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Limitations and possibilities of digital restoration techniques using generative AI tools: Reconstituting Antoine François Callet's Achilles dragging hector's body past the walls of troy

Charles O'Brien
The University of Alabama in Huntsville

James Hutson
Lindenwood University, jhutson@lindenwood.edu

Trent Olsen
Lindenwood University, tolsen@lindenwood.edu

Jay Ratican
Lindenwood University, jratican@lindenwood.edu

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Limitations and possibilities of digital restoration techniques using generative AI tools: Reconstituting Antoine François Callet's *Achilles dragging hector's body past the walls of troy*

Charles O'Brien[1], James Hutson[2]*, Trent Olsen[2], and Jeremiah Ratican[3]

[1]Department of Art, Art History, and Design, University of Alabama in Huntsville, Huntsville, Alabama, USA

[2]Department of Art History and Visual Culture, College of Arts and Humanities, Lindenwood University, Saint Charles, Missouri, USA

[3]Department of Art, Media, and Production, College of Arts and Humanities, Lindenwood University, Saint Charles, Missouri, USA

Abstract

Digital restoration offers new avenues for conserving historical artworks, yet presents unique challenges. This research delves into the balance between traditional restoration methods and the use of generative artificial intelligence (AI) tools, using Antoine François Callet's portrayal of *Achilles Dragging Hector's Body Past the Walls of Troy* as a case study. The application of Easy Diffusion and Stable Diffusion 2.1 technologies provides insights into AI-driven restoration methods such as inpainting and colorization. Results indicate that while AI can streamline the restoration process, repeated inpainting can compromise the painting's color quality and detailed features. Furthermore, the AI approach occasionally introduces unintended visual discrepancies, especially with repeated application. With evolving restoration tools, adaptability remains crucial. Integrating both AI and traditional techniques seems promising, though it is essential to maintain the artwork's inherent authenticity. This study offers valuable perspectives for art historians, conservators, and AI developers, enriching discussions about the potential and pitfalls of AI in art restoration.

Keywords: Digital restoration; Generative artificial intelligence; Stable diffusion; Inpainting techniques; Synergistic techniques; Art restoration

***Corresponding author:**
James Hutson
(jhutson@lindenwood.edu)

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1. Introduction

Digital innovations have ushered in transformative approaches to cultural heritage preservation, introducing capabilities such as three-dimensional modeling of historical cities and interior spaces[1,2]. Early digital twins and virtual environments enabled a deeper exploration and understanding of heritage sites and artifacts for both scholars and the general public[3,4]. The integration of 3D scanning and photogrammetry stands out, adeptly digitizing collections like the sculpture displays of the Uffizi Galleries[5]. Such digital resources, in conjunction with industrial tools, have been instrumental in real-time monitoring of historical sites, proactively addressing potential deterioration concerns[6,7].

While earlier technological integrations primarily centered around photogrammetry, digital twins, and 3D modeling, the rise of generative artificial intelligence (AI) tools heralds a new era, boasting transformative capabilities in swiftly reconstructing damaged or lost artworks[8]. Advancements such as hand-held scanning technologies coupled with cutting-edge rendering engines have facilitated the production of high-quality digital assets, ensuring both precision and speed[9,10]. Given this backdrop, the present research seeks to elucidate the potential and pitfalls of deploying generative AI tools in the realm of digital restoration, complementing traditional methods while also resolving pressing questions about the ethical and aesthetic dimensions of these collaborative techniques.

In advancing this academic dialogue, focus shifts to the conceptualization of a novel workflow centered on generative AI. Beyond the conventional paradigms of capturing or replicating cultural heritage artifacts, this research aims to unearth the possibilities of reconstructing works — whether they are damaged or entirely lost. Guided by a methodical analytical structure, the research will critically assess the technological constraints and challenges of prevailing digital restoration techniques, paving the way for the refined implementation of AI-driven solutions. The amalgamation of AI with traditional techniques presents an opportunity not only to streamline the reconstruction process but also to re-evaluate the ethical, esthetic, and interpretative facets intrinsic to the preservation of cultural heritage. Therefore, the subsequent discourse stands as an incisive exploration of this nascent domain, offering both practical revelations and academic reflections to those immersed in the stewardship of the world's cultural treasures.

