Infrastructure as a Service

Infrastructure as a Service, or IaaS is a service offering by most cloud providers that provides *virtual machines* and the acco
service is built.

Virtual machines

In a hurry?

Modern CPUs have several operation modes:

- Ring 3 (unprivileged) runs the application
- Ring 0 runs the operating system kernel
- Ring -1 runs the hypervisor managing serveral kernels
- Ring -2 runs the Intel Management Engine

Other components are responsible for virtualizing other hardware components. For example, the IOMMU is responsible for virtua

Virtualization is a surprisingly old technology. The first virtualized system was the IBM System/370 mainframe with the VM/3
virtualization today, but the goal was the same: separate workloads from each other.

When you think about mainframes you have to consider that these machines were *very* expensive and machine time was a
large set of data at once and then terminated.

Initially CPUs in personal computers did not have application separation. The x86 line of Intel CPUs only received the *protec
real mode* and applications could then switch into the new mode to isolate applications from each other. One such applicatio

Protected mode introduced the concept of *rings* in the CPU. The operating system *kernel* would run in ring 0, device drivers
meant the higher privilege level.

Note

Device drivers today typically run on ring 0 instead of 1 or 2.

This ring system allowed the operating system to restrict the higher ring numbers from accessing certain functions or memo
mode and could not run in the new mode.

Note

If you try and set up a really old computer game like Commander Keen in DOSBox you will realize that you have to provide the g
your sound card. This is because the game itself incorporated sound card drivers for Sound Blaster 16 or Gravis Ultrasound card

To work around the problems with protected mode the 80386 successor introduced virtual mode. The new virtual 8086 mod programs in a multitasking environment such as Windows without problems.

For instance the CPU would create a simulated *virtual* memory space the program could write to and translate the virtual ad them over for control to the kernel.

> **Note**
>
> VM86 does not capture *every* instruction the application runs in virtual mode, only the sensitive CPU instructions. This enables le

In the mid 2000's CPUs became so powerful that it made sense to not only virtualize applications but whole operating syste without CPU support only *software virtualization* could be achieved. In other words early virtualization software had to *simul* Xen required the guest operating system to run a modified kernel to facilitate them running in ring 3. Others employed a nur

Hardware vendors, of course, followed suit. In 2005 Intel added the VT-x (Vanderpool) feature to its new Pentium 4 CPUs fo 64 FX processors.

VT-x and AMD-V added new ring -1 to accommodate *hypervisors*. This new ring allowed for separation between several ope Output virtualization, network virtualization or even graphics card virtualization. These features allowed for more efficient vir

> **Note**
>
> Intel also introduced a ring -2 for the Intel Management Engine, a chip that functions as an OOBM in modern Intel chips. The ME its secrecy and power over the machine. Several bugs have been found in the ME that let an attacker hide a malware inside the

Virtualization also gave rise to Infrastructure as a Service. AWS was the first service that offered virtual machines as a servi did so that a customer could order or cancel the service using an Application Programming Interface.

This allowed customers to create virtual machines as they needed it and they were billed for it on an hourly basis. (Later on

The presence of an API makes the difference between IaaS and plain old virtual machines as a service. IaaS allows a custo

What component of the software stack runs on Ring 3 in virtual mode?

- ◯ The application
- ◯ The kernel
- ◯ The hypervisor
- ◯ The management engine

What component of the software stack runs on Ring 0 in virtual mode?

- ◯ The application
- ◯ The kernel
- ◯ The hypervisor
- ◯ The management engine

What component of the software stack runs on Ring -1 in virtual mode?

- ◯ The application
- ◯ The kernel
- ◯ The hypervisor
- ◯ The management engine

What component of the software stack runs on Ring -2 in virtual mode?

- ◯ The application
- ◯ The kernel
- ◯ The hypervisor
- ◯ The management engine

What does virtualization mean?

- ◯ Every instruction by a virtual machine is captured by the kernel and translated.
- ◯ Critical instructions like memory operations are captured or translated by the kernel.
- ◯ Critical instructions like memory operations are captured or translated by the CPU and the hyperv

Typical instance types

When the cloud became popular in the late 2000s several providers attempted to offer a service that was fully dynamic in th cores. However, this model has been phased out by most providers since it is difficult to manage such a dynamic environme

Instead most cloud providers nowadays opt to offer fixed machine sizes. To accommodate high-CPU and high RAM workloa

- **Shared CPU:** These are small instances where a single CPU core is shared between multiple virtual machines, someti the Amazon T instances) where a VM can temporarily use more CPU.
- **Standard, dedicated core CPU:** These instance types receive one or more physical cores leading to a more stable pe
- **High CPU:** These instance types are usually hosted on physical servers that have a very high CPU to RAM ratio. Acco
- **High RAM:** This offering is the exact opposite of the high CPU offering. The machines on offer here include more RAM
- **Storage:** These instance types contain large amounts of local storage (see below in the storage section).
- **Hardware-specific:** These instance types offer access to dedicated hardware such as graphics cards (GPUs) or FPGA

Automation

In a hurry?

