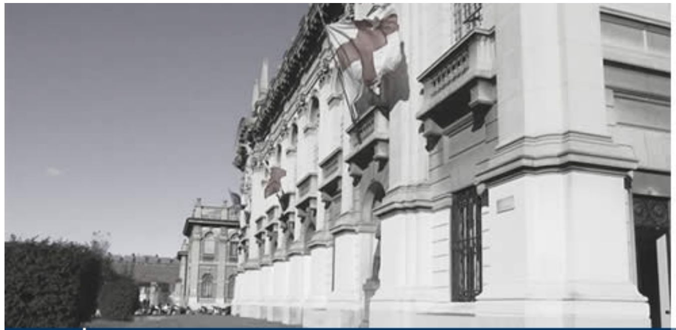


POLITECNICO DI MILANO

# Computing Infrastructures

# The Datacenter as a Computer

# The topics of the course: what are we going to see today?

## HW Infrastructures:

**System-level:** Computing Infrastructures and **Data Center Architectures, Rack/Structure;**

**Node-level:** Server (computation, HW accelerators), Storage (Type, technology), Networking (architecture and technology);

**Building-level:** Cooling systems, power supply, failure recovery

## SW Infrastructures:

**Virtualization:** Process/System VM, Virtualization Mechanisms (Hypervisor, Para/Full virtualization)

**Computing Architectures:** Cloud Computing (types, characteristics), Edge/Fog Computing, X-as-a service

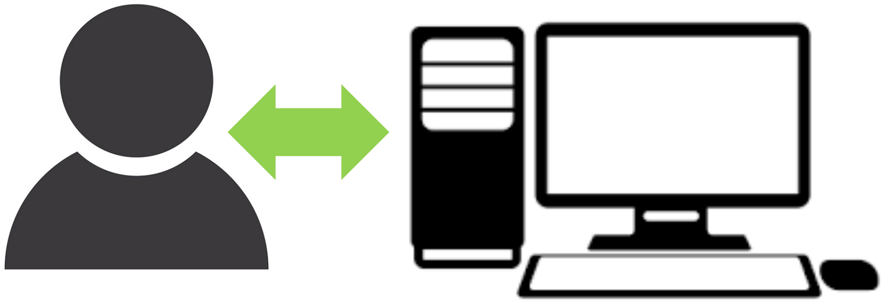
## Methods:

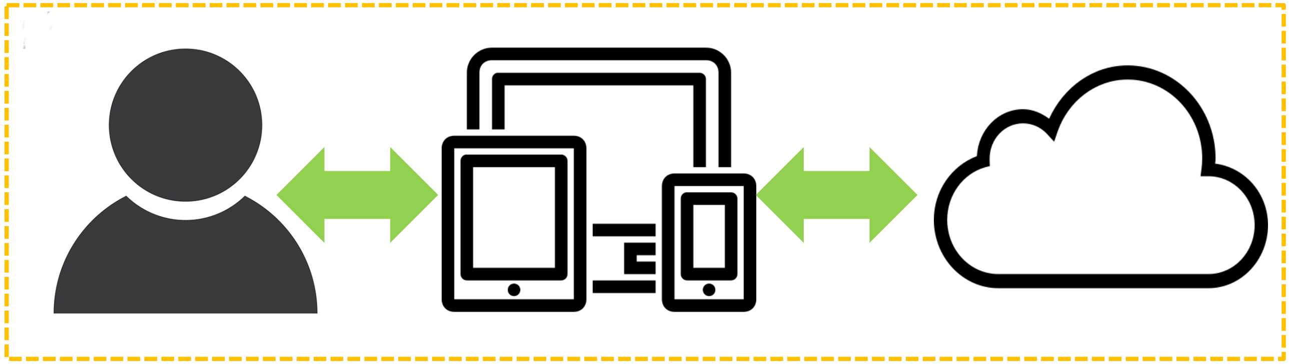
**Reliability and availability of datacenters** (definition, fundamental laws, RBDs)

**Disk performance** (Type, Performance, RAID)

**Scalability and performance of datacenters** (definitions, fundamental laws, queuing network theory)

- In the last few decades, computing and storage have moved from PC-like clients to smaller, often mobile, devices, combined with large internet services.

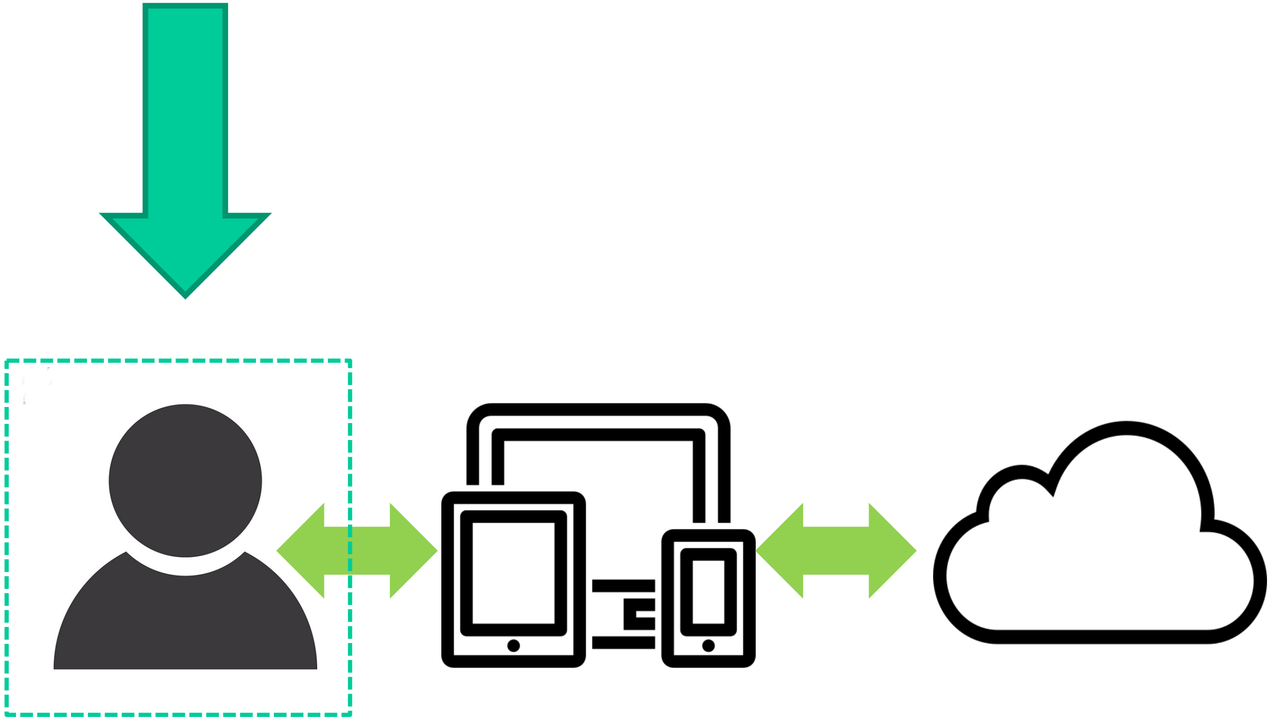




- Traditional enterprises are also shifting to Cloud computing.

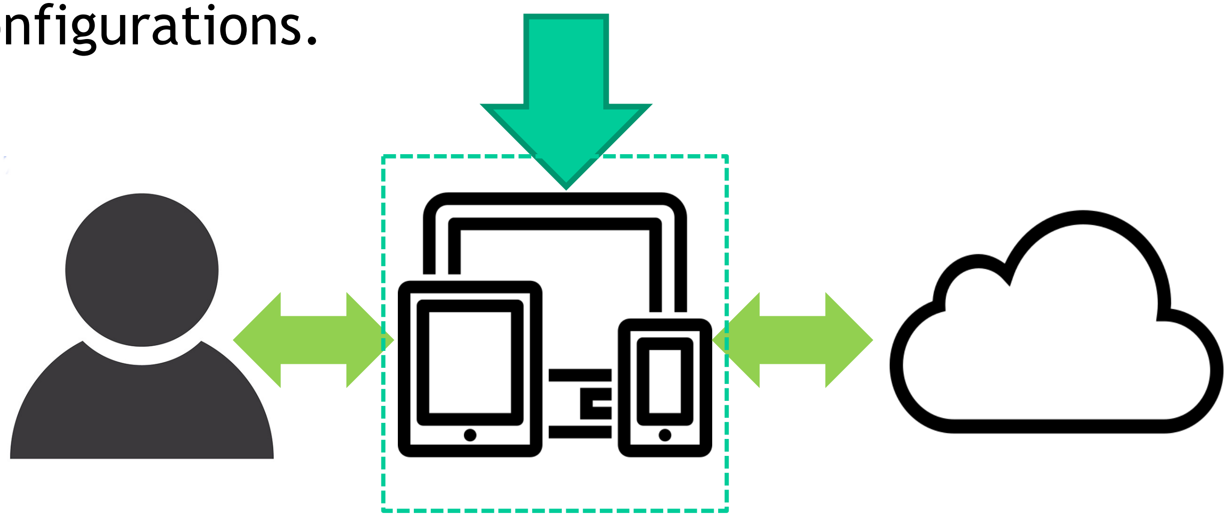
# The need(s) of this shift

- **User experience improvements:**
  - Ease of management (no configuration or backups needed)
  - Ubiquity of access, but I need connectivity



