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This study uses conceptual content analysis to examine and compare definitions of "emulation," "migration," and other key terms in the digital preservation literature. Eight terms were coded and analyzed including "digital object," "authenticity," and "significant properties." Particular attention is paid to definitions of emulation and migration, and arguments for and against each process are reviewed.

Within the library science literature there is a significant consensus about the definitions of many of these key terms. However, there still exists some ambiguity and disagreement about how these fundamental concepts should be understood. Those undertaking digital projects must be deliberate about defining these foundational terms before they begin work.

Headings:

Electronic data archives/Conservation and restoration

Conceptions of Emulation, Migration, and Related Concepts in Digital preservation Litterature

by
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Introduction

There are two predominant traditional approaches to digital preservation: emulation and migration. This paper uses content analysis to examine the definitions of these two strategies and related concepts in the digital preservation literature. It aims to fully explore how these two concepts have been understood.

This paper is divided into four sections. The first is an introduction which explains the structure of the paper and provides a very short explanation of the basics of digital preservation. The second section explains the methodology used for this study, conceptual content analysis. The third and largest section presents and discusses the results of the content analysis. It discusses how several key terms for digital preservation have been used in the literature, paying particular attention to the two most popular approaches to digital preservation: emulation and migration. The final section of the paper offers concluding remarks, explains some of the limitations of this study, and suggests some practical implications.

Digital Preservation Basics

Digital documents have many advantages, making it easier to create, manipulate, disseminate, locate, and store information. In all these ways and more digital documents are superior to their paper counterparts. However, preserving digital documents over the long term is much more difficult, or at least much more complicated, than preserving paper documents.[1]

Archivists have been debating about how to best preserve digital materials for more than forty years.[2] However, it has become an increasing concern in the past decade as the volume and complexity of digital documents has grown exponentially. Single institutions now produce hundreds of thousands, if not millions of digital files per year. With this growth, archivists, computer scientists, and digital data managers, to name just a few, have become concerned about preserving digital information into the future. Some of these preservationists are motivated by concerns about the cultural record, others are devoted to preserving data for future use, and still others are motivated by legal obligations or business needs to collect and preserve digital objects. The problem of digital preservation also affects those wanting to keep accessible their private photo, audio, or video collections.[3] Hedstom describes the problem of digital preservation as "a time bomb for digital libraries."[4] One contemporary response, among many, to this problem is illustrated by initiatives of the federal government. In December of 2000 the US Congress appropriated $99.8 million to establish the National Digital Information Infrastructure and Preservation Program (NDIIPP), a collaborative research program to explore the problem of digital preservation.[5]

Simply stated, digital preservation is the process of ensuring that digital information remains meaningful and accessible over time.[6] Often this means not only saving the digital files themselves, but also preserving as much of the context used to create and interpret them as possible.[7] Scholars and practitioners have understood the theoretical nuances of digital preservation many different ways. Some focus on preserving the "authenticity" of digital records. Others have focused on preserving the "look and feel" of digital information. Still others have focused on preserving the

functionality of digital objects. Many of these theoretical underpinnings, manifested in pragmatic approaches like emulation and migration, will be discussed later in this paper.

Digital preservationists usually identify two distinct challenges to digital preservation. The first is preserving the physical medium containing the digital material from decay over time. Physical media such as CDs, DVDs, and magnetic discs deteriorate over time and may corrupt the bit-stream of a digital file, ultimately making it unreadable. Thus, the physical manifestations of digital materials must be maintained using trusted storage environments or reliable distributed server systems.[8]

Preserving the physical formats of digital materials is the simpler of the two challenges to digital preservation. Software format obsolescence represents a much greater threat. The demand for better, more powerful computing hardware and software has fueled rapid growth and innovation in technology. Thus, technology cycles are fast and product lifetimes tend to be short.[9] As users move from one product to another, old software and hardware becomes obsolete. If not cared for, all of the digital files intended to work with these obsolete products will become unusable.[10]

There are three traditional approaches to combating software format obsolescence. One, the computer museum approach, attempts to circumvent the problem completely by simply preserving old, obsolete computers, both hardware and software, and using them render to old digital files. This approach has not been widely adopted. Some of the reasons for this are discussed later in this paper. Emulation and migration, the two other strategies for combating software obsolescence, are by far the most prominent and most widely used strategies.[11] As traditionally understood, migration is the process of moving digital files from obsolete formats to non-obsolete formats, and emulation is the process of re-creating old environments so digital files can be used in

their original software formats. However, these two strategies, emulation and migration, have been defined and understood in many different ways.

METHODOLOGY

This project used conceptual content analysis of a broad range of information and library science literature pertaining to emulation and migration. This methodology can be broken down into two processes: (1) identifying the literature and (2) analyzing the literature.

IDENTIFYING THE LITERATURE.

A complete literature review to identify articles that discuss the concepts of emulation, migration and related concepts was undertaken. Articles and other materials were identified using a variety of means to ensure that the analysis would be as comprehensive as possible. Germane articles for review were identified through several methods:

a) Careful searches in general and subject specific databases, including Academic Search Premiere, Google Scholar, Library and Information Science Abstracts (LISA), ACM Digital Library, and Library Literature and Information Science. All told, the information and library science specific databases index over 750 information science periodicals from 1969 to the present. The searches were conducted between October 2008 and August of 2009.

b) Bibliographies prepared by Lee,[12] Lee and Tibbo,[13] Pomerantz,[14] and Hank and Tibbo[15] at the School of Information and Library Science at UNC Chapel Hill between 2007 and 2009.

c) Bibliographies and citations from sources obtained elsewhere, including: 1) the websites of several digital preservation projects such as Creative Archiving at Michigan and Leeds Emulating the Old on the New (CAMiLEON)[16], Keeping Emulation Environments Portable (KEEP)[17], Carolina Digital Curation Curriculum (DigCCurr)[18], and institutions, like the Digital Curation Centre[19]; and 2) professionally compiled library science bibliographies, such as the Scholarly Electronic Publishing Bibliography.[20]

The literature discovered through these methods was initially reviewed for relevance to the research questions. From the initial result set, articles were further evaluated based on currency and treatment of substantial definitions of emulation, migration and related concepts.

