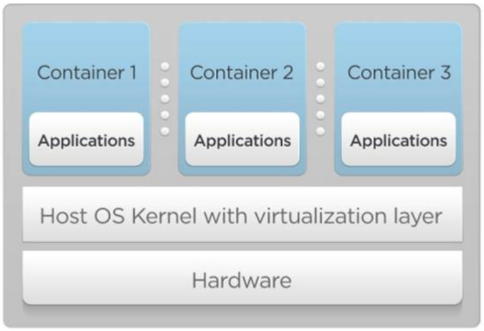
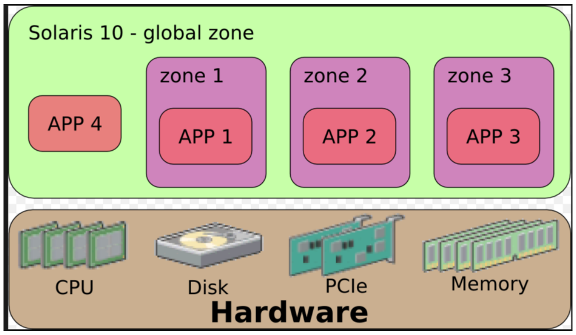
Module 1: OS Virtualization

- Emulate OS-level interface with native interface
- “Lightweight” virtual machines
  - No hypervisor, OS provides necessary support

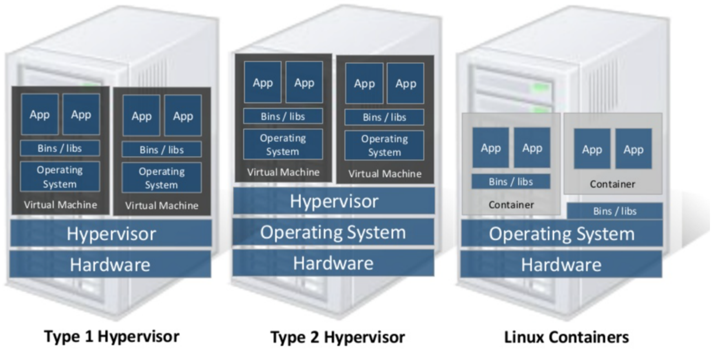




- Referred to as *containers*
  - Solaris containers, BSD jails, Linux containers

Linux Containers (LXC)

- Containers share OS kernel of the host
  - OS provides resource isolation
- Benefits
  - Fast provisioning, bare-metal like performance, lightweight



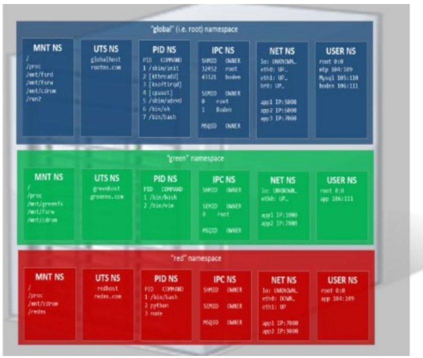
Material courtesy of “Realizing Linux Containers” by Boden Russell, IBM

OS Mechanisms for LXC

- OS mechanisms for resource isolation and management
- namespaces: process-based resource isolation
- Cgroups: limits, prioritization, accounting, control
- chroot: apparent root directory
- Linux security module, access control
- Tools (e.g., docker) for easy management

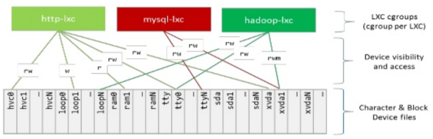
Linux Namespaces

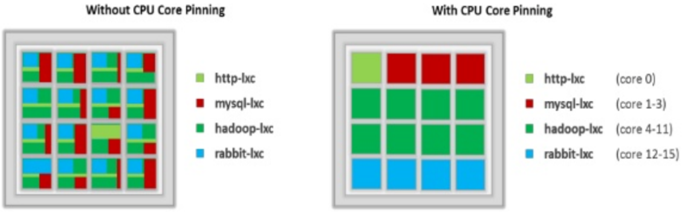
- Namespace: restrict what can a container see?
  - Provide process level isolation of global resources
- Processes have illusion they are the only processes in the system
- MNT: mount points, file systems (what files, dir are visible)?
- PID: what other processes are visible?
- NET: NICs, routing
- Users: what uid, gid are visible?
- chroot: change root directory



