194.049 VU 2019S

Energy Efficient Distributed Systems
Lecture 1

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1st lesson: Content

- **Part I: Organizational and Administrative Issues**
  - Contact, Grading, Timetable, etc.
  - Assignments organization
  - Lesson organization
- **Part II: Introduction**
  - **common forms of distributed systems**
  - **energy efficiency taxonomies**

Grading

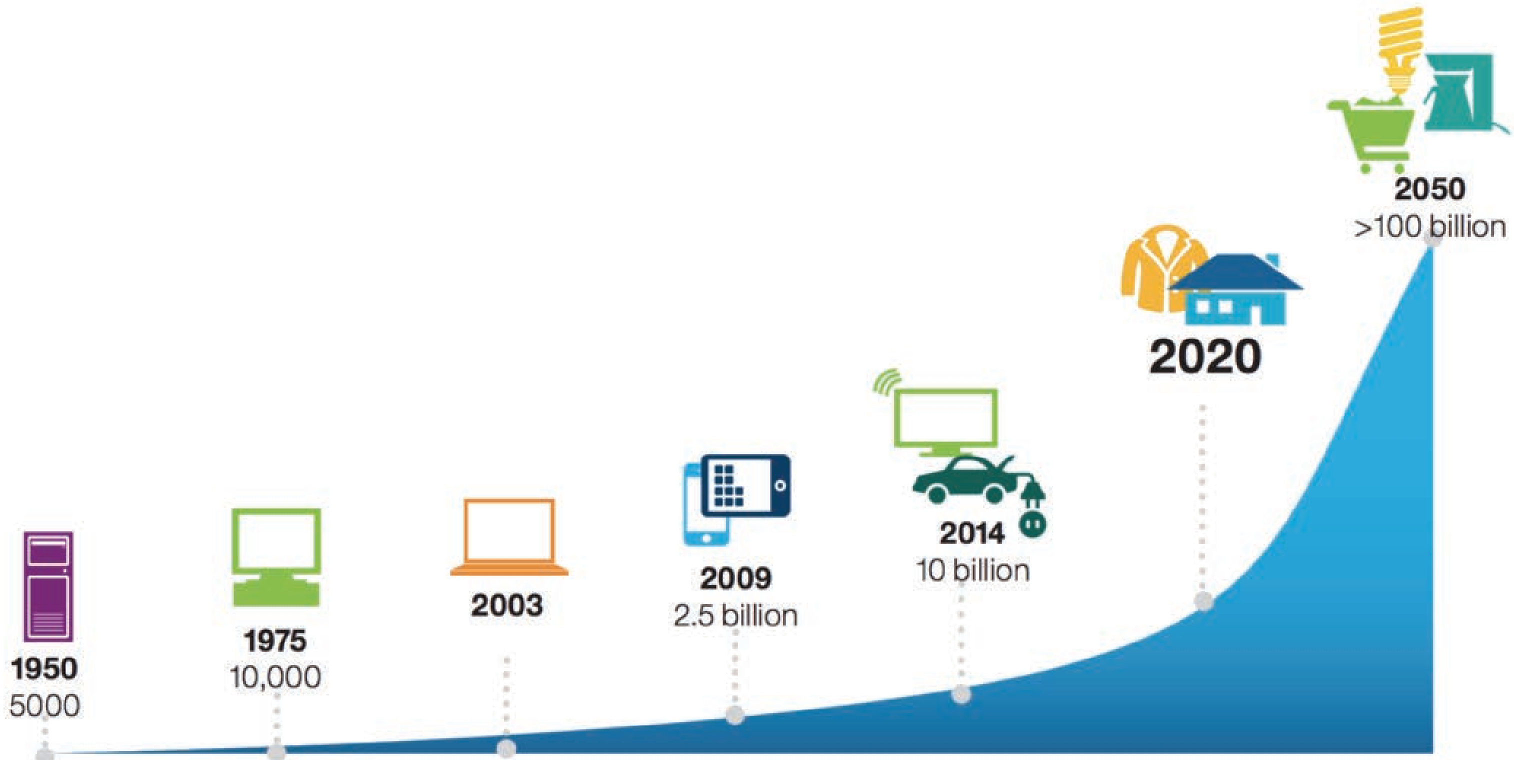
- Lecture / project work breakdown: 2,5h ECTS, 1,5h UE.
- ECTS Breakdown:
  - 30h lecture
  - 30h preparation for exam
  - 38h for project work
  - 2h exam
- Grading lecture: *oral exam*
- Grading practical part: *evaluation and discussion during group presentations*
- Both parts have to be positive!

Lecture and Project Timeline

- **6 March:** LECTURE: **Introduction to EEDS (Ivona)**
- **13 March:** PROJECT: Discussion and Presentation of the assignment **(Ivan Lujic)**
  "EDGE-CLOUD MECHANISM FOR AUTOMATIC AND ACCURATE RECOVERY OF INCOMPLETE SENSOR DATA"
- **20 March:** PROJECT: Background on Time series data, etc. **(Ivan Lujic)**
- **27 March:** LECTURE: **Current forms of Distributed Systems II:** Micro Data Centers **(Ivona)**
- **3 April:** LECTURE **: Tools & techniques for EE system management I: (Ivona)**
  - SLAs, Autonomic Cloud Management Controller Design in distributed virtualized systems
- **10 April:** LECTURE: **Tools & techniques for EE system management III:** Management based on geo temporal conditions **(Ivona)**
- **8 Mai:** PROJECT: Design of the Project work, presentation of the selected algorithms/ data staging approaches **(Ivan Lujic)**
- **15 Mai:** LECTURE: **Tools & techniques for EE system management II:** Cyber foraging, energy harvesting **(Vincenzo de Maio)**
- **22 Mai:** LECTURE: **Tools & techniques for EE system management IV:** Scalable Monitoring **(Ivona)**
- **29 Mai**: PROJECT: Simulation infrastructure, Preliminary implementation **(Ivan Lujic)**
- **5 Juni**: LECTURE: **Speculative Resource allocation I (Ivona)**
- **12 Juni** **Current forms of Distributed Systems (Atakan Aral)**
  - VMMs; Cloud ecosystem, Cloud Oss: Xen, VI management (Eucalyptus, etc.), Cloud management, Network virtualization, Smart and micro grids
- **19 Juni:** PROJECT: End Presentation, Results and Discussion **(Ivan Lujic)**
- **26 June:** Exam

COMMON FORMS OF DISTRIBUTED SYSTEMS: CLOUD COMPUTING

Problem - Inflection points in the history of computing



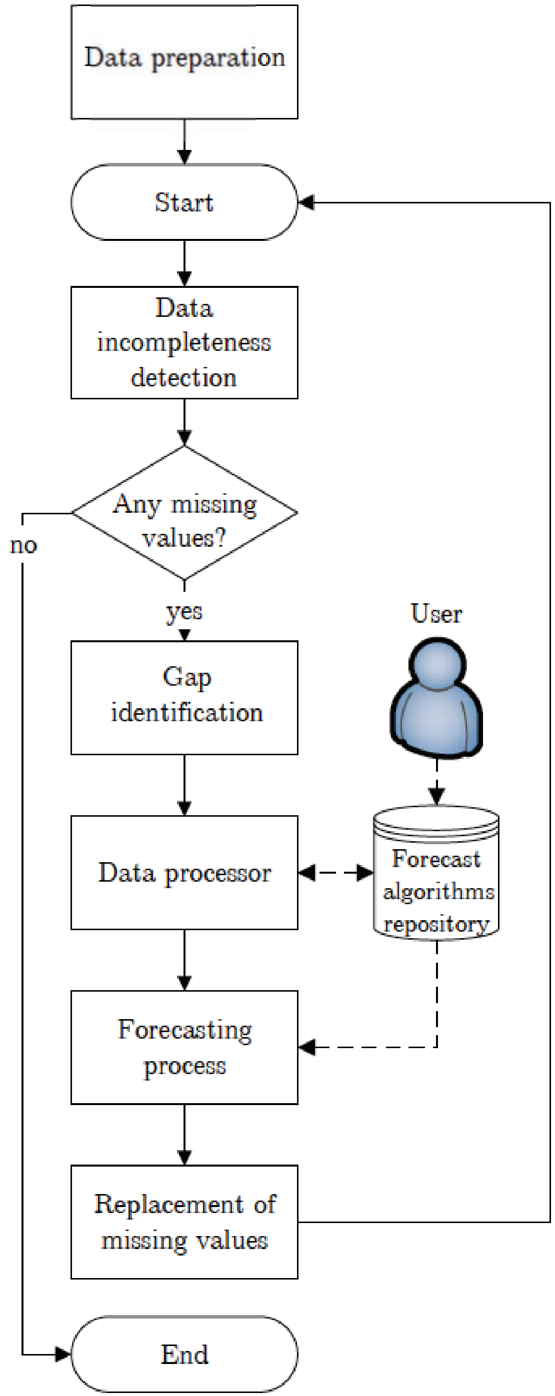
→ **Explosion of energy demands!**

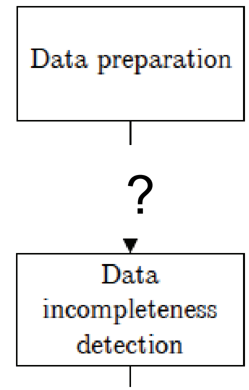
1. **Devices**
2. **Software/Programs/Algorithms**

→ **Rethink how to develop and deploy algorithms**

Source: https://bluehorizon.network/documentation/introduction

1969 Margret Hamilton with her Apollo flight code





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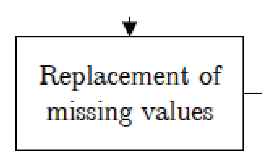
Machine Learning - Meta algorithms



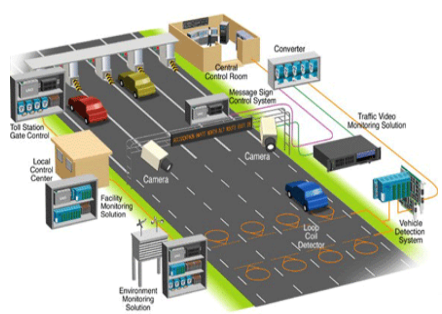
Typical Applications

Common Features:

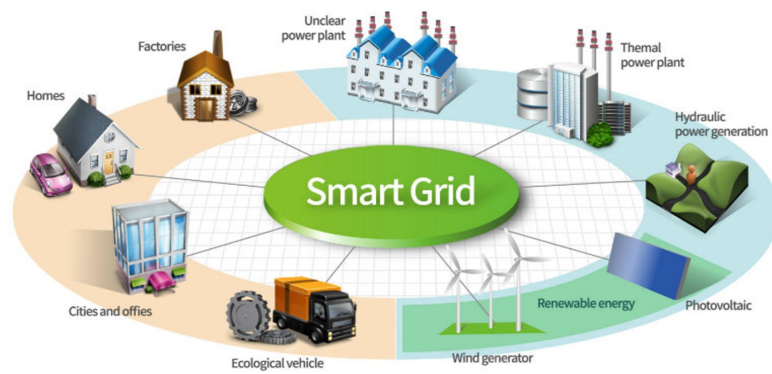
- Time-sensitive
- Data-intensive
- **Distributed**
- **Non-stationary**

