Understanding and Supporting Collaborative Annotation of Neuroanatomical Images through Semantic Versioning and Interactive History Exploration

Names of PhD Advisors

Julien Gori, CR CNRS
Gilles Bailly, DR, CNRS

Host Laboratory
ISIR (Institut des Systèmes Intelligents et de Robotique), Campus Pierre et Marie Curie, 4 place Jussieu, 75005 Paris.

Short Abstract

Large-scale neuroanatomical atlases rely on the contributions of multiple annotators with different levels of expertise working over long periods of time. However, existing tools provide limited support for tracking changes, understanding differences between annotations, and coordinating contributions across users.
This PhD aims at understanding and supporting collaborative annotation of neuroanatomical images. More precisely, it first studies current practices and identifies the constraints that impair collaboration in the long term. In particular, how current representations influence coordination, interpretation of changes, and conflict resolution among annotators. Based on these findings, it then proposes to study how novel versioning mechanisms can support collaborative annotation of complex image data. The outcome will be the design and the implementation of an open-source system that integrates semantic similarity metrics and interactive visualization of annotation histories. The system will be evaluated in-situ, in collaboration with neuroscientists using the ICM brainstem atlas, combining performance benchmarks with user studies to analyze both efficiency and collaborative practices.

Short Description of Hosting Research Lab
ISIR (https://www.isir.upmc.fr) is a multidisciplinary research center that brings together expertise in robotics, artificial intelligence, human-computer interaction (HCI), and more. The team involved in this project specifically draws on its strengths in HCI and interactive visualization, particularly in the design of adaptive and explainable systems enabling the intuitive exploration of complex data and meeting the needs of neuroscience experts.
ICM (https://icm-institute.org) is a research institute specializing in the field of neuroscience. It contributes its expertise in neuroanatomical imaging, provides access to specialized annotators, and offers a real clinical evaluation environment, particularly in relation to the brainstem atlas. The laboratory thus provides a solid scientific and practical foundation for testing and refining the tools being developed. The person of interest at ICM is Eric Bardinet.
The collaboration between ISIR and ICM offers a unique synergy between technological innovation and medical applications. It enables the development of powerful interactive tools validated in real clinical contexts, paving the way for better understanding and visualization of complex brain structures.

1. Context

Neuroanatomical atlases are essential resources in neuroscience, built through the annotation of large 3D image datasets (see Figure 1). Producing these annotations is time-consuming and requires domain expertise. In practice, annotation is a collaborative process involving multiple contributors with different levels of expertise.
This collaboration is typically asynchronous: annotators work independently, and experts later review and consolidate their contributions. Our first investigations suggests that their current tools offer limited support for:

- tracking the evolution of annotations over time,
- comparing different contributions,
- understanding how and why changes were made.

As a result, coordination relies heavily on manual effort, and important aspects of the collaborative process such as disagreements or iterative refinements remain difficult to trace and analyze.