- Cloud-init allows for running a script, or other initial configuration on virtual machines on first boot.
- It is also responsible for managing password resets when desired. It can be used to fully automate the setup of a virtual mac
- Terraform and Ansible are tools that interact with the cloud API to provision virtual machines programmatically.
- Ansible is also capable of running inside a virtual machine to configure the software within.
- Terraform requires full control of the machines it is managing and implements what's called immutable infrastructure.

As discussed before, what makes an IaaS cloud provider a cloud provider is the fact that they offer an API to automate the p Simply starting a virtual machine is not enough, the software needs to be installed in it.

Initially this problem would be solved by creating *templates* for the operating system that launches. In larger cloud setups th to a central service and fetch its manifest of software to install.

Thankfully in the last decade a lot has happened and Cloud Init has established itself as a defacto standard in the IaaS worl a virtual machine. This user data field is read by Cloud Init (or its Windows alternative Cloudbase Init) and is executed at the

A DevOps engineer can simply inject a script that runs at the first start that takes care of all the installation steps required.

Tools like Terraform or Ansible assist with managing the whole process of provisioning the virtual machines and supplying it

What is the role of cloud-init?

- ◯ It initializes a cloud account.
- ◯ It creates a virtual machine.
- ◯ It runs initial machine configuration on a virtual machine.

Virtual machine pools

In a hurry?

- Virtual machine pools automatically create and destroy machines to keep up a desired pool size.
- Some implementations also have autoscaling.

One other use of user data are virtual machine pools. Each cloud provider adopts a different name for them, ranging from ir cloud with a configuration how you would like your virtual machines to look like and the cloud will take care that the given nu deletes the machine and creates a new one.

The number of machines in a pool can, of course, be changed either manually or in some cases automatically using rules fo

Combined with the aforementioned user data this can be a very powerful tool to create a dynamically sized pool of machine

These pools are often integrated with the various load-balancer offerings cloud providers have in their portfolio to direct traff Functions as a Service offering as well allowing you to run a custom function whenever a machine starts or stops. This can

Storage

In a hurry?

- Local disks offer affordable performance at the cost of redundancy.
- Network block storage offers resilience to machine failures, but costs more to ensure the same performance. Not all NBS im
- Network file systems offer access from multiple virtual machines in parallel at the cost of performance.
- Object storage offers parallel access from multiple VMs and scalability at the cost of performance and consistency.
- Object storages are typically integrated on the application level rather than the OS level.

When it comes to data storage virtual machines work exactly like your physical machine would: there is a physical disk (or r use of a distributed storage architecture instead of using a local disk. In a distributed storage system the data isn't stored on cause a data loss.

However, a distributed storage system is generally either slower or more expensive for the same performance by several m

When we talk about storage systems we are talking about two types: block devices and filesystems. On the physical disk da which file. Filesystems organize data into *blocks* of a fixed or dynamic size and then create a database (mapping table) of w may be distributed all over the whole disk randomly so that's something the filesystem must keep track of.

Therefore we traditionally call raw disk devices *block devices*. Block devices are (with very few exceptions) only accessible synchronize their file system operations on that device. The only notable exception is GFS2. While you can use GFS2 over VM access policy. In other words, one block storage device can only ever be used by a single VM.

Local Storage

As described above the simplest and most widely supported option to store data from your virtual machine is a disk that is lo performance at a relatively low price point. The reason for that is that it is the simplest and cheapest to build.

Some cloud providers offer disk redundancy (RAID) while others don't. At any rate a hardware failure of the physical machin lost.

It is therefore very advisable to solve redundancy on top of the virtual machine, e.g. by building a replicated database setup expensive storage options and this can be a great way to save costs.

Which of the following is provided by local storage?

- ◯ Fault-tolerance in the face of a machine failure.
- ◯ High IO performance.
- ◯ The ability to move the data volume to a different machine.
- ◯ The ability to access the data volume from several machines at once.
- ◯ Data consistency.

