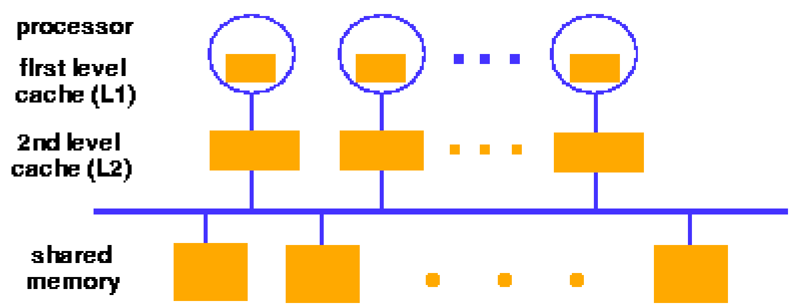
Multiprocessor Scheduling

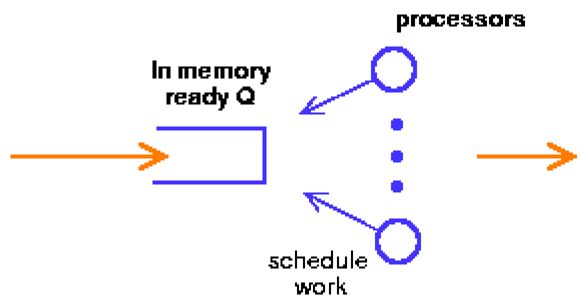
- Will consider only shared memory multiprocessor



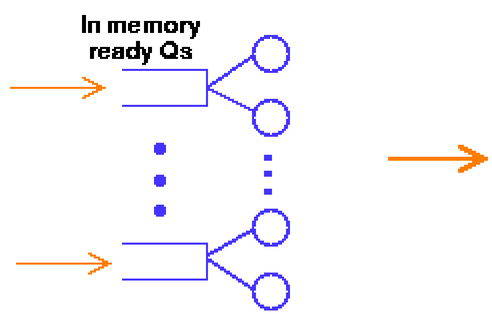
- Salient features:
  - One or more caches: cache affinity is important
  - Semaphores/locks typically implemented as spin-locks: preemption during critical sections

Multiprocessor Scheduling

- Central queue – queue can be a bottleneck



- Distributed queue – load balancing between queue



Scheduling

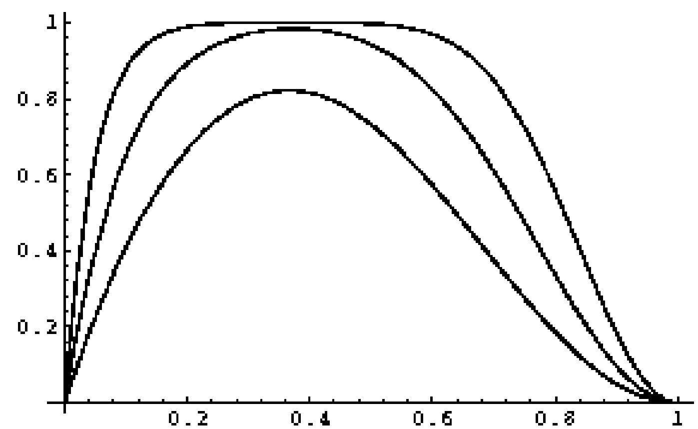
- Common mechanisms combine central queue with per processor queue (SGI IRIX)
- Exploit *cache affinity* – try to schedule on the same processor that a process/thread executed last
- Context switch overhead
  - Quantum sizes larger on multiprocessors than uniprocessors

Parallel Applications on SMPs

- Effect of spin-locks: what happens if preemption occurs in the middle of a critical section?
  - Preempt entire application (co-scheduling)
  - Raise priority so preemption does not occur (smart scheduling)
  - Both of the above
- Provide applications with more control over its scheduling
  - Users should not have to check if it is safe to make certain system calls
  - If one thread blocks, others must be able to run

Distributed Scheduling: Motivation

- Distributed system with *N* workstations
  – Model each w/s as identical, independent M/M/1 systems
  – Utilization u, P(system idle)=1-u
- What is the probability that at least one system is idle and one job is waiting?



Implications

- Probability high for moderate system utilization
  - Potential for performance improvement via load distribution
- High utilization => little benefit
- Low utilization => rarely job waiting
- Distributed scheduling (aka load balancing) potentially useful
- What is the performance metric?
  - Mean response time
- What is the measure of load?
  - Must be easy to measure
  - Must reflect performance improvement

Design Issues

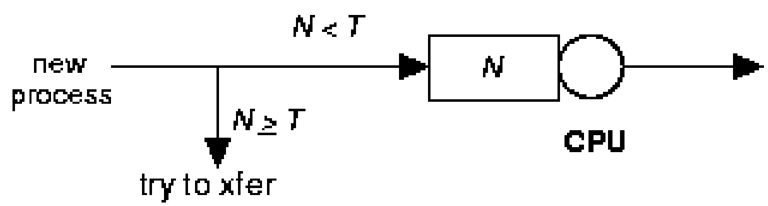
- Measure of load
  - Queue lengths at CPU, CPU utilization
- Types of policies
  - Static: decisions hardwired into system
  - Dynamic: uses load information
  - Adaptive: policy varies according to load
- Preemptive versus non-preemptive
- Centralized versus decentralized
- Stability: $\square > \square$ => instability, $\square_1 + \square_2 < \square_1 + \square_2$ =>load balance
  - Job floats around and load oscillates