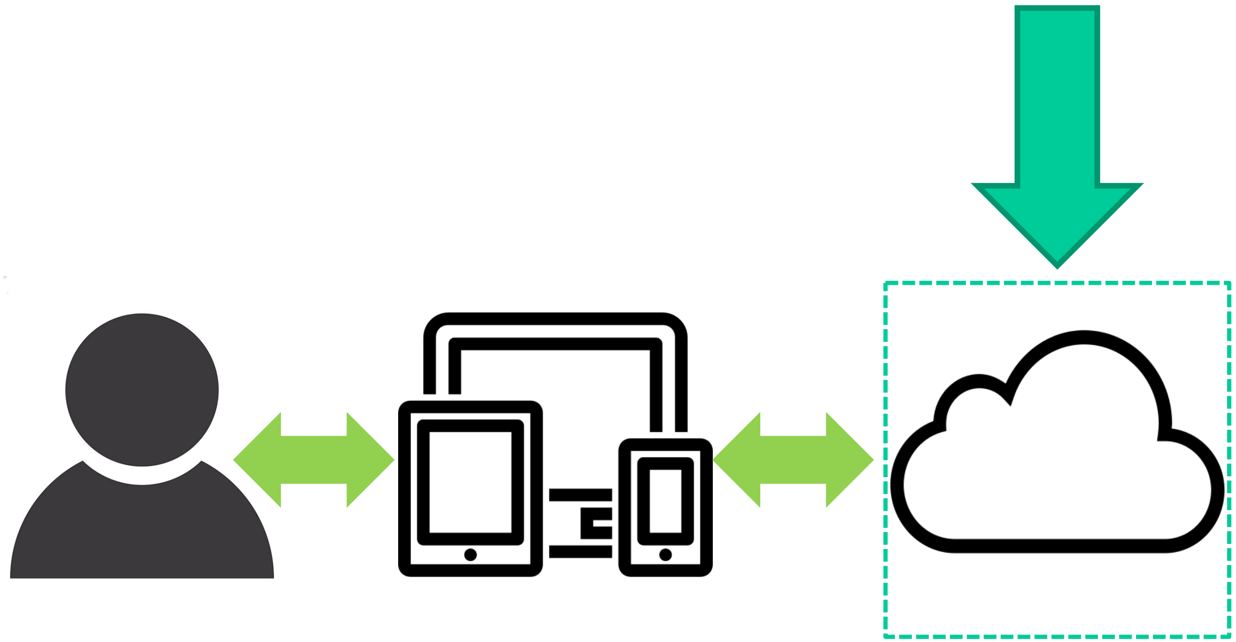
## The need(s) of this shift

- **Advantages  to vendors:**
  - Software-as-a-service allows faster application development (easier to make changes and improvements)
  - Improvements and fixes in the software are easier inside their data centers (instead of updating many millions of clients with peculiar hardware and software configurations)
  - The hardware deployment is restricted to a few well-tested configurations.



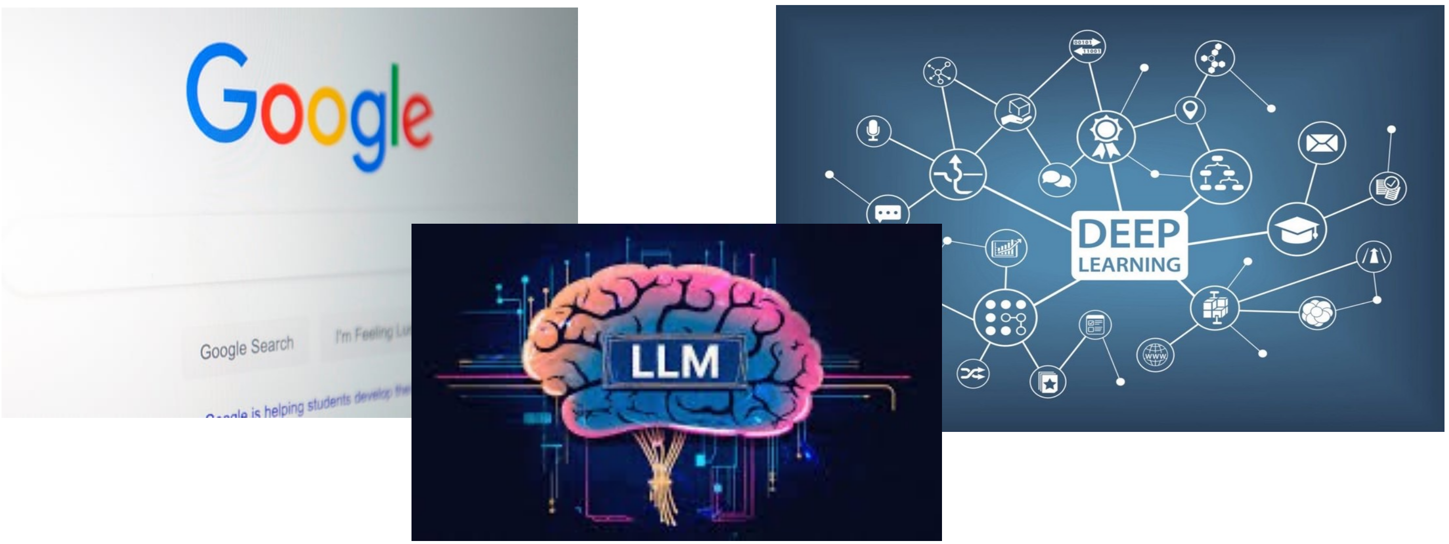
# The need(s) of this shift

- **Server-side computing allows:**
  - Faster introduction of new hardware devices (e.g., HW accelerators or new hardware platforms)
  - Many application services can run at a low cost per user.



# One more need …

- Some workloads require so much computing capability that they are a more natural fit in datacenter (and not in client-side computing)
- A couple of examples:
  - Search services (web, images, and so on)
  - Machine and Deep Learning, LLMs




https://www.datacenterdynamics.com/en/news/openai-pitched-white-house-on-multiple-5gw-data-centers/

From Data centers…

…to Warehouse-scale computers

# Warehouse-scale computers: Introduction

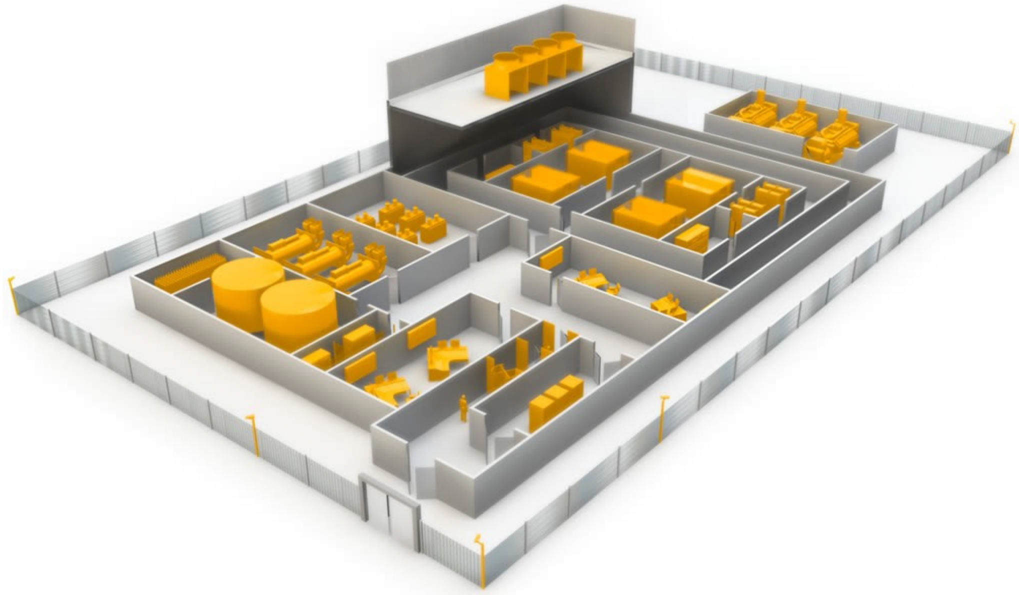
- The trends toward server-side computing and widespread internet services created a new class of computing systems: ***warehouse-scale computers*** (WSCs):

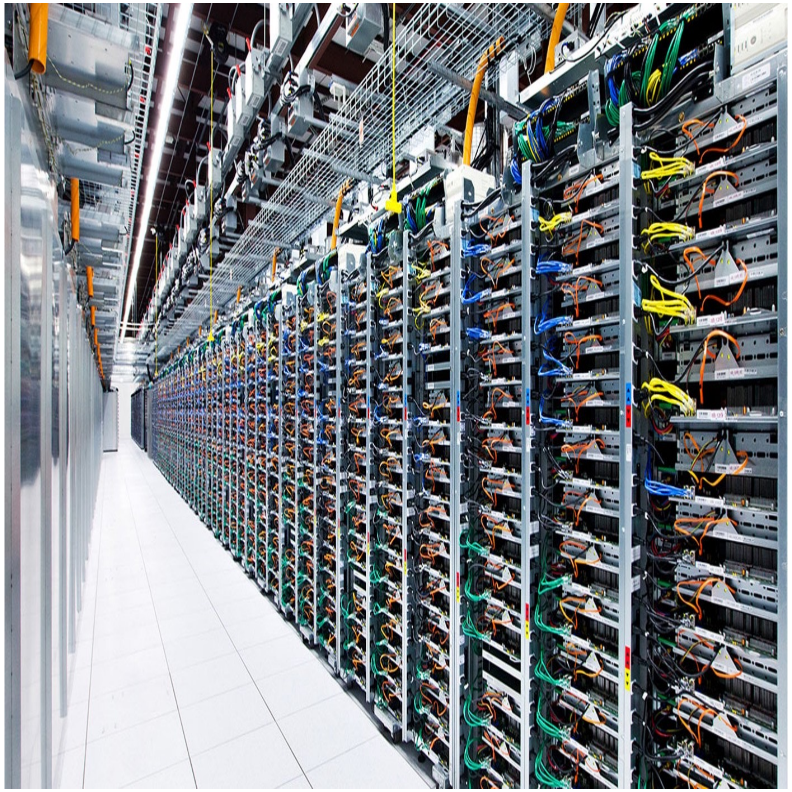
The *massive scale* of the software infrastructure, data repositories, and hardware platform.

- The **program in warehouse-scale computing**:
  - ✓ is an internet service,
  - ✓ may consist of tens or more individual programs
  - ✓ such programs interact to implement complex end-user services such as email, search, maps or machine learning.

# Warehouse-scale computers vs. DATACENTERS (1)

- Data centers are **buildings where multiple servers and communication units are co-located** because of their common environmental requirements and physical security needs, and for ease of maintenance.





