Realizing Modular Digital Hermeneutics: A Microservice-based Approach

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Abstract

Research in Digital Humanities encompasses a wide range of research materials, including audiovisual materials, texts, letters, images, and social media content. The diversity of methods and research workflows poses significant challenges for designing reusable, adaptable software tools. Existing software often provides only generic functionality, such as transcription and annotation. Heterogeneous research environments impede the adaptation of emerging technologies such as Large Language Models and other Generative Artificial Intelligence (AI) tools, whose applicability varies and requires adaptations across languages and materials. An AI-in-the-loop [1] approach supports the trustworthy use of machine learning and AI by enabling researchers to review and adjust computational results. This paper presents a microservice-based approach to designing and implementing software for digital hermeneutic research workflows (from analyzing and understanding to arguing based on source materials) that explicitly addresses this heterogeneity, with flexibility and exchangeability incorporated into the software design. The approach is grounded in a lifecycle-oriented perspective, aligning software components with the recurring phases of the Information Extraction Lifecycle (IELC), including data collection, preparation, extraction, organization, and access. We propose a generalizable architectural separation for hermeneutic research systems by categorizing workflow functionalities by lifecycle phases. Microservices encapsulate and strictly separate original source materials from those producing, deriving, or transforming materials for interpretation and argumentation through isolated service-level storage. This distinction enables fine-grained preservation decisions at the granularity of individual services, distinguishing invaluable archival records from reproducible, regenerable derivations. We generalize across hermeneutic domains by encapsulating transformation and interpretation functionalities in independently replaceable services, supporting adaptability to other domains, languages, or materials.

Keywords

Digital Hermeneutics, IVIS4DH, IELC, Microservices, OAIS, Preservation

1. Introduction

The interdisciplinary field of Digital Humanities (DH) combines computational methods with humanistic inquiry to support large-scale analysis, interpretation, and contextualization of cultural heritage materials. The increasing digitization of archival sources enables new forms of scholarly research while raising methodological questions, particularly regarding transparency and reproducibility, when computational tools are integrated into interpretive workflows.

Within DH, digital hermeneutics covers two aspects [2]: the understanding and reflecting on the implications of digital tools on hermeneutic research [3, 4], and "the use of digital methodologies to process, handle, analyze, and interpret" [2]. Both aspects – the use of digital tools and their critical reflection – are closely interrelated [5] and typically span the entire lifecycle, from the acquisition of sources to their transformation into interpretable representations and their use in scholarly argumentation.

For hermeneutics, the technological advancements are a double-edged sword. Digital tools support individual researchers by automating routine tasks; however, these technologies may lack transparency for users – one of the key requirements for digital hermeneutics. Reflexive engagement with software

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tools means evaluating whether those tools are suitable and transparent for the current context. Artificial Intelligence (AI) should "complement, empower, and in no way replace human capabilities" [6]; however, to do so, AI must provide transparency and control to its users.

The need to choose the right tools is even more pronounced, as digital hermeneutics typically involves complex, heterogeneous workflows. The workflows share common elements but also have differences, which would require a large number of specialized software tools to meet all the needs. Research materials further underscore the diversity of workflows: different materials often require separate tools. Software tools such as Large Language Models (LLMs) perform differently depending on the language or the type of source material used. Managing this diversity across the full lifecycle of information processing—rather than at isolated workflow steps—poses a central architectural challenge.

Complicated monolithic architectures impede long-term preservation, requiring detailed, individual decisions on the scope and mechanics of preservation. Different data types exacerbate preservation, since long-term preservation requires storing not only the material but also additional information to enable rendering materials decades from now.

In particular, we argue for architecturally separating hermeneutic artifacts according to their preservation requirements to dissect the long-term preservation problem.

Minor modifications to monolithic platforms may yield significant consequences for the entire platform, thereby discouraging experimentation. Experimentation and reusability motivate architectures encapsulating changes. Once these components are tested, functional, and mature enough, incorporation into larger platforms is a natural next step.