ANALYZING THE LITERATURE.

Conceptual content analysis was used to identify and analyze definitions of emulation and migration within the literature. Both implicit and explicit definitions and understandings of emulation, migration, and related concepts were used in this study.

This study used the framework for content analysis developed by Carley[21] and White and Marsh[22]. Seven steps of this process were used in this study:

1.) *Choosing the Level of Analysis*: This is the process of selecting key words and terminology used to identify the concepts being studied. Because digital preservation is a young field, and emulation and migration are fairly new concepts, this is not a simple process. For example, the process of migration has also been referred to as "translation," "conversion," and identified with a related concept "standardization." All important terminology related to emulation and migration had to be identified.

2.) *Determining the number of concepts to code:* This is the process of deciding how many concept terms to code for. For this study, a preliminary list of terms was developed at the beginning of the study, but the number remained flexible for a significant portion of the project so additional concepts could be used as the literature was coded and analyzed.

Ultimately, the following terms were identified, coded, and analyzed for this study:

- "emulation"
- "migration"
- "conversion"
- "translation"
- "standardization"
- "digital preservation"
- "digital object"
- "obsolescence"
- "incompatibility"
- "authenticity"
- "significant property"

3.) *Coding for existence of the concept:* Conceptual content analysis allows coding for existence and/or frequency of concepts. This study chose only to code for existence, rather than frequency. It is noted when and how the key concepts were used in literature, also paying attention to when key concepts were not discussed or discussed very briefly.

4.) *Distinguishing between concepts:* Carley's content analysis framework allows researchers to choose how concepts will be identified. Researchers may use the specific approach and identify concepts only with certain specific terms. Alternately, researchers may use a generalize approach and identify concepts by generalizing their meaning and looking related concepts.[23] This study used the

generalized approach in order to incorporate discussions of key concepts that did not explicitly use the key terms identified in step one. This more flexible approach allowed me to expand the scope of the project and incorporate a larger body of literature.

5.) *Dealing with irrelevant information:* Following the methodology of Vassailou[24] and Allard[25], information contained in the articles not relevant to the concepts being studied was ignored. Used in concert with the generalized approach to distinguishing between key concepts discussed above, this step allowed for a flexible research strategy. Irrelevant concepts could be ignored, but if the researcher came upon relevant information during the coding process, this information could be taken into account.

6.) *Coding the articles:* In this process, key concepts and terms were identified. Each instance or discussion of any of the key concepts was noted and flagged for analysis.

7.) *Analyzing the results*: Each instance of discussion of the key concepts was then analyzed and compared and contrasted with other instances. The researcher used qualitative conceptual analysis to understand how the coded definitions were related and used within the literature.

RESULTS OF ANALYSIS: KEY TERMS DEFINED

Because digital preservation is a new and rapidly growing field, it has somewhat limited theoretical foundation. Many scholars have bemoaned the lack of conceptual frameworks and have called for clearer theory in the area.[26] Thus, in order for a better understanding of the problems, challenges, and solutions to digital preservation, archival

scholars have begun to offer theoretical frameworks to elucidate the issue. The literature analyzed for this project offered many different definitions and understandings of definitions of key concepts in digital preservation such as "digital object," "significant properties," and "authenticity."

Digital Preservation.

Perhaps the most fundamental of these debates is over the definition of "digital preservation." Scholars have offered several different opinions. Strodl's definition is a typical example of the succinct, general definition of digital preservation: "Digital preservation is the process of keeping electronic material accessible and usable for a certain period time."[27]

Lin, Ramaiah, and Wal have offered a more specific definition of digital preservation, listing the essential characteristics of correctly preserved records. They assert that, "An electronic record is preserved if and only if it continues to exist in a form that allows it to be retrieved, providing reliable and authentic evidence of the activity that produced the record."[28] Specific, theory based definitions like this are much more rare. The majority of the articles surveyed for this paper do not address the concept of "digital preservation" at all.

Nearly all definitions of digital preservation are based on several other key terms. In general, we can say that digital preservation is the process of authentically preserving the significant properties of digital objects over time. "Authenticity," "significant properties," and "digital objects" are all defined below.

Digital Objects.

If digital preservation is about preserving reliable, authentic digital objects over time, we must also define what we mean by "digital object" to fully understand digital

preservation. Deceptively, the definition of digital object is by no means clear. As Clifford Lynch has pointed out, when you begin to think hard about preservation "it becomes difficult to understand and agree about exactly what we are trying to preserve."[29] Many scholars have broken the concept down into distinct parts. Most notably, Kenneth Thibodeau offers a tripartite view of digital objects. Thibodeau argues that digital objects are composed of: (1) a physical object, "the inscription of signs on some physical medium;" (2) a logical object, "an object that is recognized and processed by software;" and (3) a conceptual object that is "recognized and understood by a person." Each of these components is necessary to preserve and each presents its own preservation challenges.[30]

Jeff Rothenberg draws a similar distinction. To him, digital documents are composed of a bit-stream and intellectual content. He understands a bit-stream as "an intended meaningful sequence of bits with no intervening spaces, punctuation, or formatting."[31] This is essentially identical to the "inscription of signs" in Thibodeau's conception. Further, Rothenberg's conception of intellectual content is very similar to Thibodeau's concept of a "conceptual object."

Raymond Lorie, at the IBM research center, draws a different distinction to define digital documents. He divides digital documents into two groups: "data files" and "programs." These two types of digital information are separated by their essential characteristics. According to Lorie "Functionality" is the preservation worthy component of programs; "intellectual content" is the significant component of data files. Lorie argues this formulation "differentiates between data archiving which does not require full emulation and program emulation which does."[32]

The National Archives of Australia understands digital materials not as discrete objects, but instead as a set of instructions used to create a series of unique "performances." They argue that:

> "Digital records cease to be digital objects and are, instead, the result of the mediation of technology and data. The experience of an object only lasts for as long as the technology and data interact. As a result, each viewing of a record is a new 'original copy' of itself."[33]

Other scholars have begun to re-understand "digital objects" not as discrete entities, but instead as groupings of "significant properties."[34] In this conception, digital preservationists must think about what is most essential for different types of digital materials, and focus on preserving these characteristics. Digital preservationists' conception of "significant properties" is discussed below.

