Emulation in Practice

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Abstract

Since 1999, determining the viability of emulation as a means to preserve digital assets has been up for debate. Throughout the last twenty years, emulation has been refuted, proven effective, and compared to other digital preservation strategies, like migration, almost simultaneously. This paper analyzes the various considerations involved when using emulation as a digital preservation strategy between 1999 and 2019. Three research methodologies are employed: 1) *historical research* as described in published literature, 2) *case studies* described in various sources, and 3) personal open-ended interviews conducted with experts active in the field over the past couple of decades and currently.

Intro

Beginning in 1999, a debate began between digital preservation professionals from museums, libraries, archives, and the computer science field to identify an appropriate strategy for preserving digital assets. Based on a claim made by the non-profit RAND organization's Senior Research Scientist, Jeff Rothenberg, emulation represented Willy Wonka's elusive golden ticket to conserve digital assets. In his report, *Avoiding Technological Quicksand: Finding a Viable Technical Foundation for Digital Preservation*, Rothenberg claimed emulation is a legitimate strategy for preserving digital assets that are vulnerable in nature due to "media decay and obsolescence". According to Rothenberg, emulation can be defined as mirroring the properties "of obsolete systems on future, unknown systems". Through this mirroring effect, emulation allows digital assets that were created with their original obsolete software to become accessible once again in the future (1999, pg. 1-11)

Until 2015, using emulation for digital preservation remained a hot topic before discussion on the strategy appeared to cease almost entirely. Four years have passed, and the amount of contemporary scholarly research written on using emulation as a digital preservation strategy is slim. This paper provides digital archivists and collections managers in the museum field with a current informational guide on emulation. This addresses three questions including, "When is emulation an applicable strategy for digital preservation?", "What are the advantages and disadvantages of using emulation as a digital preservation strategy?", and "What conditions and resources are required for emulation to work effectively?". With information gathered through each question, past and present perspectives on emulation will collide and blend in anticipation that museum digital preservation professionals can determine the strategy's ongoing viability.

Literature Review

Beginning in 1996, a task force called, “Task Force on Archiving of Digital Information”, sought after and analyzed possible solutions and suggestions for “preserving digital information” (1996, pg. iii). After extensive research, the Task Force concluded by stating “there is, at present, no way to guarantee the preservation of digital information”. For digital preservation to flourish, the Commission on Preservation and Access (CPA) noted that a “legal environment” which promotes preservation is required. Organizations including libraries, corporations, and government agencies, the CPA stated, must also take it upon themselves to execute procedures and develop “economic means” for preserving 20th century “knowledge into the future”. In 1997, CPA was absorbed by “The Council on Library and Information Resources” (CLIR) and continued to look for answers to address “the troubling question of how digital information will be preserved." Fast-forward two years, CLIR’s efforts continued, and the organization recognized Jeff Rothenberg’s 1999 report, *Avoiding Technological Quicksand*, which appeared to provide one plausible solution for preserving digital information via emulation (pg. iv).

In his report, Rothenberg stated that there is no accepted solution for preserving accessibility and readability of digital documents due to “media decay”. Sadly, Rothenberg noted, there had been no method or genuine solution for preserving accompanying software or hardware that is needed to open and make digital documents accessible for future use. Emulation, Rothenberg asserted, provided a “predictable” and “cost-effective” solution for preserving original copies of digital documents compared to other digital preservation strategies, like migration, by running and mimicking their initial software “on future computers”. Migration, in comparison to emulation, “is labor-intensive, time consuming, expensive” and “error prone”, Rothenberg stated. Additionally, migration fails to effectively reproduce original digital documents due to potential loss and corruption of valuable information that is a part of the materials' initial makeup. By using migration, a digital document's "context and content" is lost amid continuous conversion to contemporary file formats over time (Rothenberg, 1999, pg. iv-16).

After extensive migration practices, Rothenberg noted, the original copies of digital documents will become almost unrecognizable. As a means to avoid countless digital preservation bound migraines and the loss of valuable information spawned by other strategies (like migration), emulation offers a remedy. However, for emulation to work, the creation of emulators for "unknown future computers" and what Rothenberg assumed to be the immanent development of metadata saving techniques would be essential for digital documents so they can be found, readable, and accessible. Lastly, Rothenberg stressed, the development of new techniques for encapsulating digital documents "attendant metadata, software, and emulator specifications" to preserve "their cohesion and prevent their corruption". Going forward, Rothenberg expressed two additional variants of emulation which pertain to a digital documents original hardware and software (1999, pg. 16-26).

Potential issues involved with using emulation, Rothenberg stressed, are property issues stemming from hardware and software developers and specifying the distinct behaviors and characteristics of a digital document's own operating program (1999, pg. 22-24). Months after Rothenberg's report was published, preservation professionals from archival, library, and computer science backgrounds began to share their emulation-related concerns. David Bearman, former president of Archives & Museum Informatics, wrote a segment for D-Lib Magazine titled, *Reality and Chimeras in the Preservation of Electronic Records*, which dismissed the viability of emulation as a digital preservation strategy because he believed it was a far more complex than Rothenberg envisioned for preservationists to conduct. An additional concern, Bearman asserted, involves encapsulating, acquiring, and layering all of a digital asset's specified metadata (especially if a material was created using proprietary software) at the cost of time managed by authorized users (1999).

While Bearman discussed emulation from an archival and technological viewpoint, Caitlin Jones, then a curator at New York's Guggenheim Museum's (Guggenheim) published a study five years later that described an experimental attempt to use emulation techniques for digital art. *Seeing Double: Emulation In Theory and Practice, The Erl King Case Study* (2004), shared valuable insight on the viability of emulation for digital preservation purposes (Jones, 2014, pg. 1).

