encapsulation in record										X												
global system preferences																							
	menu only																			X	X		
	command line																						
	configuration file	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X

Table E.5: Evaluation results for process characteristics for 16-bit systems.

Alternative		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Requirement	Unit																						
Costs																							
costs for preserving media																							
	media can be read without special hardware or media dumping is not necessary										X		X		X						X		X
	non-optical media, ROM chip directly connected to console cartridge port, readable with a standard chip reader and adapter											X		X									
	optical media not readable in industry standard optical drive, readable with hardware provide by manufacturer																						
	special hardware necessary for reading out the bytestream, additional address switching hardware available on the media which have to be re-engineered on a record-base															X	X	X	X	X		X	
	special hardware necessary for reading out the bytestream, additional processing hardware available on the media which have to be re-engineered on a record-base	X	X	X	X	X	X	X	X	X													
total number of games supported																							
	less than 10																						
	10-100																						
	101-500																			X	X	X	X
	500-2000	X	X	X	X	X	X					X	X			X	X	X	X				
	more than 2000							X	X	X	X			X	X								
fraction of games supported																							
	percent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	40	40	100	100

Table E.6: Evaluation results for costs for 16-bit systems.

Alternative		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Requirement	Unit																
Object Characteristics																	
object interpretable																	
	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
	N														X		
speed																	
	deviation in percent	0	0	0	0	0	0	0	0	0	0	0	0	20	0	98	90
Interactivity																	
Input																	
Recreated Controls with Standard Personal Computer Hardware																	
controls resemble look of original controller																	

	no controls supported																X
	Y																X
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
response delay																	
	not applicable												X	X	X		
	considerable delay															X	X
	short delay						X										
	delay not noticeable	X	X	X	X	X		X	X	X	X	X					
feel of original gaming experience																	
	unplayable												X	X	X	X	X
	fairly playable	X	X														
	well playable			X	X	X	X	X	X	X	X	X					
	perfectly recreated																
Controller Feedback																	
audible																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
visual																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
force																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
	not supported															X	
	supported																
Recreated Controls with Game Hardware																	
look																	
	controllers resembling original controller not available	X	X									X	X	X	X		
	controllers resembling original controller not supported																
	controllers resembling original controller supported			X	X	X	X	X	X	X	X					X	X
response delay																	
	not applicable	X	X		X					X		X	X	X	X		
	considerable delay															X	X
	short delay						X										
	delay not noticeable			X		X		X	X		X						
feel																	
	controllers resembling original controller not available	X	X									X	X	X	X		
	controllers resembling original controller not supported																
	controllers resembling original controller supported			X	X	X	X	X	X	X	X					X	X
Controller Feedback																	
audible																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
visual																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	not supported																
	supported																
force																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
	not supported															X	
	supported																
Overlay Support																	
response delay																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	considerable delay																
	short delay																
	delay not noticeable																
look																	
	not applicable	X	X	X		X		X	X	X	X					X	X
	not supported but necessary for game play				X		X					X		X			
	not supported and not necessary for game play												X		X		
	supported but not necessary for game play																
	supported and necessary for game play																
feel																	
	not applicable	X	X	X		X		X	X	X	X					X	X
	not supported				X		X					X	X	X	X		
	not usable																
	usable																
Support for Original Physical Layer																	
Standard Controller																	
supported																	
	not supported	X	X									X	X	X	X		
	supported with special hardware			X	X	X	X	X	X	X	X					X	X
	supported without special hardware																
response delay																	
	not applicable	X	X									X	X	X	X	X	X
	considerable delay																
	short delay																
	delay not noticeable			X	X	X	X	X	X	X	X		X				
Controller Feedback																	
audible																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
visual																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
force																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	not supported															X	X
	supported																
Special Controller																	
supported																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		

