CLOUD COMPUTING

Cameron Koob*

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I. INTRODUCTION

Over the past two decades, cloud computing has transformed the technological landscape by increasing accessibility to and reducing the expense of online services. The technological underpinnings of the cloud begin with the Internet and its antecedents. Today, cloud computing affords the world distributed access to virtual assets, applications, and resources from anywhere in the world. While cloud computing is involved in almost all networked services,[1] users are often unaware of the delivery models making these services viable. This technology explainer will describe cloud computing technology and its tradeoffs and examine the most common cloud computing delivery models and their functions before delving into the challenges and areas for further development.

II. CLOUD COMPUTING GENERALLY

* Georgetown University Law Center, J.D. Candidate 2023; Franklin and Marshall College, B.A. in Government 2016. Thank you to Emily Ehrlich, Susan Pratt, Ryan Hsu, and everyone involved for their hard work on this piece.

[1] For instance, storing photos in online albums, accessing emails, or streaming movies, television shows, or music.

Cloud computing is both a technology and an "economic model."[2] As a technology, it is defined as "a distributed computing paradigm that focuses on providing a wide range of users with distributed access to scalable, virtualized hardware and/or software over the [I]nternet."[3] Providers of cloud computing services offer a product or service through a networked connection.[4] Cloud computing providers establish servers, which contain storage space for data that they may send or receive, and make their use available to users. At the most basic level, providers program servers to make those servers available to users, who in turn receive access to the application, platform, or computational infrastructure they are paying for.

Cloud computing is also an economic model because it is scalable—an organization can select from a variety of delivery models depending on "costs, benefits, and risks . . . as an [information technology] strategy."[5] As an economic model, cloud computing offers individual consumers and businesses various benefits. It reduces the cost of developing, implementing, and utilizing Internet-based technologies. In turn, these reduced costs also increase the accessibility of powerful technology to businesses and individual users. Cloud computing's scalability also speeds up the acquisition of new capacity for more data or user traffic by shifting the resource burden to a separate business.

III. CAPABILITIES AND ACCESS

Cloud computing services can be defined by capabilities and access. Capabilities refer to the technological function and nature of the product delivered to users, and access refers to who can utilize it.[6] Cloud computing has several capabilities, as the following section discusses: (A) Software as a Service, (B) Access, (C) Platform as a Service, (D) Infrastructure as a Service, and (E) Serverless.

A. Software as a Service

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[2] GRACE LEWIS, CARNEGIE MELLON SOFTWARE ENG'G INST., BASICS ABOUT CLOUD COMPUTING 1 (2010), https://resources.sei.cmu.edu/asset_files/WhitePaper/2010_019_001_28877.pdf [https://perma.cc/9WPY-CCCN].

[3] *Id.*

[4] *Id.* at 2; ALEXA HUTH & JAMES CEBULA, U.S. COMPUT. EMERGENCY READINESS TEAM, THE BASICS OF CLOUD COMPUTING 1 (2011), http://findnerd.s3.amazonaws.com/data/152759075583.pdf [https://perma.cc/LM4C-9P5F].

[5] LEWIS, *supra* note 2, at 1.

[6] *Id.* at 2-3.

Software as a Service (SaaS) is a method of delivering software to users from the vendor's datacenter. SaaS allows consumers, businesses, and organizations to effectively stream the services they need without requiring their own systems, infrastructure, and physical space with IT services, updates, or any of the other costs associated with powerful software tools.[7] SaaS can be thought of similarly to utilities: consumers pay a fee and vendors provide services remotely.[8]

One the key advantages of the SaaS model is that it reduces overhead, allowing a user to operate in a nimble, functional manner. When the service is utilized, it is delivered in its most current form from the vendor, who can update it seamlessly on its own servers.[9] SaaS also provides greater availability and collaboration, as vendors can control traffic and resolve issues remotely.[10] A prominent example of SaaS is the word processing software on which this technology explainer was written: Google Documents. Google provides the most updated version of Google Documents to the user, this technology explainer's author. The document's file is hosted on Google's servers and accessible from phones, tablets, desktop computers, and laptops publicly around the world, as long as the user logs in with an Internet browser that can support its functionality.[11]

SaaS is the first, most prominent, and most developed form of cloud computing in use as of the publication of this technology explainer. It also provides a salient example of the differences in access.

B. Access

Access is the aspect of a cloud computing model that determines who can reach data.[12] Access is best understood through the Software as a Service (SaaS) model, whereby an application is delivered from a provider to the end

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[7] Maiara Heil Cancian et al., *Towards a Capability and Maturity Model for Collaborative Software-as-a-Service*, INNOVATIONS IN SYS. AND SOFTWARE ENG'G 245 (2020), https://doi.org/10.1007/s11334-020-00360-9.

