HoloRepository: A Cloud-Native Architecture for End-to-End Generation and Distribution of Holographic Medical Visualisations

Summary

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1 PROJECT CONTEXT AND OBJECTIVES

Recent advancements in Augmented Reality (AR) have the potential to facilitate and enhance various tasks and procedures in medicine. One key challenge is creating and distributing three-dimensional (3D) models sourced from traditional imaging studies, such as CT or MRI scans. While there are existing libraries and workflows, they are heavily dependent on technical setup and manual steps, rendering them infeasible to integrate into practitioners' day-to-day businesses [1, 6–8]. Certain neural network (NN) architectures can be leveraged to automate and streamline the manual steps; however, they impose even heavier obstacles in terms of setup, usability, and maintenance [3].

Obtaining medical requirements from Great Ormond Street Hospital (GOSH) and technical support from Microsoft, we propose HoloRepository: a distributed, cloud-native architecture to seamlessly perform all steps from browsing existing imaging studies, transforming them into three-dimensional holographic representations, to distributing the results, and eventually visualising them on the HoloLens. A public API and support for industry standard formats ensure interoperabiltiy.

2 ACHIEVEMENTS

We successfully implemented all key aspects of the HoloRepository core system, which we designed as a collection of loosely coupled, fully-integrated, microservice-like components:

- **HoloRepository UI**. A web app, enabling practitioners to browse their patients and manage the generation of 3D models sourced from DICOM files representing imaging studies like CT or MRI scans. The client-side React application is accompanied by a Node.js back-end server.
- **HoloPipelines**. A back-end service, performing the automatic generation of 3D models. We conceived a modular architecture and demonstrate it with 3 existing pipelines: Two utilising traditional image processing libraries, one incorporating a pre-trained NN for segmentation.
- **HoloStorage and Accessor API**. Database infrastructure, encompassing a FHIR (Fast Healthcare Interoperability Resources) server, a Blob Storage, and a public façade API server with a versioned, stable RESTful API to allow third-party systems to integrate with our system.

Using the most appropriate languages and frameworks for each independent component, we delivered a substantial code-base, packaged in environment-agnostic Docker containers, and deployed on an Azure Kubernetes Service (AKS) cluster. Our deliverables include the configuration of continuous integration (CI) and deployment steps as well as infrastructure setup.

Additionally, we published the **HoloStorageConnector** library as a Unity/C# package to abstract calls to the Accessor API, facilitating third-party integration for HoloLens developers. A **HoloLens Demo App** to demonstrate the system's end-to-end workflow completes our set of deliverables.

3 EVALUATION

Each component is unit-tested by means of the respective programming language's common test frameworks. For crucial components, statement coverage is above 70%. Furthermore, manual integration testing was performed at multiple stages. Key user-facing components were put under load testing, and shown to provide fast response times for up to 75 concurrent users. Furthermore, we conducted an exhaustive overall evaluation w.r.t. availability, maintainability, scalability, security, extensibility, interoperability, usability, reproducibility and the software engineering processes.

In the course of development, we compared solutions for many sub-problems, such as which cloud infrastructure to use, which platforms of pre-trained NN to support, how to best integrate existing models into the system, how to simplify and compress polygonal mesh data, and which medical standards formats to implement. All of our findings are documented in the group report [4].

4 IMPACT

Our work represents the next iteration of earlier approaches made at UCL and other institutions to present a pipeline for generating AR-suited 3D models sourced from medical images [2, 7–9]. We succeeded to overcome the main limitations of earlier work, as our solution provides a seamless end-to-end workflow, capable of generating and distributing holograms without human intervention, and is available as a service. By supporting FHIR, offering a public API to our storage systems, and presenting a modular concept for incorporating any pre-trained NN, our system is valuable to our clients not only as it is, but also provides a robust foundation for future projects. As a secondary product, we proposed a new concept for SMART on FHIR authentication in AR with the HoloLens.

5 CHALLENGES

Our project touched on several areas of cutting-edge research and required solutions to problems for which there are no commonly agreed upon answers. In particular, the research, evaluation, acquisition, and integration of pre-trained NNs was challenging in that respect. We met the challenge with extensive literature review phase and explored a multitude of existing solutions.

