Imperial College London

LSDS
Large-Scale Data & Systems Group

Cloud Computing & Data Centres

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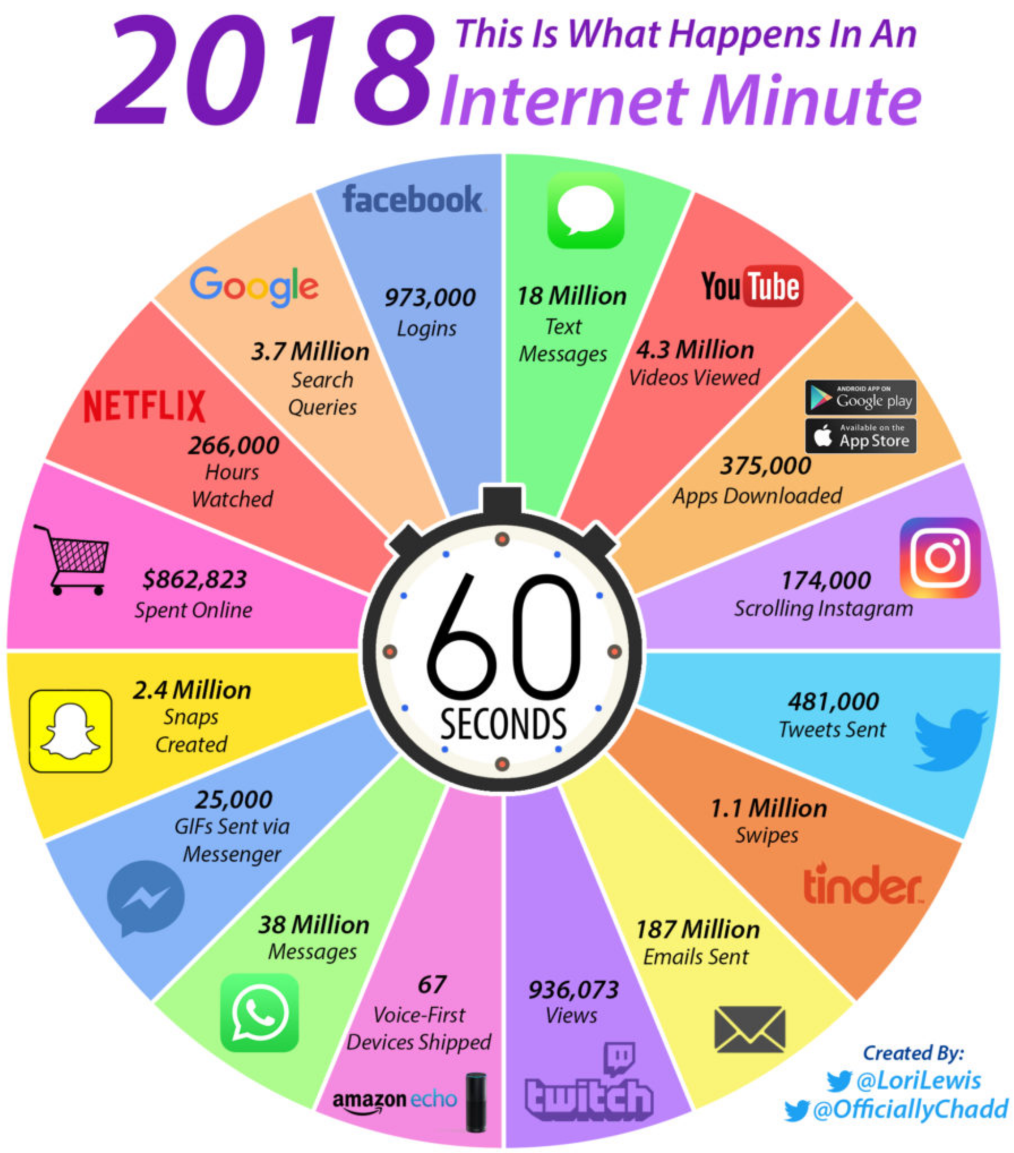
Cloud Computing

Big Data and the Need for Cloud



This is big data!

- Large **volume** of data
- Coming at a high **velocity**
- With a large **variety**
- What about **veracity**

Challenge for traditional IT systems, so now …

They are supported by moving computing to the cloud

What is a Cloud?

Data Centre hardware and software that the vendors use to offer the computing resources and services

It is a large pool of easily usable **virtualized** computing **resources**, development **platforms** and various services and **applications**

Source: image from Google data centre

What is Cloud Computing?

Cloud computing is the delivery of **computing as a service**

Where the **shared resources, software, and data** are provided to users by a provider

As a **metered service over a network**

Cloud Computing: Pros and Cons

User’s benefits:

- Speed – services provided on demand
- Global scale and elasticity
- Productivity
- Performance and Security
- Customizability

User’s concerns:

- Dependency on network and internet connectivity
- Security and Privacy
- Cost of migration
- Cost and risk of vendor lock-in

Types of Cloud Computing

Public cloud

- All hardware, software and other supporting infrastructure is owned and operated by cloud vendors (service providers)
- Cloud vendors offer their computing resources over the Internet
- Example: Amazon AWS, Microsoft Azure, Google Cloud Services

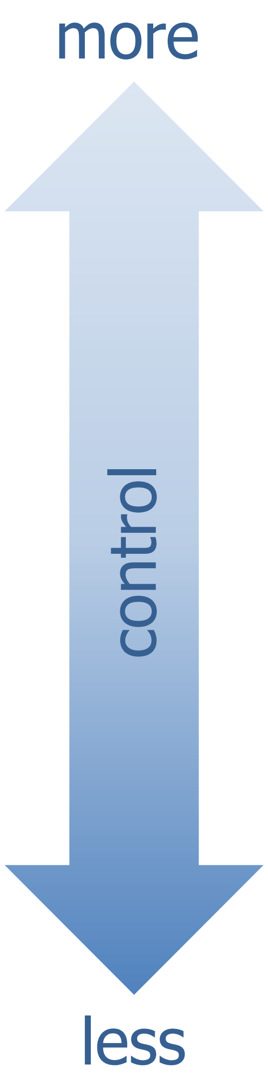
Private cloud

- Cloud computing infrastructure used exclusively by a single business or organization (e.g., physically hosted on the company’s on-site data centre)
- Services are infrastructure are maintained on a private network

Hybrid cloud

- Combines public and private clouds: allows data and applications to be shared between them
- Gives a business greater flexibility to optimize existing infrastructure, security and compliance

Cloud Service Models



Infrastructure-as-a-Service (IaaS)

- Rent IT infrastructure – servers and virtual machines (VMs), storage, networks, firewall and security

Platform-as-a-Service (PaaS)

- Get on-demand environment for development, testing and management of software applications – servers, storage, network, OS, databases, etc.

Function-as-a-Service (FaaS)

- Overlapping with PaaS, serverless focuses on building app functionality without managing the servers and infrastructure required to do so
- Cloud vendor provides set-up, capacity planning, and server management

Software-as-a-Service (SaaS)

- Deliver software applications over the Internet, on demand
- Cloud vendor handles software application and underlying infrastructure, and handles any maintenance (upgrades, patches, etc.)

Infrastructure-as-a-Service

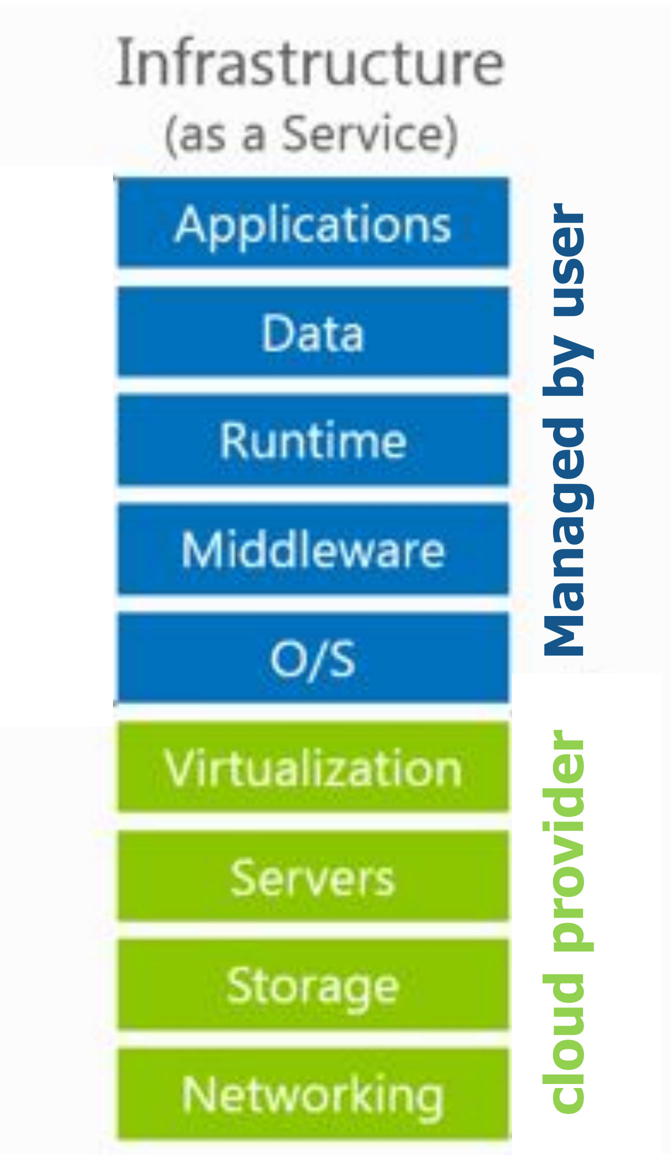
Immediately **available computing infrastructure**, provisioned and managed by a cloud provider

Computing **resources pooled** together to serve multiple users/tenants

Computing resources include: storage, processing, memory, network bandwidth, etc.

What can we use it for?

