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Keeping the Game Alive: Evaluating Strategies for the Preservation of Console Video Games

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Abstract

Interactive fiction and video games are part of our cultural heritage. 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. The public interest in early video games is high, as exhibitions, regular magazines on the topic and newspaper articles demonstrate. Moreover, games considered to be classic are rereleased for new generations of gaming hardware. However, with the rapid development of new computer systems, the way games look and are played changes constantly. When trying to preserve console video games one faces problems of classified development documentation, legal aspects and extracting the contents from original media like cartridges with special hardware. Furthermore, 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.

This paper discusses strategies for the digital preservation of console video games. After a short overview of console video game systems, there follows an introduction to digital preservation and related work in common strategies for digital preservation and preserving interactive art. Then different preservation strategies are described with a specific focus on emulation. Finally a case study on console video game preservation is shown which uses the Planets preservation planning approach for evaluating preservation strategies in a documented decision-making process. Experiments are carried out to compare different emulators as well as other approaches, first for a single console video game system, then for different console systems of the same era and finally for systems of all eras. Comparison and discussion of results show that, while emulation works very well in principle for early console video games, various problems exist for the general use as a digital preservation alternative. We show what future work has to be done to tackle these problems.[1]

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[1] This article is based on the paper given by the authors at iPRES 2008; received September 2009, published June 2010.

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Introduction

New and more complex video games are released as new hardware, operating systems and platforms are developed. But the development of new systems and more advanced technology also means that older games cease to run on modern platforms.

As interactive digital art and video games are part of our cultural heritage, they have to be preserved for future generations. Public interest in retro video games is high as demonstrated by articles in online magazines such as *The Guardian Online* (2007), periodicals like RETRO Gamer[2] as well as exhibitions like the Classic Gaming Expo[3] (CGE) in Las Vegas. Even companies releasing video games today have started to re-release old games which run on current video game hardware. One example is the Virtual Console Channel on Nintendo's Wii game console where users can buy and play classic 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. Apart from films, sound recordings, photographs and cartoons, it also includes video games (Library of Congress, 2007). A two-year project exploring methods of preserving digital games and interactive fiction, called Preserving Virtual Worlds, started in January 2008 (McDonough & Eke, 2007). The National Videogame Archive[4] in the UK which aims to preserve video game history for researchers, developers, game fans and the public, was announced in September 2008. Today it is still possible to show classic video game systems running original software in exhibitions and museums; yet more and more machines fail or are already beyond repair. Therefore, it is necessary to find ways to preserve the look and feel of the beginnings of video game history as well as games that set milestones in the video game history for future generations. The set of actions to keep the content alive, accessible and functional, as authentically as possible, is called Digital Preservation.

Video games can come in a huge variety of different forms. Games can be played on mobile phones, personal computers, arcade machines and console systems to name just a few. The challenges involved in preserving games for different platforms are diverse, for example, open or closed platforms, different media, and different game input devices, so-called "controllers". Recent developments are also completely changing the way games are being developed and played. They also pose significant new challenges concerning how to preserve and keep them playable. Preserving on-line games, virtual worlds and similar settings constitute entirely new challenges that are addressed in dedicated projects like the aforementioned Preserving Virtual Worlds or Antonescu, Guttenbrunner & Rauber (2009), and are beyond the scope of this study. This work evaluates different strategies for the digital preservation of console video games using an established preservation planning process. Console video games in this context are devices specifically made for playing games with the system's output displayed on a television screen. Some example systems are Atari 2600, Nintendo Entertainment System (NES) or the Sony PlayStation 3. Mobile devices that allow the use of a television screen as an alternative to the built-in screen are not considered as console video game systems in this study. We evaluate migration and emulation strategies for games for some of these systems. Emulators for gaming hardware are

[2] RETRO Gamer: http://www.retrogamer.net/
[3] Classic Gaming Expo: http://www.cgexpo.com/
[4] National Videogame Archive: http://www.nationalvideogamearchive.org/

developed mainly with gaming in mind. We consider these emulators and evaluate how far they adhere to the principles of digital preservation and how well alternatives can be applied for games of different system generations.

This paper is structured as follows: First we give an overview of related work and the history of selected console video game systems. The major systems of the different eras of console video games are listed along with games that represented the system best. Then we investigate the challenges for the digital preservation of console video game systems. Some of the general concepts and methods for digital preservation presented in the related work are discussed regarding console video games. We use the Planets[5] preservation planning approach 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 the last section shows the conclusions that can be drawn from the experiments and gives some suggestions for future work regarding the preservation of console video games and video games in general.

Related Work

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

The UNESCO guidelines for the preservation of digital heritage (Webb, 2005) list four layers on which a digital object can be threatened. As all digital objects have to be stored on a physical medium, a crucial threat exists on the **physical layer**. This includes not only the decay of media, but also the threat to the hardware reading these media. But it is not only necessary to be able to access the data on a physical layer (bits that are either set or not set), it is also important to know, how it is **logically** stored. If the information how data are stored on physical media is lost, it is very difficult to reconstruct the original data even if the physical media can still be accessed. The **conceptual object** is the data in human-readable form. If the data on a logical level are a compressed image, the data in their conceptual form are the image that is presented to the user when it is opened with the appropriate software to view it. 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. Finally the **essential elements** are the context in which a digital object has been created. This information describing a digital object is usually referred to as *metadata*.

In recent years migration and emulation have emerged as the main strategies used for digital preservation. Lorie differs between the archiving of data and the archiving of program behavior. While the first can be done without emulation, it cannot be avoided for the latter (Lorie, 2001). While this rigorous statement may be challenged if re-compiling and porting code to a different platform are viewed as a form of migration, emulation definitely plays an important role for the preservation of program behavior.

[5] Work presented in this paper is partially supported by European Community under the Information Society Technologies (IST) Programme of the 6th FP for RTD -Project IST-033789. The authors are solely responsible for the content of this paper. It does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of data appearing therein.

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 for which it was developed. An emulator for the original hardware is produced to keep this chain alive. Emulation can take place on different levels (software, operating system or hardware) as described in Rothenberg (2000).

Several methods to establish emulation as a long-term strategy for digital preservation are discussed by Slats (2003). The concept of an Emulation Virtual Machine (EVM) was used for development of the Universal Virtual Computer (UVC) by IBM (van der Hoeven, van der Diessen & van en Meer, 2005). An approach to developing an emulator on a hardware level is discussed as a conceptual model in (van der Hoeven & van Wijngaarden, 2005) as modular emulation. An emulator which uses the modular emulation approach (van der Hoeven, Lohman & Verdegem, 2007) is under development in the Planets Project. Planets is a project developing services and technology to address core challenges in digital preservation co-funded by the European Union under the Sixth Framework Programme (Farquhar & Hockx-Yu, 2007).

A practical experiment on how to use emulation to recreate interactive art is presented in Jones (2004). 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.