[8] Bret Waters, *Software as a Service: A Look at the Customer Benefits*, 1 J. DIGIT. ASSET MGMT. 32, 33-34 (2005), https://link.springer.com/content/pdf/10.1057/palgrave.dam.3640007.pdf [https://perma.cc/93RK-MWMW].

[9] *What is Software as a Service? A Beginner's Guide*, SALESFORCE (Jan. 16, 2022, 11:08 AM), https://www.salesforce.com/in/saas/ [https://perma.cc/4PUX-RDEM]; Cancian et al., *supra* note 7.

[10] LEWIS, *supra* note 2, at 5.

[11] GOOGLE DOCS, https://www.google.com/docs/about/ (last visited Jan. 16, 2022, 5:36 PM), https://www.google.com/docs/about/ [https://perma.cc/AB62-72VG].

[12] LEWIS, *supra* note 2, at 3.

user. When a provider delivers a service through an Internet connection from one source, it is described as "public cloud" access.[13] "Private" cloud access is another type of access, where the use of the cloud service is limited to a specific organization or set of users. Private SaaS products are less common because typically, a comparatively small market of large-scale organizations has functional use cases for them. Private SaaS products do provide substantial benefits to organizations seeking greater control over their systems, and in some cases, a more tailored product for a specific use.[14]

A notable example of private SaaS is the software holding over half of all U.S. patient records, Epic.[15] Epic provides an application that hosts medical records to hospitals and supports other functions related to patient care.[16] A hospital's Epic system is implemented and run for that specific hospital or healthcare provider, and the business may choose to maintain its own servers or purchase hosting services through an Epic subsidiary. In contrast with a public SaaS application like Google Documents,[17] Epic is hosted in a dedicated cloud environment and implemented according to each customer's use case.

As enterprise software becomes more ubiquitous, the lines between public and private cloud access blur. "Community" clouds can provide software to support multiple organizations,[18] straddling the functionality of private and public SaaS. For example, Kaiser Permanente uses Epic across all of its hospitals,[19] each of which may be considered a separate "organization" in that use case. Additionally, use cases that involve elements of public, private, and community access, commonly referred to as a "hybrid" cloud exist.[20]

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[13] HUTH & CEBULA, *supra* note 4, at 2.
[14] CDW-G, PRIVATE CLOUD AND SOFTWARE AS A SERVICE, 2-3 (last visited Apr. 22, 2022, 3:30 PM), https://fedtechmagazine.com/sites/default/files/108135-wp-private_cloud_df2.pdf [https://perma.cc/7GFB-P484].
[15] Lauren Sieben, *Epic: Medical Records Innovator*, BIZTIMES (May 9, 2018, 12:00 AM), https://biztimes.com/epic-systems-medical-records-innovator/ [https://perma.cc/JJ9Y-GLEK].
[16] *Clinicals*, EPIC (Jan. 16, 2022, 5:28 PM), https://www.epic.com/software#Clinicals [https://perma.cc/L8QJ-FKZP].
[17] *Public Cloud Vs. Personal Cloud: Which is Right for You?*, CONSUMER REPORTS (June 26, 2014, 10:30 AM), https://www.consumerreports.org/cro/news/2014/06/public-cloud-vs-private-cloud-which-is-right-for-you/index.htm [https://perma.cc/XK8F-CS5K].
[18] HUTH & CEBULA, *supra* note 4, at 2.
[19] Milt Freudenheim, *Digitizing Health Records, Before It Was Cool,* N.Y. TIMES (Jan. 14, 2012), https://www.ny
times.com/2012/01/15/business/epic-systems-digitizing-health-records-before-it-was-cool.html?pagewanted=1&_
r=1&smid=fb-share [https://perma.cc/HY2E-T24F].
[20] HUTH & CEBULA, *supra* note 4, at 2; LEWIS, *supra* note 2, at 4.

C. Platform as a Service

Platform as a Service (PaaS) provides users with the capability to develop software for their use or even for publication.[21] Put simply, if SaaS is a meal delivery service, PaaS is a rental kitchen. PaaS providers ensure that the difficulties of developing software are handled seamlessly in the background, allowing developers to spend their time meaningfully as they develop and scale applications.[22]

PaaS typically involves an Application Runtime Environment (ARE) that supports scalability, reliability, and security, and an Integrated Development Environment (IDE), providing the tools for software development.[23] IDE can involve everything from coding language support to testing and update capabilities. Returning to the kitchen analogy, ARE functions like counter space, walls, cabinets, floors, and a door, while IDE serves in the same manner as appliances, pots, pans, and utensils.