What are the advantages?



src image from Microsoft Azure

Platform-as-a-Service

Complete development and deployment environment

Includes system software (OS, middleware), platforms, DBMSs, BI services, and libraries to assist in development and deployment of cloud-based applications

Examples:

Windows Azure

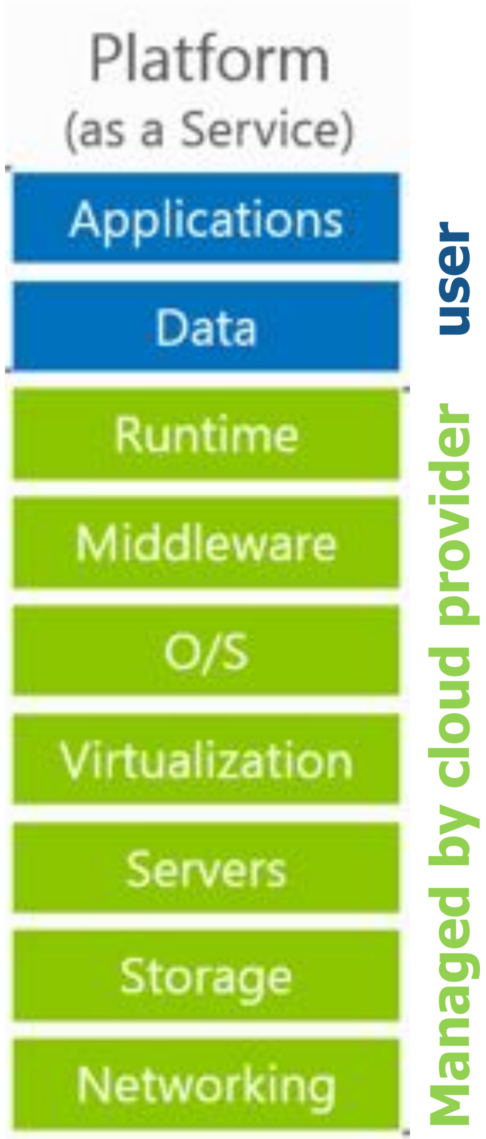
ORACLE CLOUD PLATFORM

Google app engine

amazon web services

What are the advantages?

What is serverless computing then?



src image from Microsoft Azure

Software-as-a-Service

Google Apps

Dropbox

Office 365

salesforce

slack

Data Centres

What is a Data Centre?

A data centre (DC) is a physical facility that enterprises use to house computing and storage infrastructure in a variety of networked formats

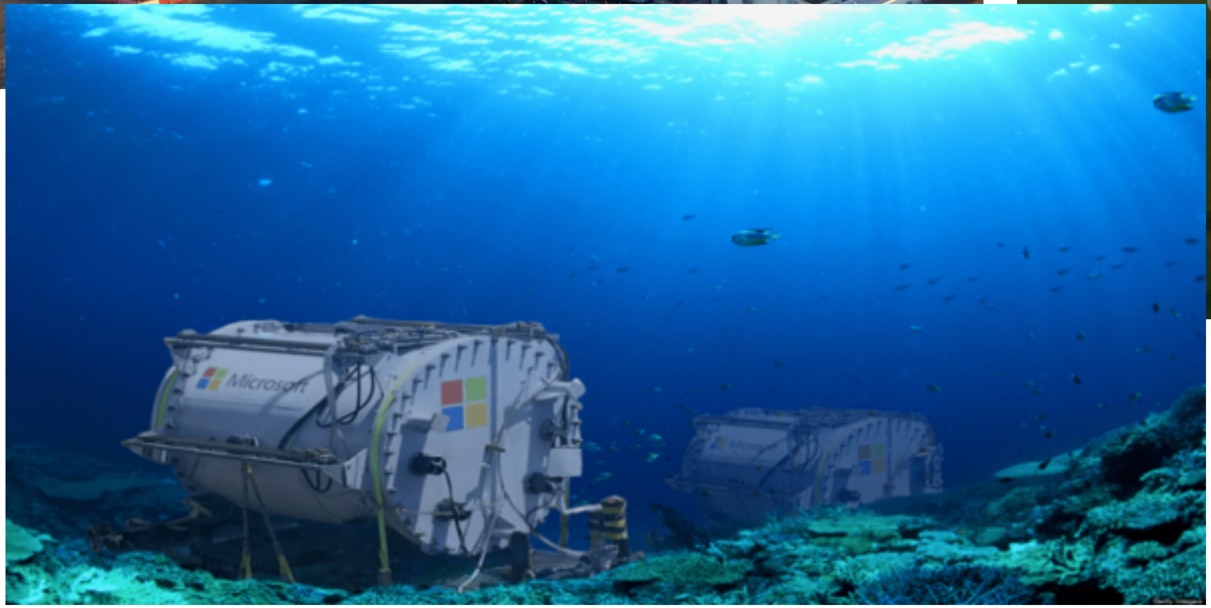
Main function is to deliver utilities needed by the equipment and personnel:

- Power
- Cooling
- Shelter
- Security

Size of datacenters:

- 500-5000 sqm buildings
- 1 MW to 10-20 MW power (on average around 5 MW)

Sample Data Centres



What Should You Optimise For?

Does the business require mirrored data centers?

How much geographic diversity is required?

What is the necessary time to recover in the case of an outage?

How much room is required for expansion?

Should you lease a private data centre or a public service?

What are the bandwidth and power requirements?

Is there a preferred carrier?

What kind of physical security is needed?

Data Centre Standards and Classification (ANSI-TIA-942)

Tier	Generators	UPSs	Power Feeds	HVAC	Availability
1	None	N	Single	N	99.671%
2	N	N+1	Single	N+1	99.741%
3	N+1	N+1	Dual, switchable	N+1	99.982%
4	2N	2N	Dual, simultaneous	2N	99.995%