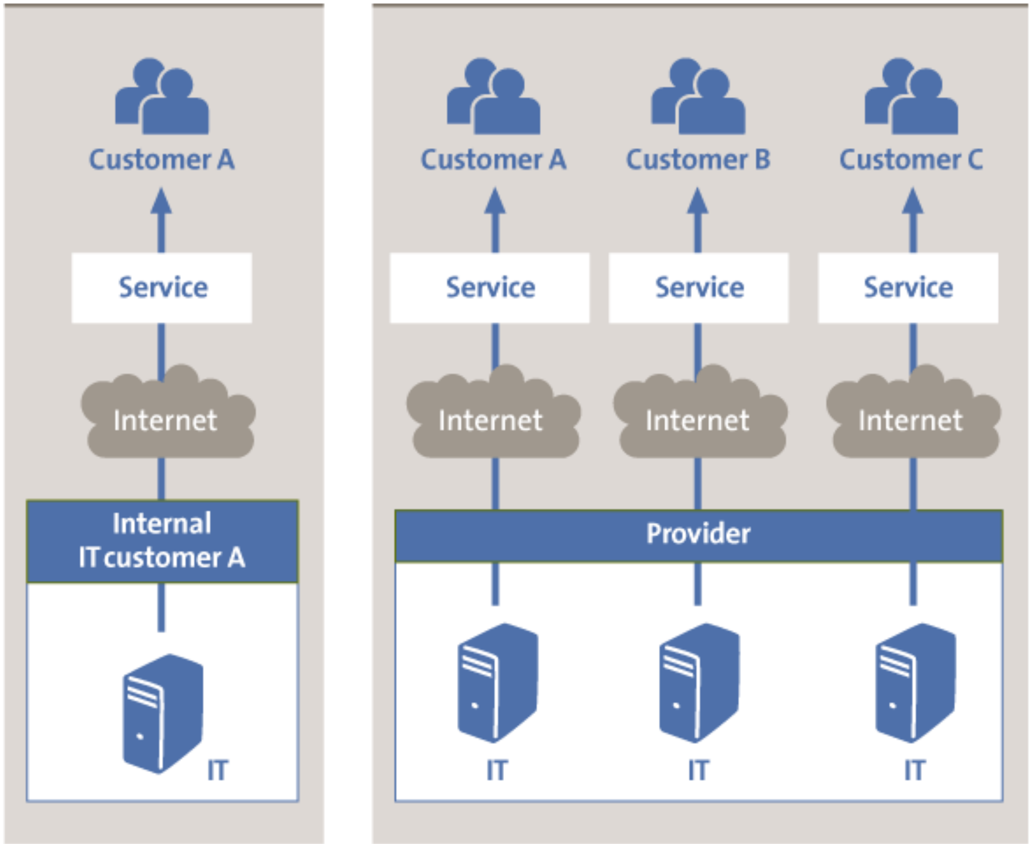
# Warehouse-scale computers vs. DATACENTERS (2)

- **Traditional data centers**:
  - typically host a large number of relatively small- or medium-sized applications,
  - each applications is running on a dedicated hardware infrastructure that is de-coupled and protected from other systems in the same facility,
  - applications tend not to communicate each other.

- Those data centers host hardware and software for **multiple organizational units or even different companies.**

# Warehouse-scale computers vs. DATACENTERS (3)

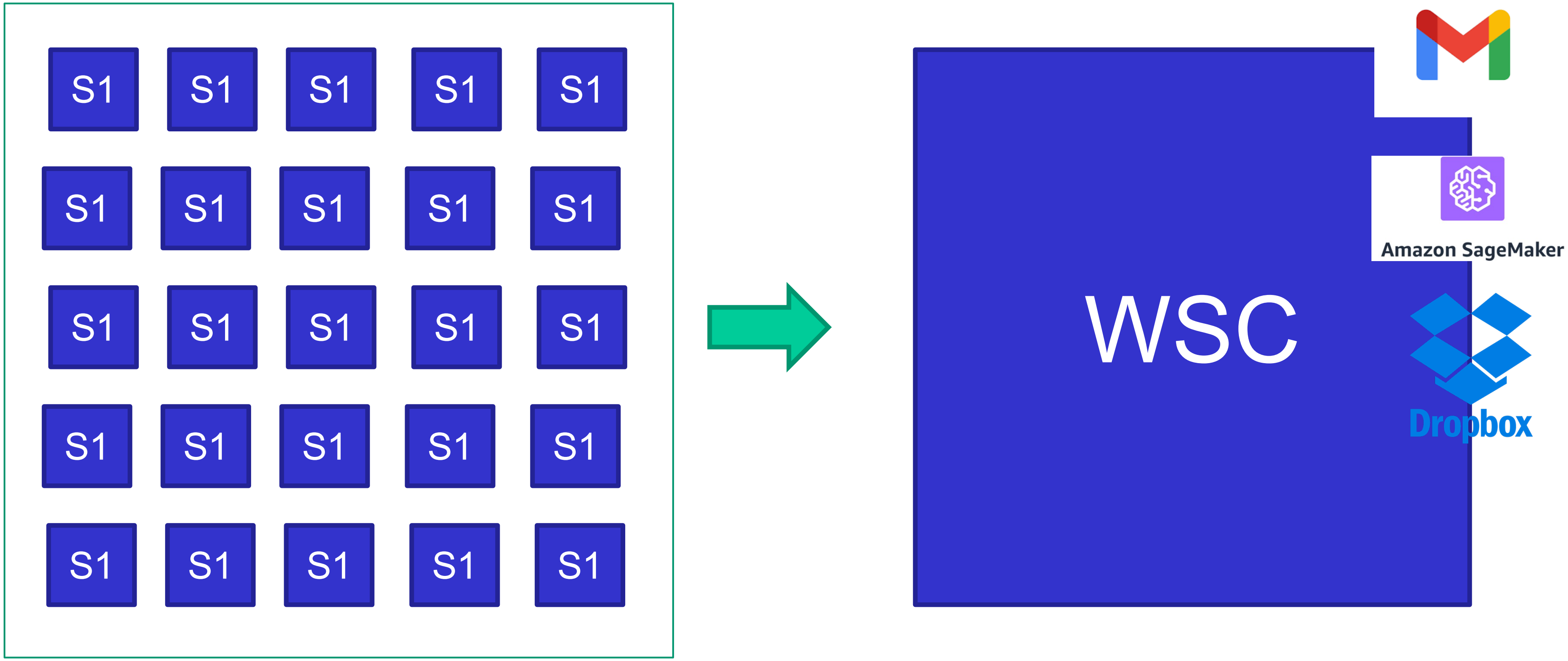
Traditional Datacenters



# WAREHOUSE-SCALE COMPUTERS vs. Datacenters (4)

WSCs belong to a single organization, use a relatively homogeneous hardware and system software platform, and share a common systems management layer

# WSCs: not just a collection of servers



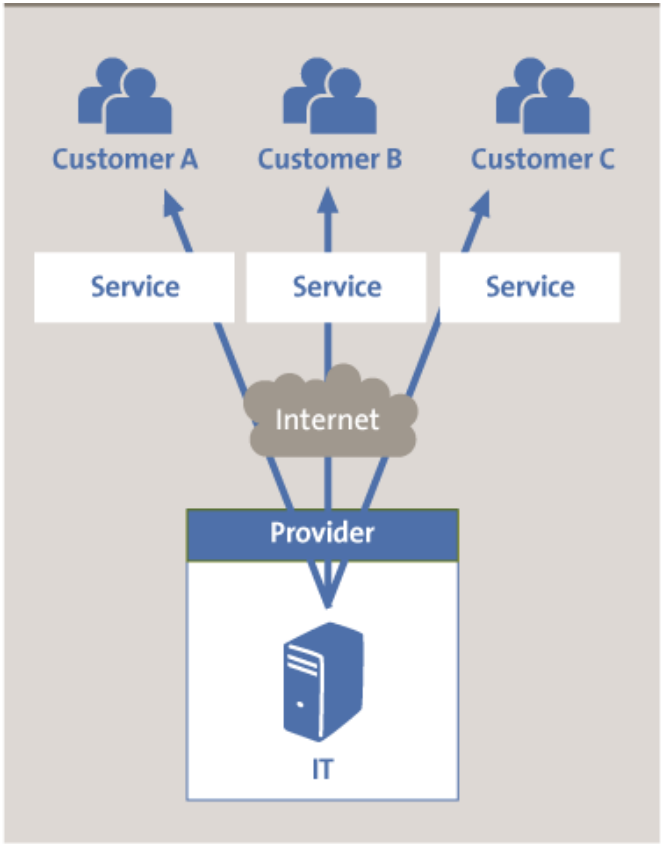

- The software running on these systems executes on clusters of hundreds to thousands of individual servers (far beyond a single machine or a single rack)
- The machine is itself this large cluster or aggregation of servers and needs to be considered as a single computing unit.

# WAREHOUSE-SCALE COMPUTERS vs. Datacenters (5)

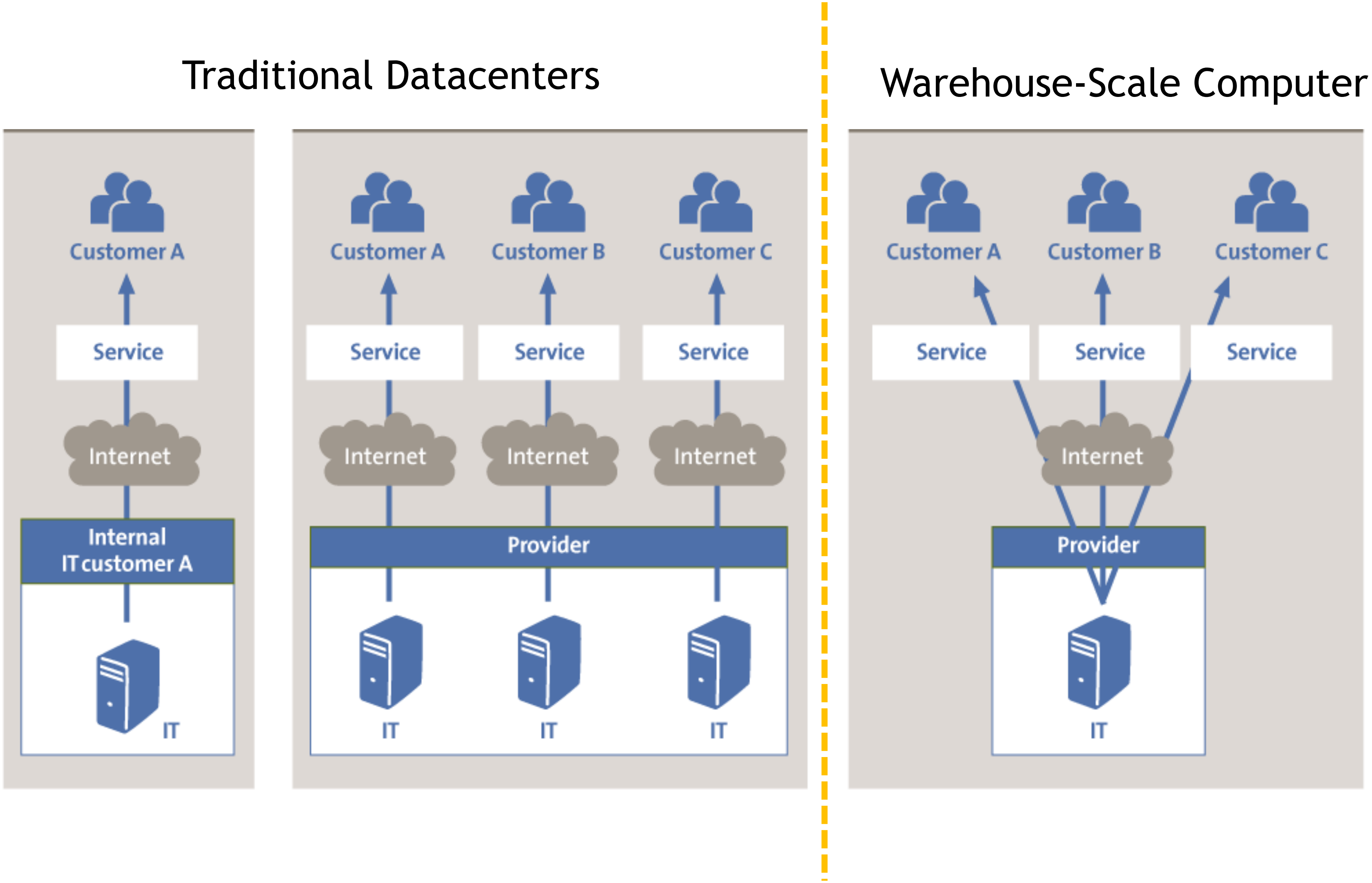
- WSCs run a smaller number of very large applications (or internet services)
- The common resource management infrastructure allows significant deployment flexibility.
- The requirements of
  - homogeneity,
  - single-organization control,
  - cost efficiency

  motivate designers to take new approaches in designing WSCs

Warehouse-Scale Computer



# WAREHOUSE-SCALE COMPUTERS vs. Datacenters: a graphical comparison



From Data centers…

…to Warehouse-scale computers

and back!

