Reference Model of Real-Time Systems

Introduction

- Keep track of relevant details.
- A good model focuses on:
  - timing properties,
  - Resource requirement,
  - Way the OS assigns available resources to system components.
- In this chapter, points 1 and 2 will be covered.

Processors and Resources

- Processors (servers or active resources):
  - Computers: execute machine instructions,
  - Transmission links: move data from place to another,
  - Disks: Retrieve files,
  - DB servers: process queries.
- Identical Processors: Can be used interchangeably.
- *m* processors are denoted P_1, P_2, …, P_m.

Processors and Resources

- Resources (passive resources): Memory, sequence numbers, mutexes, DB locks.
- Example 1: Job sharing data with other jobs. Data protected by semaphores. The lock of a semaphore is a resource.
- Example 2: DB jobs (update, query). The DB server uses a locking mechanism. The lock is a resource.
- Reusable Resources.
- A resource has one or more units, each unit is used by one job.
- Plentiful resources (memory) are not mentioned in the model.
- Resources are denoted with the letter *R*.

Jobs Characteristics

- Temporal parameters.
- Functional parameters.
- Resource parameters.
- Interconnection parameters.

Temporal Parameters of RT Workload

- Reminder: Job and Task definitions.
- Assumption: Many parameters of hard RT jobs (tasks) are known. Example: Number of tasks is known.
- Number of jobs of a hard RT system is known.
- Reminder: Release Time (r_i), absolute deadline (d_i), relative deadline (D_i).
- Feasible interval: (r_i, d_i]

Fixed, Jittered and Sporadic Release Times

- $r_i \in [r_i^-, r_i^+]$
- $[r_i^-, r_i^+]$ is called the jitter in r_i or release-time jitter.
- If jitter negligible compared to other temporal parameters ➔ Fixed release time.
- Release time of jobs in response for an external events: Sporadic release time.
  - $A(x)$ probability distribution of the interrelease time.

Execution Time

- Execution time (e_i): amount of time required to complete execution of J_i when it executes alone and has all resources required.
- $e_i \in [e_i^-, e_i^+]$
- e_i is unknown a priori.
- e_i^- and e_i^+ are known for hard real-time job.

Periodic Task Model

- Well known deterministic workload model.
- Characterizes many hard real-time applications.
- Good performance and well-understood behavior.

Periods, Execution Times and Phases of Periodic Tasks

- Periodic Task: jobs executed repeatedly at regular or semi-regular time intervals.
- Period p_i of a periodic task T_i : minimum length of all time intervals between release times of consecutive jobs.
- Execution Time of T_i : Maximum execution time of all the jobs in T_i.

Remark

- Definition differs from one found in literature.
- Accuracy of periodic task model decreases with:
  - Increasing jitter in release times
  - Variation of execution times.
  - Example: Transmission of variable bit-rate video.

Notations

- Tasks in system: $T_1, T_2, \ldots, T_n$.
- Jobs in task T_i : $J_{i,1}, J_{i,2}, \ldots, J_{i,\mathrm{k}}$.
- Phase of T_i (Release time of the 1st job of T_i): $\phi_i = r_{i,1}$.
- Hyperperiod of periodic tasks H: least common multiple of $(p_i)_{i = 1, 2, \ldots, n}$
- Max number of jobs in H = sum (H/p_i)
- Example: periods 3, 4 and 10. Hyperperiod = 60. N = 61

Notations

- Utilization of the task T_i : $u_i = e_i / p_i$
- Total utilization U : sum of u_i
- Example:
  - Execution times: 1, 1 and 3
  - Periods: 3, 4 and 10
  - Utilizations: 0.33, 0.25 and 0.3
  - $U = 0.88$
  - These tasks can keep processor busy 88% of time.

