

ICT Infrastructure - Appunti

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Course info

Don't be shy to send multiple emails, prof. Cisternino receives many emails, and he known he can't reply to each one. He is okay to be contacted through teams using the symbol to "mention" him.

He designed the UniPi datacenters.

"Italy is more about the multiple micro businesses than the few existing industries"

Exam

The exam is **oral**.

Prof. Cisternino expects students to get the full picture, and understand key concepts, not to remember everything—which still wouldn't be bad ☺—.

Chapter 1

Introduction

Prof. Cisternino dropped a lot of measures in terms of Watts, Dollars, Gigabits and so on.

He mentioned with emphasis the problem of energy consumption. To give an idea, a single rack of a datacenter designed ~ 10 years ago, absorbs up to 15kW. The datacenter in *San Piero a Grado* is made up of 60 racks. It is not meant to provide the maximum energy possible for all racks simultaneously, but it still helps to get an idea of how things work in similar contexts.

1.1 Course map

1. Elements
 - i. Datacenters
 - (a) Power
 - (b) Cooling
 - ii. Cabling
 - iii. Networking
 - iv. Storage
 - v. Compute
 - vi. Virtualization
 - (a) Hypervisor
 - (b) Containers
2. Cloud
 - i. Reference architecture
 - ii. Resilience
 - iii. Security
 - iv. Legal aspects
 - (a) GDPR
 - (b) Security frameworks
 - v. Procurement aspects
 - vi. Operations
 - i.e. Keep the system up and running while upgrading the system

Chapter 2

Datacenter

10 years ago datacenters were no more than a room with some computers, air conditioners and some plugs to power up the devices. Later on, customers started asking server vendors to include in the servers utilities to allow an *automated datacenter management*. Thus the trend moved towards **Software Defined Datacenter**, which currently is the only possible way to deploy a Datacenter.

An **Active Datacenter** allows for internet storage (?)

A Datacenter should be **future-proof**: servers may be replaced, but updating a whole datacenter is at least a 1-year project.

2.1 Structure

Racks are made of —~ 42— units.

Besides server themselves, there is a **cooling system**. The first issue is the how to provide cool air. Then there is also how to define an evacuation plan, which must take into account dust.

However also the **floor** is not to be neglected.

- ◊ *Floating* floor or Ground floor
 - “A “floating floor” in a data center, also known as a “raised floor”, is a type of construction used in data centers to create a void between the actual concrete floor and the floor tiles where the servers and other equipment are located¹². This space is typically used for routing cables and for air circulation, which helps with cooling the equipment¹. ”¹
- ◊ Resistance usually around $1\frac{\text{ton}}{\text{m}^2}$

For example, in San Piero A Grado, there was a power cabin receiving current from three lines. Now the whole power management components are in a container outside the building placed close to the facility.

Cables are not super-resistant to current. A lot of current passing through a copper wire will *exhaust* both the wire and the components receiving such current; hence the current should also be balanced among different cables, to avoid exhausting some components before the others.

A UPS —first of all— stabilizes the output current.

In theory $1V * 1A = 1W$, but in reality, performing such conversion something gets lost, so we have

$$I * V * \cos\phi = W$$

2.2 Power Management

Electric panels (aka *switchboards*) allow segmenting the power supply in the various zones of the datacenter.

PDUs stands for *Power Distribution Units*, and allow to distribute power for a server units in a rack. Typically, for each PDU there is another one, providing redundancy and thus resilience/robustness.

Definition 2.1 (PUE) *Power Usage Effectiveness PUE measures the efficiency of a Datacenter.*

$$PUE = \frac{\text{Total energy}}{\text{ICT energy}}$$

¹ChatGPT 4.0 - Generated

The reason for improving Datacenter design is to lower the PUE; basically to save money, but also for “green-environment” concerns.

But when should PUE be measured?

The PUE in January is very different from the one in August, so generally it is calculated as the average of one year.

Note that a poorly designed datacenter placed in Siberia with -20° may have a lower PUE than a datacenter in Italy, for instance.

In particular geographical zones with high temperature variations over the year (e.g. in Italy the temperature variates from 40 to 50 Celsius degrees), are strongly unrecommended to build datacenters in. A counterintuitive example is the desert, where the temperature is very high during the day and very low during the night, but in general the temperature over the year is **stable**; allowing for defining physical processes exploiting such stability.

Also the oceans have a very stable temperature; not on the surface, but deep down it is very stable.

2.3 Cooling

Note that racks are always placed back-to-back, because the front requires cool air, and the back outputs hot air.

2.3.1 CRAC



Figure 2.1: CRAC/CRAH cooling architecture

Chillers take hot air from above and push cool air in the bottom. Then air pushed under the floating floor wants to exit, and does so going through the grates placed in front of the racks. The racks suck the cool air in front and output hot air from the back.

There are two **drawbacks**:

1. It is difficult to confine and keep separated hot air and cool air. The mixup between the two leads to cooling inefficiency, thus energy and money waste
2. In case a rack has a workload heavier than others and thus requires more cooling air, the chiller must provide more cool air to all the racks in the same row; this makes this architecture particularly inefficient for datacenter which have heterogeneous workloads.

2.3.2 Inrow Cooling

The fan “towers” are called *inrow cooling*.

The first advantage is that it allows for heterogeneous cooling in the datacenter. Secondly, a fan outputs hot air directly where another fan expects it to be. This allows to confine hot air and to avoid wasting energy in outputting air and sucking it.

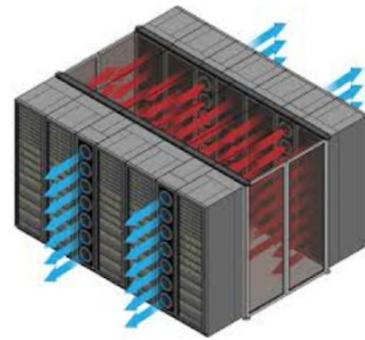


Figure 2.2: Inrow cooling architecture

2.3.3 Chilling water outside



Figure 2.2: Outside chillers

Outside of a datacenter there are chillers which cool down water which is then pumped into the datacenter, where it is used by CRAC/InRow chillers to cool down air.

It is important to ensure that the temperature does not heat up while travelling from the outside chillers to the datacenter, because it would mean wasting energy.

In SPG the outside chillers cool the water down to 18°, which seems high temperature, but in fact it is not: the datacenter is designed to work up to 26°.

The higher the “allowed” temperature is, the more is the energy saved.

Besides, **adiabatic** chillers —such as the ones in SPG— can use **free cooling** in case the outside temperature is lower than 18°², which basically exploits the lower outside temperature to *passively* chill water, without involving the compressor used in the standard cooling way.

Also **humidity** must be managed. An environment which is too dry leads to water condensation onto racks and plugs, possibly resulting in damage to devices and humans.

2.4 Redundancy for Resilience

Active-Passive means that aside from the active system, there is a mirrored one which is shut down waiting for failure and boots up *“just in case”*. This approach is usually not the ideal one, because the second system is very unlikely to be used and is costful. Besides, there are two critical issues with Active-Passive:

- Cons*
1. There is a non-negligible time interval where the switch from the active broken system and the passive one has to happen.
 2. If when booted the backup system reveals itself to be flawed and not working, well... *very sad* ☹

²common case in winter and autumn

Active-active systems are usually better, because they also allow for load balancing. In case of SPG there are three cooling systems, and in case one breaks, the other two can keep working. Active-active costs even more, but it is the standard way to go.

