

An Annotation Tool for Digital Restoration of Wall Paintings

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Abstract

Antique paintings are essential to study and understand our past. Paintings, and specifically mural paintings, are delicate artworks that are affected by multiple deterioration conditions. Weathering and human interventions cause different damage problems, and physical and chemical changes degrade their visual color appearance. As a consequence, art historians and archaeologists require a huge effort to attempt to rebuild their original appearance. The annotation of digital images of the paintings is a valuable tool in this process. In this paper we analyze major requirements from art historians concerning the annotation of painting regions from the point of view of digital restoration. We also describe a tool prototype (based on TagLab) intended to facilitate the annotation and segmentation of mural paintings. The tool assists art historians in formulating multiple hypotheses on the original appearance by supporting multiple annotation layers for degradation and color, providing both hand-drawn and semi-automatic segmentation, and offering web-based dissemination and sharing of the annotations through the W3C Web Annotation Data Model.

CCS Concepts

• Applied computing → Fine arts; • Computing methodologies → Image processing;

1. Introduction and Previous Work

Antique paintings are a major component of our cultural heritage. Besides their intrinsic aesthetic qualities to express ideas and emotions, antique paintings play an essential role in helping scholars to understand our past. Unfortunately, antique paintings suffer a degradation process over the years that hinder their study and prevent viewers to fully appreciate the artworks.

Mural paintings are affected by multiple deterioration processes [ico15, SMFPSu20]: humidity, weathering, ambient conditions, structural problems and anthropogenic interventions are some of the factors affecting mural paintings. These factors result in degradation, flaking and cracking, and thus the loss of artistic content. Even in well-conserved regions, the passage of time produces physical and chemical changes that modify the visual appearance of the colors. As a consequence, the colors seen by contemporary visitors might depart significantly from the color palette used by the artists, and reconstructed tonal ranges are often speculative.

Virtual restoration aims at recovering the original state of a digitized artifact or art work, as it would appear after a real, physical restoration [Lim17]. Many authors have focused on the restoration of paintings, either by removing the effects of color degradation [PP00, MAM21], cracks [GP98], or detached and lost parts [ODH12]. Complex interventions, however, still often rely on manual work [Lim17, LP20]. Prior to restoration, a diagnostic stage is often necessary to analyse the state of conservation of the paint-

ing and its constituent materials. In this matter, multispectral analysis has become a common practice in order to identify pigments and degradation patterns [CPD*18]. From this data, a common mapping stage is typically done by experts to annotate damaged regions and identify painting regions, so there is a need of appropriate tools to facilitate this task [PGF*20].

The more content is missing, the more critical is to facilitate archaeologists and art historians to formulate and share different hypotheses on the missing parts. Such hypotheses cover a large range of topics, such as the original color palette, the shapes, tones, and textures in the missing parts, as well as the resources used by the artists; furthermore, such annotations must be linked to the different pictorial phases and restoration campaigns.

All this knowledge can greatly benefit from digital image annotation tools, and thus software designed specifically for Cultural Heritage often allows users to annotate the models. Examples include 3DHOP [PCS18], Cher-ob [WSA*18] and Aioli [CCDL*20]. Ponchio et al. [PCDS20] and Croce et al. [CCDL*20] review several methods for 2D/3D annotations over CH models. Most approaches focus either on how hand-drawn annotations are entered and presented, or provide fully-automated solutions for specific problems.

In this paper we present a prototype tool to assist art historians in the process of annotating mural paintings. Our tool fills the gap between automatic tools for specific problems (crack detection, segmentation, inpainting) and manual (hand-drawn) techniques. The



Figure 1: Example of virtual restoration: acquired image, line-drawing reconstruction, color restoration, and degradation map. Image credit: [LP20].

tool, based on TagLab [PGF*20], provides computer-assisted annotation for digital restoration, covering common needs of art historians, who need to annotate image fragments ranging from coarse selections (e.g. rectangles) to precise pixel-wise segmentations. Our main contributions are the definition of experts' requirements on annotations processes and the prototype that fulfills them.

2. Annotations for digital restoration: expert needs

The needs below have been identified thanks to our collaboration with art history teams from different countries, in the context of *anonymous*, an ongoing research project for the analysis, documentation, interpretation, restoration, and communication of medieval artistic heritage. We focus on needs closely related with the study and digital restoration of mural paintings.

