Introduction to Real-Time Systems

ECE 397-1

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Homework index

Goals for lecture

- Sensor networks
- Finish overview of scheduling algorithms
- Mixing off-line and on-line
- Design a scheduling algorithm: DCP
  - Will initially focus on static scheduling
- Useful properties of some off-line schedulers

Lab two?

- Everybody able to finish?
- Any problems to warn classmates about?
- 18 motes should be arriving tomorrow
  - No equipment sign-out required for next motes lab
- Linux vs. Windows development environments

Sensor networks

- Gather information over wide region
- Frequently no infrastructure
- Battery-powered, wireless common
- Battery lifespan of central concern

Low-power sensor networks

- Power consumption central concern in design
- Processor?
- Wireless protocol?
- OS design?

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- OS design?
  - Static, eliminate context switches, compile-time analysis

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  - Avoid unnecessary dynamism
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Low-power sensor networks

- Power consumption central concern in design
- Runtime environment?
  - Avoid unnecessary dynamism
- Language?
  - Compile-time analysis of everything practical

Multi-rate tricks

- Contract deadline
  - Usually safe
- Contract period
  - Sometimes safe
- Consequences?

Scheduling methods

- Clock
- Weighted round-robbin
- List scheduling
- Priority
  - EDF, LST
  - Slack
  - Multiple costs

Scheduling methods

- MILP
- Force-directed
- Frame-based
- PSGA

Linear programming

- Minimize a linear equation subject to linear constraints
  - In **P**
- Mixed integer linear programming: One or more variables discrete
  - **NP-complete**
- Many good solvers exist
- Don't rebuild the wheel

MILP scheduling

P the set of tasks

t_{max} maximum time

$start(p,t)$ 1 if task p starts at time t, 0 otherwise

D the set of execution delays

E the set of precedence constraints

$$t_{start}(p) = \sum_{t=0}^{t_{max}} t \cdot start(p,t)$$ the start time of p

MILP scheduling

Each task has a unique start time

$$\forall_{p \in P}, \sum_{t=0}^{t_{max}} start(p,t) = 1$$

Each task must satisfy its precedence constraints and timing delays

$$\forall \{p_i, p_j\} \in E, \sum_{t=0}^{t_{max}} t_{start}(p_i) \geq t_{start}(p_j) + d_j$$

Other constraints may exist

- Resource constraints
- Communication delay constraints

MILP scheduling

- Too slow for large instances of $\mathbf{NP\text{-}complete}$ scheduling problems
- Numerous optimization algorithms may be used for scheduling
- List scheduling is one popular solution
- Integrated solution to allocation/assignment/scheduling problem possible
- Performance problems exist for this technique

Force directed scheduling

- P. G. Paulin and J. P. Knight, “Force-directed scheduling for the behavioral synthesis of ASICs,” *IEEE Trans. Computer-Aided Design of Integrated Circuits and Systems*, vol. 8, pp. 661–679, June 1989
- Calculate EST and LST of each node
- Determine the force on each vertex at each time-step
- Force: Increase in probabilistic concurrency
  - Self force
  - Predecessor force
  - Successor force

Self force

F_i all slots in time frame for i

F_i' all slots in new time frame for i

D_t probability density (sum) for slot t

δD_t change in density (sum) for slot t resulting from scheduling

self force

$$A = \sum_{t \in F_a} D_t \cdot \delta D_t$$

Predecessor and successor forces

pred all predecessors of node under consideration

succ all successors of node under consideration

predecessor force

$$B = \sum_{b \in \textbf{pred}} \sum_{t \in F_b} D_t \cdot \delta D_t$$

successor force

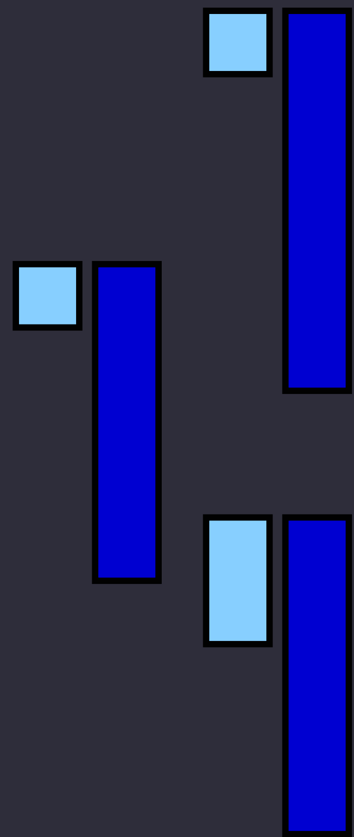
$$C = \sum_{c \in \textbf{succ}} \sum_{t \in F_c} D_t \cdot \delta D_t$$