Linux cgroups

- Resource isolation
  - what and how much can a container use?
    - Set upper bounds (limits) on resources that can be used
    - Fair sharing of certain resources
- Examples:
  - cpu: weighted proportional share of CPU for a group
  - cpuset: cores that a group can access
  - block io: weighted proportional block IO access
  - memory: max memory limit for a group



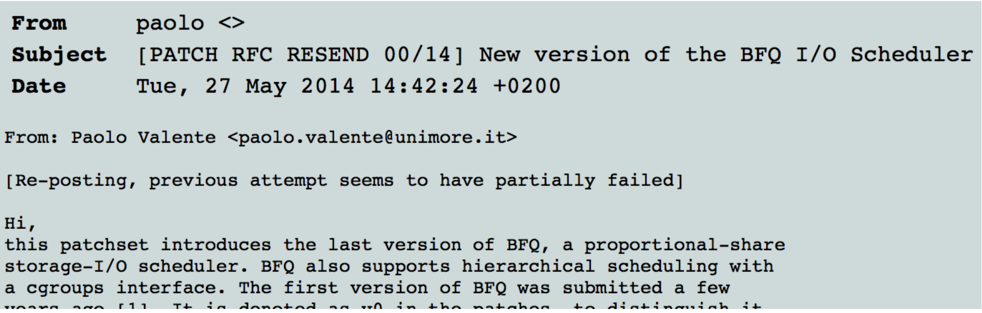


Module 2: Proportional Share Scheduling

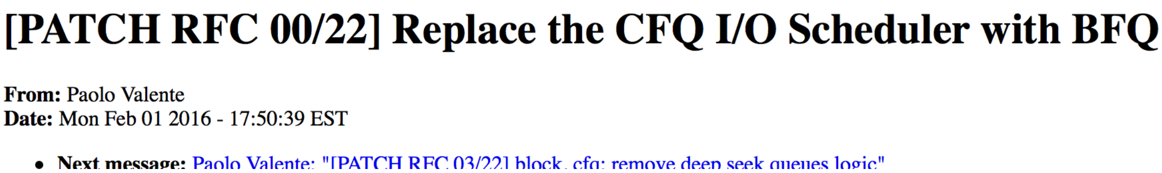
- Uses a variant of *proportional-share scheduling*

- *Share-based* scheduling:
  - Assign each process a weight w_i (a “share”)
  - Allocation is in proportional to share
  - fairness: reused unused cycles to others in proportion to weight
  - Examples: fair queuing, start time fair queuing
- *Hard limits*: assign upper bounds (e.g., 30%), no reallocation
- Credit-based: allocate credits every time T, can accumulate credits, and can burst up-to credit limit
  - can a process starve other processes?

Share-based Schedulers



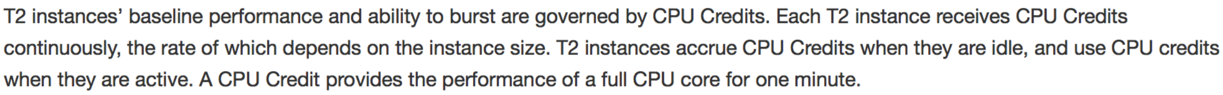
```
From      paolo <>
Subject   [PATCH RFC RESEND 00/14] New version of the BFQ I/O Scheduler
Date      Tue, 27 May 2014 14:42:24 +0200

From: Paolo Valente <paolo.valente@unimore.it>

[Re-posting, previous attempt seems to have partially failed]

Hi,
this patchset introduces the last version of BFQ, a proportional-share
storage-I/O scheduler. BFQ also supports hierarchical scheduling with
a cgroups interface. The first version of BFQ was submitted a few
years ago [1]. It is denoted as v0 in the patches, to distinguish it
```