"Pure" PaaS solely provides users the platform to create, while application-based PaaS allows them to add and modify an existing piece of software.[24] A notable example of a product with a pure PaaS feature is Microsoft Azure, which permits developers to create applications or websites independent of any underlying design.[25] Application-based PaaS is perhaps more common, with companies like Salesforce integrating it into their SaaS offerings to create a more tailored experience for users.[26] For example, if utilized for customer relationship management (CRM) records, Salesforce can be programmed to contain a field for data on a customer's favorite color, on top of more standard customer information data.

D. Infrastructure as a Service

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[21] Daniel Beimborn et al., *Platform as a Service (PaaS)*, 3 BUS. & INFO. SYS. ENG'G 381, 381-82 (2011), https://doi.org/10.1007/s12599-011-0183-3 [https://perma.cc/SW44-38XN].
[22] *Id.*; Claudio A. Ardagna et al., *Scalability Patterns for Platform-as-a-Service*, 2012 IEEE FIFTH INT'L CONF. ON CLOUD COMPUTING 718 (2012), https://doi.org/10.1109/CLOUD.2012.41 [https://perma.cc/5PX3-TV45].
[23] Beimborn et al., *supra* note 21.
[24] *Id.*
[25] Note that Microsoft Azure is not solely a pure PaaS product and has both SaaS and IaaS offerings. The nature of the PaaS product Microsoft Azure offers fits the definition of pure PaaS. *See What is PaaS?*, MICROSOFT AZURE (Jan. 16, 2022, 10:32 AM), https://azure.microsoft.com/en-us/overview/what-is-paas/ [https://perma.cc/EGU6-3GP7].
[26] *What is PaaS (Platform as a Service)?*, SALESFORCE (Jan. 16, 2022, 10:07 AM), https://www.salesforce.com /paas/overview/ [https://perma.cc/AW8X-E3PR].

When a user needs to manage a large enterprise at scale, they may seek to purchase Infrastructure as a Service (IaaS). IaaS outsources all server and system resources to a cloud provider that creates a dedicated environment where all of the user's data, traffic, and operating systems are maintained.[27] Though facially these components seem similar to pure PaaS, IaaS requires the user to manage and update development tools.[28] If PaaS is the equivalent of a rental kitchen, IaaS is renting a building then building a kitchen inside of it. The building's foundations and support, electricity systems, and central AC, allow the kitchen with its counter spaces and appliances to function. IaaS servers, storage, traffic control, and data management can support the implementation of PaaS and SaaS products. Amazon Web Services (AWS) is a prominent example of IaaS, in which Amazon provides users both the environment on which to host an application and the servers through which their online traffic will move.[29]

E. Serverless Computing and Function as a Service

At the forefront of cloud computing is the utilitarian architecture of serverless computing, sometimes considered interchangeable with Function as a Service (FaaS).[30] FaaS will be the focus of this technology explainer as it is the most common and inclusive application of serverless computing.[31] FaaS is a form of serverless computing delivered to clients that outsources all operational tasks, allowing them to focus on their specific work product.[32]

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[27] *IaaS vs. PaaS vs. SaaS*, IBM CLOUD EDUCATION (Sept. 2, 2021), https://www.ibm.com/cloud/learn/iaas-paas-saas [https://perma.cc/95UQ-XSKV].
[28] *Id.*
[29] *See* Naomi Eide, *AWS Captures 45% of Worldwide IaaS Revenue. That's Only Part of the Story*, CIO DIVE (Aug. 7, 2020) https://www.ciodive.com/news/Gartner-Iaas-PaaS-2019-AWS-Microsoft/583082/ [https://perma.cc/PN8Q-3F6L]
[30] "Serverless and Functions-as-a-Service (FaaS) are often conflated with one another but the truth is that FaaS is actually a subset of serverless. Serverless is focused on any service category, be it compute, storage, database, messaging, api gateways, etc. where configuration, management, and billing of servers are invisible to the end user. FaaS, on the other hand, while perhaps the most central technology in serverless architectures, is focused on the event-driven computing paradigm wherein application code, or containers, only run in response to events or requests." *FaaS (Function-as-a-Service)*, IBM CLOUD EDUCATION (July 30, 2019), https://www.ibm.com/cloud/learn/faas [https://perma.cc/5W27-JVST].
[31] *Id.*; *see, e.g.*, Erwin van Eyk et al., *Serverless Is More: From PaaS to Present Cloud Computing*, IEEE INTERNET COMPUTING, Sept.–Oct. 2018, at 8, https://doi.org/10.1109/MIC.2018.053681358 [https://perma.cc/VAV2-6YMJ] (highlighting FaaS as an application of serverless computing).
[32] Theo Lynn et al., *A Preliminary Review of Enterprise Serverless Cloud Computing (Function-as-a-Service) Platforms*, IEEE 9TH INT'L CONF. ON CLOUD COMPUTING TECH. AND SCI. 162, 162 (2017), https://doi.org/10.1109/CloudCom.2017.15 [https://perma.cc/5TGD-WH9J].