Network Block Storage

Network block storage means a block storage that is delivered over the network. The network here can mean a traditional IP

As described before block storage is, in general, single-VM only. You can't access the files stored on a block storage device

Also note that Network Block Storage does not automatically come with redundancy. Some solutions, such as iSCSI simply provider offerings such as EBS by Amazon, however, do offer redundancy.

At any rate, using Network Block Storage does not absolve you from the duty to make backups and have a documented an

Which of the following is provided by network block storage?

- ◯ Fault-tolerance in the face of a machine failure.
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- ◯ The ability to access the data volume from several machines at once.
- ◯ Data consistency.

Network File Systems

In contrast to network block storage network file systems offer access to data not on a block level, but on a file level. Over th
and write files, and even place locks on them.

The filesystem has to keep track of which machine has which file open, or has locks on which file. When multiple machines
This means that network file systems are either much slower than block-level access (e.g. NFS) or require a great deal mor
cloud providers also offer this, for example Amazon's EFS.

Which of the following is provided by network filesystems?

- ◯ Fault-tolerance in the face of a machine failure.
- ◯ High IO performance.
- ◯ The ability to move the data volume to a different machine.
- ◯ The ability to access the data volume from several machines at once.
- ◯ Data consistency.

Object storage

Object storage systems are similar to network file systems in that they deal with files rather than blocks. However, they do n
only be read or written as a whole and they also don't have the ability to lock a file.

While object storages technically *can* be used as a filesystem on an operating system level for example by using s3fs this is

Operating system level integration should only be used as a last resort and object storages should be integrated on the app

Which of the following is provided by object storages?

- ◯ Fault-tolerance in the face of a machine failure.
- ◯ High IO performance.
- ◯ The ability to move the data volume to a different machine.
- ◯ The ability to access the data volume from several machines at once.
- ◯ Data consistency.

Which storage type is Amazon's EBS?

- ◯ Local disk
- ◯ Network block storage
- ◯ Network filesystem
- ◯ Object storage

Which storage type is Amazon's EFS?

- ◯ Local disk
- ◯ Network block storage
- ◯ Network filesystem
- ◯ Object storage

Which storage type is Ceph RBD?

- ◯ Local disk
- ◯ Network block storage
- ◯ Network filesystem
- ◯ Object storage

Which storage type is iSCSI?

- ◯ Local disk
- ◯ Network block storage
- ◯ Network filesystem
- ◯ Object storage

Which storage type is S3?

- ◯ Local disk
- ◯ Network block storage
- ◯ Network filesystem
- ◯ Object storage

Network

The next big topic concerning IaaS services is networks. Before we go into the cloud-aspect let's look at how the underlying
familiarize yourself with the basics of computer networking, such as the Ethernet, IP and TCP protocols as you will need the

So, let's get started. Imagine a data center from the first lecture. Your task is to build an IaaS cloud provider. You put your se
connected to the Top-of-Rack switches (yes, two for redundancy) using 10 GBit/s network cables. The switches are themse

This sounds like a lot of bandwidth available but keep in mind that your virtual machines get assigned to the physical machi
latency between two virtual machines. Generally cloud providers only state the theoretical bandwidth of the connection a vir
virtual machines.