Created by visual artists Grahame Weibren and Roberta Friedman, "'The Erl King' (1982-85)" is an interactive art video that allowed viewers to progress through the piece's narrative by touching and making selections via a "touch-screen monitor". The Erl King is one of several digital assets the Guggenheim ("in collaboration with the Daniel Langlois Foundation for Art, Science, and Technology") chose to emulate for its 2004 exhibition which focused entirely on emulation titled, *Seeing Double*. To ensure authenticity between The Erl King's emulated and original version, the Guggenheim's "conservation department employed computer programmers and technicians to" utilize proper preservation practices (with Weibren and Friedman working in conjunction with them). The Erl King, in its entirety, is a unique piece to emulate because Weibren and Friedman created it with a custom video switcher, hardware, "three laser disc players, Carroll touch screen, CRT monitors and laser discs". In one year, after continuous coding and considerations on replacing old pieces of equipment with contemporary counterparts, emulation of The Erl King proved successful (Jones, 2014, pg. 1-4).

According to Jones, emulation of The Erl King would have been difficult to hold the piece's authenticity if its original hardware was not mimicked precisely (2014, pg. 4-6). In their 2014 collaborative book, *Recollection: Art, New Media, and Social Memory*, director of the Samek Art Museum, Richard Rinehart (located at Bucknell University in Lewisburg, Pennsylvania) (Rinehart, 2019) and Jon Ippolito (the University of Maine's director of Digital Curation program) (Ippolito, 2019) provided additional information on another of *Seeing Double*'s emulated pieces. *Jet Set Willy*, a video game developed for an obsolete computer, the 1980s ZX Spectrum (Spectrum), was chosen to "remix" via emulation by "artist duo jodi "(Joan Hemskeerk and Dirk Paesmans)". To emulate Jet Set Willy, jodi had to "dive" into the game's original programming features and analyze differences between a Spectrum and contemporary computers. From their dive, jodi found that a Spectrum did not utilize alphanumeric keys for creating "BASIC programs", which caused programmers to write an entire string of command lines with a "secular key or combination of keys" compared to contemporary computers (Rinehart and Ippolito, 2014, pg. 1132).

A command line is a text-based interface for a user's computer. Using the interface requires a user to develop a string of commands that his or her computer's operating system takes "to run" (Codeacademy, 2019). To initiate a Spectrum's GOTO command, unlike contemporary computers, simply pressing the keys G-O-T-O did not work, Hemskeerk noted (Reinhart and Ippolito, 2014, pg. 1132). The GOTO command for a computer is used to take a "batch" of command lines developed by a programmer, and direct them to an identified line of interest with a label ("Directs cmd.exe to a labeled line in a batch program") (Plett, Poggemeyer, and Mammen, 2017). Instead, a programmer trying to utilize a Spectrum's GOTO command had to punch "the key labeled with the word GOTO" and press "any required auxiliary keys" ("Alt or Ctrl") as well (Rinehart and Ippolito, 2014, pg. 1132).

If it were not for having the required source code via an emulator, emulating Jet Set Willy would have been difficult. Luckily, by using an emulator, jodi was able to display Jet Set Willy for Guggenheim visitors in both its original and emulated state. In Jet Set Willy's emulated state, jodi ran the game on a computer operating on Windows XP. This experience allowed visitors to conduct side-by-side comparisons between the original and emulated version of Jet Set Willy. Three additional emulated pieces exhibited in Seeing Double include work from artists Mary Flanagan and her piece, *[phage]*, and John F. Simon Jr.'s, *Color Panel* (Rinehart and Ippolito, 2014, pg. 1333-1405).

Based on results from a viewer survey created by the Guggenheim for *Seeing Double*, a large majority of visitors considered emulated pieces on display to be great representations of their original versions. Despite *Seeing Double*'s success among viewers, jodi felt that several attributes of the original Jet Set Willy were "lost in translation" through emulation. For jodi, it was a bit upsetting to transition from presenting Jet Set Willy in its original form on a CRT (cathode-ray tube) display onto a more contemporary (at the time) LCD monitor. According to Heemskerk, an LCD monitor's "crisp look and antiseptic feel" does not authentically resemble the warm buzzing sensation produced by Jet Set Willy's original CRT Spectrum display. Lastly, Heemskerk noted that from running Jet Set Willy Windows XP emulator, *Seeing Double*'s guests had no idea that a piece of the game's authenticity was lost because it originally ran on an audio tape which was inserted into a Spectrum's tape drive (Rinehart and Ippolito, 2014, pg. 1333-1405).

David S. H. Rosenthal, former LOCKSS's (Lots Of Copies Keep Stuff Safe) Chief Scientist (MIT Libraries, 2019), released a report in 2015 titled, *Emulation & Virtualization as Preservation Strategies*, which elaborated on a handful of current practices that utilize emulation to preserve digital assets. While working in unison with a *virtual machine* (VM), emulation allows a user to apply a VM onto a "host computer" "whose instruction set is *different* from the host computer's". A VM, Rosenthal noted, is a computer with no actual physical existence which mimics the exact "instruction set and hardware" specifications of a user's physical "host" computer. For emulation and VM to function, specific software known as an *emulator* must be developed to translate and mimic a "VM's instruction set and its virtual hardware configuration". Emulators, Rosenthal noted, have been available for a considerable amount of time for digital preservation purposes, however, they appear too complex, costly, and hard to use (2015, pg. 1-2).