# From Datacenter to WSCs (and back) …

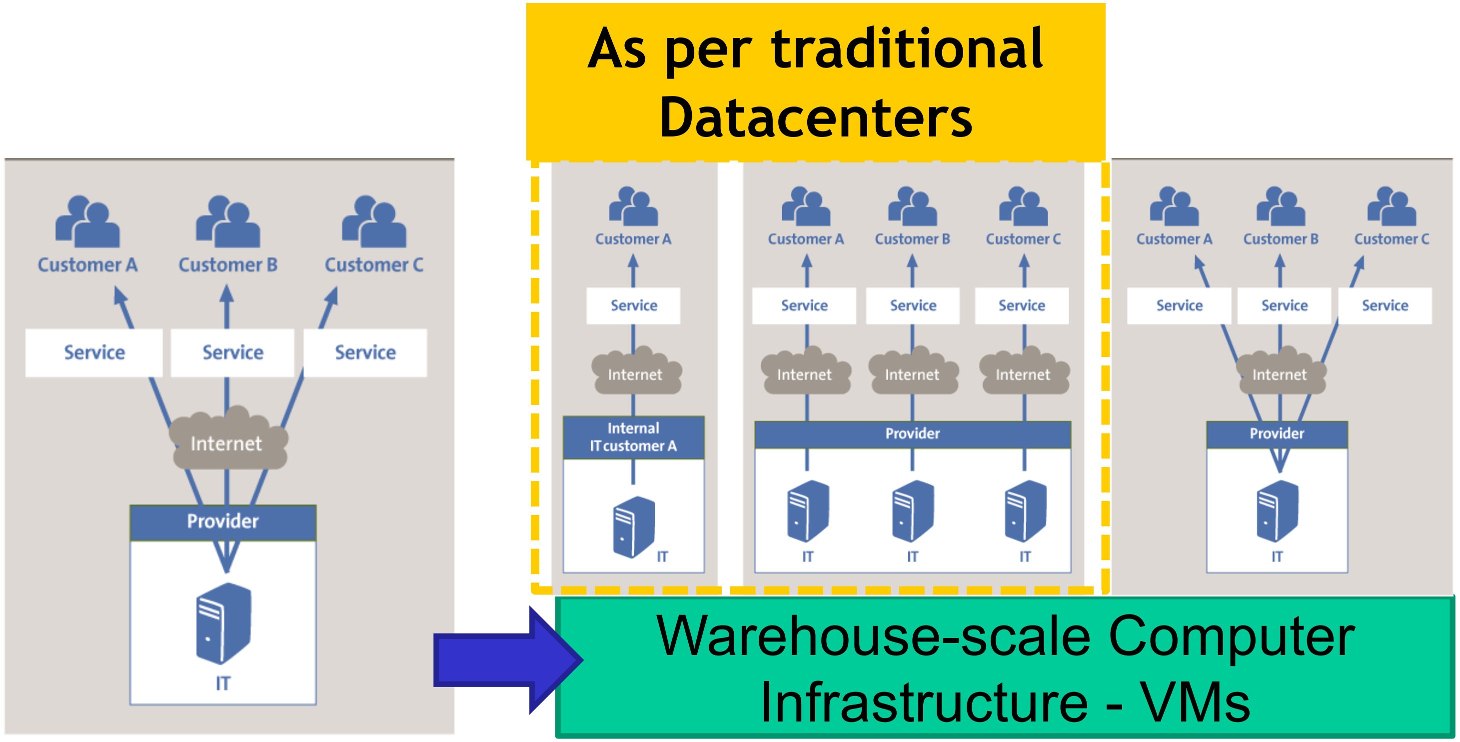
- Initially designed for online data-intensive web workloads, **WSCs also now power public clouds computing systems** (e.g., Amazon, Google, Microsoft)

- Such public clouds do run many small applications, like a traditional data center
- All of these applications rely on Virtual Machines (or Containers), and they access large, common services for block or database storage, load balancing, and so on, fitting very well with the WSC model.

**We will come back on this during the course**

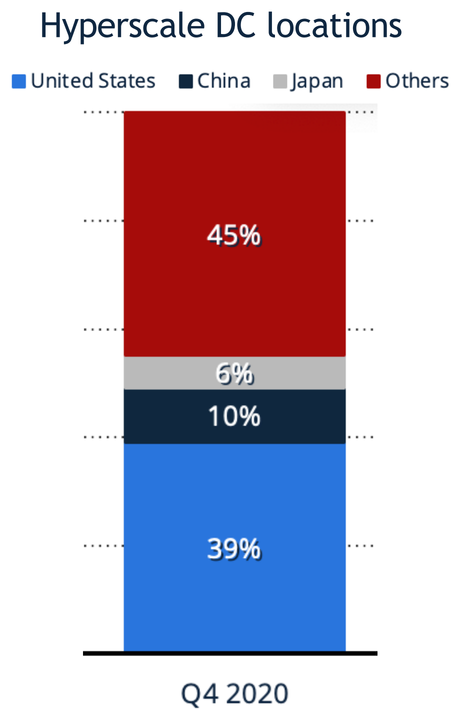
# From Datacenter to WSCs (and back) …

Warehouse-Scale Computer



# What about several datacenters?

- One data center vs multiple data centers located far apart.
- Multiple data centers are (often) replicas of the same service:
  - ✓ to reduce user latency
  - ✓ improve serving throughput
- A request is typically fully processed within one data center


https://www.datacenterknowledge.com/sites/datacenterknowledge.com/files/wp-content/uploads/2016/09/aws-azure-dc-map.png

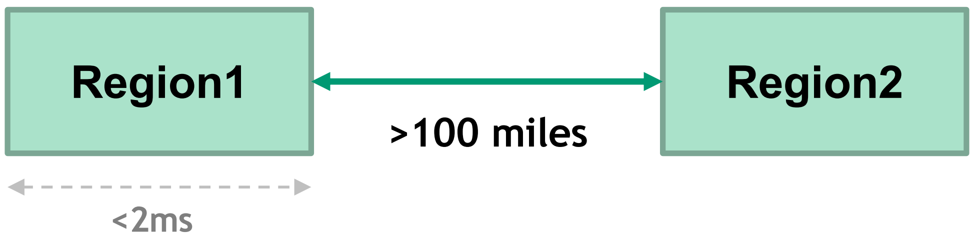
# Hierarchical approach: Geographic Areas and Regions

The world is divided into **Geographic Areas (GAs)**

- Defined by Geo-political boundaries (or country borders)
- Determined mainly by data residency
- In each GA there are at least 2 computing regions

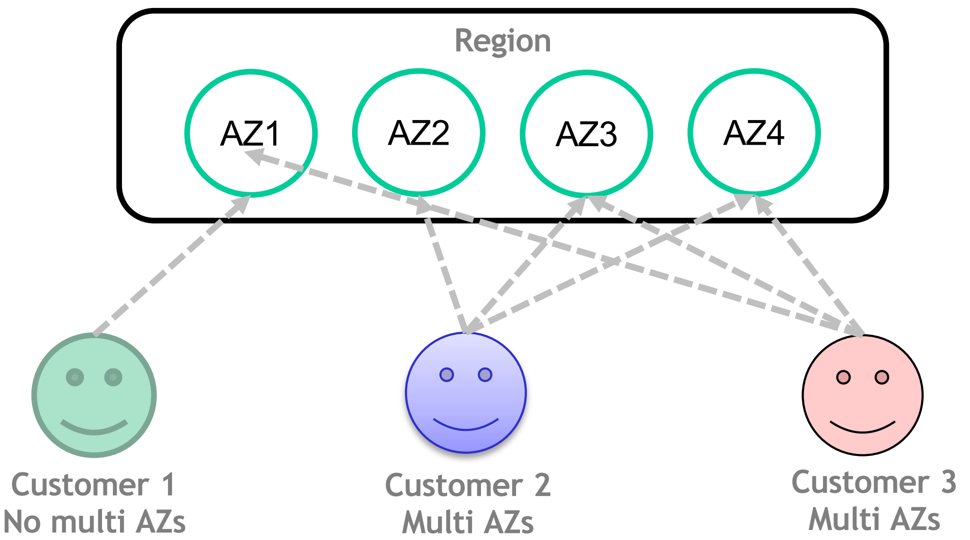
Computing **Regions (CRs)**:

- Customers see regions as the finer grain discretization of the infrastructure
  - Multiple DCs in the same region are not exposed
- Latency-defined perimeter (2ms latency for the round trip)
- 100's of miles apart, with different flood zones etc...
- Too far for synchronous replication, but ok for disaster recovery