2.5 Cooling CPU

High-end CPUs heat up so much that it has became unreasonable to cool them using air.

However, note that water conducts electricity, so a flaw in a waterpowered cooling system may lead to consistent damage and possible fires.

Oil instead doesn't conduct electricity, and there are some systems which are *submerged* in oil, but there are two drawbacks:

1. **Price:** oil is way more expensive than water
2. **Servicing:** it is impossible to maintain the system's hardware.

Distilled water is not conductive, but even not considering that distilling it is expensive, it is impossible to guarantee that it stays pure when travelling in pipes, chillers, and so on.

Most datacenters tend to have an hybrid approach to cooling, called **air-to-liquid**. The idea is simple: It is acceptable to use cool air to chill water, which is then used to chill the air by InRow coolers, which chills the liquid which chills the CPUs.

(Woah! We need a schema...)

This is not the most efficient approach.

A nice question would be, “*Can't we simply chill the liquid and send it directly onto the CPUs?*” **No ☺.**

- ◊ Required pressure is different
- ◊ Required temperatures do not match
- ◊ ... TODO

2.5.1 Spilling Pipes

Liquid cooling systems manufacturers allow customers to ensure that their pipes are not spilling by injecting in the pipes a known gas at a known pressure. The customer can measure the pressure when the product is shipped and check whether it is the expected one, and if not, send back the device.

Handling spills

Handling spills is an **open problem**. Theoretically, the idea would be to check for pressure variations, but this is currently *impossible* to be done on each entrance of each rack. Too much actuation and sensoring would be required.

Besides, in case a pipe is spilling, the operators must act *quickly*, before the water spills onto other racks and cause critical damage.

2.5.2 Chassis

Chassis are needed for various reasons:

- ◊ 2.4GHz is the frequency at which water in our cells resonates, and circuits generate electromagnetic fields, so it may be unsafe to directly expose humans to circuitry
- ◊ Act as Faraday cages
- ◊ TODO

Chapter 3

Cabling

Cabling is of paramount importance.

Prof. Cisternino learnt it “the hard way” when he performed the cabling of the first UniPi datacenter by himself

1. Maintenance
2. Cooling
 - i. Cables may heat up
 - ii. Cables may obstruct air flow
3. Determines which machines interact with each other (*fabric*)
4. Bandwidth
5. Not neglectable cost

3.1 Bandwidth

3.1.1 Storage implications

A standard datacenter has servers connected with 25Gbit links in both directories, summing up to 50Gbit total bandwidth. Current SSDs provide much more. 4 drives are enough to saturate a 100Gbit/s link.

We moved from a situation where the **bottleneck** were slow Hard Drives, to the current one where the bottleneck is the —network— **bandwidth**.

Recently the PCI 3.0, which lasted very long —providing $\sim 1000\text{Gbit/s}$ —, suddenly become unsufficient to handle the needed traffic.

Considering this, datacenters must be designed to allow *Terabytes* of data to be moved in east-west traffic.

The fabric is the glue that makes the datacenter possible.

Besides, a single server is *unable* to handle 10TBs of data and handling requests from 3000 users simultaneously. It is necessary to **distribute** the requests.

HDDs are still currently used for **cold storage**; CPUs will access data exclusively from SSDs, and sometimes the server is shipped with on board **full-flash storage**.

The difference in price between SSDs and HDDs becomes negligible since you pay for top CPU, top GPU, top RAM; furthermore, you can’t waste —the high amount of— energy —consumed by such components— by waiting for a slow drive.

SSDs have a known write limit, but today, they usually last enough time: if you write the whole disk every day it will last for 5 years. Most-likely after five years you’d have to renew some components anyway, besides the failure is a predictable event.

3.1.2 Fabric and Cables

Optical

Electric current propagates at a speed $s = \sim 0.6c$. Hence **optical fiber** is —at least in theory?— faster.

Lasers are a coherent beam of equal photons. It is possible to transfer energy through such photons. Something resembling a laser is used for optical fibers.

Blu-Ray came out when scientists managed to create light using frequencies in the Blu area, which are the higher ones. Currently, the best and most expensive optical fibers exploit blu-lasers as source of light.

Note that with optical you always need 2 fibers, one sending and the other receiving. The two possible connectors are **SC** and **LC**. Sometimes the two ends of the cable are detachable so that the cables may be switched; this is useful because sometimes you may want to attach the TX cable on the RX plug and viceversa.



Figure 3.1: SC and LC connectors

Copper wires

In case of electricity there are many aspects to be considered. Interferences, cable diameter/size, length, and also the fact that if a 1 has been transmitted for some time, it takes longer to transmit a 0, due to the *commutation* that must happen.

RJ45 is a standard physical interface for copper wires, which allows up to 1Gbit regularly. The Cat 7 cables still use the RJ45 as connector and provide instead 10Gbit/s, but are very uncomfortable, they are so thick that they are difficult to bend.

It is estimated that there have been installed $70 \times 10^9 m$ of Ethernet cables, making them the most used.

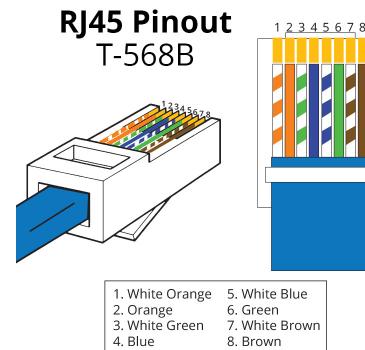


Figure 3.3: RJ45 - T568B

The aim of SFP is to decouple the optical transceivers from the server modules.

Is this correct?

They allow to go *optic-copper*, *copper-optic*, *optic-optic* and *copper-copper*.

SFP and GBIC (oldest one, now dead) pluggable modules acting as active transceivers for optical wiring using RJ45 connector.

A single cable having SFP ends costs about 100€. The cost ain't neglectable ☺.

SFP → 1Gbit
 SFP+ → 10Gbit
 SFP28 → 25Gbit

Fun fact: ci sono 9 cavi USB-C e solo due portano informazioni video.



Figure 3.4: SFP transceivers form factors

3.2 Cabling Issues

The key point is that it would be desirable for cabling to be reconfigurable.

There are things called “*Muffole*”, which are used for joining optical fiber cables, allowing for longer distances to be covered. They are designed to be underground.

Data traffic is always at least SFP+. Current standard is SFP28. Various SFP are typically compatible, the shape of the plug should stay the same. On switches there also some ports which are QSFP+ or QSFP28, which allow up to 40 and 100Gbit/s respectively, and are used for north-south traffic.

The Q letter stands for *Quality*

Switches for datacenters should be **non-blocking**, meaning that no port has to wait for other ones —or any other thing— before transmitting, they can also transmit simultaneously.

In every datacenter it is *MANDATORY* to document the cabling.