QEMU, MAME, Basilisk II, and DOS Box are four emulators which Rosenthal considered "state of the art" and were created to promote the use of free open-source software. Emulation as Service (EaaS) is another avenue digital preservationists can investigate based on Rosenthal's work. Created by a team at the University of Freiburg, bwFLA is one example of EaaS which utilizes emulators through an online "cloud service". Organizations can utilize EaaS on a fee-for-service basis through bwFLA to emulate their digital assets for them without needing internal expertise and pertinent equipment (Rosenthal, 2015, pg. 5-7). According to bwFLA's website, the EaaS has several emulators available for end-user use including PPC, m68k, and Intel-based x86 (2015). While using bwFLA, a user initiates an interaction with an Emulation Component Proxy (a service manager) and requests a desired digital asset he or she wants emulated (Rosenthal, 2015, pg. 5-7). In addition, from a 2013 article published by several of bwFLA's creators titled, *Emulation as an Alternative Preservation Strategy - Use-Cases, Tools, and Lessons Learned*, the team explained that migration-through-emulation (MtE) is a vital component of the service. MtE, according to bwFLA's founders, involves the notion of utilizing a digital asset's "original or a compatible environment" to operate "in a virtual machine" which replaces an "original hardware and/or software stack" (Suchodoletz, Rechert, Valizada, and Strauchand, 2013, pg. 602).

Despite making promising progress, emulation has its downfalls (just like migration), Rosenthal claimed. Similar to Bearman's 1999 notion, it is imperative to obtain and preserve metadata associated with *usability* (associated with specific key bindings for a computer), *usage* (essential "for provisioning and" and trying to obtain funding), *bibliographic* (to help locate emulated digital assets) for emulation to work. Additional hurdles emulation faces, Rosenthal asserted, are legal (in regard to "intellectual property difficulties"), technical, and having inadequate tools "for creating preserved system images" which embody everything on a computer's hard drive. According to Rosenthal, "Emulation is not a panacea". When considering using emulation, Rosenthal claimed, the risk of utilizing too many resources is exacerbated due to its "higher per-artefact" (digital asset) "ingest cost" for preservation purposes. I believe, based on a claim made by Rosenthal, it is imperative to note that emulation can only be utilized appropriately for *legacy digital artefacts* because "Technical, scale and intellectual property difficulties make many current digital artifacts infeasible to emulate". According to Rosenthal, legacy digital artefacts are digital assets which were created from "the last century" (2015, pg. 1-31).

An additional report by Julia Y. Kim, a Library of Congress Digital Assets Associate, published work entitled, *Researcher Access to Born-Digital Collections: an Exploratory Study*.

Kim's report adds further information to determine the use of emulation as a viable digital preservation strategy. The report provides results from a 2014 exploratory study where emulation and two additional methods (migration and leaving materials accessible "as-is") were used to try to increase access to preserved digital assets from Yale University's Jeremy Blake Papers and Exit Archive collections. The Jeremy Blake Papers collections is comprised of about 400 pieces of digital artwork (consisting of multiple Photoshop images stacked within a secular file) created by digital artist, Jeremey Aaron Blake, and stored on various media devices including "optical media, digital linear tape, and Jaz drives". Digital assets from the Exit Archive collection reside on a 2 terabyte HDD (hard drive) which contains a plethora of materials including word document, image, email, and spreadsheet files. The HDD was given to the Fales Library in 2012 after Exit Art, a renowned art gallery located in New York, closed its doors. Based on findings from the study's five researchers, emulation showed slight inadequacies in relation to movement speed for digital assets comprised of moving components and seemed "technically challenging" (Kim, 2018, pg. 1-9).

Sadly, for many digital assets found in the Jeremy Blake Papers, emulation represented a band-aid which required continuous "maintenance and preservation". Regardless, in relation to Rosenthal's remarks in 2015, Kim stated that emulation has appeared to find a foothold for digital preservation use through organizations offering it as a service (like bwFLA). Legal and metadata related based emulation issues, Kim noted, are currently being investigated by an organization called "The Software Preservation Network". For emulation based accessibility to succeed further into the future, Kim suggested that "archivists must preserve bit-exact disk images of collections, software, and "documentation of dependencies, behavior and donor intent in order to secure the potential for emulation for access and preservation". According to Kim, "instead of adopting a 'wait-and-see' assumption of future use", archivists "should also invite and solicit feedback from researchers and donors" (2018, pg. 8-13).

Based on the case studies described here, emulation is viable for making digital assets that were created with obsolete software and hardware accessible on contemporary computer systems. As seen in results from the Guggenheim's viewer survey for *Seeing Double*, emulated pieces on display mirrored their original counterparts quite well based on visitors' perspectives. For museum representatives with little technical skills, EaaS offers these individuals to not only access, but, utilize digital assets created using obsolete software and hardware easily via emulators hosted on an organization website's (like bwFLA). Emulation is also known as a contributing factor in the implementation of VMs on a host computer and the peanut butter to migration's jelly for conducting MtE.

As it appears, major concerns towards emulation revolve around legal, technical, and authenticity related issues. Additional stressors include, the belief that emulation is costly, time consuming, and requires museum, library, and archive digital preservation professionals to have a considerable amount of knowledge on different hardware and software implications hidden behind every digital assest's creation. These stressors are important for digital preservation professionals at museums, libraries, and archives to keep in mind especially when using EaaS to conserve their digital assets is not an option. Also, lest not be forgotten, that it is only possible to emulate digital assets from the last century because of technical, scalable, and intellectual proprietary issues associated with contemporary materials.

