The Edge of the Cloud

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Two of the most important technological developments of the last few years are the emergence of mobile and cloud computing. By shifting the hardware and staffing costs of managing the computational infrastructure to third parties—such as Google, Microsoft, or Amazon—cloud computing has made it possible for small organizations and individuals to deploy world-scale services while paying only the marginal cost of actual resource usage. At the same time, the deployment of 3G and 4G networks and the rapid adoption of feature-rich smartphones have brought mobile computing into the mainstream.

Here, we explore the intersection of pervasive and cloud computing. Mobile devices let users access cloud-based services and data anywhere and anytime, extending such devices' reach into everyday life. Simultaneously, cloud computing platforms address the lack of local resources in mobile devices, thereby enabling resource-intensive next-generation applications. The articles in this issue consider how to secure data stored in the cloud and maintain access to cloud services despite disruptions in network communication.

Exploiting Scarce Location Data

The first article in this issue, "Capturing Urban Dynamics with Scarce Check-In Data," explores the use of scarce check-in data—through services such as Foursquare—to build a model of a city's dynamic patterns and identify interesting trends. Andreas Komninos, Vasilios Stefanis, Athanasios Plessas, and Jeries Besharat set up "listening posts" throughout the business and social areas of a medium-sized city in Greece. Using these posts, they queried Foursquare periodically to collect check-in data for nearby businesses. They found that the check-in data was quite scarce, with an average of just 10 users checking in to any particular location over the course of the day. They then explored

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whether they could use such scarce data to identify interesting trends.

They validated the city's "rhythm" in terms of rush hour and busy times against two baseline datasets and their own knowledge of the city. The first of the two datasets comprised pollution records with diurnal hourly measurements of several pollutants, including two strongly associated with traffic. The second dataset was from a recent traffic study conducted to help determine the feasibility of implementing a new tram system. The authors found that the trends identified with the pollution and traffic data matched those found using their scarce dataset from Foursquare check-ins. The implications of this result—that scarce data can, in fact, be used to identify trends—are important, given the strong interest in participatory sensing in cities.

Immersive Collaboration on the Edge

In "Leveraging the Cloudlet for Immersive Collaborative Applications," Tim Verbelen, Pieter Simoens, Filip De Turck, and Bart Dhoedt discuss how the cloud can help enable immersive, collaborative applications. They explore how mobile devices with extensive capabilities—such as Google Glass—might open the door for augmented reality applications. For example, in a museum setting, visitors might see visual annotations as they look at artifacts.

The authors discuss the challenges of realizing this vision, including the inherent limitations of mobile devices and the fact that a naïve off-loading of work to a cloud environment won't overcome such limitations. The authors adopt a component-based approach in which they split the immersive, collaborative application into different components that are loosely coupled together. These components can then be independently off-loaded to a cloudlet, depending on the situation. When multiple users happen to be in the same environment and doing (or looking at) similar things, the application can off-load components in such a way as to enable sharing of the results. In the museum scenario, nearby visitors can share a common model as well as object recognition.

Disconnected Operation for the Cloud

In "The Role of Cloudlets in Hostile Environments," Mahadev Satyanarayanan, Grace Lewis, Edwin Morris, Soumya Simanta, Jeff Boleng, and Kiryong Ha consider the use of cloudlets in situations in which access to the cloud can't be assumed—such as during military operations and natural disasters or in developing countries. In these situations, or other environments that might be hostile, they advocate using cloudlets as surrogates for the cloud, using a design strategy in which the cloudlet is transparent during normal operations but takes over essential cloud functions, to the extent possible, during failure conditions.

Cloudlets were originally conceived as a way to bring the cloud closer to a mobile device by reducing the end-to-end latency of offloading work from the resource-constrained mobile device to the resource-rich back-end datacenter. In this article, the authors consider how cloudlets can address failures expected to occur with mobile devices in hostile environments. They use military operations as their example, describing how the approach can defeat denial-of-service attacks orchestrated from a distance and reduce the risk of information leakage through traffic analysis. They also discuss how the cloudlet approach makes multiuser collaboration easier in these environments, because the synchronization required can be performed in the cloudlet rather in the more distant cloud.

Their main message is the importance of proximity for survivability and resilience. They generalize beyond military operations and natural disasters, pointing out that should cyberattacks ever become commonplace, the cloudlet approach would help improve the everyday operations of mobile devices accessing cloud resources.

Cloud Storage Security

In "Security Concerns in Popular Cloud Storage Services," Cheng-Kang Chu, Wen-Tao Zhu, Jin Han, Joseph K. Liu, Jia Xu, and Jianying Zhou present a security analysis of popular cloud storage services The authors consider three popular services—Dropbox, Google Drive, and Microsoft Skydrive—and reveal some shocking behaviors.

Given the production nature of these services, it was surprising to see the variety of weaknesses that the authors uncovered. Each of these services has security weaknesses that can result in data leakage without user awareness. Furthermore, the authors provide techniques and recommendations for mitigating such risks and suggest practical countermeasures that can be directly integrated into these and similar systems.

The intersection of cloud and mobile computing will remain an interesting and active area for research and development for the foreseeable future. The ability to access services and data from any location at any time makes mobile devices a compelling force in the marketplace. The ability to extend the capabilities and resources of the mobile device by using the cloud helps address the inherent limitations of these devices. We hope you enjoy reading the articles in this issue, and we look forward to further advances at the exciting intersection of these two technologies. ℗