Components

- *Transfer policy:* when to transfer a process?
  - Threshold-based policies are common and easy
- *Selection policy:* which process to transfer?
  - Prefer new processes
  - Transfer cost should be small compared to execution cost
    - Select processes with long execution times
- *Location policy:* where to transfer the process?
  - Polling, random, nearest neighbor
- *Information policy*: when and from where?
  - Demand driven [only if sender/receiver], time-driven [periodic], state-change-driven [send update if load changes]

Sender-initiated Policy

- *Transfer policy*



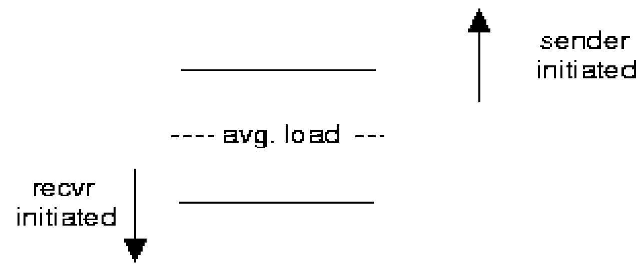
- *Selection policy*: newly arrived process
- *Location policy*: three variations
  - *Random*: may generate lots of transfers => limit max transfers
  - *Threshold:* probe *n* nodes sequentially
    - Transfer to first node below threshold, if none, keep job
  - *Shortest*: poll N_p nodes in parallel
    - Choose least loaded node below *T*

Receiver-initiated Policy

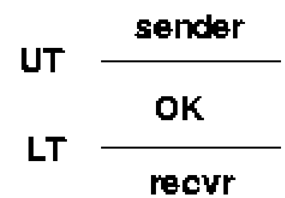
- Transfer policy: If departing process causes load < *T*, find a process from elsewhere
- Selection policy: newly arrived or partially executed process
- Location policy:
  - Threshold: probe up to N_p other nodes sequentially
    - Transfer from first one above threshold, if none, do nothing
  - Shortest: poll *n* nodes in parallel, choose node with heaviest load above *T*

Symmetric Policies

- Nodes act as both senders and receivers: combine previous two policies without change
  - Use average load as threshold



- Improved symmetric policy: exploit polling information
  - Two thresholds: *LT, UT, LT <= UT*
  - Maintain sender, receiver and OK nodes using polling info
  - Sender: poll first node on receiver list …
  - Receiver: poll first node on sender list …



Case Study: V-System (Stanford)

- State-change driven information policy
  - Significant change in CPU/memory utilization is broadcast to all other nodes
- *M* least loaded nodes are receivers, others are senders
- Sender-initiated with new job selection policy
- Location policy: probe random receiver, if still receiver, transfer job, else try another

Sprite (Berkeley)

- Workstation environment => owner is king!
- Centralized information policy: coordinator keeps info
  - State-change driven information policy
  - Receiver: workstation with no keyboard/mouse activity for 30 seconds *and* # active processes < number of processors
- Selection policy: manually done by user => workstation becomes sender
- Location policy: sender queries coordinator
- WS with foreign process becomes sender if user becomes active: selection policy=> home workstation

Sprite (contd)

- Sprite process migration
  - Facilitated by the Sprite file system
  - State transfer
    - Swap everything out
    - Send page tables and file descriptors to receiver
    - Demand page process in
    - Only dependencies are communication-related
      - Redirect communication from home WS to receiver

Code and Process Migration

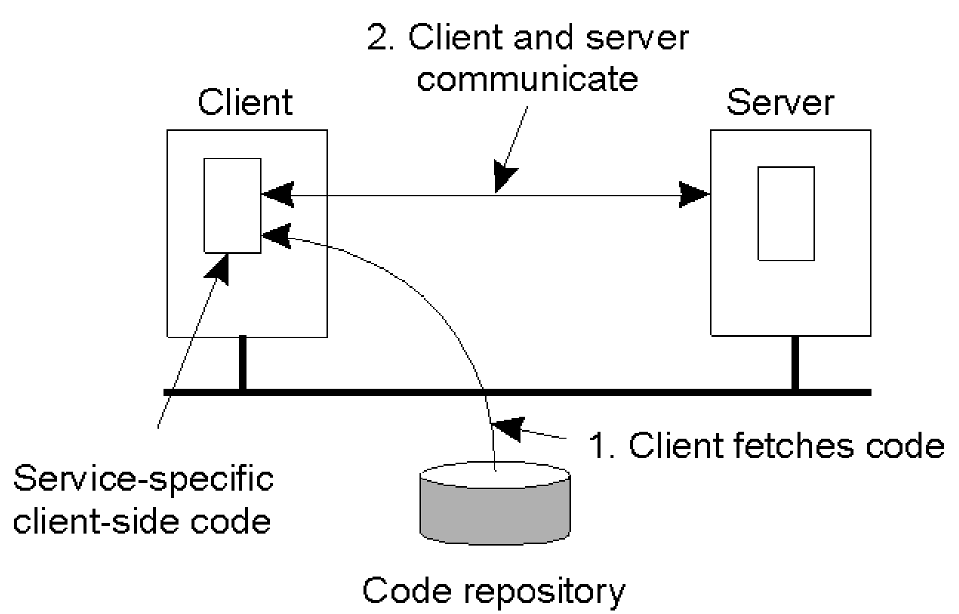
- Motivation
- How does migration occur?
- Resource migration
- Agent-based system
- Details of process migration