[PATCH RFC 00/22] Replace the CFQ I/O Scheduler with BFQ

From: Paolo Valente
Date: Mon Feb 01 2016 - 17:50:39 EST

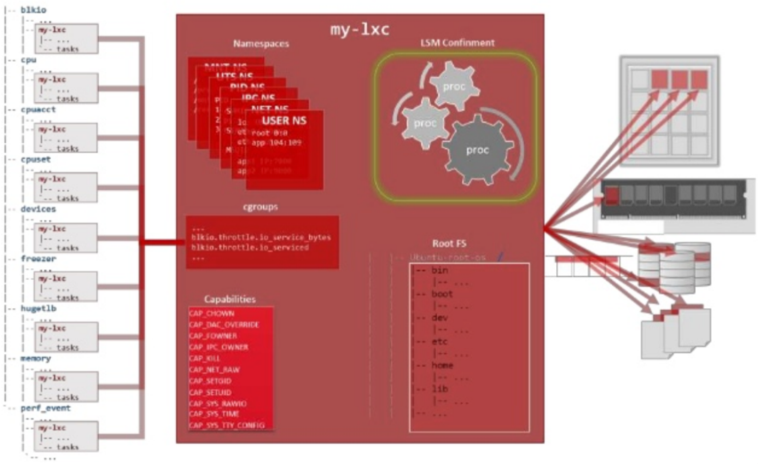
- **Next message:** Paolo Valente: "[PATCH RFC 03/22] block, cfq: remove deep seek queues logic"



T2 instances' baseline performance and ability to burst are governed by CPU Credits. Each T2 instance receives CPU Credits continuously, the rate of which depends on the instance size. T2 instances accrue CPU Credits when they are idle, and use CPU credits when they are active. A CPU Credit provides the performance of a full CPU core for one minute.

Putting it all together

- Images: files/data for a container
  - can run different distributions/apps on a host
- Linux security modules and access control
- Linux capabilities: per process privileges

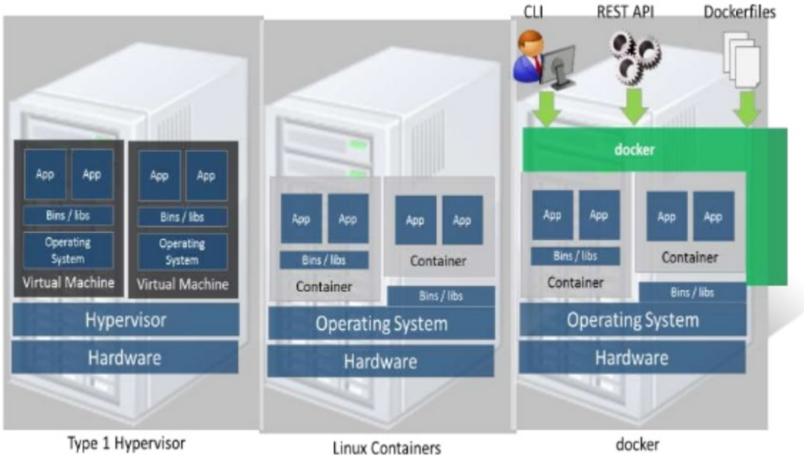


Module 3: Docker and Linux Containers

- Linux containers are a set of kernel features
  - Need user space tools to manage containers
  - Virtuozo, OpenVZm, VServer,Lxc-tools, Docker
- What does Docker add to Linux containers?
  - Portable container deployment across machines
  - Application-centric: geared for app deployment
  - Automatic builds: create containers from build files
  - Component re-use
- Docker containers are self-contained: no dependencies

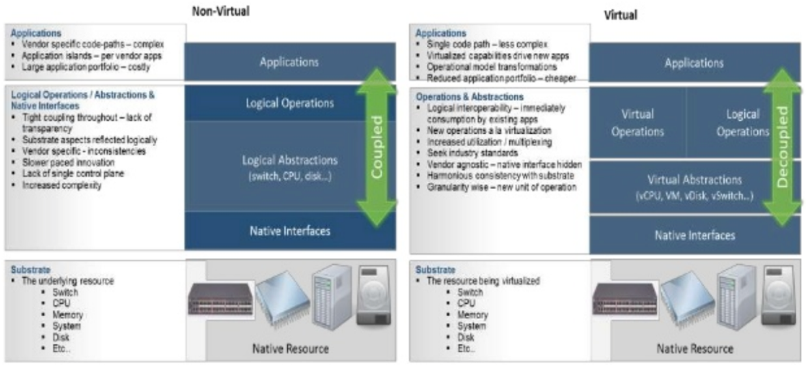
Docker

- Docker uses Linux containers



LXC Virtualization Using Docker

- Portable: docker images run anywhere docker runs
- Docker decouples LXC provider from operations
  - uses virtual resources (LXC virtualization)
    - fair share of physical NIC vs use virtual NICs that are fair-shared