Besides the benefits of experimentation, a microservice-based architecture enables the development of software components for different types of research materials while reducing effort in developing standard, uniform functionalities inherent to Hermeneutic Research Workflows (HRWs). The Information Visualization for Digital Hermeneutics (IVIS4DH) [7] model covers the heterogeneity and similarities in these workflows, serving as a base for the functional decomposition of workflows. The Information Extraction Lifecycle (IELC) [8] describes lifecycle phases that support the determination of preservation requirements.

Consequently, the key challenge is to design a software architecture that supports heterogeneity, flexibility, and lifecycle continuity while enabling experimentation and reuse. This paper addresses the challenge by proposing a microservice-based architectural approach aligned with the IELC and IVIS4DH.

This paper presents a high-level, generalizable modular architecture based on microservices, supporting flexible composition, exchangeability, and experimentation with state-of-the-art technologies. The stringent separation of original, original-like, and derived materials comes with service-level storage, allowing fine-grained preservation decisions at the service level.

2. Related Work

The related work is divided into two main areas: digital hermeneutics as the application domain, and microservices. The latter focuses on the benefits of its application in digital hermeneutics, the migration strategies that are fundamental to this work, and considerations of data storage.

2.1. Application Domain

Prior work identified structural characteristics relevant to system design. Automation decreases when tasks require more creativity, contextual understanding, and human judgment [2].

The IVIS4DH model [7] provides a structured overview of the HRW, including the workflow steps and tasks involved. By distinguishing workflow stages and the tasks involved, the model provides a foundation for aligning business requirements and lifecycle-oriented transformations of research material. Building on this, prior work [9] analyzes the hermeneutic argumentation workflow and proposes an approach to connect hermeneutic elements, such as observations and interpretations, to their sources.

From a lifecycle perspective, the IELC [8] conceptualizes information extraction as a cyclical process, including data collection, data preparation, extraction/enrichment, information & knowledge organization, and information access & retrieval. These phases correspond to the transformations described in the IVIS4DH model.

Beyond lifecycle considerations, the trustworthiness of sources and their interpretations is a central concern in digital hermeneutics. Ongoing research [10, 11] investigates explainability and trustworthiness in the scope of big data processing and information retrieval.

Prior work [12, 13] has characterized hermeneutic research as highly iterative, non-linear, exploratory, and spontaneous, and identified the need to revisit earlier steps regularly. User interfaces should start with understanding the users' needs [14, 15]. We design the system to respect user needs while focusing on preservation requirements. Taken together, this body of work suggests that Humanities scholars benefit from software tools that accommodate the flexible, non-linear nature of their work. In this work, we therefore investigate a microservice-based approach to support such flexibility.

2.2. Microservice-based Architecture

This section reviews the state of the art in microservice-based architectures, including benefits, trade-offs, and considerations for data storage and long-term preservation across lifecycle phases.

Similar work [16] demonstrated a transition from a DH monolith to a microservice-based architecture, with an intermediate modular monolith that faced challenges in migration effort, performance, and data consistency on the one hand, and scaling benefits on the other. Their exemplary application offers user-driven functionality rather than AI analysis [17].

A performance and scalability evaluation [18] finds that monolithic approaches perform well for small, single-purpose applications. At the same time, microservice-based architectures offer advantages in settings that require flexibility, favor distributed development, and favor smaller software changes. Microservices increase the overall software's complexity, requiring greater effort in testing, deployment, debugging, and monitoring. Further complexity arises from database synchronization when using multiple databases.

An empirical evaluation [19] states that microservice-based architecture increases maintainability through its modularity and notes easy technology experimentation as a significant benefit. Smaller granularity allows building and replacing individual microservices in different programming languages, selectively replacing them with superior versions or providing alternatives better suited to a use case. Software changes affecting only a single service enable developer teams to change and test their services independently. The modular nature and relatively small size of microservices improve code understandability, significantly simplifying distributed development [20]. Further mentioned benefits include scalability [19], fault tolerance, separation of software responsibilities [19], and ease of deployment [18].

Prior work [21] recommends deploying microservices as sets of small, independent services, running each service as its own process.