Motivation

- 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



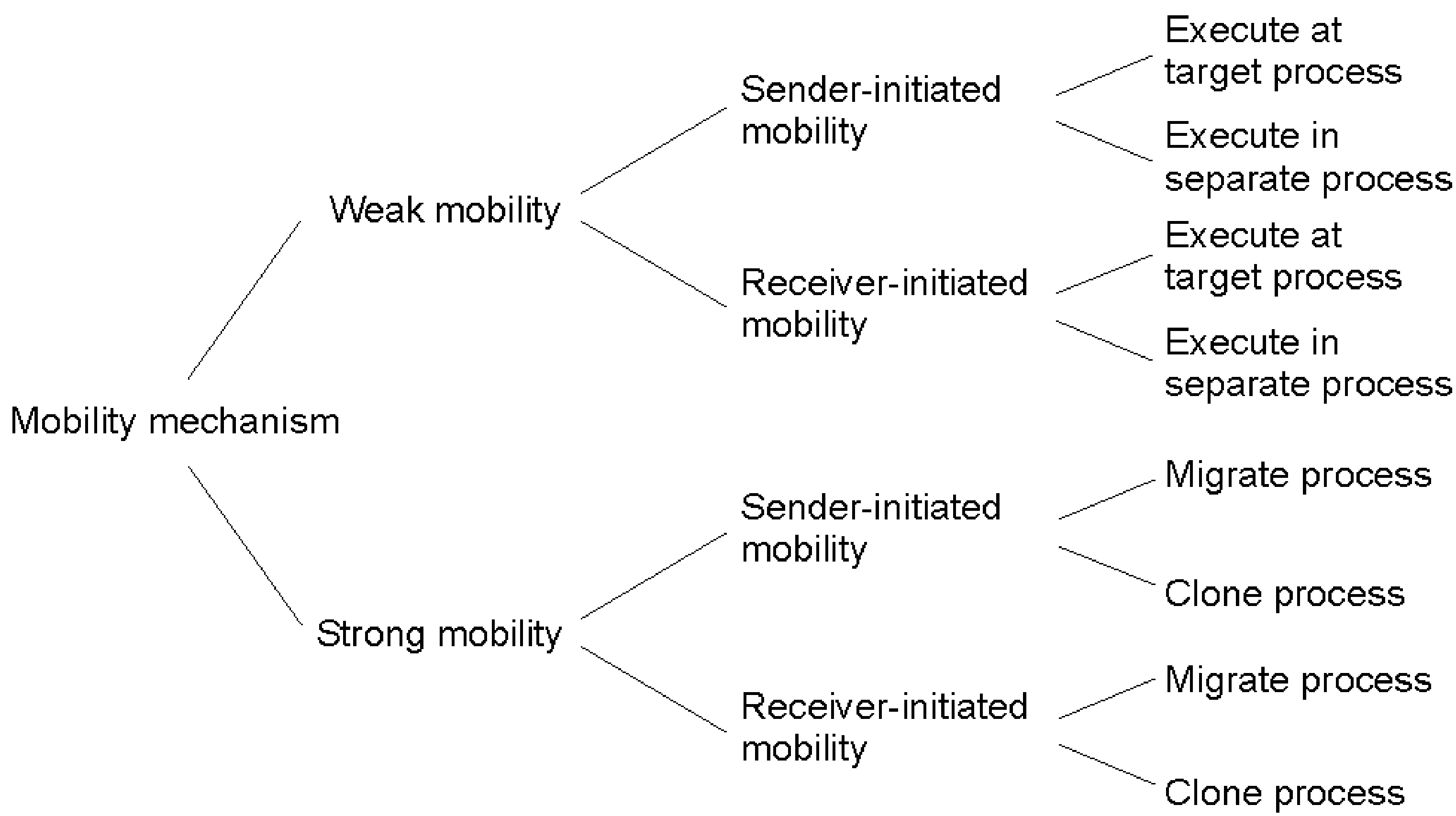
Migration models

- 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 (code is with sender)
  - Client sending a query to database server
  - Client should be pre-registered
- Receiver-initiated
  - 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

		Unattached	Fastened	Fixed
Process-to-resource binding	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]