Identification of degraded fragments Antique paintings often exhibit fragments with varying degrees of degradation; from small cracks only visible in close-up views, to large missing parts with no traces of the original paint. Figure 1 shows one example. The image shows a mix of nearly well-conserved parts and deteriorated areas. The delimitation of the different regions is important for art historians. For example, image restoration techniques (e.g. through inpainting or line drawings) should exclude non-recoverable regions. For this reason, art historians need to identify these different regions and associate the corresponding label to them. Notice that the regions to be annotated have arbitrary shapes and thus require complex contours. Therefore, supervised classification techniques based on user-provided examples can greatly reduce the manual selection effort.

Annotation by presumed original color A major task of art historians and restorers is to formulate hypotheses on the original color palettes. Simulating visually the result of applying different color palettes requires a segmentation of the painting into different regions that are assumed to share the same original color. In well-conserved regions, a color-based selection should suffice. Unfortunately, degraded areas imply that experts should decide the boundary of these regions. Ideally, the tool should allow users to perform automatic, example-based segmentations, and let them to manually correct the boundaries/labels of misclassified regions. The tool should also provide a quick preview of a digitally restored painting according to different color palettes.

Annotation by resources, techniques and materials Digital restoration and painting analysis is a complex process and art his-

Concept	Image regions	Label values	Label colors	Attributes
Degradation	Complex contours	Dict-based	Arbitrary	Confidence
Presumed color	Complex contours	Dict-based	User-defined	Confidence
Resources	Simple contours	Dict-based	Arbitrary	User-defined
Content	Basic contours	Free	Arbitrary	User-defined

Table 1: Summary of mural painting concepts, along with some typical requirements for their annotation.

torians rely on multiple types of knowledge about the paintings. Besides degradation and color, art historians often require additional information about each zone, such as current color, pigments, preservation state, and resources used by the artists: the density and thickness of the paint, how the figures and volumes were modeled, and so on. Moreover, annotations modeling different concepts should be grouped into independent layers to facilitate their inspection and editing with minimal clutter.

Pictorial content annotations Besides the pixel-wise annotations above, art historians also need to annotate larger parts of the paintings with a rough, coarse boundary (single points, rectangular regions). These annotations can be used for example to highlight figures and identify parts of the iconography.

Easy sharing A crucial need of art historians is to share easily the annotated images with colleagues. Ideally, other experts should be able to inspect and edit the annotations in commodity hardware (PC, tablets), using a web-based solution.

Table 1 summarizes and compares the needs described above in terms of the complexity of the image regions to be annotated, the required labels, their visual representation, and typical region attributes.

3. Proposed solution

Structuring annotation projects Figure 3 illustrates the structure of a project using a representative example. A project (e.g. a particular wall within a monument) consists of a collection of maps. Maps have associated an RGB image (e.g. a photo of the painting) and optionally a depth map. Users can add an arbitrary number of annotation layers to a map: degradation, presumed color at a specific decoration phase, artistic resources, and so on. Degradation and color layers have dictionary-based labels that are part of the project configuration, although users can create and edit labels through the application GUI. Each annotation layer includes an arbitrary number of regions (defined by one outer contour and zero or more inner contours) that can be assigned a label and different user-defined attributes. The organization of the annotations into different layers is key for avoiding clutter and to create independent annotations when studying different problems such as color or decay. The proposed structure is quite similar to that of [PGF*20]; the most notable differences are the fact that we require multiple annotation layers (each one with its own label dictionary) and therefore a different default dictionary is required for each type of annotation layer (e.g. degradation labels, color labels, artistic resource labels).

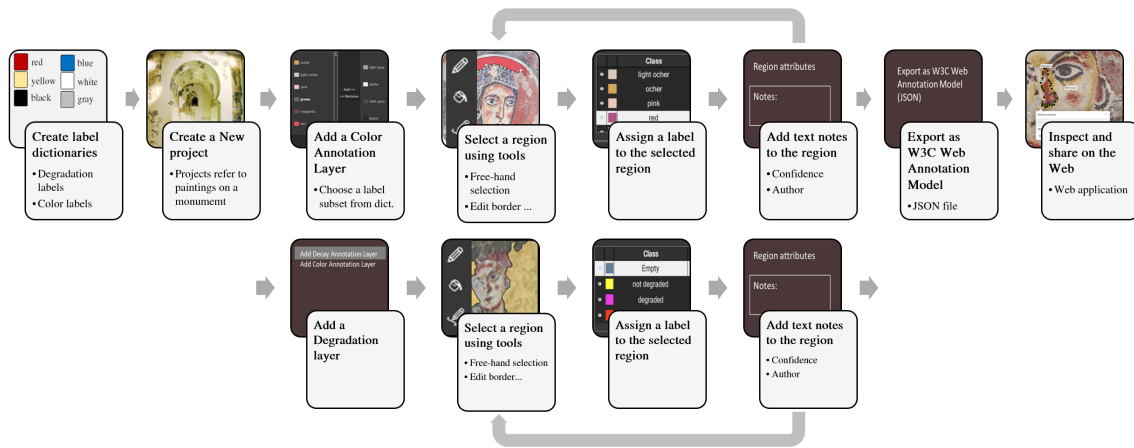


Figure 2: A suggested workflow for annotating mural paintings.