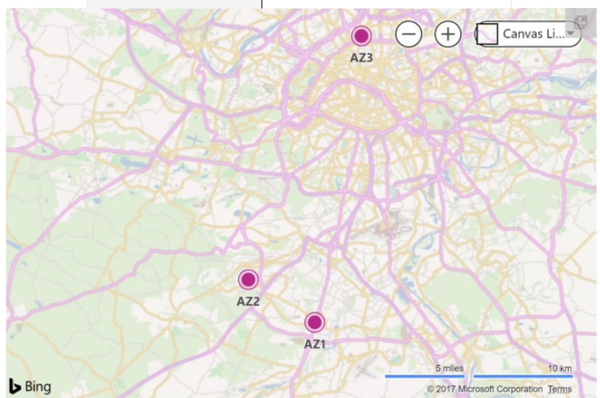


# Hierarchical approach: Availability Zones

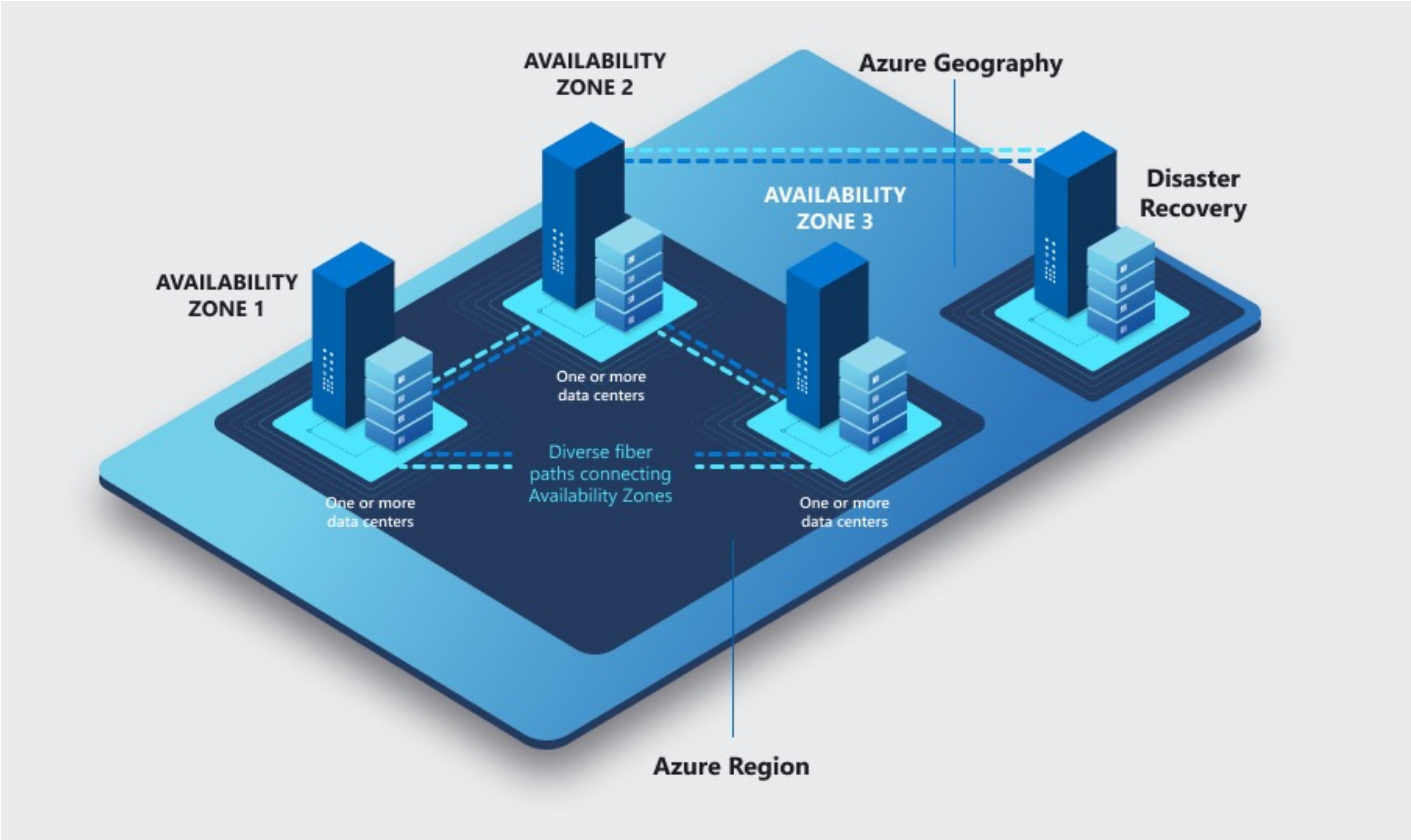
- **Availability Zones (AZs)** are finer grain location within a single computing region
  - allow customers to run mission critical applications with high availability and fault tolerance to datacenter failures
    - Fault-isolated locations with redundant power, cooling, and networking
    - Different from the concept of **Availability Set**
  - Application-level synchronous replication among Azs
  - 3 is minimum and enough for quorum




| Regions | France Central<br>Start free > |
|---|---|
| LOCATION | Paris |
| YEAR OPENED | 2018 |
| AVAILABILITY ZONES PRESENCE | Available with 3 zones |

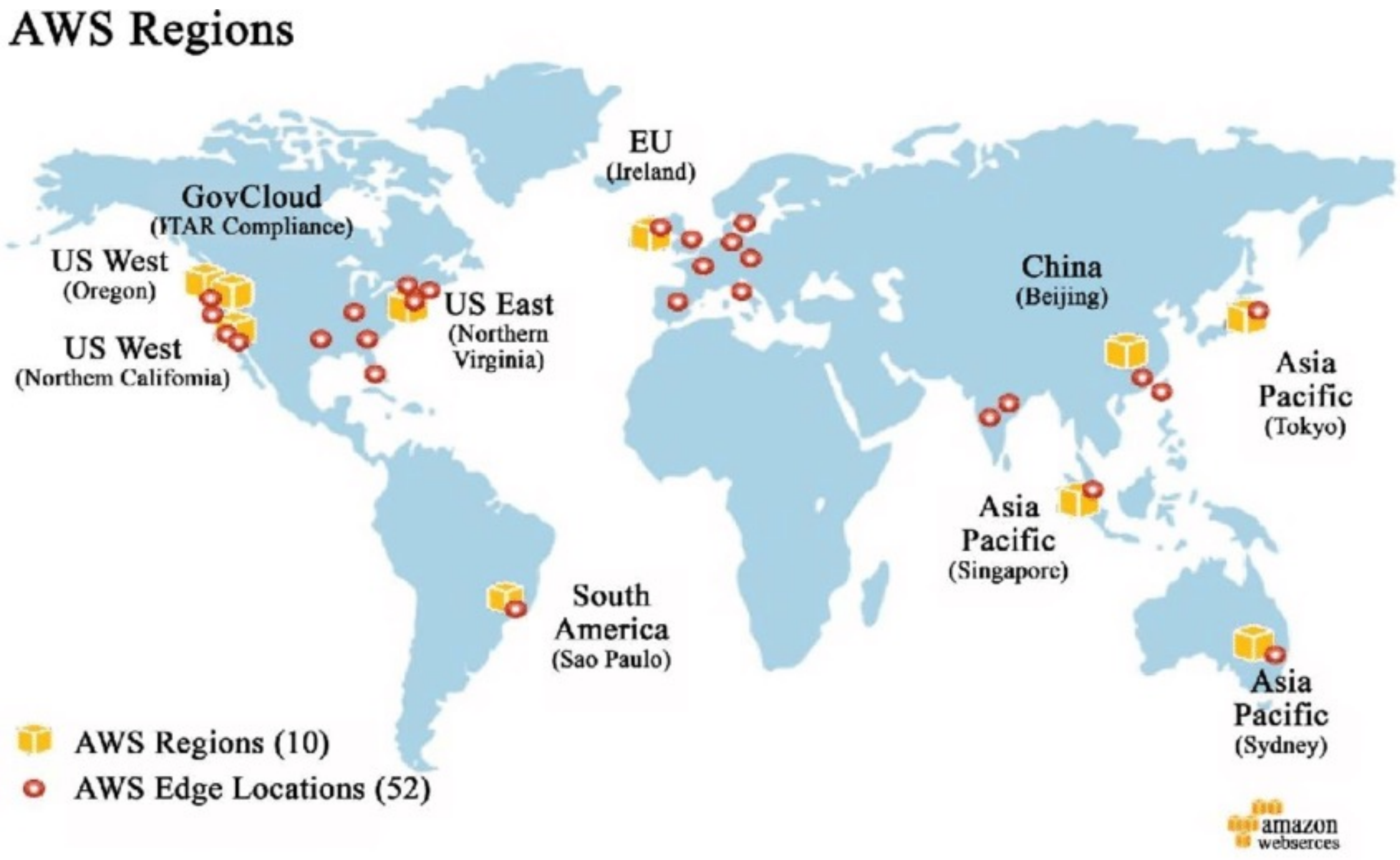


# Overview: Azure Example




https://docs.microsoft.com/en-us/azure/availability-zones/az-overview

# Edge Locations



# WSCs/DCs and availability

- Services provided through WSCs (or DCs) must guarantee high availability, typically aiming for at least 99.99% uptime (i.e., one-hour downtime per year). Some Examples:
  - **99,90%** on single instance VMs with premium storage for an easier lift and shift;
  - **99,95%** VM uptime SLA for Availability Sets (AS) to protect for failures within a datacenter.
  - **99,99%** VM uptime SLA through Availability Zones
- Achieving such fault-free operation is difficult when a large collection of hardware and system software is involved.
- DC workloads must be designed to gracefully tolerate large numbers of component faults with little or no impact on service level performance and availability!!!