The Planets preservation planning approach used for this case study is described in detail in Strodl, Becker, Neumayer and Rauber (2007). Becker, Kolar, Kugne and Rauber (2007) present case studies on sample objects of interactive multimedia art from the collection of the Ars Electronica[6].

Experiments shown in this work have been presented as a case study by Guttenbrunner, Becker and Rauber (2008) with a focus on applying the Planets preservation planning approach on different preservation strategies in the same planning process. Gooding and Terras give a snapshot of contemporary computer game preservation, showing how little has been done so far to legally preserve video games (2008).

A Short History of Console Video Game Systems

This section gives a brief overview of the development of video games for home use and concentrates on console systems like those described in the introduction. It covers only systems which had substantial market share in the specified eras and as such are considered as major systems of the era. Figure 1 shows a time-line of release years.

The different names of console systems in different regions (Europe, Japan and US) are listed in this section. For the remaining paper only the release name in the US is used when referring to a system.

[6] Ars Electronica: http://www.aec.at

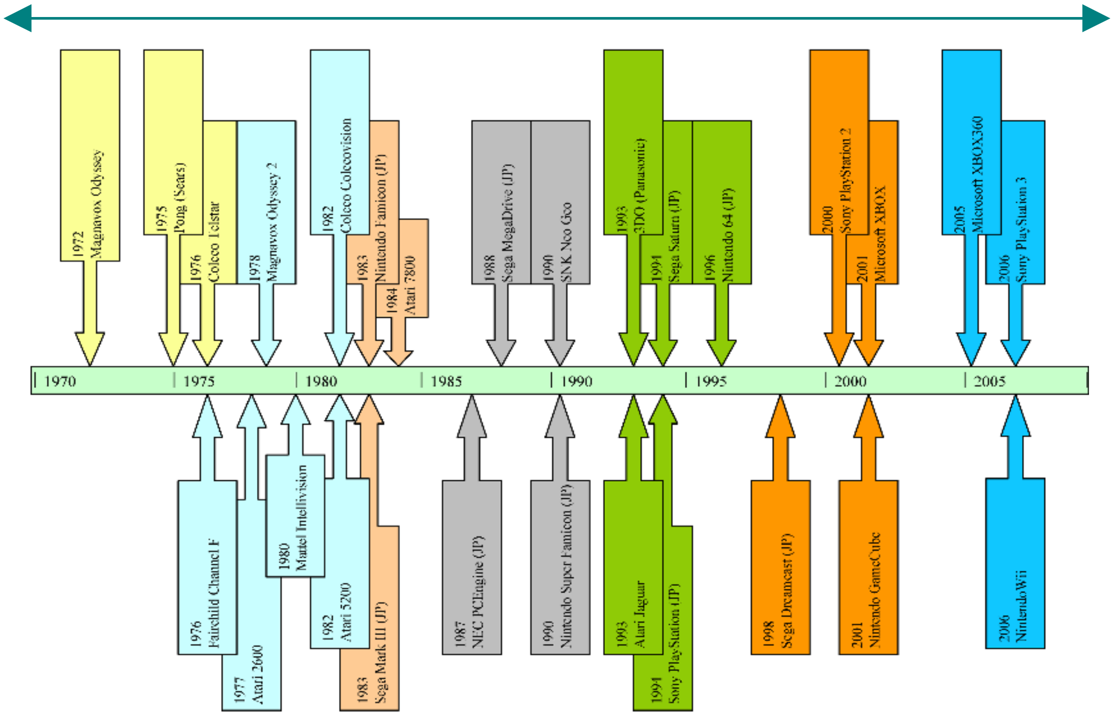

Figure 1. Release years for console video game systems covered in this study. Systems of the same era are shown in the same color. For every system the year of the first release and the name in the region (US or Japan) of first release is listed. If a system was released earlier in a different region and in a different year than in the US, then this region is also listed.

The Road to Video Game Consoles

The first game which is widely acknowledged as video game was invented by Willy Higinbotham in 1958. He designed a simple tennis game that used an oscilloscope as display device. Its purpose was to have something with which people could interact on the open house day at the US Government's Brookhaven National Laboratory.

In 1962 a team around Steve Russell developed the game "Space War" on a Digital Equipment Corporation PDP-1 mainframe computer at the MIT. 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.

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 analogue components. Due to the fall in price of microchips, later systems of this era were built around a single chip.

One major system in this era was the Magnavox Odyssey. It sold with cartridges which actually did not contain any software but worked as a key to unlock games already built into the system. The system was able to produce only simple black and white graphics so the games were sold with colored overlays for the TV screen as well as playing chips and cards to enhance the playing experience. As microchip prices dropped, the company Atari, which was in the arcade business at that time, started to produce a chip of its own version of the arcade video tennis game called Pong in 1974. The microchip was used by Sears in Pong console systems starting 1975 and also later in systems produced by Atari. In 1976 Coleco started producing their Telstar, a video tennis game console based on a microchip produced by General Instruments which cost only $US5 to produce.

The First Cartridge-based Video Games

In the second era of video gaming, games were stored in microchips inside cartridges. This development gave manufacturers the option to develop games after their system had been released.

The first system to feature programmable cartridges was the Fairchild Channel F which was released in 1976. The game graphics of this system were nearly as simple as the ones of advanced Pong systems. When Atari released the Atari 2600 (Figure 2, left) 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, Centipede, Asteroids). Originally planned to be sold with built-in games the Magnavox Odyssey^2 (Philips G7000 in Europe) was changed to a system with cartridges after the Atari 2600's release. Major games for the system were action games like K.C.Munchkin and Killer Bees. Magnavox also released a series of cartridges packaged with board games (Quest for the Rings (shown in Figure 2, right), Conquest of the World and Wall Street Fortune Hunt). In 1980 Mattel released the Intellivision. Mattel licensed sport brands as Atari had done with arcade games and used overlays for its controllers which showed real playing fields (e.g., a baseball field). The Colecovision by Coleco was released in October 1982. It offered the same system specification as the home computers of that time, however it was cheaper. Major games for the system included arcade hits like Donkey Kong, Zaxxon, and Ladybug. In 1982 Atari released the Atari 5200 which was based on their home computer series hardware of that time.

Figure 2. Left: Atari 2600; right: Magnavox Odyssey^2 Quest for the Rings game board with playing pieces, keyboard overlay, box with cartridge.

The 8-bit Era

In this era Japanese companies which had sold systems locally in Japan (like the Sega Game 1000 (SG 1000)) started to manufacture consoles for the US and European market. While most of the systems in the era before this were already built around 8-bit processors, systems of this era are usually referred to as 8-bit systems to differentiate them from their 16-bit successors.

The Nintendo Entertainment System (NES) was released under the name Famicom (Family Computer) by Nintendo in Japan in 1983. The quality of games was ensured by Nintendo by controlling the release of every game through a special licensing model. The system is well known for games like Super Mario Bros., Tetris, Teenage Mutant Ninja Turtles, Excitebike and The Legend Of Zelda. The Sega Master System was the first Sega system which was sold worldwide. It was based on a system developed in 1983 (the Sega Mark III) and 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 MasterSystem. Some of these games were Sonic, Hang-On, After Burner, Choplifter!, Double Dragon and Ghouls'n'Ghosts. Atari started to sell the Atari 7800 in 1986. It was backwards-compatible to the Atari 2600, but only a handful of original titles were released.

