Real-Time on General Purpose Systems

Real-Time and Embedded Systems (M)

Lecture 12

UNIVERSITY *of* GLASGOW

Lecture Outline

- Real-time on general purpose systems
- Need for flexible applications
- Implementation strategies
- Scheduling

Material corresponds to parts of chapters 10 and 12 of Liu's book

Real-Time on General Purpose Systems

- Many real-time systems built using a general purpose operating system, not an RTOS
  - Internet telephony; streaming audio and video; set-top boxes running Linux
  - DVD player software
- Operating system may provide limited real-time support, but not engineered for robust real-time operation, with many sources of unpredictability
  - Virtual memory and/or disk activity
  - Limited timer resolution
  - Limited scheduler granularity
- Need to engineer applications around these constraints
  - Consider how to make your application flexible

Flexible Computation

- Some real-time applications must tolerate fluctuation in available resources or workload
  - A real-time network server may receive more traffic than expected
  - A failure may divert load onto a backup system
  - Real-time performance may degrade due to load from non-real-time tasks sharing the processor

- A real-time system has two degrees of flexibility when it becomes impossible to meet all deadlines
  - Graceful degradation in timeliness
  - Graceful degradation in quality

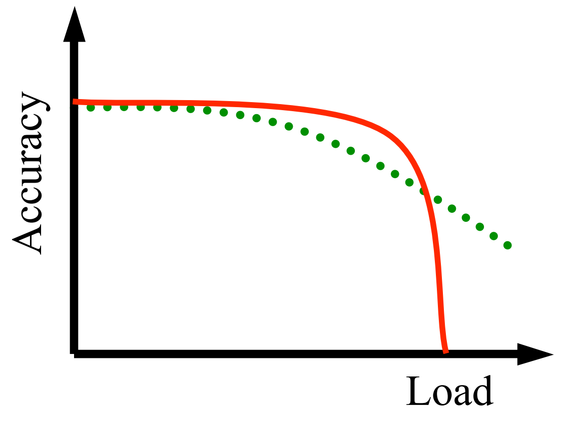
Flexible Computation: Timeliness

- A task has an (l, L) deadline if at least $l \geq 0$ jobs among any consecutive set $L \geq l$ must complete before their deadline
  - The parameter L is the *failure window* of the task; clearly a spectrum of requirements
  - A hard real-time task has (1, 1) deadlines
  - A soft real-time task has $(0, L)$ deadlines

- Depending on the application, systems may degrade by relaxing their deadlines, allowing some tasks to complete late
  - Not generally desirable, but suitable for applications with fixed resource demands and flexible timing requirements
    - Example: a DVD player running on a general purpose operating system might pause if the system is overloaded, rather than dropping frames
  - Often requires statistical analysis of performance, to estimate probability of missing deadline

Flexible Computation: Quality

- Some applications can trade-off, at run time, quality of results for the amount of time and resources used to produce those results
- As a system moves into overload, it gracefully degrades rather than suddenly failing
- Assumption: a timely result of poor quality is better than a high quality, but late, result



- Examples:
  - A telephony application might prefer a brief glitch in output, rather than a pause that leaves the other party wondering what's happening
  - An air traffic control system should deliver a timely collision warning with estimated location, rather than an exact warning, delivered too late

Implementing Flexible Computation

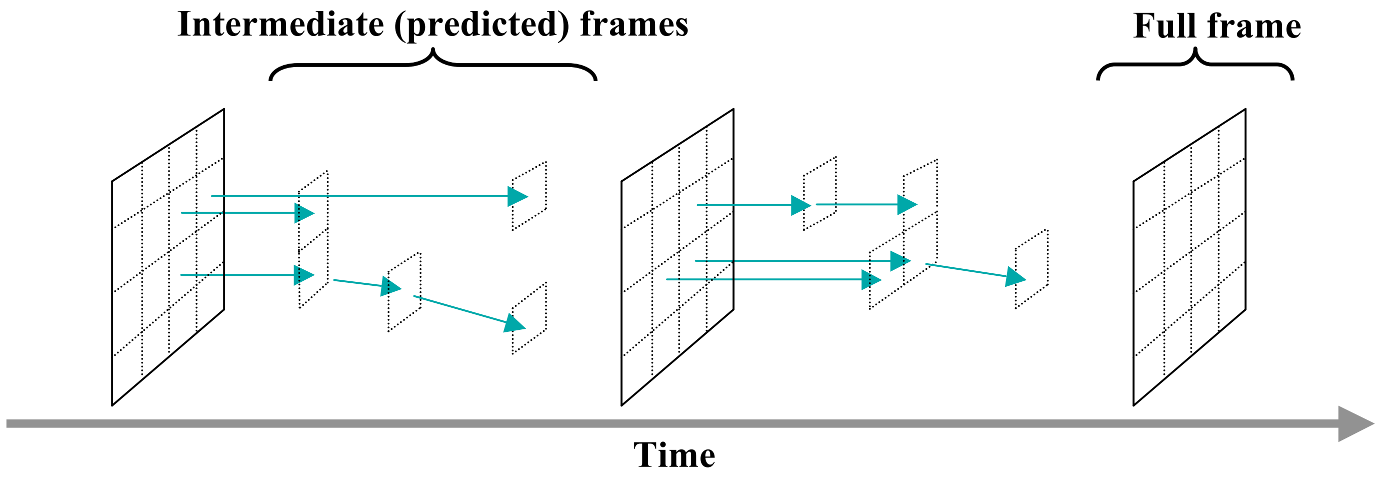
- Jobs are divided into an optional part and a mandatory part
  - With sufficient resources, both mandatory and optional parts complete; a *precise* result
  - With limited resources, the optional component is discarded, giving an *imprecise* result

