Cloud Computing

Organisational information, Introduction to Cloud Computing
Slide set 1

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FRANKFURT UNIVERSITY OF APPLIED SCIENCES

Agenda

FRANKFURT UNIVERSITY OF APPLIED SCIENCES

Organizational Information

- **Website:**
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- **Office:**
  - Room 1-230
- **Consultation:**
  - **Best via E-Mail!**
- **Course material:**
  - Lecture notes (PDF slides) and semester project related information can be found at the course website

!!! ATTENTION !!!

- Beginning WS2021, the cloud computing course does not have a written exam anymore!
- Your grade will depend 100% on your work and the results in the semester project (see the course web page for more information)

Cloud Computing – Admission to Exam

We only have a limited capacity...

therefore we have a strict limit for the admission to Cloud Computing!

Admission Cloud Computing - winter semester 2025

Unless you have at least **40 ECTS** from previous courses in the **High Integrity System Master** you **should not** participate in the Course **Cloud Computing**!!!
We have to give students with higher ECTS precedence over others, since the capacity of the course is limited to 40 students!!!

Group Poll

Please take part in the group poll in CampUAS

Semester project – Sky Computing

Examination

The examination in the master course **Cloud Computing** will be a research project over the course of the semester. You need to form groups of **4-5 people** and work on the project with the whole class.

Details on the semester project

Details on the project will be given in a separate presentation.

Announcement

I won't be here in November!

No classes in November!

There will be no lectures or exercises from **November 4 to November 26**! However, the project will continue regardless!

Important

Make sure you have everything setup till then (GitLab, Teams, etc.)! In the month of November you will work autonomously on the project in a self organized manner!

Literature

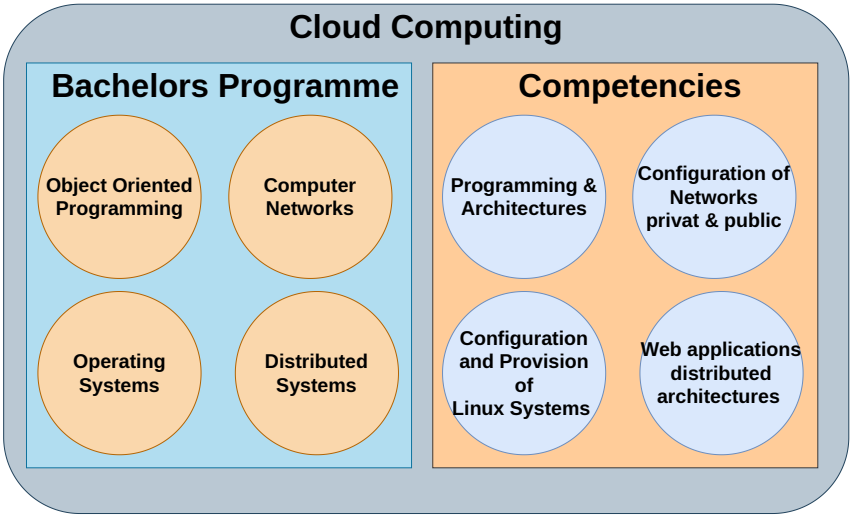
Fundamentals from Bachelors courses

- **Operating Systems / Betriebssysteme: Bilingual Edition: English - German / Zweisprachige Ausgabe: Englisch - Deutsch**, *Christian Baun*, Springer Vieweg (2023), ISBN: 978-3-658-42229-5.
- **Computer Networks / Computernetze: Bilingual Edition: English - German / Zweisprachige Ausgabe: Englisch - Deutsch**, **Christian Baun**, Springer Vieweg (2022), ISBN: 978-3-658-38892-8.
- **Distributed Systems: Principles and Paradigms**, *Andrew S. Tanenbaum, Maarten van Steen*, Pearson (2023), ISBN: 978-1530281756.
- **Foundations of Scalable Systems**, *Ian Gorton*, O'Reilly (2022), ISBN: 978-1098106065.

Cloud Computing

- **Cloud-Native Computing**, *Nane Kratzke*, Hanser (2023), ISBN: 978-3-446-47914-2. *German*
- **Cloud Strategy: A Decision-based Approach to Successful Cloud Migration**, *Gregor Hohpe* (2020), ISBN: 979-8665253046.
- **Multi-Cloud Architecture and Governance**, *Jeroen Mulder*, Packt Publishing (2020), ISBN: 978-1800203198.
- **Cloud Computing: Web-Based Dynamic IT Services**, *Christian Baun, Marcel Kunze, Jens Nimis, Stefan Tai*, Springer (2011), ISBN: 978-3-642-20916-1.
- **Cloud Application Architectures**, *George Reese*, O'Reilly (2008), ISBN: 978-0596156367.