Chapter 4

Networking

The two key aspects of a network are:

1. **Bandwidth** → amount of data per second that can be moved through a specific connection
2. **Latency** → is the amount of time required for transmitting data, measured from the moment it is sent from the source to the one it is available to the source.

Latency—in a datacenter—to transmit data on the cable using “*pure ethernet*” is of the order of $0.5 \times 10^{-6} s (\mu s)$. If the TCP/IP stack is used (standard application case), latency is about $70 - 90 \mu s$.

Furthermore, current drives have reached speeds such that latency may act as bottleneck between them and the CPU.

Cable aggregation (e.g. aggregating 4 cables 10Gbit/s, providing 40Gbit/s total) can be performed only at a low—physical—level. Otherwise the TCP/IP stream will be associated to a single cable of the ones aggregated, resulting in less bandwidth.

4.1 Layers

Programmers usually do not care about anything under layer 3/4 traffic. However, in datacenters it is fundamental to understand how layer 2 works.

Also because in datacenters there are no routers doing the work for you; you are building the fabric in the first place.

Layer 2 is fundamental for 2 reasons:

1. East-west is Ethernet in the datacenter
2. All the dozens of protocols used in switches are really used, so they are important.
3. MTU - Maximum Transmission Unit

4.1.1 Protocols inside switches

- ◊ LLDP Link Layer Discovery Protocol - Allows to reconstruct at least partially the functioning of the network.
- ◊ DCBX Data Center Bridging Exchange - A meta-protocol so that two devices can agree on the configuration of a bunch of protocols, typically related to storage/data
 - e.g. “I need 50% percent of the bandwidth otherwise a can’t work”.
 - It represents part of some kind of QoS for Ethernet
 - .
- ◊ PFC Priority Flow Control
- ◊ ETS Enhanced Transmission Selection
- ◊ RSTP Rapid Spanning Tree Protocol - Uses BPDU packets to explore the graph of the network and compute the spanning tree of the network and detect the —malicious— cycles if any.

This just to recall that the switch is not a stupid thing! It is complex, fascinating, and deserves love; it’s crucial to understand its functioning, also because its protocols occupy bandwidth.

4.2 Ethernet Topology

Typically nowadays the network is a **graph**, where internal nodes are switches or routers, and the leaves are servers.

The physical medium is no more shared, but conceptually the data link layer behaves as if it was.

On a switch, the only way to emulate a **shared bus**, is to “*copy-paste*” a frame onto multiple ports, losing the “identity” of frames. Packets in higher layers (IP?) have an ID, but frames don’t, making it impossible to recognize whether a frame is a copy of another one or not. This approach makes **loops** a problem, because they disrupt performance by generating a packet storm.

The solution would be to ensure that the topology resembles a **tree**, instead of a graph. But, at the same time, a **fully connected graph** allows to have multiple routes for the same destination, possibly enhancing performance, reducing “hops” before reaching the destination.

4.2.1 RSTP

So... how can we leave the graph to be connected, but making it a tree from a logical point of view?

The answer is the **RSTP** protocol.

RSTP sends *probes* to understand whether there are loops and where are PCs located.

4.2.2 Spine Leaf architecture

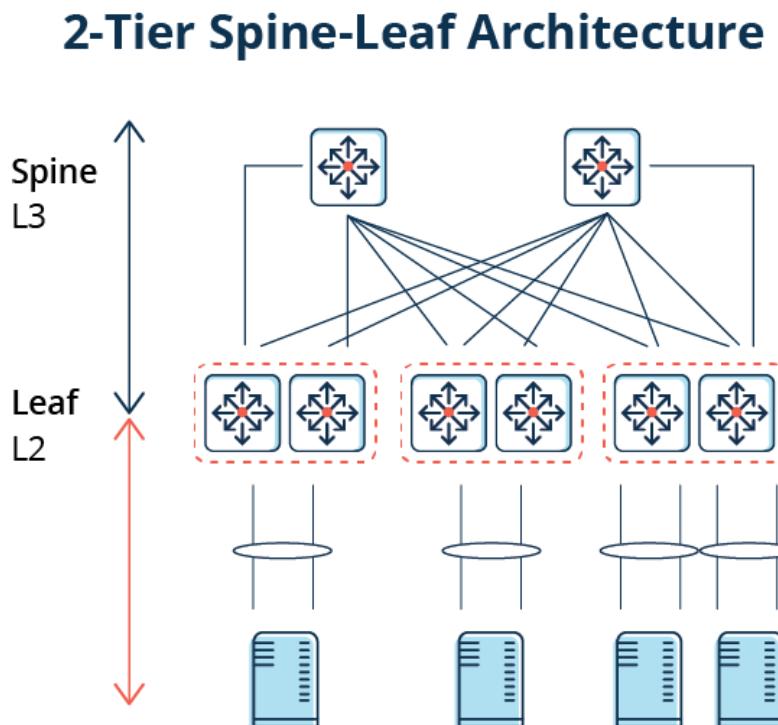


Figure 4.1: Spine-leaf architecture schema (from Arubanetworks.com)

A **spine-leaf** architecture is data center network topology that consists of two switching layers: a spine and leaf. It ensures traffic is always the same number of hops from its next destination, so latency is lower and predictable (fixed).

Capacity also improves because STP is no longer required. While STP enables redundant paths between two switches, only one can be active at any time. As a result, paths often become oversubscribed. Conversely, spine-leaf architectures rely on protocols such as *Equal-Cost Multipath* (ECMP) routing to load balance traffic across all available paths while still preventing network loops.

Spine-leaf allows *scale-out* opposed to *scale-up*, by adding additional spine switches, ultimately increasing capacity.

4.2.3 Full fat tree

In a —full?— **fat tree**, branches nearer the top of the hierarchy are ”fatter” (thicker) than branches further down the hierarchy. In a telecommunications network, the branches are data links; the varied thickness (bandwidth) of the data links allows for more efficient and technology-specific use.

Full-fat tree is rarely needed.

4.3 Virtualization

With VLAN frames are extended by 4 bytes. Every switch nowdays automatically sets the **VLAN_ID** to 1; if the field is not existent, it is appended, making an **tagged** an **untagged** frame.

Switches ensure that data cannot spill/leak from a VLAN to another. VLAN became largely of use when 10Gbit connection came out, because only 1Gbit was a too constrained bandwidth to be splitted into multiple VLANs.

VLAN are used to partition the traffic at data link layer without having to redo the fabric. They are particularly useful in cloud environments.

4.4 Network Administrator POV

The switch is split in two planes:

- ◊ **Control Plane**

This plane is necessary to configure the data plane to make it behave according to our needs. Here there is an *OS*, which used to be proprietary with a functioning fitting a specific network configuration, but nowdays they are usually more configurable and may even be *open OS*.

Dell's switches now have an *open OS* on board.

- ◊ **Data Plane**

Here lies the chip responsible to perform all the data link operations required, runs protocols, handles VLANs, etc.

OpenFlow allows us to manage the flow table inside of a switch.

The two planes are linked by a low-bandwidth PCIe.

It is possible to use a very fast and simple —reduced number of keystroke down to the strict necessary ones (e.g. `en` instead of `enable`)— CLI to program a switch. It is also possible to create a script file to be automatically executed by the switch at boot time.