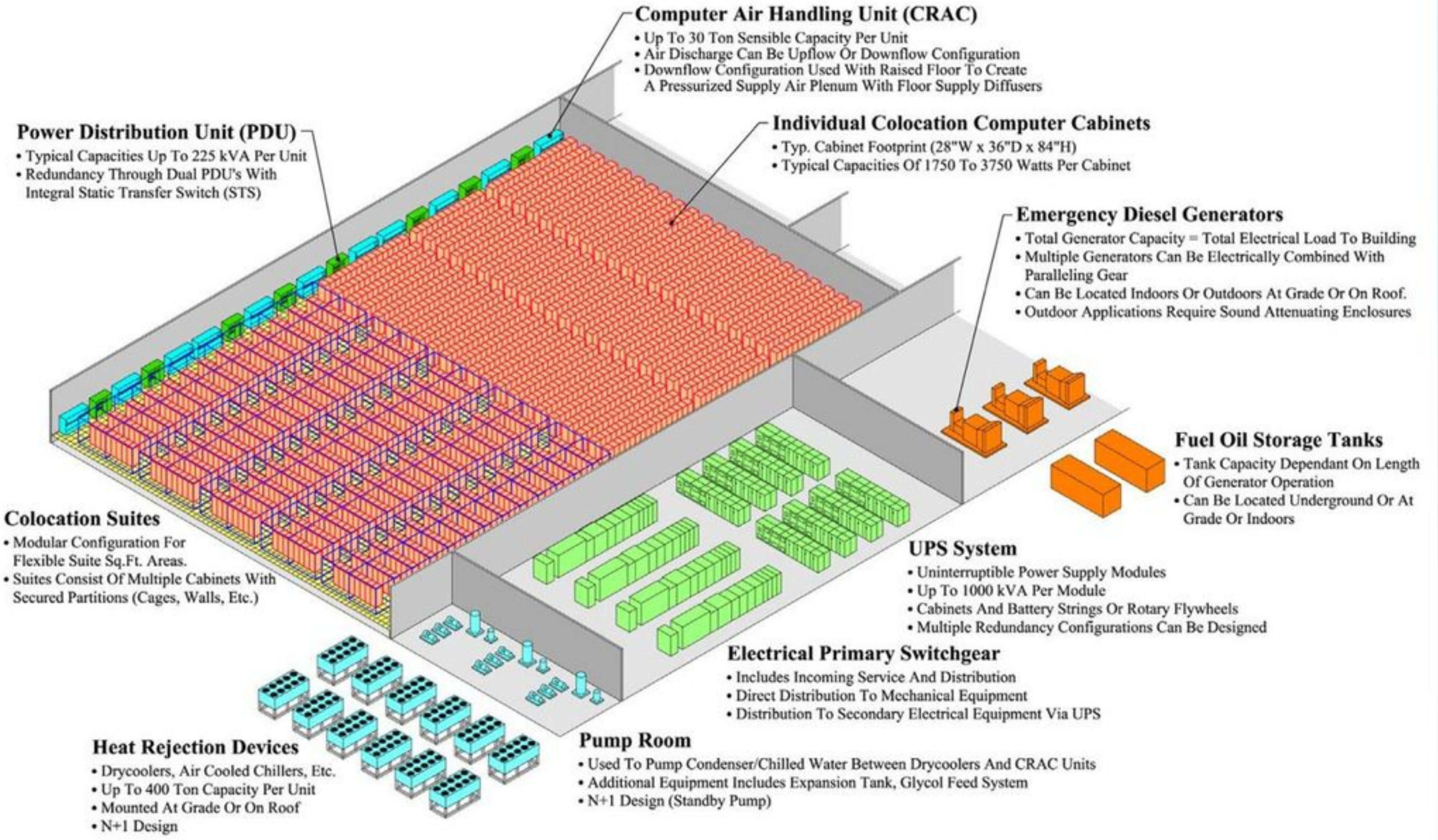
Rate-1: Basic Site Infrastructure

Rate-2: Redundant Capacity Component Site Infrastructure

Rate-3: Concurrently Maintainable Site Infrastructure

Rate-4: Fault-Tolerant Site Infrastructure

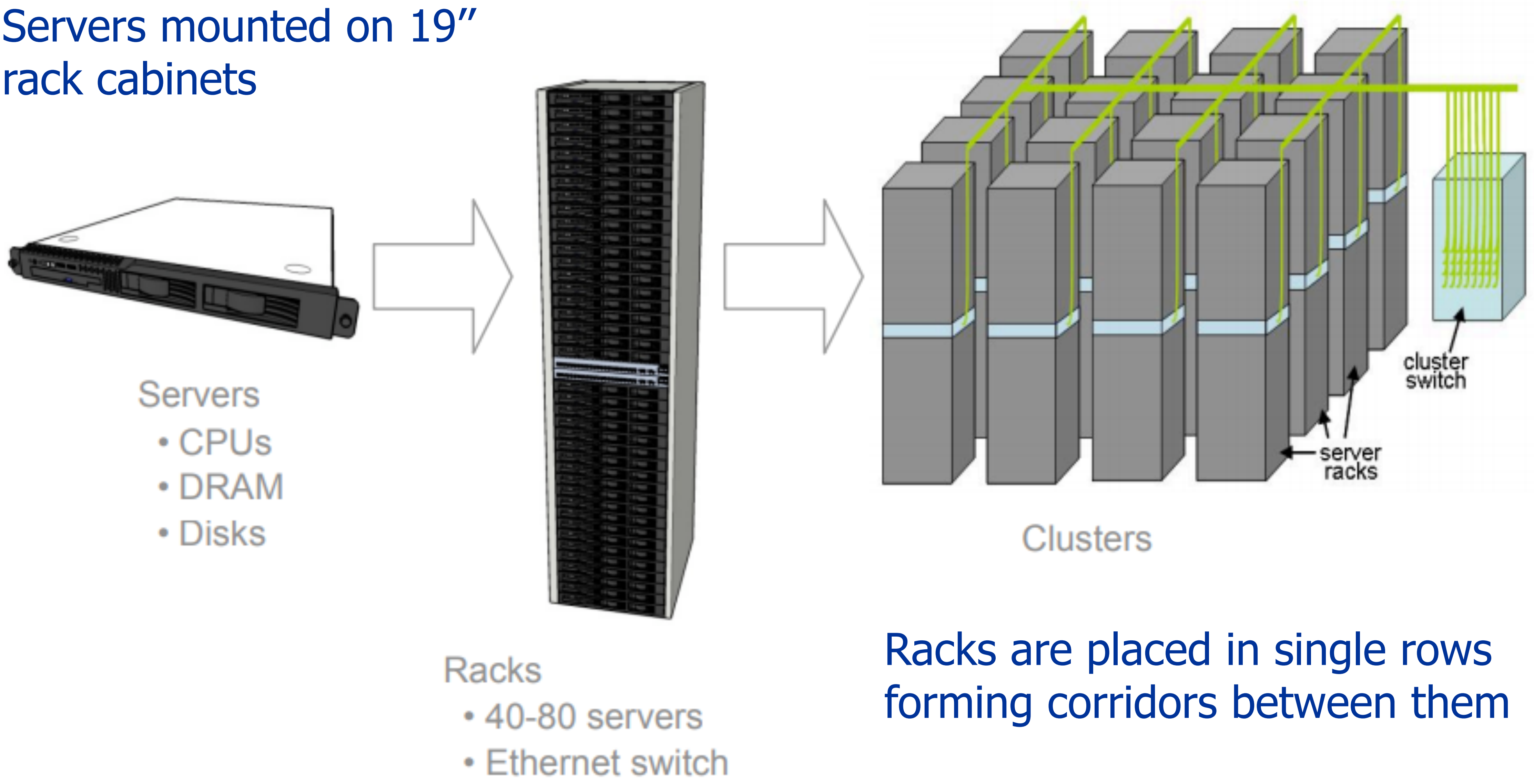
What are the Main Components of a Data Centre?



src: The Datacenter as a Computer – Barroso, Clidaras, Holzle

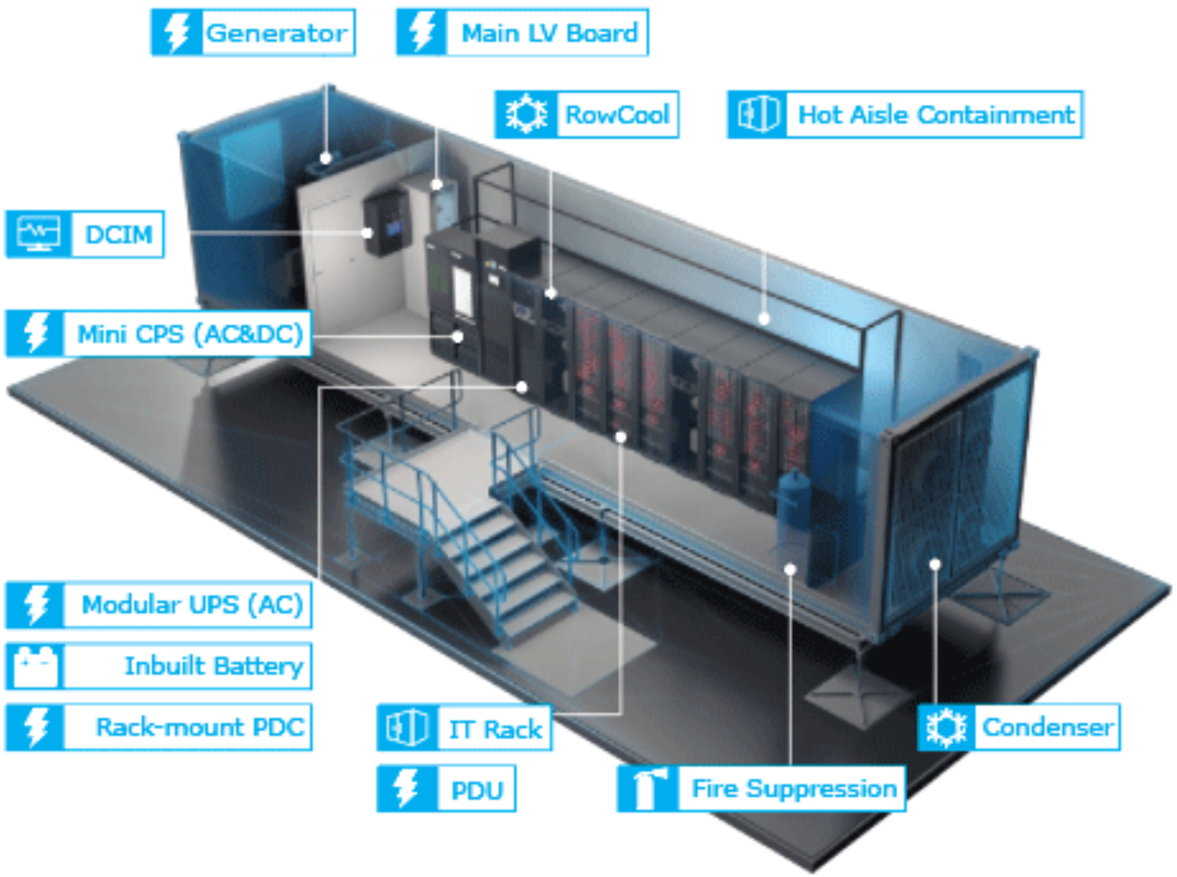
What’s inside a Data Centre?

Servers mounted on 19” rack cabinets



Racks are placed in single rows forming corridors between them

What's inside a Data Centre?



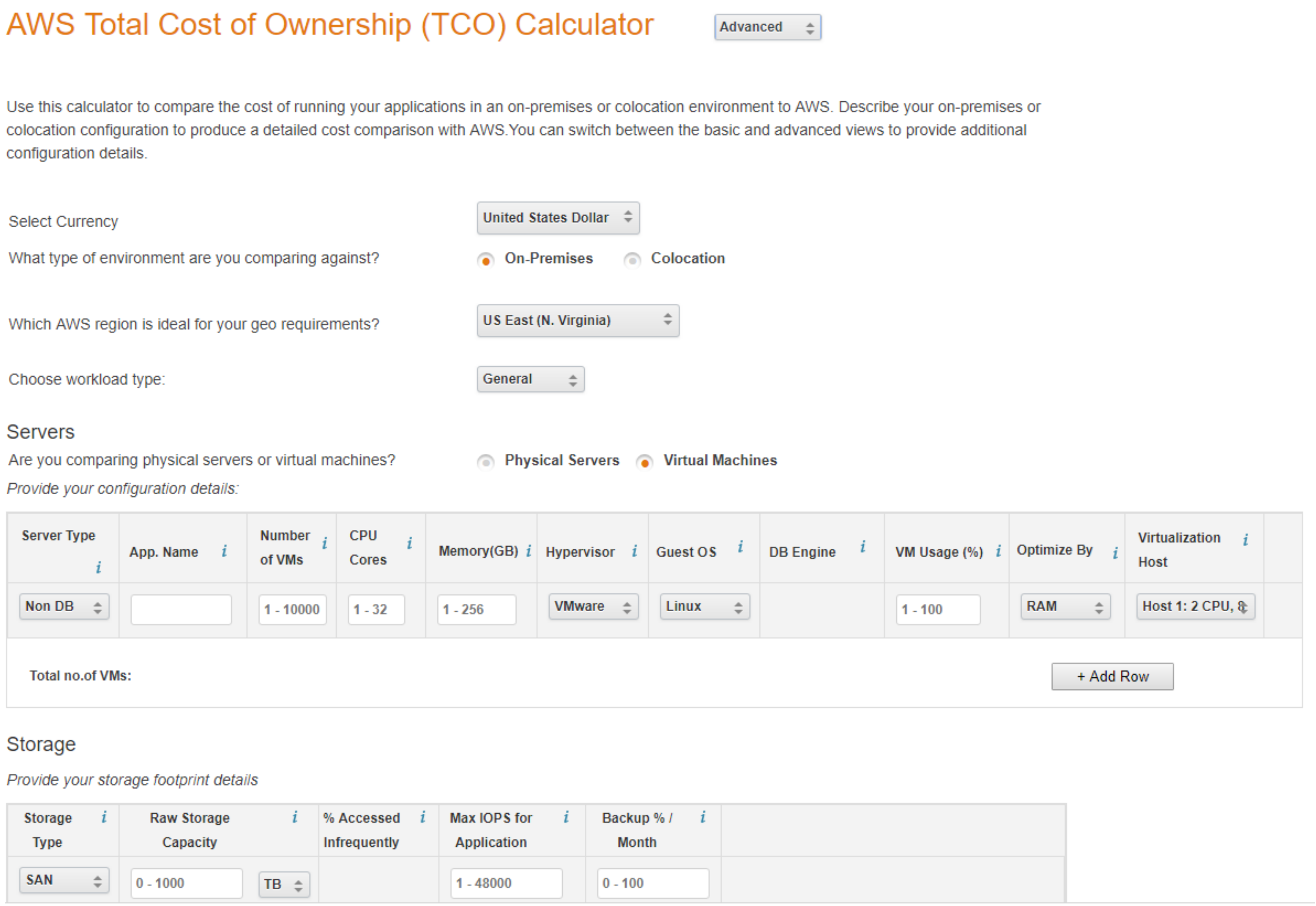
Today's DCs can use shipping containers packed with 1000s servers each

For repairs, whole containers are replaced

Costs for Running a Data Center

TCO = CapEx + OpEx

- CapEx – capital expenses, investments that must be made upfront
- OpEx – operational expenses, monthly costs of running the equipment: electricity, maintenance, etc.