What topics are part of Cloud Computing?



What are prerequisites for the course?

You should have basic knowledge from the bachelors programme on the following topics:

- **Computer Programming**
  - Java and Python! (object-oriented and functional paradigm)
- **Operating Systems**
  - Linux, Kernel architectures, command-line, block and file storage, virtualization, ...
- **Computer Networks**
  - ISO-OSI reference model, Switching, Routing, CIDR, Application layer protocols, ...
- **Distributed Systems**
  - Definitions, cluster systems, RPC, web technologies, SOAP, REST, ...
- **Software Architectures**
  - Client/Server Architectures, 3-Tier Architectures, Web applications, ...

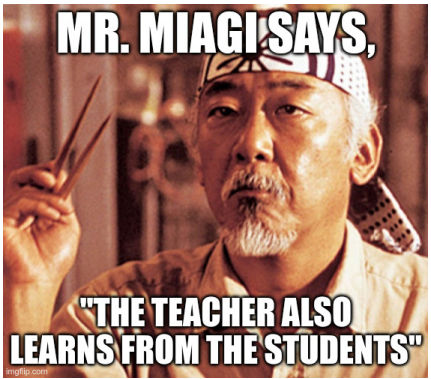
If you want to read up again

You can read the books under **Fundamentals from Bachelors courses** on slide 7!

Objectives of the course

- Getting an overview on Cloud Computing and cloud services and their importance!
- Getting an overview on the technological foundations for the operation and implementation of cloud services!
- Gaining knowledge on Cloud Computing related topics (service models, features, etc.)!
- Gaining knowledge and understanding strategies for the adoption of Cloud Computing!
- Gaining knowledge on software architectures for the implementation of cloud services!
- Gaining knowledge on Cloud-Native applications and their benefits for the implementation of cloud services!
- An outlook on future trends in Cloud Computing!

Course Material

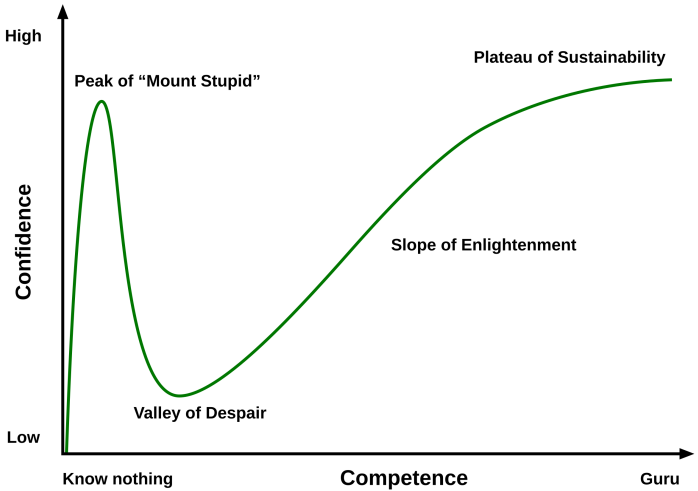


Slides of the lecture

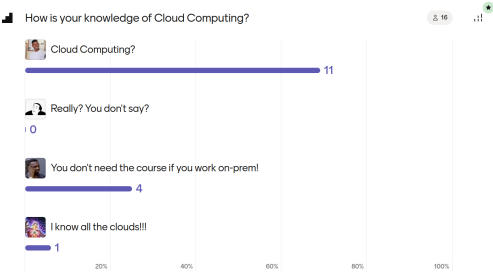
Most of the material and the slides are mostly still work in progress! So whenever you spot mistakes or faults let me know ;-) Whenever you have some ideas or facts on cloud computing you can always let me know! :-)

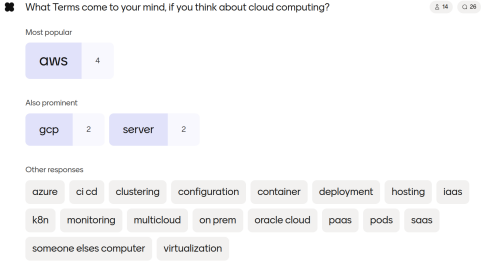
The General Knowledge in Cloud Computing