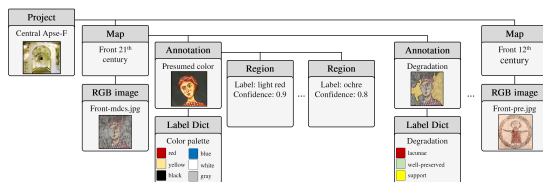


Figure 3: Simple version of a representative annotation project.

Intended workflow Figure 2 shows one suitable workflow for the annotation of mural paintings. A first step is to define the default dictionaries containing the labels for the different types of annotation layers. For example, the degradation dictionary might include the labels *non-degraded*, *degraded*, and *support*, whereas the color dictionary would include names for the different colors in a mural painting. After this step, art historians are expected to create a new project for each part of the monument, add one or more maps (photos) with the desired annotation layers, and then populate them by selecting regions using a variety of tools (hand-free drawing, border editing, and other selection tools typically found in image processing applications). Each selected region is then associated to a label and text notes and attributes. Annotation layers can be exported using the W3C Web Annotation Model, which is supported by a number of JS libraries.

Implementation details: creating annotations None of the annotation platforms we analysed completely fulfilled the requirements in Section 2. We thus opted to (a) adapt TagLab [PGF*20] to suit our needs, and (b) use the W3C Web Annotation Model together with a simple HTML+JS application for sharing the annotations. Most of the functionality we required for the annotation was already available in TagLab [PGF*20], a segmentation application currently focused on marine corals. TagLab uses a project structure quite close to that required by art historians, and provides a collection of selection tools (some of them relying on DeepLab V3+ [Jfz19] segmentation network) that greatly facilitate the selection of regions on the paintings. Furthermore, TagLab allows users

to train a segmentation network from an example segmentation of an image. The resulting model can be used to provide an initial automatic segmentation for similar images. We adapted TagLab interface to the particular task of annotating mural paintings. Major changes included the addition of multiple types of annotation layers (e.g. degradation layer, color layer), the addition of specific default dictionaries for the corresponding labels, and a new GUI to select a subset of the labels in the default dictionaries. We also added a per-region *confidence* value. This field is user-adjustable and it is also automatically filled from the probability map provided by DeepLab V3+ [Jfz19], in the case of automatic segmentations. Figure 5 shows a general view of the adapted interface, and Figure 4 a couple of dialogues.

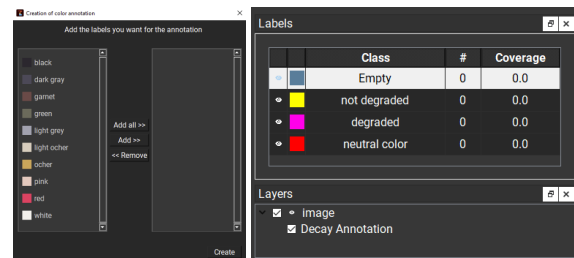


Figure 4: Selecting a subset of the color labels from the dictionary (left); assigning a degradation label for the selected regions (right).

Implementation details: sharing annotations Unfortunately, TagLab requires a Python kernel and multiple dependencies (e.g. PyTorch) which might not be suitable for easy sharing of the annotations to other art historians. We addressed this issue by exporting the annotations in a JSON file following the W3C Web Annotation Model. The model support SVG-based polygonal contours as well as varied text-based annotations. The resulting JSON files can be inspected using a simple web-based application based on the JS library *Annotorious*, which allows importing, rendering and editing the annotations (both the contours and the labels).



Figure 5: Interface of the tool, showing a segmentation in progress.

4. Results

The tool prototype is nearly ready for production. The authors have managed to use the tool to (a) create decay and color annotations manually, (b) train a neural network for the automatic segmentation according to the degradation level, and (c) train a neural network for color-based segmentation (we used existing TagLab features for training and inference). Figure 6 shows some examples. More examples can be found in the Github page of the project (*anonymous*).