Non-Virtual

Applications
- Vendor specific code-paths – complex
- Application islands – per vendor apps
- Large application portfolio – costly

Logical Operations / Abstractions & Native Interfaces
- Tight coupling throughout – lack of transparency
- Substrate aspects reflected logically
- Vendor specific - inconsistencies
- Slower paced innovation
- Lack of single control plane
- Increased complexity

Substrate
- The underlying resource
  - Switch
  - CPU
  - Memory
  - System
  - Disk
  - Etc..

Applications

Logical Operations

Logical Abstractions (switch, CPU, disk...)

Native Interfaces

Coupled

Native Resource

Virtual

Applications
- Single code path – less complex
- Virtualized capabilities drive new apps
- Operational model transformations
- Reduced application portfolio – cheaper

Operations & Abstractions
- Logical interoperability – immediately consumption by existing apps
- New operations a la virtualization
- Increased utilization / multiplexing
- Seek industry standards
- Vendor agnostic – native interface hidden
- Harmonious consistency with substrate
- Granularity wise – new unit of operation

Substrate
- The resource being virtualized
  - Switch
  - CPU
  - Memory
  - System
  - Disk
  - Etc..

Applications

Virtual Operations

Logical Operations

Virtual Abstractions (vCPU, VM, vDisk, vSwitch...)

Native Interfaces

Decoupled

Native Resource

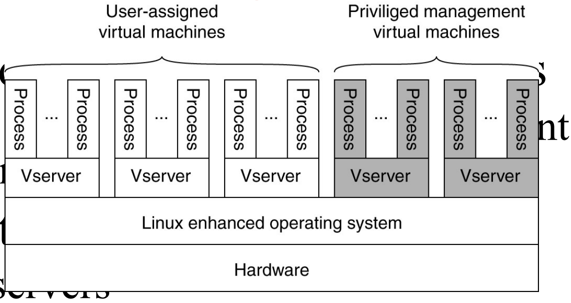
Docker Images and Use

- Docker uses a union file system (AuFS)
  - allows containers to use host FS safely
- Essentially a copy-on-write file system
  - read-only files shared (e.g., share glibc)
  - make a copy upon write
- Allows for small efficient container images
- Docker Use Cases
  - “Run once, deploy anywhere”
  - Images can be pulled/pushed to repository
  - Containers can be a single process (useful for microservices) or a full OS

Use of Virtualization Today

- Data centers:
  - server consolidation: pack multiple virtual servers onto a smaller number of physical server
    - saves hardware costs, power and cooling costs
- Cloud computing: rent virtual servers
  - cloud provider controls physical machines and mapping of virtual servers to physical hosts
  - User gets root access on virtual server
- Desktop computing:
  - Multi-platform software development
  - Testing machines
  - Run apps from another platform

Case Study: PlanetLab


User-assigned virtual machines
Priviliged management virtual machines
Process
...
Process
Vserver
Linux enhanced operating system
Hardware

- Distribute s
  - Used for nts and faculty in networki
- Uses a virt
  - Linux Vservers
  - Node manager per machine
  - Obtain a “slice” for an experiment: slice creation service

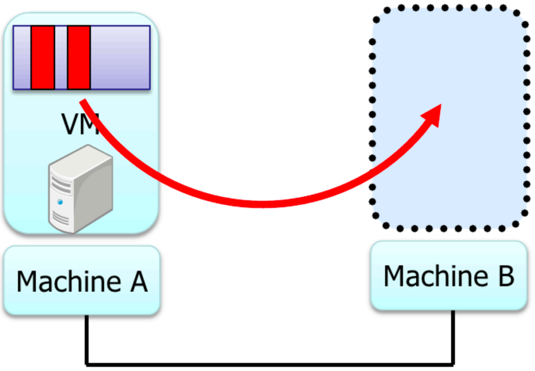
Module 4: Virtual Machine Migration

- VMs can be migrates from one physical machine to another
- Migration can be live - no application downtime
- Iterative copying of memory state
- How are network connections handled?