Methodologies

This paper uses three different research methodologies. Resources this paper uses for each methodology derives from four academic fields including museums, libraries, archives, and computer science. When applicable, articles from the video game industry will also be examined because it has been associated with emulation in relation to digital preservation. The first methodology this paper utilizes is *historical research*, which involves reconstructing past discussions on emulation. Through historical research, materials including books, journal articles, reports, and blog posts have been collected and analyzed to establish facts. These materials help identify trends, and possible causes that aid in describing current beliefs on using emulation as a viable digital preservation strategy.

The second methodology involves using *case studies*. Case studies provide valuable information for the use of emulation as a digital preservation strategy. Several case studies in this paper contain information that was gathered and discussed from experiments. These case studies discuss and examine the notion of using emulation to preserve born-digital materials, including time based media art (TBMA).

The third methodology is open-ended *personal interviews*. This research contains information from five digital preservation professionals including Cynde Moya (the Living Computers: Museum + Labs Software Preservation Lab Manager), Euan Cochrane (the EaaSI program's Principal Investigator) and Seth Anderson (the EaaSI program's Manager), Ben Fino-Radin (founder and lead conservator of Small Data Industries), and Deena Engel (computer scientist and professor at New York University). The data gathered through each methodology describes the advantages, disadvantages, past scenarios, and current use of emulation as a digital preservation strategy. Additional information that has been gathered addresses when emulation can be used in conjunction with other digital preservation strategies (like migration and virtualization), and its possible applications for the future.

Research and Results

First, let's rewind back to Rothenberg's 1999 report when he discussed another notion bouncing around in the mind of digital preservation professionals looking for ways to conserve their materials. Aside from using emulation, an idea surfaced around this time to create computer museums which would preserve and run "old machines" that will provide future access to digital assets that were created with obsolete hardware and software throughout time. According to Rothenberg, there are four discrepancies related to the creation of computer museums that digital preservation professionals must keep in mind. Rothenberg mentioned in his first discrepancy that trying to preserve and run multiple old machines over extended periods of time is prone to be a costly endeavor (and ultimately lead to the untimely demise of each machine sooner rather than later). If it were indeed cost effective and possible to keep old machines constantly running (without worry), based on Rothenberg's second discrepancy, "true access to the original forms of old" digital assets would be limited to only "a few sites in the world" (1999, pg. 12).

Rothenberg's third discrepancy for establishing computers museums is "the fact that old digital" assets "will rarely survive on their own digital media". However, Rothenberg noted, if an older digital asset and its accompanying software were to "survive into the future, this will probably be because their bit streams" were copied "onto new media that did not exist when the" material's "original computer was current". The final discrepancy, Rothenberg added, is that every computer chip built within machines new and old "have limited physical lifetimes". Over time, Rothenberg pointed out, computer chips "Integrated circuits" decay, and their semiconductors will lose functionality due to "dopant fusion (the atoms that make semiconductors semiconduct over time". Aside from these discrepancies, Rothenberg noted that if computer museums were to exist, these institutions could perform heroic acts "to retrieve digital information from old storage media" (1999, pg. 12-13).

A second heroic act computer museums could perform, Rothenberg stated, is to verify "the behavior of emulators" and compare them to mannerisms of old machines they are trying to mimic" (Rothenberg, 1999, pg. 13). Press fast forward, and thirteen years later, a computer museum was established in Seattle thanks to the ambition of Microsoft co-founder and Vulcan Inc. CEO, Paul G. Allen. Starting with the purchase of a TOAD-1 System created by XKL Systems Corporation (known now as XKL LLC) in 1997, it was Allen's ambition to collect, preserve, and to make vintage computers (and their accompanying software) publicly accessible at the Living Computers: Museum + Labs (LCM+L). Presently, LCM+L exudes Allen's ambition through its philosophy which involves continuous efforts to collect and restore "historically significant computers and software" for visitors at the institution to utilize. Onsite, visitors to LCM+L have the opportunity to use three emulated versions of vintage computers including the ContrAlto (intended to simulate the 1973 Xero Alto), a 1973 MULTICS system, and sImlac (developed to mimic the 1970's "Imlac PDS-1 computer/terminal") (Living Computers: Museum + Labs, 2019).

If interested, former onsite visitors or online users can download at home the ControAlto and sImalc emulators for personal use via LCM+L's "github page" (Living Computers: Museum + Labs, 2019). Recently, LCM+L's own software engineer, Josh Dersch, created and released an emulator for the "1981 Xerox Star" computer titled, Darkstar in 2019. For users interested in using Darkstar, according to Dersch, they can also download the emulator for free through LCM+L's github page (Dersch, 2019). Via LCM+L's website, users can request a personal login to interact with eleven "actual, working, time-sharing computer systems" (Moya and Ebner, 2019) that are running on the institution's personal servers. Three emulated vintage computers users can access through LCM+L's servers include the TOPS-20 (Toad-2), NOS 1.3 (CDC-6500), and VM/SP5 (IBM 4361) (Living Computers: Museum + Labs, 2019).

To Cynde Moya, LCM+L's Software Preservation Lab Manager, emulation is beneficial and applicable to implement when certain programs in our rapidly expanding technological world cease to exist entirely. According to Moya, emulation provides an additional solution towards preserving digital assets and their accompanying hardware and software if there are currently no viable migration tools available for a museum's digital preservation professionals to use. A third yet gruesome point, Moya mentioned, is that digital preservation professionals should be aware that every computer and software company is bound to go out of business at some point in time. In this regard, Moya stated, trying to preserve digital assets created using specific computer hardware and software could be difficult with no support from their non-existent parent companies. For Moya, in this almost post-apocalyptic sounding graveyard full of long forgotten computer hardware and software companies, emulation is an excellent strategy to use for digital preservation (Moya, 2019).

