# Code, Process, and VM Migration

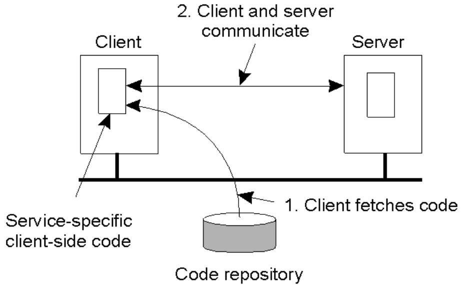
- Motivation
- How does migration occur?
- Resource migration
- Agent-based system
- Details of process migration
- Migration of Virtual Machines

# 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



2. Client and server communicate

Client

Server

1. Client fetches code

Service-specific client-side code

Code repository

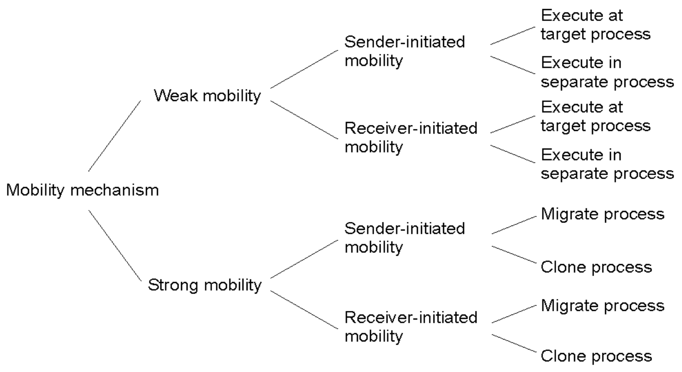
# Migration models

- 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



Mobility mechanism

Weak mobility

Sender-initiated mobility

Execute at target process

Execute in separate process

Receiver-initiated mobility

Execute at target process

Execute in separate process

Strong mobility

Sender-initiated mobility

Migrate process

Clone process

Receiver-initiated mobility

Migrate process

Clone process

- Alternatives 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**

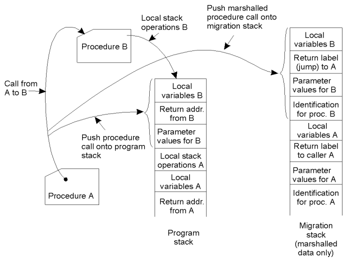
**Process-to-resource binding**

| | 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]



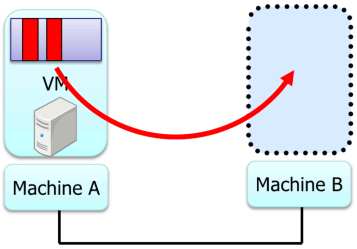
# Part 2: Virtual Machine Migration

- VMs can be migrated 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

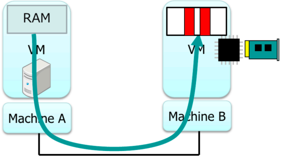
- 1. Enable dirty page tracking
- 2. Copy all memory pages to destination
- 3. Copy memory pages dirtied during the previous copy again
- 4. Repeat 3rd step until the rest of memory pages is small.
- 5. Stop VM
- 6. Copy the rest of memory pages and
- non-memory VM states
- 7. Resume VM at destination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



Figures Courtesy: Isaku Yamahata, LinuxCon Japan 2012

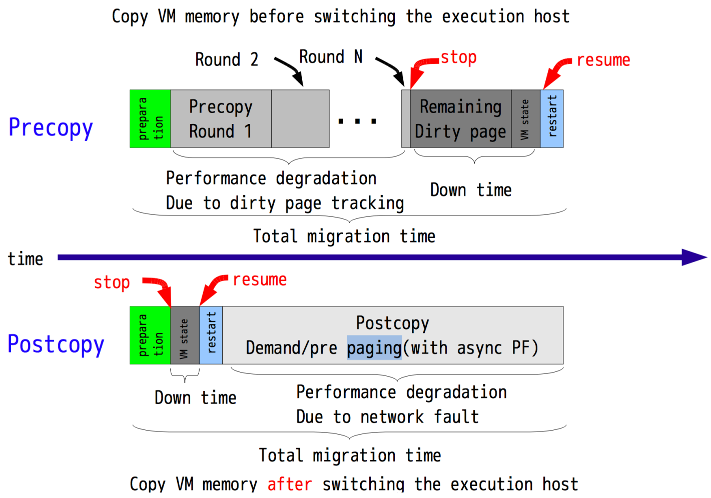
# Post-Copy VM Migration

- 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

Precopy

preparation | Precopy Round 1 | Round 2 | ... | Round N | stop | Remaining Dirty page | VM state | restart | resume

Performance degradation Due to dirty page tracking

Down time

Total migration time

time

Postcopy

stop | preparation | VM state | resume | 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

# 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

# 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