Cloud-Edge Continuum

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Agenda

1. What's Cloud computing?

2. What's Edge computing?
   1. Use cases

3. What's the Cloud-Edge Continuum?
   1. Use cases

4. Challenges

5. Opportunities
   1. HW heterogeneity
   2. Security and data privacy
   3. Green computing
   4. Real-time

Digression: the history of computers and paradigm changes

1930

1940 mainframes
(first computers as we know them)

1950

1960
integrated (microchip) circuit

1970
microprocessor ARPANET

1980
personal computers

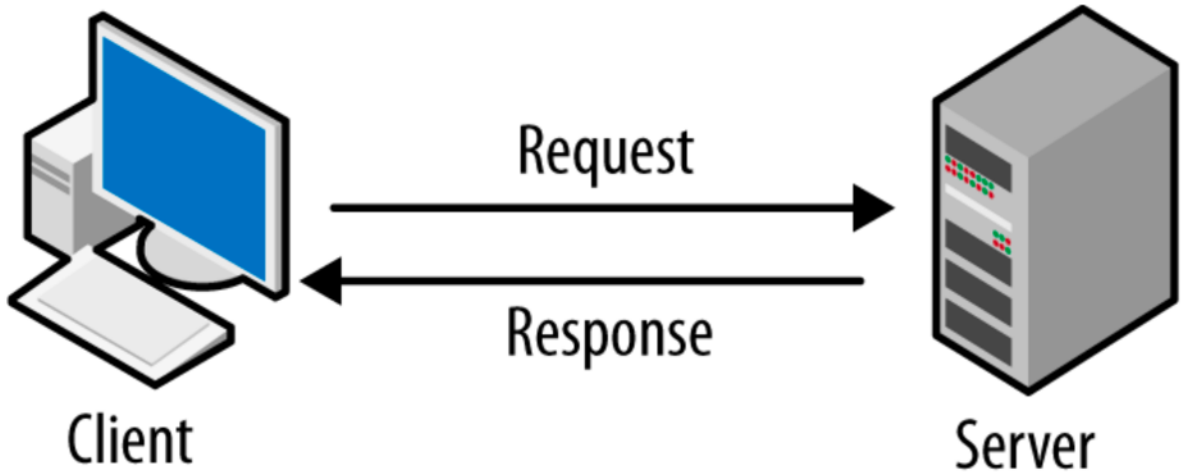
1990 Windows
WorldWideWeb cloud computing

2000

2010 iPhone

2020 edge computing

ChatGPT



What’s Cloud computing?

„Cloud computing is the delivery of computing services — including servers, storage, databases, networking, software, analytics, and intelligence — over the Internet on demand.”

Benefits

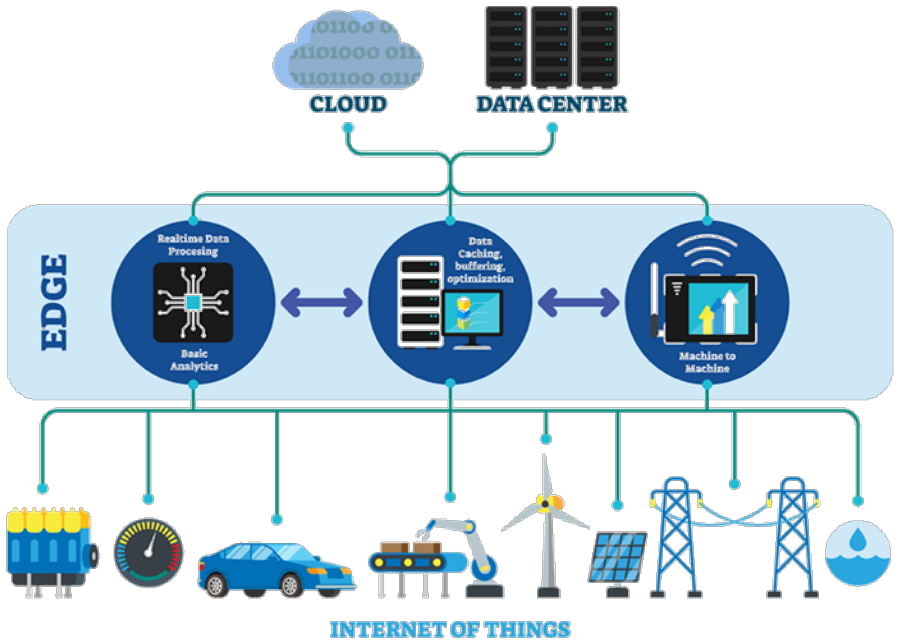
- **Cheaper**: thanks to economy of scale, cloud providers can offer cheaper prices than what it would cost for small companies to host their own services
- **Simple**: solution developers can easily deploy their software on the cloud, without having to manage the infrastructure
- **Elastic**: clouds are elastic, so users can start small and scale up as needed – usually in seconds