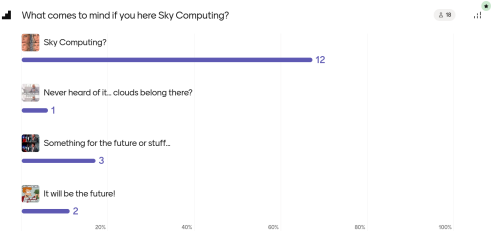
Source: Wikimedia Commons

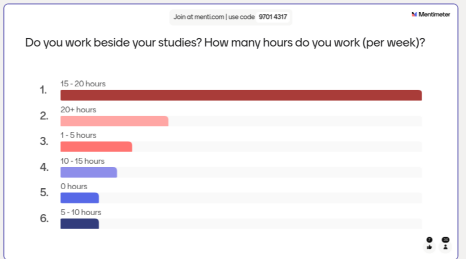


Your Knowledge in Cloud Computing – Result AI

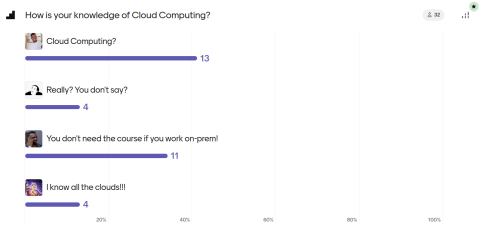


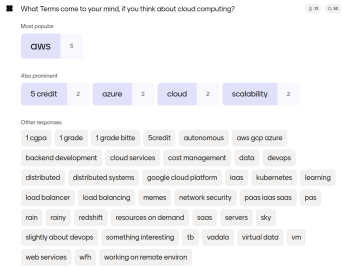


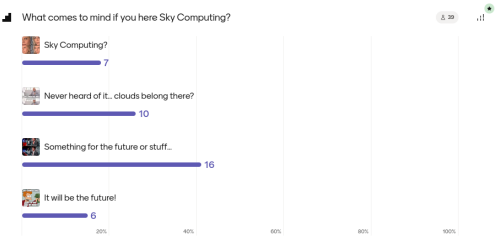


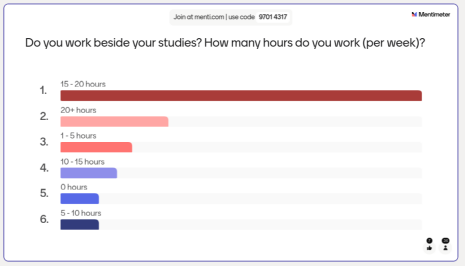


Your Knowledge in Cloud Computing – Result HIS









What is Cloud Computing?

Group Discussion

- **What is Cloud Computing?**
- **What Cloud Computing offerings do you use?**
- **How would you define Cloud Computing?**

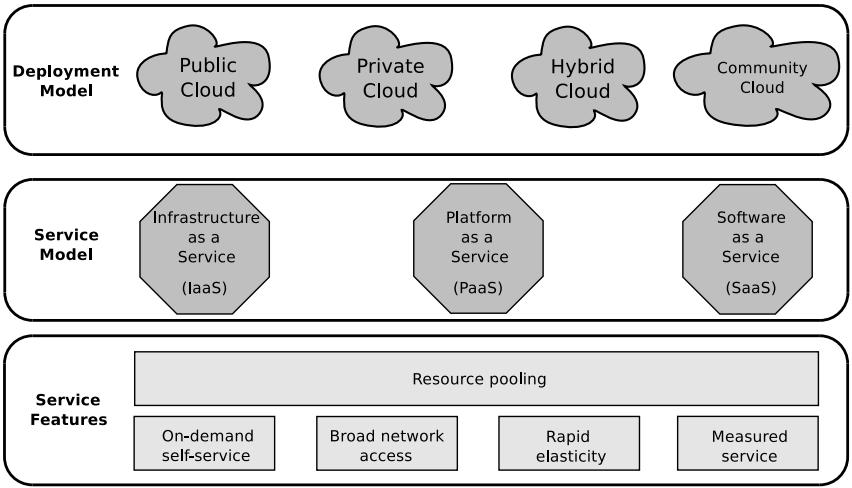
Computing of the future? – Quote from 1961

"computation may someday be organized as a public utility, just as the telephone system is a public utility. We can envisage computer service companies whose subscribers are connected to them [...]. Each subscriber needs to pay only for the capacity that he actually uses, but he has access to all programming languages characteristic of a very large system." – John McCarthy[a]

[a] It is an old quote and therefore not gendered. Sorry!

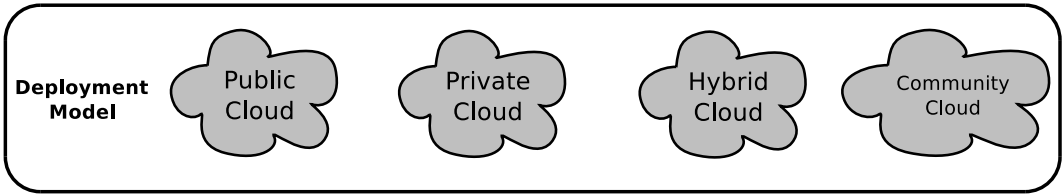
This is pretty close to cloud computing!