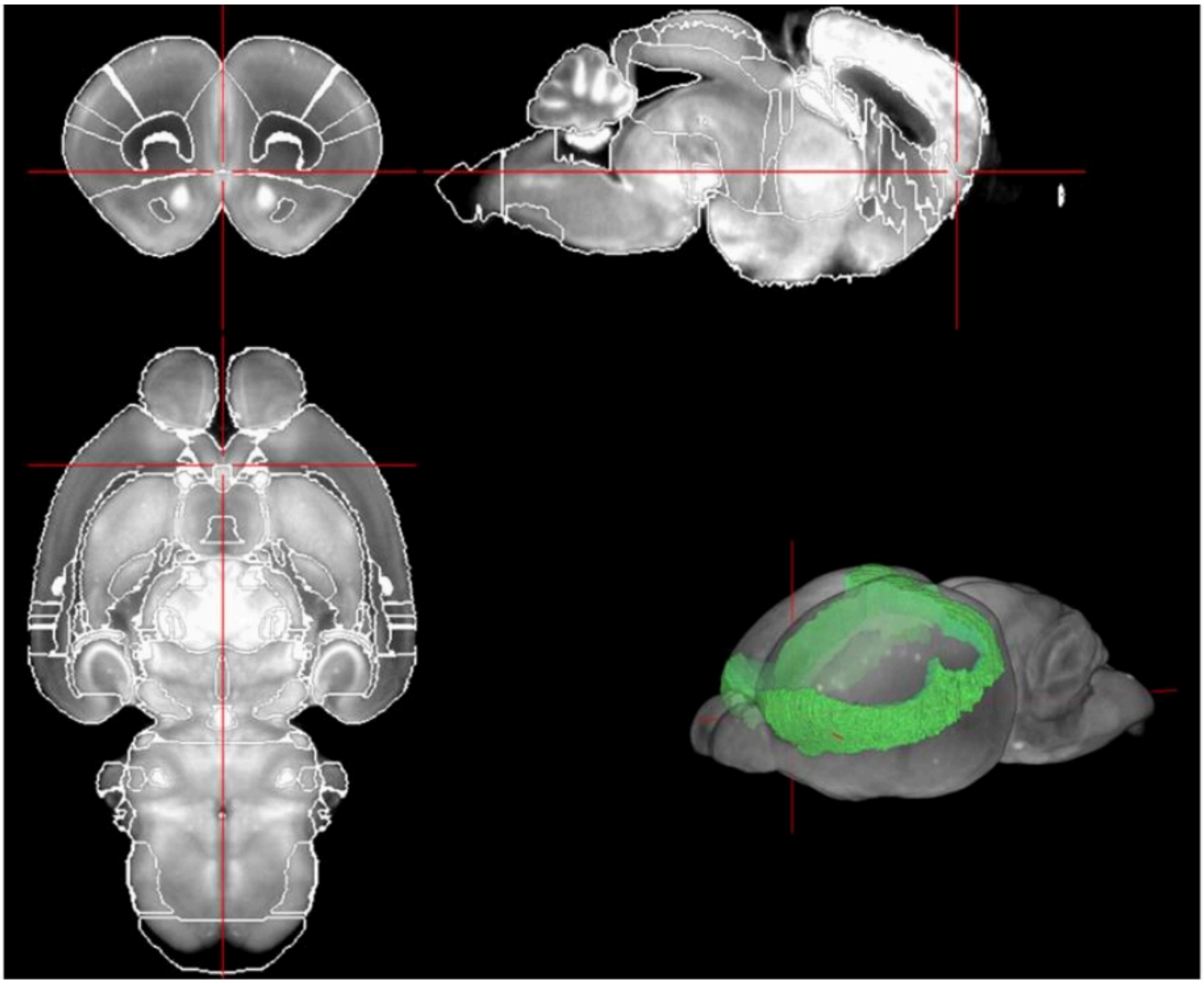

Fig1. screenshot of the ICM neuro-anatomical atlas. A segmentation of the gustatory area of the isocortex of an adult mouse is highlighted in green.

2. Problem Statement and Objectives

Traditional version control systems are not adapted to annotated image data. They treat images as binary files; thus they do not provide comparison mechanisms that capture meaningful differences between images and their annotations.

Beyond this technical limitation, there is also a lack of understanding of how versioning tools can support collaborative work on complex visual data. In particular:

- What constitutes a meaningful “difference” between annotations?
- How do users interpret and act upon these differences?
- How can these tools support the resolution of disagreements between contributors?

The objective of this PhD is therefore twofold:

- Understand the specificities of the neuromedical images and current collaborative practices around them.
- Design a versioning system adapted to neuroanatomical image annotations, integrating semantic similarity metrics and interactive history exploration.
- Study how such a system affects collaborative annotation practices, including coordination, interpretation of changes, and conflict resolution.

3. Research Questions

This project is structured around the following questions:

- RQ1 – Semantic Differences: How can meaningful differences between annotated images be defined and detected beyond pixel-level comparisons?
- RQ2 – Interpretation of Changes: How do annotators interpret differences between versions, and how does this influence their decisions during review and validation?
- RQ3 – Coordination through History: How do representations of annotation history support users in understanding past contributions and coordinating their work?
- RQ4 – Conflict and Resolution: How can versioning mechanisms support the identification and resolution of disagreements between annotators?