Costs for Operating a Data Centre

DCs consume 3% of global electricity supply

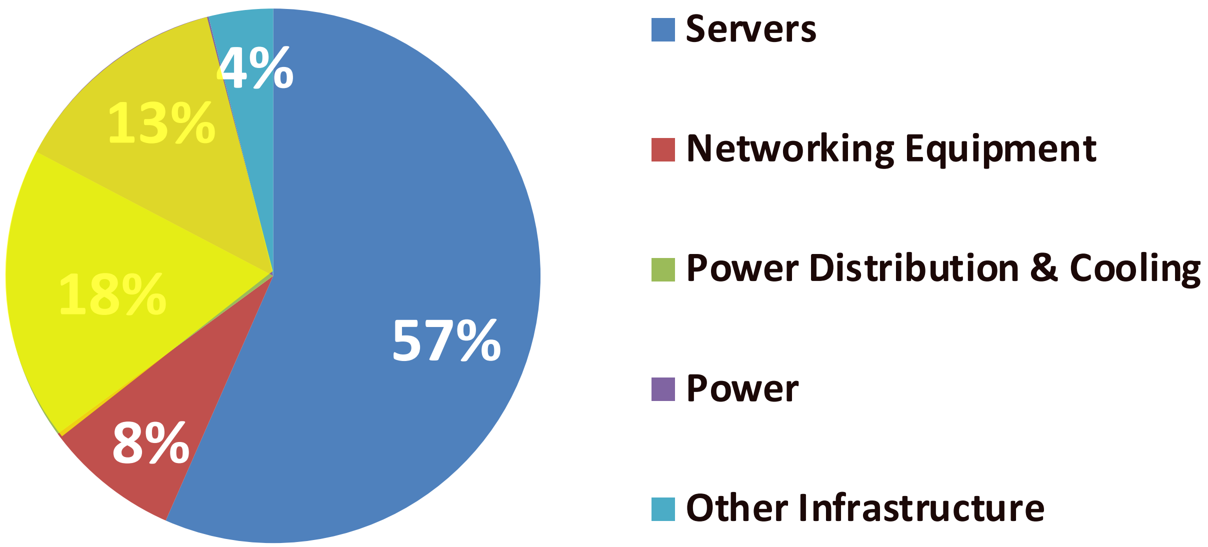
(416.2 TWh > UK's 300 TWh)

DCs produce 2% of total greenhouse gas emissions

DCs produce as much CO_2 as The Netherlands or Argentina

Monthly costs = $3,530,920

31 %
Power



45,978 servers, 3yr server & 10 yr infrastructure amortization

Power Usage Effectiveness (PUE)

PUE is the **ratio** of

- total amount of energy used by a DC facility
- to the energy delivered to the computing equipment

PUE is the inverse of data center infrastructure efficiency

Total facility power = covers IT systems (servers, network, storage) + other equipment (cooling, UPS, switch gear, generators, PDUs, batteries, lights, fans, etc.)

How can DC Operators Reduce Costs?

Location of the DC – cooling and power load factor

Raise temperature of aisles

- usually 18-20 C; Google at 27 C
- possibly up to 35 C (trade-off failures vs. cooling costs)

Price per Kilo Watt Hour	Where?	Possible Reason Why
3.6 cents	Idaho	Hydroelectric Power; Not Sent Long Distance
10.0 cents	California	Electricity Transmitted Long Distance over the Grid; Limited Transmission Lines in the Bay Area; No Coal Fired Electricity Allowed in California.
18.0 cents	Hawaii	Must Ship Fuel to Generate Electricity

Reduce conversion of energy

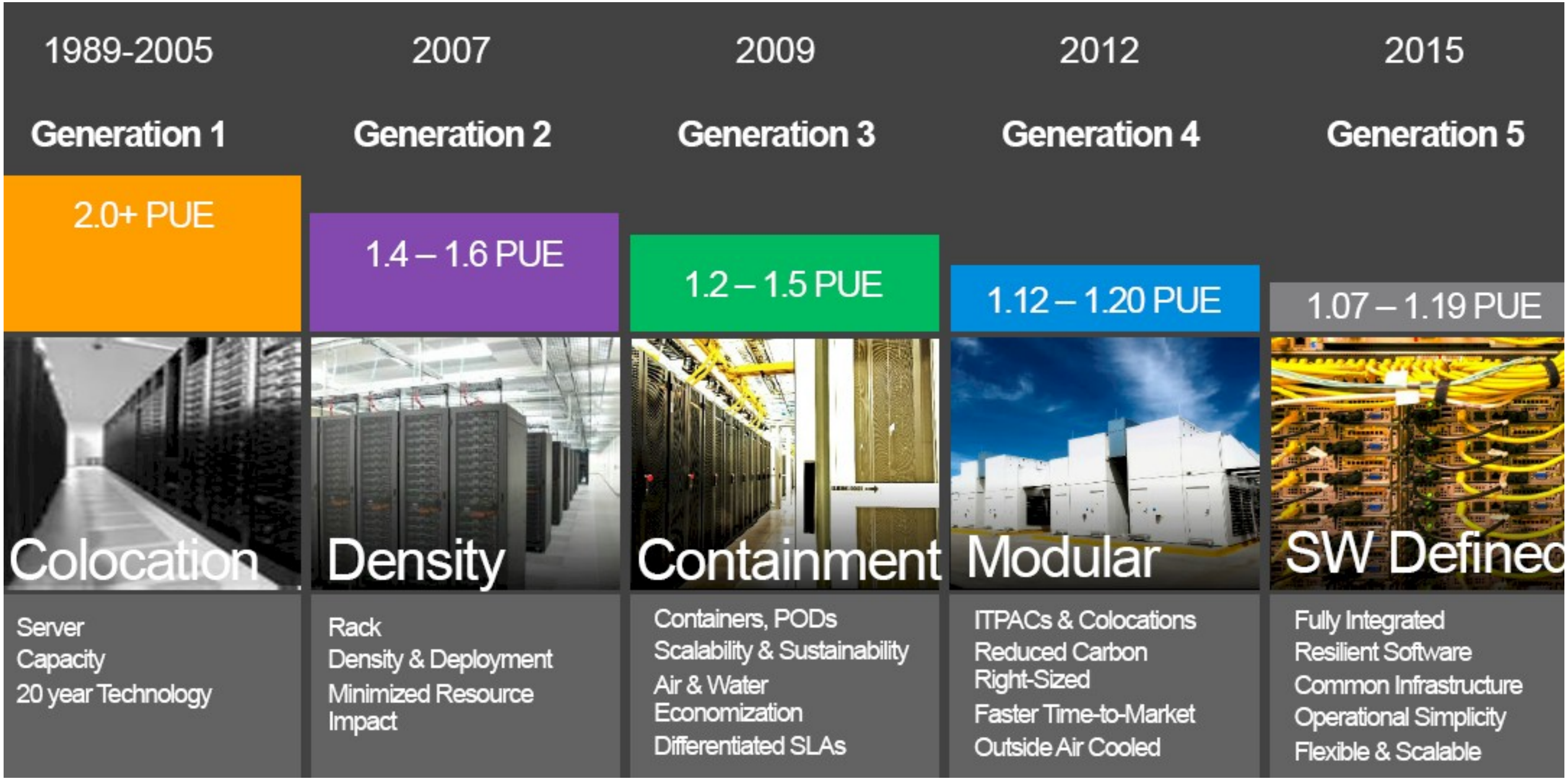
- eg Google motherboards work at 12V rather than 3.3/5V
- distributed UPS more efficient than centralised one

Go to extreme environments

- Arctic circle (Facebook)
- Floating boats (Google)
- Underwater DC (Microsoft)

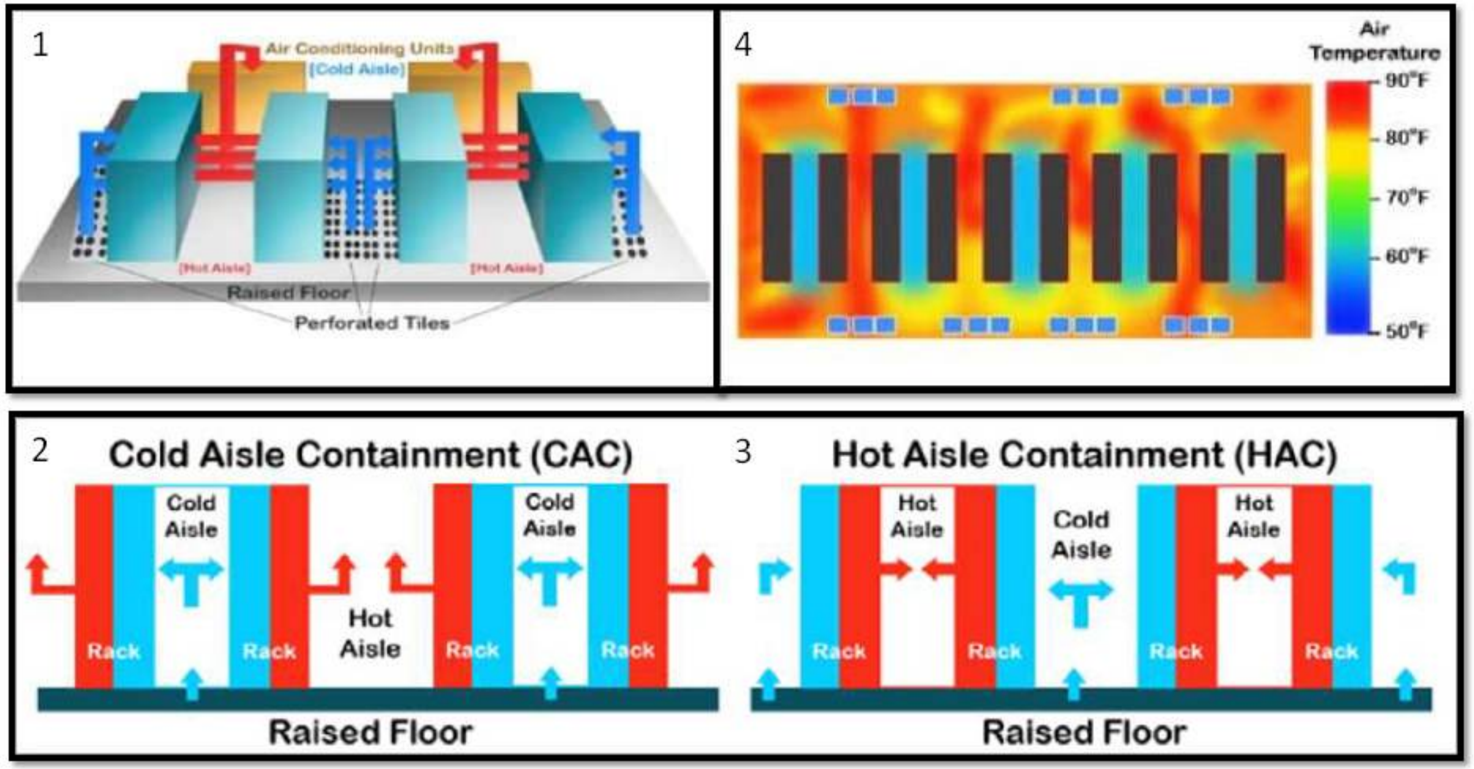
Reuse dissipated heat

Evolution of Data Centre Design (Case Study: Microsoft)



https://www.nextplatform.com/2016/09/26/rare-tour-microsofts-hyperscale-datacenters/