NIST definition of Cloud Computing



[0] Source: https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf

Deployment models



Public Cloud

The cloud infrastructure is provisioned for open use by the general public.

Private Cloud

The cloud infrastructure is provisioned for exclusive use by a single organization.

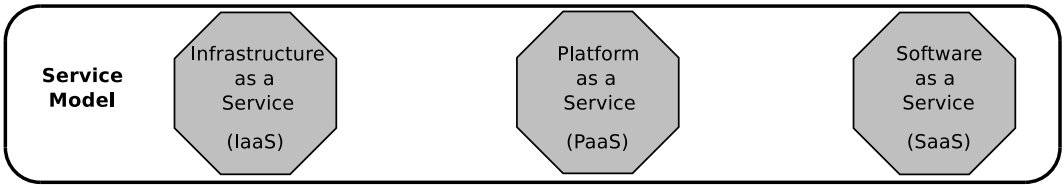
Hybrid Cloud

The cloud infrastructure is a composition of two or more distinct cloud infrastructures.

Community Cloud

The cloud infrastructure is provisioned for exclusive use by a specific community.

Service models



Infrastructure as a Service

Provided to provision processing, storage, networks, and other fundamental computing resources.

Platform as a Service

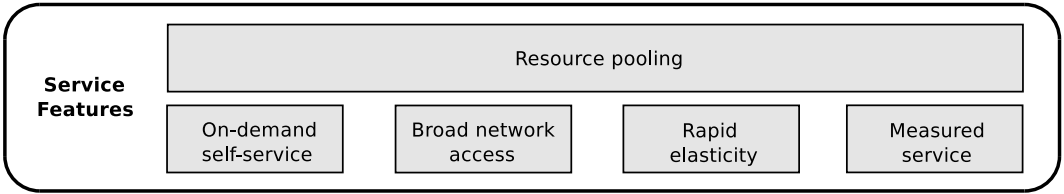
Provided to deploy applications created using programming languages, libraries, services supported.

Software as a Service

Provided to use the provider's applications running on a cloud infrastructure accessible from various devices.

[0] We will discuss more than these service models in this course ;-)

Service Features



Resource pooling

Computing resources are pooled to serve multiple consumers.

On-demand self-service

Consumer can provision computing capabilities automatically.

Broad network access

Capabilities are available and accessed over the network.

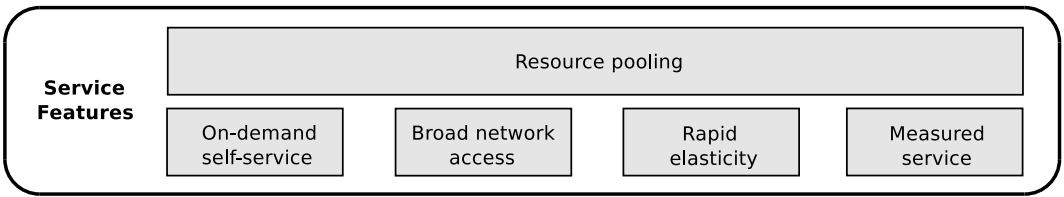
Rapid elasticity

Capabilities can be elastically provisioned to scale with demand.

Measured service

Automatically controlled and optimized resources with metering.

Service Features



Question

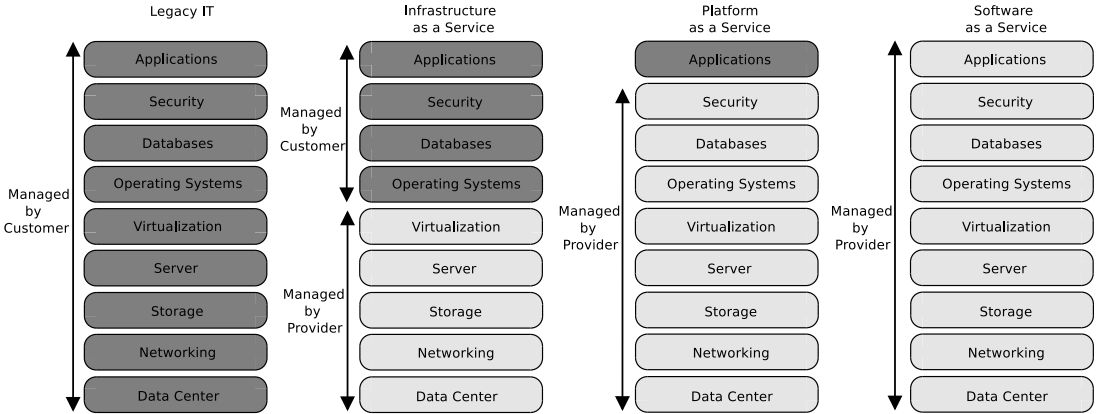
How can we technically realize the listed features?