	not supported																X
	supported with special hardware															X	
	supported without special hardware																
response delay																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
	considerable delay															X	
	short delay																
	delay not noticeable																
Controller Feedback																	
audible																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
visual																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
force																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported																
additional items supported																	
	not applicable	X	X	X		X		X	X	X	X	X	X	X	X	X	X
	not supported				X		X										
	supported																
Sound																	
Music																	
quality																	
	no music supported												X	X	X		
	severe errors apparent															X	X
	errors noticeable					X	X		X								
	near perfect																
	like original	X	X	X	X			X		X	X	X					
synchronous to video																	
	not applicable	X	X										X	X	X		
	severe errors noticeable															X	X
	small errors noticeable								X								
	no errors noticeable			X	X	X	X	X		X	X	X					
Sound Effects																	
quality																	
	no sound effects												X	X	X		
	severe errors apparent															X	X
	errors noticeable					X	X		X								
	near perfect							X									
	like original	X	X	X	X					X	X	X					
synchronous to video																	
	not applicable												X	X	X		
	severe errors noticeable															X	X
	small errors noticeable								X								
	no errors noticeable	X	X	X	X	X	X	X		X	X	X					
Graphics																	

screen overlay																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	not supported																
	supported manually by loading image																
	supported by auto-detection																
	supported through encapsulation																
frame rate																	
	deviation in percent	0	0	0	0	0	0	0	0	0	0	0	0	20	0	90	90
image quality																	
	nothing displayed												X		X		
	severe errors on whole image		X			X	X							X			X
	errors noticeable but do not affect gameplay																
	near perfect	X						X								X	
	no difference to original noticeable			X	X				X	X	X	X		X			
2D collision detection																	
	not applicable											X		X		X	
	no 2D objects displayed												X		X		X
	severe errors	X															
	errors noticeable but do not affect gameplay																
	no errors noticeable		X	X	X	X	X	X	X	X	X						
2D object position placement																	
	not applicable																
	no 2D objects displayed												X		X		X
	severe errors on whole image																
	errors noticeable but do not affect gameplay							X									
	no errors noticeable	X	X	X	X	X	X		X	X	X	X		X		X	
2D object layer placement																	
	not applicable															X	
	no 2D objects displayed												X		X		X
	severe errors on whole image																
	errors noticeable but do not affect gameplay																
	no errors noticeable	X	X	X	X	X	X	X	X	X	X	X		X			
2D background scrolling																	
	not applicable	X	X	X	X	X	X					X		X		X	X
	no 2D objects displayed												X		X		
	severe errors on whole image																
	errors noticeable but do not affect gameplay							X									
	no errors noticeable								X	X	X						
3D object calculation																	
	not applicable	X	X	X	X	X	X	X	X	X	X				X		X
	no 3D objects displayed												X			X	
	severe errors on whole image													X			
	errors noticeable but do not affect gameplay																
	no errors noticeable											X					
3D object clipping																	
	not applicable	X	X	X	X	X	X	X	X	X	X				X		X
	no 3D objects displayed												X			X	
	severe errors on whole image													X			
	errors noticeable but do not affect gameplay																
	no errors noticeable											X					

3D texture quality																	
	not applicable	X	X	X	X	X	X	X	X	X	X						X
	no 3D objects displayed												X		X	X	
	severe errors on whole image													X			
	errors noticeable but do not affect gameplay																
	no errors noticeable						X					X					
hardware supported special effects																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X		X		X	X
	no objects displayed												X		X		
	severe errors on whole image																
	errors noticeable but do not affect gameplay																
	no errors noticeable																
Network Support																	
network protocols																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	not supported																
	supported															X	X
lag for network play																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	not acceptable															X	X
	acceptable																
	no differences to original noticeable																
use of original servers																	
	not applicable	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	not supported																
	supported															X	X

Table E.7: Evaluation results for object characteristics for all generations systems.

Alternative		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Requirement	Unit																
Context and Data Characteristics																	
Metadata																	
Documentation																	
box artwork available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
manual available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
original media available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
originally supplied additional items available																	
	Y																

	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TV standard information available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
video display frequency information available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
region lock-out information available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
description of original media available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
context details available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
necessary system configuration available																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
reference to console video game system																	
	Y																
	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
reference to application																	
	not available	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	without system configuration																
	with system configuration																

Table E.8: Evaluation results for context and data characteristics for all generations systems.