Challenge: Cooling Data Centres



1- Conventional cooling
2- Cold Aisle Containment (CAC)
3- Hot Aisle Containment (HAC)
4- Thermal modelling

Cooling plant at a Google DC in Oregon

Challenge: Energy Proportional Computing

Average real-world DC and servers are too inefficient

- Average DC wastes 2/3 or more of its energy

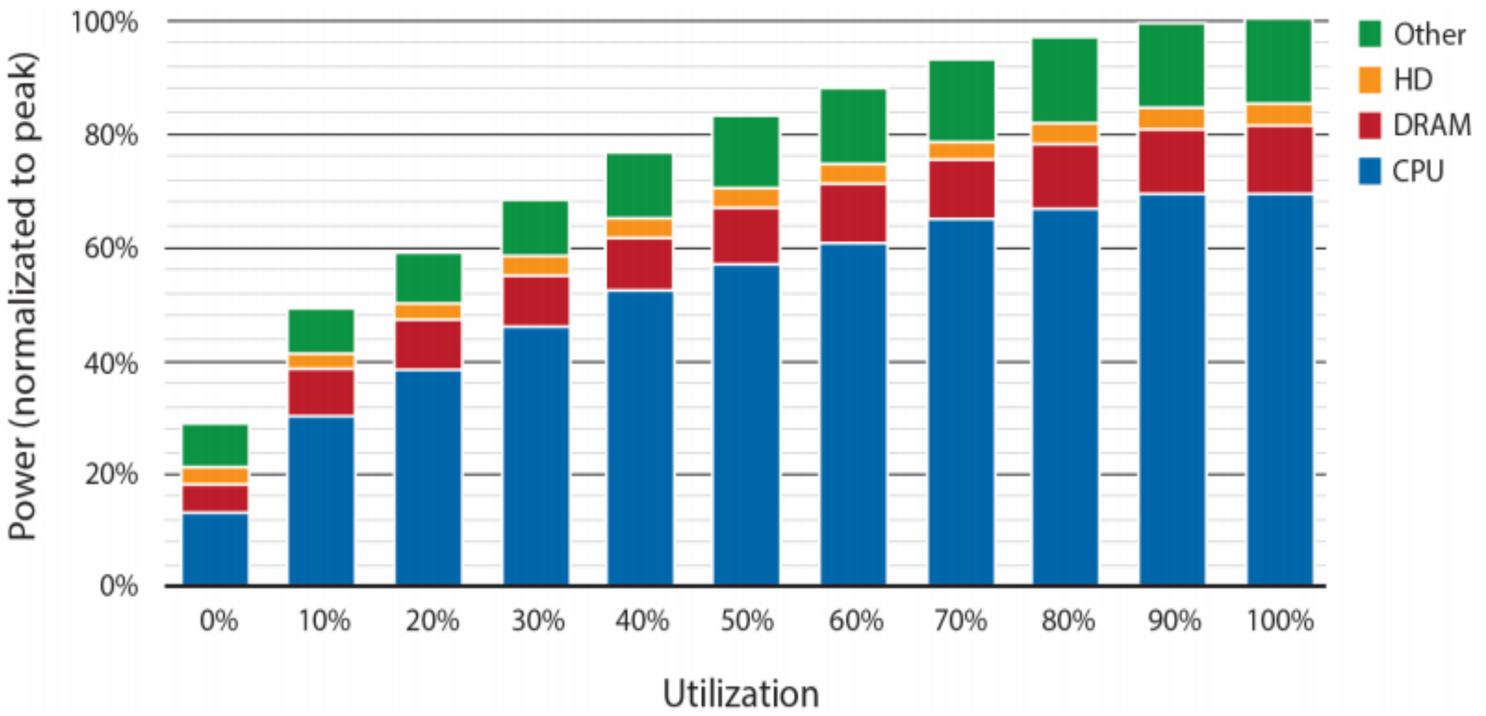
Energy consumption not proportional to load

- CPUs not so bad but other components are
- CPU is the dominant energy consumer in servers – using 2/3 of energy when active/idle

Try to optimise workloads

Virtualisation to consolidate service on fewer servers

Subsystem power usage in an x86 server as the compute load varies from idle to full (reported in 2012)



src: "The Datacenter as a Warehouse Computer"

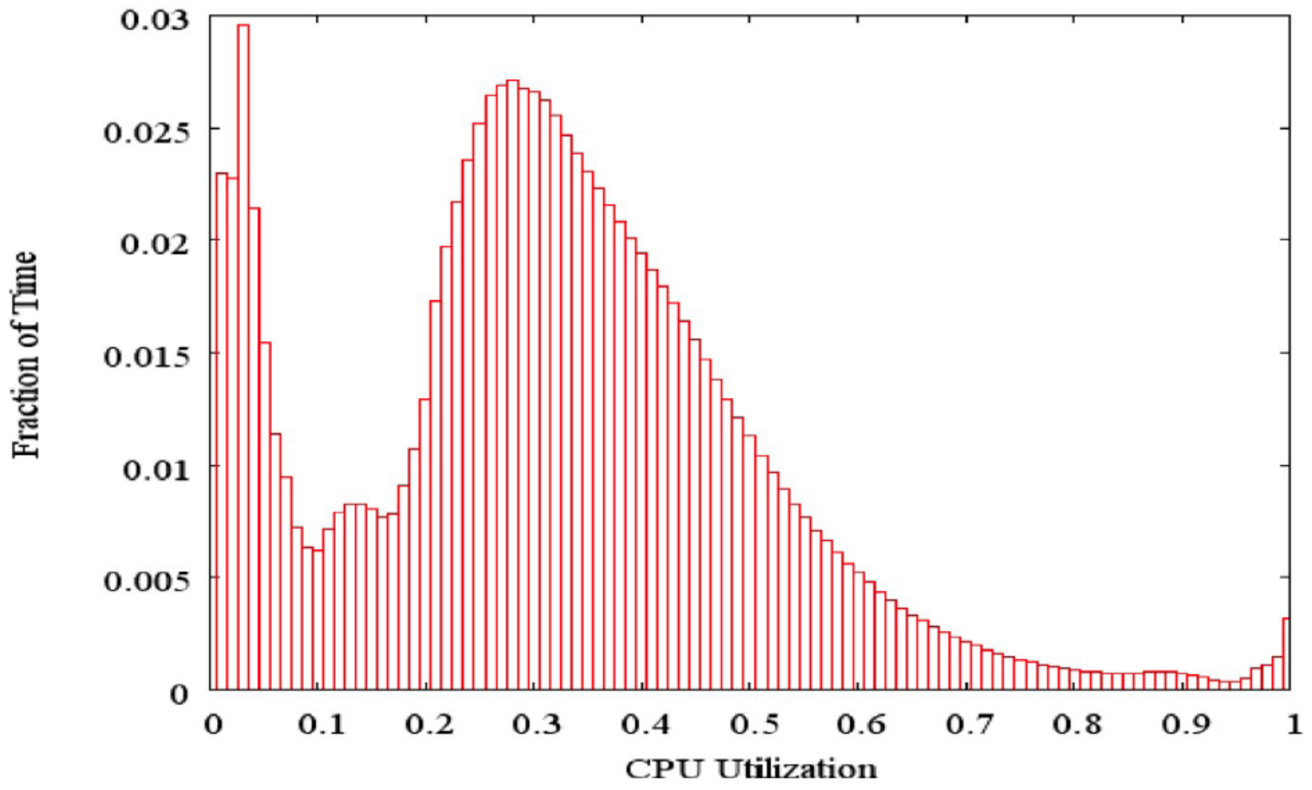
Challenge: Managing a Data Centre and its Resources

Servers idle most of the time

- For non-virtualized servers 6%-15% utilisation
- Virtualization can increase it to an average utilisation ~30%

Need for resource pooling and application and server consolidation

Need for resource virtualization



src: Luiz Barroso, Urs Hölzle "The Datacenter as a Computer"

