Code, Process, and VM Migration

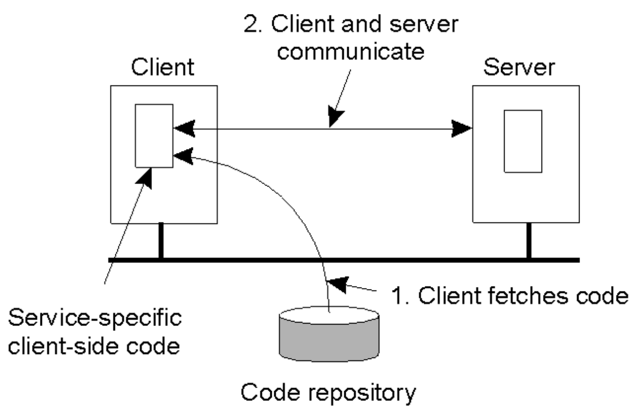
- Motivation
- How does migration occur?
- Resource migration
- Agent-based system
- Details of process migration
- Migration of Virtual Machines

Part 1: Migration Introduction

- Key reasons: performance and flexibility
- Process migration (aka *strong mobility*)
  - Improved system-wide performance – better utilization of system-wide resources
  - Examples: Condor, DQS
- Code migration (aka *weak mobility)*
  - Shipment of server code to client – filling forms (reduce communication, no need to pre-link stubs with client)
  - Ship parts of client application to server instead of data from server to client (e.g., databases)
  - Improve parallelism – agent-based web searches

Motivation

- Flexibility
  - Dynamic configuration of distributed system
  - Clients don't need preinstalled software – download on demand



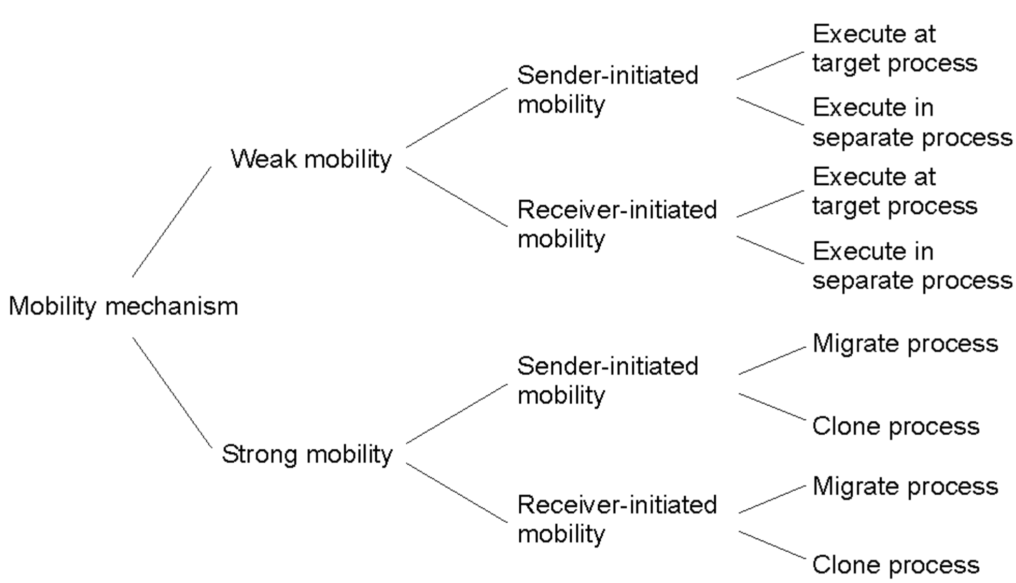
Migration models

- Process = code seg + resource seg + execution seg
- Weak versus strong mobility
  - Weak => transferred program starts from initial state
- Sender-initiated versus receiver-initiated
- Sender-initiated
  - migration initiated by machine where code resides
    - Client sending a query to database server
      - Client should be pre-registered
- Receiver-initiated
  - Migration initiated by machine that receives code
  - Java applets
  - Receiver can be anonymous

Who executes migrated entity?

- Code migration:
  - Execute in a separate process
  - [Applets] Execute in target process
- Process migration
  - Remote cloning
  - Migrate the process

Models for Code Migration



Do Resources Migrate?