Alternative		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Requirement	Unit																
Infrastructure																	
Scaleability																	
plug-in system																	
	not available	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	available, closed specification																
	available, open specifications															X	X
modular design																	
	code not available	X	X							X	X	X	X				
	code not modular			X	X												
	code modular and one system supported							X	X							X	X
	code modular and different systems supported					X	X							X	X		

portable code																	
	code not available	X	X							X	X	X	X				
	platform dependent code							X	X							X	X
	platform independent code			X	X	X	X							X	X		
	Virtual Machine used																
hardware dependencies																	
	code not available	X	X							X	X	X	X				
	platform dependent libraries are used			X	X											X	X
	platform dependent libraries are not used					X	X	X	X					X	X		
Stability																	
development procedure																	
	commercial and open source																
	not commercial but open source			X	X	X	X	X	X					X	X	X	X
	commercial but closed source																
	not commercial and closed source	X	X							X	X	X	X				
in active development																	
	new version in last 3 month					X	X							X	X	X	X
	new version in last 6 month																
	new version in last year			X	X												
	no release in last year	X	X					X	X	X	X	X	X				
community																	
	official forum available with more than 200 active users					X	X			X	X			X	X	X	X
	unofficial forum available with more than 200 active users																
	official forum available with less than 200 active users																
	unofficial forum available with less than 200 active users			X	X												
	no forum available or no active users	X	X					X	X			X	X				
Legality																	
recreation level																	
	high level and no BIOS is needed	X	X														
	low level and no BIOS is needed							X	X	X	X	X	X	X	X		
	high level and BIOS is needed																
	low level and BIOS is needed			X	X	X	X									X	X
expected manufacturer approval																	
	manufacturer out of business	X	X														
	manufacturer in video game business							X	X	X	X	X	X	X	X	X	X
	manufacturer no longer in video game business			X	X	X	X										
Media																	
supported media type																	
	not applicable	X	X														
	neither byte-stream nor original media supported														X		
	original media but no byte stream supported																
	byte stream but no original media supported			X	X	X	X	X	X	X	X	X	X	X			
	byte stream and original media supported															X	X
byte-stream																	
	not applicable	X	X														
	not supported														X		
	supported as stand-alone file			X	X	X	X	X	X	X	X	X	X	X		X	X

	supported encapsulated in file																
original media																	
	not applicable	X	X														
	not supported			X	X	X	X	X	X	X	X	X	X	X	X		
	supported with special hardware																
	supported without special hardware															X	X
logical layer information																	
	not applicable	X	X														
	hard-coded in preservation solution			X	X	X	X	X	X	X	X	X	X	X	X	X	X
	plug-in system																
	encapsulation supported																
special hardware on physical media																	
	not applicable	X	X	X	X	X	X	X	X	X	X				X	X	X
	hard-coded in preservation solution											X	X	X			
	plug-in system																
	encapsulation supported																
Additional Accessories																	
original accessories supported																	
	not applicable	X	X	X	X	X	X	X		X		X		X		X	
	not supported								X		X		X		X		X
	supported with special hardware																
	supported without special hardware																
necessary accessories supported																	
	not applicable	X	X	X	X	X	X	X		X		X		X		X	
	Y								X				X		X		X
	N										X						

Table E.9: Evaluation results for infrastructure for all generations systems.

Alternative		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Requirement	Unit																
Process Characteristics																	
Usability																	
game start																	
	only through user interface	X	X									X	X			X	X
	only through command line			X	X												
	through command line or user interface					X	X	X	X	X	X			X	X		
encapsulated details viewable																	
	encapsulation not supported	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	no																
	yes																
Configurability																	
game configuration																	
	menu only	X	X					X	X			X	X			X	X

	command line					X	X							X	X		
	auto-detection by preservation solution			X	X					X	X						
	configuration file for record																
	encapsulation in record																
global system preferences																	
	menu only	X	X									X	X				
	command line			X	X												
	configuration file					X	X	X	X	X	X			X	X	X	X

Table E.10: Evaluation results for process characteristics for all generations systems.

