

# Reflecting on the past, preparing for the future: from peer-to-peer to edge-centric computing

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Centralization and decentralization fight an eternal battle in many fields of the human culture. In federal states, power shifts back and forth between the federal government and the constituent states. Energy generation was first concentrated in large power plants but is now moving to decentralized power grids.

In computing, we have witnessed similar shifts between centralized and decentralized control. In the 1980s, a wave of decentralization led to shifting away from centralized mainframes to personal computers and local networks, which culminated in fully decentralized systems using peer-to-peer and autonomous computing approaches.

In recent years, however, we observed an important wave of centralization: the control, data and intelligence of computing systems moved back to the cloud. There are strong reasons behind this migration: cloud computing with the enormous capacities of its dedicated data centers and the use of simple centralized architectures creates effective economies of scale.

However, we believe that when pushed to such a logical extreme, full centralization brings more harm than good in several ways. The most important problem is the loss of privacy by releasing personal and social data to centralized services such as e-commerce sites, rating services, search engines, social networks, and location services. A second problem is the complete delegation of the applications and systems control from the users to the cloud, which requires unilateral trust from clients to the clouds and prevents establishing finer grain trust between users. Third, there is the missed opportunity of exploiting the enormous amount of computational, communication, and storage power of modern personal devices. Finally, centralization hampers novel human-centered designs that would allow to bring the human in the application, blurring the boundaries between man and machine and making possible for novel applications to emerge.

Recently, in cooperation with Garcia Lopez and many others [1], we positioned that the advent of clouds should not be the final paradigm shift, and that a new decentralization wave is necessary. We advocate for *edge-centric computing* as a novel paradigm that will push the frontier of computing applications, data, and services away from centralized nodes to the periphery of the network.

There are several compelling reasons for pushing towards edge-computing:

- *Proximity is in the edge*: It is more efficient to communicate and distribute information between close-by nodes

than to use far-away centralized intermediaries. Here, “close-by” can be understood both in a physical and a logical sense.

- *Intelligence is in the edge*: Edge devices become more and more powerful. This opens the way to autonomous decision-making in the edge such as novel distributed crowdsensing applications, but also human-controlled actuators or agents reacting to the incoming information flows.
- *Trust is in the edge*: Personal and socially-sensitive data is clearly located in the edge. The control of trust relation and the management of sensitive information flows in a secure and private way must therefore also belong to the edges.
- *Control is in the edge*: The management of the application and the coordination also comes from the edge machines that can assign or delegate computation, synchronization or storage to other nodes or to the core selectively.
- *Humans are in the edge*: Human-centered designs should put humans in the control loop, so that users can retake control of their information. This should lead to the design of novel crowdsourced and socially-informed architectures where users control the links of their networks.

While we push for decentralization, we do not push for purely decentralized systems, like P2P networks. Instead, an edge-computing architecture may consist of hybrid federations of services, running in large datacenters, in nano-datacenters closer to the clients, and in personal devices. Following the decentralized nature of the Internet, hybrid edge services may be deployed by different vendors and must be able to talk to each other.

We position that this paradigm will retain core advantages of using clouds as a support infrastructure, but will put back the control and trust decisions to the edges and allow for novel, human-centered computing applications.

In this tutorial, we will survey on the latest developments in the area of decentralized and edge computing, including peer-to-peer-networks, blockchains, hybrid and decentralized cloud architectures, and we will elaborate on the growing importance that such technologies will have in the future.

## REFERENCES

- [1] P. Garcia Lopez, A. Montresor, D. Epema, A. Datta, T. Higashino, A. Iamnitchi, M. Barcellos, P. Felber, and E. Riviere, “Edge-centric computing: Vision and challenges,” *SIGCOMM Comput. Commun. Rev.*, vol. 45, no. 5, pp. 37–42, Sep. 2015.