- Depends on resource to process binding
  - By identifier: specific web site, ftp server
  - By value: Java libraries
  - By type: printers, local devices
- Depends on type of "attachments"
  - Unattached to any node: data files
  - Fastened resources (can be moved only at high cost)
    - Database, web sites
  - Fixed resources
    - Local devices, **communication end points**

Resource Migration Actions

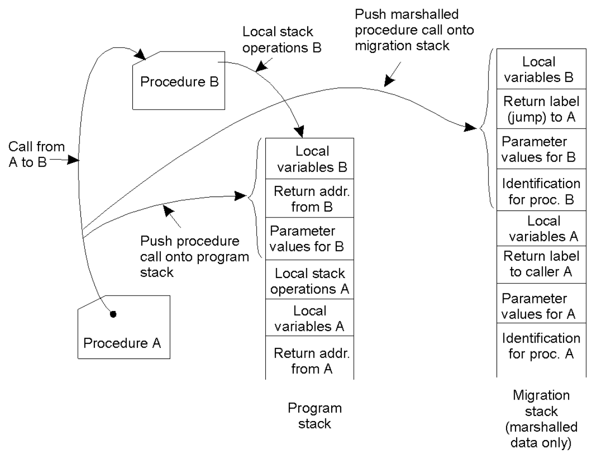
Resource-to machine binding

Process-to-resource binding		Unattached	Fastened	Fixed
	By identifier	MV (or GR)	GR (or MV)	GR
	By value	CP (or MV, GR)	GR (or CP)	GR
	By type	RB (or GR, CP)	RB (or GR, CP)	RB (or GR)

- Actions to be taken with respect to the references to local resources when migrating code to another machine.
- GR: establish global system-wide reference
- MV: move the resources
- CP: copy the resource
- RB: rebind process to locally available resource

Migration in Heterogeneous Systems

- Systems can be heterogeneous (different architecture, OS)
  - Support only weak mobility: recompile code, no run time information
  - Strong mobility: recompile code segment, transfer execution segment [migration stack]
  - Virtual machines - interpret source (scripts) or intermediate code [Java]



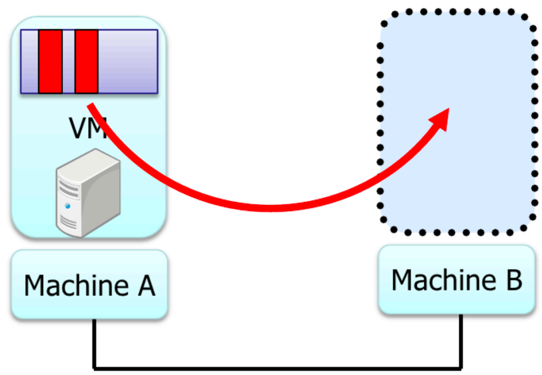
Part 2: Virtual Machine Migration

- 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

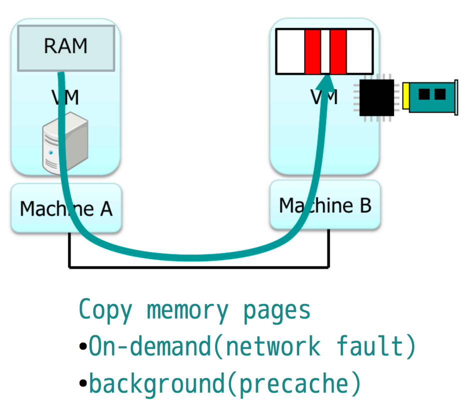
- 1. Enable dirty page tracking
- 2. Copy all memory pages to destination
- 3. Copy memory pages dirtied during the previous copy again
- 4. Repeat 3rd step until the rest of memory pages is small.
- 5. Stop VM
- 6. Copy the rest of memory pages and
- non-memory VM states
- 7. Resume VM at destination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