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 and to CD-based versions of nearly all the systems.

The NEC PCEngine 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. It was sold in Europe as TurboGrafx and in the US as TurboGrafx 16. The PCEngine is still well known for its excellent 2D shooting games. A new Sega console was released as Genesis in the US and as Mega Drive in Japan and Europe in 1988. It was based on a 68000 CPU by Motorola. Games for the system included Sonic The Hedgehog, Populous and Revenge of Shinobi as well as the first games in the Electronic Arts sport series NHL, NBA and NFL. Nintendo released its new system called Super Famicom in Japan in 1990. The system was called Super Nintendo Entertainment System (SNES) in the United States and Europe and was technically comparable to the Sega Mega Drive. 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. In 1990 arcade game manufacturer SNK entered the console market with a system that was a direct conversion of its arcade system which also used cartridges as media. Most of the games released for the NeoGeo AES were 2D fighting games and shooters like the Metal Slug series and the King of Fighters series.

The 3D Era

With the increasing demand 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 increased calculation power of the new systems games with real-time calculated realistic 3D animations shaped this era of console video games.

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 3DO Interactive Multi-player was licensed to the manufacturers Panasonic, Goldstar and Sanyo which named their systems Panasonic FZ-1 3DO, Goldstar System 32 and Sanyo Try 3DO. Atari's last console video game system, the Jaguar, was released in 1993. Some of the more successful games for the Jaguar were Alien vs. Predator, Tempest 2000 and Rayman. The Sega Saturn released in 1994 had a cartridge slot for hardware expansions but already used CDs for storing the games. The system had good 3D games like the Virtua Fighter series, but it became famous for its 2D shooters like Radiant Silvergun and DoDon Pachi. Sony started to step into the video game business developing a CD-ROM add-on for the Nintendo SNES, though it was ultimately cancelled. Sony then developed its PlayStation which entered the market in late 1994 and sold the system cheaper than the other new consoles on the market while still offering the same capabilities. A lot of successful game series started on the Sony PlayStation, like Ridge Racer, Gran Turismo and Tekken. While the other major console manufacturers used optical media for their systems, Nintendo still used ROM cartridges for its Nintendo 64 released in 1996. 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 and Donkey Kong 64.

The 128-bit Era

As with 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 began with some of the systems offering DVD and music playback. Moreover consoles were designed for the first time to appeal not only to children but also to adults (with the exception of the Nintendo GameCube). Sega's last console release was the Dreamcast. It was released in Japan in 1998 and was far superior to the Sony Playstation, market leader at that time. 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 and the Japanese game Densha De Go 2, a train simulator which was released with a special controller. Other milestone games included Sonic Adventure, Shenmue and Space Channel 5. The Sony PlayStation 2 was released in 2000. It supported DVD playback and was backwards-compatible with the original Sony PlayStation. 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 and the SingStar series, a karaoke-like game type which was shipped with microphones. Microsoft entered the console market with the XBOX in 2001. The company was able to gather experience of earlier video gaming with its game division for PC game development and its involvement in the WindowsCE support for the Sega Dreamcast. Some of the most important Xbox titles were Halo and Halo 2, Project Gotham Racing and the Burnout series. The GameCube was the first Nintendo console which favoured an optical medum (Mini-DVD) over ROM cartridges. Nintendo released games for the GameCube starring its most successful characters like Super Mario Sunshine, Wario World and Super Monkey Ball. The game Donkey Konga was shipped with a special Drum-Controller.

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 the capacity to play new home cinema formats (HD-DVD and Blue-Ray). Nintendo, on the other hand, invented a new motion-sensitive controller and sold its lower-end system for far less than the competition. This broadened the market for motion sensitive controls and casual gaming. The other major manufacturers currently develop motion control systems to follow up on Nintendo's success. All the systems sold in this era are aiming for multimedia applications instead of video games only. Online access to the manufacturers' networks with content (not only games but also movies) to download is available for all the systems. With the availability of increased bandwidth, voice chat during online play enhanced the multi-player gaming experience in this generation.

Microsoft was the first to release a console system of this generation in 2005. The Xbox 360 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[7] and an HD-DVD Drive is available as an accessory. Some of the best-selling games are the Gears of War series, Halo 3, Call of Duty series and Grand Theft Auto 4. Games can also be downloaded from the online platform Xbox Live Arcade; this includes classic arcade games but also newly developed games like Braid. With the Wii, Nintendo released a system showing only minor improvements in system specification over its GameCube, but with a radically different type of control. While most systems featured motion-sensitive controllers for special games before, Nintendo made its Wiimote the default control for its new system. The system also offers the Virtual Console[8], a software emulator to play classic games on various systems. These games have to be downloaded from the Wii's online shopping channel. Some major games released are Wii Sports, The Legend of Zelda: Twilight Princess, Super Mario Galaxy and Wii Fit. Sony's PlayStation 3 was released in Japan and the US in 2006 and in Europe in 2007. Some of the best-selling games are Metal Gear Solid 4, Resistance: Fall of Man and MotorStorm.

Challenges

Digitally preserving interactive console video games is very different from digitally preserving static documents. Even games on other platforms like personal computers, home computers or arcade machines offer different challenges to preservation than console video games. This section will list the challenges of preserving console systems, game code, and look & feel, and will compare them to other system types. Specifically, we discuss the following aspects: documentation of console system hardware, preservation of game code, look and feel and legal aspects.

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. They can be lost if a manufacturer goes out of business or decides

[7] Microsoft Xbox Q & A: Backward Compatibility:
http://www.xbox.com/en-GB/games/backwardcompatabilityqa.htm
[8] Nintendo Virtual Console - Playing Virtual Console and WiiWare Games:
http://www.nintendo.com/consumer/systems/wii/en_na/channelsShop.jsp#play

not to keep this documentation any longer. 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 obtain information how this code was interpreted on the original machine. Without the support of the manufacturer, it can be difficult to preserve a video game of a particular system.

Preservation of Game Code

Console video games have always been offered on various types of media which in most cases cannot 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 listed below.

ROM Cartridges.

Especially in the early years of video gaming ROM cartridges were the most commonly 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. ROM cartridges were actually hardware that included software. Some contained additional circuits to increase storage capacity (e.g., Atari 2600, Magnavox Odyssey[2]). 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). For digital preservation purposes it is thus crucial to not only 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 may use different kinds of circuits, the original cartridge has to be opened (and in some cases even destroyed in this process) and reverse-engineered in order to obtain this kind of information.

Optical Media.