A sound definition of digital object takes into account all of the different facets discussed in the literature. Such a definition would understand digital objects as computer-mediated processes, rendered by a set of software instructions that create human-readable information with certain human-selected, preservation-worthy significant properties. The significant properties of a digital document might include not only the appearance, content, functionality or "look and feel" of digital materials but also the processing speed, hidden data, code structure, or any other property of the material deemed significant.

Obsolescence and Incompatibility.

There is little disagreement about the definition of incompatibility or obsolescence in the literature. Obsolescence and incompatibility are related concepts used to explain the cause of digital objects inaccessibility. Incompatibility caused by obsolescence is the

single greatest threat to digital preservation.[35] Incompatibility is understood as the inability of two or more sets of instructions used to authentically render a digital to work together to render the digital object. For example, files created with the WordStar program are incompatible with MS Word 2007. That is, the instruction set in the WordStar file cannot be used by other programs to render the digital object. Similarly, programs intended for Apple's OS X are incompatible with the Windows Vista operating systems. Once again, the set of instructions within the Apple programs cannot be used by the Vista operating system. Obsolescence is a special case of incompatibility which implies that incompatibility has taken place because of technological change over time. We will return to these definitions of incompatibility and obsolescence in a later section.

AUTHENTICITY.

Digital preservationists, particularly digital archivists, have also struggled to define "authenticity" in digital environments. Authenticity is fundamental to all preservation or archival endeavors, including digital preservation.[36] After all, what's the good of preserving digital materials if they cannot be trusted?

In the paper world, the concept of authenticity is quite clear. The Society of American Archivists defines authenticity as: "The quality of being genuine, not a counterfeit, and free from tampering, and is typically inferred from internal and external evidence, including its physical characteristics, structure, content, and context."[37] In digital environments, the concept becomes much muddier. As Thibodeau has insightfully pointed out, there is an "inherent paradox" about authenticity in digital preservation. Digital preservationists must strive to deliver unaltered, authentic documents to the future; however, because of the nature of computing environments, doing so inevitably requires alteration.[38] Thus, the traditional understanding of authenticity cannot apply.

In 1994 David Bearman took a firm stance on digital authenticity, claiming that most digital documents are not records and therefore inauthentic. He claimed that:

> ". . . most information created and managed in information systems is not a record because it lacks the properties of evidence. . . Information captured in the process of communication will only be evidence if the content, structure, and context information required satisfying the functional requirements for record keeping is captured, maintained, and usable."[39]

In May of 2000, the Council on Library and Information Resources (CLIR) outlined four fundamental questions about authenticity in digital environments: (1) How much and what parts of a digital document must be preserved to maintain authenticity? (2) What does "original" mean in digital environments? (3) What role does provenance play in the authenticity of digital documents? (4) What are the implications of the fact that digital documents depend on suites of hardware, software, and networks to be rendered.[40]

The CLIR report offered several different answers to these questions, but ultimately agreed on a few principles. Collectively, they asserted that authentic digital documents need to be kept in a trusted repository. They also agreed that the authenticity of digital documents could be measured against three points of reference:(a) another reference object; (b) metadata; and (c) the "digital recipe" or set of instructions used to create the object. Digital archivists and users might use any of these points of reference to assess the authenticity of a document. The CLIR report also emphasized the role of reliable provenance in digital preservation, arguing that it is "as important in the digital world as in the analog world, if not more so."[41]

Others have not paid explicit attention to defining authenticity but have implicitly interpreted the concept within their preservation strategies. To ensure the authenticity of

digital objects, preservationists must preserve not only the objects themselves but also significant amounts of context use to interpret and identify the object. Lim Siew Lin has pointed out that "the absence of critical metadata has made most collections of electronic data, electronic documents, or information not records because they cannot qualify as evidence."[42] Lin and his team at Nanyang Technological University in Singapore have developed five criteria to judge the authenticity of digital materials. They argue that:

> "Demonstrating the authenticity of electronic records depends on verifying that:
> - The right data was put into storage properly.
> - Either nothing happened in storage to change this data or alternatively any changes in the data over time are insignificant.
> - All the right data and only the right data were retrieved from storage.
> - The retrieved data were subjected to an appropriate process; and
> - The processing was executed correctly to output an authentic reproduction of the record."[43]

Perhaps wisely, they leave evaluative terms such as "properly," "insignificant," and "appropriate" fluid and undefined.

Margaret Hedstrom and other members of the CAMiLEON project have encouraged archivists to re-think authenticity concerns in terms of user demands. In one of their studies, which tested user's reactions to emulated, migrated, and original digital documents, they found that users "inferred [authenticity] mainly from the contents and writing style" of documents, rather than metadata or chains of provenance, to determine and judge the authenticity of digital documents.[44] With this finding, Hedstrom and her team imply an important question: if users are satisfied with the authenticity of digital documents, do digital archivists need to be worried? This question suggests a practical, if somewhat tautologous definition of authenticity: documents are authentic if users judge them to be authentic, digital documents are trustworthy if they are trusted.

In most of the literature reviewed for this paper, many scholars have largely avoided directly defining the concept of authenticity. Instead, they reference the concept of authenticity, identify it as a challenging concept and concern, and make simple, general statements about its meaning in digital environments, such as "in general, the closer one stays to the original technology and original data format of the records, the less the problem of authenticity."[45]

Working from this assumption, some have attempted to side-step the problem of digital authenticity by advocating systems that preserve the "original" bit-stream of digital documents and render them in their "original" environments. Proponents of emulation and the computer museum approach claim that their methods are superior because they preserve "original" documents.[46] These arguments, however, prove dubious when one considers how the nature of digital technology "obviates the idea of a unique item."[47]

These are only a few perspectives on "authenticity" in digital environments. The question of what constitutes an authentic, reliable digital record is by no means settled. However, considerations about "significant properties" and what is "essential" to digital documents subsume and make tangible concerns about authenticity.