Alternative		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Requirement	Unit																
Costs																	
costs for preserving media																	
	media can be read without special hardware or media dumping is not necessary												X		X	X	X
	non-optical media, ROM chip directly connected to console cartridge port, readable with a standard chip reader and adapter							X	X	X	X	X		X			
	optical media not readable in industry standard optical drive, readable with hardware provide by manufacturer																
	special hardware necessary for reading out the byte-stream, additional address switching hardware available on the media which have to be re-engineered on a record-base			X	X	X	X										
	special hardware necessary for reading out the byte-stream, additional processing hardware available on the media which have to be re-engineered on a record-base	X	X														
total number of games supported																	
	less than 10	X	X														
	10-100			X	X							X	X	X	X		
	101-500							X	X								
	500-2000									X	X						
	more than 2000					X	X									X	X
fraction of games supported																	
	percent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table E.11: Evaluation results for costs for all generations systems.

Appendix F

Transformation Values

This appendix shows the values used to transform the results of the experiments described in Chapter 4.

Requirement	Unit	Transformed Value
Object Characteristics		
object interpretable	Y N	5 0
speed	0 - 5 percent deviation 6 - 20 percent deviation 21 - 50 percent deviation 51 - 100 percent deviation more than 100 percent deviation or not running	5 4 3 2 1
Interactivity		
Input		
Recreated Controls with Standard Personal Computer Hardware		
controls resemble look of original controller	no controls supported Y N	0 5 1
response delay	not applicable considerable delay short delay delay not noticeable	5 1 3 5
feel of original gaming experience	unplayable fairly playable well playable perfectly recreated	1 2 4 5
Controller Feedback		
audible	not applicable not supported supported	5 1 5
visual	not applicable not supported supported	5 1 5
force	not applicable not supported supported	5 1 5
Recreated Controls with Game Hardware		
look	controllers resembling original controller not available controllers resembling original controller not supported controllers resembling original controller supported	1 3 5
response delay	not applicable considerable delay short delay delay not noticeable	5 1 3 5
feel	controllers resembling original controller not available controllers resembling original controller not supported controllers resembling original controller supported	1 3 5
Controller Feedback		
audible	not applicable not supported supported	5 1 5

visual	not applicable not supported supported	5 1 5
force	not applicable not supported supported	5 1 5
Overlay Support		
response delay	not applicable considerable delay short delay delay not noticeable	5 1 3 5
look	not applicable not supported but necessary for game play not supported and not necessary for game play supported but not necessary for game play supported and necessary for game play	5 1 2 4 5
feel	not applicable not supported not usable usable	5 1 3 5
Support for Original Physical Layer		
Standard Controller		
supported	not supported supported with special hardware supported without special hardware	1 3 5
response delay	not applicable considerable delay short delay delay not noticeable	5 1 3 5
Controller Feedback		
audible	not applicable not supported supported	5 1 5
visual	not applicable not supported supported	5 1 5
force	not applicable not supported supported	5 1 5
Special Controller		
supported	not applicable not supported supported with special hardware supported without special hardware	5 1 4 5
response delay	not applicable considerable delay short delay delay not noticeable	5 1 3 5
Controller Feedback		
audible	not applicable not supported supported	5 1 5
visual	not applicable not supported supported	5 1 5
force	not applicable not supported supported	5 1 5
additional items supported	not applicable not supported supported	5 1 5
Sound		
Music		
quality	no music supported severe errors apparent errors noticeable near perfect like original	1 2 3 4 5
synchronous to video	not applicable severe errors apparent small errors noticeable no errors noticeable	5 1 3 5
Sound Effects		
quality	no sound effects severe errors apparent errors noticeable near perfect like original	1 2 3 4 5