Cloud Services: IaaS, SaaS, PaaS, …

What’s Edge computing?

a.k.a. Fog computing, Mobile Edge Computing, Multi-access Edge Computing

„Edge computing is computing that takes place at or near the physical location of either the user or the source of the data.“



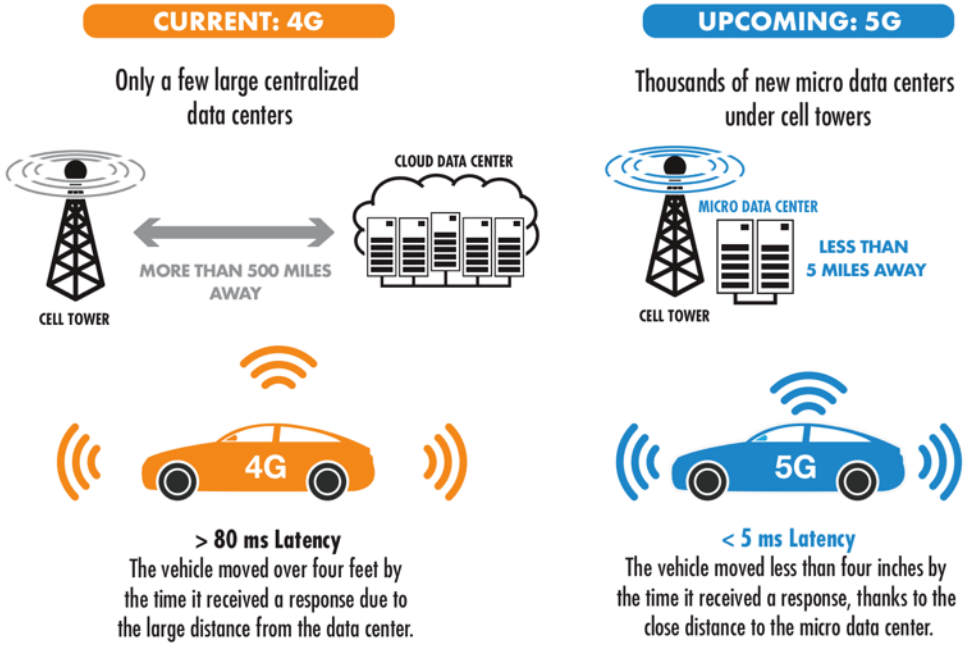
Benefits

- **Low latency**: the processing is closer to the data producers/ consumers, so the data requires less time to reach its destination
- **It saves bandwidth**: because we now process data on the edge, we save the bandwidth that we would otherwise need to send the data to the cloud
- **It saves energy**: we save energy because we save data transfers and edge nodes use less energy

