

# Wandering and getting lost: the architecture of an app activating local communities on dementia issues

Nicklas Sindlev Andersen  
University of Southern Denmark  
Odense, Denmark  
sindlev@imada.sdu.dk

Marco Chiarandini  
University of Southern Denmark  
Odense, Denmark  
marco@imada.sdu.dk

Jacopo Mauro  
University of Southern Denmark  
Odense, Denmark  
mauro@imada.sdu.dk

**Abstract**—We describe the architecture of Sammen Om Demens (SOD), an application for portable devices aiming at helping persons with dementia when wandering and getting lost through the involvement of caregivers, family members, and ordinary citizens who volunteer.

To enable the real-time detection of a person with dementia that has lost orientation, we transfer location data at high frequency from a frontend on the smartphone of a person with dementia to a backend system. The backend system must be able to cope with the high throughput data and carry out possibly heavy computations for the detection of anomalous behavior via artificial intelligence techniques. This sets certain performance and architectural requirements on the design of the backend.

In the paper, we discuss our design and implementation choices for the backend of SOD that involve microservices and serverless services to achieve efficiency and scalability. We give evidence of the achieved goals by deploying the SOD backend on a public cloud and measuring the performance on simulated load tests.

**Index Terms**—System architecture, Serverless, Microservices, Data processing, Scalability, Load testing

## I. INTRODUCTION

An increasing number of people in the world are estimated to be affected by dementia [1]. As such, there is an increasing effort to conceive social and technological innovations to help people affected by dementia syndrome along with their relatives, friends, and communities [2]. Wandering, disorientation, and getting lost are common in people with dementia, even in the early stage, and there is a considerable effort to provide technological solutions aimed at alleviating the troubles related to these situations [3], [4].

In line with this effort, we developed an application for portable devices, dubbed “Sammen Om Demens” (SOD), in the context of a Danish municipality. The goal of SOD is to create awareness among ordinary citizens and to involve them in helping persons affected by dementia, ultimately alleviating the anxiety of these latter and their closest caregivers. The main functionality of SOD that is expected to achieve this goal is a software component that will be able to automatically detect episodes of wandering and getting lost.

In this paper, we focus on the architecture of SOD that relies on a *frontend* software deployed on portable devices (i.e., smartphones) and a *backend* system that runs in the cloud. The frontend collects and sends location data at a high frequency to the backend system that processes the information

received. The backend is designed to allow the integration of the software component that automatically detects wandering and getting lost situations. For this reason, the backend is required to be able to process an expected high throughput of data efficiently and reliably, while being structurally flexible to allow to easily deploy artificial intelligence techniques for the detection of persons with dementia that get lost. It is thus vital to design the backend of the system that can operate efficiently and reliably, easily scaling as the number of users of SOD increase. Our solution has been to adopt microservices and serverless services. Here, we will argue and give evidence that these types of architectural components offer several advantages, among them indeed scalability and architectural flexibility [5], [6]. In the paper, we restrict ourselves to describe and evaluate the microservices and serverless architecture and its performance. Testing the app with real users, comparing it against other approaches (see e.g. [7], [8]), or detailing the automatic detection of anomalous behavior is left as future work for a follow-up article.

The paper is structured as follows. In Section II, we give more details on the features of SOD, that need to be supported by the backend system. In Section III, we describe the underlying paradigms and technologies that we used in the development of the backend system. In Section IV, we describe the implemented infrastructure before presenting its validation in Section V. We conclude in Section VI discussing related work and future research plans.

## II. SAMMEN OM DEMENS (SOD)

In this section, we give an overview of the features of SOD that need to be supported by the backend system.

The backend system accommodates three user types: i) users with dementia (from light to medium cases) who can use to a certain degree a smartphone and remember to bring it with them ii) closest caregivers and relatives linked to one or more users with dementia and iii) ordinary citizens, not linked to any specific user, who volunteer to help. Relatives to a person with dementia are handled as volunteers but have enhanced functionalities towards the user with dementia to whom they are linked. For the final users, the app consists of three components each providing a different functionality: a knowledge base providing information about the local organization of the municipality around dementia, a help component providing

arXiv:2103.06777v2 [cs.SE] 25 Oct 2021

functionalities to activate relatives and near volunteers in cases of need, and a recreational activity calendar with the additional feature of proposing accompanying persons.

The *help component* is concerned with the detection of persons with dementia that exhibit some form of anomalous behavior such as becoming lost or being confused about their location. Through the app, it is possible for a user with dementia to directly trigger an alarm if he/she became lost and wishes assistance. Alternatively, a relative of a user with dementia can detect the anomaly through the enhanced capability of this user type to track the location of their linked users on a map. They can then trigger the alarm to contact their linked user and activate volunteers. Most interestingly, the same alarm can also be triggered *automatically* by the app if the backend system detects anomalous behavior in the stream of location data sent by the frontend. Eventually, if an alarm is directly or indirectly triggered, the backend system has the task of sending out notifications to the nearest available volunteers and to the available relative of the user with dementia. In case of more relatives, the one registered with the highest priority is chosen. When the notification is received by a user, it triggers an alarm sound to warn the user to react fast. The volunteer users that receive the notification have the choice to either accept or decline a request to help the user with dementia. The activation of the users starts a *mission*, in which volunteers and a relative coordinate and work together to bring the user with dementia to a *safe place*, e.g., a care home, a police station, or the like. Throughout the mission, the location of the user with dementia is broadcasted to all other involved users. This is done to enable one or more of the involved users to be able to navigate to the user with dementia and assist them. When the user with dementia has been brought to a safe place the mission is closed by one of the involved users.