According to Moya, utilizing emulation and emulators is advantageous because it avoids the ongoing hassle of trying to have multiple vintage computers running all at once to retrieve or recreate digital assets with obsolete hardware and software. Like Julia Kim, Moya believes that EaaS will become very useful as time moves forward in terms of providing increased accessibility for digital preservation professionals at museums, libraries, and archives to utilize the strategy. However, Moya noted, emulation does have disadvantages. When it comes to preserving the authentic look, feel and sound of a digital asset's original hardware components, emulation is disadvantageous. Using emulation, Moya stated, prevents the preservation of various nuances that are associated with a digital asset's original hardware including the sound of fans running in old computer towers and humming produced by CRT monitors. In relation to preserving the appropriate timing and speed characteristics of digital assets and TBMA, emulation still presents many difficulties. Lastly, Moya claimed, proprietary issues can arise when trying to use emulation for digital preservation purposes (Moya, 2019).

In order to utilize emulation appropriately, Moya noted, there are several resources and conditions that need to be in place. Aside from organizations utilizing EaaS, three essential resources needed to implement emulation include proper funding, time, and trained staff who can perform the strategy. When it comes to having the right set of trained staff, LCM+L is fortunate because it has multiple software and hardware engineers with a background in computer science who can take care of all the coding and in-depth technological aspects of a digital asset (including an assets origin hardware and software). If possible, Moya noted, it is beneficial to own copies of original hardware and software manuals that were used for creating a digital asset because the information contained in these materials can be used in test scenarios. At LCM+L, Moya stated, the institution tries its best to acquire and study these manuals for testing and comparing emulated materials alongside their original counterparts (Moya, 2019). In fact, LCM+L has a donation page on their site with a form for donors to fill out and describe any (and all) hardware and software manuals they want to donate to the institution to help preserve its collections (Living Computers: Museum + Labs, 2019).

Another promising use of emulation is a program created by “Yale University’s Digital Preservation Services team” (located in New Haven, Connecticut) called EaaSI. According to the team, EaaSI is intended to expand the size and development of technology-based services through EaaS. To achieve their initiative of expanding the use of EaaS services, EaaSI’s team has four driving goals. Through its first two goals, EaaSI’s team aims to establish a community among partner institutions and provide effective “resource sharing functionality” between them. Via its last two goals, EaaSI’s team intends to broaden the use of EaaS by improving “description and discovery capabilities” of data contributed to Wikidata, and consistent “Prototyping of various modules and services” intended for managing end-user access. Outside of Yale University, EaaSI’s main supporter is the Software Preservation Network and three additional affiliates including “OpenSLX, DataCurrent” and PortalMedia (Software Preservation Network, 2019).

Carrying the ambitious torch from bwFLA (while adding more inspiring flair as well), EaaSI’s team has been successfully providing EaaS services to clients since 2014. One successful case EaaSI’s team has performed for “An Arts PhD student” involved emulating copy of artist Laurie Anderson’s interactive artwork, “Puppet Motel” (circa 1997) by using the Basilisk II emulator. In a second successful case, EaaSI’s team provided a Yale Judacia librarian with access to a “Windows XP CD-ROM” containing Hebrew Texts (circa 2004) that would not operate on a computer running Windows 7 within the university’s library. Now, information stored within this Windows XP CD-ROM can be accessed by using Oracle’s Virtual Box or the emulator QEMU. An additional successful emulation case EaaSI conducted involved making financial information (from around 1998-2003) created with Windows 98 and stored on a CD-ROM available for “A Finance PhD student (Owens, 2014).

To make the financial information available, EaaSI once again utilized VirtualBox and QEMU (Owens, 2014). In 2018, EaaSI’s team has been working on another method for handling digital assets via emulation by utilizing links as a new component of their program called UVI (universal virtual interactive). Using the term “automagically”, EaaSI wants to pair digital assets with designated links which will automatically open a material within its original operating environment through an emulator once selected by end users. By implementing this method, ease of use and accessibility to Yale library's digital collections is intended to increase. In addition, this method prevents digital assets from becoming "distorted changed/or lost" entirely if they were opened within modern software (Cochrane, 2018).

However, creating these links can be a bit complicated and will require EaaSI's team to match digital assets with specific "configured interaction and computing environments". These environments comprise "of a set of computer hardware and software that can be used for whatever purpose you might have". By being placed onto "a physical hard drive" or "installed and configured" into an "'image file", the hardware and software found within these environments can be opened and utilized through "an emulator" (or a virtualizor as well). Recently, EaaSI's team has been working tirelessly to develop "at least 3,000 emulated or virtualized configured computing environments during the first grant-funded phase of work". Once their work is complete, EaaSI's team hopes that they can provide end users with image files and their designated environments "in an additional attached drive (e.g. another hard drive or a floppy or CD/DVD drive and have that drive location opened automatically on boot and presented to the user for interaction)" (Cochrane, 2018).