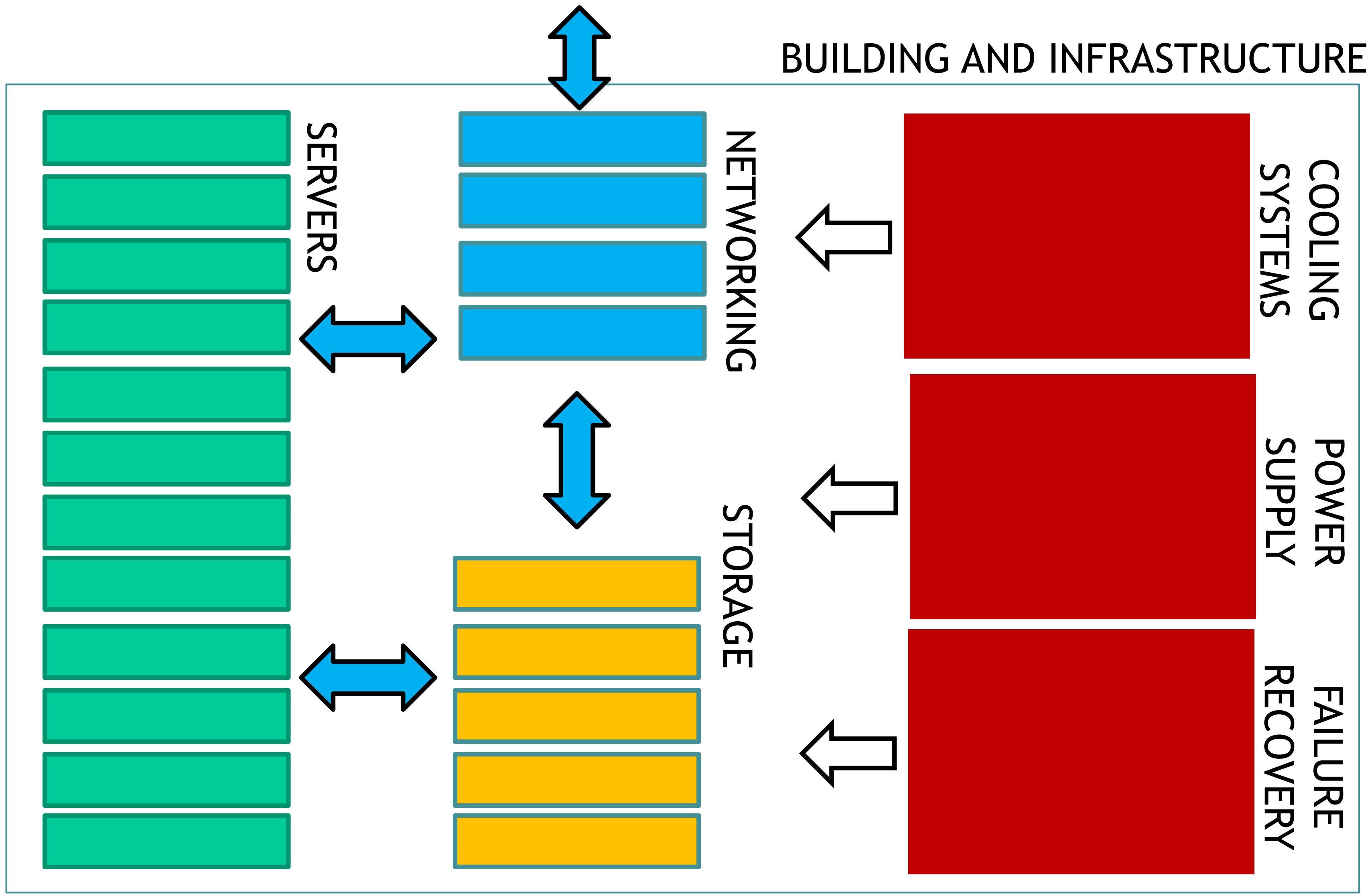
This is exactly the goal of the «Dependability» part of this course

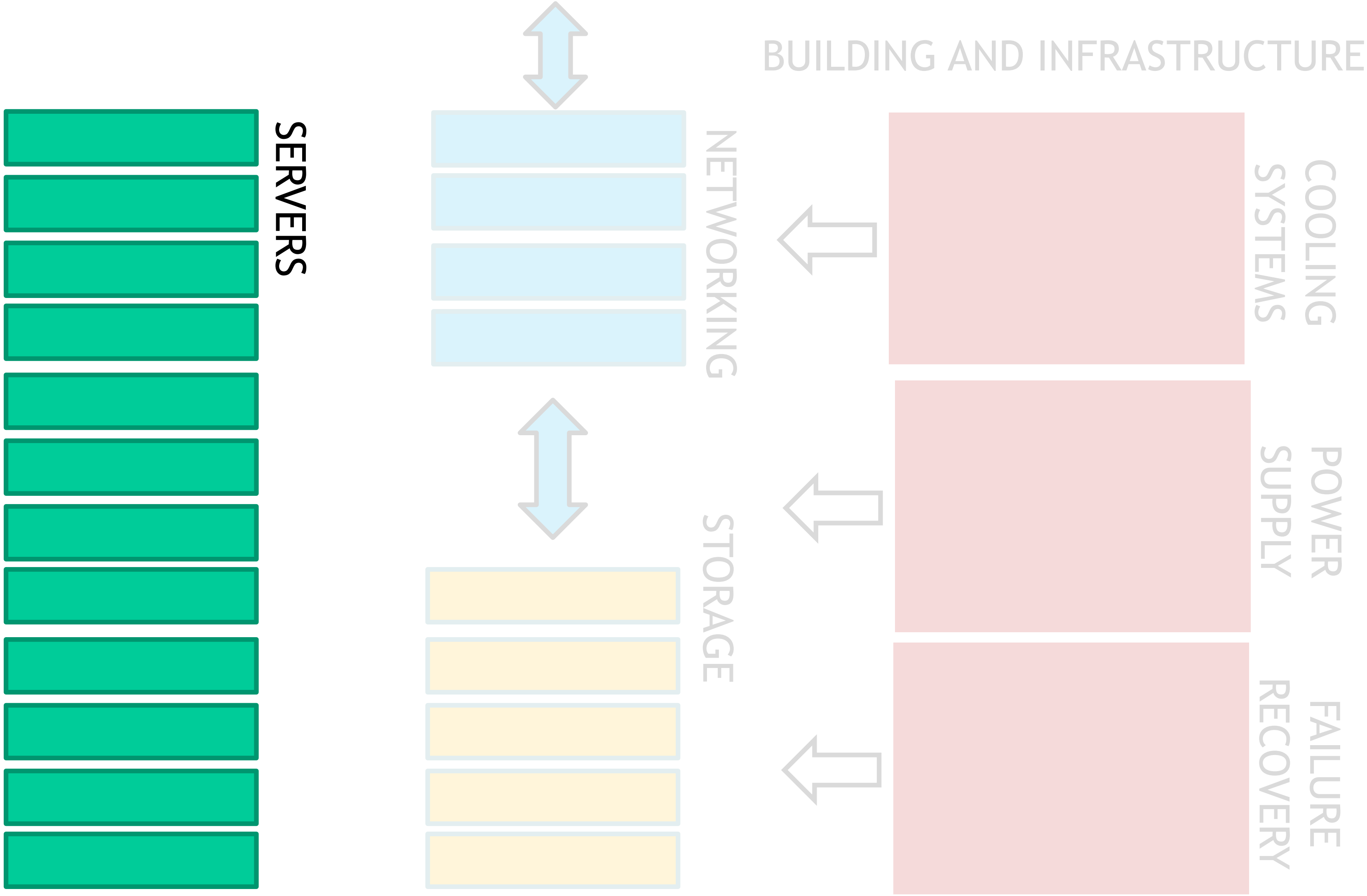
# ARCHITECTURAL OVERVIEW OF WAREHOUSE-SCALE COMPUTERS

Hardware implementation of WSCs might differ significantly each other

However, the architectural organization of these systems is relatively stable

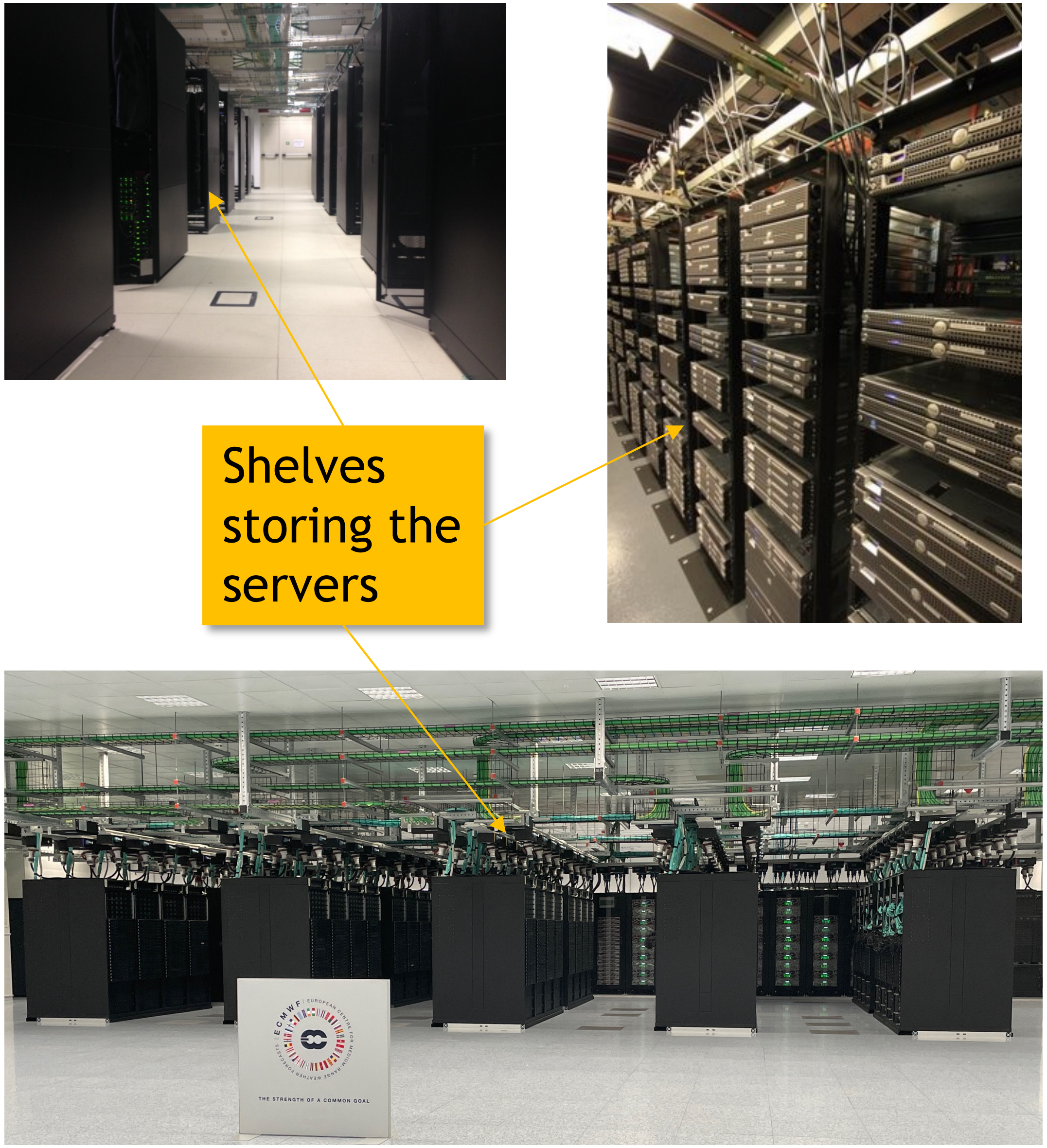
# Architectural Overview of A Warehouse-scale Computer



