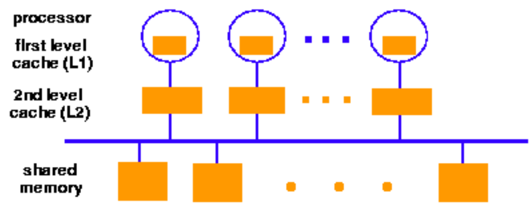
# Module 1: Multiprocessor Scheduling

- Will consider only shared memory multiprocessor or multi-core CPU

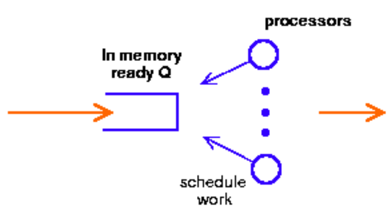



- Salient features: One or more caches: cache affinity is important
  - Semaphores/locks typically implemented as spin-locks: preemption during critical sections
- Multi-core systems: some caches shared (L2,L3); others are not

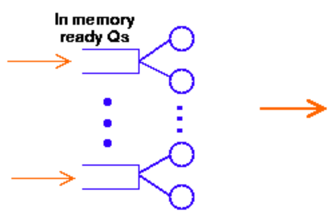


# Multiprocessor Scheduling

- Central queue – queue can be a bottleneck




- Distributed queue – load balancing between queue



# Multiprocessor 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

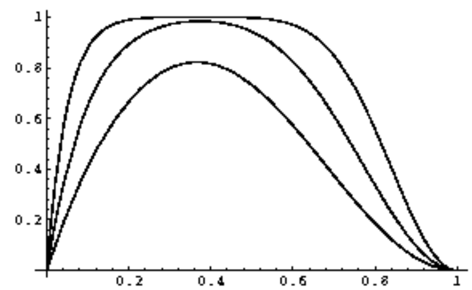


# Parallel Applications on SMPs

- *Gang scheduling*: schedule parallel app at once
- 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

# Module 2: 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: $\lambda > \mu$ => instability, $\lambda_1 + \lambda_2 < \mu_1 + \mu_2$ =>load balance
  - Job floats around and load oscillates

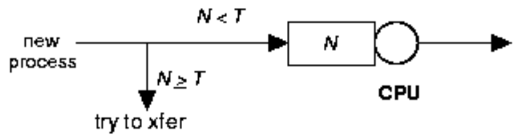


# Components

- *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*

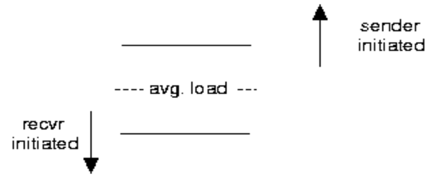


# Receiver-initiated Policy

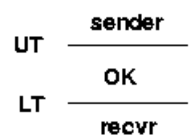
- Transfer policy: If departing process causes load < *T*, find a process from elsewhere
- Selection policy: newly arrived or partially executed process
- Location policy:
  - Threshold: probe up to $N_p$ other nodes sequentially
    - Transfer from first one above threshold, if none, do nothing
  - 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 …






## Module 3: Case Studies

# Case Study 1 : 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 from *M*, if still receiver, transfer job, else try another

# Case study 2: 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

# Case Study 3 : Volunteer Computing

- Internet scale operating system (ISOS)
  - Harness compute cycles of thousands of PCs on the Internet
  - PCs owned by different individuals
  - Donate CPU cycles/storage when not in use (pool resouces)
  - Contact coordinator for work
  - Coordinator: partition large parallel app into small tasks
  - Assign compute/storage tasks to PCs
- Examples: Seti@home, BOINC, P2P backups
  - Volunteer computing



# Distributed Scheduling Today

- Scheduling tasks in a cluster of servers
- Schedule batch jobs: Condor
- Schedule web requests in replicated servers

# Case study 4 : Condor

- Condor: use idle cycles on workstations in a LAN
- Used to run large batch jobs, long simulations
- Idle machines contact condor for work
- Condor assigns a waiting job
- User returns to workstation => suspend job, migrate
  - supports process migration
- Flexible job scheduling policies
- Sun Grid Engine: similar features as Condor
  - Evolved into cluster batch schedulers (SGE, DQS…)
- SLURM scheduler on UMass Swarm cluster



# Case study 5: Replicated Web Server

- Distributed scheduling in large web servers:
  - N nodes, one node acts as load balancing switch
  - other nodes are replicas
- Requests arrive at the load balancer queue
  - Scheduled onto a replica
- Simple policies: least loaded, round robin

- Session-based versus request-based polices
  - Will revisit this topic when studying WWW