Use Cases for Edge Computing

Smart Factories

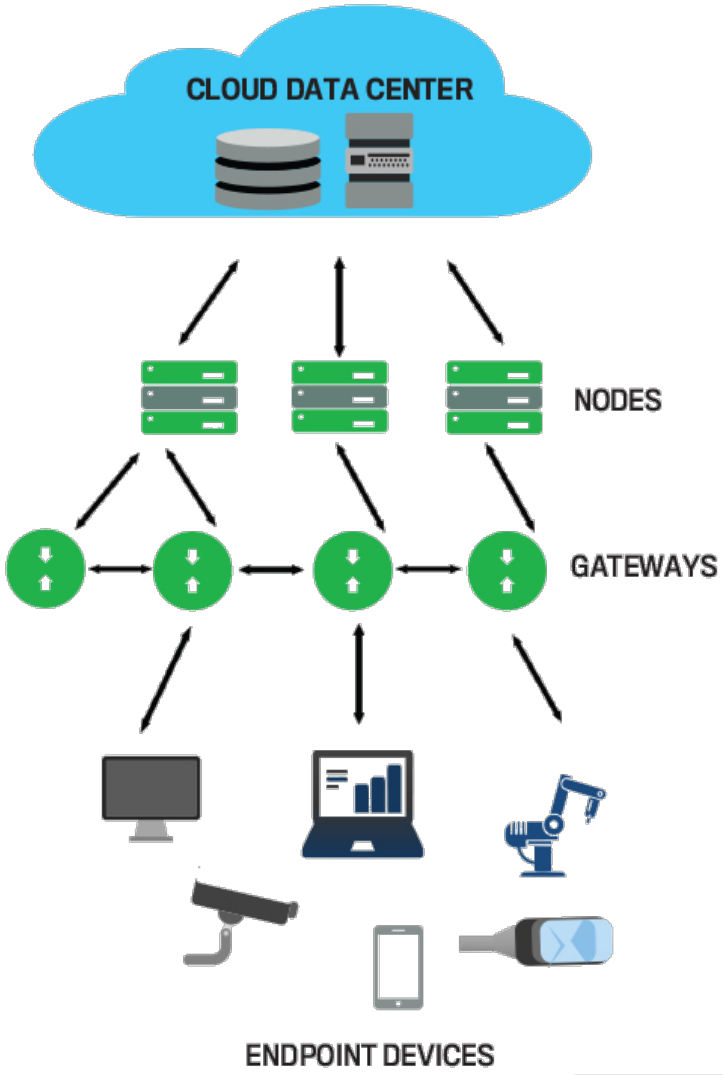
Autonomous Vehicles



What’s the Cloud-Edge Continuum?

- Distributed computing between end devices, edge and cloud

- We take full advantage of edge and cloud computing benefits
  - Low latency
  - Scalability
  - Cheaper
  - It saves bandwidth, energy

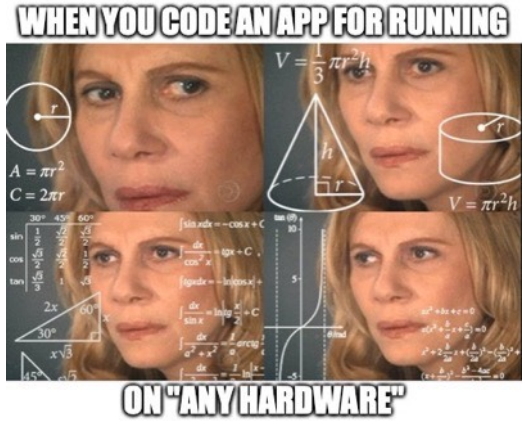


Sounds great…

…but there are challenges too

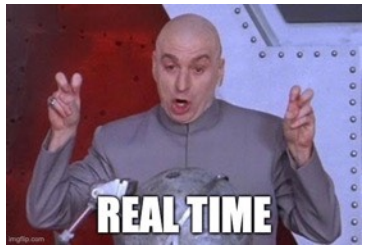
- Deploying applications on the edge and cloud is complex