Cloud Computing – Definition

„By using virtualized computing and storage resources and modern web technologies, Cloud Computing provides scalable, network-centric, abstracted IT infrastructures, platforms, and applications as on-demand services. These services are billed on a usage basis.“

- Part 1: Fundamental technologies – basis of Cloud Computing
  - **Virtualization** for shared and efficient resource utilization
  - **Web Services** (REST/SOAP) for communicating with the services
- Part 2: Cloud services and their characteristics
  - **IaaS, PaaS, SaaS**
  - **scalable** $\Longrightarrow$ „elastic“
  - **network-centric** $\Longrightarrow$ services/resources are accessible over the internet
  - **abstracted** $\Longrightarrow$ independent of the concrete hardware
  - **on-demand** $\Longrightarrow$ prompt request completion
  - **pay as you go**

Service models – layers



Service offerings in Cloud Computing

Figure: DropBox

Figure: Slack

Figure: Google Workspace

Figure: Zoom

Question

What is the service model of the presented offering?

Things to keep in mind

Questions when using cloud services

- **What about the data privacy?**
- **Where is the service hosted?**
- **Who has access to the service and data?**
- **Who controls the service offering?**

Use of Cloud Computing offerings

The previous offerings are public service offerings for customers. But what about the provider perspective?

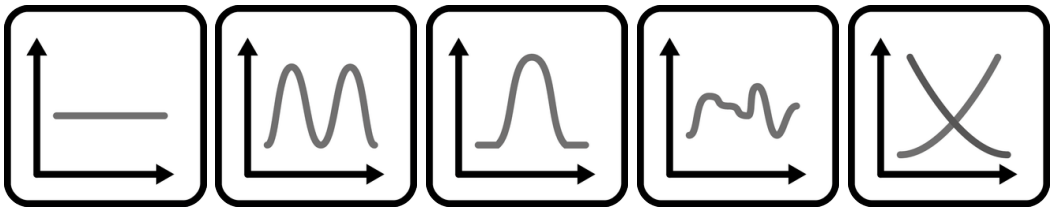
What do you need to keep in mind if you want to offer a cloud service?

Why use Cloud Computing?

Group discussion

- **When should one use Cloud Computing from a company perspective?**
- **What are the benefits of Cloud Computing for companies?**
- **Are there scenarios when Cloud Computing is suited for enterprises?**

Types of workloads - Effect of allocation period and resource size

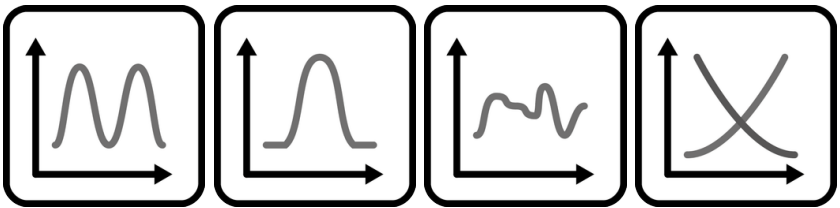


(a) Static (b) Periodic (c) Once-in-a-lifetime (d) Unpredictable (e) Continuously changing

Question?

Which of the presented workload types are suitable for a cloud computing setup?

Types of workloads



(a) Periodic (b) Once-in-a-lifetime (c) Unpredictable (d) Continuously changing

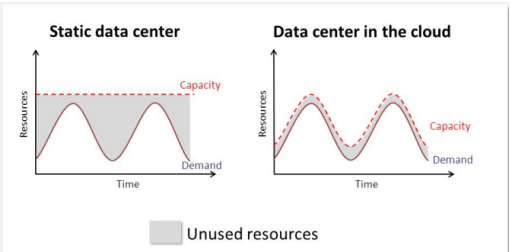
Answer!

Cloud resources are particularly economical when load fluctuations occur!

The goal of Cloud Computing

[1] CC-BY:https://cloud-native-computing.de

- Enable lowest possible average load during operation ⇒ minimize the area required to cover the load curve!
- Aim during operation: follow load curves as closely as possible ⇒ results in little over-provisioning!