Improving Resource Utilisation

Hyperscale system management software

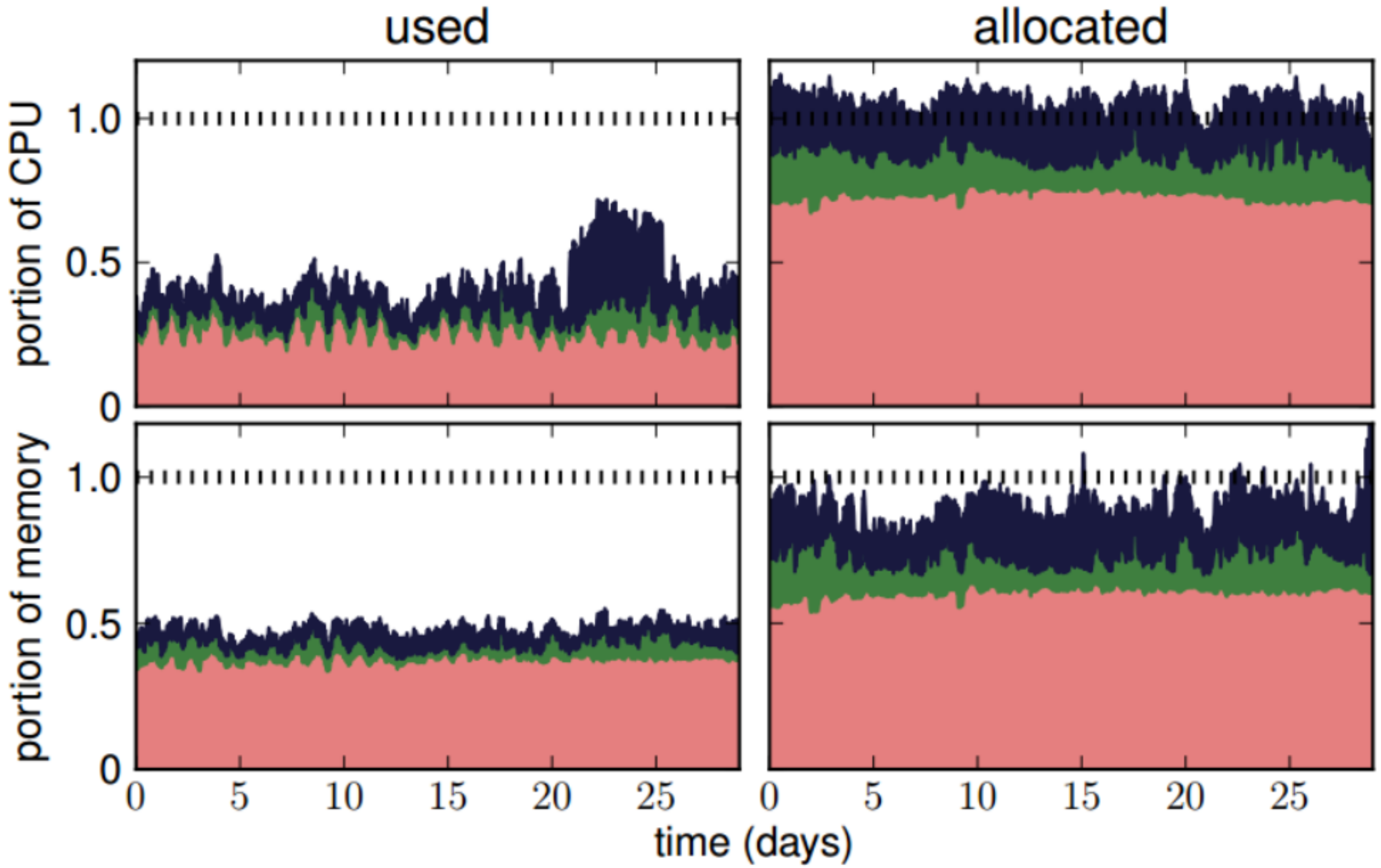
- Cloud companies treat the data centre as a warehouse-scale computer
- Software-defined data centres
- System management software that allows DC operators to manage the entire DC infrastructure
- Enables the ability to compose a system using pooled resources that include compute, network, and storage based on workload requirements

Dynamic resource allocation

- In traditional DC, resources are static, with dedicated CPU resources determined per workload
- No aligned for workloads whose requirements change over time
- Virtualization is not enough to improve efficiency
- Need the ability to dynamically allocate CPU resources across servers and racks, allowing admins to quickly migrate resources to address the shifting demand
- Drive 100-300% better utilisation for virtualized workloads, and 200-600% for bare-metal workloads

https://cloudblog.ericsson.com/digital-services/3-ways-to-boost-datacenter-utilization

Challenge: Managing a Data Centre and its Resources



src: “Heterogeneity and dynamicity of clouds at scale: Google trace analysis” SoCC’12

Even with virtualization and software-defined DC, resource utilization can be poor

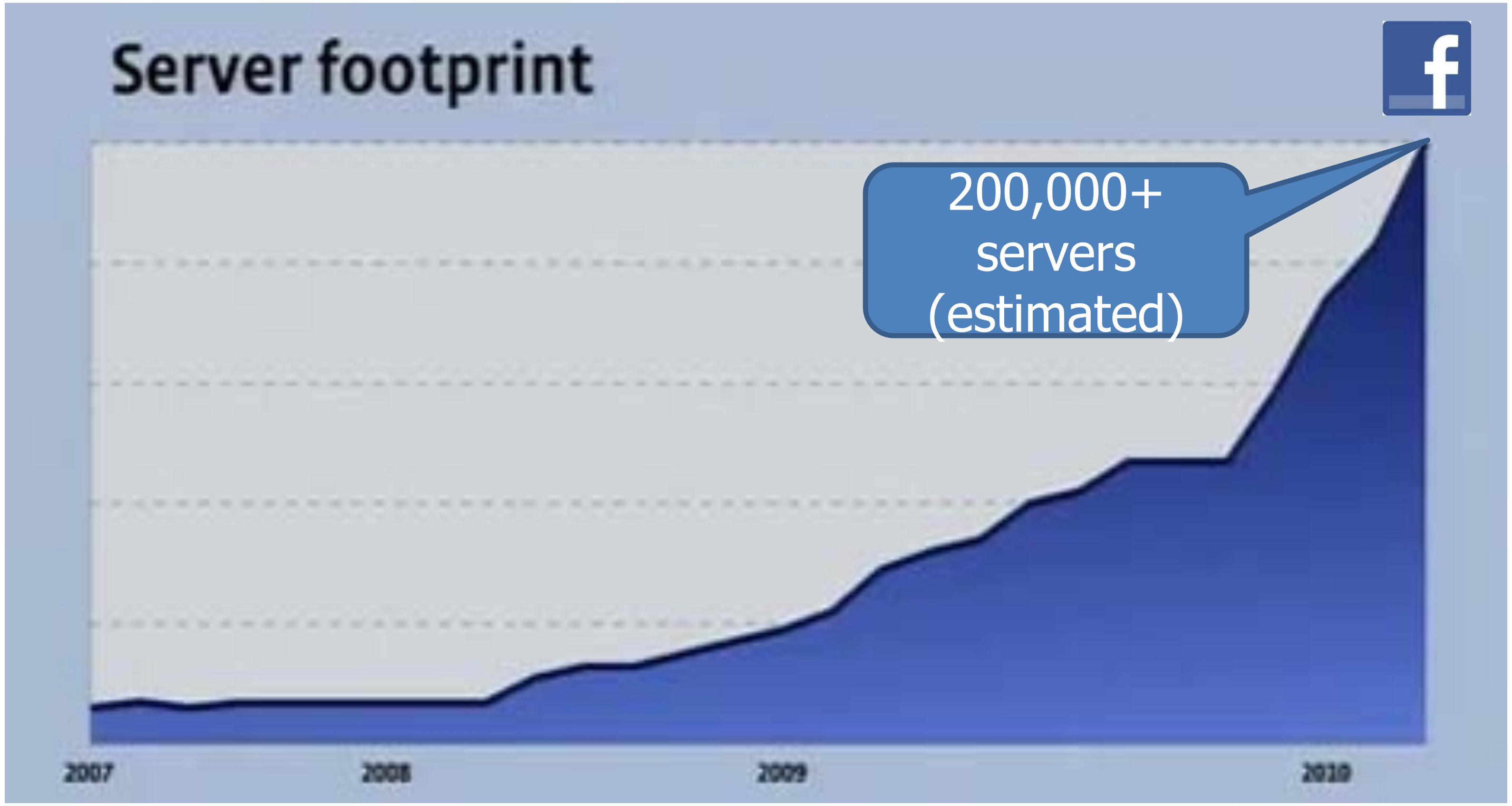
Need for efficient monitoring (measurement) and cluster management

Goal to meet service level objectives (SLOs)
Job’s tail latency matters!

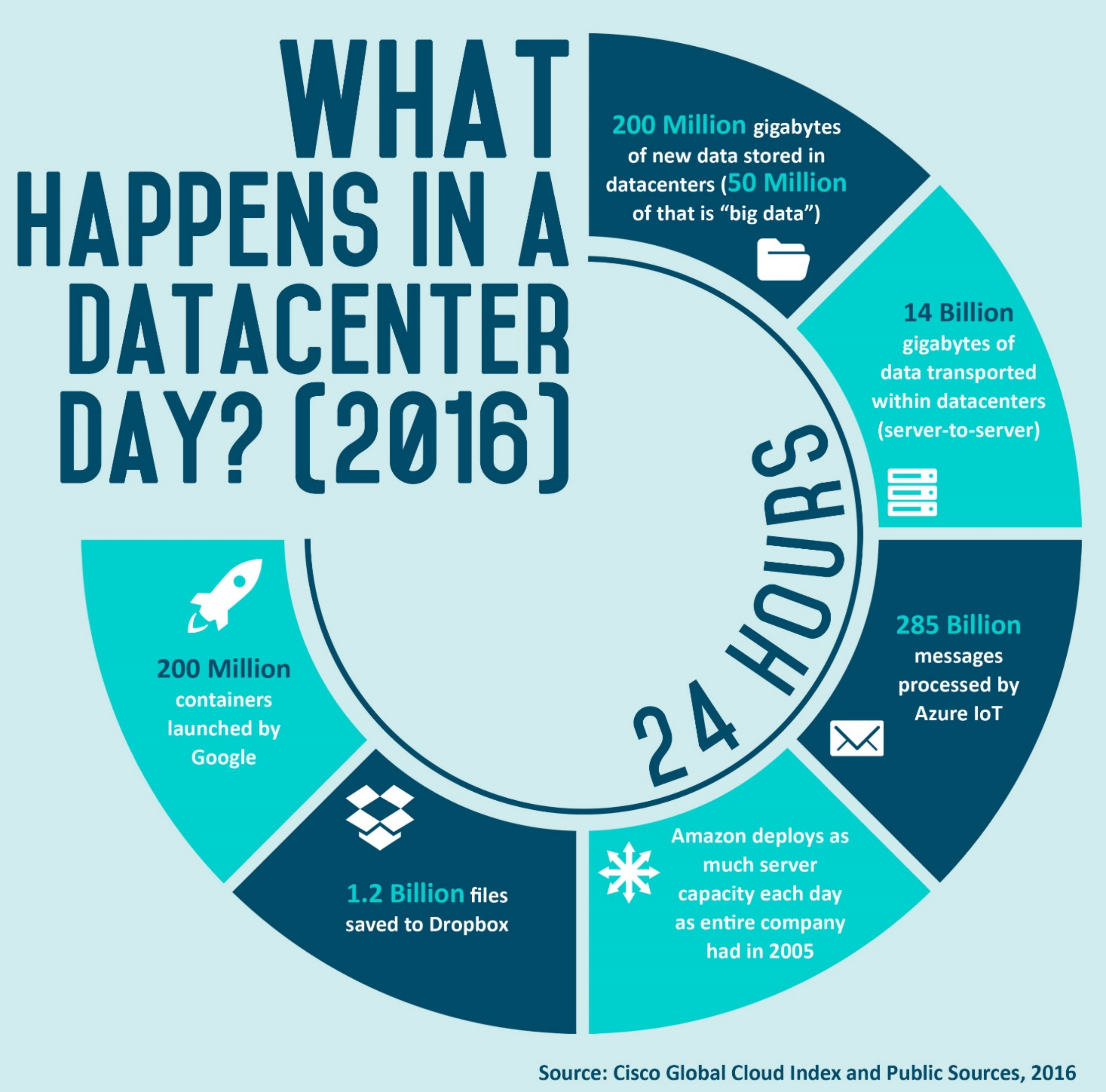
Challenge: Managing Scale and Growth

In 2016, Gartner estimated that Google has 2.5 million servers

In 2017, Microsoft Azure was reported to have more than 3 million servers



Size and Growth of Data Centres (2016 – 2020)