For Euan Cochrane, EaaSI's Principal Investigator and manager of Yale library's Digital Preservation Services team, using emulation to preserve digital assets is important because researchers should have the ability to open a material within its original software if needed. When thinking about migrating digital assets created with older software (like word doc files created using Microsoft Word for Windows 7), these materials could potentially have their formatting changed completely. In some cases, Cochrane noted, digital assets created with older software can also pickup new information during a migration process that could potentially throw off or skew the original look and feel of a material entirely (which essentially ruins a specific digital asset's authenticity). As one of the EaaSI team's main objectives, Cochrane claimed, they want to make sure that digital assets can be opened, assessed, and retrieved through their original software environments using emulation. After opening, assessing, and retrieving digital assets within their original software environments via emulation, Cochrane noted, EaaSI's team wants to validate that the materials can be migrated appropriately using contemporary programs at a later date for longevity purposes (Anderson and Cochrane, 2019, 1:30-8:30).

To Seth Anderson, EaaSI's Program Manager, emulation represents "an element of digital preservation" which serves the purpose of being "an access mechanism in the end". One of the biggest disadvantages of emulation, Anderson noted, is that it requires a digital preservationist to conserve not only digital assets, but the original software (and software dependencies) of these materials as well so they can be made accessible. However, Anderson noted, preserving legacy software (obsolete software) is a difficult because "we aren't necessarily going to keep around old computers" as they breakdown over time. Therefore, Anderson claimed, "emulation and emulation software" embodies another option digital preservationists can utilize to avoid collecting series upon series of obsolete computers for preserving digital assets. However, Anderson noted, using emulation to preserve digital assets is not easy because it requires a deep understanding of software requirements and knowledge on how to configure (and recreate) a specific piece of hardware's own environment (operating software) in an emulator (so it can "run effectively and correctly") (Anderson and Cochrane, 2019, 8:59-11:01).

Another disadvantage when it comes to using emulation, Anderson noted, involves sourcing appropriate resources and acquiring essential installation materials so that a software environment can be produced. Sourcing resources and acquiring installation materials is important, Anderson claimed, because the software environment created with these factors need to correlate with a digital asset's software dependencies so the material can be accessed. To ensure that appropriate resources and installation materials are obtained, Anderson claimed, EaaSI's team has added "the capability to share software resources and emulation environments back and forth between different instances of the EaaSI software". Anderson elaborated on his claim stating that "instead of every individual instance having to be its own collection of software, if there's another institution that is a part of this EaaSI network we are establishing", their software environments can be shared with one another to help EaaS flourish. One major challenge emulation faces when digital preservation is concerned, Anderson noted, involves trying to scale and meet the needs of a spectrum of end users with it who might not have any sort of technical expertise whatsoever (Anderson and Cochrane , 2019, 11:01-19:02).

At EaaSI, Anderson stated, they try to eliminate "a lot of the technical decision making which goes into using emulators, and allow non-expert users to just focus on what's required to set up a computer environment for their collection materials" By eliminating technical decision making components for end users, Anderson mentioned, the process of EaaS becomes more streamlined and it allows EaaSI's team to run multiple emulators with varying discrepancies all at once. As time moves forward, Anderson stated, the EaaSI team is trying to make emulation a more viable digital preservation strategy by removing a barrier associated with resources materials and user expertise. According to Anderson, at EaaSI "we saw that that barrier needed to be lowered" and the amount of time and effort needed to acquire resources and have technical expertise "shouldn't be as taxing as they currently are" (Anderson and Cochrane, 2019, 15:31-20:58).

Another promising development in the use of emulation is found in Brooklyn, New York, by a young organization known as Small Data Industries (Small Data). Founded in 2016, Small Data collaborates with museums, archives, and libraries to preserve their digital assets through several different services for conserving TBMA. According to the organization's website, three services Small Data Industries provides to its clients includes condition assessment, conservation treatment, and technical documentation. Four additional services Small Data offers its clients involves facilitation of acquisitions, digital preservation consulting, digital repository management, and digitization and format migration. By performing these services, it is Small Data's mission to aid and empower people looking "to safeguard the permanence and integrity of the world's artistic record". Two of Small Data's well known clients are the New York's Museum of Modern Art and the Cooper Hewitt Museum (Cooper Hewitt) (Small Data Industries, 2019).

In 2018, while working closely with the Museum of Moving Image (MoMI [located in Astoria, New York]), Small Data published a report on a case study titled, *Long Live the Animated GIF: A Study on the Curation, Acquisition, and Preservation of Animated GIFs,* which discussed the possibility to use emulation for preserving moving digital images known as animated GIFs. Creation of this case study derived from MoMI's current ambition to know "what a program of collecting and conserving digital moving-image art and culture may look like". Currently, MoMI owns three different forms of GIFs including "artifacts from the early web, GIFs that are artifacts of memetic culture, and animated GIFs created by contemporary artists for the museum's GIF commission series". As defined in the study, GIFs construe "a logical screen, with optional color tables, images, and optional extensions". A GIF's logical screen, the study mentioned, embodies "a virtual canvas where one or more images will be rendered" (Small Data Industries, 2018).

Images implemented into GIFs, the study noted, have the ability to utilize a designated "palette of colors defined by the global color table, or an image-specific local color table". Optional extensions, the last component of a GIF, come in two forms. Comment extensions, as defined in the article, "allows plain text to be embedded with" a GIF. "Plain text extensions" are the second form associated with GIFs which render "plain text as a graphic" on an end user's computer screen. When trying to exhibit early web animated GIFs, as stated in the study, there is one prominent issue to take into consideration for digital preservation purposes (Small Data Industries, 2018).