Computational Advertising

Spam or Fraud Detection



Intelligent Traffic Control

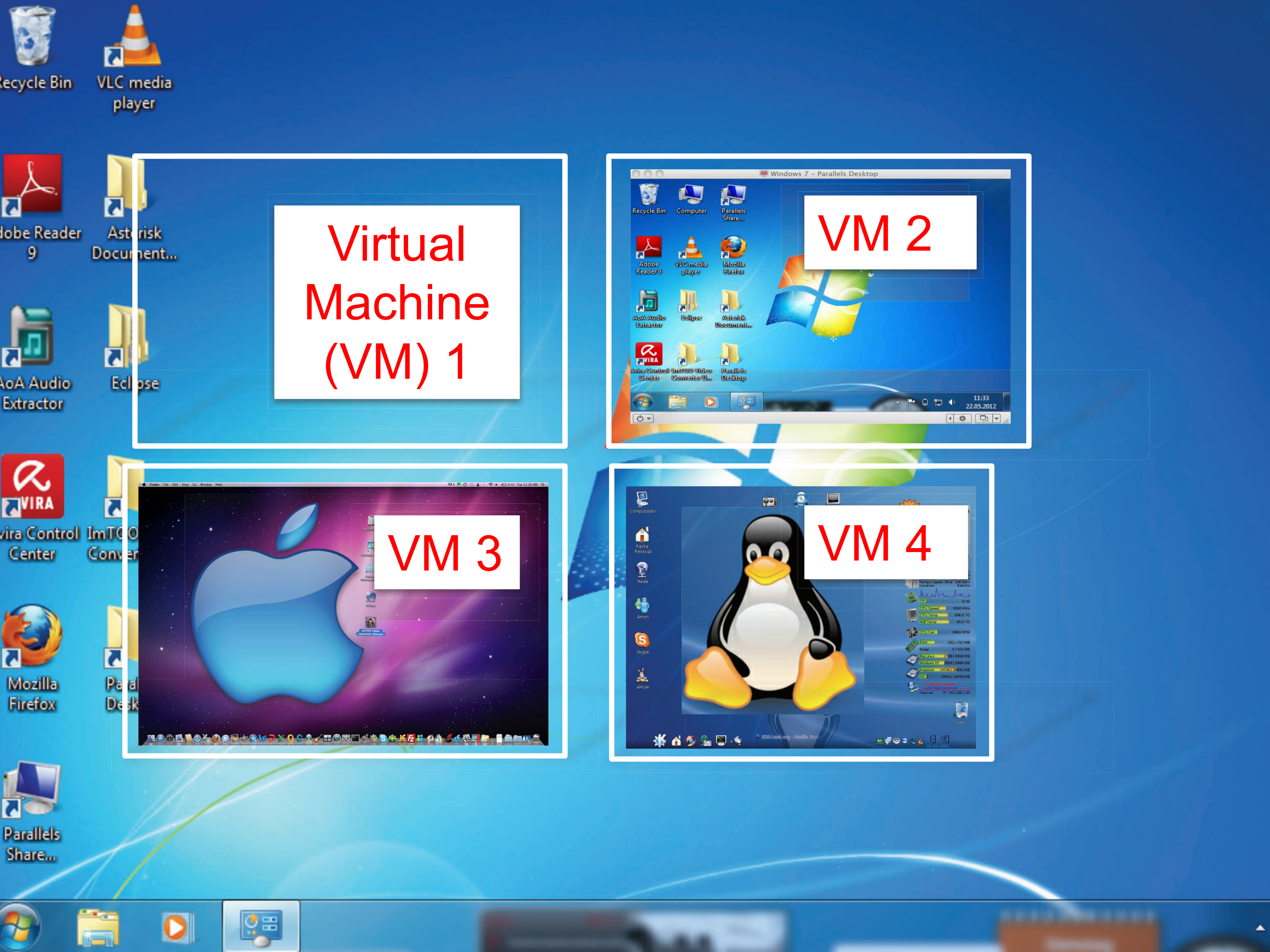


Transactive Energy Control

Some Facts

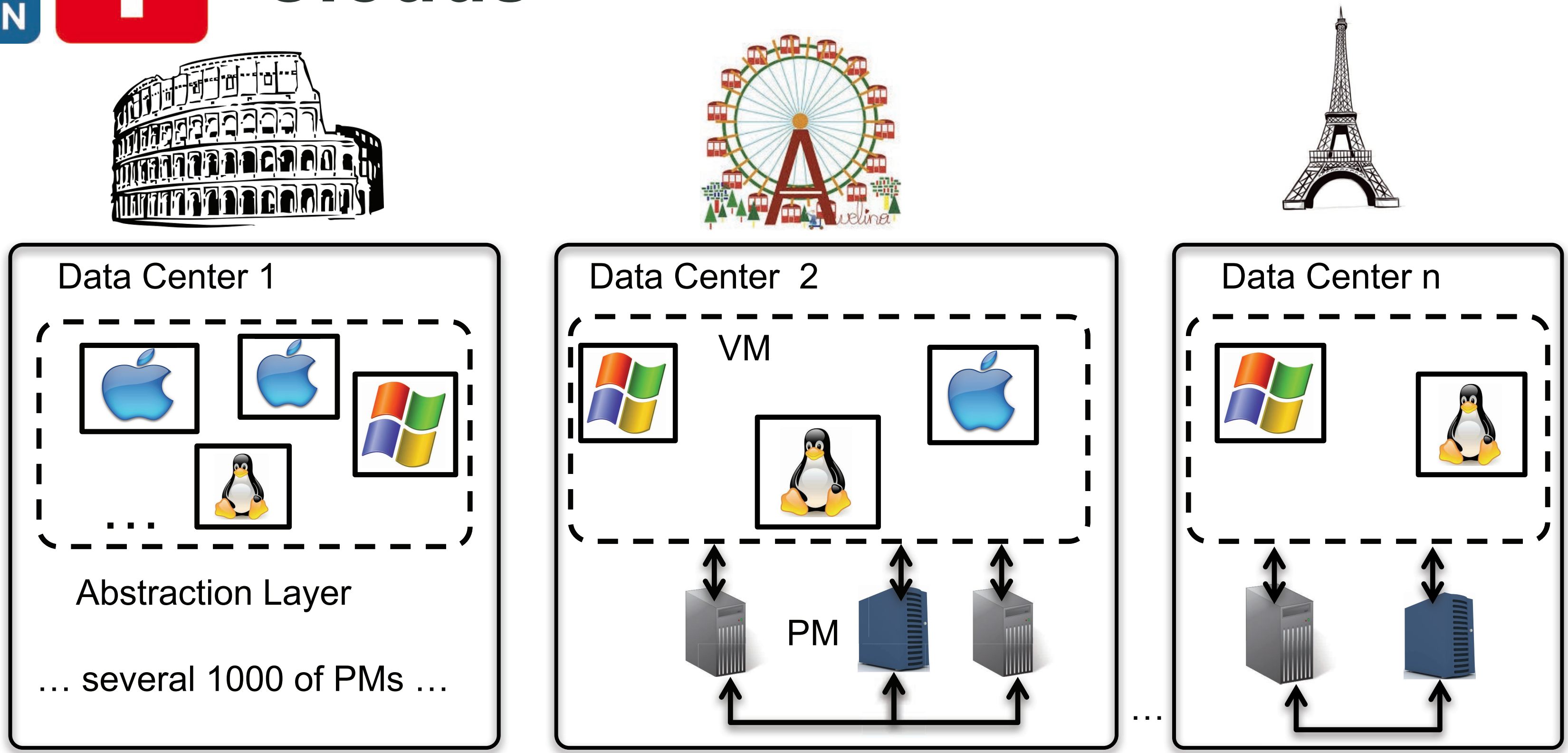
- Google in 2010: 900.000 servers ~ 2 billion kWh (~consumption of Graz)
- Facebook in 2012 ~ 532 million kWh
- In 2012 about 509.147 data centers worldwide → electricity consumption of **30 nuclear power plants**
- **Data centres of the world will consume 1/5 of Earth's power by 2025**

Source:
- *J. Koomey, Growth in Data Center Electricity Use 2005 to 2010. Analytics Press, 2011*
- *Ann-Ceclie Orgerie, Leveraging Renewable Energy in Edge Clouds for Data Stream Analysis in IoT, CCGrid 2017*
- *https://data-economy.com*



Virtual Machine (VM) 1
VM 2
VM 3
VM 4
Recycle Bin
VLC media player
Windows 7 – Parallels Desktop
Computer
Parallels Share...
Adobe Reader 9
Mozilla Firefox
AoA Audio Extractor
Eclipse
Asterisk Document...
Avira Control Center
Parallels Desktop
11:33
22.05.2012

