First Look at the Rate Monotonic Analysis

Jaroslav Kačer
jkacer@kiv.zcu.cz

University of West Bohemia
Faculty of Applied Sciences
Department of Computer Science and Engineering

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Presentation Outline

- Current Status of J-Sim
  - Features You May Not Know Yet, Building J-Sim
  - Work in Progress
  - Case Study #1
- Rate Monotonic Analysis – RMA
  - Goals of RMA, History & Background
  - Determining the Number of Priority Levels
  - Schedulability
  - Aperiodic Tasks
  - Task Synchronization
  - Mode Change Protocol

J-Sim Features You May Not Know Yet

- IPC – Semaphores
  - JSimSemaphore, P(), V()
- IPC – Message passing
  - Direct/indirect
  - Blocking/non-blocking
- Random numbers/objects
  - Streams can be initialized → repeatibility
- JiJ – simulation of Java multithreading
  - See DSS presentation from 2004-05-17 and Technical Report 2004/03
- Logging

How to Build and Use

- You must have Apache Ant 1.6.2
- build.xml – Description of the whole project
  - Cleans
  - Compiles
  - Generates API documentation, tutorial
  - Generates JARs
  - Library / examples / case studies
- Live show

Work in Progress

- Documentation translation
  - From TeX to DocBook
  - Automatic generation of (X)HTML, PDF, ...
  - PIA
- Putting J-SourceMorph on WWW
  - XML rules for JiJ needed!
- JiJ still not finished completely
  - join(), timed wait(), timed join()
  - Proper unlocking before return / throw

Case Study #1

- Completed as described in the last presentation
- Used JiJ features: locking, wait() / notify(), sleep(), mixing JiJ and classic simulation
- Invariant testing – Several invariants can be temporarily broken
- Live show

Goals of RMA

- Specify, analyze, and predict timing behavior of real-time systems
- Improve dependability of such systems
- Concretely:
  - Assigns priorities to real-time tasks
  - Maximize schedulability of real-time systems
  - Finds whether task deadlines will be met or missed

History

- 1973: CMU – Liu & Layland invent the rate monotonic scheduling theory
- 1980s & 1990s: CMU – RTSIA and RMARTS projects
  - From 1987 to 1993 = 6 or 7 years!
  - Output: ADA 9x, POSIX 1003.4, FutureBus+, ...
- IBM also worked on RMA
- 1990s: Adopted by NASA, ESA, Lockheed Martin, ...

Assigning Priorities

- Why “Rate Monotonic” Analysis?
  - A task's priority depends on its rate
  - The higher the rate (frequency), the higher the priority → Priority is a monotonic function of rate
  - Every task has its period, rate = 1/period
- Originally for periodic tasks only
- Priorities are fixed

Determining the Number of Priority Levels (1)

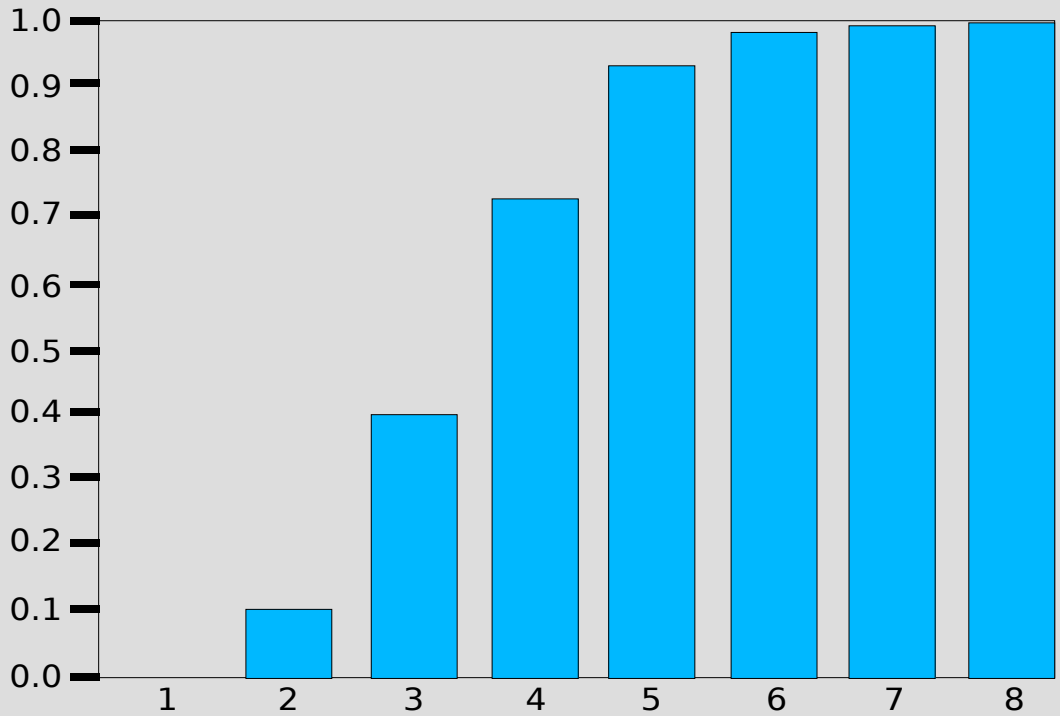
- Ideally: As many as required, not always possible
- Smaller number decreases schedulability
- Constant ratio priority grid:
  - Divide the range <min_period, max_period> into such a grid that the ratio between two adjectant points is always the same
  - Example: min = 1ms, max = 100 s, r = 2. Then L_1 = 1ms, L_2 = 2ms, L_3 = 4ms, ..., L_n = 100s