- Assumption: possible to subdivide a job, produce meaningful approximate answers

- How to implement?
  - Sieve method
  - Milestone method
  - Multiple version method

Sieve Method

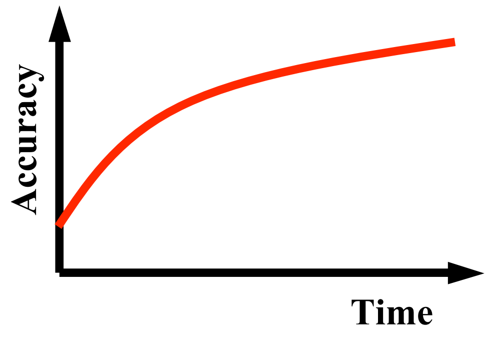
- A flexible task has a mixture of mandatory and optional jobs
- When overloaded, some optional jobs discarded
  - If they were optional, why include them in the system?
  - Useful for applications which periodically refresh state
- Example: video compression
  - Predicted frames can be discarded on overload



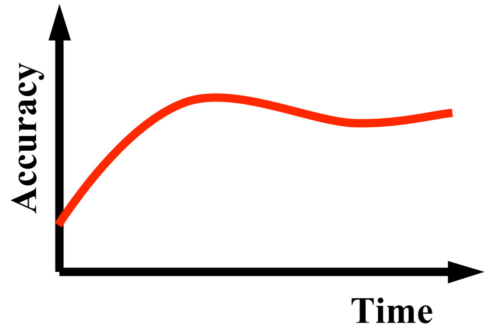
Milestone Method

- The system regularly checkpoints the result of the optional job as a set of *milestones*; when deadline reached, job terminates and latest milestone retrieved

- A *monotone* is a job with optional component that can be stopped any time; quality of result always increases with longer execution
  - Iterative numerical computation
  - Iterative statistical computation
  - Layered video encoding

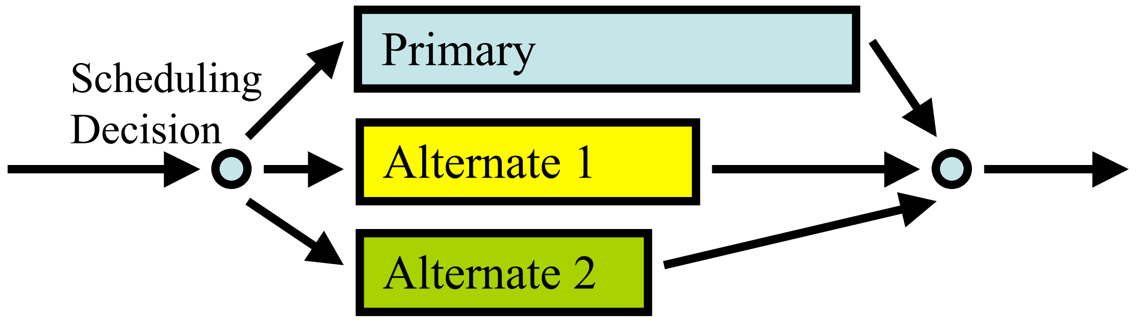


- Longer execution of a non-monotonic job may not improve results
  - E.g. approximation algorithms that don't always converge



Multiple Versions

- The flexible job can be implemented as multiple versions:
  - Primary is high quality, but has a larger execution time and resource usage
  - Alternates are lower quality, but execute quicker or use fewer resources
    - […or provide fault tolerance]



- The scheduler must make an a priori decision on which version to execute, based on load at the start of the job
  - Requires more intelligence in the scheduler than sieve or milestone methods
- Little gain from having more than one alternate

Implementing Flexible Computation

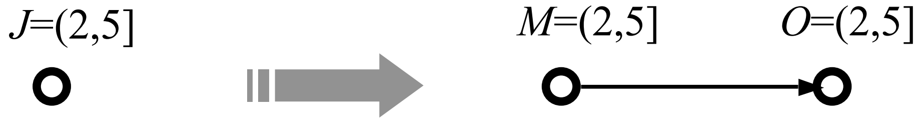
- Which is best?
  - Sieve method
  - Milestone method
  - Multiple version method

- It depends… sieve and multiple versions easiest to implement, milestones likely gives best results

- But: *highly* application dependent – what is the problem domain? What algorithm?

