Politecnico di Milano

Operating Systems

Processor allocation in distributed systems

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SUMMARY

- Processor Allocation
- Migration Strategies
- Co-scheduling

Introduction

- The system consists in a set of (fully connected) processors onto which a set of processes have to be allocated
- Possible allocation strategies
  - Non-migratory
    - P remains on the same machine until it terminates
  - Migratory
    - Move (migrate) an active (already started) process from one machine to another (target) machine
    - It requires transferring a sufficient amount of the state of a process from one machine to another
    - Better load balancing, more complex, significant impact on systems design

Overall Design issues

- Long term goals
  - Maximization of CPU utilization
  - Minimization of mean response time
  - Minimization of response ratio, i.e. the amount of time it takes to run a process on a machine divided on the value obtained executing it on an unloaded benchmark processor
- Load sharing
  - move processes from heavily loaded to lightly loaded systems
  - load can be balanced to improve overall performance

Overall Design issues

- Communications performance
  - processes that interact intensively can be moved to the same node to reduce communications cost
  - may be better to move process to where the data reside when the data is large
- Availability
  - long-running process may need to move because the machine it is running on, will be down
- Utilizing special capabilities
  - process can take advantage of unique hardware or software capabilities which are in a particular system

Allocation algorithms: taxonomy

- Deterministic vs heuristic alg.
  - Difficult prediction of process behavior and requirements
- Centralized vs distributed alg.
  - Centralized is less robust, better tuned, with system bottleneck
- Optimal vs sub-optimal alg.
  - Due to cost, typ Heuristic, distributed, sub-optimal
- Local vs global alg. (transfer policy)
  - Which information are used to decide
- Sender-initiate vs receiver initiated alg. (location)
  - Where to send the process, it cannot be local

Implementation problems

- Determination of the CPU load of all the machines
- Overhead of the algorithm
- Implementation complexity
  - Maybe…simple is better
- Stability
  - Different algorithms runs simultaneously from one other, with not up-to-date and possibly consistent information

PROCESS MIGRATION: BASIC IDEA

- Transfer of sufficient amount of the state of a process from one machine to another
- The process executes on the target machine
- Must destroy the process on the source system and create it on the target system
- Process control block and any links must be moved

PROCESS MIGRATION: MOTIVATION

- Load sharing
  - Move processes from heavily loaded to lightly load systems
  - Load can be balanced to improve overall performance
- Communications performance
  - Processes that interact intensively can be moved to the same node to reduce communications cost
  - May be better to move process to where the data reside when the data is large
- Availability
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  - Process can take advantage of unique hardware or software capabilities

WHO BEGINS THE MIGRATION?

- Operating system
  - when goal is load balancing
- Process
  - when goal is to reach a particular resource

Classes of algorithms

- Deterministic Graph-based
- Centralized
- Hierarchical
- Distributed Heuristic
- Bidding

Deterministic Graph-based

- Assumptions
  - Knowledge of CPU and memory requirements for each process and of a matrix with the average traffic for each processor pair (**difficult)**
- Model: The system is a weigthed graph
  - Nodes = processes, arcs msg flow
- Problem
  - Assignment of multiple proc. to the CPUs so that net traffic is minimized, while fuflfilling processes constr.
  - Find a graph partition in disjoined sub-graphs subject to contraints, i.e. discovering “clusters”

Centralized (UP-DOWN)

- Does not requires *a priori* knowledge, is heuristic
- A coordinator maintains a global **usage table (**of Workstations), that is updated sending msg
- The allocation decisions are based on the infos of the usage table, on-the-fly, not only based on workload balancing
- When a process is created, the owner ws can move it on other machine cumulating *penality points* that are summed to the owner table entry (UP)
- If no pending requests, table values decrese (DOWN)

Centralized (UP-DOWN)

- Entry values
  - + : the corresp. workstation is a big user of resorces
  - - : the ws needs resources
  - 0 : neutral
- Heuristic
  - When a processor becomes free, the pending request whose owner has the lowest score wins
- Consequence: fair capacity allocation
  - a user occupying no processor, rising a request peding for a long time, always beat someone using many processors
- Good in many cases, but do not scale well to large systems