- Inherently migrates the OS and all its processes

Pre-Copy VM Migration

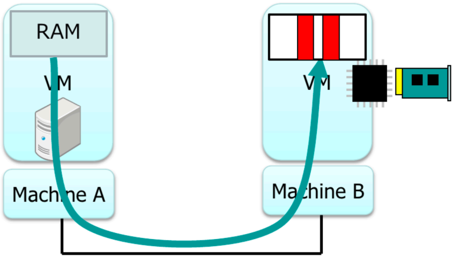
- 1. Enable dirty page tracking
- 2. Copy all memory pages to destination
- 3. Copy memory pages dirtied during the previous copy again
- 4. Repeat 3rd step until the rest of memory pages is small.
- 5. Stop VM
- 6. Copy the rest of memory pages and
- non-memory VM states
- 7. Resume VM at destination
- 8. ARP pkt to switch



Figures Courtesy: Isaku Yamahata, LinuxCon Japan 2012

Post-Copy VM Migration

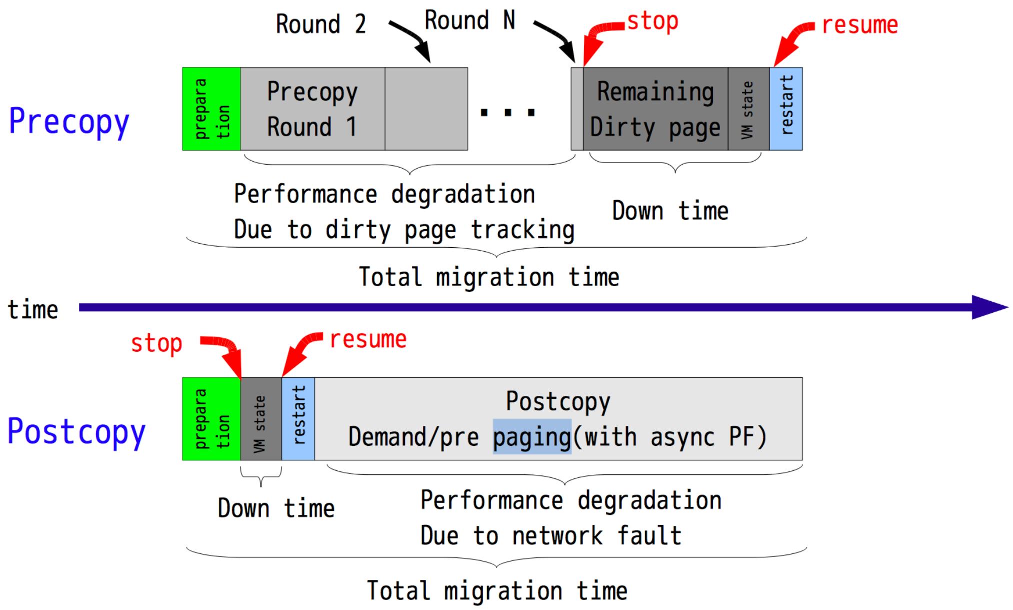
- 1. Stop VM
- 2. Copy non-memory VM states to destination
- 3. Resume VM at destination
- 4. Copy memory pages on-demand/background
  - Async page fault can be utilized



Copy memory pages
•On-demand(network fault)
•background(precache)

VM Migration Time

Copy VM memory before switching the execution host


Round 2
Round N
stop
resume
Precopy
prepara tion
Precopy Round 1
...
Remaining Dirty page
VM state
restart
Performance degradation
Due to dirty page tracking
Down time
Total migration time
time
stop
resume
Postcopy
prepara tion
VM state
restart
Postcopy
Demand/pre paging(with async PF)
Down time
Performance degradation
Due to network fault
Total migration time

Copy VM memory after switching the execution host

Figure Courtesy: Isaku Yamahata, LinuxCon Japan 2012