SIGNIFICANT PROPERTIES.

Many scholars and digital preservationists have begun to understand digital preservation as the process of authentically preserving the "significant properties" or "essence" of digital materials, rather than the materials themselves. Thinking in these terms somewhat clears up concerns about authenticity. Preservationists need not worry about the authenticity of the document as a whole, and instead ask if the significant properties of a document have been authentically preserved. Thus, there is no all-

encompassing criterion for authenticity, but rather unique sets of criteria for specific digital documents used for specific purposes. When considering the significant properties of digital objects, the focus of preservation moves from the records themselves to human judgments about the records. As David Bearman's has argued, some preservationists are "fundamentally trying to preserve the wrong thing by preserving the information system functionality rather than the record itself."[48] Focusing on the significant properties of a digital object will help digital preservationists overcome this tendency.

The definition of significant properties that most digital preservationists have used is intuitive and somewhat uninformative. Helen Helsop provides a convenient example: "the essential characteristics of a record are what we call the 'essence' of a record . . . the characteristics that must be preserved for the record to maintain its meaning over time."[49] Members of the CAMiLEON project offer a similar, if more substantial definition: "Significant properties are the features, attributes, or properties that impinge upon the future use are understood as significant properties . . . [which] warrant ongoing preservation to their demonstrated or predicted contributions to the appearance, interpretation, or usability of digital objects."[50] The significant properties of a digital object may be, it seems, whatever archivists choose them to be.

This is somewhat uncomfortable for preservationists because it is subjective and open to human error. As Helsop has noted, "determining the essence of records is not a science and is open to subjectivities and archival interpretation, but it is essential to an efficient, effective, and accountable preservation program."[51]

Understanding digital objects as suites of significant properties is a somewhat uncomfortable departure from long-standing conceptions from paper preservation. However, it is necessary. If digital preservationists fail to consider the significant

properties of their materials, they potentially risk either loosing essential qualities of their materials or squandering resources to preserve inessential parts of digital documents.

Approaches to Combating Obsolescence.

As discussed in an earlier section, obsolescence is the most significant challenge of digital preservation.[52] The useful information in digital documents can only be accessed in very specific hardware and software environments. To access digital information you must open the right file in the right program running on the right operating system in the right hardware environment. This is only the simplest model. Some materials require two or more specifically configured operating systems as well as one or more supporting applications. Some digital materials also require special input-output hardware. To render a digital document each of these components must be able to work with the others. If one component along this chain of software and hardware becomes unusable, the entire digital document becomes inaccessible.

Digital archivists have traditionally used three different approaches to combat the problem of hardware and software obsolescence: (1) the computer museum model; (2) migration; and (3) emulation.[53] This section of the paper will explore each of these in turn, focusing particularly on the final two, emulation and migration. It will first describe each process, how it helps combat obsolescence, and the advantages and disadvantages of each process.

Computer Museums

The computer museum approach is perhaps the simplest strategy for combating software adolescence. This approach does not combat obsolescence so much as simply circumvent it. In this model, old software, hardware, and files are simply preserved

together in their original formats. No components go obsolete because everything is always rendered in the hardware and software environment for which it was intended.[54] For example, WordStar word processing documents intended for use on computers from the early 90's running Windows 3.1 are preserved by saving the original files, on their original physical media, as well as a computer from the early 90's running WordStar and Windows 3.1. Thus, when the files are booted in 2009 they appear exactly as they did in the early 1990's because they are running an identical hardware and software environment. Earlier in the history of computing this may have seemed an attractive option. It is conceptually and practically simple, and seems to circumvent some concerns about authenticity in digital environments. The National Archives of Australia has called it "archivists' first reaction" to the problem of digital obsolescence.[55]

In two related papers, D.O. Stephens has given the computer museum approach more complete attention than other scholars. In Stephens' formulation, proper implementation of the computer museum approach relies on five criteria: preserving (1) the original hardware and software of systems as well as (2) recording systems and media, (3) operating systems, (4) operation manuals and (5) "ample" spare parts. Stephens also suggests that digital archives be transcribed every 10 – 20 years.[56]

The drawbacks of this approach are immediately obvious and scholars have been quick to point them out. Most notably, to use Steward Granger's language, "it is unlikely that old machines could be kept running indefinitely at any reasonable cost" because "old digital documents will rarely survive on their original digital media" and "computer chips have a limited life span."[57] Given the rate of decay of computer hardware and media, scholars have estimated that obsolete systems are unlikely to be functional for more than 15 years.[58]

Further, the computer museum approach allows for no back-up plan. Other preservation strategies save digital materials in multiple formats and in multiple places. In the computer museum model, once your last machine is broken all the materials intended to run on it are essentially lost. To digital preservationists this is a very unwelcome prospect.

Computer museums also fail in other significant ways. They limit access by rooting digital documents to a certain physical location. They are also incapable of preserving the complex networks of files used by many modern digital objects. For these and other reasons, most of the literature dismisses the computer museum approach or simply excludes it entirely. As Andrew Waugh has put it, the computer museum approach is ill advised in "all but exceptional circumstances."[59]

Some scholars, however, have pointed out the value of the computer museum approach if used in concert with other digital preservation strategies. Kynong-Ho Lee argues that the computer museum approach may be the best short-term solution for some types of digital objects because it preserves access tools as well as the object itself.[60] Stewart Granger has pointed out "minor roles" for the computer museum approach: testing emulators and helping with data recovery.[61] Thus, it is probably unwise to dismiss the computer museum approach entirely, but, based on an analysis of the literature addressing this approach, its place in successful digital preservation is decidedly limited.

MIGRATION

Software obsolescence is caused by the incompatibility of old file formats with new computing environments. One way to overcome this problem is to "move digital documents from obsolete software and hardware formats to contemporary ones."[62]

This is the Society of American Archivists' definition of the process called "migration." This process has also been called "conversion" or "translation."[63] Further, migration has been more broadly defined as the process of simply moving digital objects from one format to another.