Aperiodic and Sporadic Tasks

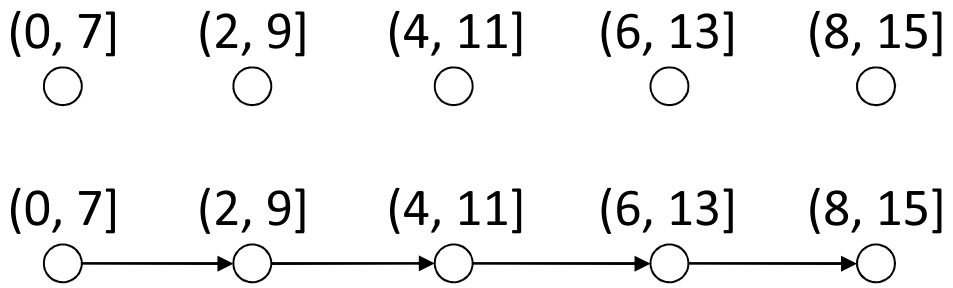
- Aperiodic and Sporadic jobs: jobs executed in response to an external events.
- Their release-times are unknown a priori.
- Aperiodic Task: jobs have soft deadlines or deadlines.
- Sporadic Task: jobs have hard deadlines.

Precedence constraints and data dependency

- Execution order constraints.
- Jobs with *precedence constraints* must be executed with some order.
- *Independent* jobs: no precedence order.
- *Consumer* job can't begin until *Producer* job completes.
- Examples: Radar surveillance system, information system.

Precedence Graph and Task Graph

- J_i is a *predecessor* of J_k: J_k can't begin until J_i completes. Notation: $J_i < J_k$.
- J_k is a *successor* of J_i.
- *Immediate* predecessor/ successor.



Data Dependency

- Jobs communicating via shared data.
- Data dependency cannot be captured by a classical precedence graph.

Other Types of Dependencies

- Temporal Dependency: Jobs constraints to complete within certain time from one another.
- AND/OR precedence constraints:
  - AND precedence constraints: All immediate predecessors must complete before execution.
  - OR precedence constraints: One or more of immediate predecessors must complete before execution. Represented by a square.

Conditional Branches

- Only one immediate successor to be executed.
- Represented by filled circles on task graph.

Pipeline Relationship

- Consumer (job) can begin execution when Producer (job) have completed.

Functional Parameter

- Preemptivity of jobs.
- Criticality of jobs.
- Optional Execution.
- Laxity type and Laxity Function.

Preemptivity of jobs

- Preemptable Job: can be suspended and resumed from the suspension point.
- Examples: Computations.
- Nonpreemptable: Data transmission.

Criticality of Jobs

- Criticality of a Job: Positive number indicating how critical (important) the job is.
- Criticality increases with the importance of the job.
- Don’t use the terms *Priority* and *Weight*.

Optional Executions

- If an *Optional job* or *optional portion* completes late or is not executed at all, the system still functions satisfactorily.
- Non-Optional job: Mandatory.

Laxity Type and Laxity Function

- Laxity type: indicates whether the job is hard or soft.
- Recall: Usefulness function that gives usefulness of job results as a function of tardiness.
- Hard RT Jobs: Usefulness becomes zero or negative as soon as job is tardy. "*Better never than late*".
- Soft RT Jobs: Usefulness decreases gradually.

Resource Parameters of Jobs and Parameters of resources

- Preemptivity of Resources.
- Resource Graph.

Preemptivity of Resources

- Describing processors and resources independently of application → Parameter of resources: Preemptivity.
- Nonpreemptable resource: Each unit is to be used serially.

Resource Graph

- Use letters *P* for processors and *R* for (passive) resources.
- Resource parameters:
  - Type.
  - Number of available units.

Scheduling Hierarchy

- Task graph:
  - Processor time
  - Resource requirement
  - Timing constraints
- Resource graph:
  - Amounts of available resources
  - Resources attributes
  - Usage rules

Scheduler and Schedules

- Scheduler: implements scheduling algorithms
  - Schedules Jobs,
  - Allocates Resources. Example: Processors assignment on jobs (or vice versa).
- Schedule: Assignment of all system jobs on available processors produced by the scheduler.

Valid schedule

- Every Processor is assigned to at most one job at any time.
- Every job is assigned at most one processor at any time.
- No job is scheduled before its release-time.
- Total amount of processor time assigned to a job is equal to its execution time.
- Precedence and resource usage constraints are satisfied.

Feasibility, Optimality and Performance measures

- Feasible schedule: valid schedule where every job meets its timing constraints.
- Schedulable set of jobs: the scheduler always produces a feasible schedule.
- Optimal scheduling algorithm: always produces a feasible schedule, if it exists, for a set of hard real-time jobs.