Cloud Computing, Containers and VMs

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Cloud Computing

- "X as a service"
- Infrastructure as a Service
  - user manages software - from kernel to applications
  - cloud manages "infrastructure" (power, cooling, etc.)
  - Ex: Amazon EC2
- Platform as a Service
  - user manages application and specifies software configuration (e.g., which runtime to use) on cloud
  - Ex: Heroku
- Software as a Service
  - application runs on servers in the cloud
  - Ex: Google Docs

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Deployment Models

- Cloud
- Hybrid Cloud
- On-prem cloud

Defining characteristics

- Elasticity
  - scale up and down number of instances (often automatically)
  - only pay for what you use
- Multi-tenant
  - ensure resources are highly utilized (statistical multiplexing)
- Isolation
  - each user has "private view" of system
  - tenants should not interfere with each other
  - may be mutually distrusting

How to run user workloads?

- Process?
  - private address space..
- How to package application dependencies?
  - executable built on different system
  - will target system have the right shared libraries?
- Will processes interfere with each other?
  - Yes - because so much of the system is shared:
  - shared filesystem - what if different needs for /etc/config?
  - shared port space - what if multiple on port 80?
  - shared pids
  - others...

Bottom Line

Processes are an ill-suited abstraction for a multi-tenant cloud scenario.

How to run user workloads? Solutions:

- Bare Metal
  - each user workload gets its own physical machine
- Virtual Machines
  - each user workload gets its own virtual machine
  - everything application needs is in a virtual disk image
  - guest kernels: entire kernel is not shared
  - hypervisor/virtual machine monitor multiplexes physical machine
- Containers
  - private filesystem (chroot/layered)
  - kernel mechanisms provide "private view" of resources (namespaces, cgroups)

Virtual Machines in the 70s

- Goldberg 1972, 1974
- Some reasons:
  - improving and testing OS software
  - running H/W diagnostic software
  - running different OSes or versions
  - running with a virtual hardware configuration different than physical machine
  - etc.
- Popek/Goldberg Requirements (1974)
  - equivalence/fidelity
    - program should exhibit same behavior
  - resource control
    - VMM must have full control of resources
  - efficiency
    - most instructions should execute natively

How to run a virtual machine

- Direct Execution
- Basic idea: deprivilege (run OS as user instead of supervisor)
- "trap and emulate"
- question: will all instructions trap?
  - IBM/360 (70's) yes
  - x86 (prior to VT extensions) no...

VM resurgence in early 2000s

- Dynamic binary translation
  - replace supervisor instructions in guest or force them to trap for trap-and-emulate
  - VMware workstation released in 1999
- Modify guest: paravirtualization
  - Xen (open source 2002)
  - Amazon EC2 was originally based on Xen
- Hardware extensions
  - 2005/2006 Intel VT-x AMD-V

Memory management in a VM

- Extra layer of translation
  - guest virtual $\rightarrow$ guest physical $\rightarrow$ host physical (machine)
- Approaches:
  - Shadow page table
    - hypervisor makes copy of page table, installs copy in MMU
  - Paravirtualization
    - cooperation of guest
  - Extended/nested page tables
    - hardware performs additional translation

Resource management for virtual machines

- OSes are used to fixed/dedicated RAM/CPU/devices
  - can we get better efficiency?
- Virtual CPUs
- Memory
  - Page sharing
  - Memory ballooning
- I/O devices
  - virtio
  - passthrough
  - "smart devices"

Resource management

Lots of classic mechanisms to rethink for VMs!

Are VMs Overkill?

OS kernel is already good at resource management…

Kernel mechanisms for Containers

- chroot
  - "chroot jail"
  - use some other directory as "/" for this process and all children
- Namespaces
  - private filesystem (chroot/layered)
  - UTS - hostname
  - mount - filesystem
  - PID - pids (ps only shows pids in namespace)
  - IPC - shmem, semaphores
  - user - users, groups, etc.
  - network - ports, devices, etc.
- Cgroups
  - limit resource consumption
  - CPU, mem

Clone and unshare(2)

- Recall *fork* and *pthread_create* use *clone* under the covers
- Flags to *clone* control sharing (e.g., CLONE_VM), including namespaces!
- Can also *unshare* after the fact (e.g., CLONE_NEWPID)

So what is a container?

- a set of processes sharing dedicated chroot, namespaces, cgroups

How to build containers

- Dockerfile - defacto standard for building containers
  - filesystem image for container
  - build from other images: layering

Building containers: Dockerfile

```
# Pull base image.
FROM dockerfile/ubuntu

# Install Nginx.
RUN \
  add-apt-repository -y ppa:nginx/stable && \
  apt-get update && \
  apt-get install -y nginx && \
  rm -rf /var/lib/apt/lists/* && \
  echo "\ndaemon off;" >> /etc/nginx/nginx.conf && \
  chown -R www-data:www-data /var/lib/nginx

# Define mountable directories.
VOLUME ["/etc/nginx/sites-enabled", "/etc/nginx/certs", "/etc/nginx/conf.d", "/var/log/nginx", "/var/www/html"]

# Define working directory.
WORKDIR /etc/nginx

# Define default command.
CMD ["nginx"]

# Expose ports.
EXPOSE 80
EXPOSE 443
```

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The container ecosystem

- CNCF - cloud native computing foundation
- Kubernetes
- Service Mesh
- Pods and sharing
  - containers that share some namespaces
  - e.g., share filesystem, network

Virtualization spectrum

- threads
- processes
- containers
- virtual machines
- physical machines

- higher density, lower overhead, ease of sharing
-
-
-
- better isolation, protection, more user control

Container security concerns

- Attack surface through system call interface
- Same as processes!
- How to reduce it:
  - filter system calls (ex: seccomp)
  - use virtualization!?

Virtual machine concerns

- Large, unwieldy images
- Slow to boot
  - problem for serverless

Serverless: a new model

- function as a service
- user only writes/supplies function in supported language
- event-based: attach to event
  - thumbnail example
- "stateless"
- charged on ms granularity

State of the art "containers": microVMs

- run container in a lightweight VM
  - AWS Firecracker
  - Kata containers
- Integrated with container orchestration systems (e.g., Kubernetes)

References