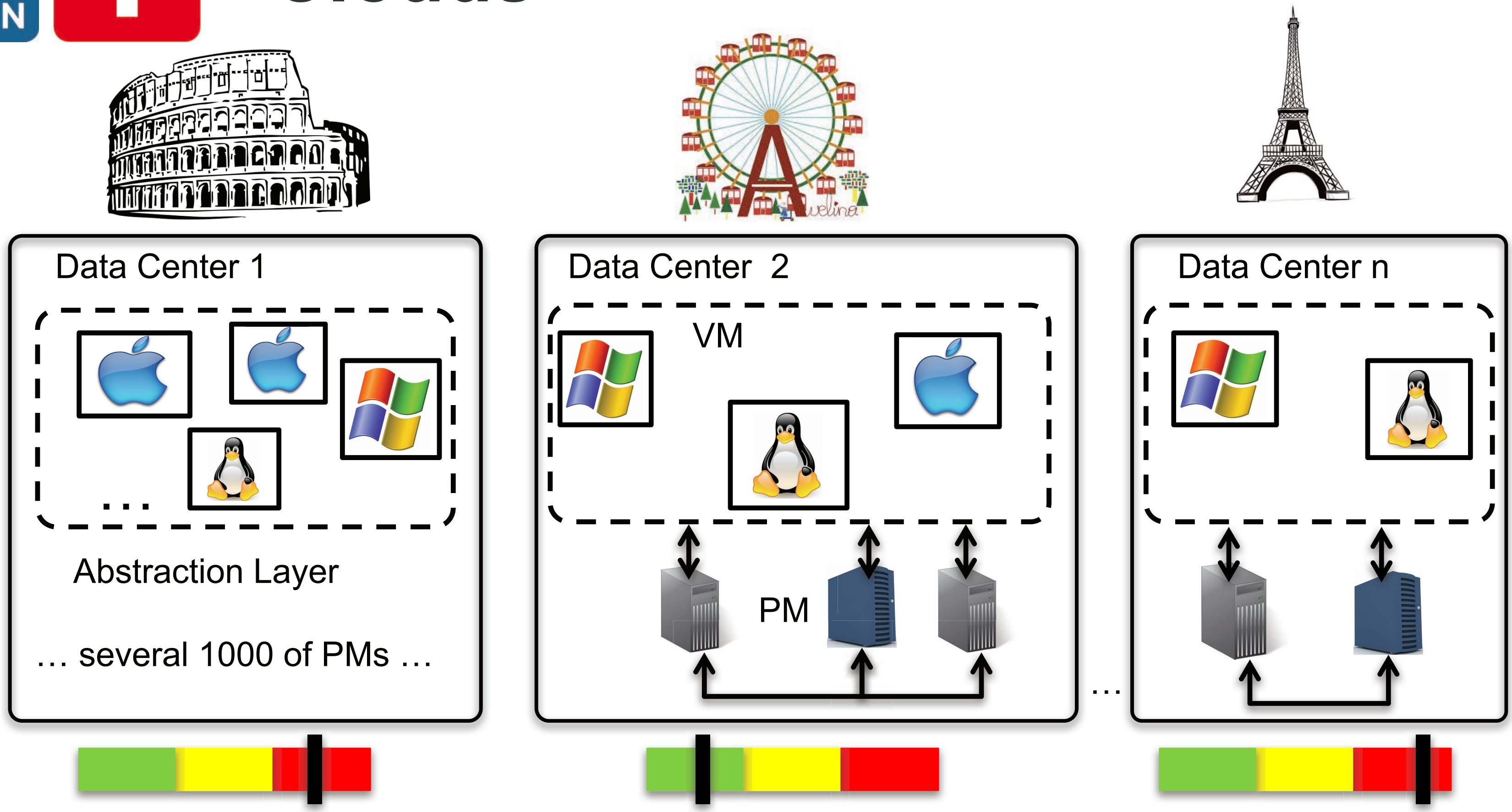
Clouds



Physical Machine (PM)

Virtual Machine (VM): Abstraction of a physical machine, "*simulation of a computer*"

Clouds



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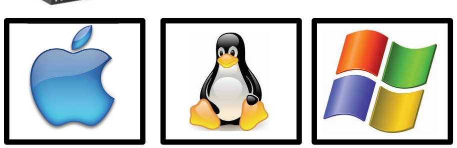
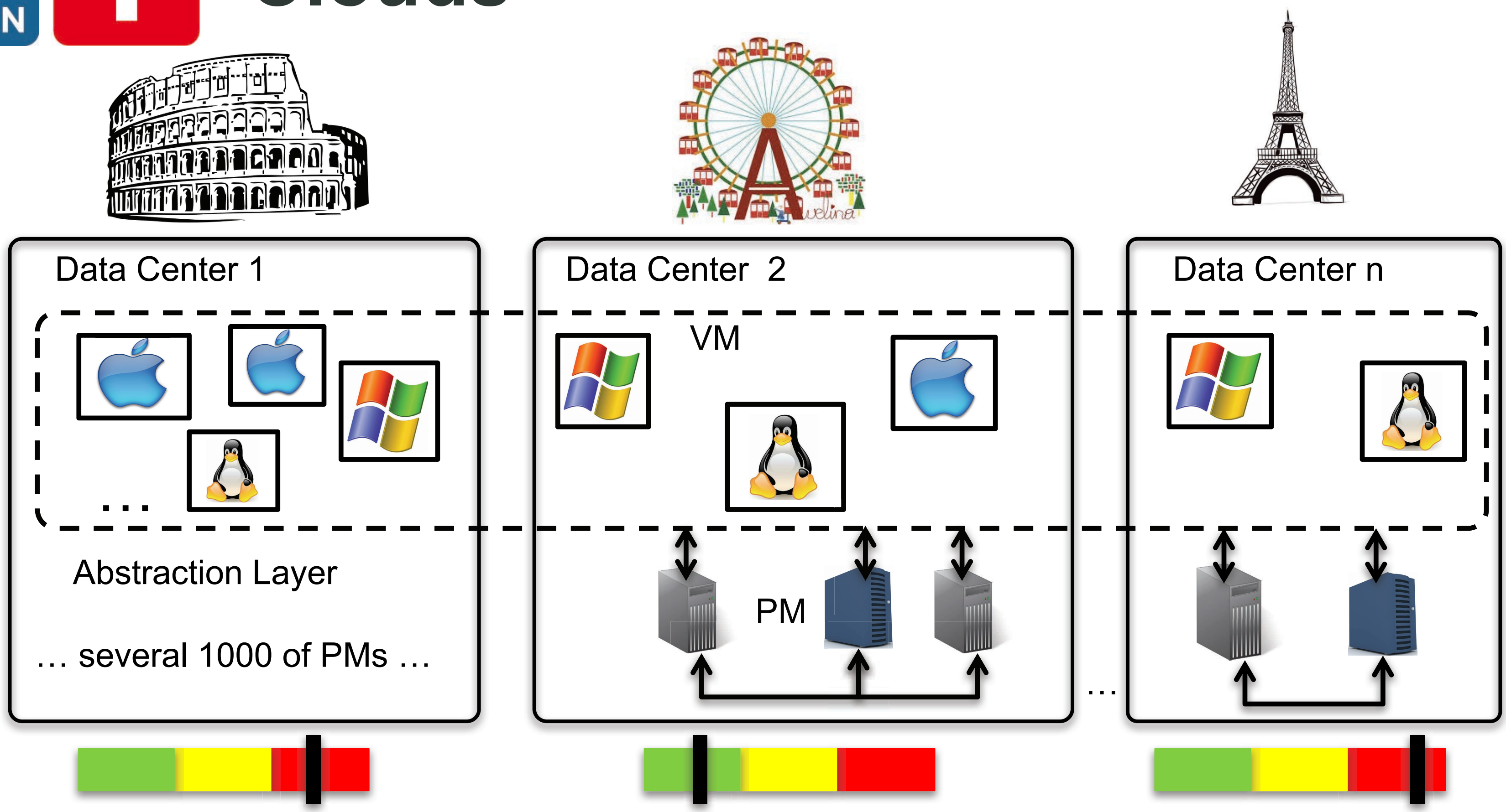


Virtual Machine (VM): Abstraction of a physical machine, "*simulation of a computer*"

Clouds



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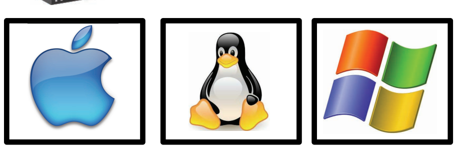


Virtual Machine (VM): Abstraction of a physical machine, "*simulation of a computer*"

Cloud: economic and ecological data center solutions

ImmersiveDeck

A Multi-User VR System

TU Wien

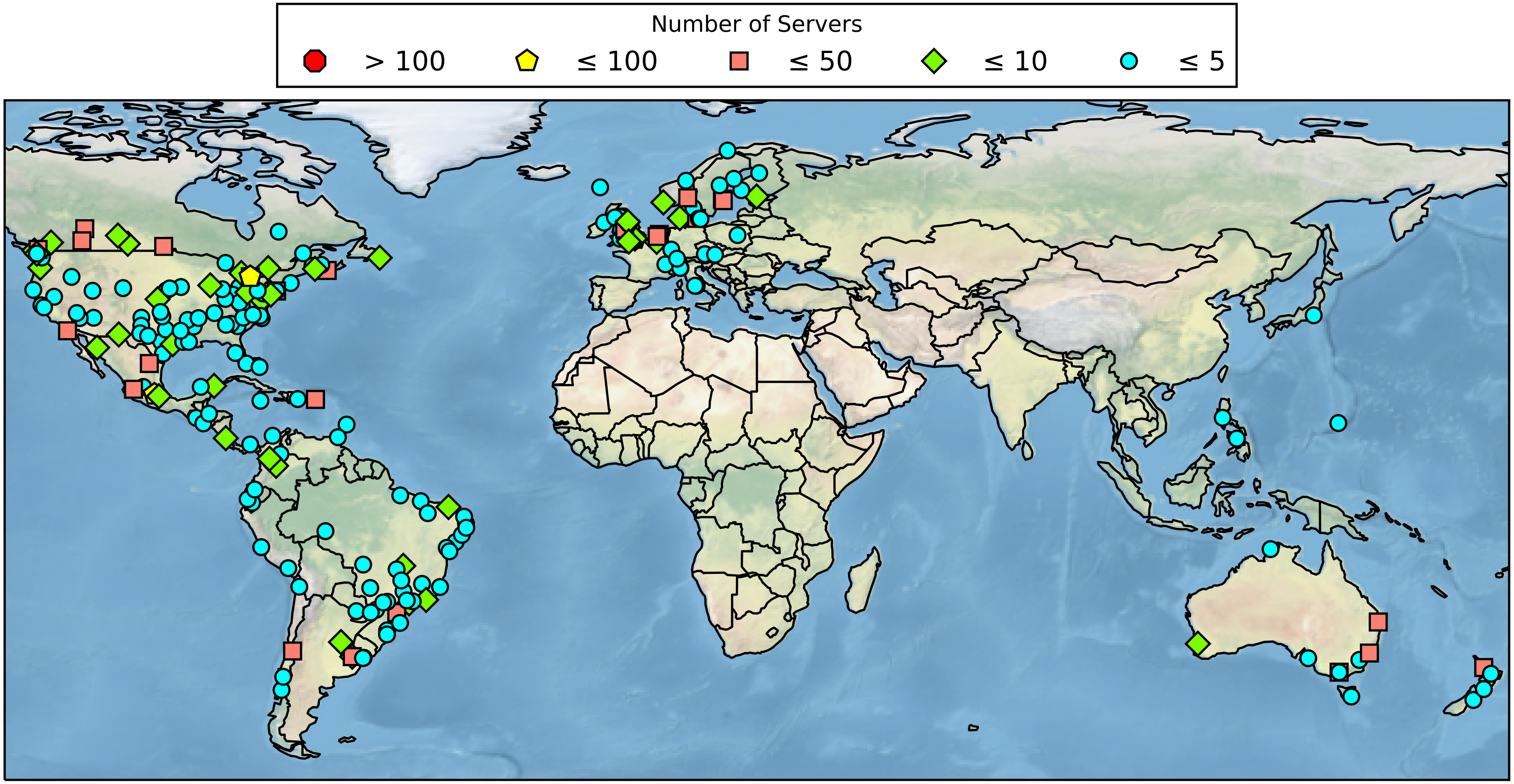
Khrystyna Vasylevska, Iana Podkosova, Peter Fikar, Elisabeth Broneder, Emanuel Vonach, Georg Gerstweiler, Hannes Kaufmann

INTERACTIVE MEDIA SYSTEMS
TU Wien
Vienna | Austria

in cooperation with

ILLUSION WALK
IMMERSIVE EXPERIENCE PROVIDER

Data Locality



CDN servers deployed within ISPs.