2. Literature review

The academic investigation of digital preservation within cultural heritage, viewed through the prisms of digital art history and digital humanities, is an evolving domain, a notion echoed by Hutson and Olsen.[11] Tracing back to 2001, the initial efforts to digitize cultural artifacts were largely anchored within academic and institutional realms. Pioneering projects, such as those by the Foundation of the Hellenic World, harnessed CAVE technology to produce digital replicas of historical sites, with Miletus — a former Athenian colony and later under Roman dominion — standing out as a prime illustration[1]. The potential of this technological advance for museums and heritage institutions quickly gained traction, encapsulated by Roussou's concept of "edutainment."[12]

As the new millennium progressed, museums started integrating extended reality experiences. Noteworthy early endeavors include The Museum of Pure Form and The Virtual Museum of Sculpture[13], tailored to a general audience and designed for brief interactions, optimizing visitor movement within exhibition spaces[14]. These *in situ* digital experiences gradually evolved into comprehensive virtual museum environments, as seen in ventures like The Exploratorium and the EU-sponsored CREATE project[15]. Parallel to these advances, augmented reality tools were pivotal in the comprehensive digital representation of museum collections, with a notable instance being the endeavors of the Center for the Art of East Asia at the University of Chicago[16]. Yet, a significant democratizing shift in virtual learning environments (VLE) can be attributed to the 2011 inception of Google's Arts and Culture platform, amplified by the 2014 introduction of Google Cardboard, an affordable head-mounted display designed for educational immersion[17]. Subsequent years witnessed the birth of diverse VLEs, such as those associated with the Rijksmuseum and the National Archeological Museum of Marche[18,19].

In contemporary times, the proliferation of digital twins for preserving cultural heritage has seen notable expansion, accentuated by global events like the pandemic. Bevilacqua *et al.*[20] have illuminated applications ranging from the digital replication of Italy's inaugural Parliament to the illustrious Charterhouse of Pisa in Calci. Conversely, Tan *et al.*[21] shed light on Asian methodologies, accentuating the digital archiving of Xiegong, a salient architectural motif prevalent in historic Chinese edifices. Such eclectic endeavors underscore the pressing need for synergistic collaboration between technical experts and academicians, aiming to devise authentic digital analogs that champion the cause of cultural heritage conservation.

Yet, despite the richness of existing literature detailing various case studies and techniques centered on digital twins within the realm of cultural heritage preservation, a discernible lacuna persists: a comprehensive exploration of the instrumental role that generative AI tools might play in hastening the restoration of tarnished or vanished cultural artifacts. Indeed, while endeavors have been made harnessing AI in the domain of cultural heritage conservation, the ascendancy of refined machine learning algorithms, coupled with burgeoning computational prowess, has positioned AI's role in conservation and restoration as a paragon of pioneering scholarship. Multiple academic pursuits traverse this confluence of technological innovation and heritage preservation, bequeathing the academic world with an array of methodological and conceptual frameworks.

Kim and Lee's research,[22] centered around the utilization of artificial neural networks, illuminates the

intricate restoration of cultural treasures by meticulously identifying distinct roof tile variations. The pivotal essence of their undertaking stems from the adept employment of AI in distinguishing nuanced deviations in cultural motifs, a vital prerequisite for precision-led restoration endeavors. Parallelly, Li's scholarship[23] accentuates the virtuosity of amalgamating virtual reality with AI in championing the cause of cultural heritage conservation. This melding foregrounds the viability of embracing expansive, multi-dimensional strategies for heritage preservation.

A recent breakthrough in AI-centric scholarship is epitomized by the work of D'Orazio*et al.* in 2023,[24] wherein the trio delved into the potential of long short-term memory neural networks. Their primary objective entailed processing maintenance requests from end-users, thus laying the groundwork for anticipatory conservation paradigms. Such paradigms, if effectively deployed, could circumvent potential deterioration, thereby eliminating the exigency for more invasive restoration techniques. This investigative trajectory finds resonance with the research endeavors of Moreno *et al.*,[25] where fuzzy logic served as the linchpin to evaluate environmental ramifications on heritage structures, thereby weaving together an intricate tapestry of conservation strategies. Contrarily, Bordoni *et al.*[26] postulate that AI's methodologies and techniques stand as potent catalysts for the archival, conservation, and appreciation of cultural heritage. Their academic exploration offers an expansive vista, paving the way for successive research endeavors and shedding light on the transformative potential of AI in the realm of heritage conservation. Not to be overlooked is the contribution of Ranaldi and Zanzotto,[27] which ventures into the conceptual territory of self-empiricist logic. Their proposition articulates the transformative capability of contemporary AI mechanisms in reshaping the traditional paradigms of heritage preservation.

