Cyclic Scheduler

Today

> Intro to real-time scheduling

> Cyclic executives

- Scheduling tables
- Frames
- Frame size constraints
- Generating schedules
- Non-independent tasks
- Pros and cons

Real-Time Systems

> The correctness of a real-time system depends not just on the validity of results but on the times at which results are computed

- Computations have deadlines
- Usually, but not always, ok to finish computation early

> Hard real-time system: missed deadlines may be catastrophic

> Soft real-time system: missed deadlines reduce the value of the system

> Real-time deadlines are usually in the range of microseconds through seconds

Real-Time System Examples

> Hard real-time
- Most feedback control systems
  - E.g. engine control, avionics, …
  - Missing deadlines affects stability of control
- Air traffic control
  - Missing deadlines affects ability of airplanes to fly

> Soft real-time
- Windows Media Player
- Software DVD player
- Network router
- Games
- Web server
- Missing deadlines reduces quality of user experience

Real-Time Abstractions

> System contains n periodic tasks T1, … , Tn

> Ti is specified by (Pi, Ci, Di)

- P is period
- C is worst-case execution cost
- D is relative deadline

> Task T is “released” at start of period, executes for Ci time units, must finish before Di time units have passed

- Often Pi==Di, and in this case we omit Di

> Intuition behind this model:

- Real-time systems perform repeated computations that have characteristic rates and response-time requirements

> What about non-periodic tasks?

Real Time Scheduling

> Given a collection of runnable tasks, the scheduler decides which to run

- If the scheduler picks the wrong task, deadlines may be missed

> Interesting schedulers:

- Fixed priorities
- Round robin
- Earliest deadline first (EDF)
- Many, many more exist

> A scheduler is optimal when, for a class of real-time systems, it can schedule any task set that can be scheduled by any algorithm

Real-Time Analysis

> Given:
- A set of real-time tasks
- A scheduling algorithm

> Is the task set schedulable?
- Yes → all deadlines met, always
- No → at some point a deadline might be missed

> Important: Answer this question at design time

> Other questions to ask:
- Where does worst-case execution cost come from?
- How close to schedulable is a non-schedulable task set?
- How close to non-schedulable is a schedulable task set?
- What happens if we change scheduling algorithms?
- What happens if we change some task’s period or execution cost?

Cyclic Schedule

> This is an important way to sequence tasks in a real-time system
  - We'll look at other ways later

> Cyclic scheduling is static – computed offline and stored in a table
  - For now we assume table is given
  - Later look at constructing scheduling tables

> Task scheduling is non-preemptive
  - No RTOS is required

> Non-periodic work can be run during time slots not used by periodic tasks
  - Implicit low priority for non-periodic work
  - Usually non-periodic work must be scheduled preemptively

Cyclic Schedule Table

$$T(t_k) = \begin{cases} T_i & \text{if } T_i \text{ is to be scheduled at time } t_k \\ I & \text{if no periodic task is scheduled at time } t_k \end{cases}$$

> Table executes completely in one hyperperiod H

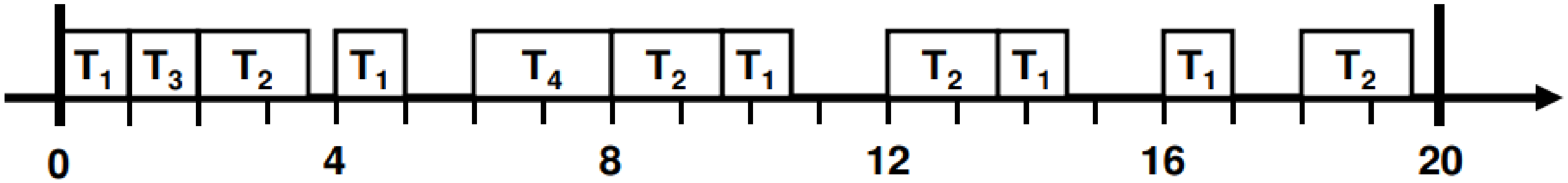
- Then repeats
- H is least common multiple of all task periods
- N quanta per hyperperiod

> Multiple tables can support multiple system modes

- E.g., an aircraft might support takeoff, cruising, landing, and taxiing modes
- Mode switches permitted only at hyperperiod boundaries
  - Otherwise, hard to meet deadlines

Example

- Consider a system with four tasks
  - T1 = (4,1)
  - T2 = (5, 1.8)
  - T3 = (20, 1)
  - T4 = (20, 2)
- Possible schedule:



- Table starts out with:

  (0, T1), (1, T3), (2, T2), (3.8, I), (4, T1), …

Refinement: Frames

> We divide hyperperiods into frames

- Timing is enforced only at frame boundaries
- Each task is executed as a function call and must fit within a single frame
- Multiple tasks may be executed in a frame
- Frame size is f
- Number of frames per hyperperiod is $F = H/f$