FaaS works by providing need-based access to infrastructure and platform, allowing the user to utilize and scale them, and desisting resources when they are not in use. Though servers are still utilized, users no longer have to contemplate traffic, implementation of code, or how to scale their services.[33] Returning to the rental kitchen analogy, serverless computing would manifest as a veritable "room of requirement," where the user simply opens a door to any type of cooking device, space, or utensil required for their purposes. Whether they are cooking for as many as one hundred, or as few as three people, they are given no more and no less than what is precisely needed. Developers and businesses benefit from the opportunity to implement powerful applications at a moment's notice and save resources during downtime.[34]

Providers of FaaS services handle almost all backend necessities for developers and only charge them for the computing resources they utilize.[35] It constrains resources when they are not in use, instead of permanently apportioning these resources in large and expensive amounts.[36]

IV. CHALLENGES

Many challenges face the cloud computing industry and the implementation of its technology. Chief among user concerns is provider management of their data, particularly with regard to security and privacy. Further, many cloud computing capabilities are still in development, especially as they relate to serverless computing.

Security concerns pervade the discussion of cloud computing technology, as technological tradeoffs are at work. While well-established access controls and firewalls can be updated quickly by professional organizations with expertise and resources, a broader surface area exists for an attack.[37] Providers like Apple, Google, and Amazon boast incredible security capabilities,[38] but they have broader exposure and vulnerability, and

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[33] ERIC JONAS ET AL., CLOUD PROGRAMMING SIMPLIFIED: A BERKELEY VIEW ON SERVERLESS COMPUTING 5-6 (Feb. 9, 2019), https://arxiv.org/pdf/1902.03383.pdf [https://perma.cc/9ZQF-FPWY].

[34] *Id*. at 9.

[35] Van Eyk et al., *supra* note 31, at 2.

[36] JONAS ET AL., *supra* note 33, at 9.

[37] *See* Nicholás Serrano et al., *Infrastructure as a Service and Cloud Technologies*, IEEE Software Tech. (Mar.–Apr. 2015), at 32-33.

[38] LEWIS, *supra* note 2, at 6; *iCloud Security Overview*, APPLE (last visited Jan. 16, 2022, 11:01 AM), https://suppo
rt.apple.com/en-us/HT202303 [https://perma.cc/TM6N-EGWB]; *AWS Cloud Security*, AMAZON WEB SERVICES (last visited Jan. 16, 2022, 11:04 AM), https://aws.amazon.com/security/ [https://perma.cc/LL65-8AMZ]; *Trust and Security*,

where they store data is often unclear. An infirmity in Amazon Web Services (AWS)[39] or Apple iCloud[40] could affect millions of users, though their ability to implement new forms of encryption and security procedures will outstrip any business seeking to maintain its technology in-house.

Cloud computing presents novel challenges for the privacy and handling of user data.[41] With distributed access to vast amounts of data and services, regional policy restricting access to personal information could frustrate developers and privacy advocates. For example, if a cloud computing application in France (covered by General Data Protection Regulation (GDPR)) processes user data on a server in India, it could run afoul of Article 46 of the GDPR if safeguards and legal rights and remedies are not in place.[42] Developers collaborating on international teams in differing jurisdictions may be forced to integrate compliance protocols into their work that create additional opportunity costs, or they may inadvertently violate regulations they have never heard of.[43] In addition, the capability of massive cloud providers to comb through user data to identify misuse or even general trends contravenes any expectation of online privacy.[44]

Beyond the realms of security and privacy, providers are always working to offer users better rates for more comprehensive cloud computing services. SaaS providers seek to improve functionality for users, and provide a more seamless experience in using their products.[45] PaaS providers are

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GOOGLE CLOUD (last visited Jan. 16, 2022, 11:02 AM), https://cloud.google.com/security [https://perma
.cc/4YFK-SPDF].