The initial format need not be obsolete and the new format need not be contemporary. Digital preservationists might migrate digital files from less useful contemporary formats to other more tractable contemporary formats.[64] Lee calls the process of migrating digital objects from less desirable file formats to more desirable file formats "standardization."[65] Most often however, migration involves both an update to a newer format and an update to a more standard format. Thus, the processes of "standardization" and "migration" are often indistinct.[66]

Software developers have a strong economic motivation to build backwards compatible software that facilitates migration. Developers want users to purchase their new software, not continue with an old system that is compatible with their older files.[67] Despite this, old software is often made obsolete by newer software, and given the rapid pace of technological innovation, digital preservationists predict that migrations may need to be carried out as often as every two or three years.[68] When newer software is released there is usually a "window of opportunity" in which software exists to open both types of files. During this window, digital objects can be migrated fairly easily using proprietary software.[69] Thus, migration, if done by hand, often requires little programming skill.

The critics of a migration approach usually offer two arguments against the process: (1) it threatens the authenticity of digital objects by gradually changing them over time, and (2) it is labor intensive and thus squanders resources.

Nearly all of the literature reviewed for this paper addresses the potential erosion of digital documents from continual migration. Stewart Granger makes a typical statement: "The notable danger [of migration] is that of data loss, or in some cases, the loss of the original functionality or the 'look and feel' of the original platform."[70] This is because each migration preserves only a "certain fraction" of the characteristics of a digital object.[71] Sometimes that fraction is substantial and encompasses all of the significant properties of a digital object, sometimes it does not.

Nonetheless, the potential threat migration poses to digital objects remains largely a matter of theory. Scholars predict that migration will change digital documents, but find it difficult to predict how and to what extent digital documents will be altered.[72] Proponents of migration are unable to prove that migration will work reliably into the future. All they can say is that migration has worked until now.[73]

In addition to gradual erosion of digital objects, critics of migration have also argued that migration is more expensive and labor intensive than emulation. Erik Oltmans of the National Library of the Netherlands focused on this argument for a 2005 comparison of the costs of emulation and migration. Oltmans argues that because "each and every single object in the digital archive has to be converted, again and again . . . the size of the collection directly affects the migration costs." So, while migration is appropriate for small collections, "the bigger an archive gets the higher the migration costs." This, Oltmans concludes, makes migration a less scalable and sustainable preservation strategy than emulation.[74]

Jeff Rothenberg offers a critique of migration as a digital preservation strategy. In his piece "Avoiding Technological Quicksand: Finding a Viable Technical Foundation for Digital Preservation," Rothenberg vehemently argues that migration is labor

intensive, time-consuming, expensive, error prone, risky, and non-scalable. As a result, Rothenberg advocates emulation as a superior digital preservation strategy over the long-term.[75]

Despite these arguments, many scholars have endorsed the migration approach as a strong candidate for long-term preservation. Stewart Granger dismisses arguments about the work and expense of migration, arguing that "one has to ask 'labor intensive, expensive, etc' compared with what? It is impossible to evaluate these claims . . . since so much of it remains a long way off."[76] Similarly, researchers for the CAMELiON project have pointed out that:

> "All preservation strategies [not just migration] can alter the presentation, appearance, behavior, and even content of digital objects, whether converting digital information from one format to another, migrating it to current generations of hardware and software, or using emulation."[77]

Many of the authors analyzed in this study advocated migration in certain cases. David Bearman, writing in response to Rothenberg, endorses migration as a useful strategy in many, if not most, digital preservation scenarios.[78] Raymond Lorie feels that "migration is quite reasonable when the information that is being converted will, most likely, be used in the near future."[79] Clifford Lynch claims that migration is "a very effective strategy, at least for a large class of materials that have 'document like' characteristics."[80] Thus, the analysis supports that there is scholarly consensus that migration has an important role to play in digital preservation to a lesser or greater extent.

EMULATION

Emulation is the mirror image of migration. Rather than modifying older digital documents to make them compatible with newer hardware and software this strategy attempts to create software to run on new computers to allow them to render digital

materials in their original formats.[81] This is done using a piece of software called an emulator which attempts to faithfully re-create the original computing environment of digital documents.[82]

Emulation is formally defined by the Society of American Archivists as "the process of reproducing obsolete software and hardware environments on contemporary systems so that old documents may be accessed in their original form."[83] The National Library of Australia defines emulation more broadly, removing the temporal element: "Emulation is the process of setting up a system to perform in the same way as another system of a different type in order to run its programs."[84]

Digital preservationists have clarified these formal definitions by pointing out the emulation can be carried out at any level of a computing environment. Most often it entails emulating a particular program, but preservationists might also emulate an operating system or hardware environment.[85] Further, emulators need not reproduce all of the functionality and characteristics of the original system. If it suits a repository's goals, emulators need only reproduce some of the functionality of the original system.[86]

Emulators have been used in computer science and engineering for many decades. In the 1950s and early 1960s IBM used emulators to allow computer scientists to use programs created for earlier machines on updated hardware. At that time, each hardware system was completely different than its predecessors and thus required emulators. This practice was in place until the System 360 computer was introduced in the mid-1960s.[87]

Apple also used emulators in the early 1990's when it moved from Motorola 6800 chips to PowerPC chips in its Macintosh computers. These emulators seamlessly integrated into the new hardware and software. Most users didn't even know that they were using emulators.[88]

A thriving, grass-roots emulation community has also sprung up around preserving old video games and making them compatible with modern personal computers. Video game enthusiasts have created emulators to mimic the hardware of nearly every video game platform, from cartridge consoles to old arcade machines.[89]

Although it had been around for decades, Jeff Rothenberg first introduced emulation as a potential method of long-term digital preservation in 1995.[90] Since then, digital preservationists have debated, analyzed, and tested the concept. It has both its champions and its critics.