Emerging from the academic discourse is two pronounced trajectories: the first emphasizes the conservation and rejuvenation of physical artifacts and architectural edifices, while the second plumbs the depths of the ethereal dimensions of cultural heritage. Delving into the realm of the intangible, Yu *et al.*[28] proffer an incisive exploration, accentuating the versatility of AI in architecting recreational spaces dedicated to intangible cultural legacies. Regardless of whether the emphasis lies in the adept utilization of neural networks for meticulous restoration endeavors or in the orchestration of foresight-driven models for anticipatory conservation, AI's potential as a transformative agent in cultural heritage stewardship stands uncontested. Consequently, the synthesis of expertise from AI connoisseurs with insights from heritage conservators represents an indelible imperative, ensuring the evolution of holistic and potent strategies within this domain. The forthcoming segment pivots toward an emergent paradigmatic trajectory: an intricate dissection of generative AI and its prospective significance in reviving and restoring absent or impaired facets of cultural heritage.

3. Methodology

3.1. Selection of artwork and region of interest

For this investigative endeavor, the selected artwork was Antoine François Callet's (1741–1823) portrayal of *Achilles Dragging Hector's Body Past the Walls of Troy* from the years 1784–1785 (Figure 1). The artwork's established provenance is anchored in Pietro Antonio Martini's (1738–1797) panoramic engraving of the Salon from 1785 (Figure 2). A particular area of interest for this research is the top right section of the painting, showcasing a celestial or demonic female entity, characterized by extended wings and armed with a likely dagger or athame. This specific segment was earmarked for experimental restoration, given the significant wear and tear surrounding this figure. Notwithstanding the damage, the depicted figure remains largely preserved.

3.2. Software utilization and algorithmic approach

The restoration experiment incorporated the use of the generative imaging platform known as Easy Diffusion (referenced from Easy Diffusion README, n.d.). This software is underpinned by the algorithmic framework of Stable Diffusion 2.1. The choice of this tool was motivated by its economic viability and its adherence to the General Public License (https://stability.ai/blog/stablediffusion2-1-release7-dec-2022). The software offers two primary modes of operation: text-to-image and image-to-image, thereby allowing a range of flexibility for the restoration process. Of particular note is the software's "inpainting" feature, where users can selectively mask areas for flaw correction or detail generation.

3.3. Initial recolorization and area-specific restoration

For the restoration, the experiment harnessed the capabilities of image-to-image prompts for inpainting, an approach grounded in the methodology prescribed by Oncu *et al.*[29] The inaugural recolorization was concentrated on the painting's background facets. Focal elements,—namely, the female figure, the brown fabric, the hands of Achilles, and the equine figure —benefited from a refined restoration process, marked by the introduction of semi-transparent color masks. The application of these masks was executed with precision, ensuring a congruent alignment with

Figure 1. Antoine François Callet, *Achilles Dragging Hector's Body Past the Walls of Troy* (1784–1785), Louvre, Paris. Source: Photo by the authors on November 16, 2022.

Figure 2. Pietro Antonio Martini, *View of the Salon 1785,* 1785, engraving. Metropolitan Museum of Art, New York (detail of Antoine François Callet, *Achilles Dragging Hector's Body Past the Walls of Troy* (1784–1785), Louvre, Paris). Source: Photo by the authors on November 16, 2022.

their neighboring regions, thereby curbing any visual discrepancies. To further enhance visual cohesiveness, supplemental layers of color masks were superimposed onto the background, with specific emphasis on areas proximal to the female figure and the depicted limbs.

3.4. Stable diffusion terminology and technique

Within the Stable Diffusion framework, several terminologies define the nuanced processes integral to restoration. The term "inference steps" pertains to the methodical enhancement of the image, with each step leading to further refinement. The stabilization of this enhancement is embodied in the "diffusion" process. The use of "guidance" signifies the deployment of reference imagery to bolster accuracy, while "prompt strength" dictates the degree of initial input into the system. The resultant image's clarity and authenticity are encompassed under "image quality." Of paramount significance to this research, the "inpainting" procedure encompasses the act of designating specific regions of the image for modification or the infusion of new details, as articulated in Stable Diffusion 2.1 (2022).

3.5. Stable diffusion prompting procedures

In undertaking the restoration process, the Stable Diffusion framework was initialized using a random seed and tailored to accommodate an image dimension of 768 × 768 pixels. The restoration commenced with an initial series of 25 inference steps, followed by additional sequences of 25 steps each, all meticulously evaluated for their visual consistency and quality. Within this process, a guidance scale of 7.5 was consistently adhered to. The prompt strength oscillated between 0.25 and 0.5, an adjustment designed to ensure an equilibrium between authenticity and revitalization during the restoration. Aiming to mirror the integrity of the original piece, the image quality parameter was anchored at 75. Furthermore, during the inpainting process, the prompt strength was elevated to 0.7, thereby broadening the spectrum of potential restoration nuances.