4. State of the Art

Versioning system. Existing tools such as ITK-SNAP and 3D Slicer provide powerful annotation capabilities but lack collaborative versioning features.

General-purpose systems like Git LFS and DVC manage large files but treat images as binary objects, limiting meaningful comparison and merge operations.

Recent work in computer vision, such as LPIPS (Zhang et al. 2018), introduces perceptual similarity metrics that better reflect human judgments of visual differences. In parallel, systems like RevG (Chen et al. 2011) and VRGit (Zhang et al. 2023) explore visual representations of editing history, while FileWeaver (Gori et al. 2020) demonstrates the potential of graph-based file management.

Collaborative annotation tools such as CATMAID (Saalfeld et al. 2009) have enabled multiple users to label large 3D image datasets together, while recent methods increasingly rely on weak or partial annotations (e.g., scribbles or sparse points) to reduce effort. These approaches make annotation more scalable, but they typically assume that labels come from a single user or are internally consistent. In practice, however, collaborative settings often involve multiple annotators providing incomplete and sometimes conflicting inputs. Existing systems offer limited support for resolving such disagreements, especially when labels are sparse, leaving conflict management in collaborative weak annotation largely unaddressed in current research. Further, these approaches do not investigate the larger question of how such tools impact collaborative practices.

5. Approach and Methods

5.1 Overall Approach

The project combines system design and empirical study. We will follow an iterative process:

- Study current annotation practices (interviews, observations)
- Design and prototype the system
- Deploy and evaluate it with users
- Analyze how it changes collaboration and decision-making

5.2 System Design

The study will require considering at least three aspects of collaborative mechanisms:

- Semantic Versioning: Integration of perceptual similarity metrics (e.g., LPIPS) to detect meaningful changes between annotation versions and guide commit and comparison operations.
- Dual Representation of Data and History, as in FileWeaver: 1/ A dependency view representing anatomical structures and their relationships 2/ A history view showing the evolution of annotations over time. These views will be linked to allow users to explore both structure and change.
- Interaction for Review and Comparison. Users will be able to:
    - compare versions,
    - identify significant changes,
    - navigate the history of annotations,
    - inspect differences in context.

5.3 Studying Collaborative Activity

A key aspect of this PhD is to analyze how the current and proposed systems are used in practice. We will study:

- how annotators interpret differences between versions,
- how they decide to accept, reject, or modify changes,
- how disagreements emerge and are resolved,
- how the history of changes is used to understand past decisions.

This analysis will rely on:

- user studies,
- interaction logs,
- qualitative observations.

6. Expected Contributions

Scientific Contributions

- A better understanding of how versioning supports collaborative work on complex visual data
- New insights into how users interpret differences and histories in annotation tasks
- Design principles for systems supporting collaborative annotation

Technical Contributions

- An open-source versioning system for annotated images
- Methods for semantic comparison of image annotations
- Interactive visualizations for exploring annotation history

7. Evaluation

Quantitative

- Performance of diff and merge operations
- Accuracy of semantic difference detection

Qualitative

- User studies with annotators and experts
- Analysis of collaboration patterns and decision-making processes
- Evaluation of how the system supports understanding and coordination

Bibliography

1. Chen, Tim & Wei, Li-Yi & Chang, Chun-Fa. (2011). Nonlinear Revision Control for Images. ACM Trans. Graph.. 30. 105. 10.1145/2010324.1965000.
2. Zhang, Lei & Agrawal, Ashutosh & Oney, Steve & Guo, Anhong. (2023). VRGit: A Version Control System for Collaborative Content Creation in Virtual Reality. 1-14. 10.1145/3544548.3581136.
3. Zhang, Richard & Isola, Phillip & Efros, Alexei & Shechtman, Eli & Wang, Oliver. (2018). The Unreasonable Effectiveness of Deep Features as a Perceptual Metric. 10.48550/arXiv.1801.03924.
4. Gori, Julien & Han, Han & Beaudouin-Lafon, Michel. (2020). FileWeaver: Flexible File Management with Automatic Dependency Tracking. 22-34. 10.1145/3379337.3415830.
5. Saalfeld, S., Cardona, A., Hartenstein, V., & Tomančák, P. (2009). CATMAID: collaborative annotation toolkit for massive amounts of image data. *Bioinformatics*, *25*(15), 1984-1986.