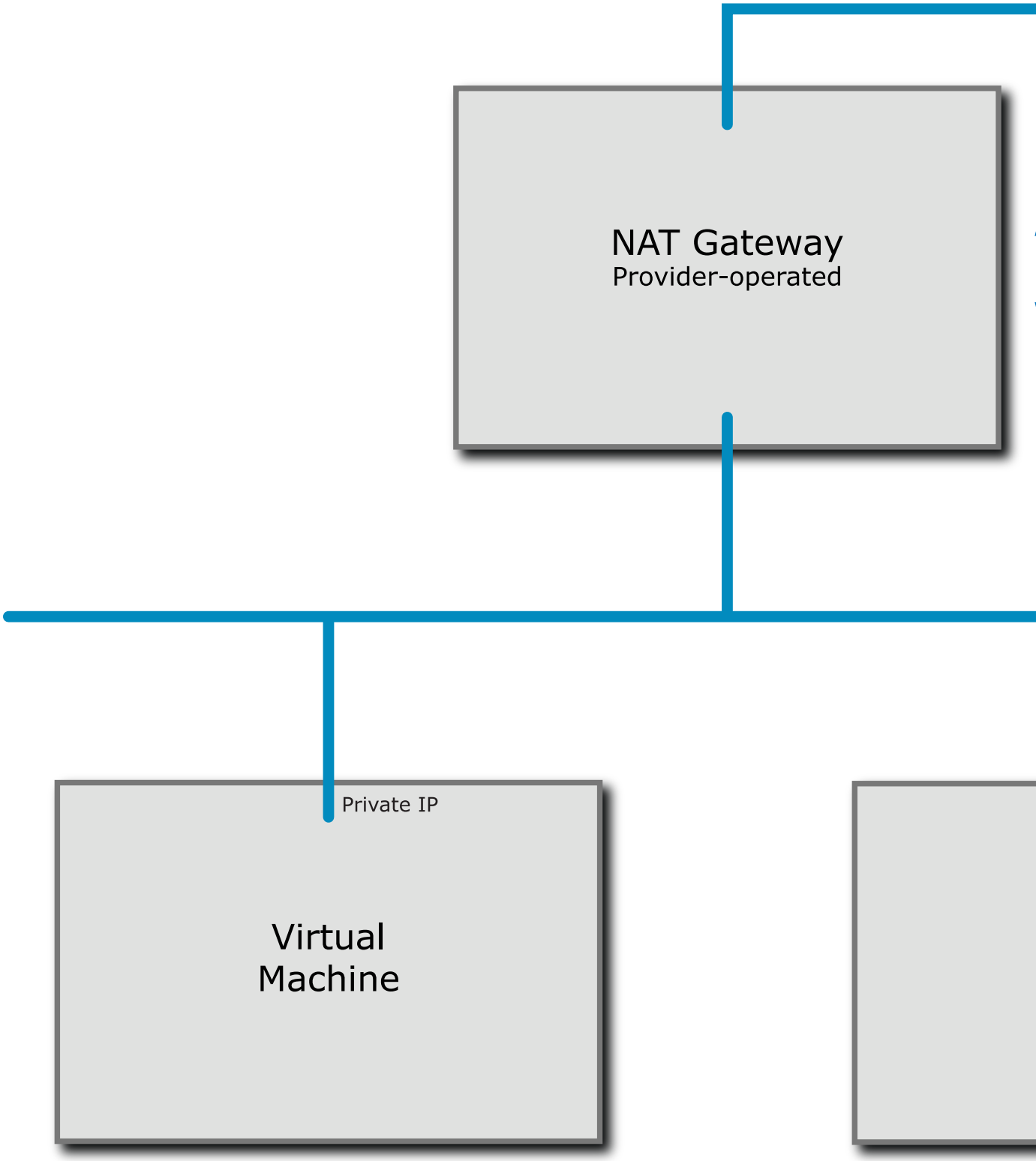
This is part of the reason why in the cloud scaling horizontally (adding more machines) is preferred rather than creating hug

Network architectures offered by cloud providers

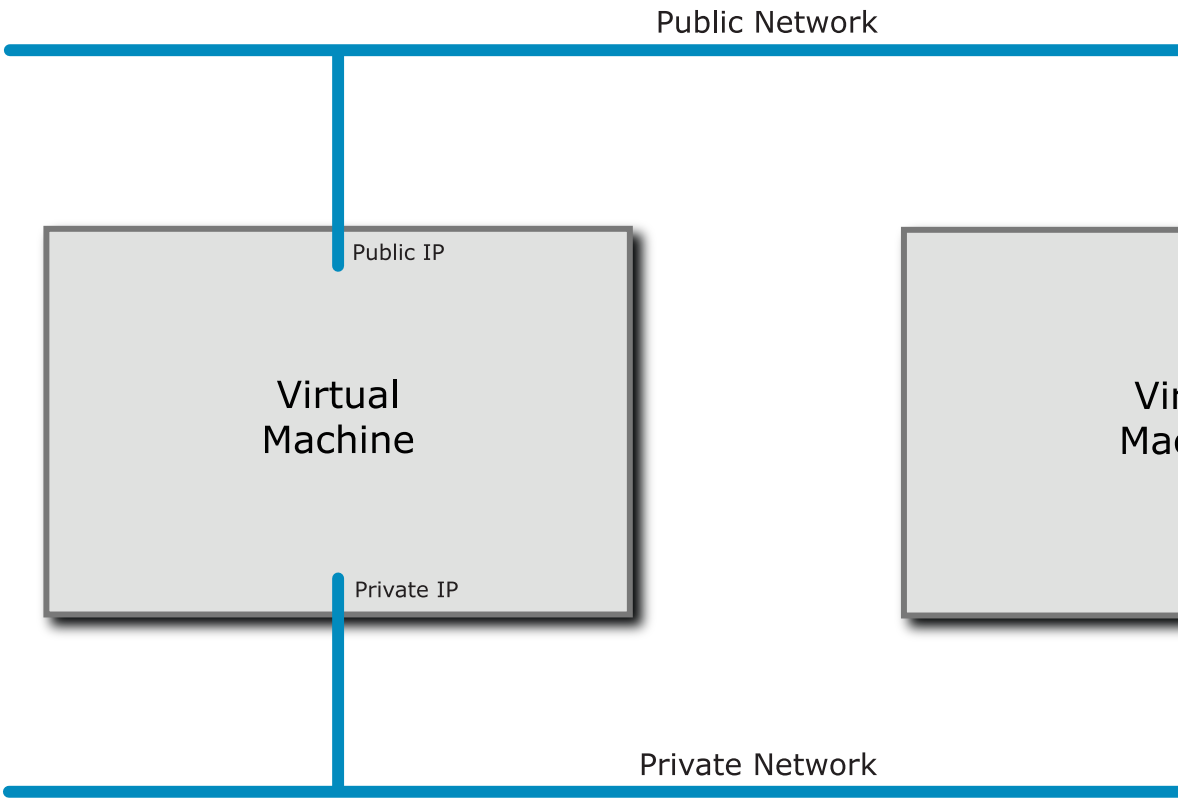
When we look at the network offerings by cloud providers there are three types:

1. **Private-only network with NAT**: This option is provided by the larger cloud providers such as AWS, Azure, GCP and I
   When a public IP address is needed that public IP is handled by the gateway provided by the cloud provider and the inc

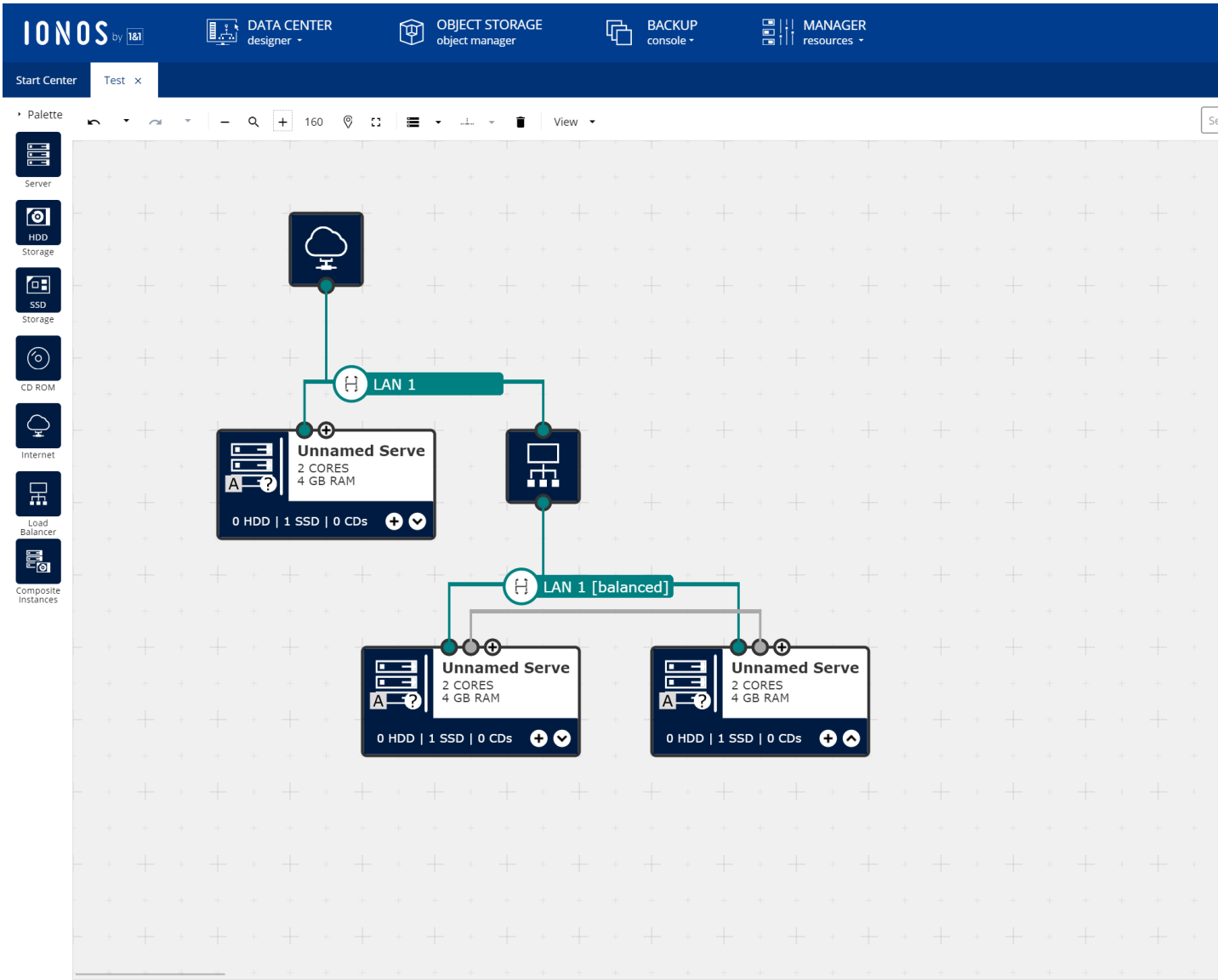
NAT. Multiple private networks (VPC's) can be assigned to a virtual machine and they can work independently.