Prof. Cisternino performed a demo of this in class.

Interestingly, the behaviour of the `netsh` command in Windows is very similar to the one of a switch.

4.5 SDN

Software Defined Networking is a new approach to networking that uses software-based controllers or application programming interfaces (APIs) to communicate with the underlying hardware infrastructure and direct traffic on the network.

The problem was that the network infrastructure was “ossified” and not programmable. SDN allows to program the network, and to make it more flexible and adaptable to the needs of the applications, without having to disrupt the existing infrastructure.

The key idea proposed in the OpenFlow article, which eventually became a standard, is to separate the control plane from the data plane, and to have a controller that can program through an API the data plane, where the **Flow Table** resides.

An interesting use of OpenFlow was implemented by a University and called Sandwich firewall, which consisted in routing the first part of the stream through a firewall and if the stream was not malicious, it was routed directly to the destination, otherwise it was dropped.

Latency-sensitive

Some workloads are called *latency-sensitive*, making the latency introduced by TCP-IP stack a problem. Inside a datacenter nowadays the typical latency is sub microsecond.

InfiniBand is a fabric technology that allows to have a very low latency, and is used in HPC¹ environments. *OmniPath* is a technology that is similar to InfiniBand, but is more scalable.

Fibre Channel switches are used in storage area networks, and are used to connect storage to servers CPUs. They are used in datacenters, but not for networking.

¹High performance computing

Chapter 5

Storage

Data Loss

“Storage is crucial because, if a switch fails, or a server fails, the service will be interrupted, but the data will still be there. If the storage fails, the data will be lost.” -Prof. Cisternino

Data is the most important of a system. Since data loss is **permanent**, the storage is completely different from computing or networking.

Historically the storage was the slowest part of the system, *ms* against *ns* of the CPU. Today, with SSDs, the gap is considerably reduced to *us*.

NVMe stands for *Non-Volatile Memory Express*, and is a protocol (*not a HW component!*) that allows to access the storage directly from the PCIe bus, without having to go through the SATA controller. This allows to have a much higher throughput, and a much lower latency.

Optane was a technology developed by intel which is now end of life

SSDs were invented by Toshiba back in 1980, but they were not popular for almost 30 years, until they eventually became cost-effective. Sometimes extra size in SSDs is used for redundancy, to increase the lifespan of the disk e.g. on a 30TB disk, only 10TB are used, the rest is used for redundancy, extending x3 the lifespan of the disk.

Why would a 15TB disk be better than a 27TB disk?

Assume the same performance, and the same price.

It would be preferable because it would take less time to extract all the data from the disk¹, since it is smaller.

However, large capacity drives are used for *cold storage*, where the data is not accessed frequently, speed is not a priority, and even if the data is accessed, only a portion of the disk is needed at a time; in case of failure and thus needing to retrieve an entire backup, the time taken to retrieve the data is not a priority, since this —hopefully— happens only “once”.

5.1 SSDs - QLC and TLC

TLC stands for *Triple Level Cell*, and QLC stands for *Quad Level Cell*. The difference between the two is the number of bits stored in each cell. The more bits stored in each cell, the cheaper the disk is, but the slower it is. The more bits stored in each cell, the more difficult it is to read and write the data, and the more difficult it is to keep the data stored in the cell.

¹i.e. taking advantage of the space provided

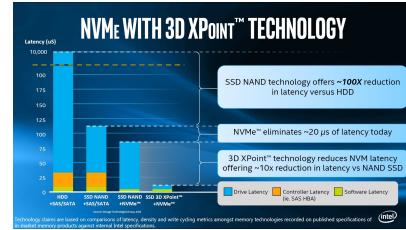


Figure 5.1: Storage types comparison

Generally QLC disks are used for cold storage, while TLC disks are used for hot storage. TLC in general is more reliable than QLC, has a longer lifespan and better performance, however they cost more.

5.2 Latency

A mechanical hard drive introduces 2.71% of latency when reading, for instance, 40MB of data. Optane can perform 416 accesses in the same time needed by a mechanical hard drive to perform 1 access. It looks like the latency in this latter case is negligible. Someone may be tempted to reduce the size of read/write operations and perform multiple smaller ones, since “it’s free”.

5.3 Checkpoints

It’s unpractical for a system to go down after 5 months. For this reason it is necessary to have checkpoints, which are points in time where the system can be restored to. The system can be restored to the last checkpoint, and the data that was written after the checkpoint can be re-applied. This is similar to what happens to applications on smartphones are closed and then re-opened, the application is restored to the last checkpoint.

5.4 RAID

RAID stands for *Redundant Array of Independent Disks*. It is a technology that allows to combine multiple disks into a single logical unit, in order to increase the performance, the reliability, or both. There are different levels of RAID, each with different characteristics.

Historically *Redundant Array of Inexpensive Disks*, because it was more common for disks to eventually fail, so RAID was the only countermeasure to this. Today, disks are more reliable, so RAID is used more for performance reasons.

In RAID, **XOR** is used to calculate the parity of the data. The parity is used to recover the data in case of a disk failure. The parity is calculated by XORing the data of the disks. The parity is stored on a separate disk, called the parity disk. The parity disk is used to recover the data in case of a disk failure.

5.5 Network sharing

SMB/CIFS is a protocol that allows to share files over the network. It is used by Windows, but it is also supported by Linux and MacOS. NFS is a protocol that allows to share files over the network, it is used by Linux and MacOS, but it is also supported by Windows.

NFS is faster than SMB, but it is also less secure. SMB is slower than NFS, but it is also more secure.

NAS instead are devices that are connected to the network, and that are used to store files. They are used to store files that are accessed by multiple users, and that need to be accessed from multiple devices. NAS devices are used to store files that are accessed by multiple users, and that need to be accessed from multiple devices. NAS devices are used to store files that are accessed by multiple users, and that need to be accessed from multiple devices.

HBA stands for *Host Bus Adapter*, and is a device that allows to connect a computer to a storage device. It is used to connect a computer to a storage device, and to allow the computer to access the storage device.

When we talk about **capacity**, there are two measures which we can refer to:

1. **Scale-up**: adding more disks to the same server
2. **Scale-out**: adding more servers to the same network

SAN stands for *Storage Area Network*, and is a network that is used to connect multiple storage devices to multiple servers. It is used to connect multiple storage devices to multiple servers, and to allow the servers to access the storage devices. It is used to connect multiple storage devices to multiple servers, and to allow the servers to access the storage devices.

SAN was, before SSDs, one of the datacenter pillars. Its architecture included a “Head” to which drives were attached, and the head was connected to the network. The head was used to manage the drives, and to allow the servers to access the drives.

When SSDs became popular, the head became a bottleneck, because it was not able to keep up with the speed of the SSDs (Recall that 4 SSDs are enough to saturate a 10Gbit link, See Sec. 3.1.1). For this reason, the head was removed, and the drives were connected directly to the network. This is called **DAS**.

5.5.1 Synchronization Software and its Price

The “storage guy” must ensure that there is no condition under which can happen data loss, because it is never an option. It is also important to have powerful **synchronization algorithms**, which must allow data to be copied and synchronized in multiple locations without disrupting performance and handling concurrency; such software is typically *costful*.