The *recreational activity calendar* is at the most basic level, just a calendar where relevant activities can be posted by volunteers. The calendar also functions as an intermediary entity that tries to create opportunities for volunteers and users with dementia to participate in activities together. This is done by matching volunteers to activities based on submitted activity preferences and suggesting relevant activities to users with dementia based on the keywords that they use when searching through the activity calendar. Whenever a user with dementia navigates to the description of an activity that he/she finds interesting, one or more volunteers will be suggested to the user with dementia as a possible accompanying person for the activity. It is then up to the user with dementia to take contact with one of the possible suggested volunteers.

### III. PRELIMINARIES

Several architectural models exist to design and develop applications, but the *microservice* and *serverless computing* architectural models are especially interesting for us as they provide an excellent framework for building a *distributed system* that is maintainable, efficient and that can easily scale [9]. In the following, we first give a brief overview

of these architectural models and then describe the concrete technologies adopted for the development of SOD.

#### A. *Microservices & Serverless Computing*

The microservice architectural model allows a developer to manage and deploy several smaller autonomous and modular pieces that communicate through an API via network messaging protocols. As a result of using this type of architectural model, it can be easier to horizontally scale software components that make up a system. These modular pieces usually run in their own isolated environment possibly using their own technology stack.

The popularity of the microservice architectural model has grown hand in hand with the increased adoption and usage of application containerization. Containers are lightweight virtualization runtime environments that allow a developer to run an application locally for testing purposes, as well as in a production environment on a server. They present a consistent and portable software environment, where all dependencies can be packaged as a deployable unit. Multiple application components that run in containers can be managed by orchestration tools such as Docker Compose [10], Kubernetes [11], or Docker Swarm [12].

Serverless computing is a relatively new emerging architectural model that embraces the concept of Function as a Service (FaaS). The concept of FaaS encompasses the idea that developers should be able to manage and deploy independent functions that execute in response to events that are triggered by internal and/or external sources of a system. Serverless functions are deployed as containers that are stored and managed in private or public registries (e.g., Docker Hub [13]). The execution of a function means pulling and running one or more corresponding containers from the registry.

Serverless computing comes with many advantages scalability-wise, but certain inherent problems are also associated with the type of execution model. More precisely, retrieving a container image and starting a container can take some time, i.e. it adds additional overhead to the function call. This phenomenon is usually referred to as a *cold start* and, to avoid it, running containers are often reused for subsequent invocations of the same serverless function.

#### B. *Technologies*

At the core of the backend system, SOD uses the *k3s* Kubernetes distribution by Rancher Labs [14] to deploy and run all microservices. K3s is a lightweight certified Kubernetes distribution [15] designed for production workloads and optimized for resource-constrained environments (e.g., small servers or IoT appliances). The system requirements are less demanding in comparison to those of a traditional Kubernetes cluster, but the same core functionality can be expected. In this context, *k3s* makes it possible to run workloads on the master node controlling the system as well as having the possibility to easily add additional worker nodes or even other master nodes to create a *high availability* cluster. With *k3s* it is thus possible to easily scale from a single computing node

to several. A contributing factor to the simplicity of k3s is that, with some exceptions, only the most essential components for running a bare-minimum high availability Kubernetes cluster have been included into the distribution of k3s. Moreover, another noteworthy advantage with k3s is that it is possible to package k3s into a single binary. This greatly simplifies the process of installing, configuring, and updating a production Kubernetes cluster.

Most of the microservices running in the Kubernetes cluster have been developed using the Django REST framework [16]. The Django REST framework is an extension built on top of Django, one of the most popular open-source web development frameworks written in the Python language. The reason for choosing this framework is primarily because of its wide adoption and maturity (the initial release of Django was in 2005). Another reason for choosing this framework is that a lot of different technologies integrate well with the framework since Django supports a wide variety of databases, caching solutions, and programming interfaces. To store the microservices data, PostgreSQL databases are used. PostgreSQL databases utilize a host-based persistent volume and are created automatically using the storage application of k3s.

For implementing the data processing pipeline, SOD relies on the OpenFaaS serverless computing framework [17]. OpenFaaS provides a platform for easily scaling CPU-bound computations implemented as functions. OpenFaaS comes with default auto-scaling based on the number of requests per second. Functions can be invoked asynchronously via message brokers, as well as synchronously through simple HTTP requests. OpenFaaS also has a large community and supports a wide range of programming languages with a lot of pre-defined and useful templates to choose from.

Finally, SOD also uses Redis [18], i.e., an in-memory distributed data structure store that can be used as a message queue and broker, but also as a Key-Value store and cache system.

#### IV. IMPLEMENTATION

Figure 1 gives an overview of the architecture of the backend of SOD that provides all needed services to the iOS/Android frontend. Components ②-⑥ are microservices and component ⑦ is the OpenFaaS serverless computing provider.

The entry point of the entire system is an Ingress Controller ① that receives requests from the smartphone application (frontend). Ingress is a standard component of the Kubernetes platform that provides routing rules to manage external users' access to the services in a Kubernetes cluster. The Ingress Controller redirects most traffic to the Orchestrator ② but also reserves a direct route to a Django Photo Service whose sole purpose is to serve photos such as user profile photos efficiently. Through the Ingress Controller, a cluster administrator is also able to access monitoring services such as Prometheus and Grafana.