Most manufacturers use standard formats readable by standard optical drives for personal computers. They can be widely varying formats like CDs (e.g. Sega Saturn), DVDs (e.g., Microsoft Xbox360) and Blue-Ray discs (Sony Playstation 3). Some systems, such as the Nintendo Gamecube, use less common formats like mini-DVDs. Other companies invented optical media just for the use in their console system (e.g., Gigabyte-Discs (GD) on Sega Dreamcast, also used in Sega's arcade machines). 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 obtaining hardware that is able to read proprietary formats like the GD, but also to read discs with copy protection as well as interpret the data on a disc.

Online Content.

This is usually only accessible by using the original system directly and thus only for the period the system is supported by the manufacturer. Online Content can come in different forms, either as downloadable software or as server software needed to play with or against other users, or to take part in virtual environments. For example, some games for the Sega Dreamcast are no longer playable because the necessary servers were turned off in 2003[9]. For these games the network protocols and necessary server software are not publicly available and only known by the manufacturer, so the risk of losing 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. Software updates of online content that are downloaded to the console's hard disc on later-generation console systems make it more difficult to determine which version of the server- and client-side software has to be preserved. But not only the systems behavior, even that of other players, has to be preserved or replicated to recreate the original experience in a multi-player online world.

Look and Feel

While for non-interactive content a recording of the original media can be sufficient, it is preferable to preserve the user experience with interactive fiction like video games. Some non-digital items like specific devices used to interact with a game are crucial for preserving the original experience of playing a game.

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 were 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. 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 Odyssey^2/Philips Videopac. They were 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 create a different gaming experience is to use special controllers designed for either a single game or a group of games. The earliest examples are light guns 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 good as current video game consoles, console 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 or Nintendo's Donkey Konga use special controllers which are shaped like maracas or drums. The experience with these games lies in the use of the special controllers. To recreate the experience, once the original system is no longer functional, it is therefore necessary to find a way to play the games such that the feel of these games is preserved. But not only the effect of an input device has to be replicated, also the effects of physical responses from the game ("Force Feedback" or "Rumble") have to be preserved in the controller technology.

[9] Phantasy Star Online: Sega schaltet Dreamcast-Server ab. (Phantasy Star Online: Sega switches off its Dreamcast server.) (Golem.de (2003).

Multi-player Experience.

As distributed gaming grows more popular with every new generation of console video games, it is necessary to preserve the multi-user experience. The interaction with other players is a major part of the gaming experience (either in the form of cooperative play or competitive play). The behavior of these other "players" has to be preserved as part of a game as well. Even though "massively multi-player online role-playing games" (MMORPGs) are more popular on PCs than on video game consoles, these games are an especially big challenge for preservation, as the social interaction with other players is one of the defining aspects of this genre.

Display Technology.

With analogue cathode ray tube (CRT) displays being replaced by LCD, LED or plasma displays, even the look of original systems changes when they are running on screens using new technologies. When trying to preserve the look aspect of console video games the original TV artifacts of standard display units[10] that were used when the system was released have to be preserved to recreate the look aspect of these games.

Legal Aspects

When it comes to legal issues, various parties are involved in the preservation of video games. The manufacturers of the original hardware usually conceal information that might be instrumental in obtaining 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. Emulation of the original hardware requires the approval of the video game systems manufacturer. To transfer the video game code to different media, the approval of all rights-holders involved in the game has to be obtained. Slats points out some issues with emulation (2003). Nintendo of America, Inc. provides some information on its website[11] about the legal use of emulators and the copyrights involved. Ayre and Muir suggest some solutions to the rights issues with digital preservation which also apply to the digital preservation of console video games (2004).

Responsibility for the preservation of digital data in general and video games in particular is currently unclear. The current copyright laws of most countries do not exempt archives from laws against circumvention of copy protection mechanisms or copyright laws. In the current situation archives can legally collect video games only on their original media.

In 2004 The Digital Game Archive issued a statement[12] to the German Federal Minister Brigitte Zypries in which it (unsuccessfully) demanded, among other things, the exclusion of video games from the current laws on copy protection mechanism circumvention.

[10] A Television Simulator: http://www.bogost.com/games/a_television_simulator.shtml
[11] Nintendo of America Inc. - Legal Information (Copyrights, Emulators, ROMs, etc.): http://www.nintendo.com/corp/legal.jsp
[12] The Digital Game Archive – Statement: http://www.digitalgamearchive.org/works/computerspielebuendnis_av_eng.rtf

Preservation Strategies for Console Video Games

With regard to the challenges presented in the section above, the principal common strategies for preserving digital data as listed in the UNESCO guidelines (Webb, 2005) have to be interpreted somewhat differently for the preservation of console video games. The fact that the original media are prone to deterioration and cannot be easily reproduced has to be considered. With these things in mind, one can look at the various approaches in the following way:

Museum Approach

Maintaining the original software and hardware to display the data to be preserved may be possible for machines built from standard components, but console video game systems are usually built from custom-manufactured parts. The latter are no longer available once the console system production stops, so they usually cannot be replaced once broken. The same is true for video game software, as most modern systems do only run originally manufactured media as a copy protection mechanism. While it is necessary to keep original specimens of systems and games for museum purposes, this can only be an approach for the digital preservation of the software for the very near future (short-term).

Backwards Compatibility

Backwards compatibility describes the concept of making software or hardware able to interpret older versions of data. For video games it means that games of previous generations of systems are playable on subsequent-generation systems. As this is also achieved on current systems by downloadable content that is emulated, we use the following definition of backwards compatibility in this work: 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 (Herman, 2001), early models of Sony's Playstation 3 are able to play games from previous system versions. As this is a commercial strategy and since it is not done with preservation in mind, usually only the previous generation of games is supported.

Backwards compatibility could be successfully used for digital preservation with chained emulation. Only the newest system in a chain of backwards compatible systems would have to be emulated. Some systems implement mechanisms to improve the image quality of the original games, so this leads to differences in the reproduction of the look aspect, which may or may not be a significant difference for the user in terms of preservation.

Migration Approaches

The migration approach is to migrate data to a new format for every new technology. Migrating the contents of a video game (structure, graphics and sound data, behavior of the program) to a different universal standard may be possible by defining universal structures for simple text adventures or point-and-click games with linear game flow. It does not seem to be possible to convert action games that rely on exact timing and intense graphical presentation as well as random game-play seems not to be possible. One migration approach that seems more feasible is the Game Engine Recreation where game engines used to interpret game data on the original system are reprogrammed on new host systems. The original game data are then used to recreate the game. A popular example is ScummVM[13] which was developed to interpret LucasArts Games (e.g. Maniac Mansion) but is now also able to interpret games from other manufacturers like Sierra.

Code re-compilation for new platforms is another migration approach. It is also known as Source Ports. While in most cases unavailable source code is the biggest obstacle, the proprietary hardware of console video game systems and the usually very platform-dependent code also make it a very time-consuming process to migrate a game to a new platform. This is especially true for older games that were not written in a high level-language, and were not intended for a multisystem release.