It is difficult nowdays to establish what is the “right” price for software. The shift from highly specialized and costful hardware to general hardware-plus-software, gave the software, which still a non-physical entity, increasingly more value, perhaps even too much.

5.6 Snapshots, Compression and other features

5.6.1 Storage Provisioning

Storage provisioning is the process of assigning storage to a server. It is used to assign storage to a server, and to allow the server to access the storage. To decide how much storage to assign to a server, usually the architect overbooks the storage, even beyond an estimation of how much storage it will need in the future.

Besides, available space may decrease over time. **Snapshots** are to blame in this case. Snapshots consists in saving the differences between the current state of the data and the previous state of the data. This allows to recover the *overwritten* data in case of a failure, but it also takes up space. The more snapshots are taken, the more space is taken up. The more space is taken up, the less space is available for the data.

5.6.2 Compression

Compression grants less space to be used, but it also requires more CPU power. However note that also allows to save some **bandwidth**, which we know to be critical. *Searching* in compressed data is not trivial, but there are tools to do it, such as the [FM-index](#).

5.6.3 Pools and LUNs

Storage pools are used to combine multiple storage devices into a single logical unit, in order to increase performance and reliability. **Storage LUNs** define a storage partition and are used to assign storage —a portion of the pool— to a server, and to allow the server to access the storage, using ACLs.

SCSI is a protocol whose idea is to create a BUS of drives to be accessed together. It is an old protocol, designed in 1979 for small computers, but it is still used today, because it is very reliable. The key idea was for multiple drives to share the same physical flat cable.

It had been “deprecated” in favor of **NVMe**, but it is still used today, because it is very reliable.

5.7 Hyperconverged Infrastructure

SAN started to create a sensible bottleneck, so designers started to “move drives towards the servers”. **DAS** stands for *Direct Attached Storage*, and is a technology that allows to connect multiple storage devices to a single server, in order to increase the performance, the reliability, or both. The limitations is that you can only attach up to 2 or 3 drives to a server.

An idea came out to use the servers’ internal drive to build a Storage Area Network, and this is called **VSAN**.

HCI stands for *Hyperconverged Infrastructure*, and is a technology that allows to combine multiple servers into a single logical unit, in order to increase the performance, the reliability, or both. The idea was born to allow a scale-out architecture, where you can add more servers to the network.

The **Hypervisor** is the software that allows to run multiple virtual machines on a single server. There should be some locality between the VM and the storage, because the VM should be able to access the storage quickly. **read** operations are always performed locally on local drives; **write** operations instead sometimes require to retrieve a remote piece of data.

5.7.1 Riak

Riak is a distributed database that is used to store data in multiple locations.

Recently it has been recognized that using general purpose hardware is no longer a feasible option.

Chapter 6

Computing

“In a server how many OSs are ran at the same time?”

2 in general, one is “Base Management Console”¹.

The BMC is a full OS running in a board which executes also when the server is off, but attached to a power supply. It is a component which allows you to manage the server as if you were physically handling the server.

Prof. Cisternino display iDRAC (Dell’s BMC) in class. It is a web interface which allows you to manage the server, check its status, and even turn it on and off.

It is also possible to access a console, which is a virtual console, which allows you to interact with the server as if you were physically there with keyboard and mouse attached; such console also allows to install a new OS by uploading an **iso** and make the server boot from it as if it was attached to it.

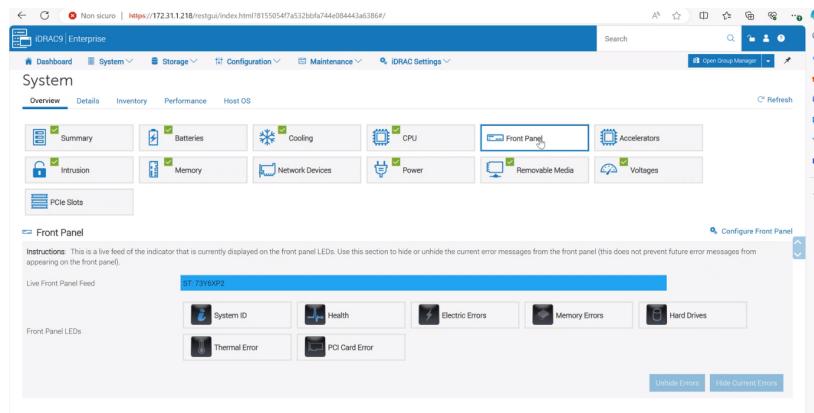


Figure 6.1: DEMO Interface displayed by prof cisternino in class
It is possible to remotely control and check the server’s status.

CPU Affinity of a RAM bank indicates which CPU is connected to that bank.

The BMC typically has a dedicated network interface, which is used to connect to the server, separated from the standard network interface. Redfish is a standard which is used to manage servers. It is a RESTful API which allows to manage servers and automate some tasks.

Predict Storage failure

A disk may fail without any prior notice, at any time, just like a heart attack. However there are some signs which may indicate that a disk is about to fail; these are detected by the *Smart* technology. Also AI may be used to predict disk failure.

¹May have other names, but this is a common one, used by **Supermicro**

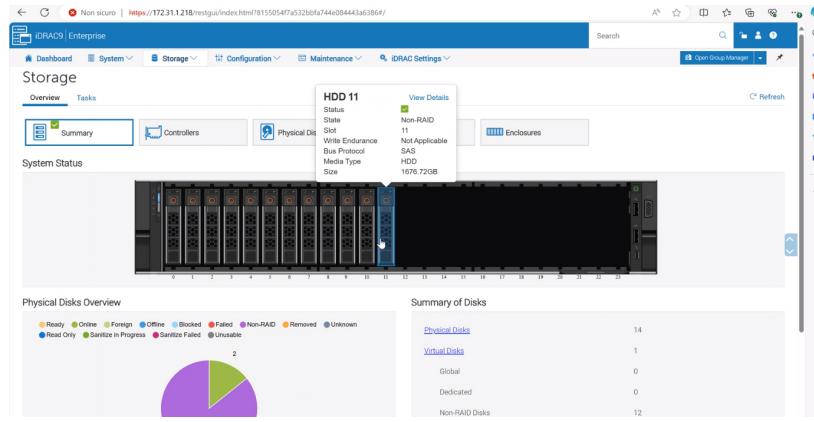


Figure 6.2: Monitoring storage
SAS bus protocol is used for storage devices.

No physical security means no security at all

The BMC is very useful because allows for administrators to manage server remotely, without having to physically access the server. This is not only “handy”, but often necessary, since the physical security of the datacenter must be high, and not everyone should be allowed to access the server room.

Measuring Bus Speed

PCIe speed, as well as CPU speed is measured in GT/s, which stands for *Giga Transfers per second*. It is a measure of how many transfers can be performed in a second.

6.1 Knights Landing and high performance computing

Knights Landing is an old multi —up to 72— core architecture is designed to be used in supercomputers. The memory had a super high bandwidth, to avoid bottlenecking the many cores inside, since such memory is shared among them.

NUMA is a technique used to avoid bottlenecking in multi core architectures. It is a technique which allows to have multiple memory banks, each one connected to a subset of the cores. This way, each core can access its own memory bank without having to wait for the others to finish accessing the shared memory.