2. **Default public IP**: This option is provided by smaller IaaS providers such as DigitalOcean, Exoscale, Hetzner, Linode, directly assigned one public IP address. Optionally private networks can be attached as well but the first public IP gene



3. **Fully customizable:** This setup allows the customer to design their network connectivity as they see fit. This setup is s without changing their architecture (lift-and-shift). This option is offered by 1&1 IONOS.



Note

There are several other cloud providers which we have no information on, such as the Deutsche Telekom/Open Telekom Cloud, categories.

Note

Out of group 2 it is worth mentioning that the services that are available on the public network (firewalls, load balancers) are ofte

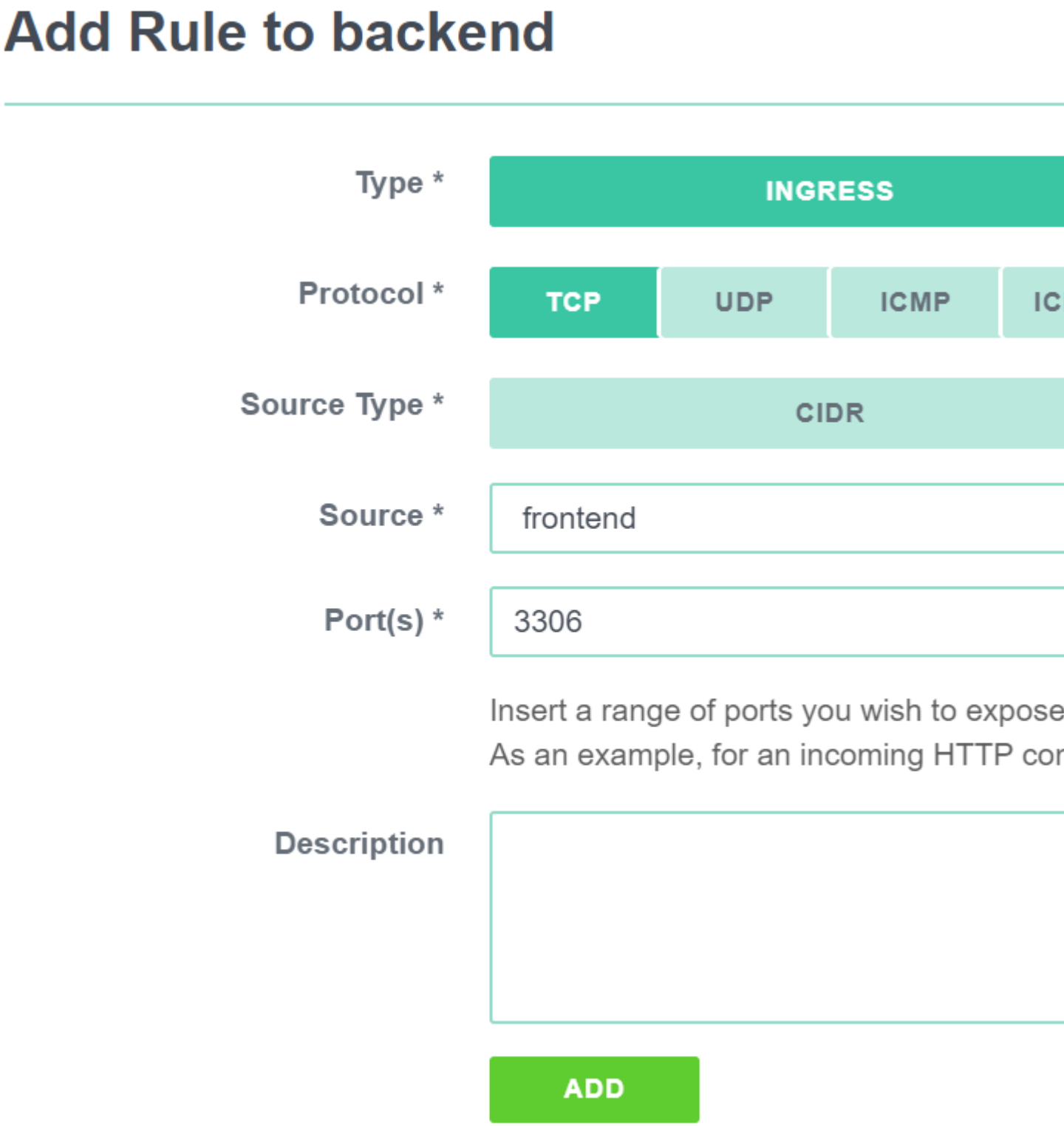
Firewalling

IaaS providers often also offer network firewalls as a service, included in the platform. Firewalls generally have two rule type current VM to everywhere else).

Firewall providers often employ the concept of *security groups*. The implementation varies greatly, but in general security gr

For most cloud providers you will need to create an explicit rule allowing traffic to flow between two machines in the same s

The advantage of security groups is that the rules can be made in such a way that they reference other security groups rath
allow connections only from the `appserver` security group but not from anywhere else. This can help with the dynamic natu
servers.