- Increased complexity for development (security, distributing tasks, data management)



-  Edge computing saves energy → not so easy in practice

- Edge offers low latency →



Dealing with HW heterogeneity

- It is difficult (if not impossible) to know where our software will be run on the edge
- Edges are not elastic, so we're limited

Solutions

- There are several edge computing platforms that aim to facilitate the development and deployment of edge solutions
- As of now, there's no golden standard
- Function as a Service (FaaS) model

- Virtualization of edge infrastructure → GEC ONCITE

- There's plenty of research on this topic
  - E.g., Elastic services for Edge Computing (Fürst et al., 2018)

FogFlow
Programming Cloud-Edges

Azure IoT Edge

ioFog

Improving security and data privacy

- Edge computing can improve data privacy: we (pre-)process data on the edge
  - It still has it dangers

„Fitness tracking app Strava gives away location of secret US army bases“

The Guardian, 2018

- Moral of the story: even aggregated can compromise security

- Edges are susceptible to attacks; edges can also be malicious
  - Data encryption mechanisms → homomorphic encryption

- Hot topic in research: federated learning, differential privacy, Gaia-X project

gaia-x

Green Scheduling

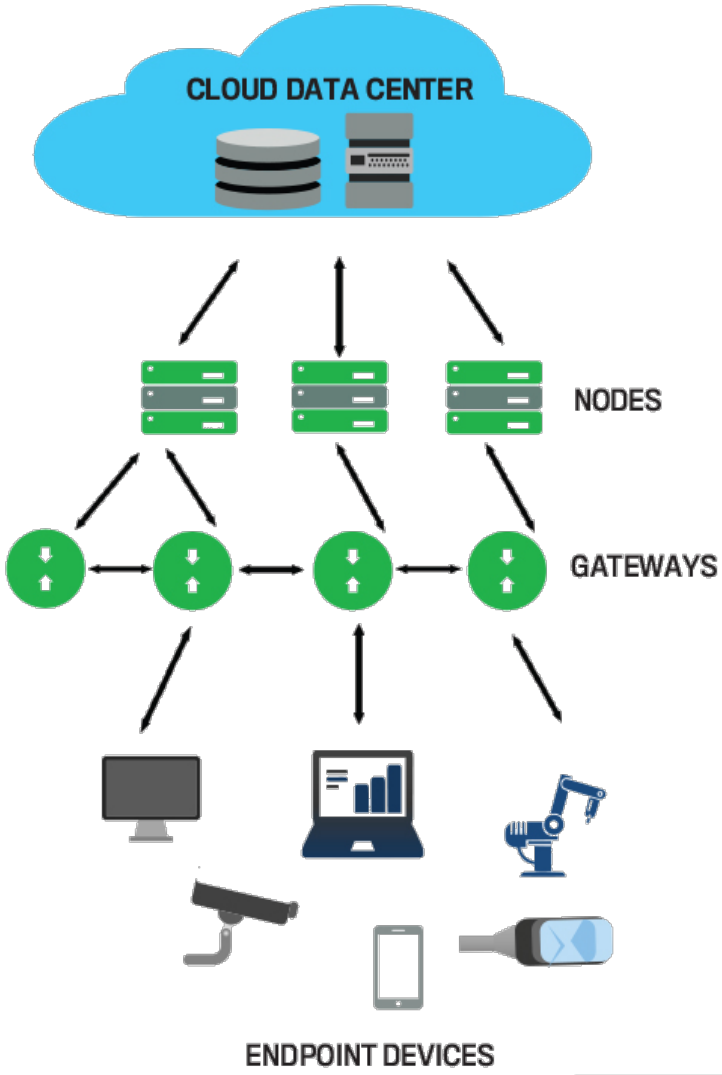
How can we distribute workloads for improving energy efficiency?