Determining the Number of Priority Levels (2)

- Percentage loss in worstcase schedulability: loss = 1 – (ln (2/r) + 1 - 1/r) / ln 2
- Example: min = 1 ms, max = 100 s, 256 priority levels
- $r = (L_1/L_0) = (L_2/L_1) = \ldots = (L_{256}/L_{255})$
- $r = (L_{256}/L_0)^{1/256} = 1.046$
- Loss = 0.0014

Determining the Number of Priority Levels (3)

- Example: max = 100000*min, changeable number of priority bits (and thus priority levels)
- Schedulability = f(no. of priority bits)



Schedulability – Basic Tests

- Periods T_i, Worst-case execution times C_i
- Asymptotic processor utilization bound for n r.m. processes: $U(n) = n(2^{1/n}-1)$; $\lim = \ln 2$
- Processor utilization for n r.m. processes: $C_1/T_1 + ... + C_n/T_n$
- Schedulability:
  - $\text{sum}(C_i T_i) < U(n)$ → schedulable
  - $U(n) < \text{sum}(C_i T_i) < 1$ → inconclusive
  - $1 < \text{sum}(C_i T_i)$ → unschedulable

Schedulability – Response Time Test

- If basic test is inconclusive, RTT can be used
- For every task, a_i is computed recursively
- If a_i < task's deadline, task is schedulable
- Compute a_i until a least fixed point is reached
- $a_0 = sum_{\{j=1..i\}}(C_j)$, j ... tasks with higher prio
- $a_{n+1} = C_i + sum_{\{j=1..i-1\}}(ceil(a_n/T_j)*C_j)$

Aperiodic Tasks

- Aperiodic server
- Execution budget
- Replenishment period
- Budget depleted → Run at backgroud priority until budget replenished
- Types:
  - Priority exchange algorithm
  - Deferrable server algorithm – replenished at every period beginning
  - Sporadic server algorithm – replenished DeltaT after spent completely

Task Synchronization (1)

- Danger from synchronization: A low-prio task can block a high-prio task
  - Low, Medium, High prio tasks
  - Low locks the samaphore
  - High preempts, tries to lock, blocked
  - Medium preempts Low
  - Medium blockes High
- Unbounded priority inversion – Duration of priority inversion not bounded by the duration of critical section

Task Synchronization (2)

- Priority ceiling protocol
  - Priority ceiling of S = max pr. of T_i that can lock S
- If task T blockes higher prio tasks, T must execute at the highest prio level of all b. t.
- CS entered only if it executes at a higher prio level than inherited prio level of any preempted CS
- Prio ceilings of all semaphores not hold by T
- Enter CS: If T blocked (prio <= prio ceiling of other S), the blocker must inherit T's priority

Mode Change Protocol (1)

- Deletion or addition of tasks
- Parameter changes of some tasks
- Deadlines must be met before, during, and after
- Tasks:
  - T can be removed if it has not started its execution
  - If T has started, it can be removed after the end of its execution in this period

Mode Change Protocol (2)

- Semaphores:
  - Unlocked S's prio ceiling can be raised immediately
  - Locked S's prio ceiling can be raised after S is unlocked
  - Lower prio ceiling: When all tasks that may lock S and have higher prio are deleted
  - If T's prio affects S's prio ceiling, S's p.c. must be raised before T is added

Possible Pitfalls

- Interrupts
- I/O operations can relinquish CPU time to lower-prio tasks
- Some portions of OS may not be preemptable

Practical Usage

- Influenced Futurebus+, POSIX, ADA 95
- US Navy: submarine sonar system
- ESA: RMA selected as the baseline theory for a hard real-time operating system project
- Lockeed Martin: Avionics applications
- NASA
- IBM

What We Need Now

- How to put RMA and Java together
  - Real-Time Java
- Scheduler or simulator or what?
- RMA is probably much more complex
- Books ordered on RT-Java and RMA