Stewart Granger has laid out the three positions on emulation within the digital preservation community. There are those who believe it is "a simple universally acceptable, quick fix," those who believe that "emulation has no role to play in digital preservation" and those in the middle who feel that "emulation, sometimes at least, may play a role in rescue operations."[91]

Jeff Rothenberg is the most notable champion of emulation as a digital preservation strategy. In his 1999 piece "Avoiding Technical Quicksand," Rothenberg offers a ringing endorsement of emulation. He claims that it better preserves the "look and feel" of digital objects and therefore more reliably ensures authenticity. He argues that because digital preservationists are not certain what parts of a digital document will be used, they best serve their users by preserving digital objects whole-sale, in their original formats. Rothenberg supplements his argument with the critique of migration discussed in the previous section.[92]

Rothenberg correctly identifies many of the strengths of emulation as a preservation strategy. Emulation has much in common with the computer museum approach in that it allows materials to be run in their original formats in software

environments similar to their original environments. This often means that more characteristics of digital documents are preserved and may lessen preservationists' concerns about authenticity.[93] Clifford Lynch has suggested that whatever digital information is preserved "deliberately or by accident, sooner or later some scholar will undoubtedly exploit it to very interesting use in some context."[94]

Rothenberg and other scholars have also correctly argued that emulated digital objects tend to be more similar in "look and feel" to their original form than migrated documents. Migration, scholars have argued, often focus on the intellectual content of records while emulation preserves "not only the content of the record, but also the tangible aspects of its presentation, such as color, layout, and functionality."[95]

Proponents of emulation also point out that emulation is automated and, once emulators are created, they can be used to render all of the digital material intended to run on the emulated format. Thus, although emulation requires a significant initial investment of time and resources, it requires very little extra cost once the emulator has been created. Because of this, some have argued that emulation is more cost effective than migration for large repositories over the long term.[96]

Just as there are proponents of emulation, there are also critics. David Bearman has been the most vocal of these critics. Writing in response to Rothenberg, Bearman argued against emulation in, "Reality and Chimeras in the Preservation of Electronic Records." Bearman argued that emulation is often "serious overkill." Here, he argues that preserving the significant properties of a digital object often does not require full emulation and repositories are better served with simple, cost effective, migration solutions.[97]

Kenneth Thibodeau, writing in 2005, agreed with Bearman that "the preserving of a digital information object does not necessarily entail maintaining all of its digital attributes. . . it is common to change digital attributes substantially to ensure that essential attributes of an information object are preserved."[98]

The National Archives of Australia also agrees: "Preserving all the characteristics of a performance [of a digital object] can result in a large amount of resources being spent on preserving elements that are inconsequential to the records archival meaning . . . archivists need to determine which elements of a performance are essential for the record to retain its meaning, and to focus on preserving them."[99] Considerations of significant properties seem to subsume debates about how emulation better preserves the authenticity of digital objects.

Copyright restrictions also present a challenge to emulation strategies. Often both the source and target of emulation are protected by the copyright of software producers. When preservationists create emulators copyright may be violated.[100] This has been a significant problem in the world of video game preservation. Game creators have taken substantial measures to protect their copyrights and many websites that offered emulators and ROM images of video games have been shut down.[101]

Scholars have also pointed out that emulation may potentially limit access to digital documents. Migration converts digital files to common formats that can likely be used with software already installed on users' computers. Emulation, however, requires users to install the emulation environment and obtain the original file before they can view the object. This may limit some users from using digital documents remotely.[102]

AMBIGUITIES ABOUT EMULATION AND MIGRATION IN PRESERVATION LITERATURE

The benefits and drawbacks of both emulation and migration have been hotly debated among digital preservationists and neither preservation strategy has emerged as the out-and-out superior strategy. Rather, recent publications endorse a multi-faceted strategy involving elements of emulation and migration as well as considerations about significant properties, resource allocation, and user needs.[103] The next section of this paper attempts to further endorse this view by illustrating the conceptual similarities between emulation and migration for user-focused repositories.

Although there has been much debate about emulation and migration and which is the superior strategy., findings from the literature analysis suggests ambiguity in the definition of emulation and migration, and is illustrative of how the concepts sometimes overlap, especially when viewed from a user perspective.

The CAMELiON project, which focused on user reactions to emulation and migration, illustrates this ambiguity. Users were asked to compare emulated, migrated, and original versions of two different digital objects. The CAMELioN team found that "subjects noticed very minor differences between the original and the emulated and migrated versions."[104] There was little difference in users' perceptions of emulated and migrated versions. Through careful migration, the team had created what Thibodeau has called a "respectful conversion": "a conversion cannot be distinguished when viewed from an interface of the same type."[105] From a user perspective, a "respectful conversion" appears very similar to an emulated "original" object.

Similarly, in "Migration – A CAMiLEON discussion Paper," Paul Wheatley points out that "with more complex digital objects it is not immediately clear how these would be migrated or what migration in this context actually means."[106] In a related

CAMELiON paper, Margaret Hedstrom argues that "high-level comparisons of emulation versus migration are not very useful for evaluating different digital preservation strategies . . . migration is not a single, unified concept."[107]

Ken Thibodeau has also illustrated the similarity between emulation and migration. Not only with this concept of "respectful conversion" but also with his understanding of "conceptual objects." Conceptual objects, once again, are digital objects "as recognized and understood by a person." Conceptual objects are those understood by the user. Further, he asserts that "there can be different digital encodings [using emulation or migration] of the same conceptual object and that different encodings can preserve the essential characteristics of the conceptual object."[108] So, a set of significant properties are the same conceptual object whether they are rendered using emulation or migration.

Conclusion

The terms coded and analyzed for this study have been used in various ways throughout the literature. The definitions of some terms, like "obsolescence" and "incompatibility," are fairly stable, well agreed on definitions. Other terms, such as "authenticity," and "digital object" have been defined many different ways by different scholars. There has been a great deal of debate about "emulation" and "migration," the two most popular digital preservation strategies. These two processes have been defined and understood in different ways by different scholars who argue for or against a certain processes. Certain articles have even pointed out some ambiguity in popular conceptions of emulation and migration.

The results of this study suggest that digital preservationists and scholars should pay close attention to the concepts they use before they begin a digital preservation project. Because there is some disagreement about how the key terms defined in this paper were understood in the literature, ambiguities in the definitions could lead to miscommunication or unclear results.

Like any study, the methodology and conclusions of this paper are limited. The most notable of these limitations comes from the methodology. There is a very large body of literature about digital preservation, and time and technology restraints may have resulted in an incomplete survey. Further, using a more subjective methodology like content analysis necessary limits and colors the analysis, which is always effected by the mind of the researcher.