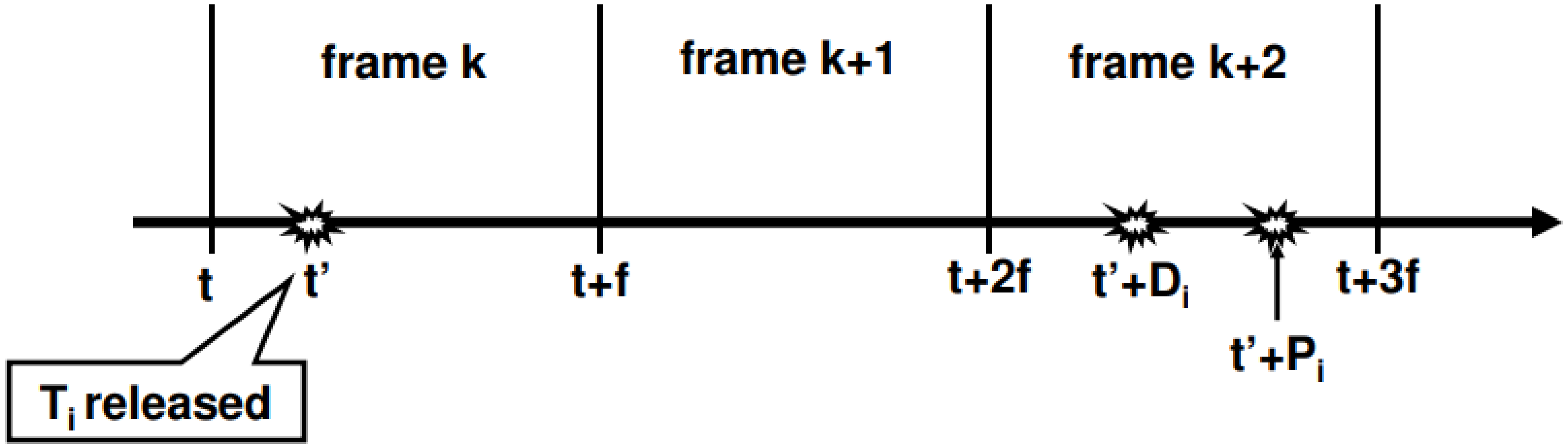
Frame Size Constraints

1. Tasks must fit into frames
   - So, f≥ Ci for all tasks
   - Justification: Non-preemptive tasks should finish executing within a single frame
2. f must evenly divide H
   - Equivalently, f must evenly divide P for some task i
   - Justification: Keep table size small

More Frame Size Constraints

3. There should be a complete frame between the release and deadline of every task

- Justification: Want to detect missed deadlines by the time the deadline arrives
- Therefore: 2f – gcd (Pi, f) ≤ Di for each task i



Example Revisited

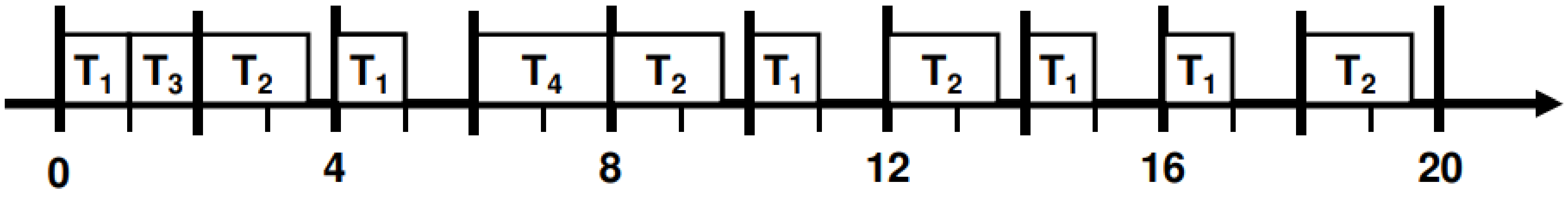
> Consider a system with four tasks

- T1 = (4,1), T2 = (5, 1.8), T3 = (20, 1), T4 = (20, 2)
- H = lcm (4,5,20) = 20

> By Constraint 1: f≥ 2

> By Constraint 2: f might be 1, 2, 4, 5, 10, or 20

> By Constraint 3: only 2 works



Task Slices

> What if frame size constraints cannot be met?

- Example: T = { (4, 1), (5, 2, 7), (20, 5) }
  - By Constraint 1: $f \geq 5$
  - By Constraint 3: $f \leq 4$

> Solution: “slice” a task into smaller sub-tasks

- So (20, 5) becomes (20, 1), (20, 3), and (20, 1)
- Now $f = 4$ works

> What is involved in slicing?

Design Decision Summary

> Three decisions:

- Choose frame size
- Partition tasks into slices
- Place slices into frames

> In general these decisions are not independent

Cyclic Executive Pseudocode

```
// L is the stored schedule
current time t = 0;
current frame k = 0;
do forever
    accept clock interrupt;
    currentBlock = L(k);
    t++;
    k = t mod F;
```

- if last task not completed, take appropriate action;
- execute slices in currentBlock;
- sleep until next clock interrupt;

Summary

> Cyclic executive is one of the major software architectures for embedded systems

- Historically, cyclic executives dominate safety-critical systems
- Simplicity and predictability win
- However, there are significant drawbacks
- Finding a schedule might require significant offline computation

Thank You