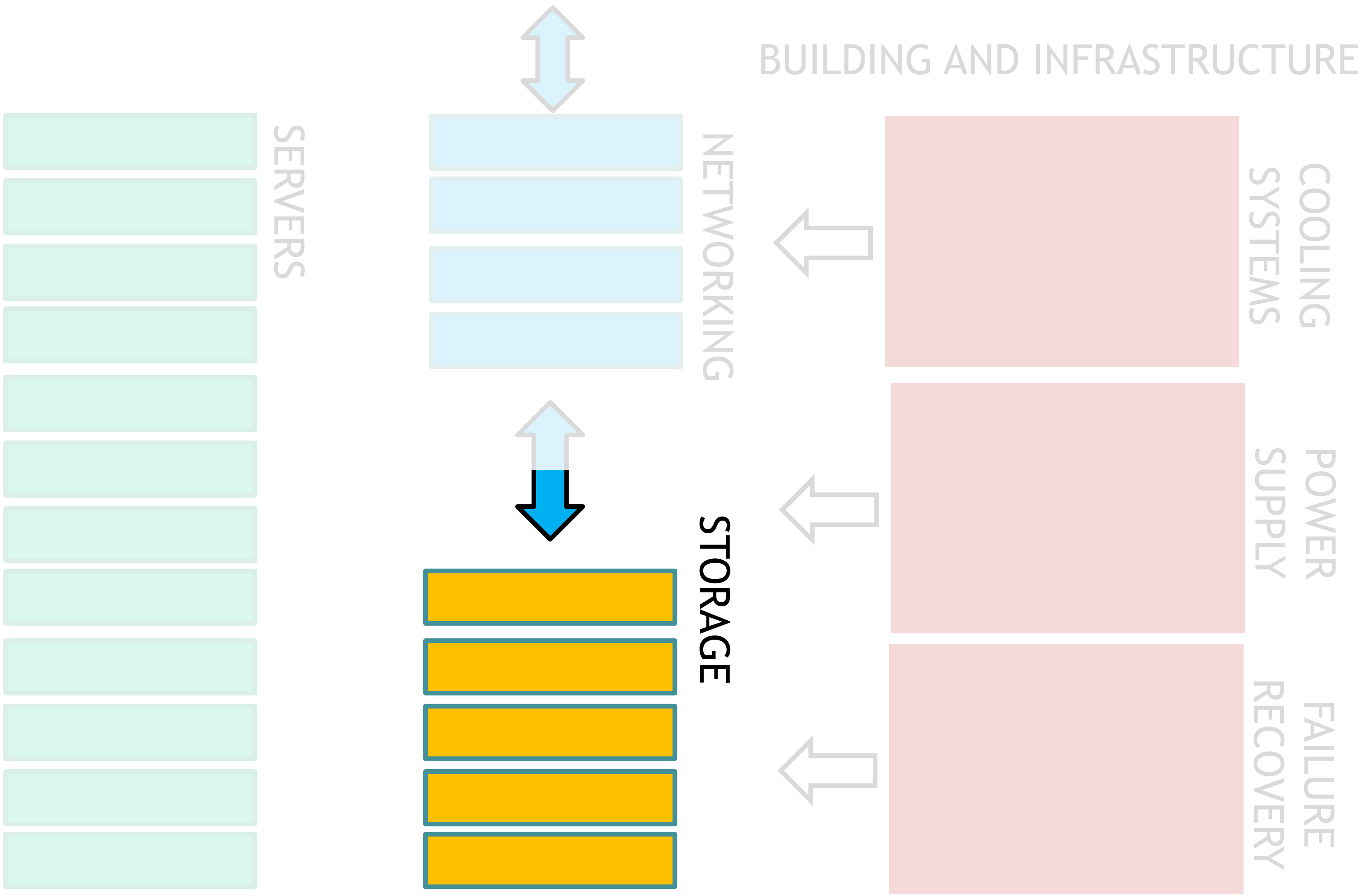

BUILDING AND INFRASTRUCTURE
SERVERS
NETWORKING
STORAGE
COOLING SYSTEMS
POWER SUPPLY
FAILURE RECOVERY

# SERVER AND RACK OVERVIEW

- Servers are the main processing equipment
  - Different types according to CPUs, RAM, local storage, accelerators, and form factor
- Servers are hosted in individual shelves and are the basic building blocks of DCs and WSCs
- They are interconnected by hierarchies of networks, and supported by the shared power and cooling infrastructure.



# STORAGE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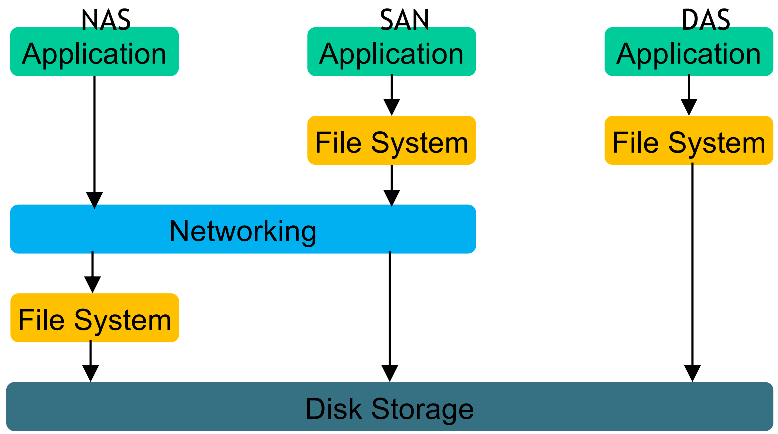
# STORAGE: how and where to store the information

- Disks,Flash SSDs, and TAPES (!) are the building blocks of today's WSC storage systems.

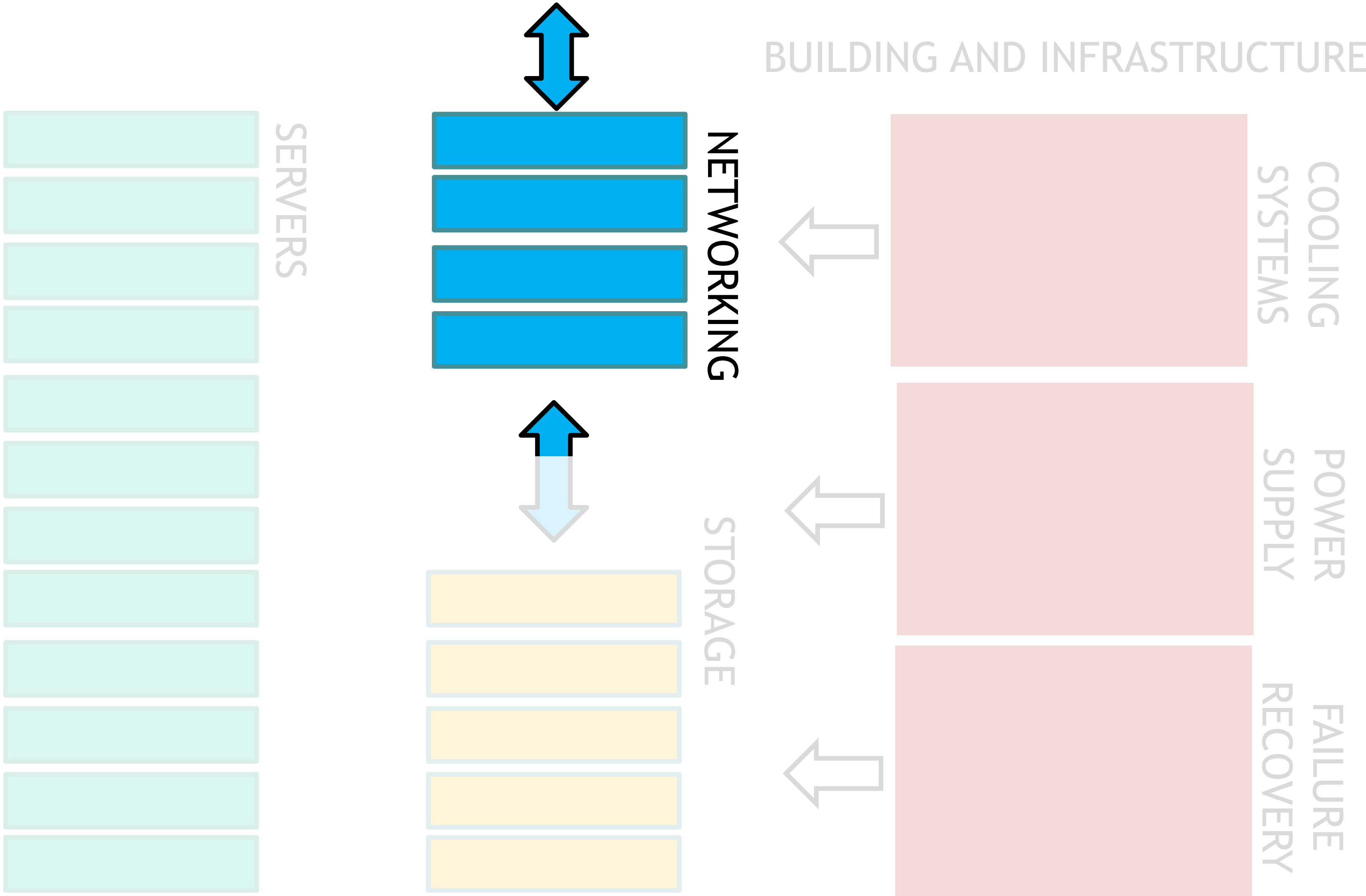
- These devices are connected to the datacenter network and managed by sophisticated distributed systems

Examples:

- Direct Attached Storage DAS
- Network Attached Storage (NAS)
- Storage Area Networks (SAN)
- RAID controllers