6.2 Rings

Bachelor's professors fooled us into thinking that CPUs have two operating modes, *user* and *kernel* mode. Sadly, this ain't true, it is an abstraction. In reality, CPUs have 4 rings, which are used to separate the different levels of privilege. The higher the ring, the higher the privilege level. The kernel runs in ring 0, while the user runs in ring 3.

Nowdays there are multiple units in the CPU, which are used to execute instructions, and there is a head unit which decides which instruction to execute next and on which unit.

Chiplets are a way to increase the number of cores in a CPU. They are small chips which are connected to the main CPU. Even at CPU the “general-purpose” methodology is not feasible anymore, and the CPU is divided into multiple units, each one specialized in a specific task.

6.3 Random notions on Hardware

GPUs became of paramount importance for datacenter in the last years, mostly because of the rise of AI and machine learning. They are used to perform parallel computations, and are much faster than CPUs for such tasks. However, they are very expensive.

NPUs (Neural Processing Units) are a new kind of processors, which hardware acceleration for AI and machine learning tasks. They are much cheaper than GPUs, and are becoming more and more popular.

[TOP500](#) is a list of the 500 most powerful supercomputers in the world. It is updated twice a year, and is used to compare the performance of supercomputers.

Chapter 7

Virtualization

Virtualization consists in virtualizing hardware resources, such as CPU, memory, storage, and network interfaces. This allows to run multiple operating systems on the same physical machine, which is called *host*.

It is not equal to *emulation* which consists in simulating hardware, and is much slower than virtualization.

TODO more on this

Virtualization is a strong way of isolating things.

There are two kind of virtualization systems:

1. VirtualPC (Microsoft), VirtualBox (Oracle), VMware Workstation (VMware), Parallels (Apple) : these are desktop virtualization systems, which are used to run multiple operating systems on the same physical machine. These solutions aim to provide “interactive” computers, with a GUI, peripheral support, etc.
2. VMware ESXi, Microsoft Hyper-V, KVM, Xen : these are server virtualization systems, which are used to run multiple servers, typically GUI-less, on the same physical machine.
Hypervisors introduce a **crucial** piece of software called **Virtual Switch**, which is responsible for managing the network of the virtual machines. The virtual switch’s uplink is the host’s physical network interface.

Similar to the ones in storage systems, there are **checkpoints**, which are used to save the state of a virtual machine at a certain point in time. This is useful to revert to a previous state in case of problems.

7.1 Network

VMware is the leader in virtualization, but lately they have been changing pricings and licensing, which has made some customers unhappy.

Broadcom is chip manufacturer, and we might end up with virtualization software already inside the chip.

VMware virtual switch is called **vSwitch**. It is a software-based switch that is responsible for managing the network of the virtual machines.

Every network interface of a virtual machine has its own MAC address, and may be connected to a vSwitch.

An hypervisor may handle multiple vSwitches.

From a network point of view, a virtual machine is just like a physical machine, assuming that the network card is in **promiscuous** mode, it can see all the traffic that is going through the vSwitch.

7.2 Live Migration

Hypervisors provide also the migration of virtual machines from one host to another, which is called **vMotion** in VMware. This is useful for load balancing, maintenance, etc. In Windows Hyper-V, this primitive is called **Live Migration**.

The migration is performed *without any service interruption*, only some degradation in performance and network latency. This also allows to move virtual machines from one host to another in case of hardware failure or physical

maintenance. Besides, by redundancy VMs we may also live switch from an older to a newer version of the software, without users noticing.

Live migration can be performed like a context switch, by saving the state of the virtual machine and restoring it on the other host. This is possible because the virtual machine is not aware of the underlying hardware, and the hypervisor is responsible for managing the hardware resources.

Assuming that the disk is shared, the migration is performed like so:

1. The memory (and the registries) of the virtual machine is copied to the other host
2. If the copied memory is sufficient, the new VM starts to run on the other host
3. When data from the older memory host is requested, the virtual machine is paused, and the memory is copied again to the other host

vSwitches are also migrated, so that the network configuration is preserved. The old vSwitch may communicate with the new one, and if needed forward packets, until ARP tables are updated.

7.2.1 Replication

Replication is the process of copying data from one host to another, in order to have a backup in case of failure. Happens the same way as live migration, but the virtual machine is not running on the other host.

Chapter 8

Containers

A VM is better than a process because it provides **isolation**: a typical problem in cybersec is that if an attacker cracks a process, he may access the whole system; with a VM, the attacker can only access the VM, not the host. However, a VM introduces overhead due both to the hypervisor and to the OS (cache, kernel, storage management...).

The idea is to tell a process that its root is a subdirectory of the host's root, resulting in a strong isolation.

Docker provides a *differential filesystem*, which is a filesystem that is a diff of the host's filesystem.

Docker has become the de facto standard for containers, but there are other solutions like **LXC** (Linux Containers) and **rkt**. A Dockerfile contains the information to build a container.

One of the key differences between a VM and a container is that containers **do not have a virtual switch**. A container uses the same MAC address of the host.

Docker containers are processes, and only see a portion of the host's filesystem.

Inside a Dockerfile you may create temporary containers by exploiting multiple images and lastly build the resulting slimmed image.

8.1 Docker compose

Docker compose is a tool to define and run multi-container Docker applications. It uses a YAML file to configure the application's services, networks and volumes. With a single command, you can create and start all the services from your configuration.

Kubernetes is a more advanced tool for container orchestration, way more complex than Docker compose, it allows to manage thousands of containers, providing fundamental scalability features.

8.2 Docker security

An attack is to put the machine under heavy workload and observe from the container the performance to infer what other processes may be. This is called **side channel attack**.

Google has thousands of VMs and each runs a *container for each query*.

Chapter 9

Cloud

Cloud came out as a business model, not as a technology. It was needed to handle peak of requests and to allow scalability, without oversizing Infrastructures.

e.g. Amazon needs to handle way more requests on Christmas than on a normal day.

So, Cloud was a mean to reduce the cost of the ICT infrastructure.

Resource pooling is the key concept of Cloud. It means that the services are provided to users using a multi-tenant model, with physical and virtual resources being dynamically allocated and deallocated according to the demand. Cloud was needed also to provide rapid elasticity, meaning that capabilities may be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the customer it means that the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

Benefits of Cloud:

- ◊ **Business agility**
 - Quick resource provisioning
 - Facilitates innovation
 - Reduces time to market
- ◊ **Reduces IT costs**
 - Reduces up-front capital expenditure (CAPEX)
 - Improves resource utilization
 - Reduces operational expenditure (OPEX)
- ◊ **High availability**
 - Ensure resource availability based on customer's requirements
In RAI, prof. Cisternino experienced people complaining because their servers' CPUs were running at 98% of their capability, and they wanted to exploit also the remaining 2%, because "they paid for it".
 - Enables fault tolerance
Recall active-active, active-passive, etc. configurations.
- ◊ **Business continuity**
- ◊ **Flexible Scaling**
- ◊ **Flexibility of Access**
- ◊ **Application Dev and Testing**
- ◊ **Simplified infrastructure management**
- ◊ **Increased collaboration**
- ◊ **Masked complexity**

Cloud has the magic power of decoupling the software from the hardware.