Workload Model

- To schedule flexible computations, need a workload model
- Definitions:
  - As usual a task, T, is comprised of a series of jobs J_i
  - Each flexible job, J_i, is logically decomposed into a chain of two jobs, M_i and O_i which are the mandatory and optional components
  - The release times and deadlines of M_i and O_i are the same as J_i but O_i is dependent on M_i
  - Execution time $e = e_m + e_o$



- A generalisation of the model used previously:
  - non-flexible jobs scheduled as-if e_o is zero

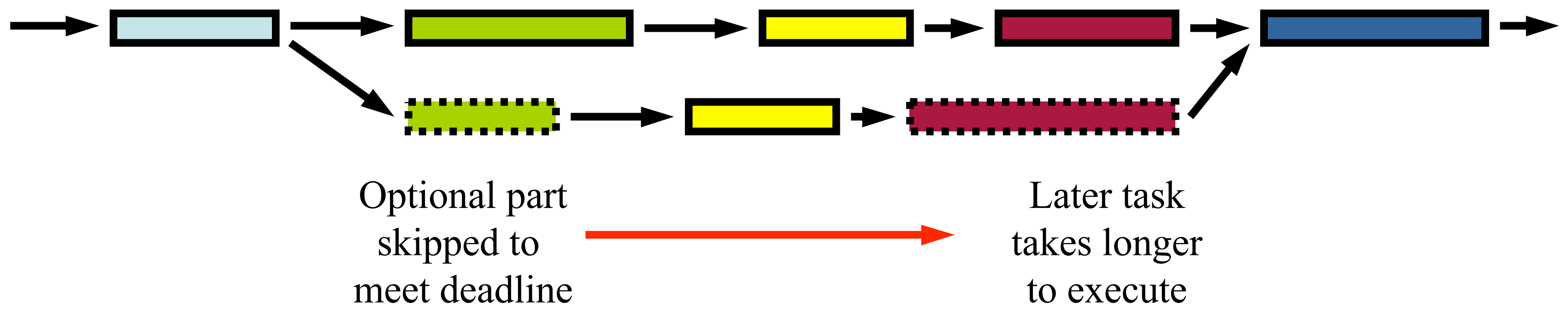
Workload Model

- Jobs are scheduled so mandatory tasks meet their deadline:
  - A schedule for a flexible application is *valid* if J_i is allocated processor time at least equal to e_m and at most equal to e
  - The schedule is *feasible* if each job is allocated at least e_m units of processor time before its deadline
  - Exactly the same definitions we saw in lecture 2 for non-flexible tasks, adapted to allow for e_o

- Optional components of each job execute if there is time before the deadline
  - An optional job completes it if receives e_o before the deadline
  - An optional job shouldn't execute beyond its deadline
    - May be terminated, and revert to the last milestone
    - May be pre-empted, and continue to execute at low priority if killing the job would leave the system inconsistent

Dependent Jobs

- Assumption: the execution time of a job is independent of the previous jobs
- In some systems, saving time in an early job – by skipping its optional component – makes a later job in the task take longer
  - Often occurs if errors are cumulative: eventually need to run the full computation periodically, to bring the error back to an acceptable level
- Need to take this into account when building the schedule, by modelling both branches of the task graph