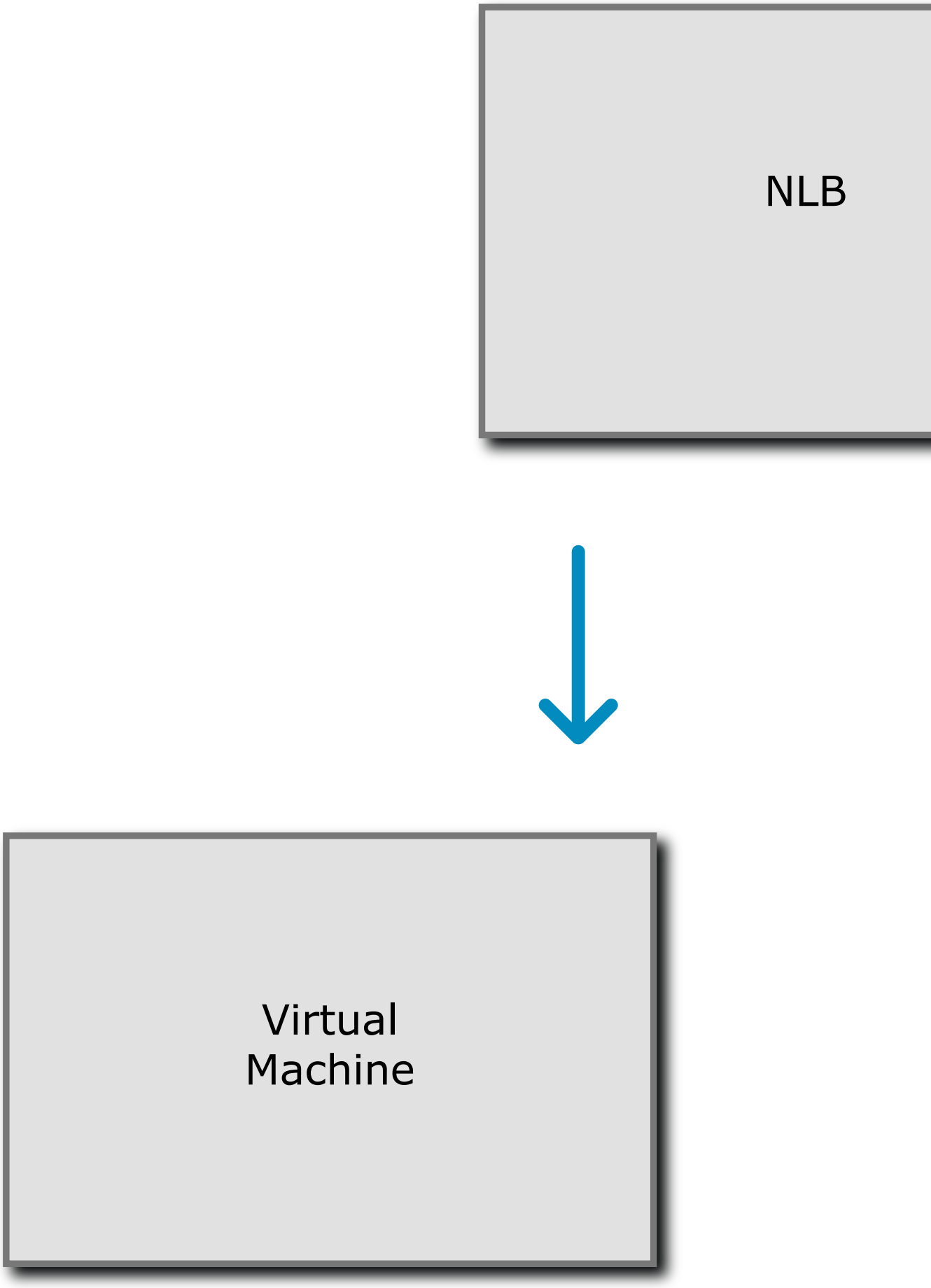


What do security groups offer?

- ◯ Filtering based on IP address
- ◯ Filtering based on the requested service
- ◯ Filtering based on the requested domain name
- ◯ Filtering based on the requested subpage on a website

Network load balancers

Network load balancers are an option some cloud providers offer. In contrast to Application Load Balancers they do not offe
address), they only balance incoming connections to a pool of backends.


NLB
Virtual
Machine

Depending on the cloud provider in question network load balancers may or may not offer terminating encrypted connection load balancers are offered in private networks or not.

When designing an architecture it is worth considering if the real IP address of the connecting client will be needed. If the ba handles SSL/TLS termination that combination may not be suitable for the task unless a specific trick such as the proxy pro general, make the client IP available to the backends.

In order to make sure requests are not sent to faulty backends NLBs include a health check feature. This health check eithe from the backend (HTTP check). If the check fails the backend is removed from the rotation. When integrated with virtual ma often not the case. It is on the operator to destroy faulty machines.

When talking about load balancers an interesting question is the load balancing strategy. Most load balancers support eithe connecting IP to the same backend).

What do NLBs typically offer?

- ◯ Spreading incoming connections across multiple backend machines equally.
- ◯ Spreading incoming connections across multiple backend machines, sending connections from th
- ◯ Spreading incoming connections across multiple backend machines, based on the domain name
- ◯ Spreading incoming connections across multiple backend machines, based on the subpage requ
- ◯ Terminating encrypted connections so the backend doesn't have to (SSL/TLS offloading).

VPNs, private interconnects, and routing services

While it seems convenient at first to use only the public network several organizations have security models that prevent ac with security groups) but also by not having private services on the public internet at all. To connect these internal services y