Hierarchical

- Try to remove the bottlenek of centralized
- The processors (workers and managers) are hierarchically organized, indipendently of the physical organization of network
  - For each group of workers, a manager traks who is busy or idle and distributes the works
  - Possibility of several levels of managers, but only one reports to the upper level: reduced communication
  - To prevent vulnerability, the hierarchy should not be a pyramid, the top level contains >1 managers

Hierarchical

- If a manager receives a request and is in shortage of resources, it pass the request upwards to the tree
- The number of processor R associated to a manager must be properly chosen
  - R large: too many processors allocated, waste of computational capacity
  - R small: overhead due to upwards passing of requests
- Potential problems
  - Random multiple requests happens at various stages of the algorithms, giving out-of-date estimates of workers capability, race conditions, deadlocks

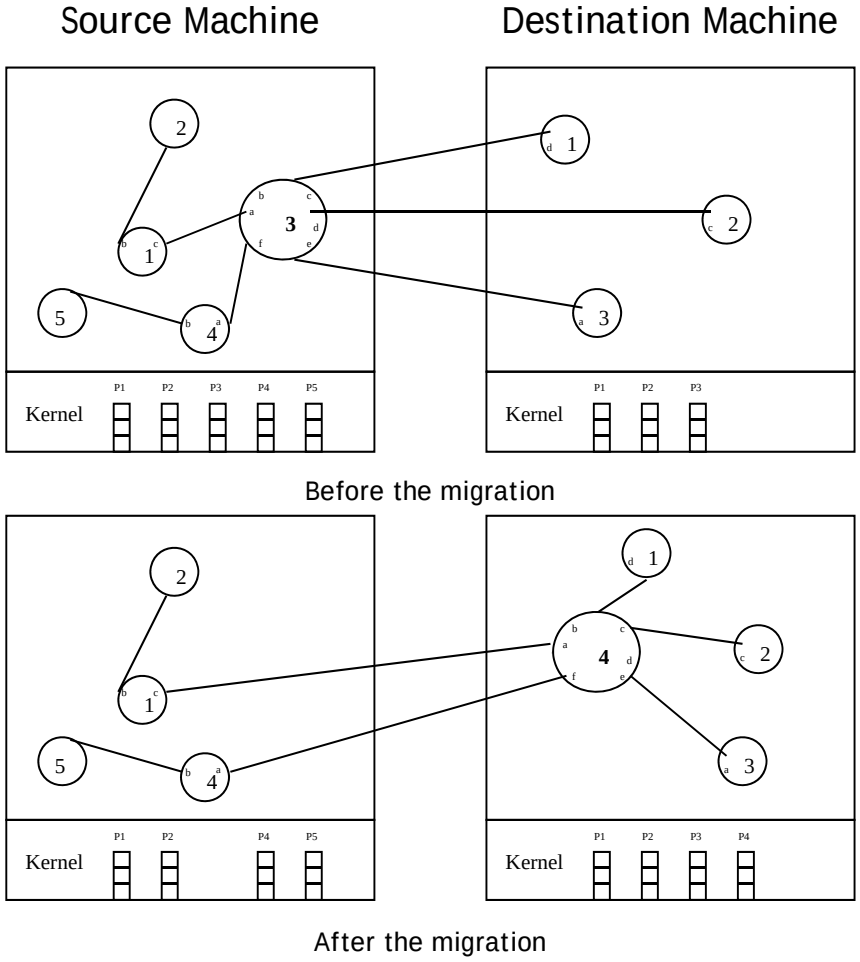
Distributed Heuristic

- Studied mainly by Eager (see next)
- A process is created, and the machine on which it is created send a probe msg to a randomly chosen machine, asking if its load is under a given threshold
  - If yes: the process is sent there
  - If no: another machine is chosen for probe
- It exists a upper bound N to the probes, then the process will run on the originating machine

Bidding

- Computer system actors
  - Buyers, Sellers of services, Prices set by supply/demand
  - The price of a processor depends on memory size, hardware, espected response time, ...
- Processes must buy CPU time, Processors provides their services to the highest bidder
- A process starts a child
  - Determine the set of processors offering the needed services and chose the cheapest, fastest, or best price/performance
  - Prices/offers are periodically updated