- We set different SLAs to comply with (latency, energy consumption, etc.)
  - → these define the **constraints** of our problem
- We want to minimize energy consumption
  - → this is our GOAL
- We can express the problem as

$$\min \sum_{d \in D} E_d$$

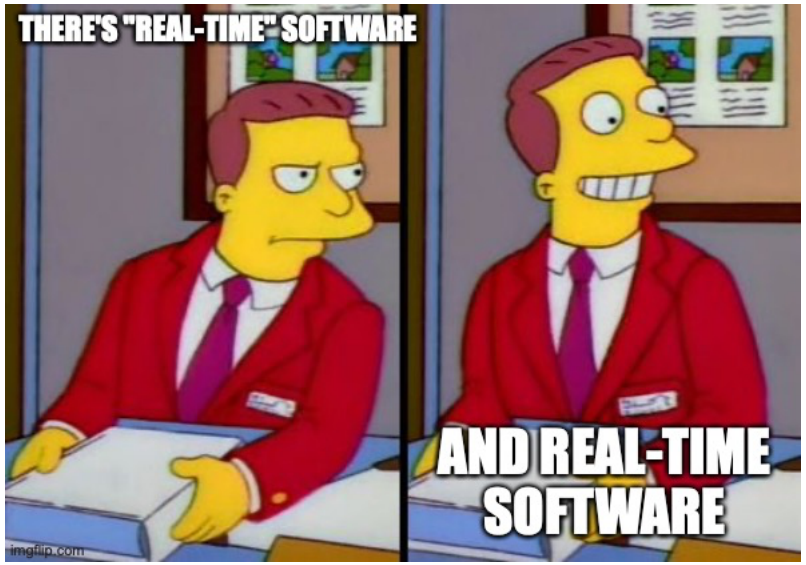
$$s.t.: sla_0,\ sla_1,\ \ldots,\ sla_n$$

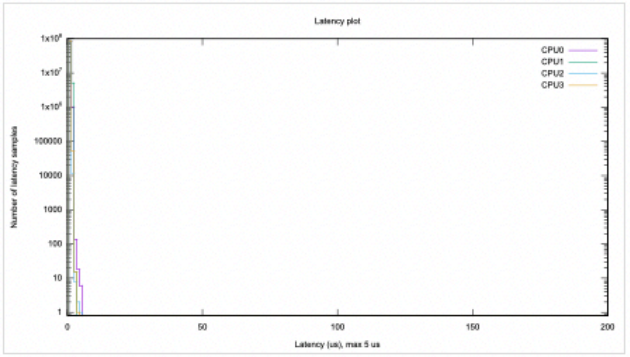
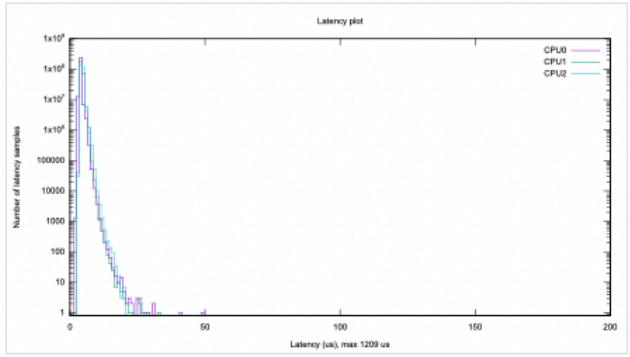
- For this we need to:
  - Estimate the energy consumption of a workload on any given device
  - Estimate the energy needed to transfer data between devices
  - Implement necessary mechanisms to transfer data and workloads