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 properly reproduced. More of a re-interpretation of the original, this is also called the *Documentary Strategy* (Depocas, 2002) or *Simulation*.

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 prove both considerably expensive and difficult, as most games would have to be re-engineered in order to reproduce them properly on a different platform.

Another migration strategy is the approach to create a video of the game. Although all interactivity is lost, this gives a good representation of the original visual and audible characteristics of a game and can even be used as a future reference for recreating the game in an interactive way. For multi-player games, several videos could be taken at the same time showing different people playing the game, thus having a more complete representation of the game. In video games where the interaction with other players is a substantial part of the game, this might be the only approach that preserves the original gaming experience. Apart from taking a video of the game, it can also be beneficial to record a video of a person playing the game to capture the use of special controllers or the context in which a game was played.

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. In this work the meaning of *Emulator* is used as defined by Slats (2003) for a program that virtually recreates a system that is different to the one on which it is running. The concept of using emulation for digital preservation is to keep the data in their original, unaltered form and keep using the software originally used to display the data. For video games this means that an emulator for the original hardware is created and the original operating system (if necessary) is run on this hardware along with the game that is to be preserved.

This may prove the most promising solution for console video games, as most systems have to be well documented for video game software developers to write

[13] ScummVM: http://www.scummvm.org/

games. The software itself is most probably not documented as well, or is unavailable in source code form and cannot be easily migrated in a playable form to new platforms. Furthermore, 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.

Evaluation of Strategies

Various alternatives and strategies to preserve video games have been outlined in the previous section. We used the Planets preservation planning workflow described in Strodl et al. (2007) and supported by the Planning Tool Plato[14] to evaluate available alternatives. The workflow is used for making informed, repeatable and accountable decisions on a preservation strategy.

For this case study we assumed a future library that is expected to have a mandate similar to a national library to collect published digital games and make them available for the public over the long term. The target audience is visitors to the library. It is not necessary to publish the collection online. Access to games from the library collection in order to experience the games' original look & feel should be possible for the public. Access to original media will be restricted to avoid damage to rare specimens. Further goals are an easy accessibility to the games without expert knowledge about system settings, a solution that is suitable for long-term preservation over various generations of systems running the digital archive, and high compatibility with all games for the console systems.

As an empirical evaluation of all available games for a system is just not feasible, we selected a representative subset for each evaluated system as sample records. They were chosen with the following considerations in mind:

- As first sample record a popular game for the system was selected. They are usually the first games to work on emulators, as they receive more public response than unpopular games, so developers concentrate on those. This was done to rule out the danger of a random selection of games which might include ones that could not be interpreted at all.
- The second game is a game which uses a special input device or overlays. This allows us to test the alternatives' support for look and feel properties apart from the standard controls.
- Finally, a game that uses special hardware (either on the cartridge or as a system add-on) or that was released very late in the life cycle of the system was selected. These are usually the games that make the most intensive use of the systems hardware.

The games selected for the evaluation can be found in Table 1.

Next, the requirements for preserving the games were collected and arranged in a tree structure called a requirements tree which divided into five main categories (Figure 3):

[14] Plato - Preservation Planning Tool: http://www.ifs.tuwien.ac.at/dp/plato

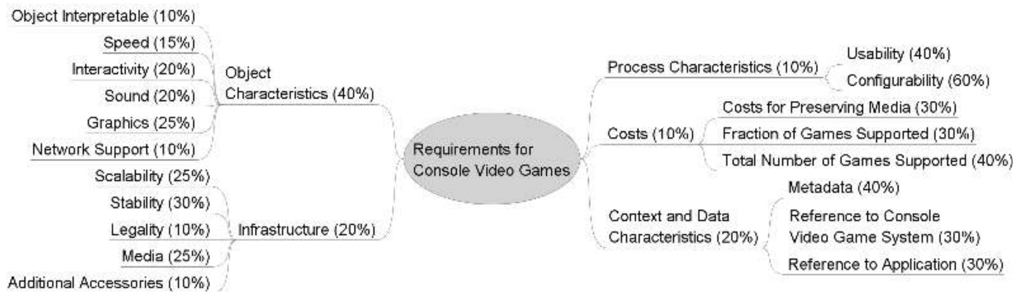

Figure 3. Requirements tree for console video games with importance factors (first two levels only).

Object Characteristics

The requirements to preserve the significant properties of video games were classified into the visual, audible and interactive characteristics. They are shown in the sub-tree in Figure 4. Visual aspects are divided into overall image impression as well as 2D and 3D features of the evaluated games. Sound aspects are divided into music and sound effects and taking account of both their quality as well as synchronicity. Deviation from the original frame rate and the support of additional aspects like network support were tested as well.

The typical scale that was used for measuring the degree to which an object requirement was met is:

- feature not applicable for this game
- feature not supported by the alternative
- feature supported but severe errors noticeable
- feature supported, errors noticeable but not affecting game-play
- no errors noticeable

System	Alternatives	Games
Nintendo SNES	• ZSNES 1.51 • SNES9X 1.51 • MESS 0.119	• Super Mario World • Super Scope 6 • Starfox
Nintendo SNES	• video/audio grabbing • with Hauppauge WinTV PVR and viewed with VLC 0.8.6c	• Super Mario World
NEC TurboGrafx 16	• MagicEngine 1.0.0. • MESS 0.119	• Bonk's Revenge • Gates of Thunder
Sega Genesis	• Gens32 1.76 • Kega Fusion 3.51	• Sonic the Hedgehog 2 • Darxide
SNK NeoGeo	• NeoCD 0.3.1 • Nebula 2.25b	• Metal Slug • Crossed Swords 2
Coleco Telstar	• Pong 6.0 • PEmu	• Tennis
Magnavox Odyssey^2	• O2EM 1.18 • MESS 0.119	• K.C. Munchin • Quest for the Rings
Sega MasterSystem	• Dega 1.12 • Kega Fusion 3.51	• Alex Kidd in Miracle World • Space Harrier 3D
Atari Jaguar	• Project Tempest 0.95 • MESS 0.119	• Doom • Highlander
Sony PS2	• PCSX2 0.9.2	• Gran Turismo 3 • Eye Toy Play

Table 1. Alternatives and games chosen for the experiments. All listed alternatives are emulation approaches except one migration video-taping approach for Nintendo SNES and simulation approaches for Coleco Telstar.

The interactive requirements describe the look, feel and feedback aspects. We differ between the use of standard PC components supported, the support of special controllers replicating the original controls, and possible support for the original controls themselves. Additional game items like overlays or off-screen game pieces have been considered in the requirements tree as well. Crucial criteria are if an object is interpretable at all by the preservation alternative, and if interaction with the game is possible. A game is considered interpretable if any kind of output (audible or visible) is produced.

Process Characteristics

Part of this branch of the requirements tree is the configurability of a solution. It represents how easy it is to set configurations for a specific game and the system itself. A tool that can be configured on the command line is easier to integrate into an existing digital preservation solution than a tool that can only be configured by setting parameters in a graphical user interface.