The Orchestrator microservice ② is responsible to route the requests to other microservices but also to handle the creation,

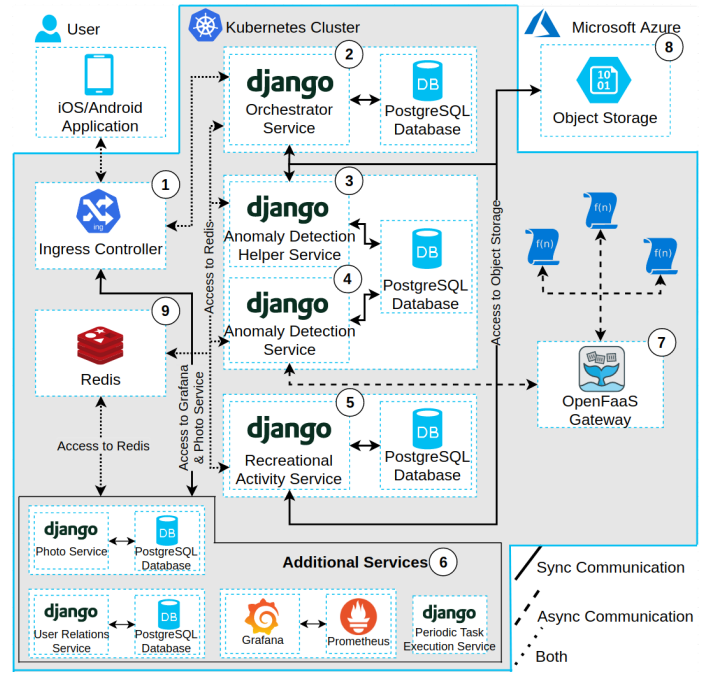


Fig. 1. A simplified overview of SOD architecture.

activation, deletion, update, and retrieval of users. Moreover, it allows to forward notifications to the smartphone by handling the WebSocket connections, i.e., persistent connection for bi-directional real-time messaging to the smartphone.

The Orchestrator serves as the logical entry point for all requests to the SOD's API. It was created to have a unique entry point to ease the task of monitoring, logging, and caching of requests and to handle user authorization and authentication in one place only using JSON Web Token (JWT) [19]. This means that a user only needs to authenticate once and then all internal communication between microservices can happen without further authentication requests.

Beyond the Orchestrator the backend consists of other main microservices implementing the functions discussed in Section II. In particular, the Anomaly Detection Service is implemented by microservices ③ and ④ with ③ handling bulk operations on raw location data and acting as a buffer to avoid many sequential writes to the database, and ④ handling the coordination of OpenFaaS function execution. The Recreational Activity Service is implemented by ⑤. Other utility microservices are also used and displayed at the bottom of Figure 1.

- The User Relations Service manages relations between users. It handles the linking between users with dementia and their relatives. Users' permissions and prioritization are also handled by this service, which ultimately determines in which order a relative is contacted in case a related user with dementia has lost his/her way. Finally, it handles the invitation sent by one user to another in the recreational activity component.
- The Photo Service manages images like user profile

photos or photos related to activities posted in the recreational activity calendar. The Photo Service interfaces with a Microsoft Azure Object Storage ⑧ and enables features for dynamically re-sizing and cropping photos. Furthermore, this service also works as a webserver for caching and efficiently serving image data.

- The Periodic Task Execution Service manages periodic tasks such as pushing database snapshots to the Azure Object Storage, sending out occasional reminders to volunteer users that have made themselves unavailable, removing users who did not complete the registration procedure, etc.

For logging and monitoring the microservices, SOD relies on the standard logging capabilities of the Django REST framework. Prometheus [20] is instead deployed for scraping the usage metrics of the Kubernetes cluster and its REST API that are visualized for monitoring purposes using Grafana [21]. The autoscaling of the microservices is configured based on CPU utilization. Whenever the load is increasing (resp. decreasing) for a small period of time (10 seconds) then the autoscaling mechanism is triggered by starting (removing) one or multiple replicas of a service.

Another central component of SOD's backend is the OpenFaaS Gateway ⑦. This is the entry point to the OpenFaaS framework that allows running the functions. OpenFaaS provides the infrastructure for implementing the algorithms to detect whether a user with dementia has lost the way. This includes different artificial intelligence techniques for online and offline anomaly detection. The functions deployed to OpenFaaS are developed using Python and are triggered based on the size of the individual queue in Redis. In Redis, every user has its own queue when sending location data to the backend. The functions are triggered asynchronously and can run for an unlimited amount of time. The cold start problem is avoided by keeping functions warm while there is still a need for them. The default autoscaling capabilities of OpenFaaS are used to ensure only the necessary resources are used by considering the number of requests per second.

The Microsoft Azure Object Storage component ⑧ is used for storing photos, binary machine learning model data, database snapshots, and other larger files. We decided to use Microsoft Azure Object Storage because of its easy access via the deployment platform Microsoft Azure Cloud, but other equivalent storing solutions can easily be supported.

Finally, the Redis component ⑨ is used as a message queue and broker in handling the internal communication between microservices. Two types of communication schemes have been implemented: *synchronous* and *asynchronous*. The communication scheme mostly depends on the origin of the initial event. Graphically, in Figure 1, bold arrows indicate synchronous communication and dashed lines indicate asynchronous. The dotted arrows instead indicate that the services use both synchronous and asynchronous communications with each other.