VM Migration Time

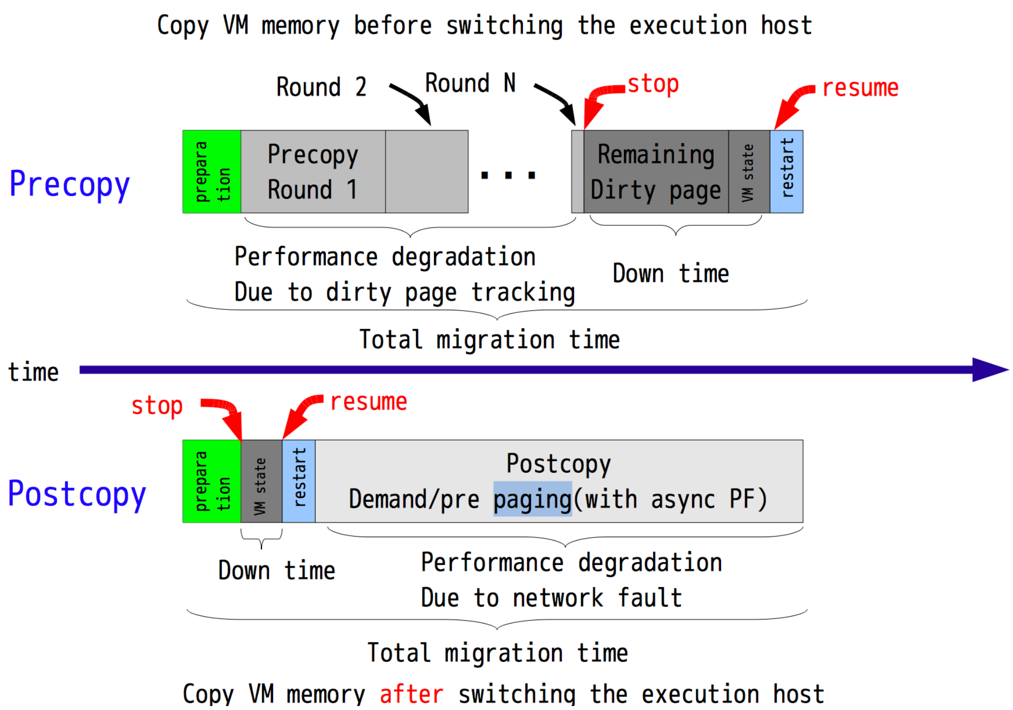


Figure Courtesy: Isaku Yamahata, LinuxCon Japan 2012

Part 3: Container Migration

- Migration techniques
- Snapshots
- Checkpoint-Resume (CRIU)

Migration Methods

- Cold migration: migrate a VM / container that is shutdown
  - Copy image and data files, start on new machine.
  - No state is preserved
- Warm migration: migrate state from previous instance
  - Suspend running VM/container to disk
  - Copy image, data, suspended memory state
  - Resume execution of suspended VM
  - preservers state, but incurs downtime
- Hot/live migration: migrate state with no downtime
  - Copy state while VM executes; no downtime

Snapshots

- Snapshot: point-in-time copy
  - General concept in operating and distributed systems
  - Snapshots preserve objects (file, disk, VM) as they existed at time of snapshot
- VM Snapshots
  - preserves VM state: memory or disk state
  - Like a backup
- Virtual snapshots: make a virtual copy
  - use copy-on-write to make changes to original
- Snapshots useful for roll-back or migration
  - Snapshots are also known as checkpoints

Checkpoint and Restore

- Warm container migration: Checkpoint and Restore
  - Pause container execution
  - Checkpoint (save) memory contents of container to disk
  - Copy checkpoint to new machine (memory + disk image)
  - Resume execution on new machine

Linux CRIU

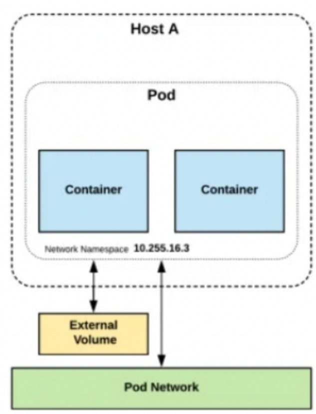
- Linux CRIU (Checkpoint Restore In Userspace)
  - Used for warm or live migration, snapshots, debugging
  - Works for individual process **and** containers migration
- Uses /proc file system to gather all info about each process in the container
  - Save process state (file descriptors, memory state etc)
- Copy saved state to another machine
- CRIU restorer
  - Use fork to recreate processes to be restored
  - Restore resources; for containers, restore namespace
  - TCP repair to restore network sockets on *same* machine
  - Can migrate active sockets only if IP address moves
    - Use virtual network device in containers and move it