The second sub-branch is usability. It shows how straightforward and quickly games can be selected and if context-specific data can be displayed with the game (e.g., user manual or box art).

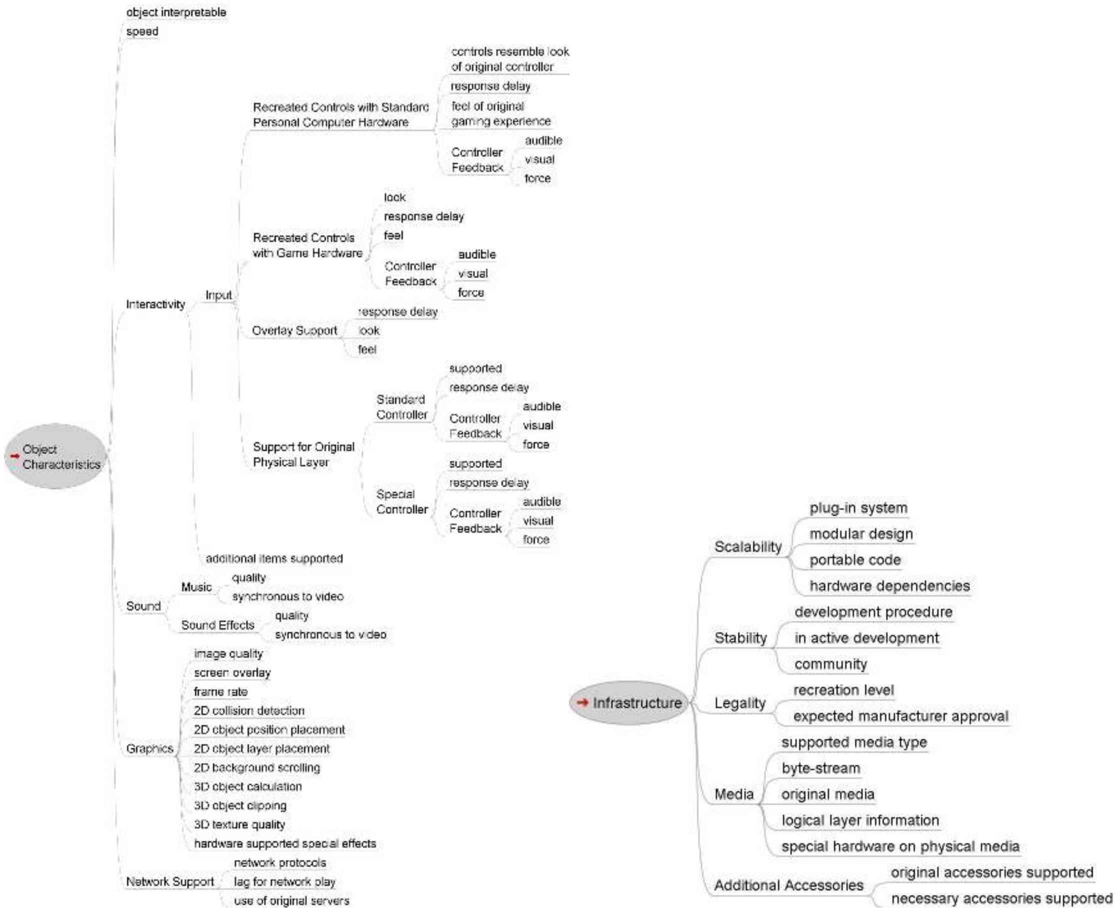

Figure 4. Left: object characteristics in the requirements tree; right: infrastructure characteristics in the requirements tree.

Context and Data Characteristics

This branch describes the support of metadata of the game and necessary configuration options either with the solution or bundled with the game data. It contains the requirements to run the game (video mode, hardware specifications) as well as metadata about a game (title, publisher, year of release, version, etc.).

Costs

This includes costs involved in retrieving data from the original media as well as costs for the preservation solution itself per supported game. It describes how many games in total are supported (for multi-system alternatives). Furthermore it shows what fraction of games for the specific system are potentially supported (e.g., only CD-based games, only games without special hard-ware on the media).

In total, the tree contains 81 leaf criteria. We set importance factors to weight these leaves (Figure 3). On the top level the greatest importance was given to the object characteristics as the presentation of the original look and feel was considered to be of the highest priority. Infrastructure for long-term sustainability as well as the support of context information on the game was also assumed to be of a high importance. Process characteristics are of less importance, as in the assumed scenario it is not necessary to browse very quickly through a high number of games.

Three experiments were defined:

- Different alternatives for one system were compared to check for differences in the performance of alternatives of the same strategy (e.g., two different emulators) as well as differences between strategies (e.g., emulation and migration to video). We decided to evaluate alternatives for the Nintendo SNES 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 evaluation was done for all three games for all selected emulation and migration alternatives.
- Next, we looked for differences in the level of support for systems from the same generation. We compared different alternatives for systems with similar hardware specifications (Nintendo SNES, Sega Genesis, NEC TurboGrafx 16, and SNK NeoGeo) to find out if systems with a bigger market share are better supported through emulation than others. For every system, two of the three games were evaluated on the selected emulators.
- Finally we evaluated alternatives for systems across all generations (Coleco Telstar, Magnavox Odyssey², Sega MasterSystem, Nintendo SNES, Atari Jaguar, and Sony PlayStation 2) to compare alternatives as systems evolved, that is, whether a single emulator can show favorable performance across a range of systems. Using a single emulator for a large number of systems would significantly lower the maintenance and deployment overhead for an archive. The systems were selected for special controllers or overlays (Magnavox Odyssey², Sega MasterSystem, Sony PlayStation 2), special hardware expansions (Nintendo SNES, Atari Jaguar) or available simulators (Coleco Telstar). Where available, two games for every system were evaluated on the emulation and simulation alternatives.

We chose suitable alternatives depending on the systems selected for evaluation. Most of the available alternatives are different emulators for a system. Only emulators that have seen at least one release in the last six months or that have been released in stable final versions were evaluated. If no emulator existed which met this criterion, the latest released emulator was 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 were evaluated. For every system a maximum of three emulators were evaluated. Alternatives were selected by using the most popular and best-rated emulators according to a popular website hosting emulators for different systems featuring a voting system[15]. Dedicated emulators as well as emulators supporting more than one system were chosen where available. Only emulators that are known to be able to launch commercial games were selected. Where available, we also selected simulation strategies as alternatives, as well as migration to video for comparison. Backwards compatibility and the museum approach were ruled out because they are short-term approaches only. Source ports and game engine recreation were not considered as the source material is not generally available for games on the evaluated platforms. The selected alternatives are shown in Table 1.

