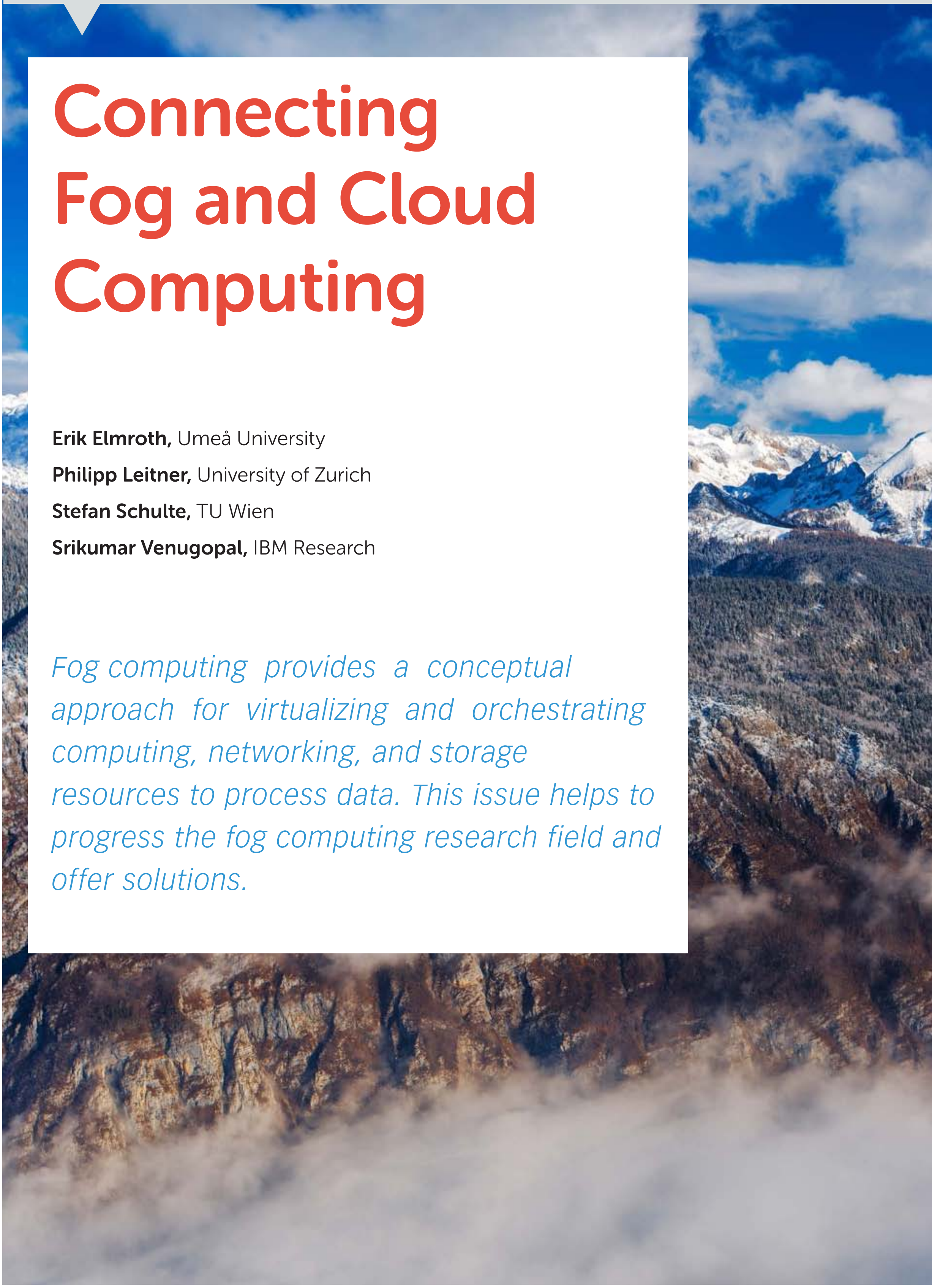

Connecting Fog and Cloud Computing

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Fog computing provides a conceptual approach for virtualizing and orchestrating computing, networking, and storage resources to process data. This issue helps to progress the fog computing research field and offer solutions.

In recent years, the cloud computing paradigm has changed how both, industry and academia, think about IT. Defined by virtualization, centralization, and the effective leverage of economies of scale, cloud computing has democratized scale-out computing and has made the processing power of the data centers of players such as Amazon or Google available and affordable for virtually everyone with access to the Internet. Consequently, we have seen more and more applications moving to the cloud through a Software-as-a-Service (SaaS) provisioning model.

