Parallel Job Schedulings

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Scheduling on UMA Multiprocessors

- **Schedule:**
  - allocation of tasks to processors

- **Dynamic scheduling**
  - A single queue of ready processes
  - A physical processor accesses the queue to run the next process
  - The binding of processes to processors is not tight

- **Static scheduling**
  - Only one process per processor
  - Speedup can be predicted
Deterministic model

- A parallel program is a collection of tasks, some of which must be completed before others begin
- Deterministic model: The execution time needed by each task and the precedence relations between tasks are fixed and known before run time
- Task graph
Gantt chart

- Gantt chart indicates the time each task spends in execution, as well as the processor on which it executes.
Optimal schedule

- If all of the tasks take unit time, and the task graph is a forest (i.e., no task has more than one predecessor), then a polynomial time algorithm exists to find an optimal schedule.
- If all of the tasks take unit time, and the number of processors is two, then a polynomial time algorithm exists to find an optimal schedule.
- If the task lengths vary at all, or if there are more than two processors, then the problem of finding an optimal schedule is NP-hard.
Graham’s list scheduling algorithm

- $T = \{T_1, T_2, \ldots, T_n\}$
  - a set of tasks
- $\mu : T \rightarrow (0, \infty)$
  - a function associates an execution time with each task
- A partial order $\prec$ on $T$
- $L$ is a list of task on $T$
- Whenever a processor has no work to do, it instantaneously removes from $L$ the first ready task; that is, an unscheduled task whose predecessors under $\prec$ have all completed execution. (The processor with the lower index is prior)
Graham’s list scheduling algorithm - Example

L = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7\}

Time

Processors

T_1  T_2  T_3  T_4  T_5  T_6  T_7
Graham’s list scheduling algorithm - Problem

L = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9\}
Coffman-Graham’s scheduling algorithm (1)

- Graham’s list scheduling algorithm depends upon a prioritized list of tasks to execute.
- Coffman and Graham (1972) construct a list of tasks for the simple case when all tasks take the same amount of time.
Coffman-Graham’s scheduling algorithm (2)

- Let $T = T_1, T_2, \ldots, T_n$ be a set of $n$ unit-time tasks to be executed on $p$ processors.
- If $T_i < T_j$, then task is $T_i$ an immediate predecessor of task $T_j$, and $T_j$ is an immediate successor of task $T_i$.
- Let $S(T_i)$ denote the set of immediate successor of task $T_i$.
- Let $\alpha(T_i)$ be an integer label assigned to $T_i$.
- $N(T)$ denotes the decreasing sequence of integers formed by ordering of the set $\{\alpha(T') | T' \in S(T)\}$.
Coffman-Graham’s scheduling algorithm (3)

1. Choose an arbitrary task $T_k$ from $T$ such that $S(T_k) = 0$, and define $\alpha(T_k)$ to be 1.
2. for $i \leftarrow 2$ to $n$ do
   a. $R$ be the set of unlabeled tasks with no unlabeled successors.
   b. Let $T^*$ be the task in $R$ such that $N(T^*)$ is lexicographically smaller than $N(T)$ for all $T$ in $R$.
   c. Let $\alpha(T^*) \leftarrow i$
   endfor
3. Construct a list of tasks $L = \{U_n, U_{n-1}, \ldots, U_2, U_1\}$ such that $\alpha(U_i) = i$ for all $i$ where $1 \leq i \leq n$.
4. Given $(T, \langle, L)$, use Graham’s list scheduling algorithm to schedule the tasks in $T$. 

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Coffman-Graham’s scheduling algorithm – Example (1)
Coffman-Graham’s scheduling algorithm – Example (2)

Step 1 of algorithm

Task $T_9$ is the only task with no immediate successor. Assign 1 to $\alpha(T_9)$

Step 2 of algorithm

- $i=2$: $R = \{T_7, T_8\}$, $N(T_7) = \{1\}$ and $N(T_8) = \{1\}$ $\Rightarrow$ Arbitrarily choose task $T_7$ and assign 2 to $\alpha(T_7)$
- $i=3$: $R = \{T_3, T_4, T_5, T_8\}$, $N(T_3) = \{2\}$, $N(T_4) = \{2\}$, $N(T_5) = \{2\}$ and $N(T_8) = \{1\}$ $\Rightarrow$ Choose task $T_8$ and assign 3 to $\alpha(T_8)$
- $i=4$: $R = \{T_3, T_4, T_5, T_6\}$, $N(T_3) = \{2\}$, $N(T_4) = \{2\}$, $N(T_5) = \{2\}$ and $N(T_6) = \{3\}$ $\Rightarrow$ Arbitrarily choose task $T_4$ and assign 4 to $\alpha(T_4)$
- $i=5$: $R = \{T_3, T_5, T_6\}$, $N(T_3) = \{2\}$, $N(T_5) = \{2\}$ and $N(T_6) = \{3\}$ $\Rightarrow$ Arbitrarily choose task $T_5$ and assign 5 to $\alpha(T_5)$
- $i=6$: $R = \{T_3, T_6\}$, $N(T_3) = \{2\}$ and $N(T_6) = \{3\}$ $\Rightarrow$ Choose task $T_3$ and assign 6 to $\alpha(T_3)$
Coffman-Graham’s scheduling algorithm – Example (3)