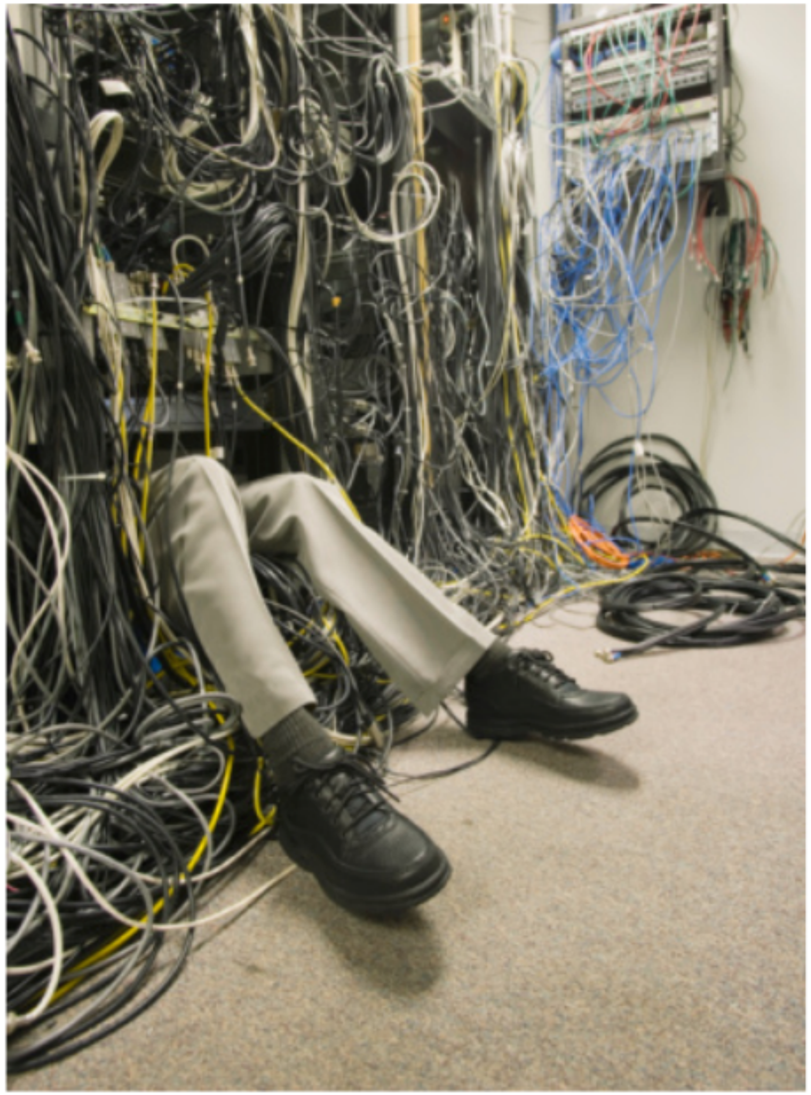


The scale and complexity of DC operations grows constantly

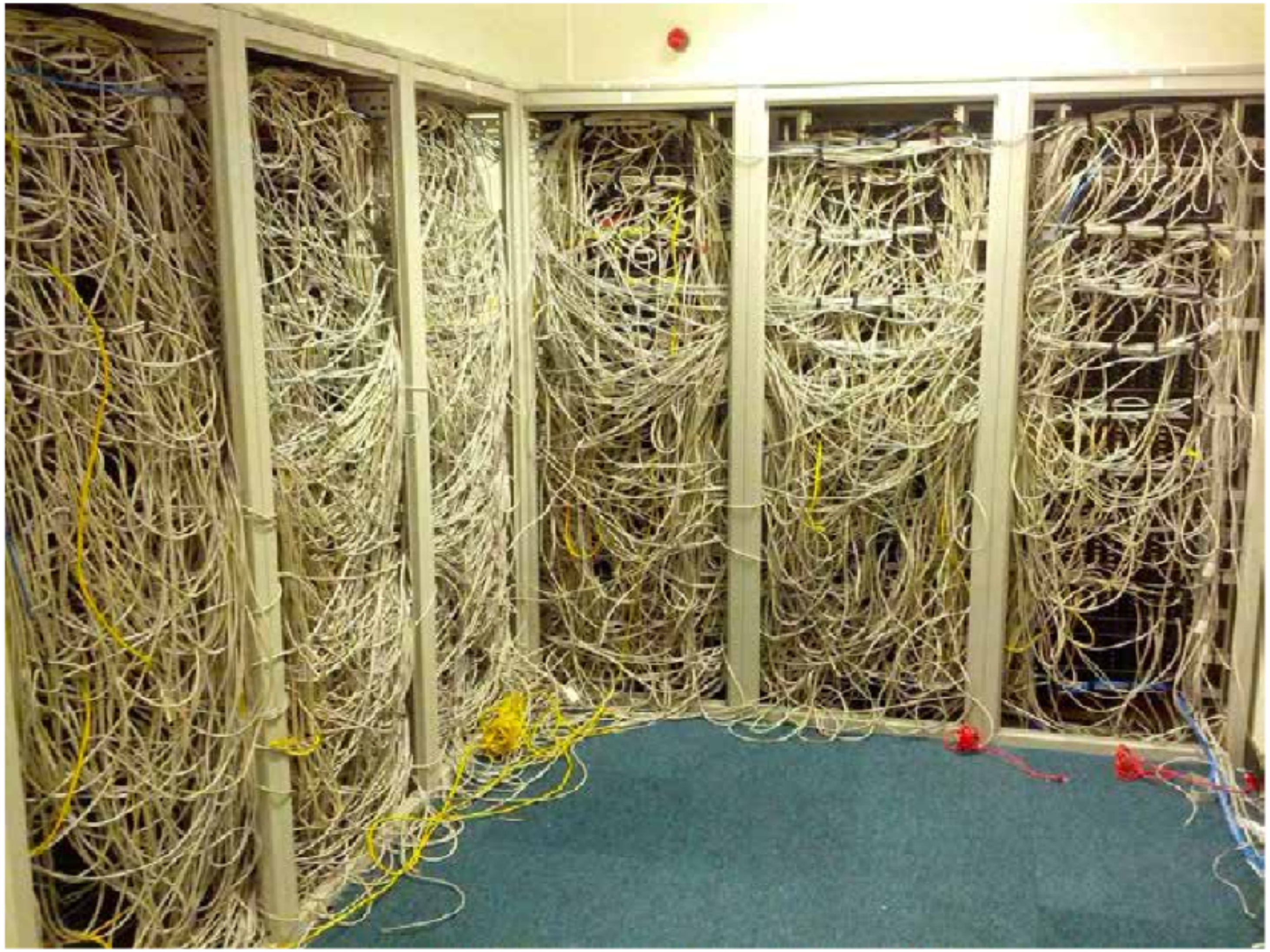
By 2020, we expect to have 600 million GB of new data saved each day (200m GB big data)

→ The volume of big data by 2020 will be as much as all of the stored data today!

Challenge: Networking at Scale



[David Samuel Robbins, gettyimages.ch]



[@AlexCWheeler, Twitter]

Challenge: Networking at Scale

Building the right abstractions to work for a range of workloads at hyperscale

Software Defined Networking (SDN)

Within DC, 32 billion GBs will be transported by 2020

src: Cisco report 2016-2026

Google's "machine-to-machine" traffic is several orders of magnitude larger than what goes out to the Internet

src: "Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google's Datacenter Network" (ACM SIGCOMM'15)

Rack-Scale Computing

What is a rack?

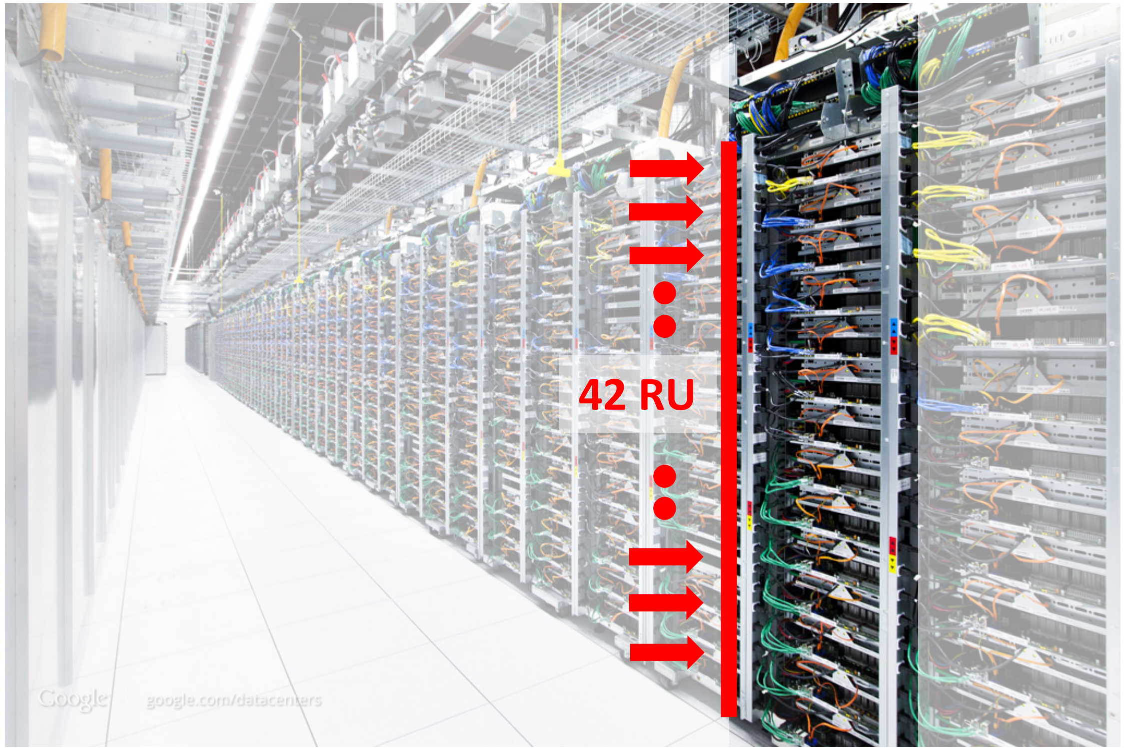
- How does it fit within a data-centre?
- What does it consists of? Which resources?
- How do we build it?
- Example rack-computers

Rack-Scale

- What is a rack?