Intuition

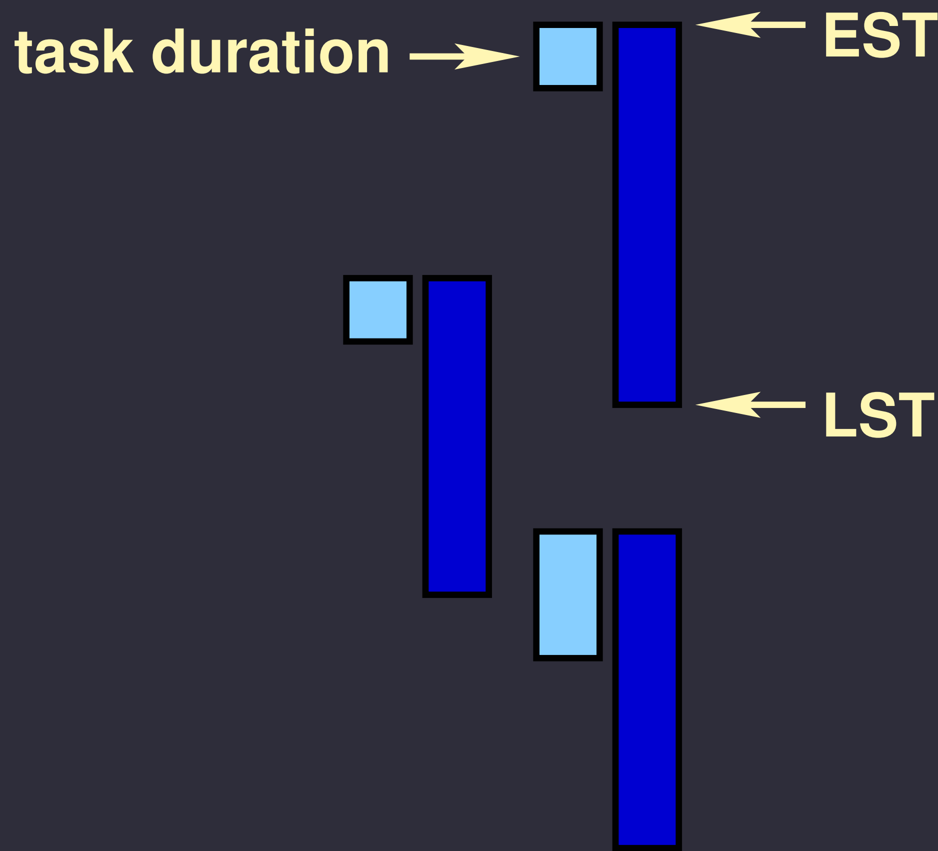
total force: $A + B + C$

- Schedule operation and time slot with minimal total force
  - Then recompute forces and schedule the next operation
- Attempt to balance concurrency during scheduling