Nature of Digital Collaboration

The creation of neuro-anatomical brain atlases has gradually shifted from isolated expert-driven efforts to collaborative efforts (e.g., the Allen Brain Atlas launched in 2006), highlighting the need for digital infrastructures that record contributions to complex hierarchical datasets.

Functions:

- Sharing & Coordination: Contributors will upload new segmentations or modified segmentations to a shared repository; reviewers will coordinate merging decisions through pull-request-style workflows. This sharing process will enable decentralized management, where each annotator or contributor can make their changes while maintaining a record of version history.

- Communication: Comments and summaries of differences between versions will facilitate discussions around specific modifications or conflicting annotations. These communication tools will promote transparency and the exchange of ideas between annotators and reviewers.

Type of Collaboration: In this system, annotators, distributed across different institutions or teams, will make their modifications independently (asynchronously). Collaboration, therefore, relies on robust version management and smooth coordination between the various stakeholders. Our system will thus bring novel insight into distributed collaboration.

Time Scale: From a few months to years: The long-term construction of atlases involves ongoing collaboration and the accumulation of knowledge, where the provenance and traceability of modifications support the cumulative building of the atlas.

Group Size: It involves a team of at least two people, including an expert for reviewing annotations. However, the system's goal is to accommodate larger consortia (about 30 contributors at the ICM level and up to 50–200 across different labs), to include dynamics that go beyond the expert/novice, such as groups of experts.

Space: Contributors work from different sites or from home.

Contribution to digital collaboration: This research aims to enhance digital collaboration in the creation and management of neuro-anatomical atlases by developing tools that enable efficient management of data contributions and versions.

Theoretical Contribution: The study of best practices for digital collaboration in the collaborative labelling of hierarchical 3D data is new. This research will further provide a better understanding of version management mechanisms, contribution coordination, and conflict resolution in collaborative environments around annotations on 3D images. It will contribute to knowledge on how hierarchical data structures and version histories can improve the efficiency and accuracy of collaborative annotations.

Technological Contribution: This project will enable the development of an interactive system for managing versions and neuro-anatomical annotations. This system will offer advanced features for visualizing dependency relationships between annotations and images, version management, and conflict resolution. It will be tested on real datasets, such as the ICM atlas, and can be adapted to other anatomical databases. Once validated, this system will be made available to the scientific community as open-source software, with comprehensive documentation to facilitate its adoption. Part of the technical work will be supported by the ICM engineering team, with a two year contract for an engineer position already secured.

These contributions are expected to improve digital collaboration in the field of neuro-anatomy while offering a flexible and extensible framework for other fields where complex and hierarchical data are collaboratively managed.

Positioning in the eNSEMBLE 2026 program:

Fit with PC2:
The PC2 “PILOT” program aims to develop infrastructures that facilitate long-term collaboration among distributed users. Our project aligns well with this program, notably with Theme 1: Future infrastructure for long-term collaboration, by proposing the design of a collaborative management infrastructure for neuro-anatomical image annotations, inspired by version control system (VCS) principles and enhanced with a dual-graph interaction paradigm.

The project intersects with WP 2.4: Collaborative Interaction Histories, which investigates how recording collaborative interaction histories (actions performed on shared objects (images and annotations) and their intermediate states (reflecting changes and commits by different users)) can help collaborators review, understand, and validate modifications. In our project, this principle is central: by visualizing annotation evolution in a Version History Graph, we hope to provide a clear overview of changes, highlighting the collaborative interactions between different users. This would enable a transparent and efficient review process and support long-term collaboration by ensuring the traceability of all modifications.