Perceived to have spawned "circa June 1987" from ancestral artist driven online "bulletin board systems", early animated GIFs were created with obsolete computer processors whose speed is drastically slower compared to CPUs of today. In this regard, it is important for museum digital preservation professionals to acknowledge intricate playback related variables while trying to conserve historic (early web) animated GIFs. Through emulation, as suggested in the article, preserving playback variables of historic animated GIFs is plausible. As implied in the study, emulating a historic animated GIF's "period specific CPU, operating system, and web browser is highly recommended" to test playback variability. By using emulation to assess this variability is suggested because it will help keep intact a historic animated GIFs authenticity while on display in a museum exhibit (Small Data Industries, 2018).

As discussed in Small Data Industries 2018 report, *Designing the Future of Design: A Vision for Collecting Digital Design at the Cooper Hewitt, Smithsonian Design Museum,* Cooper

Hewitt initiated the Digital Collections Materials Project (DCMP) (2016). The DCMP spawned from Cooper Hewitt's ambition to find ways for preserving our modern day technologies (etc. "smartphones, laptops, tablets," and "smart home assistant") so future generations can understand their functionalities. For about two years, Cooper Hewitt continued to collect "digital objects of design" (on top of decades worth of items already gathered) including "personal computers, software, interactive robot devices, and personal electronic devices" so the institution's ambition could become a reality. During this two year window, Small Data worked closely with Cooper Hewitt to address the institution's desire with one mission in mind. Divided into two phases, the first component of Small Data's mission involved conducting "a complete survey of" Cooper Hewitt's "collection to compile a list of what objects could be considered digital or physical-digital" and note "their present condition both functionally and contextually" (Small Data Industries, 2018).

Phase two of Small Data's mission involved conducting multiple "in-depth case studies" which analyzed "complex preservation challenges of a specific object" listed in their survey. Based on their findings, Small Data shared a report in 2018 titled, *Designing the Future of Design*, which addressed the possibility of using emulation to try and preserve Cooper Hewitt's collection of technological devices. In the report, Small Data addressed a notion that suggested using emulation to try and preserve various software found throughout Cooper Hewitt's technological object collection. Emulation, Small Data claimed, is beneficial "when the object at hand is a contained and singular piece of software-for instance, if an institution was trying to run a piece of software designed to work only in Windows 3.1". With this aspect in mind, Small Data pointed out that Cooper Hewitt's technology collection contains several devices which have no emulator to mimic their software components (Small Data Industries, 2018).

Aside from emulator deprivation for several of Cooper Hewitt's technology pieces, Small Data claimed "emulation is very successful" when trying to work with vintage digital materials and software applications (like apps produced for iPhones that are only two years old) that had their development ceased entirely. Additional research conducted by Small Data for Cooper Hewitt examined "in particular" "the obsolescence of iOS apps". For Small Data, the only iOS aspect they have been able to emulate successfully was "a working development environment" for an application that could "run with Apple's proprietary Xcode iOS simulator". In the future, Small Data envisioned that emulation could be used for preserving and providing museum visitors with interactive period-distinct software (Small Data Industries, 2018). According to Ben Fino-Radin, Small Data's founder and lead conservator, emulation is best applicable when there is interest in trying to achieve a high degree of fidelity associated with the look and feel of an original asset (Fino-Radin, 2019).

However, Fino-Radin declared, emulation has a learning curve associated with it and requires a particular expertise (like having software engineers similar to LCM+L) to make a setup for the strategy readily and easily accessible for creator and end user use. When considering the use of emulation for digital preservation, one must remember that a sense of authenticity is lost for digital assets going through the strategy (similar to migration). To Fino-Radin, emulation is advantageous because it does not require changing the original version of a digital asset. However, Fino-Radin noted, if a digital preservation professional has a working emulated version of an operating system (like Mac OS 9), opportunities to conserve digital assets created in this environment increases. Like Moya and Kim, Fino-Radin also believes EaaS is advantageous when available (Fino-Radin, 2019).

At day's end, Fino-Radin noted, emulation can be disadvantageous especially if an error arises within an emulator's coding and its creators do not have enough time to fix it. Software engineers and technology conservators are busy people, Fino-Radin stated, so it can be difficult to try contact them for emulator support if they are already working on other preservation cases. In this regard, Fino-Radin added, engineers and conservators might not have enough time on their hands to personally go back in and adjust any sort of issues an emulator is spitting out (therefore leaving a particular emulator unusable for extended period of time). In terms of cost, Fino-Radin noted, emulation can be just as expensive (if not more) to implement for the preservation of digital assets. The cost of trying to preserve a digital asset whether it is through migration or emulation, Fino-Radin claimed, is highly dependable in regards to what type of materials are being examined (Fino-Radin, 2019).

When speaking about materials particularly found within an archive (like manuscripts and various other text based materials), Fino-Radin stated, emulation could be considered a better option over migration in regards to cost. EaaS, regardless of its fantastic capabilities, can become a costly endeavor, Fino-Radin claimed. However, if we start to look at trying to preserve TBMA with emulation, Fino-Radin explained, there is a gray area which exists where knowing how much money using the strategy could cost is unknown. Looking at the big picture, trying to develop an emulator for preserving a digital asset is an incredibly complex task, Fino-Radin stated. Unless an institution falls in line with the services offered by LCM+L, it is highly unlikely that museums could perform emulation in house because they typically do not have seasoned software engineers (computer scientists) on staff (Fino-Radin, 2019).

