EDF Feasibility and Hardware Accelerators

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Outline

1) Introduction and motivation
2) Review of EDF and feasibility analysis
3) Hardware accelerators and scheduling
4) Extended analysis
5) Summary
Introduction

- Embedded systems
  - provides dedicated service to a larger system
  - digital embedded systems:
    - cell phone, washing machine, automotive, assembly-line
    - hard real-time is common
    - large volumes make production cost important
Introduction

- System-on-Chip
  - CPU(s), peripherals and custom logic on one IC
  - standard technique: use hardware accelerators to speed-up compute-intensive portion of software application
Introduction

- Typical Embedded Scheduling policies
  - table-based cyclic
  - fixed-priority preemptive
  - hybrid cyclic/preemptive
- Good alternative: Earliest Deadline First
  - EDF is optimal – will only miss a deadline if no other policy could make it
  - “natural” way to specify deadlines in embedded system
Earliest Deadline First (EDF)

- Definition of EDF
  - of all ready tasks, the task with the earliest deadline is executed first
  - if another task arrives with earlier deadline, it preempts the current task
Notation

- $s_i$: start time, $T_i$: period, $C_i$: worst-case execution time, $D_i$: deadline
Feasibility Analysis

- Given task set \( \tau \) composed of periodic and aperiodic tasks:
  - determine whether all tasks can be scheduled by the preemptive EDF policy such that no task misses its deadline
Feasibility Analysis

- **Technique**
  - assume synchronous start
    - all tasks start at $t=0$
    - this is the “critical instance”
  - aperiodic task replaced by sporadic task with minimum inter-arrival time $T_i$

- **tools**
  - processor utilization
  - processor demand
Processor Utilization: $U$

- Measure of overall processor business

\[ U = \sum_{i=1}^{n} \frac{C_i}{T_i} \]

- sums the fraction of processor time required per task
Processor Demand: $h(t)$

- Measure of work required before time $t$

\[
h(t) = \sum_{D_i \leq t} \left( 1 + \left\lfloor \frac{t - D_i}{T_i} \right\rfloor \right) C_i
\]

- sum execution times of all jobs (task instances) with deadlines not later than $t$
Feasibility Conditions

- Processor utilization does not exceed one
  \[ U \leq 1 \]

- Processor demand never exceeds processor time
  \[ \forall t: h(t) \leq t \]

- Cannot check every \( h(t) \)
Feasibility Conditions

- Do not need to check every $h(t)$
  - processor demand only changes at job deadlines
    - only need to check at each deadline
  - can define upper limit on interval checked
Feasibility Conditions

- upper limit for checking deadlines:
  - Theory [Liu and Layland, 1973] *When the deadline driven scheduling algorithm is used to schedule a set of tasks on a processor, there is no processor idle time prior to an overflow.*
  - interval before first idle called synchronous busy period (L)
  - only need to check until end of synchronous busy period
Feasibility Algorithm

if $U > 1$ then
    return “infeasible”
endif

calculate $L$

for each deadline in $[0, L]$
    if $h(t) > t$
        if $h(t) > t$
            return “infeasible”
        endif
    endif
endfor

return “feasible”
Accelerated Task

- Given an accelerator-blocked task
- starts on CPU, transfers to accelerator, finishes on CPU
- divide $\tau_x$ into subtasks $\tau_{x,1}$, $\tau_{x,2}$, and $\tau_{x,3}$
Accelerated Task Representation

\[
D_{x,1} = D_{x,2} - C_{x,2}
\]

\[
D_{x,2} = D_{x,3} - C_{x,3}
\]

\[
D_{x,3} = D_x
\]
Extended Analysis – First Try

- Given task set $\tau$ with accelerator-blocked task $\tau_x$:
  - replace $\tau_x$ with $\tau_{x,1}$ and $\tau_{x,3}$
  - perform feasibility analysis
- Problem: accelerator-induced idle periods
Extended Analysis - First Try

- this example would pass analysis
- missed dead-line at \( t=27 \)
- during \([18,20]\) CPU is idle because \( \tau_{x,3} \) must wait for accelerator
Lemma 1  Given task set $\tau$ in which one task $\tau_x$ blocks on an accelerator once, with logical subtasks $\{\tau_{x,1}, \tau_{x,2}, \tau_{x,3}\}$, the accelerator-induced idle results in a critical instance when:

- $\tau_{x,3}$ has no slack, and
- all other tasks are released synchronously at the end of the accelerator-induced idle (i.e. at $t=D_{x,2}$).
Accelerator-Induced Idle
Extended Analysis

- Analysis of Accelerator-Induced Idle:
  - all regular tasks released at $t=0$
  - $\tau_{x,3}$ released at $t=0$
    - no slack $\Rightarrow D_{x,3} = C_{x,3}$
  - perform feasibility analysis
Subtask Phases
Subtask Phases

\[ \phi_{x,1} = T_x - D_{x,2} \]
\[ \phi_{x,3} = -D_{x,2} \]
Extended Algorithm

if $U>1$ then
    return “infeasible”
endif

calculate $L$

for each deadline in $[0,L]$
    if $h(t)>t$
        return “infeasible”
    endif
endfor

Pass 1

$\Phi_{x,1} = \Phi_{x,3} = 0$

Pass 2

$\Phi_{x,1} = T_x - D_{x,2}$, $\Phi_{x,3} = -D_{x,2}$

modified $h(t)$, $L$

$$h'(t) = \sum_{D_i+\phi_i \leq t} \left(1 + \left\lfloor \frac{t-(D_i+\phi_i)}{T_i} \right\rfloor \right) C_i$$
Summary

Contributions

- extended EDF feasibility analysis to task sets that include one accelerator-blocked task (that blocks once per task instance)
- essentially heterogeneous multiprocessing with one preemtable and one non-preemptable processor
- extends applicability of the EDF policy to embedded systems
Summary

- Future Work
  - extend to task sets that include one accelerator-blocked task that blocks multiple times (done)
  - extend to task sets that include multiple accelerator-blocked tasks