Synchronous communication is used whenever an immediate response is required and must be returned to the requesting

entity. This communication scheme is used by all services that expose some functionality through the Orchestrator and that can be accessed by a user. For example, when activities in the recreational activity calendar are created, changed, or retrieved, then synchronous communication is used. This communication scheme is inherently synchronous as all tasks will have to be handled within the request-response cycle and if this is not possible then an error message will have to be returned.

The general sequence of actions occurring when transporting synchronously a message between two microservices is depicted in Figure 2 and goes as follows:

- 1) Microservice X enqueues a message with a Universal Unique Identifier (UUID) on a named queue.
- 2) Microservice Y dequeues and processes the message which in turn creates a result.
- 3) Microservice Y sets the result in the Redis KV store using the UUID as the key and the result as the value.
- 4) Microservice X waits for the result to become available under the UUID in the Redis KV store.
- 5) Microservice X returns or utilizes the result further if available. If the result is not available after a number of re-tries and within a certain period of time, then the failure of Microservice Y is handled gracefully, i.e., a default value and an error message are returned.
- 6) The KV pairs stored in the Redis KV store are eventually deleted after a small pre-defined Time To Live (TTL) value.

Asynchronous communication is used instead whenever an immediate response is not required. This communication scheme between microservices is used internally for functionalities that are not exposed directly through the Orchestrator service. In general, any interaction that happens outside of the HTTP request-response cycle is handled asynchronously. The primary place where asynchronous communication is used is between microservices that communicate with the anomaly detection service and the service that handles scheduled tasks for future execution. Instead, any result that needs to be communicated from the backend to the user is sent via the user's WebSocket connection to the backend or via a push notification.

The sequence of actions occurring when transporting asynchronously a message between two microservices is depicted in the bottom half of Figure 2 and goes as follows:

- 1) Microservice X publishes an event that needs to be processed by Microservice Y.
- 2) Microservice Y receives the event as it subscribes to a topic that Microservice X publishes on.
- 3) Microservice Y consumes and processes the event. Subsequently it either does nothing or the result triggers Microservice Y to publish another event that Microservice X picks up (indicated by dashed lines in Figure 2). For example, if the anomaly detection service (Microservice Y) detects an anomaly, then an event is published for the Orchestrator (Microservice X) that can process it. The

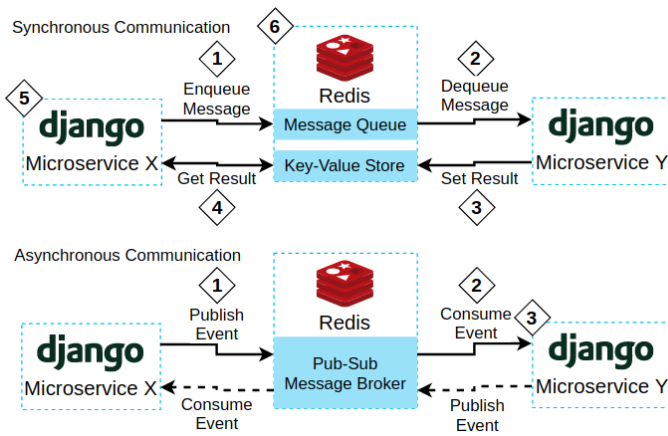


Fig. 2. Synchronous and Asynchronous communication schemes between microservices.

Orchestrator then sends a WebSocket message or push notification to the user.

Overall these communication schemes can be said to contribute to a loose coupling of the microservices as they make it easy to add new components and existing microservices will just have to subscribe to another topic or process messages from another named queue, to receive events or messages for further processing.

## V. PERFORMANCE EVALUATION

We set up experiments to test the capabilities of the backend system with respect to scalability and its ability to handle a number of scenarios with increasing, decreasing, and varying demand.

The load tests are implemented to target the part of the backend system that is responsible for providing the anomaly detection functionality. Figure 3 summarizes that part of the backend system and the communication flows tested. The frontend is able to record new locations for a user with a few seconds granularity (1-5 seconds), whenever the application is running in the foreground or background of the user's smartphone. The new locations of the user are sent to the backend system as they become available through HTTP POST requests. These requests have to be served by the backend within 5 seconds or otherwise a timeout error is returned. Hence, the backend receives between 12 and 60 new locations per minute. Less demanding operating conditions are possible. For example, to reduce the impact on battery consumption, it would be possible to pool locations collected in the frontend at lower frequency and send the pooled requests to the backend after longer intervals of time [22].

In our load tests, we simulate the behavior of real users by means of virtual users that open the application during a time window of at most 45 minutes. During this time they send HTTP POST requests with location data to the backend system every  $\tau$  seconds, with  $\tau$  uniformly distributed between 1 and 5. The data included in a POST request to the backend

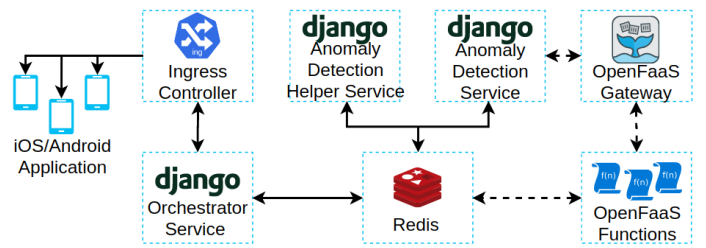


Fig. 3. An overview of the anomaly detection part of the backend. Bold arrows indicate synchronous communication and dashed arrows indicate asynchronous communication.

include a timestamp and random generated longitude, latitude, altitude, accuracy, speed, and acceleration.