The methodological exactitude underpinning this research elucidates the complementary relationship between time-honored art conservation methods and the rapidly evolving domain of AI. Following this methodology exposition, the forthcoming section will transition to an analysis of the findings, placing a pronounced emphasis on the role of generative AI in the rehabilitation of imperiled or vanished elements within the vast repository of cultural heritage.

4. Results and discussion

During the initial phase of restoration, a meticulous manual technique was employed, targeting a specific segment of the original painting (Figure 3). Intensive color masking strategies were implemented, complemented by the introduction of noise and caustic effects to accentuate select attributes. Despite these efforts, the outcome rendered only a slight revitalization of the deteriorated segments of the

artwork. The resultant image conspicuously underscored the constraints tied to the nuances of human craftsmanship and interpretation.

In the ensuing phase, AI mechanisms were employed, leveraging the capabilities of Stable Diffusion. The parameters set for this endeavor included a prompt strength of 50%, a guidance scale of 7.5, and a commencement of 25 inference steps (Figure 4). Intriguingly, the AI exhibited a propensity for misinterpretation: rather than faithfully restoring the damaged sections, the AI reconstructed them as entirely distinct celestial entities. Such an outcome underscores the challenges AI encounters in deciphering and preserving the inherent artistic intent, echoing the insights propounded by Yu *et al.* (2021) about the crucial role of human oversight in ensuring accuracy and authenticity.

Figure 3. Manual painting and recolorization. Source: Photo by the authors of their own portrayal of *Achilles Dragging Hector's Body Past the Walls of Troy* on May 22, 2023.

Venturing further, the study experimented with an integrated approach, harmonizing manual restoration techniques with AI functionalities (Figure 5). A precise descriptive prompt was input into the AI model, elaborating on various facets and elements intrinsic to the painting. This was complemented by a host of technical determinants, including seed values and specified dimensions. In this phase, the inpainting function was employed judiciously to rectify minor imperfections. The parameters deployed were comprehensive: encompassing a detailed description of the painting's elements, a designated seed, explicit dimensions, and other technicalities such as inference steps and the guidance scale. Notably, the amalgamation of manual expertise with AI acumen culminated in an outcome that bore a close resemblance to the original artwork. However, this outcome was not without minor inconsistencies, especially in terms of color fidelity and the visibility of certain superficial imperfections.

An exhaustive exploration into the efficacy of inpainting was undertaken, marked by multiple iterations to determine optimal outcomes (Figure 6). Following the initial two rounds, a conspicuous reduction in visible imperfections was observed. However, this came at the detriment of the integrity of color representation, especially affecting the nuanced details of Achilles' hands and facial contours. Proceeding to the fifth round, an almost complete obliteration of scratches was achieved, yet this was accompanied by an altered color gradient. By the ninth round, a paradoxical outcome emerged: while surface imperfections were entirely effaced, there was a discernible compromise in the granularity of intricate

Figure 4. Artificial intelligence-based restoration. Source: Photo by the authors of their own portrayal of *Achilles Dragging Hector's Body Past the Walls of Troy* on May 22, 2023.

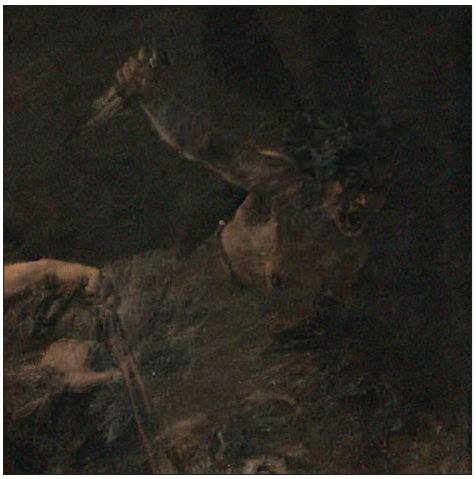

Figure 5. Confluence of manual and artificial intelligence techniques. Source: Photo by the authors of their own portrayal of *Achilles Dragging Hector's Body Past the Walls of Troy* on May 22, 2023.