Source: Researchers map Netflix's content delivery network for the first time (H2020 ENDEAVOUR Project) http://www.qmul.ac.uk/media/news/items/se/180078.html


VSC 2 @ TUWIE

Yahoo! data farm near Buffalo

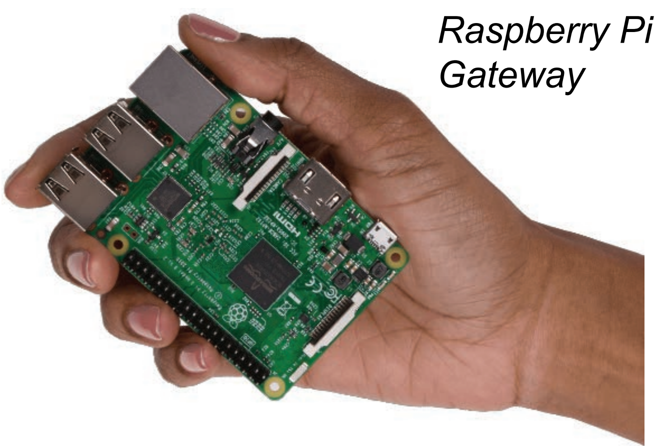
Heterogeneity of Data Centers

Natick Microsoft Underwater Micro Data Center

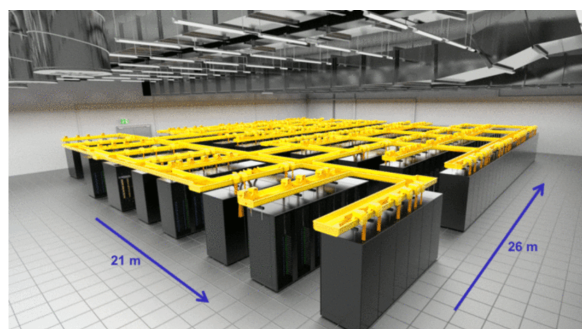
“Flying data center”

Huawei Micro Data Center

Raspberry Pi Gateway



Liquid Cooling

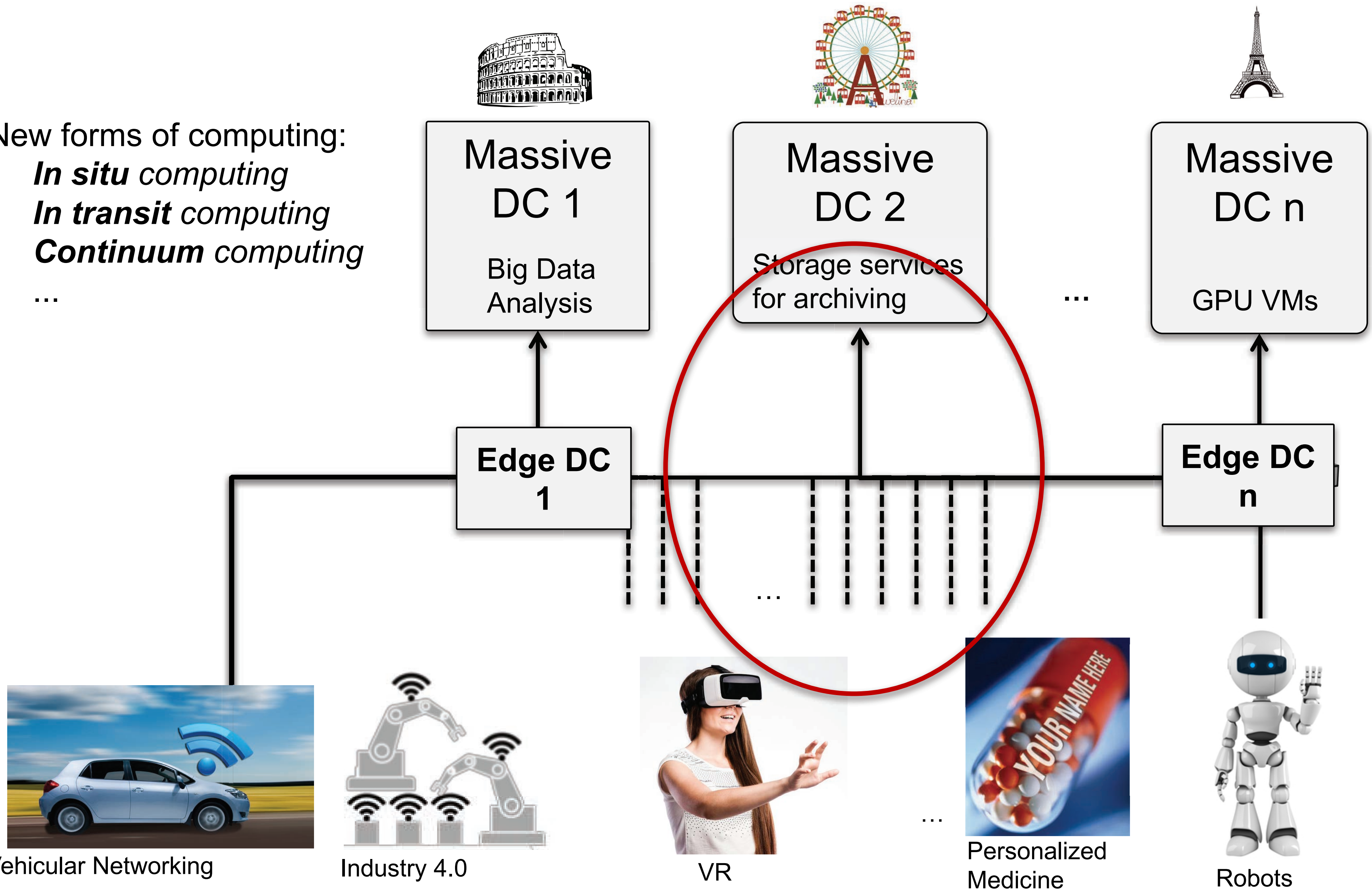


High latitude data centers

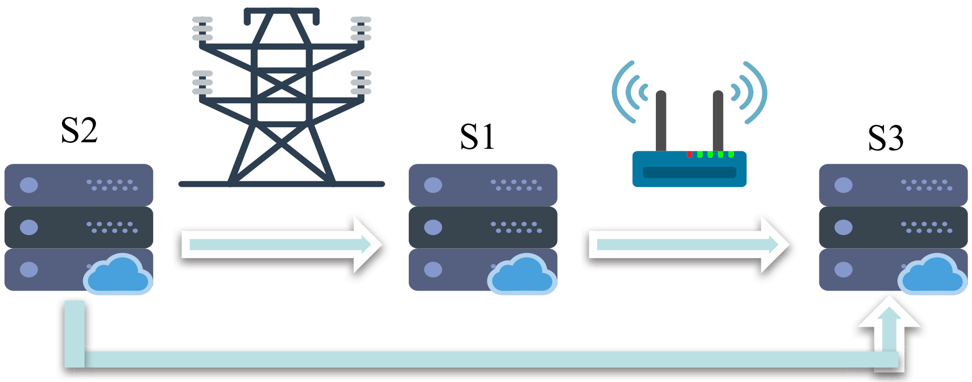
[1,2,3]

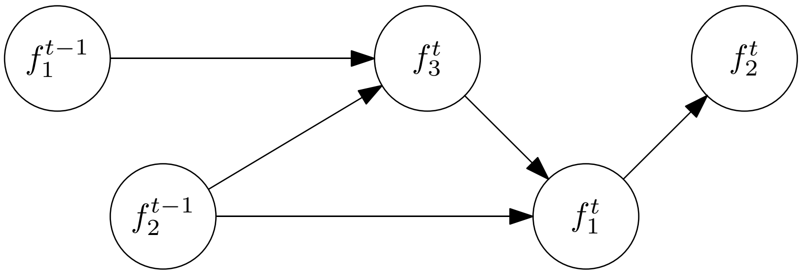
New Life Changing Applications, new Infrastructures

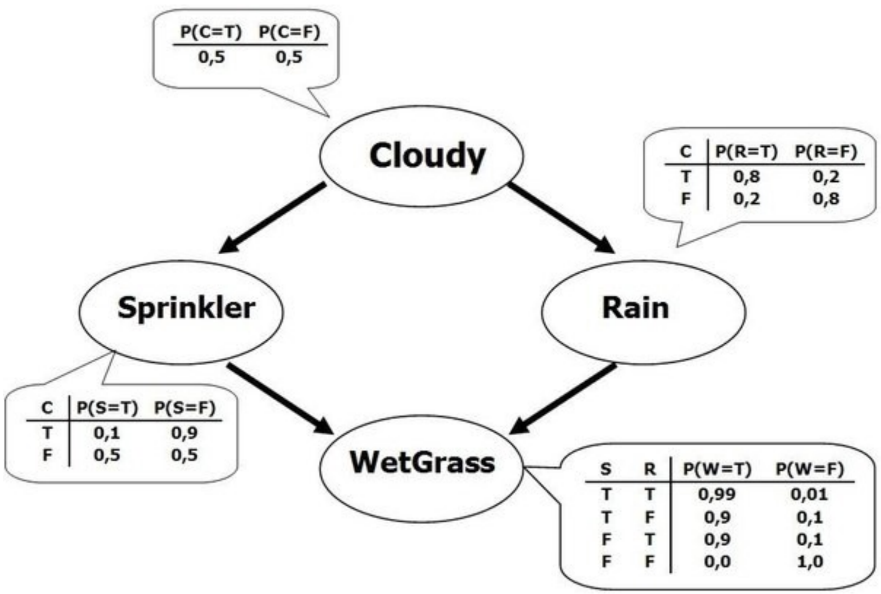
New forms of computing:
- ***In situ*** *computing*
- ***In transit*** *computing*
- ***Continuum*** *computing*
- ...

