Calculus of Cloud Computing

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ABSTRACT

Cloud computing has attracted increasing attention in academia and industries. However, its fundamentals are still controversial, for example, what is cloud computing? What is the mathematical foundation of cloud computing? How can we use mathematical methods and thinking to treat cloud computing? This paper will address these three issues. For the first issue, this paper proposes a unified framework for cloud computing as a science, technology, engineering, system, service and industry. For the second and third issues, we propose the calculus of cloud computing, which treats many aspects of cloud computing using mathematical methods and thinking. The proposed approaches in this paper will facilitate the research and development of cloud computing, intelligent analytics, and business intelligence as well as artificial intelligence.

Keywords: *cloud computing, big data analytics, intelligent analytics, and business intelligence as well as artificial intelligence.*

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NOMENCLATURE

CC	Cloud Computing
IaaS	Infrastructure as a Service
PaaS	Platform as a Service
SaaS	Software as a Service
DW	Data Warehousing
DM	Data Mining
SM	Statistical Modeling
ML	Machine Learning
Calculus	Calculus is a branch of mathematics that “deals with rates of change”, based on the Oxford Advanced Learners’ Dictionary. The term calculus is also used for naming specific methods of calculation or notation as well as some theories, such as propositional calculus and process calculus.
Analytics	Analytics is the scientific process of discovering and communicating the meaningful patterns which can be found in data.

CHAPTER 1

INTRODUCTION

Cloud computing has attracted increasing attention in academics and industry in the past decade. The core of cloud computing can be summarized by the following 3 service models, 4 deployment models and 5 characteristics.

- 3 Service Models
    - a. IaaS
    - b. PaaS and
    - c. SaaS
- 4 Deployment Models
    - a. Public,
    - b. Private,
    - c. Community and
    - d. Hybrid Cloud
- 5 Characteristics
    - a. On-demand self service,
    - b. Broad network access,
    - c. Resource pool,
    - d. rapid elasticity and
    - e. measured service.

In the following chapter we explain the above topics in more detail. However, the following three issues have not been drawn significant attention in the scholarly peer-reviewed literature:

- What is cloud computing?
- What is the mathematical foundation of cloud computing?

• How can we apply mathematical methods and thinking to cloud computing?

This report will address these three issues. The calculus of cloud computing treats many aspects of cloud computing using mathematical methods and thinking. The proposed approaches in this report will facilitate the research and development of cloud computing, intelligent analytics, and business intelligence as well as artificial intelligence.

