Last Time

- Real-time scheduling using cyclic executives

Today

- Real-time scheduling using priorities
  - How to assign priorities?
  - Will the assigned priorities work?
  - What can we say in general about the scheduling algorithms?

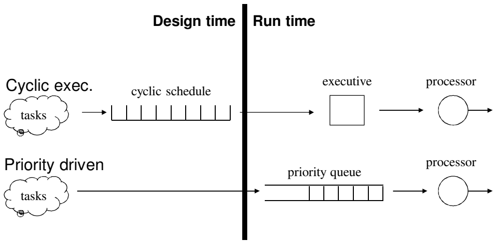
Real-Time Review 1

- Motivation
  - Your car's engine control CPU overloads → BAD
  - Airplane doesn't update flaps on time → BAD
- System contains n periodic tasks $T_1, \ldots, T_n$
- T_i is specified by (P_i, C_i, D_i)
  - P is period
  - C is execution cost (also called E)
  - D is relative deadline
- Task T_i is "released" at start of period, executes for C_i time units, must finish before D_i time units have passed
  - Often $P_i=D_i$, and in this case we omit D_i

Real-Time Review 2

- Given:
  - A set of real-time tasks
  - A scheduling algorithm
- Is the task set schedulable?
  - Yes → all deadlines met, forever
  - No → at some point a deadline might be missed
- Ways to schedule
  - Cyclic executive
  - Static priorities
  - Dynamic priorities
  - …

Cyclic Exec. Vs. Priorities



- Priorities are more flexible but less predictable
- Priorities may be fixed at design time or computed at runtime

Today's Assumptions

- Tasks are running on an RTOS
  - Each task runs in its own preemptive thread
  - Scheduled using priorities
- Uniprocessor embedded system
  - If system has multiple processors we analyze them separately
    - This works unless we want tasks to migrate between processors
- Tasks don't synchronize using locks
  - Later we'll see how to avoid this assumption
- No OS overhead
  - Later we'll see how to avoid this assumption

How to assign priorities?

- Rate monotonic (RM)
  - Shorter period tasks get higher priority
- Deadline monotonic (DM)
  - Tasks with shorter relative deadlines get higher priority
- Both RM and DM…
  - Have good theoretical properties
  - Work well in practice
- Other considerations
  - Criticality
  - Output jitter requirement

Example

- System with 4 tasks:
  - $T_1 = (4,1)$, $T_2 = (5, 1.8)$, $T_3 = (20, 1)$, $T_4 = (20, 2)$
- What is the RM priority assignment?
- What is the DM priority assignment?
- Will these priority assignments work?
  - Remember: “work” means no deadlines missed, ever

Utilization

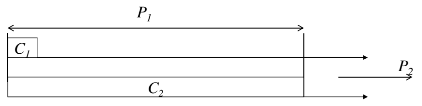
- Utilization of a task: C / P
- Utilization of a task set: Sum of task utilizations
- Schedulable utilization of a scheduling algorithm:
  - Every set of periodic tasks with utilization less or equal than the schedulable utilization of an algorithm can be feasibly scheduled by that algorithm
- Higher schedulable utilization is better
- Schedulable utilization is always ≥ 0.0 and ≤ 1.0
- Question: What is the schedulable utilization of…
  - FIFO scheduling?
  - EDF scheduling?
  - Generic fixed priority scheduling?
  - RM scheduling?

How about dynamic priorities?

- Dynamic priority means that priorities are not fixed at design time – the system can keep changing them as it runs
- Example algorithms
  - Earliest deadline first (EDF)
  - Least slack time first (LST)
  - First-in first-out (FIFO)
  - Last-in first-out (LIFO)
- Which of these work, for the example from the previous slide?

FIFO Schedulable Utilization

- $U_{FIFO} = 0.0$
  - Oops!
- Proof
  - Pick a utilization u
  - Pick an arbitrary period p
  - Create a task set with two tasks
    - Task 1 has $C = p * u/2$, $P = p$ (utilization = u/2)
    - Task 2 has $C = p$, $P = p * 2/u$ (utilization = u/2)
  - This task set has utilization u and is not schedulable

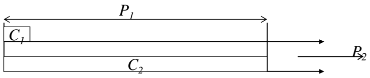


EDF Schedulable Utilization

- $U_{EDF} = 1.0$
  - As long as we ignore synchronization between tasks
- We’ll return to this result later

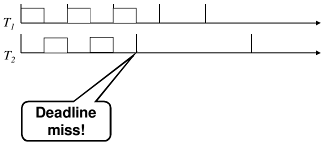
Fixed Priority Schedulable Utilization

- $U_{FP} = 0$



- $U_{RM} = ?$
  - $U_{RM} \neq 0$
  - $U_{RM} \neq 1$

$$\left.\begin{array}{l} T_1 = (2,\ 1,\ 2) \\ T_2 = (5,\ 2.5,\ 5) \end{array}\right\} \quad U = \frac{e_1}{p_1} + \frac{e_2}{p_2} = 1 \leq 100\ \%$$



Simply Periodic Case

- A set of tasks is simply periodic if, for every pair of tasks, one period is multiple of other period
- Result: A system of simply periodic, independent, preemptible tasks whose relative deadlines are equal to their periods is schedulable according to RM iff their total utilization does not exceed 1.0
- Proof:
  - Assume T_i misses deadline at time t
  - t is integer multiple of P_i and $p_k, \forall p_k < p_i$
  - Then, total time to complete jobs with deadline t is:
    $$\sum_{k=1}^{i} \frac{t \cdot e_k}{p_k} = t \cdot U_i = t \cdot \sum_{k=1}^{i} \frac{e_k}{p_k}$$
  - T_i can only miss deadline if $U > 1.0$

General RM Case

- Theorem
  - *n* independent, preemptible, periodic tasks with $D_i = P_i$ can be feasibly scheduled by RM if its total utilization *U* is less or equal to $n(2^{1/n} - 1)$
- For n=1, U = 1.0
- For n=2, U ≈ 0.83
- For n=∞, U ≈ 0.69

RM Proof Sketch

- General idea
  - Find the most-difficult-to-schedule system of n tasks among all difficult-to-schedule systems of n tasks
- Difficult-to-schedule
  - Fully utilizes processor for some time interval
  - Any increase in execution time would make system unschedulable
- Most-difficult-to-schedule
  - System with lowest utilization among difficult-to-schedule systems
  - Difficult-to-schedule situations happen when all tasks are released at once
    - First prove that this is the most difficult case
    - Then prove that in this case, the system is schedulable

Summary

- Fixed priority scheduling
- Not optimal – So why do we care?
  - Simple
  - Efficient
  - Easy to implement on standard RTOSs
  - Predictable – During overload low-priority jobs lose
- Fixed priority scheduling is heavily used in real embedded systems