Figure 6: Examples of segmentations created automatically from a training set consisting of a single photo. From left to right: photo and its color-based segmentation, and another photo with its degradation-based segmentation.

5. Conclusions and future work

The study and analysis of mural paintings is a complex process that involves different types of knowledge. In this paper we have focused on a key task to support this study: the annotation of images of the paintings. We have identified common needs from art historians regarding mural paintings, and we have used existing technologies (TagLab, Annotorious) to create a prototype to support both the manual and automatic segmentation and annotation of mural paintings. Although an art historian has already provided very positive feedback about the tool, we have conducted no user study yet with the intended users. As future work, we also plan to propagate annotations among images showing the same part of a painting (as in [CCDL*20]), even when the images to be annotated are not actual photos but projections of parameterized geometry.

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References

- [CCDL*20] CROCE V., CAROTI G., DE LUCA L., PIEMONTE A., VÉRON P.: Semantic annotations on heritage models: 2d/3d approaches and future research challenges. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 43 (2020), 829–836. 1, 4
- [CPD*18] COLANTONIO C., PELOSI C., D’ALESSANDRO L., SOTTILE S., CALABRÒ G., MELIS M.: Hypercolorimetric multispectral imaging system for cultural heritage diagnostics: an innovative study for copper painting examination. *The European Physical Journal Plus* 133, 12 (2018), 1–12. 1
- [GP98] GIAKOUMIS I., PITAS I.: Digital restoration of painting cracks. In *ISCAS’98. Proceedings of the 1998 IEEE International Symposium on Circuits and Systems* (1998), vol. 4, IEEE, pp. 269–272. 1
- [ico15] : *EwaGlos - European Illustrated Glossary of Conservation Terms for Wall Paintings and Architectural Surfaces*. Petersberg, Germany, 2015. URL: <http://openarchive.icomos.org/id/eprint/1706/>. 1
- [Jfz19] JFZHANG95: Deeplab v3+ model in pytorch. <https://github.com/jfzhang95/pytorch-deeplab-xception/>, 12 2019. 3
- [Lim17] LIMONCELLI M.: *Virtual restoration. Paintings and mosaics*. «L’ERMA» di BRETSCHNEIDER, 2017. 1
- [LP20] LIMONCELLI M., POTENZA M.: *Virtual Restoration 2. The frescoes of the Rock-Cut Church of Lama D’Antico near Fasano (Italy)*, vol. 241. «L’ERMA» di BRETSCHNEIDER, 2020. 1, 2
- [MAM21] MAALI AMIRI M., MESSINGER D. W.: Virtual cleaning of works of art using deep convolutional neural networks. *Heritage Science* 9, 1 (2021), 1–19. 1
- [ODH12] ONCU A. I., DEGER F., HARDEBERG J. Y.: Evaluation of digital inpainting quality in the context of artwork restoration. In *European Conference on Computer Vision* (2012), Springer, pp. 561–570. 1
- [PCDS20] PONCHIO F., CALLIERI M., DELLEPIANE M., SCOPIGNO R.: Effective annotations over 3d models. *Computer Graphics Forum* 39, 1 (2020), 89–105. 1
- [PCS18] POTENZIANI M., CALLIERI M., SCOPIGNO R.: Developing and maintaining a web 3d viewer for the ch community: an evaluation of the 3dhop framework. In *GCH* (2018), pp. 169–178. 1
- [PGF*20] PAVONI G., GIULIANI F., FALCO A. D., CORSINI M., PONCHIO F., CALLIERI M., CIGNONI P.: Another Brick in the Wall: Improving the Assisted Semantic Segmentation of Masonry Walls. In *Eurographics Workshop on Graphics and Cultural Heritage* (2020). 1, 2, 3
- [PP00] PAPPAS M., PITAS I.: Digital color restoration of old paintings. *IEEE Transactions on image processing* 9, 2 (2000), 291–294. 1
- [SMFSPu20] SOTO-MARTIN O., FUENTES-PORTO A., SCIENCES J. M.-G. A., UNDEFINED 2020: A digital reconstruction of a historical building and virtual reintegration of mural paintings to create an interactive and immersive experience in virtual reality. *mdpi.com* (2020), 597. 1
- [WSA*18] WANG Z., SHI W., AKOGLU K., KOTOULA E., YANG Y., RUSHMEIER H.: Cher-ob: A tool for shared analysis and video dissemination. *Journal on Computing and Cultural Heritage (JOCCH)* 11, 4 (2018), 1–22. 1