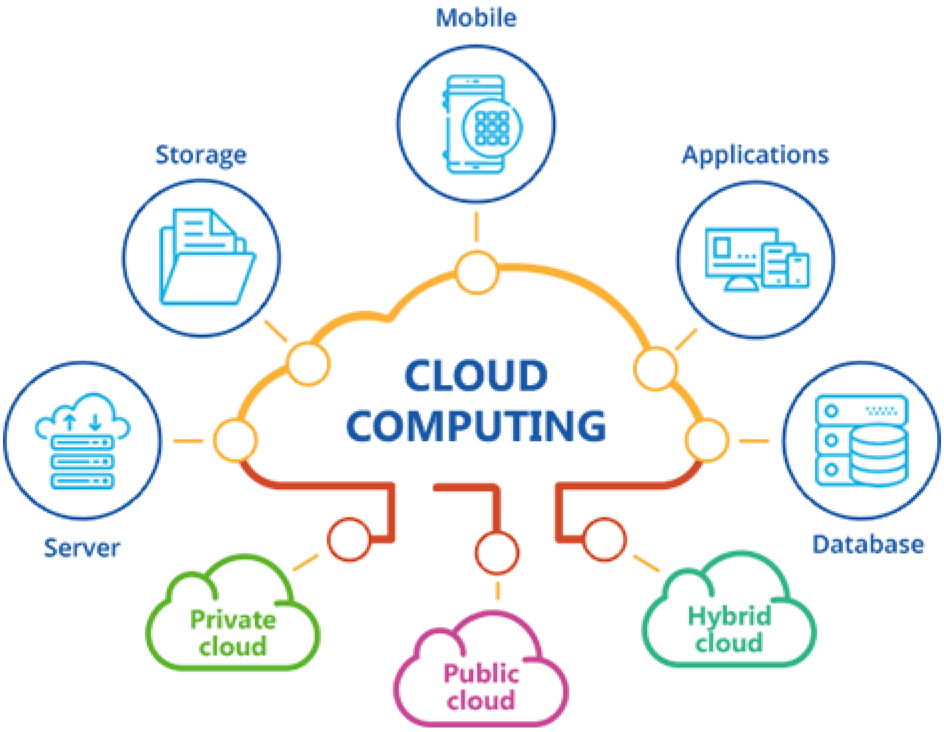

Fig. 1.1 : Cloud Computing

CHAPTER 2
SERVICE MODELS OF CC

Fig. 2.1 : Service Models of Cloud Computing

Software as a Service (SaaS)

The capability provided to the consumer is to use the provider’s applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

Platform as a Service (PaaS)

The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

Infrastructure as a Service (IaaS)

The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls).

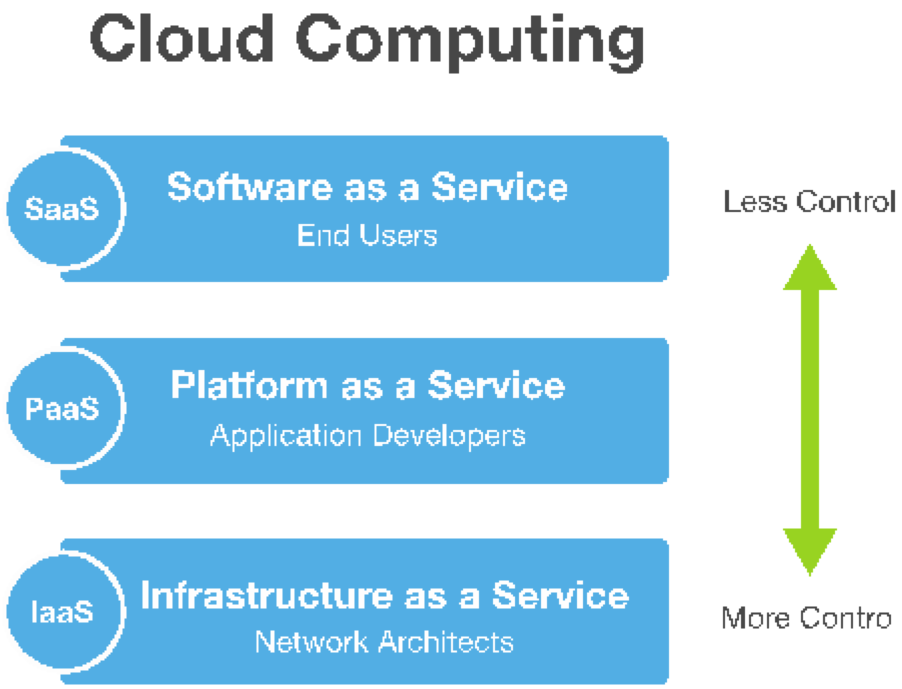

Fig. 2.2 : Control Comparison of Service Models

CHAPTER 3
DEPLOYMENT MODELS OF CC

Cloud deployment models indicate how the cloud services are made available to users. The four deployment models associated with cloud computing are as follows:

a) **Public cloud** : As the name suggests, this type of cloud deployment model supports all users who want to make use of a computing resource, such as hardware (OS, CPU, memory, storage) or software (application server, database) on a subscription basis. Most common uses of public clouds are for application development and testing, non-mission-critical tasks such as file-sharing, and e-mail service.

b) **Private cloud** : True to its name, a private cloud is typically infrastructure used by a single organization. Such infrastructure may be managed by the organization itself to support various user groups, or it could be managed by a service provider that takes care of it either on-site or off-site. Private clouds are more expensive than public clouds due to the capital expenditure involved in acquiring and maintaining them. However, private clouds are better able to address the security and privacy concerns of organizations today.