Future studies could examine a wider body of literature, or reinterpret the findings of this study to further sharpen the definitions understood in this paper. The list of terms used in this study could be expanded and updated as the field of digital preservation continues to grow. Future studies could also use alternate methodologies to analyze the key terms identified in this study. For example, researchers could survey case studies to interpret how the concepts discussed in this study have been understood in practice. Alternately, future researchers could survey digital preservationists to identify how these terms are popularly understood.

NOTES

[1]K. H. Lee et al., "The State of the Art and Practice in Digital Preservation," *Journal of Research – National Institute of Standards and Technology 107, no. 1 (2002): 93.*

[2] Margaret Hedstrom et al., "'The Old Version Flickers More': Digital Preservation from the User's Perspective," *American Archivist* 69, no. 1 (January 1, 2006): 159.

[3]S. Strodl et al., "How to Choose a Digital Preservation Strategy: Evaluating a Preservation Planning Procedure," in *Proceedings of the 7th ACM/IEEE-CS Joint Conference on Digital Libraries*, (2007), 29–30.

[4] Margaret Hedstrom, "Digital Preservation: A Time Bomb for Digital Libraries," *Computers and the Humanities* 31, no. 3 (1997): 189.

[5]Library of Congress, "Digital Preservation (Library of Congress)," http://www.digitalpreservation.gov/.

[6] Lee, "Art and Practice," 94.

[7] C. Lynch, "Preserving Digital Documents: Choices, Approaches, and Standards," *Law Library Journal* 96 (2004): 615.

[8] K. Thibodeau, "Overview of Technological Approaches to Aigital Preservation and Challenges in Coming Years," *The State of Digital Preservation: An International Perspective* (2002): 24–25.

[9] H. Heslop, S. Davis, and A. Wilson, "An Approach to the Preservation of Digital Records," *National Archives of Australia* (2002), 11.

[10]Frank McCarthy, "Digital Preservation - Making the Song Remain the Same," *Records Management Journal* 18, no. 2 (2008): 108.

[11] Strodl, "Evaluating . . Preservation Planning," 30.

[12] Christopher Lee, Syllabus: Information Technology for Digital Preservation, School of Information and Library Science, University of North Carolina at Chapel Hill, Fall 2008.

[13] Christopher Lee and Helen Tibbo, Syllabus: Seminar in Digital Curation, School of Information and Library Science, University of North Carolina at Chapel Hill, Spring 2008.

[14] Jeffrey Pomerantz, Syllabus: Digital Libraries, School of Information and Library Science, University of North Carolina at Chapel Hill, Spring 2008.

[15] Carolyn Hank and Helen Tibbo. Syllabus: Seminar in Digital Curation, School of Information and Library Science, University of North Carolina at Chapel Hill, Fall 2008.

[16] Creative Archiving at Michigan and Leeds Emulating the Old on the New, "CAMiLEON Project," http://www.si.umich.edu/CAMILEON/.

[17] Keeping Emulation Environments Portable, "KEEP - Keeping Emulation Environments Portable," http://www.keep-project.eu/ezpub2/index.php/.

[18] School of Information and Library Science, University of North Carolina at Chapel Hill, "DigCCurr Carolina Digital Curation Curriculum Project," http://ils.unc.edu/digccurr/.

[19] University of Edinburgh, "Digital Curation Centre," http://www.dcc.ac.uk/.

[20], Charles W. Bailey, Jr.,"Scholarly Electronic Publishing Bibliography." http://www.digital-scholarship.org/sepb/archive/75/sepb.html.

[21] Kathleen Carley, "Coding Choices for Textual Analysis: A Comparison of Content Analysis and Map Analysis," *Sociological Methodology* 23 (1993): 75-126.

[22] Marilyn Domas White and Emily E. Marsh, "Content Analysis: A Flexible Methodology," *Library Trends* 55, no. 1 (2006): 22-45.

[23] Carley, "Coding Choices," 1993.

[24] Magda Vassiliou and Jennifer Rowley, "Progressing the Definition of "e-Book"," *Library Hi Tech* 26, no. 3 (2008): 355-368.

[25] Suzie Allard, Thura R Mack, and Melanie Feltner-Reichert, "The Librarian's Role in Institutional Repositories: A Content Analysis of the Literature," *Reference Services Review* 33 (2005): 325-336.

[26] Thibodeau, "Technological Approaches to Digital Preservation."

[27] Strodl, "Evaluating ... Preservation Planning," 29.

[28] Lim Siew Lin, Chennupati K. Ramaiah, and Pitt Kuan Wal, "Problems in the Preservation of Electronic Records," *Library Review* 52, no. 3 (2003): 118.

[29] Lynch, "Preserving Digital Documents," 611.

[30] Thibodeau, "Technological Approaches to Digital Preservation" 3-5

[31] Rothenberg, "Ensuring the Longevity of Digital Documents," *Scientific American* 272, no. 1 (1995): 24–9.

[32] Lorie, R. A Lorie, "Long Term Preservation of Digital Information," in *Proceedings of the 1st ACM/IEEE-CS Joint Conference on Digital libraries*, 2001, 347.

[33] Helsop, "Preservation of Digital Records," 8.

[34] Bram Lohman, "Keeping the "Digital Dark Age" at Bay," *Records Management Bulletin*, no. 149 (May 2009): 23.

[35] Lin, "Preservation of Electronic Records," 119.

[36] CLIR Report, "Authenticity in a Digital Environment," http://www.clir.org/pubs/reports/pub92/contents.html. Introduction.

[37] SAA Glossary, http://www.archivists.org/glossary/term_details.asp?DefinitionKey=9.

[38] Thibodeau, "Technological Approaches to Digital Preservation," 27.

[39] D. Bearman, "Metadata Requirements for Evidence," *Manuscript. http://www.archimuse.com/papers/nhprc/BACartic.html* (1994).

[40] CLIR Report, "Authenticity in Perspective."

[41] Ibid., ¶ 14.

[42] Lin, "Preservation of Electronic Records," 120.

