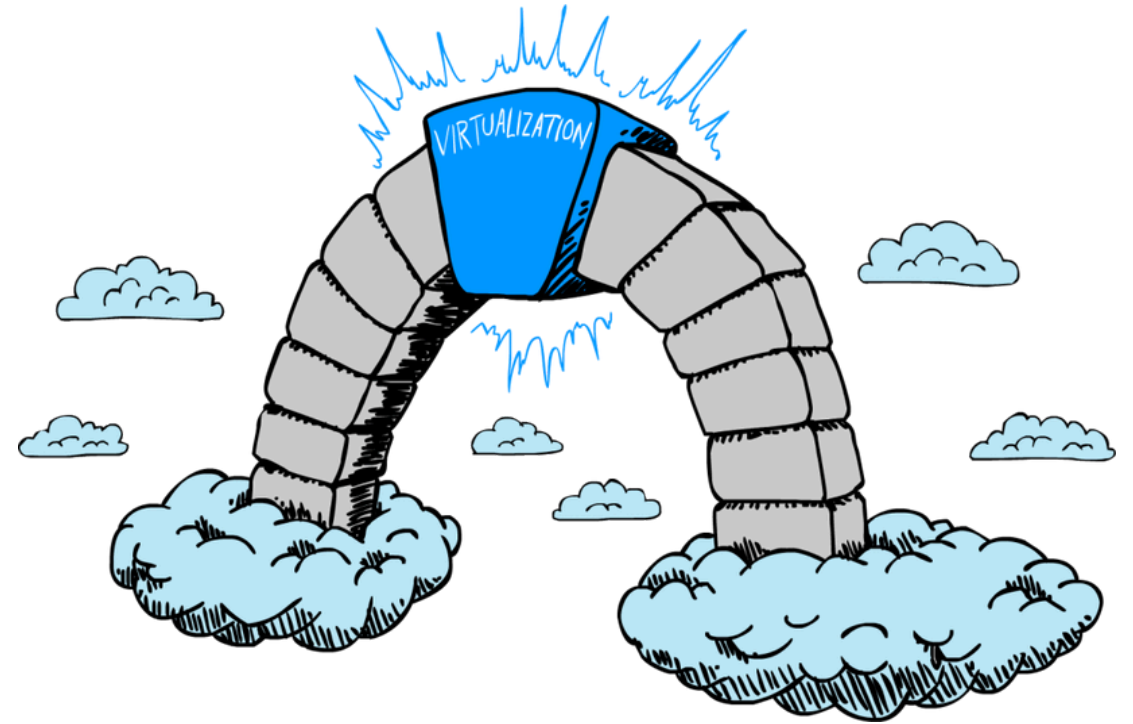


Virtualization in the cloud: techniques and technologies



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Notions

- **Technologies** that run the cloud
 - Virtualization, virtual machines (QEMU/KVM)...
 - Containers (Docker), orchestrators (Kubernetes), micro-services...
 - Serverless, Function-as-a-Service (Apache OpenWhisk)...
- **Techniques** to run on the cloud
 - Technologies vs. Application architecture
 - Availability, scalability, security...
- **Systems** point of view

Outline

1. **Hardware virtualization** (lectures 1&2)

1. What is virtualization?
2. VMs and hypervisors
3. *Demo*: QEMU/KVM
4. Internals of a hypervisor
5. Virtualization for the cloud

- *Lab*: Simple Hypervisor from Scratch (class session 1 + lab session)

- Sessions:

1. class on 2026-11-04: lecture + lab
2. class on 2026-11-09: lecture + lab
3. lab on 2026-11-23 “The Engines Lab”: free-for-all session to work on “Simple Hypervisor” and “Simple Container Engine”
4. class on 2026-11-25: lecture + lab

2. **Operating System-level Virtualization** (lectures 2 & 4)

1. VMs are hard
2. Containers and container engines
3. *Demo*: Docker
4. Internals of Docker Engine
5. *Demo*: namespaces & cgroups
6. Containers for the cloud: micro-services
7. Containers for the cloud: orchestration

- *Lab*: Simple Container Engine from Scratch (class session 2 + lab session)

3. **Serverless Computing** (lecture 4)

1. Containers are hard
2. Backend-as-a-Service
3. Function-as-a-Service
4. *Demo*: Apache OpenWhisk
5. Application architecture
6. Internals of Apache OpenWhisk
7. Limits

- *Lab 1*: Initiation to Apache OpenWhisk (class session 4)
- *Lab 2*: Scaling Horizontally a Web Service, Revisited (class session 4)

Resources

- **Class website:** <https://www-public.imtbs-tsp.eu/~mbacou/cours/>
 - Sources of demos
 - Labs
 - Lectures
- References:
 - Hardware virtualization: *Mastering KVM Virtualization, 2nd edition*. Dakic et al., 2020.
 - Operating system-level virtualization: *Docker: Pratique des architectures à base de conteneurs*. Cloux et al., 2016. [Fr.]
 - General: *Linux Containers and Virtualization: A Kernel Perspective*. Jain, 2020.