c) **Hybrid cloud** : In a hybrid cloud, an organization makes use of interconnected private and public cloud infrastructure. Many organizations make use of this model when they need to scale up their IT infrastructure rapidly, such as when leveraging public clouds to supplement the capacity available within a private cloud. For example, if an online retailer needs more computing resources to run its Web applications during the holiday season it may attain those resources via public clouds.

d) **Community cloud** : This deployment model supports multiple organizations sharing computing resources that are part of a community; examples include universities cooperating in certain areas of research, or police departments within a county or state sharing computing resources. Access to a community cloud environment is typically restricted to the members of the community.

With public clouds, the cost is typically low for the end user and there is no capital expenditure involved. Use of private clouds involves capital expenditure, but the expenditure is still lower than the cost of owning and operating the infrastructure due to private clouds' greater level of consolidation and resource pooling. Private clouds also offer more security and compliance support than public clouds. As such, some organizations may choose to use private clouds for their more mission-critical, secure applications and public clouds for basic tasks such as application development and testing environments, and e-mail services.

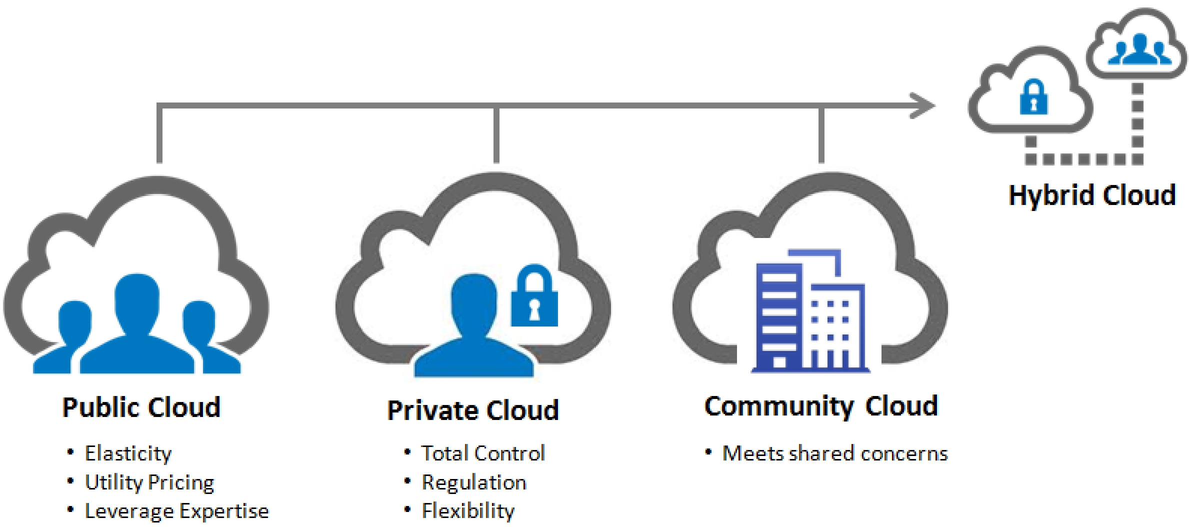

Fig. 3.1 : Deployment Models in Cloud Computing

CHAPTER 4

CHARACTERISTICS OF CC

The five essential characteristics of cloud computing:

a) **On-demand self-service**: A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.

b) **Broad network access**: Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops and workstations).

c) **Resource pooling**: The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state or datacenter). Examples of resources include storage, processing, memory and network bandwidth.

d) **Rapid elasticity**: Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

e) **Measured service**: Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth and active user accounts). Resource usage can be monitored, controlled and reported, providing transparency for the provider and consumer.

CHAPTER 5
DEFINING CLOUD COMPUTING

There are many definitions of cloud computing.

1. Cloud computing is shared pools of configurable computer system resources and higher-level services that can be rapidly provisioned with minimal management effort, often over the Internet (Wikipedia, 2019).

2. The National Institute of Standards and Technology's (NIST) defines cloud computing as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (NIST, 2018).