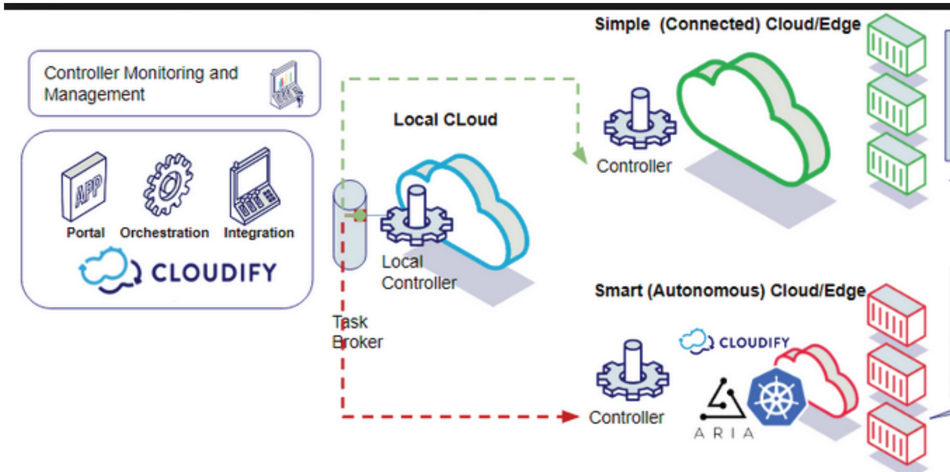


Dependency Mining





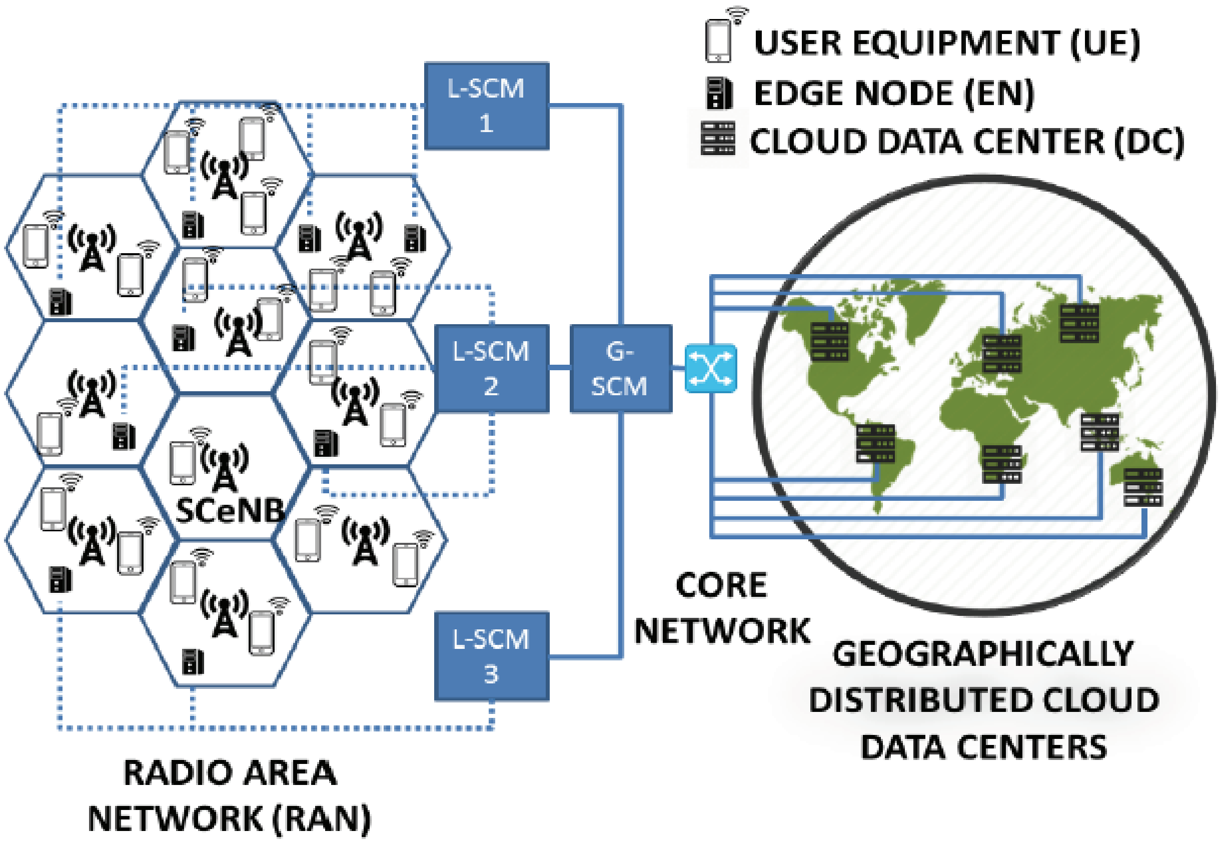




Source: Atakan Aral, Ivona Brandic. ***Dependency Mining for Service Resilience at the Edge.*** *The Third ACM/IEEE Symposium on Edge Computing. Bellevue, WA, October 25-27, 2018.*

Der Wissenschaftsfonds.

Small Cell Cloud



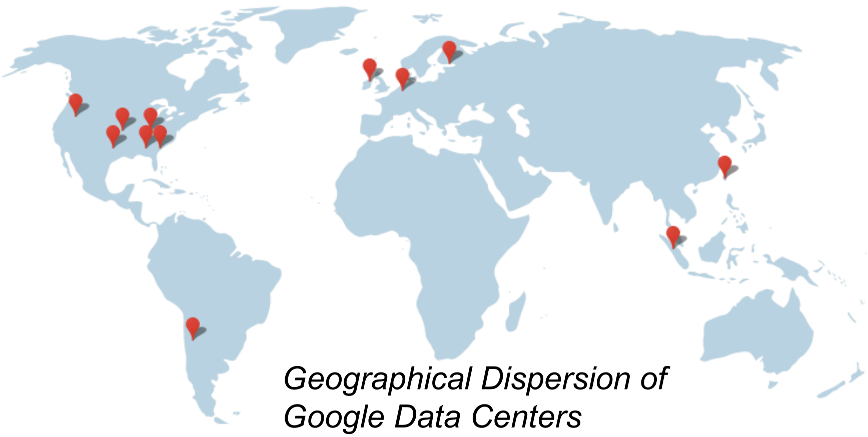
- Multi objective meta heuristics
- Generation of samples
- Live Labs
- Monte Carlo simulations to explore different settings

Source: Vincenzo de Maio, Ivona Brandic. ***Multi-Objective Mobile Edge Provisioning in Small Cell Clouds.*** *10th ACM/SPEC International Conference on Performance Engineering (ICPE 2019), Mumbai, India, April 7-11, 2019.*

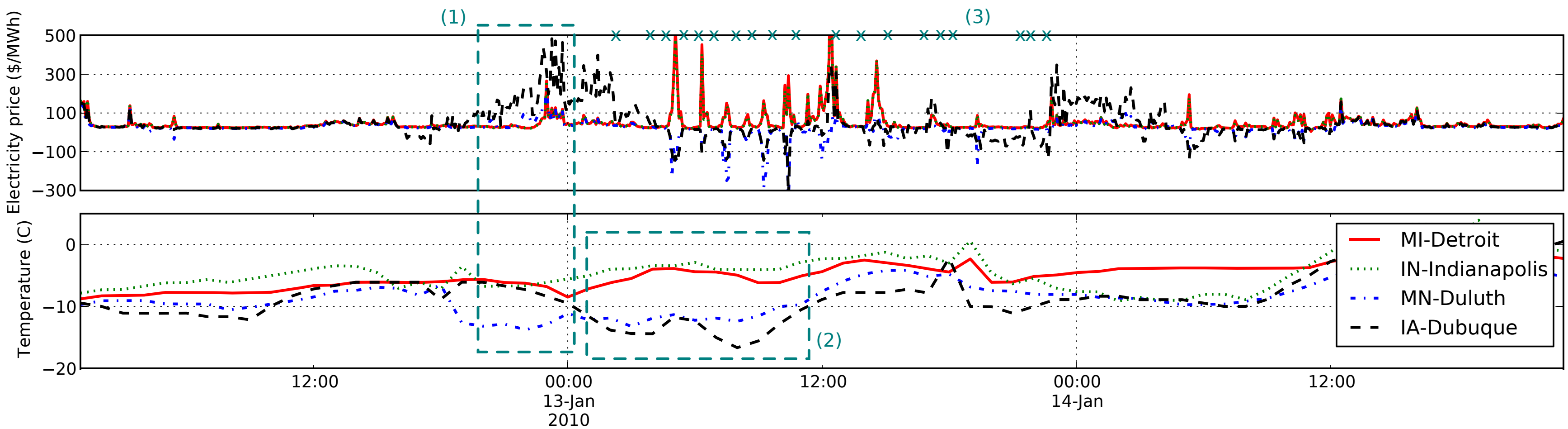
Der Wissenschaftsfonds.

Challenge: Geo temporal inputs

- Real-time electricity pricing (RTEP) options where prices change hourly or even every minute
- Cooling efficiency depending on local weather conditions



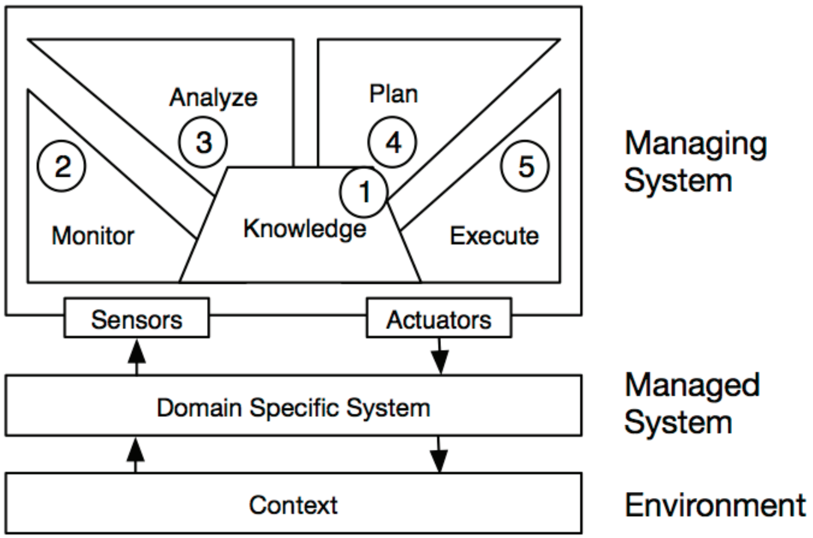
Geographical Dispersion of Google Data Centers



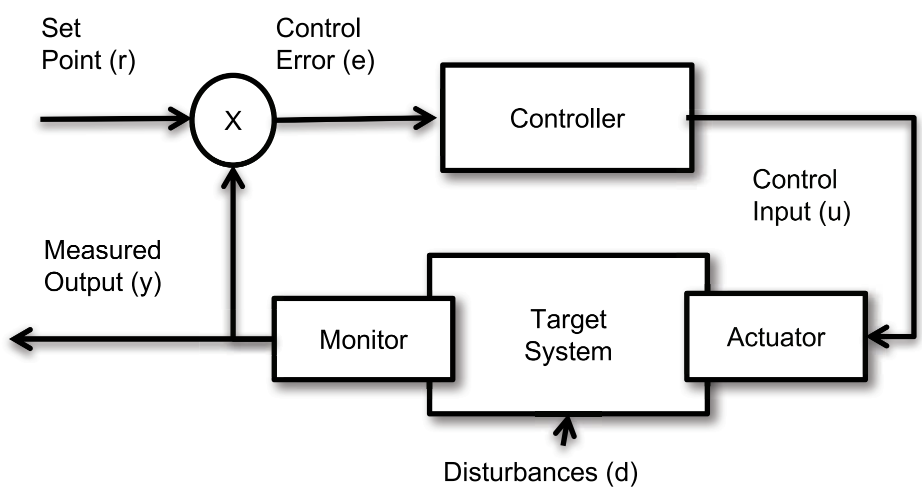
Energy Consumption vs. Resource Utilization