Figure 6. Effects of inpainting. Source: Photo by the authors of their own portrayal of *Achilles Dragging Hector's Body Past the Walls of Troy* on May 22, 2023.

details, with the background presenting a pixelated appearance. This trajectory of initial blemish rectification followed by a subsequent deterioration in image quality, particularly regarding color spectrum and intricate detailing, mirrors the experiences documented across a spectrum of AI-driven art restoration applications. Such observations underline the imperative to exercise judicious restraint when deploying inpainting techniques, given their latent inclination to inadvertently compromise the comprehensive image quality while addressing localized imperfections.

Drawing insights from Figures 4 and 5, contrasting implications emerge. The former resonates with the potency of synergizing human dexterity with AI faculties, while the latter presents an evident deviation from the quintessential characteristics of the original artwork. Such contrasting outcomes lend credence to the irrefutable role of human discernment in effectively directing machine learning trajectories. These findings underscore the pivotal relevance of a collaborative paradigm, one that synergistically integrates the precision of manual restoration with the expansive capabilities of computational methodologies. The entirety of the restoration trajectory, whether driven by manual expertise, AI modalities, or their confluence, reinforces the quintessential need for a comprehensive strategy in safeguarding cultural heritage relics. While the AI realm presents transformative capabilities, enabling unprecedented precision and detail enhancement, it concurrently poses challenges, particularly pertaining to preserving authentic color dynamics and the inadvertent risks of excessive refinement. Conversely, the domain of manual restoration remains unparalleled, especially when the requisites extend beyond mere technical rectification to encompass the domain of subjective aesthetic interpretations, a realm where human conservators excel.

In summation, the findings elucidate the profound potential inherent in the symbiotic fusion of time-honored artistic methodologies with contemporary machine-learning paradigms. These outcomes resonate emphatically with the prevailing academic discourse, advocating for an equilibrated modus operandi in restoration endeavors. Such an approach positions conservators and machine learning aficionados to adeptly traverse the intricate nexus binding the realms of art and technology. The results further affirm the arguments presented by Yu *et al.* (2021), emphasizing the imperative of an integrated framework that harmoniously aligns the precision of technology with the subjectivity and nuance of traditional conservation. The subsequent segment will delve deeper, offering a rigorous, multi-faceted critique and a comprehensive discourse on the implications of these pivotal discoveries.

5. Conclusion

The current research stands as a significant contribution to the dynamic arena of art conservation through the prism of AI. Originating from dual paradigms — namely, tangible conservation and the nuances of intangible cultural facets — the inquiry judiciously integrated both manual restoration methodologies and the advancements of AI, exemplified by the utilization of Stable Diffusion, in the restoration process of Antoine François Callet's celebrated painting, *Achilles Dragging Hector's Body Past the Walls of Troy*. Central insights gleaned from this research highlight the inherent complexity of achieving optimal restoration outcomes. While manual techniques provide depth of interpretation, they falter in terms of precision and adaptability — dimensions where AI exhibits prowess. However, the latter occasionally struggles to encapsulate the subtle essence and idiosyncrasies of original masterpieces.

The ramifications of this study are especially salient in the context of a discipline that consistently confronts challenges associated with the erosion and attrition of invaluable cultural heritage assets. Echoing the insights propounded by Yu *et al.* (2021), there exists a vast reservoir of potential within AI, capable of rejuvenating both the tangible and intangible dimensions of cultural artifacts. Through its findings, this research underscores the imperative of fostering interdisciplinary collaborations, bridging the expertise of machine learning professionals with the sensibilities of heritage conservators to forge forward-thinking conservation methodologies. Yet, as with any scholarly endeavor, this inquiry is not devoid of caveats. The deployment of inpainting techniques, while enhancing specific image attributes, inadvertently compromised the

overarching image quality. Such outcomes accentuate the pressing need for algorithmic advancements — algorithms that transcend mere replication to truly fathom the nuances of artistic creation.

Looking ahead, the logical trajectory for research would encompass melding diverse machine-learning models with the sagacious insights of human conservators. Potential explorations might span the spectrum of three-dimensional artifacts and venture into the rich tapestry of intangible heritage, encompassing oral traditions and live performances. Moreover, methodical investigations aimed at fine-tuning inpainting parameters, harmonizing meticulous detail retention with holistic image quality, emerge as promising avenues warranting academic pursuit. In essence, this research should not be perceived as an endpoint but rather as a vantage point — providing a panoramic view of past accomplishments while illuminating potential paths for future exploration. By amalgamating the virtues of both manual craftsmanship and digital innovation, this study lays a foundational stone, guiding interdisciplinary endeavors toward more holistic, nuanced, and efficacious strategies, all in service of safeguarding and celebrating the rich tapestry of global cultural heritage.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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