- i=7: \( R = \{T_1, T_6\}, N(T_1) = \{6, 5, 4\} \) and \( N(T_6) = \{3\} \) ⇒ Choose task \( T_6 \) and assign 7 to \( \alpha(T_6) \)

- i=8: \( R = \{T_1, T_2\}, N(T_1) = \{6, 5, 4\} \) and \( N(T_2) = \{7\} \) ⇒ Choose task \( T_1 \) and assign 8 to \( \alpha(T_1) \)

- i=9: \( R = \{T_2\}, N(T_2) = \{7\} \) ⇒ Choose task \( T_2 \) and assign 9 to \( \alpha(T_2) \)

Step 3 of algorithm

\[ L = \{T_2, T_1, T_6, T_3, T_5, T_4, T_8, T_7, T_9\} \]

Step 4 of algorithm

Schedule is the result of applying Graham’s list-scheduling algorithm to task graph \( T \) and list \( L \)
Classes of scheduling

- **Static scheduling**
  - An application is modeled as an directed acyclic graph (DAG)
  - The system is modeled as a set of homogeneous processors
  - An optimal schedule: NP-complete

- **Scheduling in the runtime system**
  - Multithreads: functions for thread creation, synchronization, and termination
  - Parallelizing compilers: parallelism from the loops of the sequential programs

- **Scheduling in the OS**
  - Multiple programs must co-exist in the same system

- **Administrative scheduling**
Current approaches

- Global queue
- Variable partitioning
- Dynamic partitioning with two-level scheduling
- Gang scheduling
Global queue

- A copy of uni-processor system on each node, while sharing the main data structures, specifically the run queue
- Used in small-scale bus-based UMA shared memory machines
- Automatic load sharing
- Cache corruption
- Preemption inside spinlock-controlled critical sections
Variable partitioning

- Processors are partitioned into disjoined sets and each job is run only in a distinct partition

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<th>Changes</th>
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- Distributed memory machines
- Problem: fragmentation, big jobs
Dynamic partitioning with two-level scheduling

- Changes in allocation during execution
- Work-pile model:
  - The work = an unordered pile of tasks or chores
  - The computation = a set of worker threads, one per processor, that take one chore at time from the work pile
  - Allowing for the adjustment to different numbers of processors by changing the number of the workers
  - Two-level scheduling scheme: the OS deals with the allocation of processors to jobs, while applications handle the scheduling of chores on those processors
Gang scheduling

- Problem: Interactive response times $\Rightarrow$ time slicing
  - Global queue: uncoordinated manner

- Observation:
  - Coordinated scheduling is only needed if the job’s threads interact frequently
  - The rate of interaction can be used to drive the grouping of threads into gangs

- Samples:
  - Co-scheduling
  - Family scheduling: which allows more threads than processors and uses a second level of internal time slicing
Several specific scheduling methods

- Co-scheduling
- Smart scheduling [Zahorijan et al.]
- Scheduling in the NYU Ultracomputer [Elter et al.]
- Affinity based scheduling
- Scheduling in the Mach OS
Co-Scheduling

- Context switching between applications rather than between tasks of several applications.
- Solving the problem of “preemption inside spinlock-controlled critical sections”.
- Cache corruption???
Smart scheduling

- Avoiding:
  1. preempting a task when it is inside its critical section
  2. rescheduling tasks that were busy-waiting at the time of their preemption until the task that is executing the corresponding critical section releases it.

- The problem of “preemption inside spinlock-controlled critical sections” is solved.

- Cache corruption???.

Tasks can be formed into groups

Tasks in a group can be scheduled in any of the following ways:
- A task can be scheduled or preempted in the normal manner
- All the tasks in a group are scheduled or preempted simultaneously
- Tasks in a group are never preempted.

In addition, a task can prevent its preemption irrespective of the scheduling policy (one of the above three) of its group.
Affinity based scheduling

- Policy: a task is scheduled on the processor where it last executed [Lazowska and Squillante]
- Alleviating the problem of cache corruption
- Problem: load imbalance
Threads

Processor sets: disjoint

Processors in a processor set is assigned a subset of threads for execution.

- Priority scheduling: LQ, GQ(0),…,GQ(31)
  - Global queue (GQ)
    - LQ and GQ(0-31) are empty: the processor executes an special *idle* thread until a thread becomes ready.
    - Preemption: if an equal or higher priority ready thread is present