There are two levers that can be adjusted:

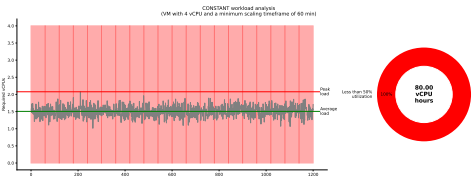
1. Allocate resources in a more granular manner (vertical adjustment).
2. Allocate resources for shorter periods (horizontal adjustment).

Cloud-Native Computing!

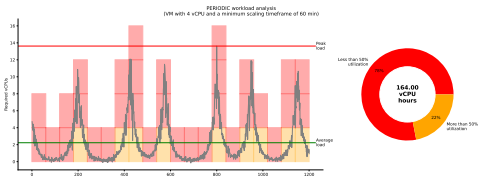
Many innovations in cloud-native computing, such as container and FaaS technologies, can be traced back to this insight.

[1] Image Source:https://www2.eecs.berkeley.edu/Pubs/TechRpts/2009/EECS-2009-28.pdf

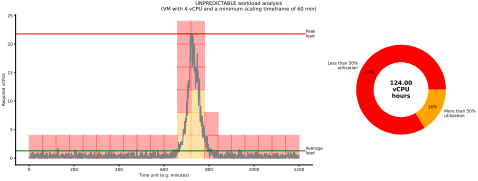
Types of workloads



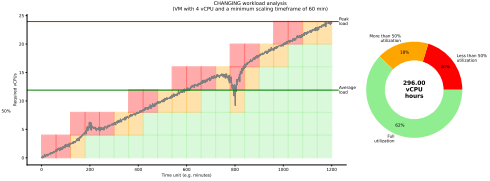
(a) Static



(b) Periodic



(c) Unpredictable



(d) Continuously changing

[2]

[2] Source of plots: https://git.mylab.th-luebeck.de/cloud-native/lab-workload-analysis

Cloud Computing - economics

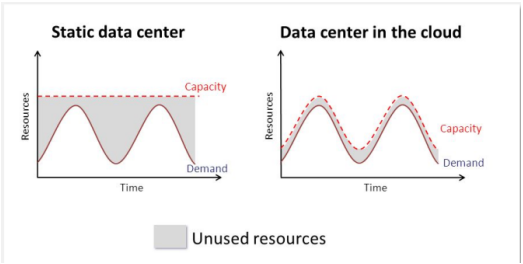


Figure: Static vs. dynamic demand[a]

[a] Source: https://www2.eecs.berkeley.edu/Pubs/TechRpts/2009/EECS-2009-28.pdf

More precise answer!

The costs per cloud resource can even be significantly higher than the in-house costs - as long as the ratio of **cloud** to **in-house** costs does not exceed the ratio of **peak load** to **average load**!

In formula!

$$\frac{cloud\ cost}{inhouse\ expense} < \frac{peak\ load}{average\ load}$$

$$\Leftrightarrow$$

$$cloud\ cost < inhouse\ expense \times \frac{peak\ load}{average\ load}$$

Pizza as a Service example

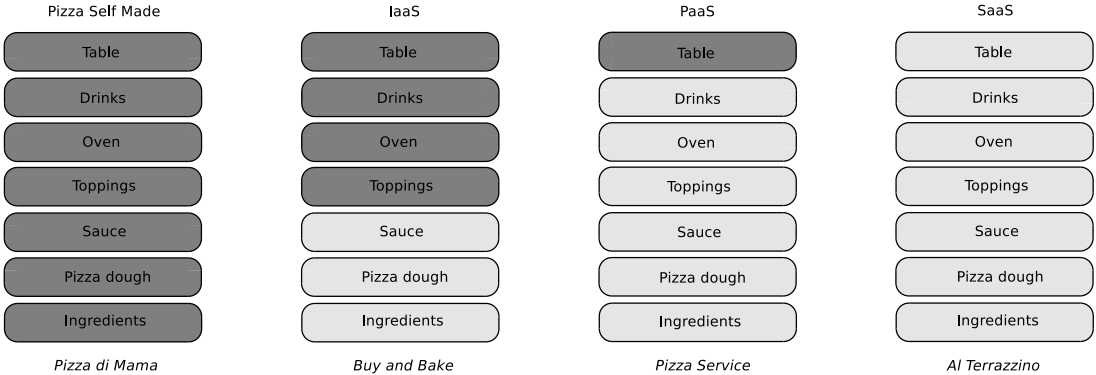
Source:https://cloud-native-computing.de

An example using Pizza ;-)

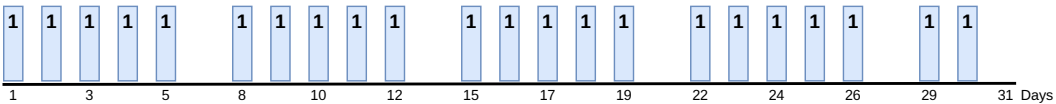
Imagine your family, friends and colleagues come over to your house and want Pizza for dinner. Now you need to investigate on the different types of service offerings you can use to feed your guests!