Link with existing projects
This project attempts to create an open and permissive environment as in the PC2 PhD project “Chaînes éditoriales collaboratives single-source pour le creative coding”. We also believe that the labeling and identification of anatomical structures is an example of *skill sharing,* as defined in the PC2 funded PhD project “Understanding and supporting skill development within teams and collectives, by capturing, packaging, and sharing procedures”.

Communication and Promotion
One of the concrete outputs of this project is expected to be a git driver for diffs and merges that is usable for images and associated labels and segmentations (git, like other VCS’s, uses the concept of diff and merge to respectively compute the difference between files and decide on how to combine to different versions of the same file into a single one. git does this by calling diff and merge drivers, and an end-user can plug in any driver that behaves as expected).

####### Version 2025

Title of the Doctoral Proposal

Design of a Collaborative Versioning System with Hierarchical Exploration for Neuro-anatomical Image Annotations

Names of PhD Advisors

Julien Gori
Sinan Haliyo
Gilles Bailly

Host Laboratory

ISIR (Institut des Systèmes Intelligents et de Robotique), Campus Pierre et Marie Curie, 4 place Jussieu, 75005 Paris.

Short Abstract
We propose to design and implement an open-source collaborative versioning system tailored for neuro-anatomical image annotations. Inspired by software version control (VCS) and enhanced with a graph interaction paradigm, our solution will integrate perceptual similarity metrics and hierarchical exploration. Validated on the ICM brainstem atlas in partnership with ISIR and ICM teams, this tool will support review and conflict resolution, and generalize to other large image datasets.

Short Description of Hosting Research Lab
ISIR (https://www.isir.upmc.fr) is a multidisciplinary research center that brings together expertise in robotics, artificial intelligence, human-computer interaction (HCI), and more. The team involved in this project specifically draws on its strengths in HCI and interactive visualization, particularly in the design of adaptive and explainable systems enabling the intuitive exploration of complex data and meeting the needs of neuroscience experts.
ICM (https://icm-institute.org) is a research institute specializing in the field of neuroscience. It contributes its expertise in neuroanatomical imaging, provides access to specialized annotators, and offers a real clinical evaluation environment, particularly in relation to the brainstem atlas. The laboratory thus provides a solid scientific and practical foundation for testing and refining the tools being developed. The person of interest at ICM is Eric Bardinet.
The collaboration between ISIR and ICM offers a unique synergy between technological innovation and medical applications. It enables the development of powerful interactive tools validated in real clinical contexts, paving the way for better understanding and visualization of complex brain structures.

Description of the PhD Proposal
1. Context

Large, richly annotated image databases (e.g., the Allen Brain Atlas) underpin breakthroughs in medicine and neuroscience. Brain atlases - 3D reconstructions with labeled structures (see Figure 1) - serve researchers, clinicians, and students. However, each 3D segmentation requires domain experts several hours to days of work. Collaboration is hierarchical: a few PhD students and interns annotate under minimal supervision; one or more senior researchers manually collect, compare, and validate annotations. Without integrated versioning, scaling atlas construction across distributed teams (academic labs, hospitals, consortia) remains a bottleneck.

Fig1. screenshot of the ICM neuro-anatomical atlas. A segmentation of the gustatory area of the isocortex of an adult mouse is highlighted in green.

2. Problem Statement and Objective
Despite the critical importance of high-quality, collaborative annotations, existing version control systems are ill-suited for non-textual data such as 3D neuro-anatomical images.