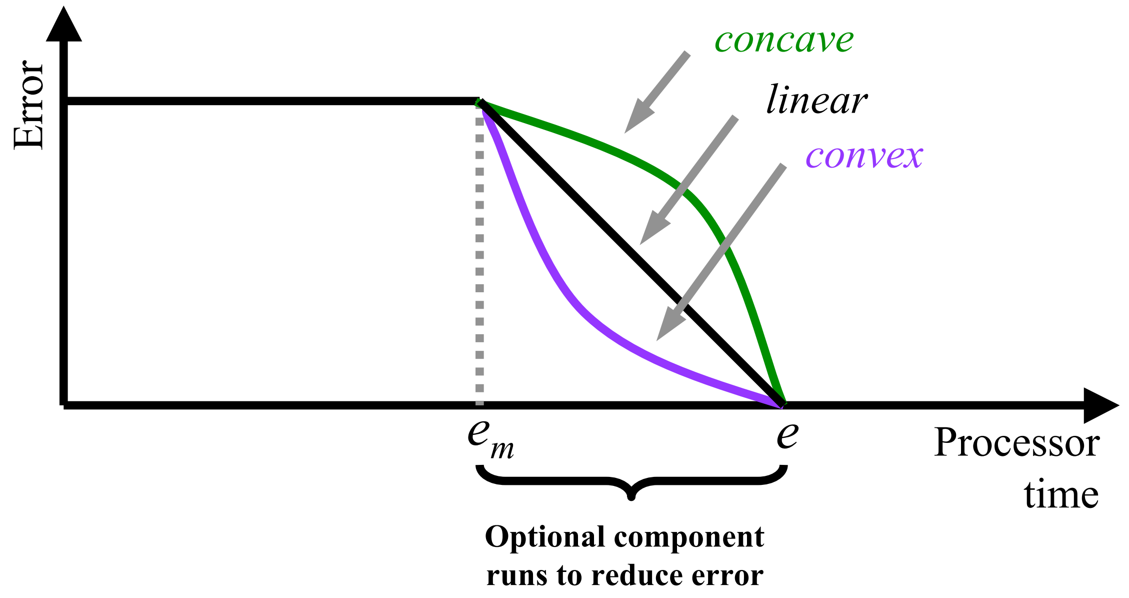

Optional part skipped to meet deadline
Later task takes longer to execute

Jobs with 0/1 Constraints

- If the sieve or alternate methods used, no point running part of an optional component
  - The optional component has a *0/1 constraint*; either runs to completion, or not at all
  - For optional jobs according to the sieve method:
    - When the optional jobs becomes eligible to run, make a choice to run the job based on available execution time
  - For optional jobs according to the alternate method:
    - Model the alternates as mandatory and optional parts
    - Let e_m be execution time of the alternate, e_o be the difference in execution time between primary and alternate
    - After scheduling the mandatory part for e_m, the optional part is scheduled. If e_o available before its deadline, this corresponds to the primary version being scheduled. Otherwise, only the alternate can be scheduled

Criteria of Optimality

- Correctness: find a feasible schedule that ensures all mandatory jobs complete
- Quality of result: fit in as many optional jobs as possible, reduce error in the result
  - Measure the error according to some domain specific metric
  - Clearly desirable if the error function is convex; may influence choice of algorithm



Criteria of Optimality

Try to reduce the error in the result… which error:

- The sum of the total errors for all jobs?
- The maximum error for an individual job?
- The average error for all jobs?

Heavily application/domain dependent… no general guidelines

Scheduling Flexible Applications

- How to schedule flexible applications?
- Two approaches:
  - On-line
  - Off-line scheduling and/or heuristics

Off-line Scheduling

- Given a set of mandatory and optional tasks, an *off-line* algorithm aims to derive a static schedule that minimises some particular error metric
  - Can be executed during design, with hard coded schedule
  - Can be executed at run-time, as a result of a significant mode change that causes more tasks to run
- Generally reduces to linear programming/constraint optimisation problem
- Exponential time complexity, unrealistic for typical error functions
  - 0/1 constraints
  - non-linear error functions

On-line Heuristic Scheduling

- All useful scheduling algorithms for flexible applications use *heuristics* or are otherwise imprecise
- Two general approaches: mandatory first and slack stealing
  - *Mandatory first* algorithms schedule the mandatory parts of the system with higher priority than the optional parts
    - Use fixed priority algorithm, like rate monotonic, to schedule mandatory parts
    - Then schedule optional parts to minimise error:
      - dynamic least-attained-time suitable if error functions are convex, since diminishing returns for tasks that have attained most time
      - dynamic best-incremental-return suitable if knowledge of error functions, since run the task which will most reduce the error
    - If don’t know error functions (common case):
      - Rate monotonic or earliest deadline schedule of optional parts
      - Earliest deadline always achieves zero average error, if possible
  - *Slack stealing* run optional tasks in slack time of mandatory tasks, dynamically according to EDF
  - Both seek to schedule mandatory parts as normal, fit in optional parts

Summary

- Flexible applications useful if system can be overloaded
- Typically only useful on soft real time systems, generally running on a general purpose operating system
  - Otherwise, engineer the system to avoid overload
  - Implication: don't have good scheduling support
    - Given knowledge of current time/deadline, application decides to shed work
      - sieve, incremental with milestones, alternate algorithm
    - Very much heuristic driven, rather than explicitly scheduled
    - Inherently imprecise, and difficult to reason about

- If you're building these systems:
  - program defensively
  - measure behaviour
  - adapt accordingly, based on domain specific heuristics and error functions