AN EXAMPLE OF MIGRATION (1)



AN EXAMPLE OF MIGRATION (2)

- The process 3 migrates from the source machine to the destination machine
- All the IDs of the links (a,b,c,d...) of the processes don't change
- The operating system has to move the process control block and it has to modify the mapping of the links
- The process migration has to be invisible either to the migrated process and its partners
  - Problems: addressing space and open files

MIGRATION STRATEGIES (1)

- Eager (all): Transfer entire address space
  - no trace of process is left behind
  - if address space is large and if the process does not need most of it, then this approach may be unnecessarily expensive
  - the initial cost of the migration can be some minutes
- Precopy: Process continues to execute on the source node while the address space is copied
  - pages modified on the source during precopy operation have to be copied a second time
  - reduces the time that a process is frozen and cannot execute during migration

MIGRATION STRATEGIES (2)

- Eager (dirty): Transfer only that portion of the address space that is in main memory
  - any additional blocks of the virtual address space are transferred on demand
  - the source machine is involved throughout the life of the process (e.g., remote memory paging)
  - good if process is temporarily going to another machine
- Copy-on-reference: Pages are only brought over on reference
  - variation of eager (dirty)
  - has lowest initial cost of process migration

MIGRATION STRATEGIES (3)

- Flushing: Pages are cleared from main memory by flushing dirty pages to disk
  - later use copy-on-reference strategy
  - relieves the source of holding any pages of the migrated process in main memory, making it available for other processes