Further readings

Hardware virtualization

- *Memory resource management in VMware ESX server*. Waldspurger. In OSDI 2002.
- *Xen and the Art of Virtualization*. Barham, Dragovic, Fraser, Hand, Harris, Ho, Neugebauer, Pratt, Warfield. In SOSP 2003.
- *kvm: the Linux Virtual Machine Monitor*. Kivity, Kamay, Laor, Lublin, Liguori. In Linux Symposium 2007.
- *Unikernels: library operating systems for the cloud*. Madhavapeddy, Mortier, Rotsos, Scott, Singh, Gazagnaire, Smith, Hand, Crowcroft. In SIGARCH 2013.
- *My VM is Lighter (and Safer) than your Container*. Manco, Lupu, Schmidt, Mendes, Kuenzer, Sati, Yasukata, Raiciu, Huici. In SOSP 2017.
- *GiantVM: a type-II hypervisor implementing many-to-one virtualization*. Zhang, Ding, Chen, Jia, Yu, Qi, Guan. In VEE 2020.
- *Firecracker: Lightweight Virtualization for Serverless Applications*. Agache, Brooker, Florescu, Iordache, Liguori, Neugebauer, Piwonka, Popa. In NSDI 2020.
- *Security and Performance in the Delegated User-level Virtualization*. Chen, Li, Mi, Liu, Zang, Guan, Chen. In USENIX OSDI 2023.
- *vPIM: Processing-in-Memory Virtualization*. Teguia, Chen, Bitchebe, Balmau, Tchana. In ACM Middleware 2024.
- *Everything You Need to Know About Virtual Machine Live Migration Between Heterogeneous Processors*. Ishiguro, Fonyuy-Asheri, Barraud, Lachaize, Bromberg, Tchana. In ACM EuroSys 2026.

Serverless

- *SAND: Towards High-Performance Serverless Computing*. Akkus, Chen, Rimac, Stein, Satzke, Beck, Aditya, Hilt. In USENIX ATC 2018.
- *From Laptop to Lambda: Outsourcing Everyday Jobs to Thousands of Transient Functional Containers*. Fouladi, Romero, Iter, Li, Chatterjee, Kozyrakis, Zaharia, Winstein. In USENIX ATC 2019.
- *Faasm: Lightweight Isolation for Efficient Stateful Serverless Computing*. Shillaker, Pietzuch. In USENIX ATC 2020.
- *Catalyzer: Sub-millisecond Startup for Serverless Computing with Initialization-less Booting*. Du, Yu, Xia, Zang, Yan, Qin, Wu, Chen. In ACM ASPLOS 2020.
- *Nightcore: efficient and scalable serverless computing for latency-sensitive, interactive microservices*. Jia, Witchel. In ASPLOS 2021.
- *BeeHive: Sub-second Elasticity for Web Services with Semi-FaaS Execution*. Zhao, Wu, Tang, Zang, Wang, Chen. In ASPLOS 2023.
- *Ilúvatar: A Fast Control Plane for Serverless Computing*. Fuerst, Rehman, Sharma. In ACM HPDC 2023.
- *DataFlower: Exploiting the Data-flow Paradigm for Serverless Workflow Orchestration*. Li, Xu, Chen, Zhao, Chen, Guo. In ACM ASPLOS 2023.
- *Process-as-a-Service: Unifying Elastic and Stateful Clouds with Serverless Processes*. Copik, Calotoiu, Rethy, Böhringer, Bruno, Hoefler. In ACM SoCC 2024.
- *RainbowCake: Mitigating Cold-starts in Serverless with Layer-wise Container Caching and Sharing*. Yu, Roy, Fontenot, Tiwari, Li, Zhang. In ACM ASPLOS 2024.
- *Dirigent: Lightweight Serverless Orchestration*. Cvetković, Costa, Djokic, Friedman, Klimovic. In ACM SOSP 2024.
- *Fork in the Road: Reflections and Optimizations for Cold Start Latency in Production Serverless Systems*. Chai, Zhou, Hu, Tan, Bie, Shen, Shen, Xing, Song, Yang, Gao, Yu, He, Du, Xia, Chen, Chen. In USENIX OSDI 2025.
- *In-Production Characterization of an Open Source Serverless Platform and New Scaling Strategies*. Nasiri, Munshi, Moser, Pirvu, Sundaresan, Maier, Premnath, Böwing, Gopalakrishnan, Shahrads. In ACM EuroSys 2026.

Other topics

- Memory management, storage, networking, power management...
- Operating systems, distributed systems...
- Security, reliability, availability...
- Programming models, orchestration...