As shown in Figure 3, the location data eventually arrives at the Anomaly Detection services that aggregate it and save it in bulk in the PostgreSQL database. The Anomaly Detection services also put the location data into a Redis message queue named after each respective user. After a number of locations have been placed into the named queue an OpenFaaS function is invoked and the data in the queue starts being processed by the function until the size of the named queue falls below a certain limit. The coordination of the function invocations is handled through Redis as well.

For the load tests, the simple task of computing a moving average of the longitude and latitude coordinates of a user with respect to a certain window size is used as a representative example of processing time series data and take into account time dependencies in the data.

More specifically, two different load testing scenarios are designed: a fixed increasing/decreasing load scenario to test constant and protracted demand variability and a varying scenario for testing rapid variability of the number of users. A steady-state is used as the initial state in both these two scenarios. It is obtained by adding users constantly until a load of 2400 virtual users is reached and then letting the system stabilize for 5 minutes without further addition or removal of users.

The *Fixed Increasing/Decreasing Load Scenario* proceeds as follows:

- 6 users per second are added over a time period of 5 minutes resulting in an additional demand of 1800 virtual users. This level of demand is maintained for a period of 5 minutes to stabilize the system;
- next, 14 users per second are added over a time period of 5 minutes reaching a total of 8400 virtual users. A period of 5 minutes follows with no change in the level of demand;
- next, 14 users per second are removed over a period of 5 minutes, such that 4200 virtual users remain. A period of 5 minutes then follows with no change in the level of demand;
- finally, 6 users per second are removed until only 2400 active virtual users remain. A period of 5 minutes follows with no change in the level of demand.

The *Varying Load Scenario* proceeds by varying more quickly the number of users without waiting for the system to stabilize. More precisely, it proceeds as follows:

- 40 users per second are added over a period of 2.5 minutes. This results in a total of 8400 virtual users;
- 56 users per second are removed over a period of 2.5 minutes, which results in 0 virtual users using the backend system.
- Immediately after, 56 users per second are added over a period of 2.5 minutes. This results in 8400 virtual users using the backend system. This step is repeated 6 times.
- next, 40 virtual users per second are removed over a time period of 2.5 minutes. This results in a total of 2400 virtual users using the backend system concurrently. A time period of 5 minutes follows with no change in the level of demand.

These load tests were written and executed using the Python framework *Locust* [23], i.e., a fairly new load testing framework and an alternative to more popular but older load testing frameworks such as *Jmeter* [24]. *Locust* was adopted because it is event-based and it allows a developer to run distributed load tests with thousands of virtual and concurrent users. It is thus very suitable for testing highly concurrent workloads, which is also what the backend system is designed to handle.

The experiments were run on a Kubernetes cluster consisting of one master node and one worker node deployed on Microsoft Azure using Standard D16v4, Ubuntu 18.04-LTS general-purpose virtual machines with standard HDD storage. In total, we allocated 32 virtual cores and 64GB of RAM distributed evenly on two nodes. All microservices displayed in Figure 1 were running in different containers deployed in individual pods. For each microservice, we configured k3s autoscaling with a minimum and maximum number of pods along with resource requests. The configuration was such that at most 20 cores were used at any time during the experiments by the cluster and 3 cores were used for running the load tests.

The performance of SOD in the two scenarios is shown in Figures 4 and 5. Specifically, the plots show the number of requests, the number of active users, the latency (median and 95 percentile), and the CPU utilization of certain key components of the system. We can see that the services are able to scale in/out to cope with the different increasing/decreasing and varying demand patterns. In general, we observe that the response time increases considerably when the demand peaks. We interpret this as an indication that the saturation of the resources (i.e., configured max number of pods) is reached and that the system cannot scale up further. Interestingly, we never experience failure in responses even in times of high stress of the system.

The varying load scenario displays the backend system’s capability to be reactive and handle varying demand, while the increasing/decreasing load scenario displays the backend system’s ability to deal with sustained load.

We observe that under the sustained load of the first scenario and the resources available (the two virtual machines), the number of users that the backend system is able to handle

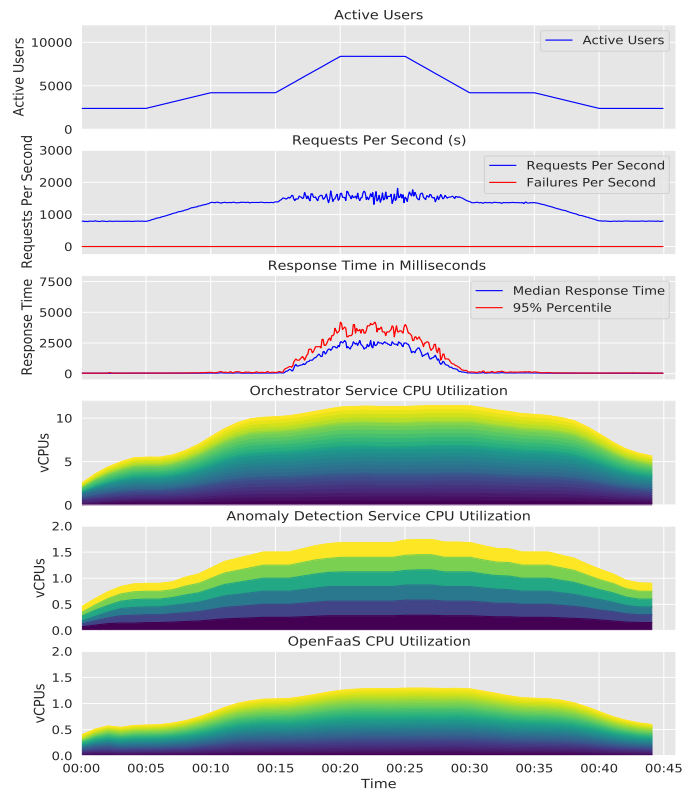


Fig. 4. Fixed Increasing/Decreasing Load Scenario. Each color gradient in the area plots correspond to the resources used by a replica of a service.