Beginning in 2018 as a collaborative attempt between computer scientists from New York University (NYU) and the Guggenheim, emulation was used once again to try and preserve

John F. Simon Jr.'s web artwork, *Unfolding Object* (2002). The idea behind trying to preserve *Unfolding Object* stems from the Guggenheim's "Conserving Computer-Based Art (CCBA)" initiative (Phillips, Engel, Farbowitz, and Rosenberg, 2018). For five years (2014-2019), "the Guggenheim Conservation Department has been partnering with the Department of Computer Science at NYU's Courant Institute of Mathematical Sciences to analyze, document, and preserve computer based artworks from the Guggenheim collection" through CCBA (Dover, 2016). Representing "one of three, seminal early web artworks in the museum's permanent collection" *Unfolding Object*'s creation was commissioned by the Guggenheim for "visitors to create their own individual artwork online by unfolding the pages of a virtual 'object'. *Unfolding Object* encompasses "a two dimensional multi-faceted structure growing around a center square" with every click of an end-user's mouse (Phillips, Engel, Farbowitz, and Rosenberg, 2018).

After extensive testing of "different emulation options", "the interdisciplinary team of NYU computer scientists and Guggenheim conservation staff" realized that emulation was not an adequate strategy to use for preserving *Unfolding Object*. Based on their test results, the team asserted that "emulation as a treatment strategy could not handle the task of constantly collecting accessing the user data and did not result in an accurate representation of all of" *Unfolding Object*'s original behaviors. Despite inadequacies after trying to use emulation, the team was able to successfully restore and preserve *Unfolding Object*'s "functionality and appearance" via "code migration from the" obsolete Java 'Crystal Applet' coding Simon used for creating the piece "to the contemporary programming language JavaScript" (Phillips, Engel, Farbowitz, and Rosenberg, 2018). As an active participant in *Unfolding Object*'s restoration, computer scientist and NYU professor, Deena Engel, shared insight on why emulation did not work during the artwork's restoration. According to Engel, legacy web artworks (e.g. *Unfolding Object)* can be difficult to restore by using emulation because these pieces tend to contain multiple layers of software dependencies that could potentially make the strategy difficult to implement. When it works, Engel noted, using emulation can be beneficial. However, that does not mean it is always appropriate to use. Similar to Rosenthal's assertion in 2015, Engel stated that emulation is not a panacea for digital preservation of software-based art (Engel, 2019).

Conclusion

Although it does not represent a digital preservation panacea, emulation is a viable strategy to use for preserving legacy-based born-digital assets when appropriate. However, the applicability of emulation varies vastly between different types of born-digital materials, due to their distinct hardware and software dependencies. Hardware and software dependencies, which are associated with digital assets, are crucial to identify because of the amount of effort and complexity behind trying to emulate a simplistic type of material (e.g. a Microsoft Word file) as compared to a material that is more robust (e.g. TBMA). In regards to contemporary born-digital assets, using emulation to try and preserve these materials is infeasible because of technical, intellectual property, and scalability difficulties.

However, unlike other digital preservation strategies, emulation is advantageous because it does not require digital preservation professionals to alter the original version of a digital asset for access purposes. If a digital preservation professional has an emulated copy of a digital asset's original operating system on hand, he or she can increase access to the material without making any alterations. By using emulation and emulators, digital preservation professionals can avoid having to manage, run, and preserve multiple obsolete computer systems at one time. This advantage is important to acknowledge because it prevents the inconvenience of having to recover or recreate digital assets with obsolete hardware and software.

Despite its advantages, emulation also has disadvantages which need to be considered. One of the biggest disadvantages associated with emulation is that it requires the preservation of digital assets in addition to their original software. Preserving the original software of a digital asset is crucial for emulation to succeed because it increases future accessibility to the material. An additional disadvantage attributed with emulation, includes sourcing pertinent materials and obtaining essential installation materials for creating software environments to access digital assets. When trying to preserve the authentic look, feel and sound of a digital asset's original hardware, emulation is disadvantageous because it can be difficult if not impossible to accurately replicate these qualities using contemporary computer systems. The third disadvantage emulation faces are coding failures associated with emulators. When the code running an emulator starts to fail, finding the appropriate computer scientist to remedy the situation can be difficult. These professionals are usually busy with other demanding projects making it troublesome to fix an emulator in a timely manner.

Unfortunately, without the appropriate conditions and resources, using emulation for digital preservation is improbable. Unless a museum, library or archives is fortunate like LCM+L, it is unlikely that the institution could use emulation in-house without having a significant amount of time, funding, and reference materials (e.g. hardware and software manuals). Furthermore, unless an organization is collaborating with another institution which has trained computer scientists or software engineers on staff (e.g. the CCBA initiative), it will be almost impossible to preserve their digital assets via emulation. However, organizations that do not have the appropriate conditions and resources in-house, EaaS programs (e.g. EaaSI) provide an alternate option to preserve their digital assets. If emulation is available for use, digital preservation professionals should seek advice and feedback from donors and outside researchers.

By obtaining donor and researcher feedback, these professionals can potentially find better ways to preserve their institutions' digital assets with emulation.

As emulation technology improves over time, the strategy could potentially become more viable. However, knowing how "emulation will work in the future" is unpredictable. According to Engel, "while artists will continue to push boundaries, emulation software will also improve over time" (Engel, 2019). In addition to the variables previously stated, it seems imperative to note the evolution of emulation. By having the ability to share emulators via the web (e.g. LCM+L's github page), and EaaS, emulation has certainly evolved. Emulation has evolved from being predominantly handled by computer scientists and software engineers towards becoming readily available for end-user use on the web. Similar to migration, emulation has its limitations and can potentially decrease the functionality of digital assets at some point in time. However, when migration appears to be failing, it can be used in unison with emulation via MtE to increase digital preservation potential. In conclusion, it would appear that emulation is not the elusive Willy Wonka golden ticket digital preservation professionals sought for twenty years.

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