- ICT consumes **10.5% of energy in Germany** and rising, (Deutscher Bundestag, 2010)
- ICT **produces 2% of worldwide CO_2 emissions and rising** - equivalent to aviation industry, (Gartner, 2007)

Autonomic System Management



Control Theory



5 Cloud Characteristics

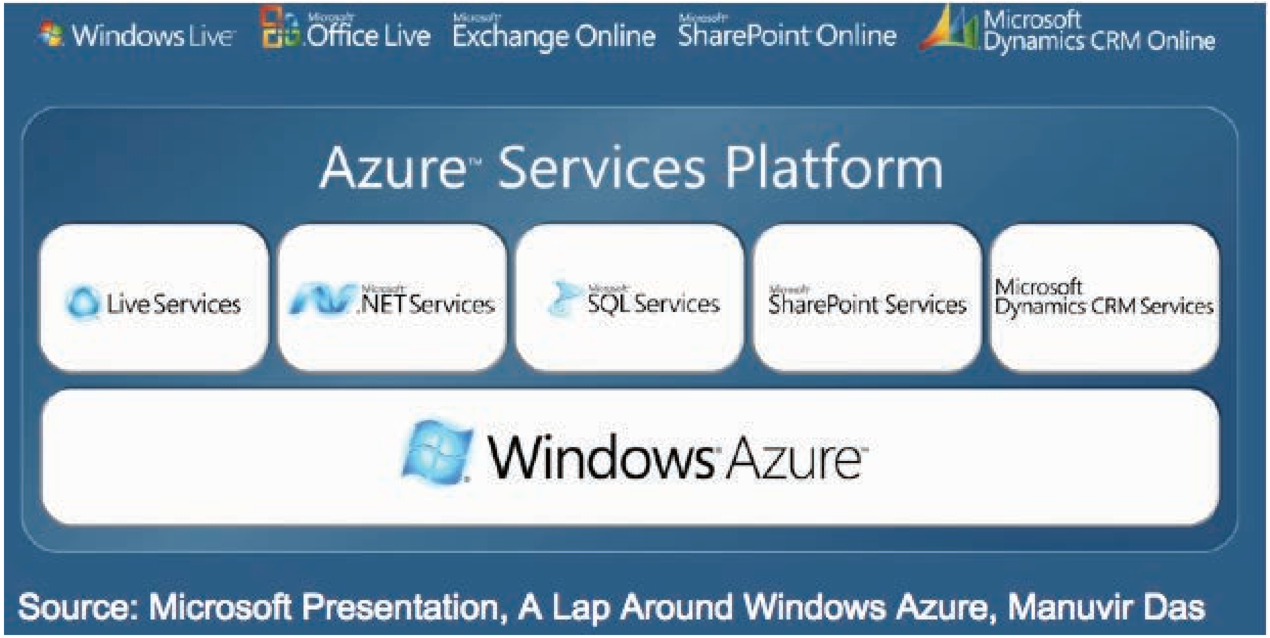
- On-demand self-service
- Ubiquitous network access
- Resource pooling
- Rapid elasticity
- Pay per use

3 Delivery Models

- **Cloud Software as a Service (SaaS)**
  - Use provider's applications over a network
  - E.g., Salesforce.com,…
- **Cloud Platform as a Service (PaaS)**
  - Deploy customer-created applications to a cloud
  - E.g. Google App Engine, Microsoft Azure, …
- **Cloud Infrastructure as a Service (IaaS)**
  - Rent processing, storage, network capacity, and other fundamental computing resources
  - E.g. Elastic Computer Cloud (EC3), Simple Storage Service (S3), Simple DB,….

Examples: SaaS

- SaaS
  - Google Application Engine
    - Google Mail, Google Calendar, Picasa, Google Talk, Google Docs, ….



4 Cloud Deployment Types

- **Private cloud** – enterprise owned or leased
- Community cloud – shared infrastructure for specific community
- **Public cloud** – Sold to the public, mega-scale infrastructure
- **Hybrid cloud** – composition of two or more clouds

Cloud Characteristics

Cloud computing often leverages:

- Massive scale
- Virtualization
- Free software
- Autonomic computing
- Multi-tenancy
- Geographically distributed systems
- Advanced security technologies

Cloud Technologies

- Virtualization
- Grid technology
- Service Oriented Architectures
- Distributed Computing
- Broadband Networks
- Browser as a platform
- Free and Open Source Software
- Autonomic Systems
- Web 2.0
- Web application frameworks
- Service Level Agreements (SLAs)

Virtualization

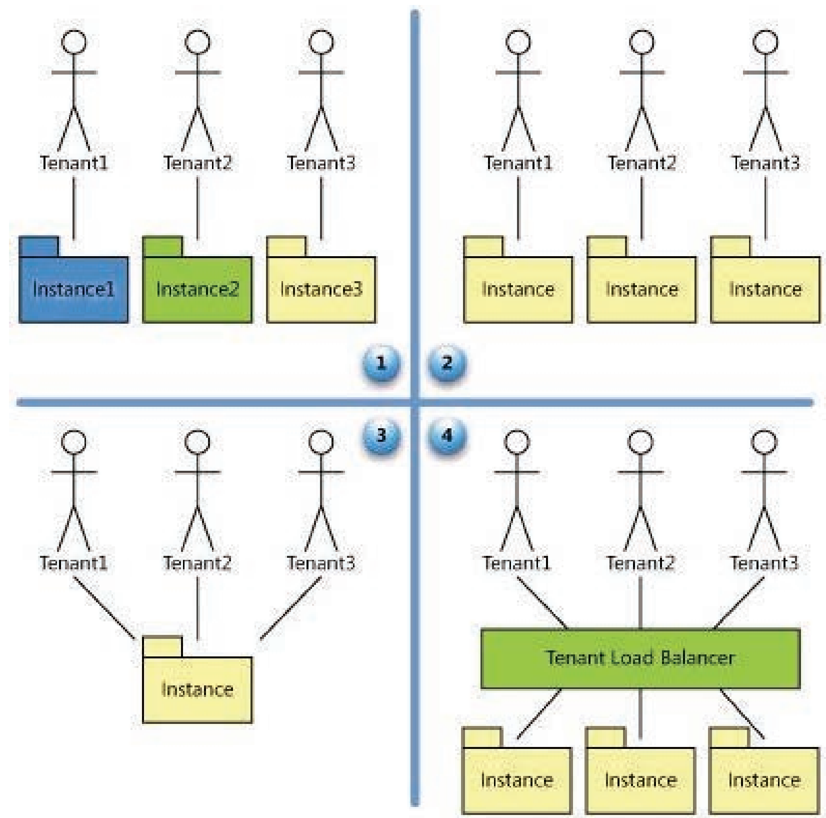
- Host operating system that provides an abstraction layer for running virtual “guest” operating systems
- “hypervisor” or “virtual machine monitor”
- Enables guest OSs to run in isolation of other OSs
- Run multiple types of Oss
- Increases utilization of physical servers
- Enables portability of virtual servers between physical servers

Web Application Frameworks

- Enables dynamic web sites
- Facilitates web and DB related programming operations (e.g., web services support)
  - Creation of Web 2.0 applications
  - Supported by most major software languages
- Separation of business logic from the user interface
- Authentication, Authorization,…

Multi-tenancy

- Level 1: Ad-Hoc/Custom
- Level 2: Configurable Level 3: Configurable, Multi-Tenant-Efficient
- **Level 4: Scalable, Configurable, Multi-Tenant-Efficient**



Source: Peter Mell, Tim Grance NIST, Information Technology Laboratory

http://vikashazrati.files.wordpress.com/

Examples for the Virtualization Middleware

- OpenNebula
  - Partly developed by the European Union's *Reservoir* project
- VMWare Vcloud
  - Further development of the Globus Tooklits
- Aneka Clouds
  - University of Melbourne
- FoSII Infrastructure
  - Vienna University of Technology

COMMON FORMS OF DISTRIBUTED SYSTEMS: EDGE COMPUTING

Edge Computing

- Also known as Fog (Cisco) or Cloudlets (Intel)
- Latency sensitive applications
- Huge amounts of data
  - Call for smaller data centers that are placed on the “edge” of the network
  - Facilitate data staging, preprocessing, filtering, but also computations
  - Typical applications:
    - Vehicular networking, video surveillance, traffic management, etc.
    - **Problem:** edge DC are usually operated in more energy *inefficient* way than massive DCs