The initial intentions of integrating and extending previous work proved to be much harder than anticipated, and eventually had to be abandoned in favour of an entirely new code-base from the ground up. This included rethinking solutions earlier work had proposed, such as the MHIF format [2], and reverse-engineering a number of undocumented technical setup steps [5, 8].

The considerable scope of the project requirements called for solutions developed in different programming languages, targeting different platforms. As a consequence, we split the workload up into different portions, with each being "owned" by a team member. While this approach succeeded to gradually build up the complete architecture in a bottom-up approach, it led to slightly disseminated group dynamics. Furthermore, supporting many different languages impeded acquiring expertise in any. With the help of agile and DevOps best practices, as well as substantial tooling support for CI, we managed to implement a connected, self-contained solution. In retrospect, the overall scope of the project may have been slightly inflated however, and as a consequence, aspects such as error handling and test coverage are below our anticipated quality goals.

6 LESSONS LEARNT

We demonstrated how a loosely-coupled, microservice-like architecture can be leveraged to break down a complicated problem. This solution has many benefits; however, our system-wide scalability is limited by one service's use of local state. We discuss this extensively in the group report [4].

We found that agile work methods helped us to operate as a team, particularly having a physical task-board to coordinate tasks. Automated CI tools helped us keep track of the different branches of work, integrate them regularly, and running all test suites on every change. Furthermore, a quality control process through code reviews conducted on GitHub helped us ensure high code quality.

We encountered multiple unexpected problems during the overall system deployment process to AKS, which demanded our time and attention. Future projects should aim to deploy their systems as early as possible, in order to give themselves enough lead time to sort out any potential issues.

REFERENCES

[1] Raffael Affolter, Sebastian Eggert, Till Sieberth, Michael Thali, and Lars Christian Ebert. 2019. Applying augmented reality during a forensic autopsyâĂŤMicrosoft HoloLens as a DICOM viewer. *Journal of Forensic Radiology and Imaging* 16 (March 2019), 5–8. https://doi.org/10.1016/j.jofri.2018.11.003

[2] Immanuel Baskaran. 2018. Medical Holographic File Format Design. https://goshmhif.azurewebsites.net/Hololens-Webapp/#/documentation.. (08 2018). (Accessed on 08/23/2019).

[3] Andrew Beers, James Brown, Ken Chang, Katharina Hoebel, Elizabeth Gerstner, Bruce Rosen, and Jayashree Kalpathy-Cramer. 2018. DeepNeuro: an open-source deep learning toolbox for neuroimaging. *arXiv:1808.04589 [cs]* (Aug. 2018). http://arxiv.org/abs/1808.04589 arXiv: 1808.04589.

[4] Niels Boecker, Wenjie Boon, Udomkarn Boonyaprasert, Fanbo Meng, and Kawai Wong. 2019. *HoloRepository: A Cloud-Native Architecture for End-to-End Generation and Distribution of Holographic Medical Visualisations (Group Report).* Master's thesis.

[5] Road Matveev, Lovepreet Singh, and Jeff Cai. 2019. HoloRespository. http://students.cs.ucl.ac.uk/2018/group19/index.html. (2019). (Accessed on 08/04/2019).

[6] Michael Page. 2017. Visualization of Complex Medical Data Using Next-Generation Holographic Techniques. (2017). https://www.academia.edu/19597566/VISUALIZATION_OF_COMPLEX_MEDICAL_DATA_USING_NEXT-GENERATION_HOLOGRAPHIC_TECHNIQUES

[7] Philip Pratt, Matthew Ives, Graham Lawton, Jonathan Simmons, Nasko Radev, Liana Spyropoulou, and Dimitri Amiras. 2018. Through the HoloLensâĎć looking glass: augmented reality for extremity reconstruction surgery using 3D vascular models with perforating vessels. *European Radiology Experimental* 2, 1 (2018), 2. https://doi.org/10.1186/s41747-017-0033-2

[8] Caroline M. Smith. 2018. *Medical Imaging in Mixed Reality: A holographics software pipeline.* Master's thesis. University College London, London.

[9] Lucian Trestioreanu. 2018. Holographic Visualisation of Radiology Data and Automated Machine Learning-based Medical Image Segmentation. *arXiv e-prints*, Article arXiv:1808.04929 (Aug 2018), arXiv:1808.04929 pages. arXiv:cs.CV/1808.04929