There are several approaches to achieving data autonomy, e.g., via private-tables-per-service, schema-per-service, or database-server-per-service [22]. Architectural decisions involve trade-offs in module sizes and database sharing among services [23], but may also affect maintenance effort [24], development time [24, 25], deployment [26, 25], and coupling [27, 28]. Microservices require mechanisms to ensure data consistency [29] and to preserve provenance and traceability of artifacts across lifecycle steps.

Long-term preservation is essential to archival materials but often overlooked in microservices discussions. Related work on long-term preservation [30] connects the Open Archival Information System (OAIS) [31] with microservices. OAIS requires storing representation information along with an information object [32]. Usage instructions, the contents of microservices, and their Application Programming Interfaces (APIs) correspond to the representation information that supports interpretability, lifecycle robustness, and reproducibility. Our work embeds OAIS consideration into architectural decisions and microservices decomposition.

In terms of migration strategies, literature [33] describes two general mechanisms to break down existing applications by decomposing software into business capabilities or by subdomain, [25] further highlights advantages of encapsulating functionality around a business domain, [34] further distinguish between functional or object-oriented decomposition, and [20] showcases a structured approach for decomposition by following these steps: 1) function analysis, 2) business functionalities identification, 3) business functionalities analysis, 4) business functionalities assignment, and 5) microservices creation.

While extensive literature exists on microservice-based architecture and digital hermeneutics, these subjects, and, in more detail, microservice decomposition with hermeneutic preservation semantics, remain largely disconnected. This work proposes addressing this gap by introducing a preservation-aware, microservice-based architectural decomposition and modularization of digital hermeneutics, grounded in the IVIS4DH model and generalizable preservation guardrails.

3. Conceptual Model and Design for Modular Digital Hermeneutics

The HRW provides a basis for decomposing the current functionalities in the monolithic software, offering an overview of high-level functions and insights into business functionalities along the IELC. Figure 1 shows the types of services by IELC phase.

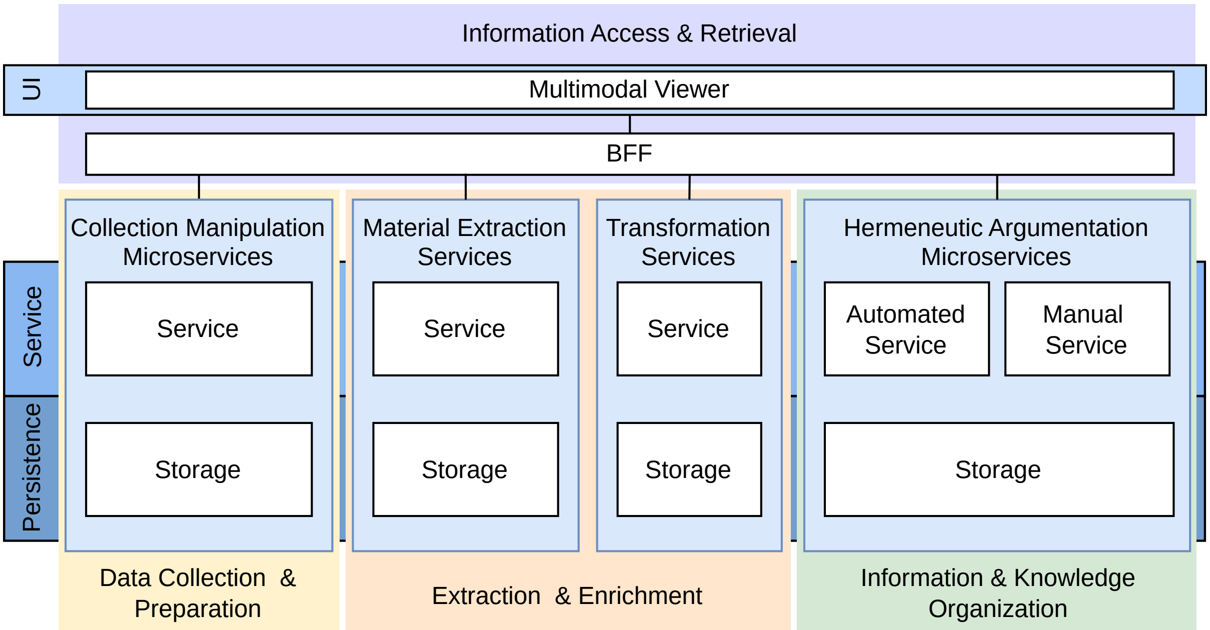

Figure 1: Hermeneutic Microservices Types by IELC phase.