Rack-Scale

- What is a rack?
  - The rack is the new unit of deployment in data centres
  - Sweet spot between a single-server and cluster deployments
  - It has 42 units (rack-units – RU) that host the compute resources



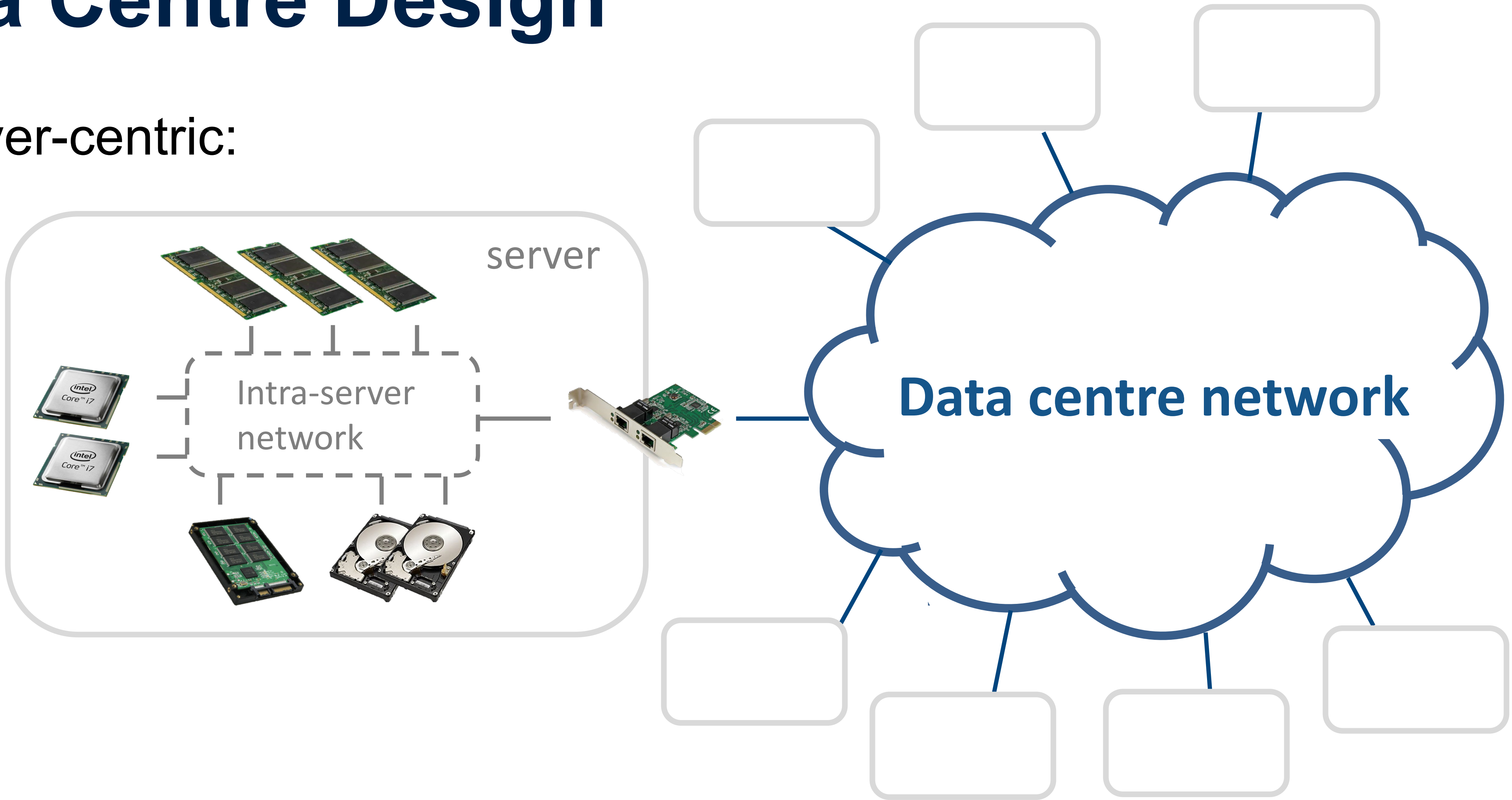
What's in a Rack-Scale computer?

- Rack-scale computer (pre-packaged)
- Compute:
  - standard compute
  - accelerators
- Storage:
  - hot / warm / cold disks
- Networking:
  - interconnect
  - software defined networking

Image source: Supermicro RSD

From Server-centric to Resource-centric Data Centre Design

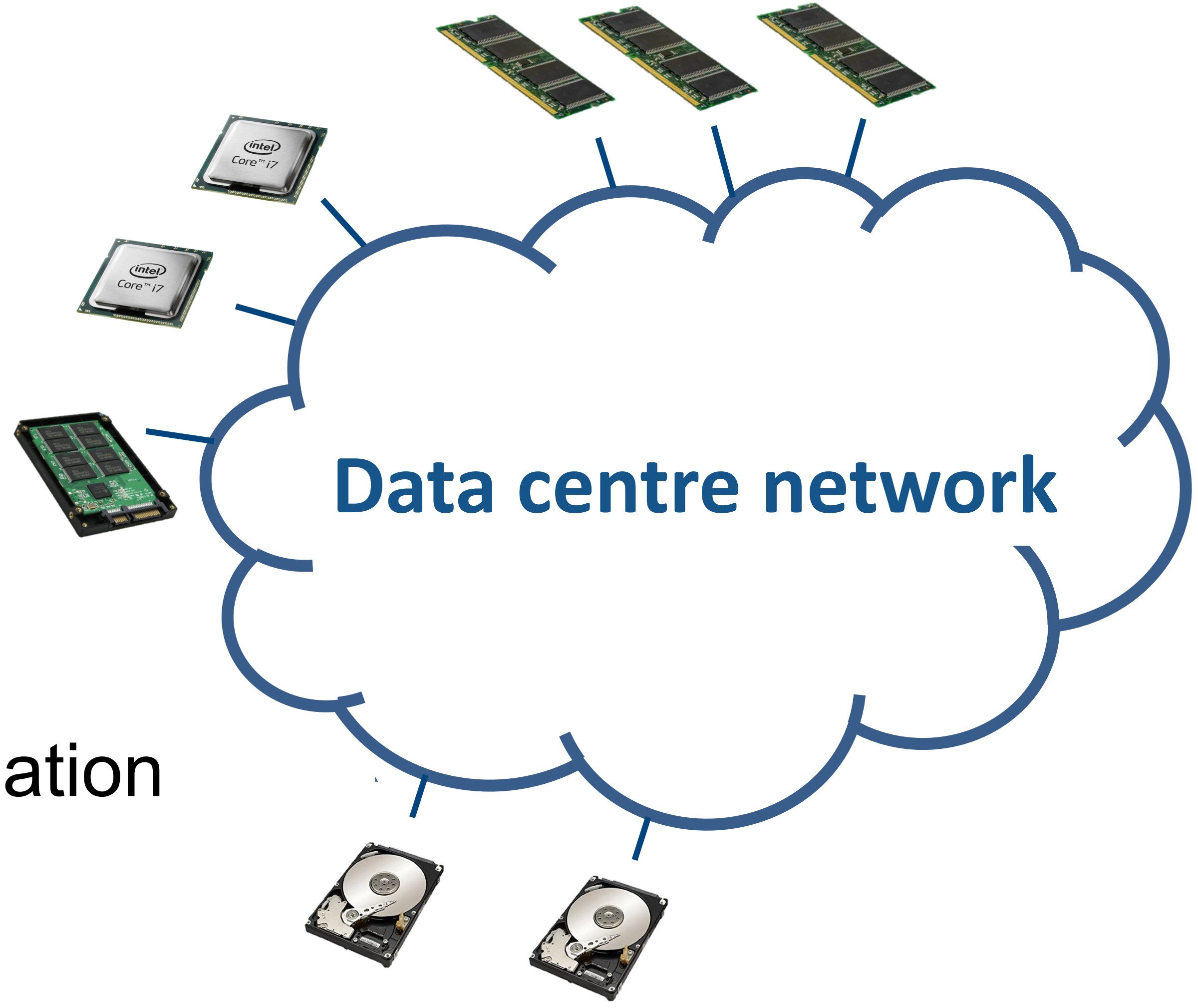
- Server-centric:



From Server-centric to Resource-centric Data Centre Design

- Towards resource-centric

- **Past:** physical aggregation
  - shared power, cooling, rack-management
- **Now:** fabric integration
  - fast **rack**-wide **interconnect**
- **Future goal:** resource disaggregation
  - pooled compute, storage, memory resources



Today's Scale within a Rack Computer

- We already have scale within a rack itself

Machine	Core count
AMD SeaMicro *SM15000-64*	2'048
HP Moonshot *Redstone*	11'520
Boston Viridis	7'680

Machine	Memory
AMD SeaMicro *SM15000-XE*	8 TB
HP Moonshot *Redstone*	11.25 TB

Machine	Network
EDR Mellanox	100 Gbps
Intel silicon photonics	100-400 Gbps

- And increasing heterogeneity of resources

AMD Rack P47 – 1 PetaFLOP of compute at FP32 single precision

CPU	GPU	Memory	Network
20x AMD EPYC 7601	80x Radeon Instinct	10 TB DDR4	2x36 port EDR switch (100 Gbps)

Future: Heterogeneous Computing Resources across the Rack

- Accelerators
- Co-processors

- Intelligent storage
- Intelligent (active) memory
- Smart NICs
- In-network data processing