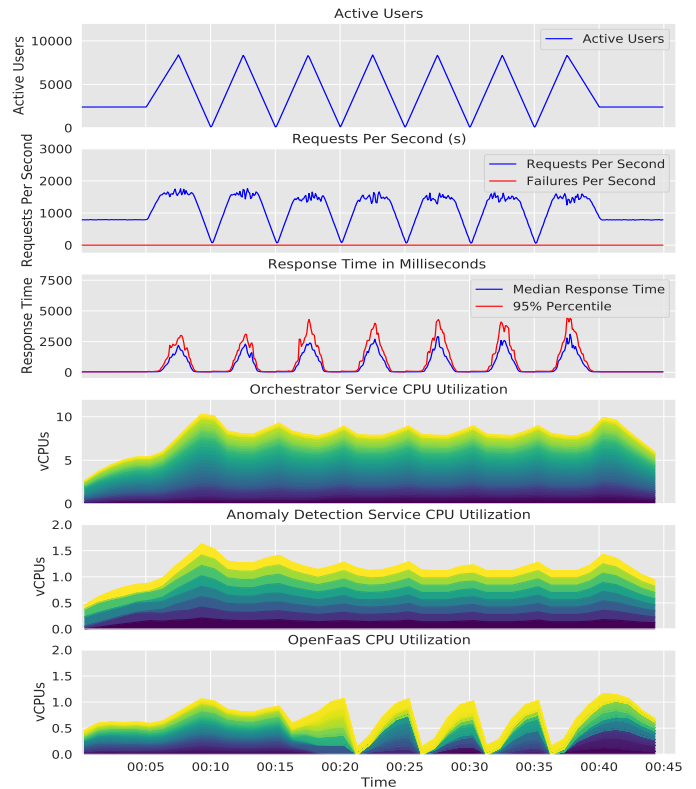


Fig. 5. Varying Load Scenario. Each color gradient in the area plots correspond to the resources used by a replica of a service.

reliably without an increase in response time is around 5000 users. Beyond 5000 users we observe that the response time starts to increase and the number of successfully served requests per second starts stagnating. A further slow down in response time beyond 5 seconds will eventually lead to timeouts because for practical reasons we set the response time limit of the backend system to 5 seconds. Nonetheless, from the tests in the second scenario, we learn that the backend system is able to recover from short periods of time with relatively high demand without any errors. We observe that initially during consistent load the resource usage is distributed evenly among OpenFaaS pods, but during rapid increases in demand certain pods are able to start earlier than others receiving more requests and thus consuming more resources.

In the last three plots of Figure 4 and 5 we can observe the impact of the different services on the system. The Orchestrator uses the largest amount of CPU resources and would be therefore the place to look at for further optimizations. On the other hand, an insignificant amount of RAM (not shown in the figures) was used throughout the tests, which makes sense as it was primarily the throughput of the system that was tested.

In these tests, we restricted ourselves to two nodes. However, the backend system can easily be deployed with no further effort on a larger cluster of nodes thanks to Kubernetes that is designed to scale to hundreds of computing nodes. Thus, we could handle a much larger number of active users.

## VI. RELATED LITERATURE & CONCLUSIONS

Smartphone apps, Internet of Things, and wearable sensors offer new opportunities in the health sector to cure or alleviate diseases as well as to collect data to gain new knowledge. In line with the current efforts in the exploitation of these technologies, we designed a software architecture that allows the collection of data in a frontend and the analysis in remote in a backend. We focused our architecture on an app for the detection of getting lost behavior in people with dementia. However, we believe that the architecture is reusable in similar data science projects.

We designed the backend system to rely on microservices and serverless services. Our simulation tests confirmed that the architecture makes it possible to cope efficiently and reliably with different types of load and to scale appropriately.

Similar to ours, other works on different applications investigate the performance, scalability, and especially the cost of running microservices and serverless architectures in the public cloud. They seem to reach similar conclusions to ours and complement them with additional remarks. For example, [25] proposes a framework for supporting analytics in mobile health applications while [26] describes the functionality and architecture of both the frontend app and the backend system for a smartphone e-health app that supports maternal health workers in rural India. The work in [27] illustrates instead the development of three concrete app examples natively on the cloud using Apache OpenWhisk [28]. Like in our work, the authors describe how easy it is to make changes and deploy functions on the fly. In [29], the authors present a case

study of the migration of a monolithic application to AWS Lambda observing great cost savings compared to running the same application on virtual machines using IaaS. Similar observations are made in [30], [31].