The overarching *Information Access & Retrieval* (violet) achievable via a multimodal viewer utilizing a Backend for Frontend (BFF) pattern is the ability to access all kinds of data, information, and knowledge. Users gain valuable insight from seeing multiple modalities simultaneously (e.g., transcripts, annotations, and arguments related to each other).

Data Collection & Preparation (yellow) addresses the setup of material (e.g., an archive or other type of collection in DH, or a collection of medical records). Depending on the material types, material *Extraction & Enrichment* (orange) services (e.g., an audio and transcription service, or an image retrieval and optical character recognition service) employ functionalities to prepare materials in such a way that they can be utilized for *Information & Knowledge Organization* (green), i.e., hermeneutic argumentation.

Automated and manual services operate on shared data structures, enabling seamless transition between machine-generated results and their refinement. Intentional coupling through shared data structures ensures that equivalent data are represented and treated uniformly across automated and AI-in-the-loop stages. The automated services are intended to be interchangeable, allowing users to experiment with the latest technology and with those specialized in certain languages, disciplines, or historical periods.

Each backend also includes the service's required persistence. Since researchers need the freedom to adjust all automatically identified results, *Information & Knowledge Organization* services offer the option to adjust the outcome of each automated step manually.

Compared to existing models, the architectural design details handover points between hermeneutic components, adding information where data and context need to align.

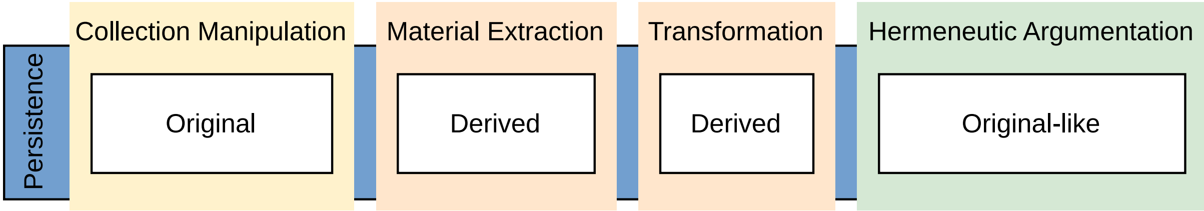

Figure 2: Distinction of Preservation Data Types by **IELC phase!** (**IELC phase!**).

Figure 2 distinguishes the type of information objects handled in different hermeneutic services. *Collection Manipulation* services contain original materials, such as archive or medical records. *Hermeneutic Argumentation* services contain original-like materials as well in terms of human- or computer-generated evidence and conclusions. Both categories have a high need for long-term preservation. The *Material Extraction* and *Transformation* services contain derived data. It is sufficient to preserve information for reproducibility (e.g., information on the transcription process).

The preservation also aligns with trustworthiness needs. Since *Extraction & Enrichment* appears to be easier to reproduce (e.g., transcription of audio files) than rerunning results with LLMs or reproducing creative and intelligible human thought processes. This strengthens the need for long-term preservation of results.

Figure 3 depicts the main business functionalities (archival retrieval, transcription, annotation, argumentation) of the IVIS4DH model, paired with an authentication module to protect archival material from unauthorized access. The duplicated boxes for the transcript, annotation, and argument backends represent exchangeable components, enabling substitution without affecting the overall workflow. Each component is a separate service with its own Graphical User Interface (GUI) accessible via APIs.