[39] AMAZON WEB SERVICES, *supra* note 38.

[40] APPLE, *supra* note 38.

[41] *See, e.g.*, LEWIS, *supra* note 2, at 6 (noting "concerns in the cloud computing community over jurisdiction, data protection, fair information practices, and international data transfer" that act as barriers to cloud computing adoption).

[42] Regulation 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data and repealing Directive 95/46/EC, 2016 O.J. (L 119) 1, 62, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A320 16R0679&qid=1650661542488 [https://perma.cc/5PB2-NH8V].

[43] Heather Burns, *How GDPR Will Change the Way You Develop*, SMASHING MAGAZINE (Feb. 27, 2018) https://www.smashingmagazine.com/2018/02/gdpr-for-web-developers/ [https://perma.cc/6V4G-282L] (explaining the various obligations to developers stemming from the GDPR).

[44] *See* Michael R. Overly, *What can my cloud provider do with my data?*, CSO, (Aug. 29, 2017, 6:14 AM) https://www.csoonline.com/article/3217724/what-can-my-cloud-provider-do-with-my-data.html [https://perma.cc/ER4J-XVYN].

[45] *See, e.g.*, *One version. Unlimited innovation.*, WORKDAY, https://www.workday.com/en-us/pages/infographic-power-of-one-version.html [https://perma.cc/FWJ3-8AJ8] (last visited Apr. 25, 2022) (highlighting Workday's "seamless integrations," "continuous innovation," and instantaneous access to data within its SaaS product).

developing platforms with more powerful tools for programmers, while IaaS providers endeavor to improve the overall reliability and usability of their infrastructure services.[46]

Finally, serverless technology is still developing[47] and has several functionality limits in long-term use, versatility, and latency.[48] FaaS providers require more time to deliver applications to users than other methods where server capacity is dedicated.[49] It is also ostensibly difficult for providers to commit and users to afford serverless resources for high-performance computing over long periods of time, as costs can be unpredictable.[50] Serverless applications also suffer from some rigidity,[51] as current serverless products are bound to their providers, limiting the cross-application of resources developed with their use.

V. CONCLUSION

Cloud computing is a ubiquitous term with a panoply of applications, but it is ultimately a process by which data is transferred with great efficiency through a network by a provider, for a user's benefit. Substantively, cloud computing provides the capacity to build applications, deliver applications, and support applications with lower overhead. Almost all users, whether individuals, businesses, educational institutions, or government agencies, utilize cloud computing in some form.

Users may adopt SaaS, acquiring specific services through networked applications. Cloud computing can support PaaS, where providers deliver the tools to construct and implement their own applications or simply add on to existing services. Computing storage and maintenance are further simplified with IaaS, making scalability and resource utilization easier to manage than

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[46] *See, e.g.*, *Public Preview: App Service – Configure Networking in Azure Portal During App Creation*, MICROSOFT AZURE (Apr 21, 2022), https://azure.microsoft.com/en-us/updates/public-preview-app-service-configure-networking-in-azure-portal-during-app-creation/ [https://perma.cc/5RM5-HFEY] (explaining the addition of networking option configuration within Microsoft Azure's app development (PaaS) product); *see also About AWS*, AWS (Apr. 25, 2022, 1:04 PM) https://aws.amazon.com/about-aws/ [https://perma.cc/NAG9-JCFQ].

[47] JONAS ET AL., *supra* note 33, at 1.

[48] Josh Fruhlinger, *What is Serverless? Serverless Computing Explained*, INFOWORLD (July 15, 2019, 5:02 PM), https://www.infoworld.com/article/3406501/what-is-serverless-serverless-computing-explained.html [https://perma.cc/YHW2-CH67].

[49] Seungjun Lee et al., *Mitigating Cold Start Problem in Serverless Computing with Function Fusion*, 21 SENSORS 8416 (2021), https://doi.org/10.3390/s21248416 [https://perma.cc/8ESD-HLHN].

[50] JONAS ET AL., *supra* note 33, at 20.

[51] *Id.* at 21.

ever. Lastly, serverless FaaS is providing a new level of utility to the cloud computing landscape, permitting users to elastically scale up or down according to their needs.

Cloud computing exemplifies the technological value of process. Though it starts from a simple remote transfer of data, various forms of cloud computing underlie the most powerful technological tools that consumers and businesses use today. The delivery of computational resources is an inherently economic process, but the added flexibility, efficiency, and capacity of those resources creates room for boundless creativity and innovation.