Disadvantages of Cloud:

- ◊ Vendor lock-in
- ◊ Privacy
- ◊ Your software depends on someone else

- ◊ Legislation is complicated
 - In EU public administration data, must be stored in the EU.
- ◊ ... TODO

9.1 Cloud Service Models

- ◊ **IaaS** (Infrastructure as a Service)
 - Provides virtualized computing resources over the Internet
 - Examples: Amazon EC2, Google Compute Engine, Microsoft Azure
- ◊ **PaaS** (Platform as a Service)
 - Provides a platform allowing customers to develop, run, and manage applications without the complexity of building and maintaining the infrastructure
 - Examples: Google App Engine, Microsoft Azure, Heroku
- ◊ **SaaS** (Software as a Service)
 - Provides software applications over the Internet
 - Examples: Google Apps, Microsoft Office 365, Salesforce

9.2 Cloud Deployment Models

- ◊ **Public Cloud**
 - Owned and operated by third-party cloud service providers
 - Deliver computing resources over the Internet
 - Examples: Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform

It does **not** mean that the data is public. It means that the cloud services are accessible to the public.
- ◊ **Private Cloud**
 - Operated solely for a single organization
 - Managed by the organization or a third party
 - *On-premise* or *off-premise*

It does **not** mean that the data is private. It means that the cloud services are accessible only to the organization e.g. *UniPi*.
- ◊ **Hybrid Cloud**
 - Composition of two or more clouds (private, community, or public) that remain unique entities but are bound together, and resources may be moved from one cloud to another (with some performance cost obviously)
 - By standardized or proprietary technology that enables data and application portability
- ◊ **Community Cloud**
 - Shared infrastructure for specific community
 - Managed by organizations or third party
 - On-premises or off-premises

9.3 Control Layer

The control layer is responsible for managing the resources and the allocation of the resources to the virtual machines.

Definition 9.1 (Control Layer) “*The control layer is important because it’s the way pool the resources set and see all the resources in a coherent way so it’s a sort of a software layer that hides the differences and gives you primitives (such as “I need a VM, I don’t care where, but I need one”).*”

Note that you cannot allocate more virtual cores than the physical ones —same applies to memory—, but you can allocate smaller pieces so you can create a resource pooling of resources that can be taken partially (assuming that they can run on a single node), but making you perceive it as a pool of resources.

Layers above the control layer have no clue where workloads are running, they just know that they do so somewhere, it is completely up to the control layer to manage where and how.

The steps towards provisioning a resource are three

1. **Resource Discovery**
2. **Resource Pooling**
3. **Resource Provisioning**

A key component in the control layer is a Unified Manager software, which handles, by means of APIs, the tools associated to

- ◊ Compute System management
- ◊ Fabric management
- ◊ Storage System management

9.3.1 Resource Discovery

The control layer enables **unified manager** to learn about resources that are available for service deployment Provides visibility to each resource Enables to manage cloud infrastructure resources centrally

9.3.2 Resource Pooling and Provisioning

A unified manager at control layer allows to categorize in **grading pools** resources and identity pools based on predefined criteria. This helps creating variety of services decoupled from the actual hardware where they will run, but still providing choices to consumers on the type—and amount—of hardware they get (e.g. “0.5TB Flash, 4TB SATA, 1TB FC”). Multiple grade levels (e.g. “Gold”, “Silver”, “Bronze”) may be defined for each type of pool, where costs/prices of resource pools differ depending on grade level.

Resource provisioning starts when a user requests a service.

When I create a VM, i can choose the template (e.g. “Windows 2016”, “Ubuntu 18.04”), hardware, extensions, and lastly I will be asked to select a Host. At that point the system polls the control layer to see which hosts are available and which are not, and then rank them. Then I'll be asked for the chosen host the estimated workload on CPU (percentage), memory and disk. Set the host, the control software provides information regarding networking.

Lastly, it is important to recall that **Resource monitoring** is fundamental to keep track of the resources used and to prevent over-provisioning.

9.3.3 Control Software demo

Prof. Cisternino demonstrated a Control Software he uses for the UniPi Cloud, where he can see the resources available and the resources allocated to the VMs.

In the “VM and Services” view, the software allows to see the different Clouds associated to Polo 1, Polo 2, etc. and the resources allocated to each of them.

There is also another inner view to check VM networks and the actual hosts where the VMs are running.

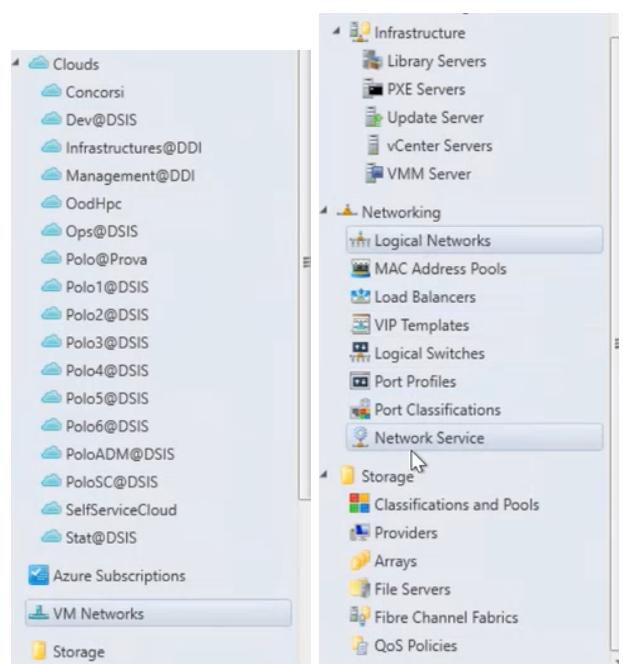


Figure 9.2: VM and Services view

He may even open a Powershell terminal on a VM.

This software allows him to manage about 1400 VMs.

9.4 Service Layer/Service Orchestration Layer

Definition 9.2 (Cloud Service) *IT resources that are packaged by the service providers and are offered to the consumers*

This means that deploying a service, does not mean simply deploying a VM, but a bunch of them, and also configuring it, installing software, etc.

Service Layer enables defining services in a service catalog, and provides a self-service portal for users to request services (enables on-demand and self-provisioning).

Essentially, the catalog is the DB while the cloud portal is the web interface for it.

9.4.1 Service Orchestration Layer

Service Orchestration layer implements the process of integrating services to support the automation of business processes: actuates the policies and the requests automatically from the user.