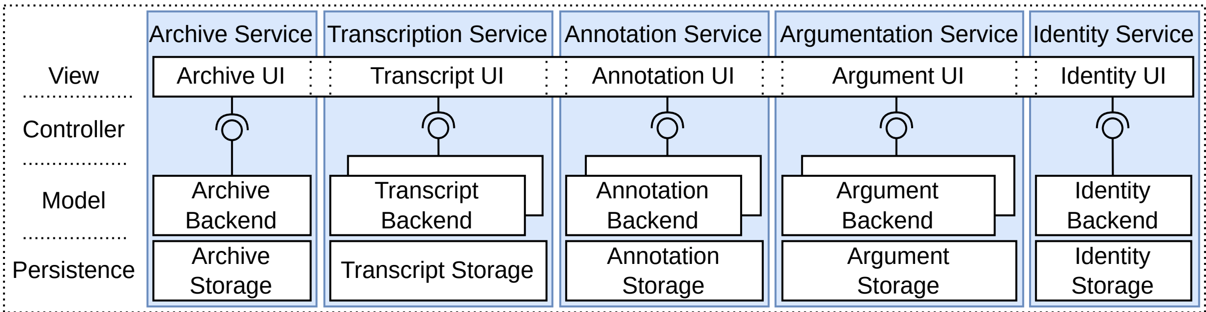

Figure 3: Microservice-based Architectural Design for Digital Hermeneutics.

When conceptually modeling and designing automation for the argumentation structure, the IVIS4DH lacks details. The argumentation reflects the IELC's *information and knowledge organization*. However, the combination of information and knowledge occurs in several iterations, representing three human actions: observe, interpret, and argue [9]. Therefore, automated services would utilize other information as a grounded source to provide different reliability in the argumentation process. The evidence, therefore, is split into observations and interpretations, which researchers can assemble in an argument.

4. Implementation and Evaluation Strategy

We will instantiate the proposed architecture using the Archive "Deutsches Gedächtnis" (ADG)[1] [35] as a representative case study from DH . The ADG holds heterogeneous archival materials, such as text and images, making it suitable for evaluating lifecycle-oriented, preservation-aware system design.

The implementation follows a two-stage approach: the first stage ensures workflow continuity by developing a prototype that covers all phases of the IELC for a single research material type, implemented as independent microservices. This stage already covers the separation of original, original-like, and derived data by service-level persistence. We assess the first stage in three dimensions. The first dimension assesses whether Humanities scholars can complete the workflow in a cognitive walkthrough. The second dimension measures the engineering effort required to implement, modify, or replace services, capturing modularity and extensibility. The third stage simulates robustness to evolutionary change, including service replacement and data type extensions.

The second stage extends the software with preservation-aware mechanisms, such as deterioration detection and provenance metadata, to support reproducibility and long-term interpretability. We assess reconstructability, traceability, and authenticity of source and derived artifacts, aligned with microservices' preservation requirements.

5. Conclusion and Future Work

This work presented a generalizable microservice-based architecture for hermeneutic workflows grounded in the IELC and IVIS4DH models. The proposed design enables modular composition and exchangeability, including a preservation-aware separation of original, original-like, and derived materials. The decomposition supports experimentation with emerging technologies.

Future work will explore four main directions. First, we will implement and validate the approach in a representative DH setting. Second, we will explore enhanced multimodal interfaces that support Humanities scholars' flexibility, enabling seamless switching between different lifecycle phases. Third, future work can investigate preservation strategies aligned with OAIS principles, including a definition of the designated community and the scope of content information. This includes the transferability of our approach to other domains, linking preservation needs, e.g., in digital hermeneutics or medicine [36], through a dedicated preservation-concept-per-service strategy. The transferability extends to investigating the validity of applying an AI-in-the-loop approach in other domains or to shifting to a human-in-the-loop approach. Finally, future work may develop systematic evaluation methods for modular microservice-based systems, including metrics for usability, maintainability, and trustworthiness.

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Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT and Grammarly for AI assisted copy editing. ChatGPT was used to provide feedback and suggestions on the clarity and structure of selected sections to improve writing quality. The tool was used solely for suggestions on structure and phrasing, and for critique; no AI-generated text was copied or directly incorporated into the manuscript. All final wording and content are the authors' own; and the authors take full responsibility for the publication's content.

[1]Translation: Archive “German Memory”

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