The experiments were developed for a defined hardware and software setting. Then, for every alternative, menu options and configuration possibilities were reviewed for the usability aspects of the requirements. A short review of the source code (if available) was performed to evaluate the figures concerning the infrastructure

[15] The Emulator Zone: http://www.emulator-zone.com/

aspects for each alternative. Finally, for every game the selection screens, 3D and 2D game sequences (if applicable) were tested for the audible and visible aspects. The preserved representation of the game was then compared to the original image on a TV screen produced by the original system. For every leaf in the requirements tree, the measured values were recorded for the selected systems and games. The measured values were then transformed to a uniform scale of 0 to 5, with 0 being a value unacceptable for the use of an alternative and 5 being the best possible result. Values not applicable for a game or system were transformed to 5 to reflect an unchanged behavior compared to the original system. The transformed values were then accumulated following the Planets preservation planning approach using weighted sum and weighted multiplication. Weighted multiplication is used to filter alternatives that do not meet knock-out criteria (e.g., interactivity) by evaluating the overall result to "0". The weighted sum is then used to compare the performance of the remaining alternatives. This yields a ranking of the evaluated alternatives, reflecting their specific strengths and weaknesses.

Analyzing the Results

By looking at the results of the experiments and the ranking of the alternatives we made the following observations for the three experiments defined.

Alternatives for One System

The data in Table 2 shows, that the aggregated results for the games on the two dedicated emulators (ZSNES and SNES9X) for the Nintendo SNES were very similar. Both were able to produce the visual and audible characteristics very well. The multi-system emulator MESS failed to reproduce the game with special hardware on the cartridge and had serious flaws on the produced images for the other games (Figure 5). One of the evaluated games uses a light gun as an input device. The original playing experience was not reproduced with standard PC controls.

Figure 5. Screenshots of Super Mario World for the Nintendo SNES. Both pictures show the same game screen. On the left is the image as rendered by ZSNES 1.51; on the right the image as rendered with errors by MESS 0.119.

While the dedicated emulators had very platform-dependent code for reasons of speed, the multi-system emulator showed much better infrastructure and process characteristics due to the platform-independent code and better configurability. Context information was only supported by the video format used in the migration-to-video approach.

While this also produced perfect audible and visible characteristics, the interactive aspect was completely lost. Weighted Sum and Weighted Multiplication results for the alternatives separated into the top level branches of the requirements tree are shown in Figure 6. As the multi-system emulator was not able to interpret all games, it was ruled out as a suitable alternative for the defined scenario.

The migration-to-video approach was ruled out as lack of interactivity was also defined as a knock-out criterion in the object characteristics. If this property was not considered critical, the video approach would have been the optimal solution, as it scored highest in all other aspects.

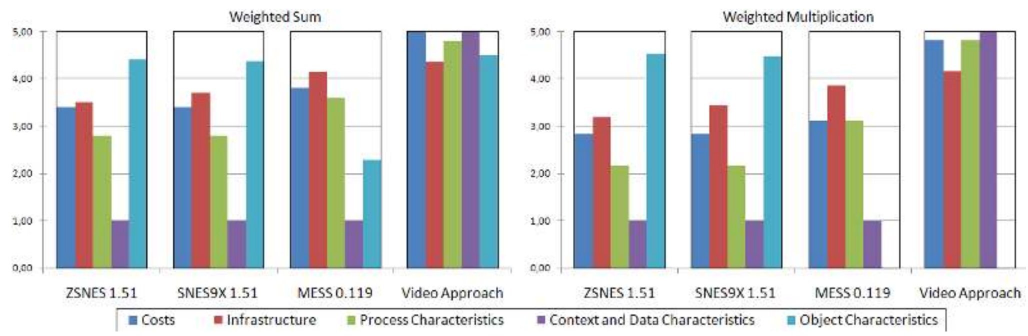

Figure 6. Aggregated results for the main categories in the requirements trees for Nintendo SNES preservation alternatives (weighted sum and weighted multiplication).

Alternatives for Systems of One Era

The observed results shown in Table 3 are similar to the first experiment. In general the object characteristics were better for dedicated emulators, while the infrastructure characteristics were better for multi-system emulators.

For three of the four evaluated systems (Nintendo SNES, Sega Genesis and NEC TurboGrafx 16) the accumulated values for the alternatives were very similar. In the case of the SNK NeoGeo the results were considerably lower and both alternatives had to be discarded due to at least one game not running at all on the emulator. While the first three were very popular systems, the SNK NeoGeo and especially its CD-based version had a very small market share, which indicates that publicly less well known systems receive less development support.

Alternatives for Systems of Different Eras

The two tested simulators for the Coleco Telstar had different approaches. While one was trying to enhance the visuals, the other tried to stay true to the original. Both had low values for most characteristics; the feel aspect in particular was reproduced inadequately.

The strength and weaknesses of dedicated and multi-system emulators described above were identified for emulators evaluated in this experiment as well as those shown in Table 4. The evaluated emulators of systems for the last three generations with more sophisticated hardware (Atari Jaguar and Sony PlayStation 2) performed worse in the accuracy of the emulation than emulators for earlier systems.

Of two games for the Atari Jaguar, only one (Doom) was rendered to a playable state on only one of the two emulators (Project Tempest 0.95, Figure 7). There were fewer emulators that could play commercial games. However the emulator for Sony PlayStation 2 featured network support as well as the option to use the manufacturers' original servers together with very good infrastructure characteristics. The feel aspect was not recreated for games which used either overlays (e.g., Quest for the Rings for Magnavox Odyssey[2]) or special accessories (3D Glasses for Space Harrier 3D, Sega Master System).

Figure 7. Screenshots of Doom for the Atari Jaguar. Both pictures show the first in-game scene. On the left is an image produced by Project Tempest 0.95, on the right the image created by MESS 0.119.

Alternative	Game	Weighted Sum / Game	Multiplied / Game	Weighted Sum Total	Multiplied Total
ZSNES 1.51	Super Mario World Super Scope 6 Starfox	3,45 3,30 **3,38**	2,75 2,70 **2,78**	3,28	2,68
SNES9X 1.51	Super Mario World Super Scope 6 Starfox	3,43 3,28 3,38	2,82 2,68 2,78	3,31	**2,70**
MESS 0.119	Super Mario World Super Scope 6 Starfox	3,56 **3,47** 2,47	**2,88** **2,79** 0,00	2,68	0,00
VLC 0.8.6c/MP4	Super Mario World	**4,65**	0,00	**4,65**	0,00

Table 2. Aggregated experiment results for preserving Nintendo SNES games. Highest values for each game as well as highest ranked alternative are highlighted in bold.