However, this presents a problem when moving data between several, geographically distributed locations. Most companies private network without going on the internet. This means that most companies have to choose one of two methods if they w VPN.

MPLS tunnels create a virtual connectivity that does not go on the Internet. While being expensive and slow to set up, it can

VPN's on the other hand create a virtual connectivity by sending data over the Internet in an encrypted form. Bandwidth or l but it's a very affordable solution.

Larger cloud providers tend to offer both options. MPLS is supported by the larger cloud providers (AWS Direct connect, Az Exoscale Private Connect).

VPN is also offered mostly by large providers (AWS VPC VPN, Azure VPN, or Google Cloud VPN). However, keep in mind as well. In other words you can't use this VPN to connect from your laptop to the cloud on the go. The only cloud service tha VPN.

It is also worth noting that VPN's can be used to connect cloud providers together.

What VPN type is offered by all major cloud providers?

- ◯ Site-to-site
- ◯ Device-to-site
- ◯ Device-to-device

What VPN protocol is offered by all major cloud providers?

- ◯ OpenVPN
- ◯ IPsec
- ◯ SSTP
- ◯ L2TP
- ◯ PPTP

What VPN type can IPsec offer by itself?

- ◯ Site-to-site
- ◯ Device-to-site
- ◯ Device-to-device

DNS

The Domain Name Service is one of the services that are all but required for building an infrastructure. It provides domain n
of your servers.

There is a difference, however, between DNS services on offer. Some DNS services by cloud providers offer only simple res
host the DNS service only on a private network without exposing it to the internet.

More advanced features may include automatic DNS failover. This involves running regular health checks on your services
IP. There are even services that offer advanced functionality such as routing traffic to different servers based on the geograp
CDN. CDNs are discussed in the next lecture.

Monitoring

Some cloud providers offer includes basic monitoring, such as CPU or memory usage. Some providers are offering monitor
interface. With some cloud providers monitoring alerts can be integrated with virtual machine pools to provide automatic sca

Often times the monitoring facilities offered by cloud providers are not sufficient for keeping an application running and more