However, using cloud-based computational resources is not always the best choice in the Internet of Things (IoT). IoT devices are numerous, and not necessarily linked through always-on, broadband Internet connections. Further, many interesting use cases for IoT (e.g., healthcare scenarios, wearable devices, etc.) have strong data privacy implications. Hence, centrally processing all data produced in the IoT in a cloud is occasionally impractical, and in some cases even illegal. In addition, the basic structure of the IoT is highly decentralized, with literally billions of IoT devices distributed around the globe. In many envisioned smart environments, thousands of devices may be connected to each other, not only in one place, but actually in a wider area. This level of decentralization does not match the rather centralized structure of the cloud with its very large data centers. Today, the basic assumption in many application domains is that IoT data sources send data to cloud data centers, the data is processed in the cloud, and then the results are sent back to the respective data owners who, in many cases, are located close to the data sources. Obviously, this leads to a very large communication overhead between data sources, cloud-based processing capabilities, and data stakeholders.

A natural approach to deal with these challenges is to process and aggregate sensitive or bulky data where, or close to where, it is produced. This concept has been coined *edge computing*.[1] Edge computing is often used in conjunction with centralized cloud services, leading to the vision of *fog computing*.[2] While a generally accepted definition of fog computing is still missing, the research community agrees that fog computing is based on some well-known principles that have made the cloud a success story and are now used at the edge of the network. This includes on-demand provisioning of computational resources, rapid elasticity, unified management interfaces, and virtualization. Thus, it is possible to provide IoT-based computational resources in a similar vein as virtual machines and software containers are offered on the cloud. The end result is a virtualized computing infrastructure that spans cloud data centers, various intermediary nodes such as routers and gateways, and IoT devices.

We are currently observing a surge of interest in the fog computing paradigm, as indicated by recent papers[4,5,6] and many scientific conferences that had their inaugural editions in 2016 and 2017.

However, plenty of challenges remain to be tackled. In fact, a number of the early approaches to fog computing provide conceptual solutions, but there is still a lack of concrete methods, tools, and frameworks that are necessary to realize fog computing. Also, as in every upcoming field, it still needs to be discussed what are the most important research questions that should be answered. As fog computing incorporates technological approaches from the IoT, cloud computing, and wireless sensor networks, there is no clear delimitation of what is actually original research in the field of fog computing.

It is the goal of this special issue to help to advance the fog computing research field and present concrete solutions. For this, we present four papers that discuss various aspects of the abovementioned challenges. The articles cover a broad topical spectrum, from network function virtualization (NVF) over workload balancing and distribution, all the way to continuous query evaluation in the fog.

Summary of Contributions

All submissions in this special issue have received at least three formal peer reviews by independent experts, in addition to meta-reviews by all of the special issue editors. The peer reviews focused on level of innovation, technical accuracy, quality of presentation, and relevance to the special issue topic. After a difficult decision process, we have decided to accept the following four papers after a second round of careful revisions.

Malensek, Pallickara, Pallickara: "Hermes: Federating Fog and Cloud Nodes to Support Query Evaluations in Continuous Sensing Environments"

This paper introduces Hermes, a framework for federated query evaluations in fog and cloud. Hermes is a mature research project that showcases the possibilities, but also the challenges, of big data analytics in fog computing. In contrast to the other papers in the special issue, this contribution focuses on data science aspects of fog computing.

Kapsalis, Kasnesis, Patrikakis, Venieris, Kaklamani: "A Cooperative Fog Approach for Effective Workload Balancing"

The second contribution in the special issue focuses on the fog as a distributed computing platform. The paper introduces a very interesting stack that defines the fog as a virtual construct on top of various devices and hubs. Applications are defined as scripts with various constraints (e.g., Quality of Service, time sensitivity), which are then scheduled over the fog by the platform.

Bittencourt, Diaz-Montes, Buyya, Rana, Parashar: "Mobility-aware Application Scheduling in Fog Computing"

Similar to the second paper, this contribution focuses on where to execute any given functionality in a fog platform. The authors again propose an intermediary layer (called "cloudlets", a notion that is also heavily used in cyber-foraging [7]). This paper and the previous paper nicely illustrate that much of what we have learned in grid and cloud computing (e.g., regarding task scheduling and placement) will need to be (re-)visited and adapted for fog computing. We can be confident that workload balancing and scheduling will remain a fruitful research topic even in fog computing.

Moreno-Vozmediano, Montero, Huedo, Llorente: "Cross-Site Virtual Network Provisioning in Cloud and Fog Computing"

The final paper in the special issue explores the topic from a network perspective. The authors propose a virtual network spanning fog and cloud data centers. This virtual network allows for automatic provisioning of cross-site virtual network functions, which also takes multi-tenancy into account. The proposed solution comes out of the European research project BEACON, and can serve as the backbone of future industrial fog computing deployments.

It is clear that we are still in the formative phase of fog computing, and only the future will reveal which parts of the (sometimes competing) visions, solution proposals, and application areas will prove to be of most value to society and industry. However, as the four papers in this special issue show, the opportunities, as well as the challenges, are manifold. Some of these challenges can be addressed by adapting solutions that have proven their value before, such as the contributions on load balancing, scheduling, and NFV in this special issue. However, the intricate nature of the fog will certainly lead to hitherto completely unexplored problems that will require completely novel approaches.

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