synchronous to video	not applicable	5
	severe errors apparent	1
	small errors noticeable	3
	no errors noticeable	5
Graphics		
screen overlay	not applicable	5
	not supported	1
	supported manually by loading image	3
	supported by auto-detection	4
	supported through encapsulation	5
frame rate	0 - 5 percent deviation	5
	6 - 20 percent deviation	4
	21 - 50 percent deviation	3
	51 - 100 percent deviation	2
	more than 100 percent deviation or not running	1
image quality	nothing displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	near perfect	4
	no difference to original noticeable	5
2D collision detection	not applicable	5
	no 2D objects displayed	0
	severe errors	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
2D object position placement	not applicable	5
	no 2D objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
2D object layer placement	not applicable	5
	no 2D objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
2D background scrolling	not applicable	5
	no 2D objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
3D object calculation	not applicable	5
	no 3D objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
3D object clipping	not applicable	5
	no 3D objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
3D texture quality	not applicable	5
	no 3D objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
hardware supported special effects	not applicable	5
	no objects displayed	0
	severe errors on whole image	1
	errors noticeable but do not affect gameplay	3
	no errors noticeable	5
Network Support		
network protocols	not applicable	5
	not supported	1
	supported	5
lag for network play	not applicable	5
	considerable delay	1
	short delay	3
	delay not noticeable	5
use of original servers	not applicable	5
	not supported	1
	supported	5
Context and Data Characteristics		
Metadata		
Documentation		
box artwork available	Y	5
	N	1
manual available	Y	5
	N	1

original media available	Y N	5 1
originally supplied additional items available	Y N	5 1
TV standard information available	Y N	5 1
video display frequency information available	Y N	5 1
region lock-out information available	Y N	5 1
description of original media available	Y N	5 1
context details available	Y N	5 1
necessary system configuration available	Y N	5 1
reference to console video game system	Y N	5 1
reference to application	not available without system configuration with system configuration	1 3 5
Infrastructure		
Scaleability		
plug-in system	not available available, closed specification available, open specifications	1 3 5
modular design	code not available code not modular code modular and one system supported code modular and different systems supported	1 2 4 5
portable code	code not available platform dependent code platform independent code Virtual Machine used	1 2 4 5
hardware dependencies	code not available platform dependent libraries are used platform dependent libraries are not used	1 3 5
Stability		
development procedure	commercial and open source not commercial but open source commercial but closed source not commercial and closed source	5 4 2 1
in active development	new version in last 3 month new version in last 6 month new version in last year no release in last year	5 4 3 1
community	official forum available with more than 200 active users unofficial forum available with more than 200 active users official forum available with less than 200 active users unofficial forum available with less than 200 active users no forum available or no active users	5 4 3 2 1
Legality		
recreation level	high level and no BIOS is needed low level and no BIOS is needed high level and BIOS is needed low level and BIOS is needed	5 4 2 1
expected manufacturer approval	manufacturer out of business manufacturer in video game business manufacturer no longer in video game business	1 3 5
Media		
supported media type	not applicable neither byte-stream nor original media supported original media but no byte stream supported byte stream but no original media supported byte stream and original media supported	5 0 1 4 5
byte-stream	not applicable not supported supported as stand-alone file supported encapsulated in file	5 1 3 5
original media	not applicable not supported supported with special hardware supported without special hardware	5 1 3 5
logical layer information	not applicable hard-coded in preservation solution plug-in system encapsulation supported	5 1 3 5

special hardware on physical media	not applicable hard-coded in preservation solution plug-in system encapsulation supported	5 1 3 5
Additional Accessories		
original accessories supported	not applicable not supported supported with special hardware supported without special hardware	5 1 3 5
necessary accessories supported	not applicable Y N	5 5 1
Process Characteristics		
Usability		
game start	only through user interface only through command line through command line or user interface	1 3 5
encapsulated details viewable	encapsulation not supported no yes	1 3 5
Configurability		
game configuration	menu only command line auto-detection by preservation solution configuration file for record encapsulation in record	1 2 3 4 5
global system preferences	menu only command line configuration file	1 3 5
Costs		
costs for preserving media	media can be read without special hardware or media dumping is not necessary non-optical media, ROM chip directly connected to console cartridge port, readable with a standard chip reader and adapter optical media not readable in industry standard optical drive, readable with hardware provide by manufacturer special hardware necessary for reading out the byte-stream, additional address switching hardware available on the media which have to be re-engineered on a record-base special hardware necessary for reading out the byte-stream, additional processing hardware available on the media which have to be re-engineered on a record-base	5 4 3 2 1
total number of games supported	less than 10 10-100 101-500 500-2000 more than 2000	1 2 3 4 5
fraction of games supported	percent	divide by 20

Table F.1: Transformation values for requirement units.