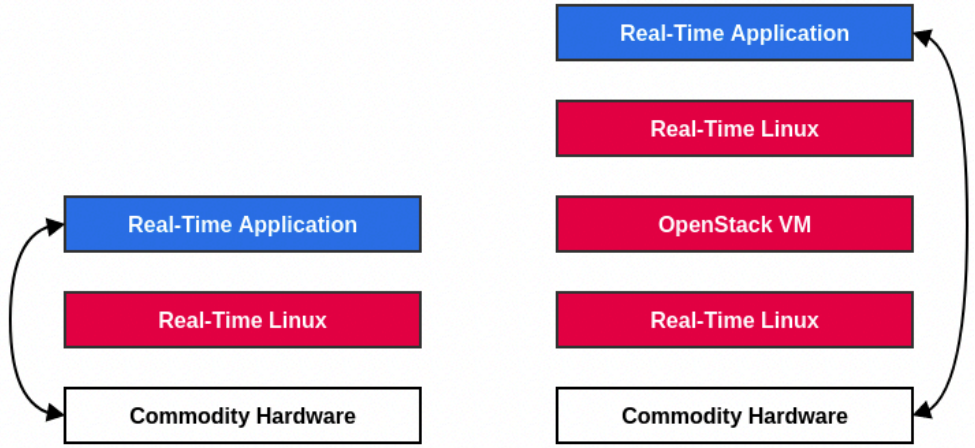


Real-time computing

- Real real-time software runs in deterministic time
  - Important for autonomous vehicles, production lines, etc.
- Hard real-time software needs to be deployed on dedicated, bare-metal hardware (no virtualization possible)
  - Also specialized software is needed (e.g., Linux real-time)
- Soft real-time software can be deployed on virtualized platforms

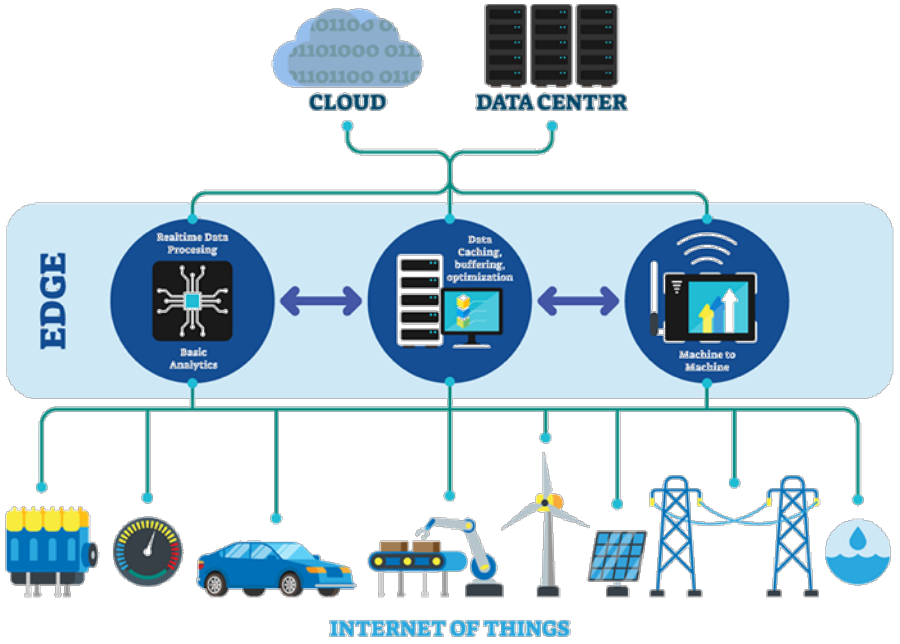


Bare-Metal	Virtualized
	
Hetzner: CPU Isolation with isolcpus (CPU Load, 24h)	VM on Hetzner: RT Configuration Identical to Host + RT Hypervisor Settings (CPU Load, 72h)



Takeaways

- In cloud computing all services reside on the cloud (we don’t know or care where)
- In edge computing we bring the processing close to the client or data source
- Cloud computing and edge computing can be combined
- Using both increases the complexity but also brings several benefits:
  - Reduced latency
  - Better use of bandwidth
  - Improved data privacy and security
  - Reduced costs



Q&A

Thank you!
Feel free to contact me on LinkedIn or via e-mail

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