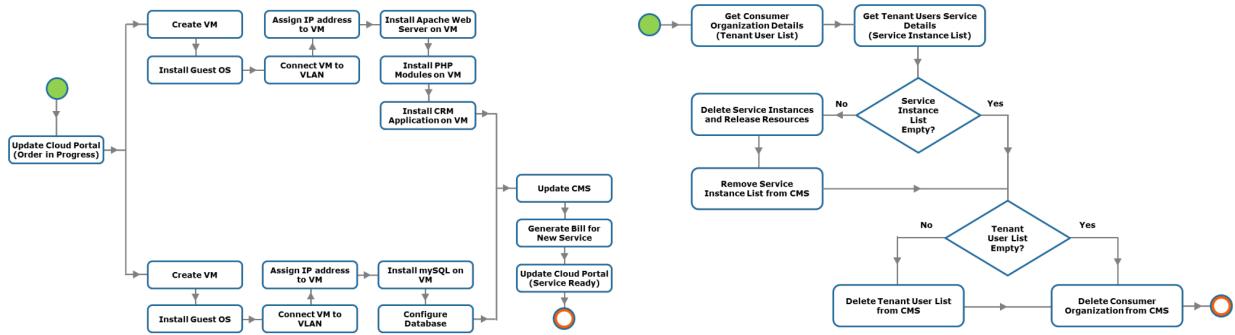


Figure 9.1: Service orchestration layer use cases. On the left, provisioning a CRM application, while on the right a tenant removal

Definition 9.3 (Tenant) *A tenant is a user of the cloud, and the cloud provider must ensure that the tenant is isolated from the others. This is done by means of **multi-tenancy**.*

UniPi.it is a tenant for Microsoft Azure.

9.4.2 Deeper into Services

We may generalize the lifecycle of a service as it is depicted in Figure 9.2, split in 4 main phases:

1. **Planning**
 - i. Assessing service requirements
 - ii. Developing service enablement roadmap
 - iii. Establishing billing policy
2. **Creation**
 - i. Defining service template
 - ii. Creating orchestration workflow
 - iii. Defining service offering
 - iv. Creating service contract

3. **Operation**
 - i. Discovering service assets
 - ii. Managing service operations
4. **Termination**
 - i. Natural termination by contract agreement
 - ii. Initiated termination by a provider or a consumer

Having defined what a Service is 9.2, we can now define the **Service Layer** as the layer that provides the services to the users.

Step 2.iv refers —also— to the Service Level Agreement, which basically is the legalese version of the set of resources that we are allocating for a user.

Aside from the SLA, other parameters are discussed such as pricing, termination of service and possibly other configuration aspects.

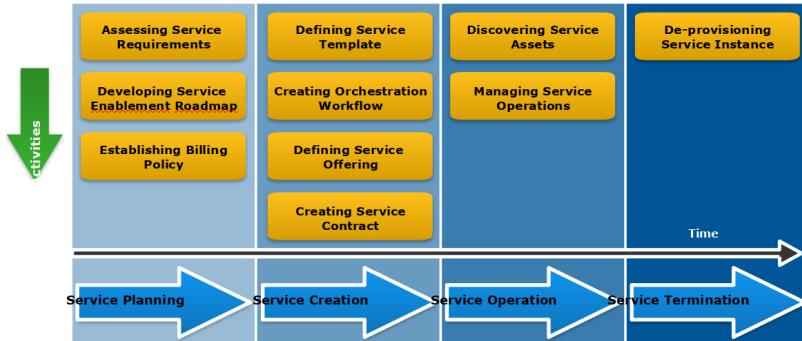


Figure 9.2: Service Lifecycle schema

"If you are smart enough you may trick the user"

Amazon tricked a user by establishing a SLA that said that the user would have a 99.999% uptime, but they considered uptime even when the service was both not available and *not* requested by the user.

9.5 Business Continuity

Definition 9.4 (Business Continuity) *The capability of an organization to continue delivery of products or services at acceptable predefined levels following a disruptive incident.*

...or ...

BC entails preparing for, responding to, and recovering from service outage that adversely affects business operations

SPOFs may occur at component level, or at site or data center level.

The key to avoid SPOFs is to have redundancy, which may be achieved by means of **replication** or **backups** (more on this later).

Definition 9.5 (Compute Clustering) *A technique where at least two compute systems (or nodes) work together and are viewed as a single compute system to provide high availability and load balancing.*

Enables service failover in the event of compute system failure to another system to minimize or avoid any service outage.

The implementation may be *active-active* or *active-passive*.

9.5.1 Data Protection

A **backup** is not simply a copy of the current data to be used in case a disk fails. In case a ransomware attack occurs, the copy will be encrypted as well, or even more trivially, if a service has a bug and it corrupts data, also the copy would contain bad data.

"Backup must allow to travel back in time."

The two critical terms are *Recovery Time Objective (RTO)* and *Recovery Point Objective (RPO)*¹. They refer to the time it takes to recover from a disaster and the amount of data that can be lost respectively.

Backups are typically done incrementally, meaning that starting from a full backup, then only differences are stored. However, saving storage in this way leads to a more complex recovery process, as all the incremental backups must be applied to the full backup to recover the data, possibly considerably increasing the RTO.

To overcome the issue, a full backup is done every now and then e.g. a week is common practice, and incremental daily backups are done until the next full backup.

This fixes the RPO to 1 day, while the RTO still may vary depending on bandwidth, storage speed, and most importantly size and amount changes throughout time; typically it is days (?) or hours.

¹Point in time

Chapter 10

Supercomputers

Recall that **TOP500** is the list of the 500 most powerful computer systems in the world. The list is updated twice a year and the first one was published in June 1993. The list is compiled by Hans Meuer of the University of Mannheim, Erich Strohmaier and Horst Simon of NERSC/Lawrence Berkeley National Laboratory, and Jack Dongarra of the University of Tennessee. The TOP500 project aims to provide a reliable basis for tracking and detecting trends in high-performance computing and to provide a basis for tracking the progress of the supercomputing industry.

10.1 Supercomputers in the TOP500 list

It is interesting that **Microsoft** has applied to have a supercomputer in the TOP500 list. It is ranked 11th in the list and is located in the United States. The supercomputer is called *Azure* and is operated by Microsoft. It has 2,596,016 cores and a performance of 27,580.0 TFlop/s. The supercomputer is based on the HPE Cray EX supercomputer and is used for commercial purposes.

Leonardo is the most powerful supercomputer in Europe and is located in Italy. It is ranked 7th in the TOP500 list and is operated by CINECA. The supercomputer has 14,000,000 cores and a performance of 32,800.0 TFlop/s. The supercomputer is based on the HPE Cray EX supercomputer and is used for research purposes.

“Alps is really really important” -prof. Cisternino

Alps is the most powerful supercomputer in the world and is located in Switzerland. It is ranked 1st in the TOP500 list and is operated by the Swiss National Supercomputing Centre. The supercomputer has 2,289,024 cores and a performance of 63,460.0 TFlop/s.

According to Cisternino it is of utmost importance because its CPU is designed by NVIDIA and it is the first supercomputer to use this technology. The CPU is called *Grace Hopper* and is based on the ARM architecture. The CPU is designed for high-performance computing and is used for research purposes.

It may represent a turning point in the CPU architecture choice, and ARM may become the new standard for high-performance computing, superseding x86.

Grace is capable of transferring up to 1Tbit/s of data between the CPU and the RAM, which is “quite a nice number”.

10.1.1 Brexit and supercomputers

Almost one third of the computers in the list are in Europe, and in the top 10 there are 3 European supercomputers (?). Since most supercomputers were made in the UK, after the Brexit Europe focused on the need to have its own supercomputers.

This is why the *Leonardo* supercomputer was built in Italy.