# NETWORKING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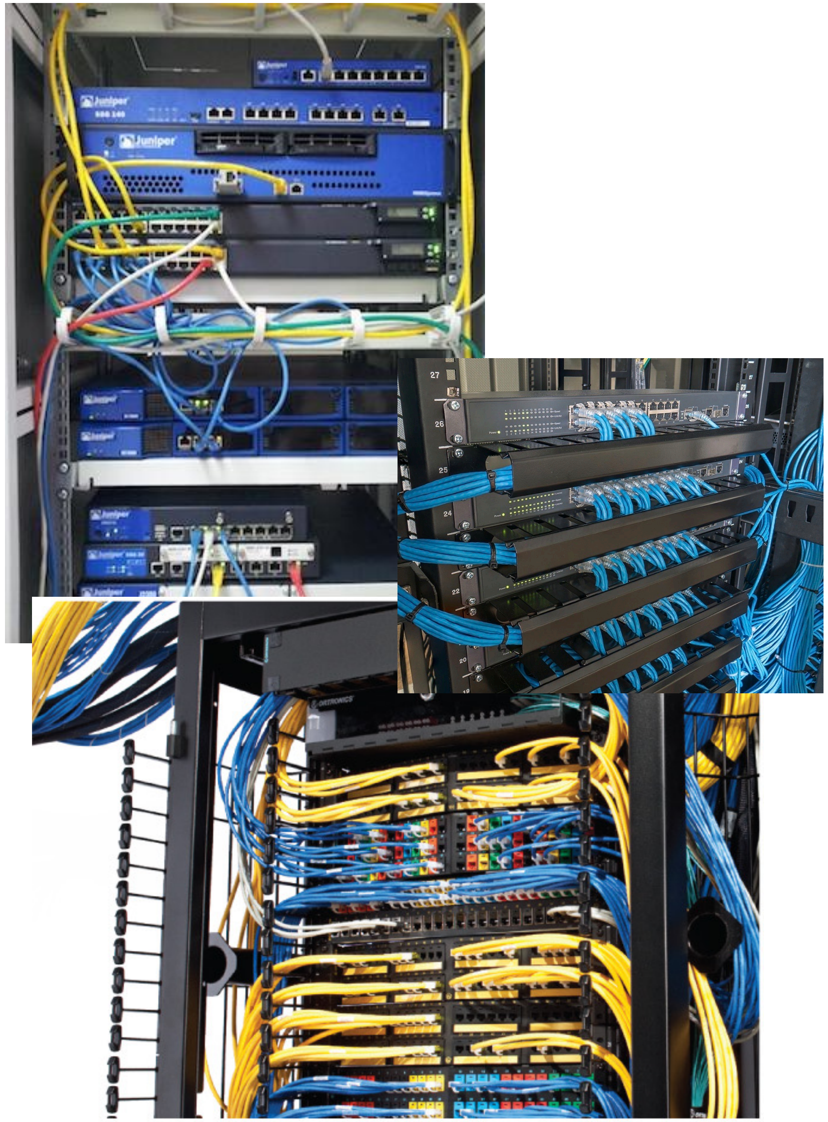
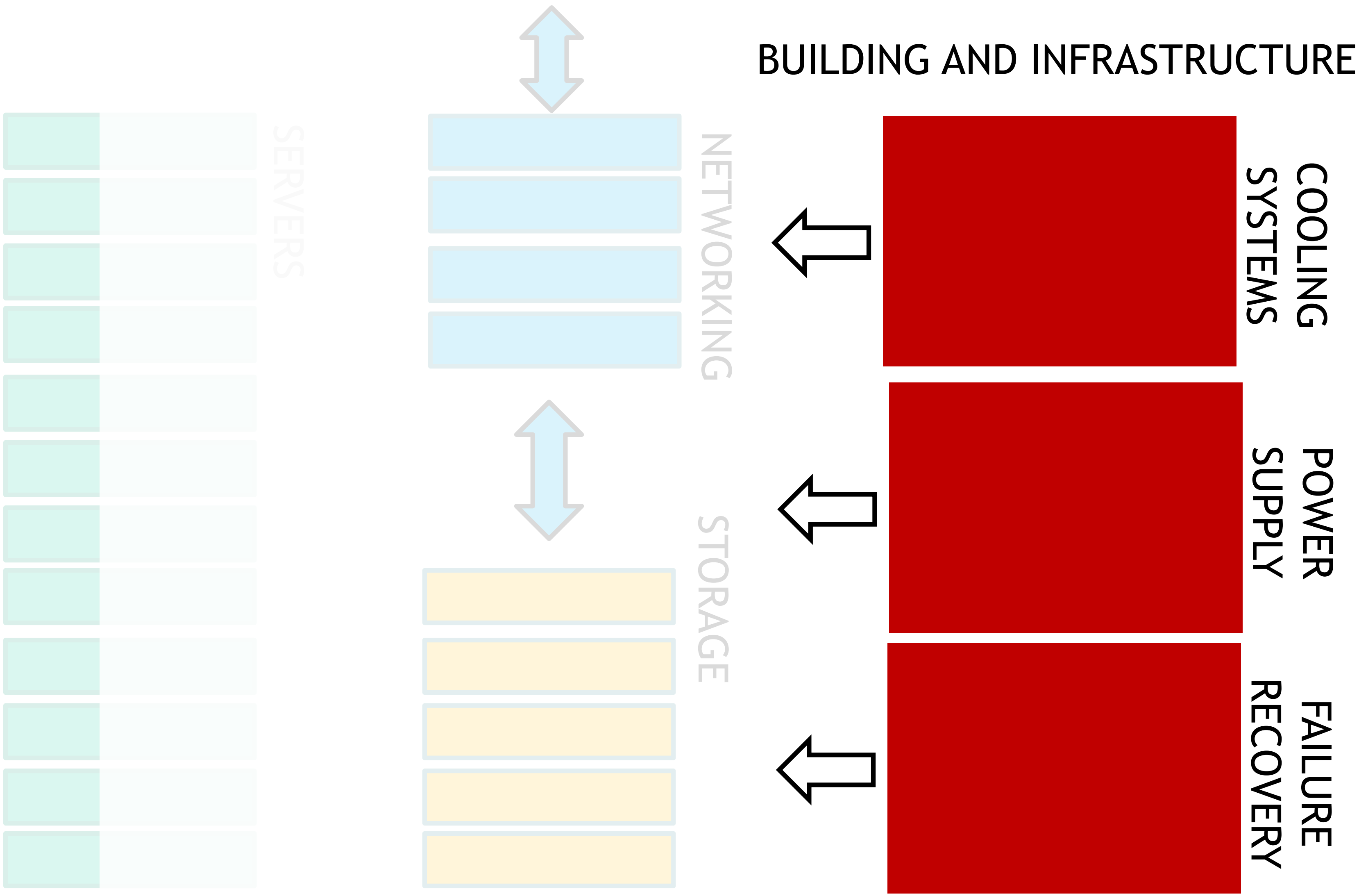
# NETWORKING: providing internal and external connections

- The DCN (Datacenter network) plays a crucial role in enabling efficient data transfer and interaction between various components.
- It is essential for the data processing ecosystem within the DCs and to reach the DC services from outside
- Examples of communication equipment:
  - Switches, Routers, cables, DNS or DHCP servers, Load balancers, Firewalls
  - ... and many more other type of devices!




BUILDING AND INFRASTRUCTURE
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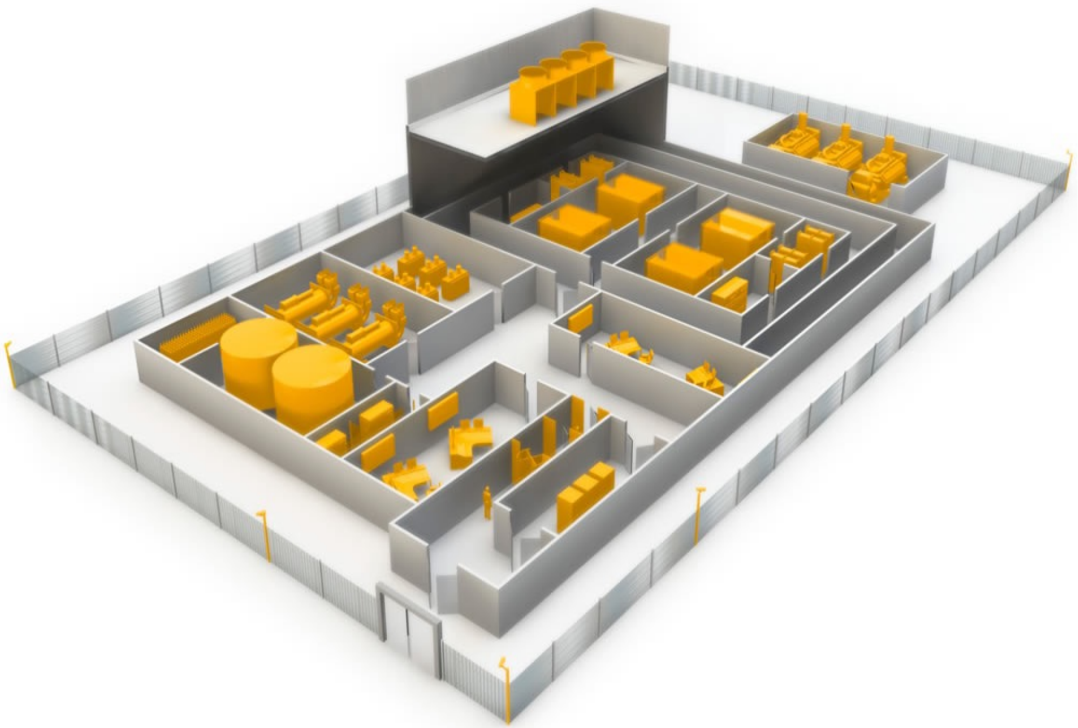
# BUILDING AND INFRASTRUCTURE

WSC has other important components related to **power delivery**, **cooling**, and **building infrastructure** that also need to be considered



Some interesting numbers:

- ✓ Datacenters with up to 110 football-pitch size
- ✓ 2-100s MW power consumption (100K houses)
  - ✓ 650MW the largest
- ✓ >99.99% uptime, i.e., one-hour downtime per year

There is the need for a comprehensive design of computation, storage, networking and building infrastructure

# https://www.switch.com/las-vegas/


## LAS VEGAS EXASCALE DATA CENTER ECOSYSTEMS AT UNPARALLELED LOW PRICING

The Core Campus located in Las Vegas, Nevada, will have up to 531 MW of power upon completion. Switch's Tier 5® Platinum exascale data center facilities make Switch the highest-rated and most cost-effective colocation environment in the industry.

###### 100% GREEN POWER

- 100% green power
- 100% power uptime guarantee
- Up to 55kW per cabinet

###### LOW OR NO TAXES

- 2% sales and use tax in Nevada
- 75% reduction in personal property tax in Nevada
- No personal state income tax in Nevada

###### 35-60% SAVINGS ON CONNECTIVITY

- 5ms to Los Angeles
- Dedicated 7ms fiber to Switch's Citadel Campus via the Switch SUPERLOOP®
- Services include: MPLS, IP, Transport, SIP and SD-WAN (Circuits do not have to terminate at Switch)
- 35-60% on connectivity savings through Switch CONNECT® telecom auditing and expense management services
- Exascale telecom purchasing is enabled by leveraging the multi-trillion dollar market cap of co-op members through The CORE Cooperative

# NSA's Utah Data Center

**Over a million square feet and 65MW**