Pizza as a Service example

Source: https://cloud-native-computing.de



Pizza as a Service example – static workload



- You buy yourself a pizza every working day at lunchtime.
- At weekends, of course not.

How much?

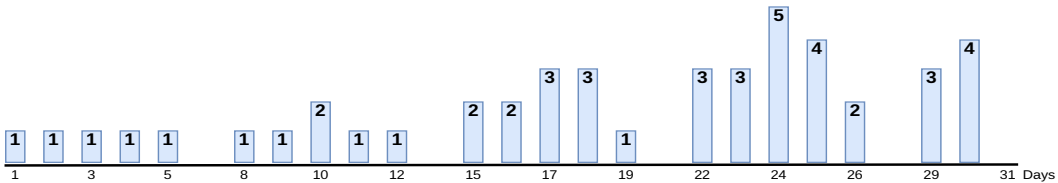
$$peak\ load = 1$$

$$average\ load = \frac{22}{30}$$

$$\frac{peak\ load}{average\ load} = \underline{1.3}$$

The cloud provider could be 30% more expensive than self made!!!

Pizza as a Service example – continuously changing workload



- You always bring your family something from the pizza trolley.
- Word gets around, and week after week you have to get more and more pizza.
- At weekends, of course not.

How much?

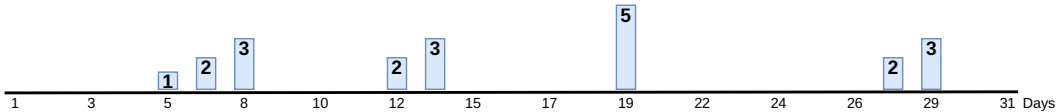
$$peak\ load = 5$$

$$average\ load = \frac{46}{30}$$

$$\frac{peak\ load}{average\ load} = \underline{3.2}$$

The cloud provider could be <u>3-Times</u> more expensive than self made!!!

Pizza as a Service example – periodically changing workload



- You and your family and friends make movie evenings on weekend and watch movies (on-demand ;-)) and serve pizza.
- During the week you do not have time.

How much?

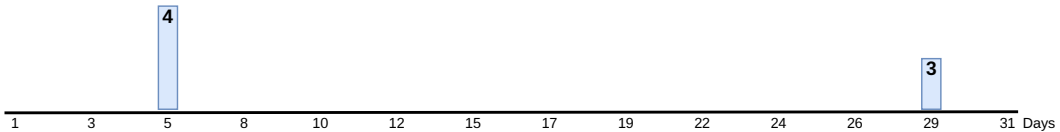
$$peak\ load = 5$$

$$average\ load = \frac{21}{30}$$

$$\frac{peak\ load}{average\ load} = \underline{7.1}$$

The cloud provider could be <u>7-Times</u> more expensive than self made, because your demand is rarer!!!

Pizza as a Service example – unpredictable workload



- You invite your family on weekends occasionally to a pizzeria.
- During the week you do not have time.

How much?

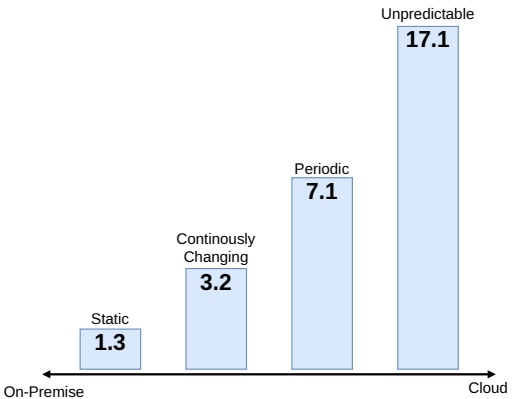
$$peak\ load = 4$$

$$average\ load = \frac{7}{30}$$

$$\frac{peak\ load}{average\ load} = \underline{17.1}$$

The cloud provider could be <u>17-Times</u> more expensive than self made, because your demand is rarer!!!

Cost advantages in Cloud Computing



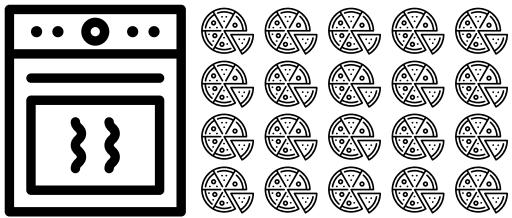
Conclusion

Cost advantages generally arise through the workload and only secondarily by the cost structure of the service.