The first definition given by Wikipedia considers cloud computing as computer system resources and higher-level services so that cloud computing is not related to science, engineering and technology, nor management. The second given by the National Institute of Standards and Technology's (NIST) considers cloud computing as a model for accessing computing resources. A model is a part of science, engineering and technology, nor management. But a model is not science, engineering and technology, nor management. Therefore, the above definitions have related to science, engineering and technology, nor management. Can we state that the definition of cloud computing is too much market-oriented, industry-oriented, far from the academic flavor. This is the reason why we consider cloud computing for our universities and students as well as scholars.

CHAPTER 6

CALCULUS OF CLOUD COMPUTING

This section proposes the calculus of cloud computing, which treats many aspects of cloud computing using mathematical methods and thinking.

6.1 How to understand resources in cloud computing?

When defining cloud computing, (Wikipedia, 2019) uses computer system resources, whereas NIST uses computing resources. (Erl, Mahmood, & Puttini, 2013) uses IT resources as resources of cloud computing. (Varghese & Buyya, 2019) uses resources for cloud computing. This means that the resources of cloud computing should be either computer system resources or computing resources or IT resources. Are computer system resources, computing resources and IT resources same? No, mathematically,

$$\text{IT} \subseteq \text{ICT} \subseteq \text{computing}.$$

That is,

$$\text{IT resources} \subseteq \text{ICT resources} \subseteq \text{computing resources}.$$

Computer system resources can be either IT resources or ICT resources. Therefore, it is a part of computing resources. The above mathematical analysis implies that the IT resources is very limited in semantics, whereas ICT is more general and computing resources are most general and can be used as resources of cloud computing.

The above analysis leads to a new question. What are the resources of cloud computing. At least we have known that the resources contain Computer system resources, IT resources, ICT resources, computing resources, storage resources, etc. It is necessary to develop a research on this topic.

Question 1: Can we consider all these resources in the cloud computing as big data.

If yes, then we have

$$\text{IT resources} \subseteq \text{ICT resources} \subseteq \text{computing resources} \subseteq \text{big data}.$$

In such a way, big data is the strategic resources of cloud computing. Big data is the basic and raw materials for resources and services processing in cloud computing.

6.2 How to understand types of cloud?

Hybrid Cloud is a multi-cloud with a combination of public and private clouds or a combination of public and private IT infrastructure.

Hybrid cloud = public cloud + private cloud

Hybrid cloud = public cloud $\vee$ private cloud $\vee$ community cloud

6.3 How to understand cloud services

IaaS, PaaS and SaaS

These three services are at three levels. Therefore, the relationships among them can be represented as

IaaS $\oplus$ PaaS < IaaS $\oplus$ SaaS.

6.4 Cloud Analytics = Big data Analytics + Cloud Computing

Wu, Buyya and Ramamohana (2016) represent Big data Analytics mathematically as

Big data Analytics = Machine learning + Cloud Computing ---(1)

Machine learning is a part of artificial intelligence, that is machine learning $\subseteq$ artificial intelligence. Then we can have

Big data Analytics = Artificial intelligence + Cloud Computing ---(2)

Now,

Big Data analytics = Big data + Big data analysis + Big DW + Big DM + Big SM + Big ML + Big Visualization

Where,

DW is data warehousing,

DM is data mining,

SM is statistical modeling,

ML is machine learning

Then we have,

Cloud Analytics = Big data + Big data analysis + Big DW + Big DM + Big SM + Big ML + Big Visualization + Cloud Computing ---(3)

This implies that the above result is more inclusive than either (1) or (2).

CHAPTER 7
CONCLUSION

This report proposed a unified framework for cloud computing as a science, technology, engineering, system, service and industry. It also presented the calculus of cloud computing, which treats many aspects of cloud computing using mathematical methods (including logic and set theory) and thinking. The proposed approaches in this report will facilitate the research and development of cloud computing, intelligent analytics, and business intelligence as well as artificial intelligence.

The future works will analyse the proposed framework of cloud computing with the cases of the real world. And also explore the calculus of cloud computing and its applications in big data analytics, web services and artificial intelligence.

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