Traditional VCS tools excel at managing text-based codebases but fail when confronted with semantic annotation differences: a line-by-line “diff” is meaningless on pixel arrays, and pixel-level comparisons are overly sensitive to slight, visually irrelevant shifts. At the same time, each high-resolution 3D image version can be several gigabytes, making naive storage of full replicas for every commit impractical.
Moreover, brain anatomy exhibits nested structures (regions containing subregions), but flat file-based VCS treat each annotation as an isolated entity, preventing hierarchical exploration and fine-grained merge operations. The lack of in-situ review tools forces senior researchers to manually collect and compare disparate files, increasing cognitive load and slowing down validation cycles.
The objective of this PhD thesis is to overcome these challenges by designing and implementing a version control system (VCS) that embeds perceptual similarity metrics directly into commit operations, enabling semantically meaningful difference detection and merge suggestions. The system will also provide an interface combining a dependency graph of anatomical elements with a history graph of version lineages, offering users a transparent and traceable environment for collaborative atlas construction.

3. Research Questions

This project is driven by two central research questions: (1) How can perceptual similarity metrics be integrated into version control hooks to automate semantic diff detection and manage commit granularity? (2) Which interactive graph techniques most effectively support users with varying levels of anatomical expertise when navigating dependency and history views?

4. Brief State of the Art

Existing medical image annotation platforms (such as ITK-SNAP (http://www.itksnap.org) and 3D Slicer (https://www.slicer.org)) offer powerful segmentation tools but only support local undo/redo without any collaborative versioning capabilities. General-purpose solutions like Git LFS (https://git-lfs.github.com) and DVC (https://dvc.org) treat images as opaque binaries, storing either full copies or coarse binary deltas, which quickly become impractical for large, frequently updated datasets. Recent research has introduced perceptual metrics to better assess visual changes between images in response to this challenge. For instance, Zhang et al. (2018) developed the LPIPS metric, based on deep neural representations, to measure perceptual similarity. This allows the system to identify significant changes without relying on pixel-by-pixel comparisons, which are often too sensitive to small, irrelevant variations.
Beyond detecting changes, the ability to understand and navigate dependencies and the history of edits is a key aspect of collaborative annotation. Chen et al. (2011) proposed a model based on a directed acyclic graph (DAG), where each node represents an image editing operation. Their interface, RevG, simplifies this graph to support user-friendly navigation. A similar approach for 3D images was taken by Zhang et al. (2023) with VRGit, a version control system for collaborative editing in virtual reality, where the revision history is visualized as a spatially anchored graph within a 3D environment. Gori et al. (2020) has introduced a system called FileWeaver for file version management, featuring interactive visualization of dependencies and history. It allows users to organize files into a directed graph, visualize dependencies between them, and access the complete history of each file. Although developed in a generic context, FileWeaver provides a solid technical foundation

for adaptation to the specific needs of medical image annotation: hierarchical exploration of annotations, management of modifications, and smooth navigation between versions.
These works demonstrate feasibility of non-textual versioning and review concepts, but none deliver a dedicated solution for collaborative anatomical image annotation.

5. Theoretical foundations

This project draws on theoretical frameworks from three domains: version control and collaborative systems, human-computer interaction (HCI), and perceptual similarity in computer vision.

- Collaborative systems and version control provide formal models for managing change over time, coordinating distributed contributors, handling conflict resolution, and ensuring the traceability and integrity of evolving datasets through mechanisms like branching and merging.
- Human-Computer Interaction (HCI) contributes through theories of cognitive load, information visualization, and interaction design, guiding the development of intuitive interfaces for navigating and understanding complex hierarchical data.
- Perceptual similarity, informed by computational neuroscience and machine learning, underpins methods for assessing visual similarity based on high-level features rather than pixel-wise comparison.

6. Approach and Methods

6.1. Approach

The project will begin with a needs analysis conducted in close collaboration with neuroanatomy experts and software engineers at the ICM. Interviews, contextual observations, and co-design workshops involving annotators and developers will be used to identify key requirements, such as annotation revision management (versioning and consistency checking), change tracking over time, conflict-resolution support, and integration with existing software platforms at the ICM (e.g., packaging components as drop-in modules).
These insights will inform the functional specifications and interaction design of the tool. An iterative design cycle will be followed, incorporating rapid prototyping and regular feedback sessions to progressively refine both the user interface and the software architecture.