[43] Lin, "Preservation of Electronic Records," 118.

[44] Headstrom et al. "Digital Preservation ... User Perspective," 183.

[45] Lin, "Preservation of Electronic Records," 119.

[46] Lee, "Art and Practice," 95;
Bearman, "Reality and Chimeras," ¶ 5.

[47] CLIR Report, "Authenticity in Perspective." ¶ 10.

[48] D. Bearman, "Reality and Chimeras in the Preservation of Electronic Records," *D-Lib Magazine* 5, no. 4 (1999): 1–5.

[49] Helsop, "Preservation of Digital Records," 13.

[50] Headstrom, "The Old Version," 162.

[51] Helsop, "Preservation of Digital Records," 14.

[52] Lin, "Preservation of Electronic Records", 119.

[53] Lee, "Art and Practice," 95.

[54] A. Waugh et al., "Preserving Digital Information Forever," in *Proceedings of the Fifth ACM Conference on Digital Libraries*, 2000: 177.

[55] Helsop, "Preservation of Digital Records," 10.

[56] D. O. Stephens, "Digital Preservation in the United Kingdom," *Information Management Journal*, Vol. 4 No. 4, (2000), 68-71.

[57] Stewart Granger, "Emulation as a Digital Preservation Strategy," *D-Lib Magazine* 6, no. 10 (2000), http://webdoc.sub.gwdg.de/edoc/aw/d-lib/dlib/october00/granger/10granger.html.

[58] Helsop, "Preservation of Digital Records," 10-11.

[59] Waugh, "Preserving Digital Information," 177.

[60] Lee, "Art and Practice," 95.

[61] Granger, "Emulation."

[62] Pearce-Moses, Richard. *Migration*. "Society of American Archivists Glossary of Archival and Records Terminology," (2005), http://www.archivists.org/glossary/term_details.asp?DefinitionKey=84.

For a more complete institutional definition of migration see the National Library of Australia's glossary at : <http://nla.gov.au/download/dsp/appendicies.pdf>

[63] Rothenburg, ". . .Longevity of Digital Documents."
Lorie, "Long Term Preservation," 347.
Lynch, "Preserving Digital Documents," 612.

[64] Strodl, "Evaluating . . Preservation Planning", 30.
Helsop, "Preservation of Digital Records," 11.

[65] Lee, "Art and Practice," 103.

[66] Granger, "Emulation."

[67]Lynch, "Preserving Digital Documents," 612.

Notably, Stewart Granger disagrees with the view that software vendors support migration. He notes that "vendors have exacerbated the problem of digital preservation" because "it suits vendors to make everyone constantly upgrade hardware, software, and operating systems and not to worry about backwards compatibility." ¶ 16

[68] Lin, "Preservation of Electronic Records", 120.

[69] Lorie, "Long Term Preservation," 347
Lynch, "Preserving Digital Documents," 612.

[70] Granger, "Emulation," ¶ 2.

[71] Strodl, "Evaluating ... Preservation Planning," 31.

[72] Lorie, "Long Term Preservation," 347.

[73] Lynch, "Preserving Digital Documents," 613.

[74] E. Oltmans and K. Nanda, "A Comparison between Migration and Emulation in Terms of Costs," *RLG DigiNews*, 9, (2006), *http://www.rlg.org/en/page.php*.

[75] Rothenberg "Avoiding Technological Quicksand."

[76] Granger, "Emulation," ¶ 26.

[77] Headstrom, "Digital Preservation . . .User Perspective," 161.

[78] Bearman, "Reality and Chimeras."

[79] Lorie, "Long Term Preservation," 347.

[80] Lynch, "Preserving Digital Documents," 613.

[81] Lynch, "Preserving Digital Documents," 613.

[82] Oltmans, "Emulation and Migration in Terms of Cost."

[83] Pearce-Moses, Richard. *Emulation.* "Society of American Archivists Glossary of Archival and Records Terminology." (2005), http://www.archivists.org/glossary/term_details.asp?DefinitionKey=83.

[84] National Archives of Australia, *Emulation,* "National Library of Australia Glossary," http://nla.gov/download/dsp/appendicies.pdf.

[85] Granger, "Emulation".
Strodl, "Evaluating . . Preservation Planning," 30.

[86] Helsop, "Preservation of Digital Records," 12.

[87] Lynch, "Preserving Digital Documents," 613-614.

[88] Lynch, "Preserving Digital Documents," 614.

[89] Saltzman, Marc "Keys to the Kingdom" *Electronic Gaming Monthly*, (2001).
Lynch, "Preserving Digital Documents," 614.

[90] Headstrom, "Digital Preservation . . . User Perspective," 161.

[91] Granger, "Emulation," ¶ 65.

[92] Rothenberg, "Technical Quicksand."

[93] Lee, "Art and Practice,",95.
Headstrom, "Digital Preservation . . . User Perspective," 161.

[94] Lynch, "Preserving Digital Documents," 612.

[95] Headstrom, "Digital Preservation . . . User Perspective," 161.

[96] Oltmans, "Emulation and Migration in Terms of Cost."

[97] Bearman, "Reality and Chimeras."

[98] Thibodeau, "Technological Approaches to Digital Preservation," 24–25.

[99] Helsop, "Preservation of Digital Records," 14.

[100] Granger, "Emulation."

[101] Marc Saltzman, "Keys to the Kingdom."

[102] Helsop, "Preservation of Digital Records," 12-13.

[103] This, ultimately, is the conclusion of several authors, including:
Thibodeau, "Technological Approaches to Digital Preservation"; Headstrom, "Digital Preservation . . . User Perspective"; Helsop, "Preservation of Digital Records"; Oltmans, "Emulation and Migration in Terms of Cost"; Strodl, "Evaluating … Preservation Planning."

[104] Headstrom, "Digital Preservation . . . User Perspective," 171.

[105] Thibodeau, "Technological Approaches to Digital Preservation," 23.

[106] Wheatley, "Migration discussion paper."

[107] Headstrom, "Digital Preservation . . . User Perspective," 186.

[108] Thibodeau, "Technological Approaches to Digital Preservation," 7.

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