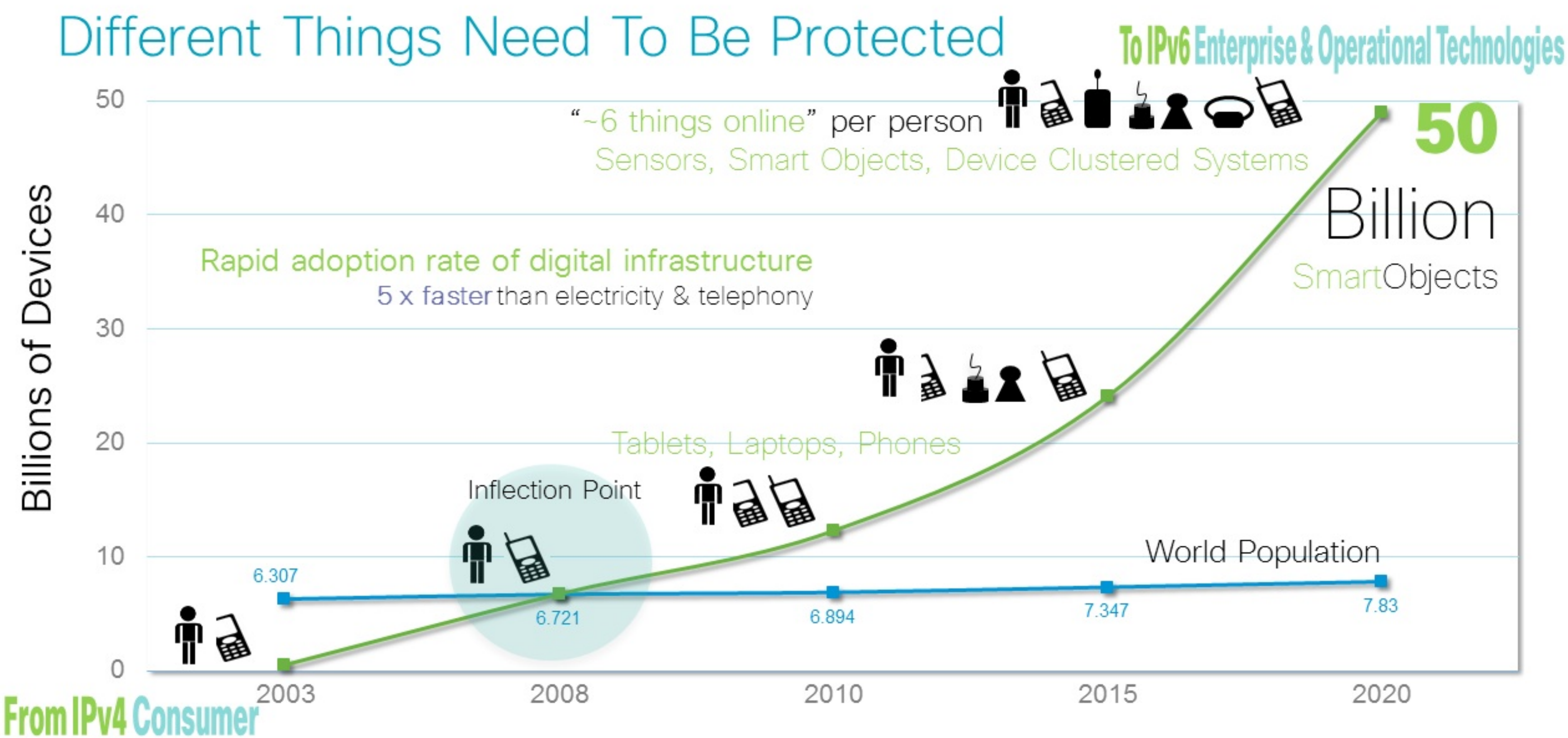
Edge Comp: Some Facts

- By 2025, researchers estimate that the IoT could have an economic impact—including, for example, revenue generated and operational savings—of $11 trillion per year, which would represent about 11 percent of the world economy; and that users will deploy 1 trillion IoT devices.
- → **Unprecedented amounts of data**
- → **calls for EE solutions**

Cloud vs. Edge

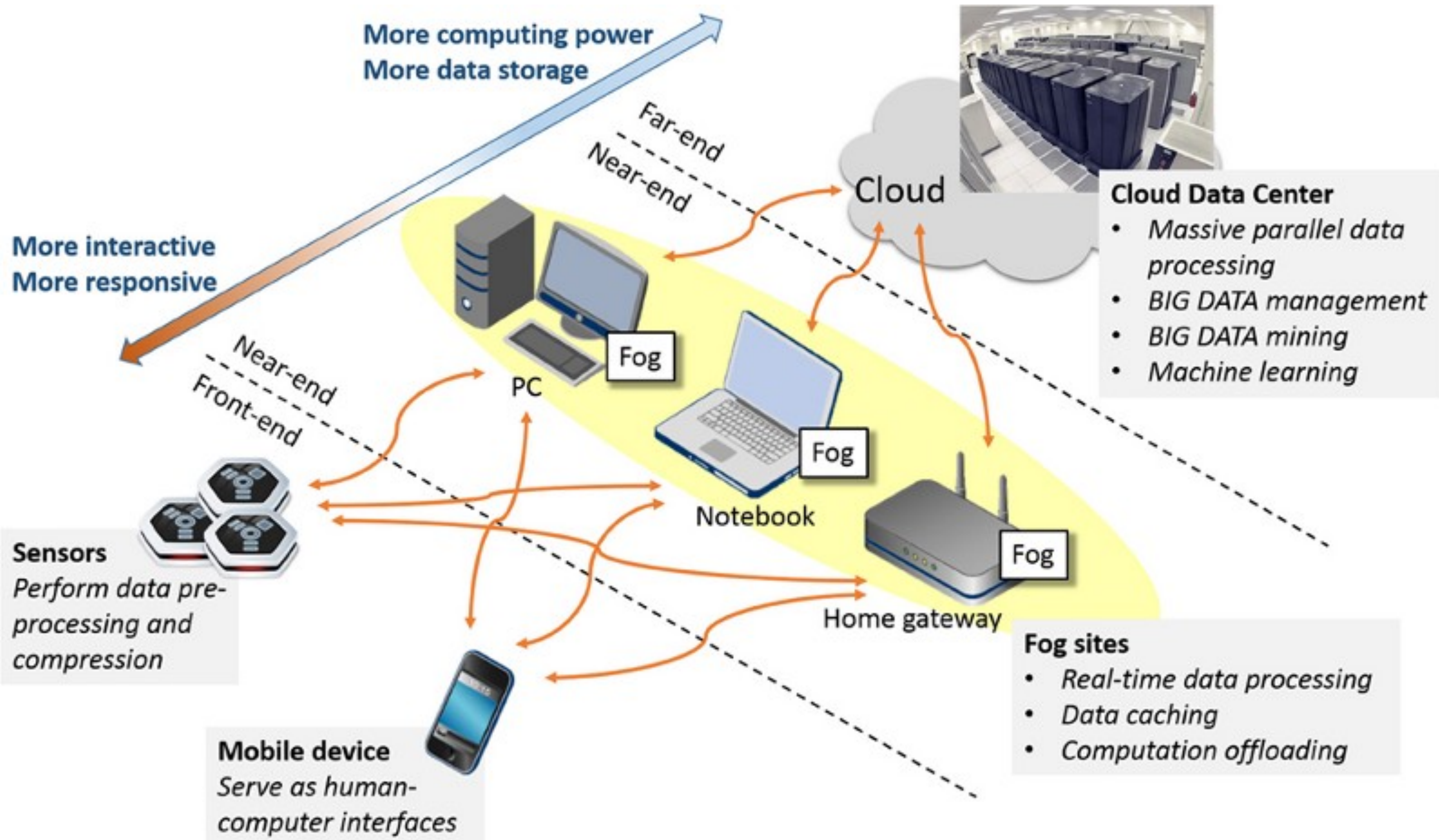
- Clouds offer “unlimited storage”
- For latency sensitive applications and applications that produce huge amounts of data not feasible (health-monitoring, emergency response, etc.)
- There is not enough bandwidth
  - Data has to be processed on the Edge

Increase of IoT devices

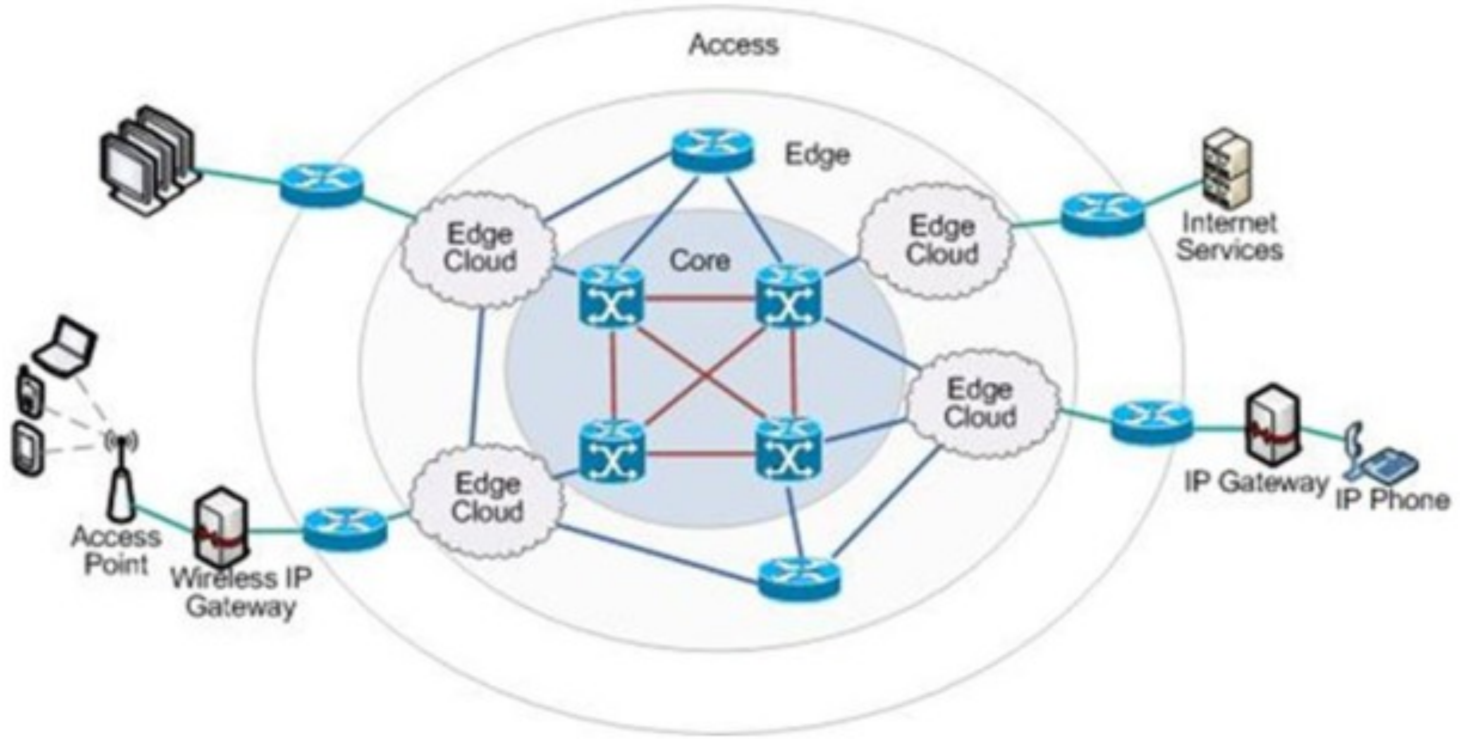


Source: Cisco IBSG projections, UN Economic & Social Affairs http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

Connection Edge-massive DCs



Edge Architecture



ENERGY EFFICIENCY TAXONOMY

Energy consumption of virtualized DCs

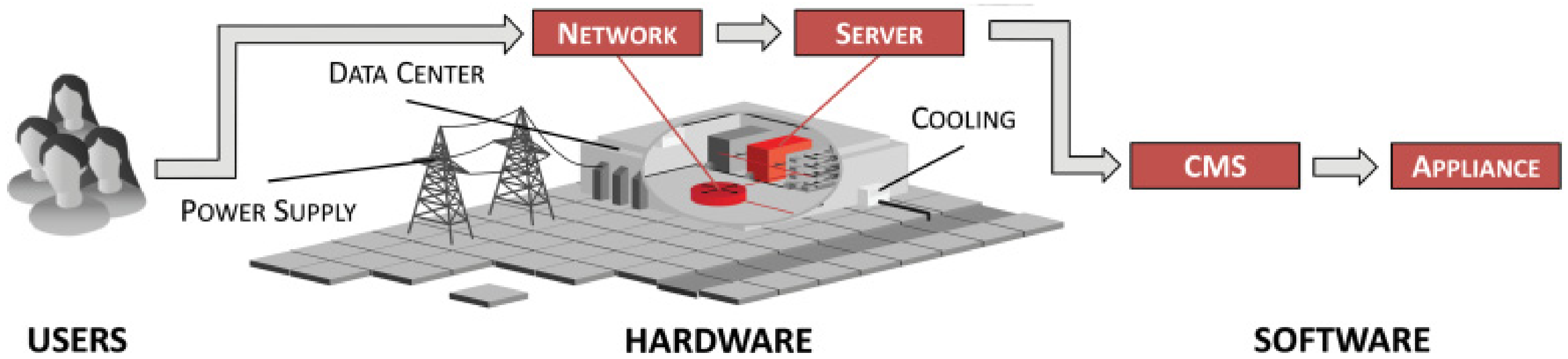


Fig. 1. Cloud computing data center domains.