Alternative	Game	Weighted Sum / Game	Multiplied / Game	Weighted Sum Total	Multiplied Total
Nintendo SNES ZSNES 1.51	Super Mario World Super Scope 6 Starfox	3,45 3,30 **3,38**	2,75 2,70 **2,78**	**3,28**	**2,68**
Nintendo SNES MESS 0.119	Super Mario World Super Scope 6 Starfox	**3,56** **3,47** 2,47	**2,88** **2,79** 0,00	2,68	0,00
NEC TubroGrafx 16 MagicEngine 1.0.0.	Bonk's Revenge Gates of Thunder	3,52 **3,47**	2,74 **2,75**	**3,49**	**2,74**
NEC TubroGrafx 16 MESS 0.119	Bonk's Revenge Gates of Thunder	**3,88** 2,61	**3,30** 0,00	3,24	1,65
Sega Genesis Gens32 1.76	Sonic the Hedgehog 2 Darxide	**3,58** **3,52**	**2,93** **2,86**	**3,55**	**2,90**
Sega Genesis Kega Fusion 3.51	Sonic the Hedgehog 2 Darxide	3,47 3,46	2,80 2,78	3,46	2,79
SNK NeoGeo NeoCD 0.3.1	Metal Slug Crossed Swords 2	1,84 **3,02**	0,00 **2,35**	2,43	1,18
SNK NeoGeo Nebula 2.25b	Metal Slug Crossed Swords 2	**3,46** 2,43	**2,82** 0,00	**2,95**	**1,41**

Table 3. Aggregated experiment results for preserving games of the 16-bit generation of console video games. Alternatives for the same system are grouped together.

Alternative	Game	Weighted Sum / Game	Multiplied / Game	Weighted Sum Total	Multiplied Total
Coleco Telstar Pong 6.0	Tennis	**2,91**	**2,09**	**2,91**	**2,09**
Coleco Telstar PEmu	Tennis	2,82	2,07	2,82	2,07
Magnavox Odyssey^2 O2EM 1.18	K.C. Munchkin Quest for the Rings	3,44 3,38	2,89 2,82	3,41	2,86
Magnavox Odyssey^2 MESS 0.119	K.C. Munchkin Quest for the Rings	**3,60** **3,52**	**2,97** **2,89**	**3,56**	**2,93**
Sega MasterSystem Dega 1.12	Alex Kidd in Miracle World Space Harrier 3D	3,46 **3,34**	2,83 **2,74**	3,40	**2,78**
Sega MasterSystem Kega Fusion 3.51	Alex Kidd in Miracle World Space Harrier 3D	**3,54** 3,34	**2,86** 2,64	**3,44**	2,75
Nintendo SNES ZSNES 1.51	Super Mario World Super Scope 6 Starfox	3,45 3,30 **3,38**	2,75 2,70 **2,78**	**3,28**	**2,68**
Nintendo SNES MESS 0.119	Super Mario World Super Scope 6 Starfox	**3,56** **3,47** 2,47	**2,88** **2,79** 0,00	2,68	0,00
Atari Jaguar Project Tempest 0.95	Doom Highlander	2,95 **2,34**	2,17 **0,00**	2,64	1,09
Atari Jaguar MESS 0.119	Doom Highlander	**3,10** 2,34	**2,51** 0,00	**2,72**	**1,26**
Sony PS2 PCSX2 0.9.2	Gran Turismo 3 EyeToy Play	**2,85** **2,72**	**0,00** **0,00**	**2,79**	**0,00**

Table 4. Aggregated experiment results for preserving games for systems of all generations of console video games.

Conclusions and Future Work

In this work we gave an introduction into console video game history as well as work related to digital preservation in general and emulation as a digital preservation strategy. We outlined the challenges for preserving console video games and discussed various different preservation strategies. We used the Planets preservation planning approach to evaluate digital preservation alternatives for an assumed library environment where console video games were to be archived as digital heritage. While only the major console video game systems of each era are covered in this work, most of the results are also applicable to other console systems.

Evaluation Results

The experiments showed that emulation is a successful strategy to interpret game software from obsolete console video game systems on modern computers. Early console video game systems can be emulated fast enough on personal computers of current standards if the emulator is written in platform-dependent code. Most emulators for systems released after the third era use assembler language for time-critical parts of the software in order 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, which is a critical drawback for using them as digital preservation alternatives.

Even popular systems of the first four generations are not perfectly emulated today. The more recent the system, the lower the degree of accuracy. Of two tested games on two emulators for the Atari Jaguar only one game was playable. The two games for the Sony PlayStation 2 proved entirely unplayable.

Moreover accuracy is also usually higher with dedicated emulators, since they 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.

Most emulators are not developed commercially. Dedicated emulators tend to receive few updates and are frequently discontinued when the authors become distracted from development. Therefore, hardly any emulators exists in a final version that perfectly emulates all games for a system. Controllers are available for personal computers today that resemble most of the standard controllers used on the evaluated original systems (e.g., paddles, joysticks, racing wheels). Unusual controllers, especially those used in the last two generations of console video games (light gun, fishing controllers, maracas, etc.) are not as yet supported.

Especially in the early generations of console video games, overlays for controllers were used for specific games. Some of the games are not playable without the overlays, but, as of yet, no evaluated emulator supports their use in any form. Neither are additional non-digital items like game boards or playing pieces that were supplied with the original games supported by the tested emulators.

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

While all tested emulators were able to reproduce the original video or audio output to some extent, most are not usable for digital preservation without modification to support the longevity. Those with better results in longevity usually failed to reproduce the object characteristics sufficiently well.

The video approach was ruled out in this case study as it lacked interactivity, even though it scored highest in almost all other aspects. In cases where a suitable emulation alternative is not available (e.g., Sony PlayStation 2, Atari Jaguar) it can be the best option until an interactive alternative does become available. It can also be a complementary strategy to emulation for quick access or to verify future emulators' visual and audible compliance. Video recordings of users playing the game can serve as an additional reference for the way games were played with special controllers and even in what context they were played.

Future Work

Different types of video game systems have different significant properties. Future work has to focus on enhancing the requirements tree for games on home computers, personal computers, arcade machines and mobile devices. As special controllers were identified in this study as not properly re-created, research should be done on improving the preservation of the experience. An encapsulation scheme for enriching the binary data streams with metadata and context information should be developed.

For automatic evaluation of emulation alternatives, it is necessary to identify properties of emulated objects that can be automatically tested. These have to be described in characterization languages and emulators have to be adopted to support the generation of result files that can be automatically compared.

Best practice guidelines for developing emulators that are used for digital preservation purposes have to be issued. Stable solutions that are not bound to a specific host-hardware or operating system have to be developed (e.g., Emulation Virtual Machines).

Given the current legal situation concerning emulation, it is not possible to preserve video games digitally using emulators and copy media to different physical layers without the manufacturer's agreement. Establishing responsibility for the preservation of digital data must be seen as a priority. Awareness has to be raised among the manufacturers of console video game systems and console video games to reach agreements about how to preserve their work. Changes in the legal deposit legislation are necessary to allow exceptions for memory organizations to archive video games. Legal deposit laws should be extended to include digital data and the legal situation would have to be adjusted to enable legal deposits to perform the actions needed for digital preservation (e.g., copy protection mechanism circumvention). Legal aspects have only been covered briefly in this paper due to the complex nature of the legal implications of game preservation and the diverse national legal jurisdictions. The technical implications identified in this paper can assist future projects in addressing the legal situation of game preservation.

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