6.2. Methods: Dual-Graph Interaction Model

To help navigate annotations and their hierarchies, as well as their versions and histories, we will construct two interactive graphs:

- Dependency Graph (Graph View): This graph represents annotations and images as nodes, with relationships (e.g., region-subregion hierarchy, annotation-image linkage) encoded as edges. Nodes and edges can carry metadata such as last modification timestamps or annotation type. Visual cues (e.g., edge color changes) will highlight inconsistencies or outdated links.
- Version History Graph (History View): This second graph captures the evolution of each image or annotation as a version tree. It supports branching, merging, and comparison of different contributions. Selecting an item in the dependency graph reveals its full version history in the second graph.

These views will be tightly coupled and navigable using established HCI interaction techniques such as zooming, filtering of information, etc.

For this part, we can, for example, draw inspiration from FileWeaver (Gori et al., 2020). We can adapt FileWeaver's paradigm specifically for neuro-anatomical annotations, and then introduce the integration of annotation confidence levels or reviewer agreement scores directly into the visual representation. This allows for quality-aware navigation and supports collaborative decision-making, such as highlighting low-confidence areas that require re-review. Furthermore, we can also introduce a contextual preview layer that dynamically overlays annotation previews, change summaries, or revision histories on top of the graphs. This interaction layer would facilitate rapid comparison of versions without requiring full navigation into each node, thereby reducing cognitive load and improving review workflows.

Perceptual Similarity Integration

We exploit perceptual similarity to assess resemblance between images in a way that is meaningful for reviewers and annotators. We will rely on existing methods such as LPIPS to compute similarity scores between versions, with configurable thresholds to trigger an automatic save, commit, or render when differences become significant.

7. Expected Results, Impact and Evaluation

The expected final result is a robust system for collaborative management of annotated images, integrating perceptual similarity and review best practices. With open-source software deliverables (e.g., a Python package), fully documented, deployable, and validated on the ICM atlas, with extensibility to other image datasets. Note that the PhD student will work in collaboration with the engineering team at ICM that develops the brain atlas to integrate the proposed solutions. This will result in the following impacts:

- Enhanced Annotation Accuracy and Quality: By leveraging the dual-graph interaction model, annotators will have clearer visual representations of image-annotation relationships, leading to more accurate annotations. The integration of confidence levels and reviewer agreement scores will help flag low-confidence areas, improving the quality of the annotations through collaborative decision-making.
- Efficient Collaboration and Conflict Resolution: With the implementation of a version control system adapted for annotated images, the system will streamline collaboration among multiple contributors. Branching and merging of annotation changes will be handled effectively, reducing conflicts and improving the overall efficiency of the collaborative process. The history view and dependency graph will provide a clear overview of past modifications, which will facilitate transparent and accountable workflows. We expect that some of our suggestions will be translated to other image-based applications of version control.

Evaluation Plan

- Quantitative Evaluation: Benchmark diff/merge runtimes on the ICM brainstem atlas to assess the efficiency of the system in handling large datasets and multiple contributors. Compute the accuracy of semantic-diff detection against expert-labeled change sets to evaluate the system's precision in detecting differences between versions. We will empirically evaluate the system's impact through controlled user studies, in particular to evaluate the reduction in review time and whether there is a significant drop in conflicts.

- Qualitative Evaluation: Conduct studies with neuroscientists and annotators, where participants will complete annotation tasks unobtrusively. We will namely consider structured and non-structured observations. This will provide insights into the usability and practicality of the system in real-world annotation workflows, especially in merge and conflict scenarios, that go beyond task completion times and error rates. Additionally, we will assess generalizability by applying the system to additional neuro-anatomical datasets, such as hippocampal and cortical atlases, ensuring the tool's adaptability and scalability.

Nature of Digital Collaboration
The creation of neuro-anatomical brain atlases has gradually shifted from isolated expert-driven efforts to collaborative efforts (e.g., the Allen Brain Atlas launched in 2006), highlighting the need for digital infrastructures that record contributions to complex hierarchical datasets.
Functions:

- Sharing & Coordination: Contributors will upload new segmentations or modified segmentations to a shared repository; reviewers will coordinate merging decisions through pull-request-style workflows. This sharing process will enable decentralized management, where each annotator or contributor can make their changes while maintaining a record of version history.
- Communication: Comments and summaries of differences between versions will facilitate discussions around specific modifications or conflicting annotations. These communication tools will promote transparency and the exchange of ideas between annotators and reviewers.