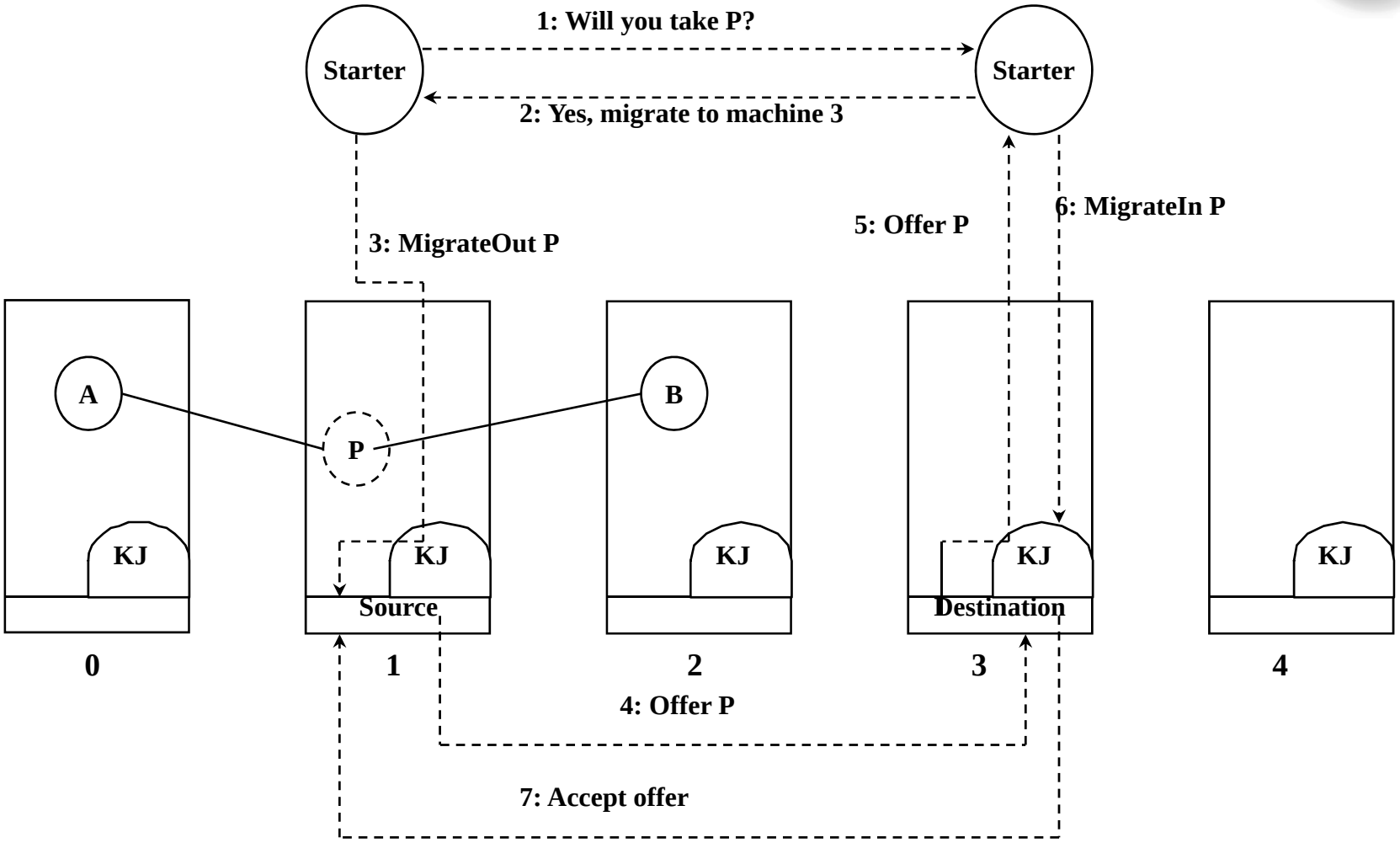
CHOICE OF A STRATEGY

- If a process uses a little address space of the source machine memory (e.g, it moves temporarly on another machine and then return back) we will choose
  - Eager (dirty)
  - Copy on reference
  - Flushing
- Otherwise, when sooner or later the entire address space will be referenced, we will choose
  - Eager (all)
  - Precopy

NEGOTIATION OF PROCESS MIGRATION

- Migration policy is responsibility of Starter utility
- Each machine has a Starter Utility which controls the process migration
- Starter utility is also responsible for long-term scheduling and memory allocation
- Decision to migrate must be reached jointly by two Starter processes (one on the source and one on the destination)

NEGOTIATION OF PROCESS MIGRATION



NEGOTIATION OF PROCESS MIGRATION

1. The Starter Utility of the source system wants the process P to migrate to a destination system. So it sends a message to the Starter Utility of the destination system
2. The destination Starter Utility answers a positive acknowledgment, if it ready
3. The source Starter Utility sends a message of migration to its kernel job (KJ), which converts msg among remote processes into system calls
4. The source kernel offers to send the process P to the destination (the offer includes statistic son P like age and communication overhead)

NEGOTIATION OF PROCESS MIGRATION

5 The destination kernel moves the offer to its Starter Utility. If it is in shortage of resources, it can reject

6 The Starter Utility uses a MIGRATE_IN call

7 The destination accepts the offer, allocating resources so to avoind stalls or other problems

- Source machine (1) must send messagges toward those containing other processes communicating with P, to update links

Eviction

- System evict a process that has been migrated to it
- If a workstation is idle, process may have been migrated to it
  - Once the workstation is active, it may be necessary to evict the migrated processes to provide adequate response time

EXAMPLE: AIX (IBM Unix) - Actions

- When a process decide to migrate (automigration)
  - it select the target machine
  - send a msg of remote tasking (part of the process image and data concerning open files)
- The server kernel of the receiver machine fork off a child with the received information
- The new process recalls data, environment, arguments and information on the stack, necessary to complete the migration
- The original process if informed of the succeded migration, it sends a ACK to the new process and suicide

Co-scheduling

- In many cases processes operate in “group”
- Scheduling can consider interprocess communication to ensure that all the member of a group run at the same time
- The algorithm uses a *conceptual* matrix
  - Column: process table for one processor
  - Row: set of processes that in a given time slot are running
- Goal: each processor uses a RR scheduling with all processes in slot 0, then RR for those in slot 1, …
- A broadcast message can be used to tell each processor when perfoming switching, to synchronize timeslicing

Co-scheduling

- Putting members of a process group in the same slot takes advantage of N-fold parallelism, to maximize communication throughput
- This scheduling techniques can be combined with hierarchical model of process managements, in some systems
- Other variation breaks the matrix into rows and concatenates consecutive slots belonging to different processors