Several open-source libraries and frameworks that utilize serverless computing for running data processing workloads in the cloud have been proposed in the literature. Most notably, the OSCAR (Open Source Serverless Computing for Data-Processing Applications) framework is presented in [32]. The framework utilizes an architecture that primarily uses serverless computing for event-driven data processing. It is a framework for general-purpose file-processing applications and it uses, like us, OpenFaaS for function execution. The authors show the capabilities of the developed framework to scale appropriately according to demand. Furthermore, the reliability and scalability of the platform is tested on a concrete use-case related to object detection in videos.

Another framework that aims to simplify the access to distributed computing through serverless computing is the PyWren framework presented in [33]. The framework is created to easily perform Python-based distributed computing on AWS Lambda by avoiding having to provision and configure complex on-premise clusters. The SIREN machine learning library proposed in [34] also takes advantage of the same benefits of deploying to AWS Lambda. The library enables a swarm of stateless functions to work on batches of machine learning training data. With this approach, the authors show that they can achieve a high level of scalability.

Several other libraries and frameworks are dedicated to solving problems with resource provisioning and management in the context of serverless computing. An example of this is the BARISTA framework introduced in [35]. It is a serverless framework that focuses on being able to dynamically manage resources by horizontally and vertically autoscaling containers based on predicted workloads. Another framework that is concerned with the same aspect of serverless computing, but with a more general and broader scope, is presented in [36].

With the architecture of SOD in place, we are currently working at the development of the functionalities and the data processing pipeline in OpenFaaS. In particular, we are deploying several artificial intelligence techniques to detect if a person with dementia is getting lost. The current infrastructure has been extended by coordinating more function calls and allowing access from the function to other components of the system, such as the Azure Object Storage.

As far as efficiency is concerned, we noted that compared to other architectures, our architecture provides a lot of functionality directly in the Orchestrator Service (e.g., gateway, authorization, authentication). While handling all these tasks at a single point might have some advantages, it has of course also the drawback of requiring more resources to perform them. Hence, looking for possible further improvements in the scalability and efficiency of the backend system, we are considering delegating all these functionalities to other separate services and make them directly accessible through

the Ingress Controller.

Our next steps for the improvement of SOD are: evaluating and combining the AI techniques for detecting getting lost episodes on the basis of benchmark data, carrying out user tests for assessing the reliability and reception of the functionalities of the app, and comparing with alternative proposals from the literature. Moreover, we plan to complement the location information with other information coming from sensors on the smartphone and ultimately also from wearable devices that could remove the need for remembering to take the smartphone when going for a walk, something we cannot rely on in advanced stages of dementia.

#### DATA AVAILABILITY

A snapshot of the repository containing the codebase for the SOD backend system and the data that support the findings of this study are openly available in Zenodo at [37].

#### ACKNOWLEDGMENTS

We acknowledge financial support for the project SammenOmDemens by TrygFonden (ID 127211), Nyborg Kommune and University of Southern Denmark.