Type of Collaboration: In this system, annotators, distributed across different institutions or teams, will make their modifications independently (asynchronously). Collaboration, therefore, relies on robust version management and smooth coordination between the various stakeholders.

Time Scale: From a few months to years: The long-term construction of atlases involves ongoing collaboration and the accumulation of knowledge, where the provenance and traceability of modifications support the cumulative building of the atlas.

Group Size: It involves a team of at least two people, including an expert for reviewing annotations. However, the system's goal is to accommodate larger consortia (about 30 contributors at the ICM level and up to 50–200 across different labs).

Space: Contributors work from different sites or from home.

Contribution to digital collaboration: This research aims to enhance digital collaboration in the creation and management of neuro-anatomical atlases by developing tools that enable efficient management of data contributions and versions.

Theoretical Contribution: The study of best practices for digital collaboration in the creation of neuro-anatomical atlases is still relatively new. This research will provide a better understanding of version management mechanisms, contribution coordination, and conflict resolution in collaborative environments around annotations on 3D images. It will contribute to knowledge on how hierarchical data structures and version histories can improve the efficiency and accuracy of collaborative annotations.

Technological Contribution: This project will enable the development of an interactive system for managing versions and neuro-anatomical annotations. This system will offer advanced features for visualizing dependency relationships between annotations and images, version management, and conflict resolution. It will be tested on real datasets, such as the ICM atlas, and can be adapted to other anatomical databases. Once validated, this system will be made available to the scientific community as open-source software, with comprehensive documentation to facilitate its adoption.

These contributions are expected to improve digital collaboration in the field of neuro-anatomy while offering a flexible and extensible framework for other fields where complex and hierarchical data are collaboratively managed.

Positioning in the eNSEMBLE program:
The PC2 “PILOT” program aims to develop infrastructures that facilitate long-term collaboration among distributed users. Our project aligns well with this program, notably with Theme 1: Future infrastructure for long-term collaboration, by proposing the design of a collaborative management infrastructure for neuro-anatomical image annotations, inspired by version control system (VCS) principles and enhanced with a dual-graph interaction paradigm.

The project intersects with WP 2.4: Collaborative Interaction Histories, which investigates how recording collaborative interaction histories (actions performed on shared objects (images and annotations) and their intermediate states (reflecting changes and commits by different users)) can help collaborators review, understand, and validate modifications. In our project, this principle is central: by visualizing annotation evolution in a Version History Graph, we provide a clear overview of changes, highlighting the collaborative interactions between different users. This enables a transparent and efficient review process and supports long-term collaboration by ensuring the traceability of all modifications.

Thus, our work directly contributes to the development of tools that enhance the efficiency of distributed collaboration, providing the infrastructure necessary for managing complex datasets like neuro-anatomical atlases over long periods of time.

Bibliography
1. Chen, Tim & Wei, Li-Yi & Chang, Chun-Fa. (2011). Nonlinear Revision Control for Images. ACM Trans. Graph.. 30. 105. 10.1145/2010324.1965000.
2. Zhang, Lei & Agrawal, Ashutosh & Oney, Steve & Guo, Anhong. (2023). VRGit: A Version Control System for Collaborative Content Creation in Virtual Reality. 1-14. 10.1145/3544548.3581136.
3. Zhang, Richard & Isola, Phillip & Efros, Alexei & Shechtman, Eli & Wang, Oliver. (2018). The Unreasonable Effectiveness of Deep Features as a Perceptual Metric. 10.48550/arXiv.1801.03924.
4. Gori, Julien & Han, Han & Beaudouin-Lafon, Michel. (2020). FileWeaver: Flexible File Management with Automatic Dependency Tracking. 22-34. 10.1145/3379337.3415830.