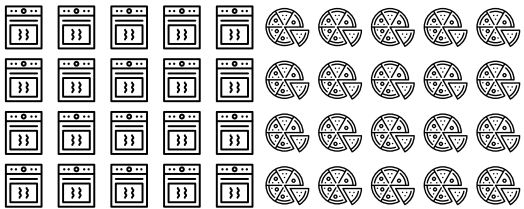
Remarks on the example. . .

The example has no **inhouse costs**!!! Reaction to different workloads is in general not an easy task for on-premise setups! (servers, infrastructure, personal, etc.)

Operational costs in Cloud Computing



1 Oven for 20 Pizzas!!!



20 Oven for 20 Pizzas!!!

With which delivery service would you order 20 pizzas?

- **The one that delivers in 5 hours (20x15 minutes) and 19 pizzas are cold?**
- **The one that delivers 20 hot pizzas in 15 minutes?**

Operational costs in Cloud Computing

Price and Effort?

- **How much extra would that be worth to you?**
- **How much extra expense does this cost the delivery service?**
- **How often do you as a delivery service need 20 ovens at the same time?**

Transaction cost theory

Transaction cost theory has often been empirically studied in connection with the decision between in-house production and outsourcing. Examples can be found in the automotive industry when it comes to the purchase or integration of entire companies.

Overall Question?

Do you want to buy and provision the 20 oven on-premise?

So why should we use Cloud Computing?

Questions

- Is Cloud Computing always beneficial?
- Is Cloud Computing the solution to all problems?
- Is using Cloud Computing always cheaper?

Answer

- It depends on the use case!
- It is beneficial for some use cases!
- It is cheaper if we take things like workload types and peak load into account!

So why should we use Cloud Computing?

Things to take into account

- **Hardware is very expensive!**
- **Personal is very expensive**
- **Housing for hardware and personal is expensive!**
- **Both scale very poorly!**

The AI Boom

An interesting article on the next (possible) bubble!
`https://hbr.org/2025/10/is-ai-a-boom-or-a-bubble`[a]

[a] Harvard Business review (October 16, 2025).

So why should we use Cloud Computing?

Cost Savings

- capital expenditures (CapEx) vs operating expenses (OpEx)!
- CapEx are large investments in fixed assets.
- OpEx are costs associated with day-to-day operations.

So why should we use Cloud Computing?

CapEx

- IT infrastructure (servers, networking, software, etc.)
- IT equipment
- Data center housing
- Infrastructure maintenance

OpEx

- Business-related operating costs (on-demand rent, utilities, salaries, etc.)
- Cloud-based software or service subscription fees (SaaS, PaaS, IaaS, etc.)
- Software and service support
- Data center or off-premises cloud costs

So why should we use Cloud Computing?

Use Cases for Cloud Computing

Whenever the actual demand is not predictable, Cloud Computing is a (possible) solution!

Outlook on the course

1st part: **Introduction** $\Longleftarrow$ *This slide set*
2nd part: **Technological foundations**
3rd part: **Service models, deployment models**
4th part: **Architectures and applications**
5th part: **Cloud-Native applications**
6th part: **Adoption and strategy**
7th part: **Current and future trends**

2nd part: Technological foundations

Topics of this slide set:

- Legacy IT (data centers, servers, networking, etc.)
- Cloud enabling technologies (networking, storage, virtualization, etc.)
- Infrastructure as Code (Vagrant, Terraform, Ansible, etc.)
- Costs of on-prem infrastructures

3rd part: Service models, deployment models

Topics of this slide set:

- Deployment models in Cloud Computing
- Service models in Cloud Computing
- Public Cloud Computing offerings
- Private Cloud Computing offerings

4th part: Architectures and applications

Topics of this slide set:

- Software architectures in Cloud Computing
- Distributed Systems and Cloud Computing
- Distributed architectures in Cloud Computing
- Properties of distributed architectures
- Decision criteria for distributed architectures

5th part: Cloud-Native applications

Topics of this slide set:

- Cloud-Native Applications
- Components of Cloud-Native Computing
- Architectures and patterns in Cloud-Native Computing
- Benefits and challenges in Cloud-Native Computing

6th part: Adoption and strategy

Topics of this slide set:

- Cloud adoption
- Cloud strategy
- Multi-Cloud strategy
- Risks and opportunities of Cloud Computing

7th part: Current and future trends

Topics of this slide set:

- Current trends in Cloud Computing
- Future trends in Cloud Computing

Thank You For Your Attention!

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