#### REFERENCES

- [1] M. Price, A. Wimo, M. Guerchet, G. Ali, Y. Wu, and M. Prina, *World Alzheimer Report 2015. The Global Impact of Dementia: An Analysis of Prevalence, Incidence, Cost and Trends*. Alzheimer's Disease International (ADI), London, 2015.
- [2] W. Moyle, "The promise of technology in the future of dementia care," *Nature Reviews Neurology*, vol. 15, pp. 353 – 359, 2019.
- [3] A. Z. Hassan and A. Khan, "A survey on wandering behavior management systems for individuals with dementia," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 2, 2019.
- [4] P. P. Ray, D. Dash, and D. De, "A systematic review and implementation of IoT-based pervasive sensor-enabled tracking system for dementia patients," *Journal of medical systems*, vol. 43, no. 9, pp. 1–21, 09 2019.
- [5] C. Richardson. Pattern: Microservice architecture. [Online]. Available: <https://microservices.io/patterns/microservices.html>
- [6] —. Pattern: Serverless deployment. [Online]. Available: <https://microservices.io/patterns/deployment/serverless-deployment.html>
- [7] E. R. Pratama, F. Renaldi, F. R. Umbara, and E. C. Djamal, "Geofencing technology in monitoring of geriatric patients suffering from dementia and alzheimer," in *2020 3rd International Conference on Computer and Informatics Engineering (IC2IE)*, 2020, pp. 106–111.
- [8] J. Berrocal, J. Garcia-Alonso, J. Murillo, and C. Canal, "Rich contextual information for monitoring the elderly in an early stage of cognitive impairment," *Pervasive and Mobile Computing*, vol. 34, pp. 106–125, 2017, pervasive Computing for Gerontechnology. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1574119216300499>
- [9] G. Kim, P. Debois, J. Willis, and J. Humble, *The DevOps Handbook: How to Create World-Class Agility, Reliability, and Security in Technology Organizations*. IT Revolution Press, 2016.
- [10] Docker Inc. Docker compose. [Online]. Available: <https://docs.docker.com/compose/>
- [11] The Linux Foundation. Kubernetes. [Online]. Available: <https://kubernetes.io/>
- [12] Docker Inc. Docker swarm. [Online]. Available: <https://docs.docker.com/engine/swarm/>
- [13] —. Docker hub. [Online]. Available: <https://hub.docker.com/>
- [14] Rancher Labs. K3s. [Online]. Available: <https://k3s.io/>
- [15] Cloud Native Computing Foundation. Software conformance (certified kubernetes). [Online]. Available: <https://www.cncf.io/certification/software-conformance/>
- [16] Django REST Framework. Django rest framework. [Online]. Available: <https://www.django-rest-framework.org/>
- [17] OpenFaaS Ltd. Openfaas. [Online]. Available: <https://www.openfaas.com/>
- [18] Redislabs. Redis. [Online]. Available: <https://redis.io/>
- [19] Internet Engineering Task Force (IETF). JSON web token (JWT). [Online]. Available: <https://jwt.io/>
- [20] The Linux Foundation. Prometheus. [Online]. Available: <https://prometheus.io/>
- [21] Grafana Labs. Grafana. [Online]. Available: <https://grafana.com/>
- [22] T. Rault, A. Bouabdallah, Y. Challal, and F. Marin, "A survey of energy-efficient context recognition systems using wearable sensors for healthcare applications," *Pervasive and Mobile Computing*, vol. 37, pp. 23–44, 2017.
- [23] C. Bystr, J. Heyman, J. Hamrén, H. Heyman, and L. Holmberg. Locust. [Online]. Available: <https://locust.io/>
- [24] The Apache Software Foundation. Jmeter. [Online]. Available: <https://jmeter.apache.org/>
- [25] P. Chowdhary, S. Lee, J. T. E. Timm, H. Ludwig, and S. E. Knoop, "Coordinating analytics methods for mobile healthcare applications," in *Proceedings of the International Workshop on Software Engineering in Healthcare Systems, SEHS@ICSE 16, Austin, Texas, USA, May 14-22, 2016*. ACM, 2016, pp. 58–61.
- [26] A. Maitra and N. Kuntagod, "A novel mobile application to assist maternal health workers in rural india," in *Proceedings of the 5th International Workshop on Software Engineering in Health Care, SEHC 2013, San Francisco, California, USA, May 20-21, 2013*, J. Knight and C. E. Kuziemsky, Eds. IEEE Computer Society, 2013, pp. 75–78.
- [27] I. Baldini, P. C. Castro, P. Cheng, S. J. Fink, V. Ishakian, N. Mitchell, V. Muthusamy, R. Rabbah, and P. Suter, "Cloud-native, event-based programming for mobile applications," in *Proceedings of the International Conference on Mobile Software Engineering and Systems, MOBILESoft '16, Austin, Texas, USA, May 14-22, 2016*. ACM, 2016, pp. 287–288.
- [28] The Apache Software Foundation. Apache OpenWhisk. [Online]. Available: <https://openwhisk.apache.org/>
- [29] W. Lloyd, M. Vu, B. Zhang, O. David, and G. H. Leavesley, "Improving application migration to serverless computing platforms: Latency mitigation with keep-alive workloads," in *2018 IEEE/ACM International Conference on Utility and Cloud Computing Companion, UCC Companion 2018, Zurich, Switzerland, December 17-20, 2018*, A. Sill and J. Spillner, Eds. IEEE, 2018, pp. 195–200.
- [30] V. Ishakian, V. Muthusamy, and A. Slominski, "Serving deep learning models in a serverless platform," in *2018 IEEE International Conference on Cloud Engineering, IC2E 2018, Orlando, FL, USA, April 17-20, 2018*, A. Chandra, J. Li, Y. Cai, and T. Guo, Eds. IEEE Computer Society, 2018, pp. 257–262.
- [31] M. Villamizar, O. Garces, L. Ochoa, H. E. Castro, L. Salamanca, M. Verano, R. Casallas, S. Gil, C. Valencia, A. Zambrano, and M. Lang, "Infrastructure cost comparison of running web applications in the cloud using AWS lambda and monolithic and microservice architectures," in *IEEE/ACM 16th International Symposium on Cluster, Cloud and Grid Computing, CCGrid 2016, Cartagena, Colombia, May 16-19, 2016*. IEEE Computer Society, 2016, pp. 179–182.
- [32] A. Pérez, S. Risco, D. M. Naranjo, M. Caballer, and G. Moltó, "On-premises serverless computing for event-driven data processing applications," in *12th IEEE International Conference on Cloud Computing, CLOUD 2019, Milan, Italy, July 8-13, 2019*, E. Bertino, C. K. Chang, P. Chen, E. Damiani, M. Goul, and K. Oyama, Eds. IEEE, 2019, pp. 414–421.
- [33] E. Jonas, Q. Pu, S. Venkataraman, I. Stoica, and B. Recht, "Occupy the cloud: distributed computing for the 99%," in *Proceedings of the 2017 Symposium on Cloud Computing, SoCC 2017, Santa Clara, CA, USA, September 24-27, 2017*. ACM, 2017, pp. 445–451.
- [34] H. Wang, D. Niu, and B. Li, "Distributed machine learning with a serverless architecture," in *2019 IEEE Conference on Computer Communications, INFOCOM 2019, Paris, France, April 29 - May 2, 2019*. IEEE, 2019, pp. 1288–1296.
- [35] A. Bhattacharjee, A. D. Chhokra, Z. Kang, H. Sun, A. Gokhale, and G. Karsai, "BARISTA: efficient and scalable serverless serving system for deep learning prediction services," in *IEEE International Conference on Cloud Engineering, IC2E 2019, Prague, Czech Republic, June 24-27, 2019*. IEEE, 2019, pp. 23–33.
- [36] J. Enes, R. R. Expósito, and J. Touriño, "Real-time resource scaling platform for big data workloads on serverless environments," *Future Gener. Comput. Syst.*, vol. 105, pp. 361–379, 2020.
- [37] N. S. Andersen. Sammen Om Demens (SOD) backend snapshot (version v1). [Online]. Available: <https://doi.org/10.5281/zenodo.4597416>