Part 4: Kubernetes (k8s)

- Cluster management using containers
- Container-based Orchestration System
  - Based on Google's Borg /Omega cluster managers
- Applications are containerized
- K8s will deploy them onto machines of the cluster
  - **Replicate** app on multiple machines if requested
  - **load balance** across replicas
  - Can **scale up** or down dynamically (vary replica pool size, a concept similar top dynamic thread/process pools)
  - Provide automated **restart** upon detecting failure (self-healing)

K8s Pods

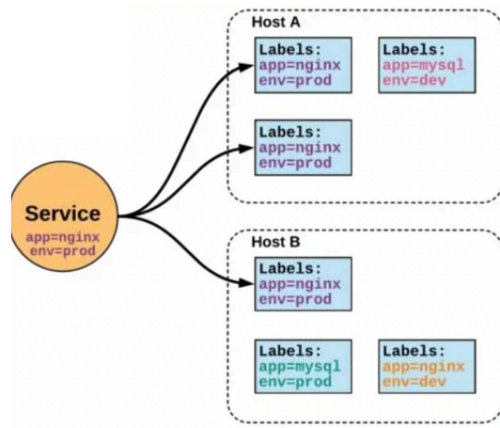
- Pod: contains one or more containers that share volumes and name space
  - Pods: smallest granularity of allocation in k8s.
- Distributed application: multiple components,
  - each component inside a container
  - Each pod consists of one or more components / containers
  - Pod can contain all containers of an application but:
    - If a component needs to be scaled, put each such component in a separate pod
  - Application consists of a set of pods, each independently scalable
    - Pods of an application can span multiple cluster machines



All k8s figures courtesy of https://www.slideshare.net/rishabhindoria52/introduction-to-kubernetes-139878615

k8s Services

- service: method to access a pods's exposed interfaces
  - static cluster IP address
  - static DNS name
  - Services are not ephemeral
  - collection of pods
- Pods are ephemeral
  - each has its own IP
  - can be migrated to another machine
  - Pods can communicate with one another using this IP



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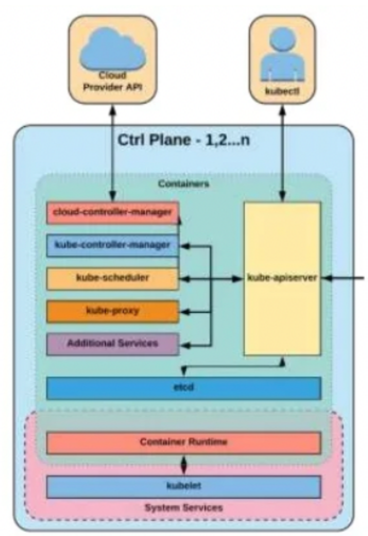
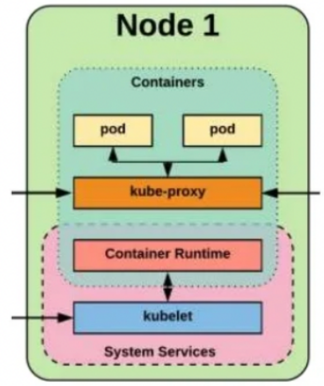
Control Plane

- **apiserver**: REST interfaces for clients to access management interface
- **etcd**: cluster key-value datastore
  - strongly consistent, highly durable (uses RAFT consensus)
- **controller-manager:** replicate pods, monitor for node failures and restart
- **scheduler:** assigns newly created pods to servers based on resource constraints
- **cloud-controller-manager**: interact with cloud platforms



K8s Node

- kubelet: agent on each node
  - ensure containers are running and healthy
- kubelet proxy
  - Manage network rules
  - Load balancing for cluster services
- container runtime
  - runtime for container execution
  - containerd/docker, cri-o, rkt



Case Study: Viruses and Malware

- Viruses and malware are examples of mobile code
  - Malicious code spreads from one machine to another
- Sender-initiated:
  - proactive viruses that look for machines to infect
    - Autonomous code
- Receiver-initiated
  - User (receiver) clicks on infected web URL or opens an infected email attachment