Energy efficiency refers to a ***reduction*** of energy used for a given service or level of activity, as defined by the World Energy Council [Moisan and Bosseboeuf 2010]

Energy efficiency of a DC: **difficult, since a complex system**

Energy consumption: critical points

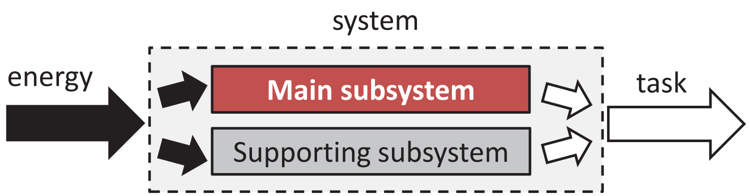


Fig. 2. A system and (sub)systems.

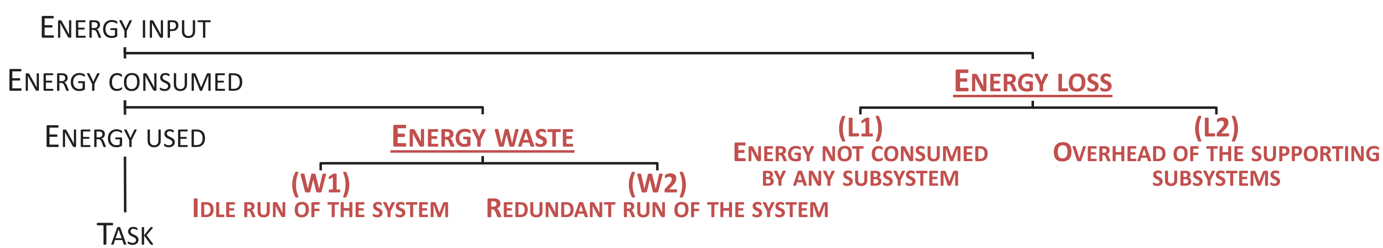


Fig. 3. Critical points within a system where energy is *lost* or *wasted*.

- Each subsystem can be optimized for itself
- To improve energy efficiency:
  - Identify problems that degrade efficiency
  - **Lost** (e.g., due to transport) and **wasted** (e.g., ide run, inefficient cooling) energy

Goals of EE

- —L1. **Minimizing a percentage of input energy** that is not consumed by a subsystem. This can be done by implementing more efficient components (e.g., using more efficient power supply units for servers that leak less energy).
- —L2. **Reduce the overhead of supporting systems** (i.e., systems that do not perform the main task of the system), for example, by implementing a single cooling unit for the entire cabinet instead of cooling each rack server separately.
- —W1. **Reduce idle run of the system** and increase utilization or achieve zero energy consumption when no output is produced (i.e., during idle time). This also implies achieving a proportional increase of energy consumption with system output (e.g., to provide twice as much bandwidth, a network router requires twice the amount of energy or less).
- —W2. **Minimize energy consumption where the system performs redundant operations**. This can be done by implementing smart functions and subsystems, such as implementing an optimized algorithm that does not require redundant steps to perform the same task.

Taxonomy for virtualized systems

- Cloud Computing infrastructure
  - **Hardware**
    - Network
      - (N-1) Data center network
      - (N-2) Inter-data center network
      - (N-3) End user network
    - Servers
      - (S-1) Enclosure
      - (S-2) Racks
      - (S-3) Components
  - **Software**
    - CMS
      - (C-1) Virtualization
      - (C-2) Monitoring system
      - (C-3) Scheduler
    - Appliances
      - (A-1) Application
      - (A-2) Runtime environment
      - (A-3) Operating system

Fig. 4. Cloud computing infrastructure domains and related systems.

Taxonomy for virtualized systems

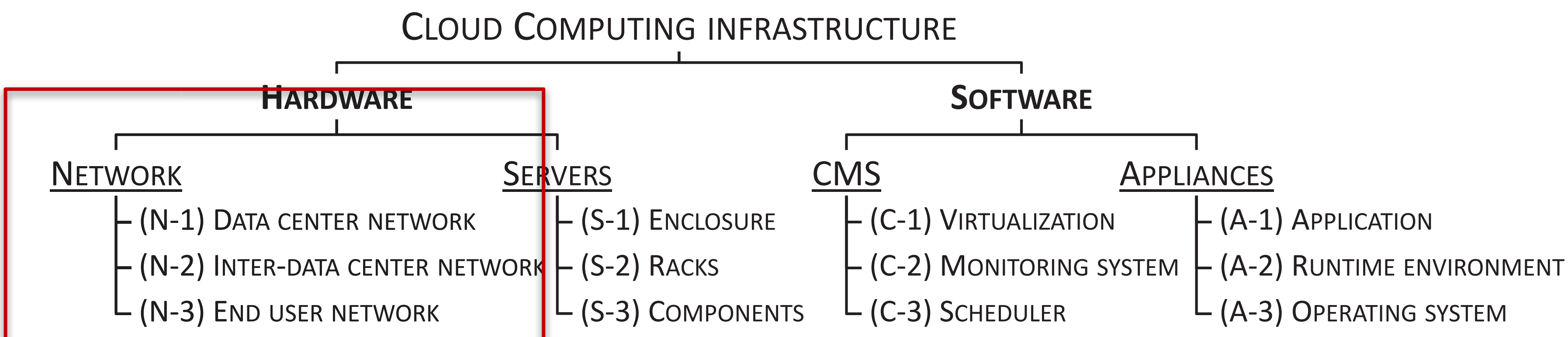
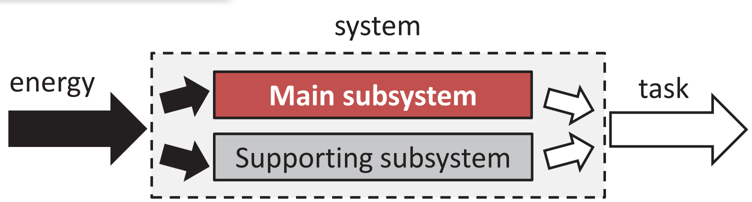


Fig. 4. Cloud computing infrastructure domains and related systems.



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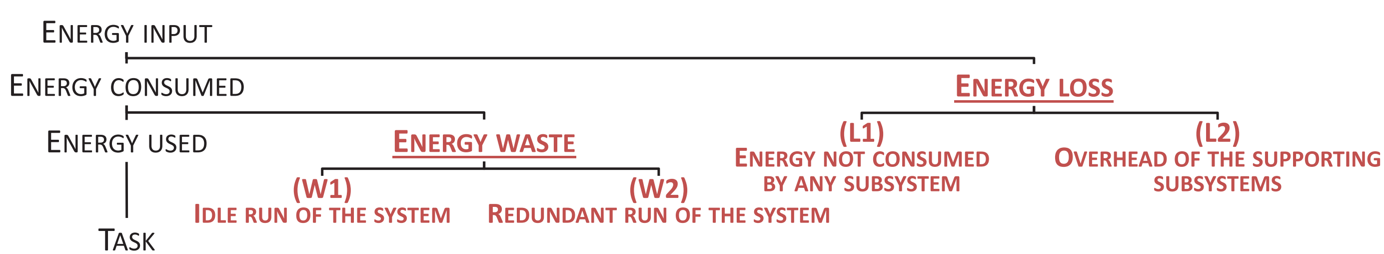


Fig. 3. Critical points within a system where energy is *lost* or *wasted*.

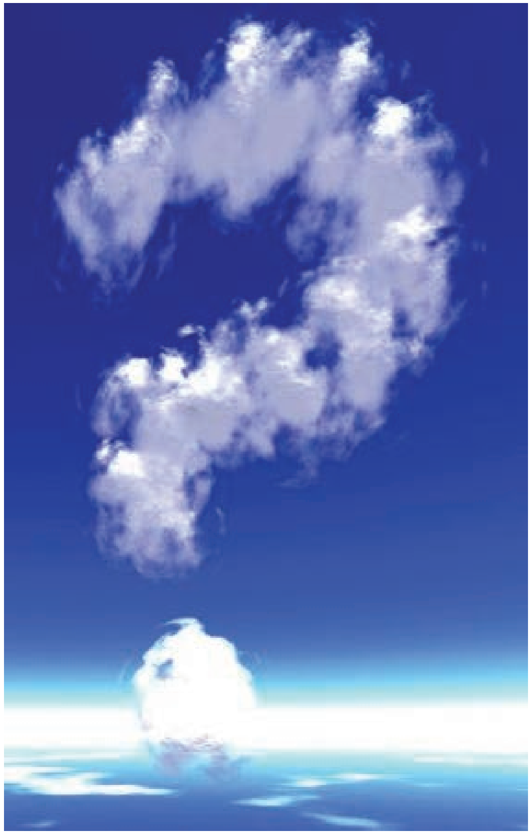
Data Center Network (N-1)

- **DCN Data center network (N-1):**
- accounts for up to **5% of its total energy consumption**
- **network power accounts for approximately 20%** of the total power when the servers are utilized at 100%. However, **it goes up to 50%** when utilization of servers decreases to 15%.
  - →This is due to the fact that many new cloud applications heavily rely on fast connectivity within a data center.
  - As a result, this leads to an increasing share in energy consumption for these networks.
- poor network architectures not suited for cloud applications can increase energy waste by unnecessarily rerouting traffic or keeping some parts of the network underutilized.
- not all energy is used for networking since communication equipment shows the highest heat load footprint accounting for lost energy not used by the system.
- → results in **additional stress** for the cooling system within a data center.

D2D Inter-data center network (N-2):

- **Connections between data centers are important** for applications that run on a global scale, where instances that serve individual users are located in the data center closest to the end user but still need to communicate between each other.
- **Migrations** of applications or data between data centers depending on the time of day, to minimize delay, energy consumption, or costs.
- **D2D communication** includes **background**, **noninteractive**, and **bulk data** transfers.

Questions & Contact information



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