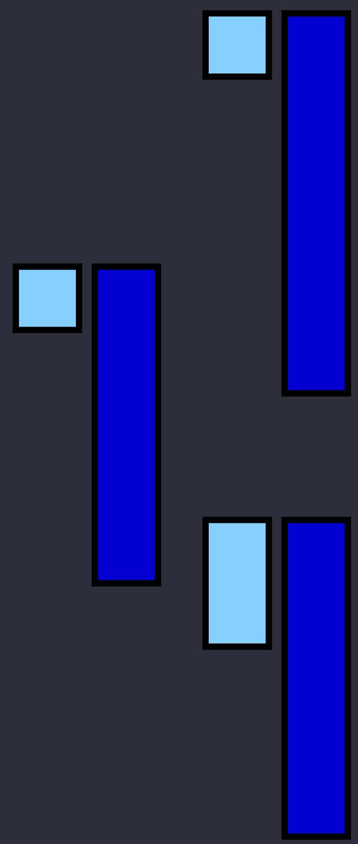
Force directed scheduling



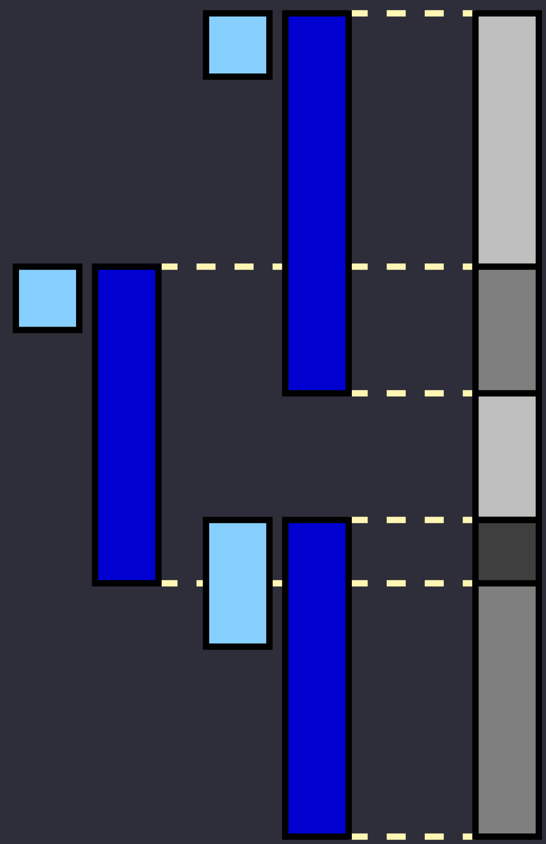
Force directed scheduling



Force directed scheduling

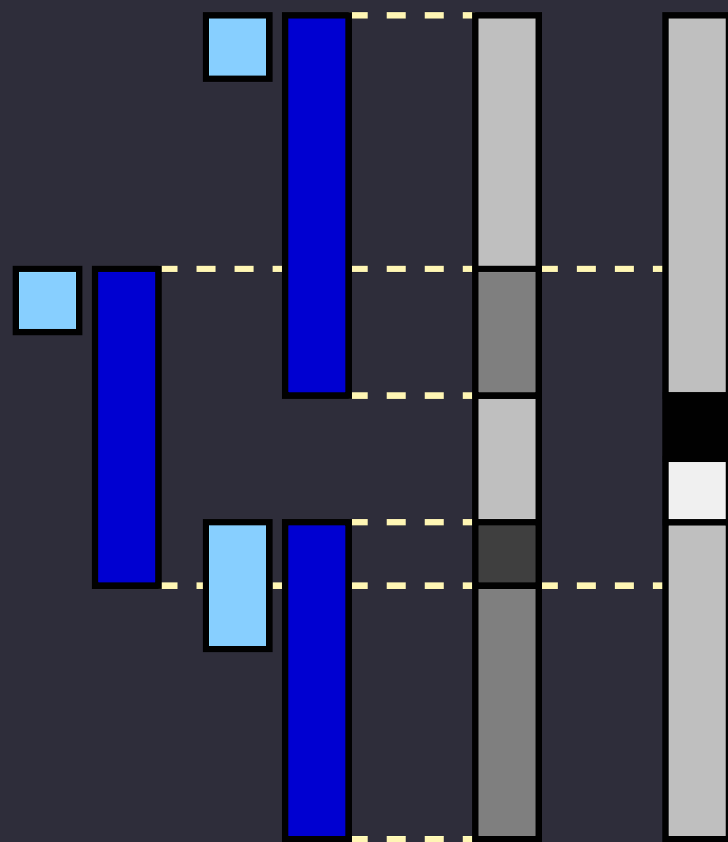


Force directed scheduling



probabilistic concurrency

Force directed scheduling



Force directed scheduling

- Limitations?
- What classes of problems may this be used on?

Implementation: Frame-based scheduling

- Break schedule into (usually fixed) frames
- Large enough to hold a long job
  - Avoid preemption
- Evenly divide hyperperiod
- Scheduler makes changes at frame start
- Network flow formulation for frame-based scheduling
- Could this be used for on-line scheduling?

Problem space genetic algorithm

- Let’s finish off-line scheduling algorithm examples on a bizarre example
- Use conventional scheduling algorithm
- Transform problem instance
- Solve
- Validate
- Evolve transformations

Examples: Mixing on-line and off-line

- Book mixes off-line and on-line with little warning
- Be careful, actually different problem domains
- However, can be used together
- Superloop (cyclic executive) with non-critical tasks
- Slack stealing
- Processor-based partitioning

Problem: Vehicle routing

- Low-price, slow, ARM-based system
- Long-term shortest path computation
- Greedy path calculation algorithm available, non-preemptable
- Don’t make the user wait
  - Short-term next turn calculation
- 200 ms timer available

Examples: Mixing on-line and off-line

- Slack stealing
- Processor-based partitioning

Scheduling summary

- Scheduling is a huge area
- This lecture only introduced the problem and potential solutions
- Some scheduling problems are easy
- Most useful scheduling problems are hard
  - Committing to decisions makes problems hard: Lookahead required
  - Interdependence between tasks and processors makes problems hard
  - On-line scheduling next Tuesday

Bizarre scheduling idea

- Scheduling and validity checking algorithms considered so far operate in time domain
- This is a somewhat strange idea
- Think about it and tell/email me if you have any thoughts on it
- Could one very quickly generate a high-quality real-time off-line multi-rate periodic schedule by operating in the frequency domain?
- If not, why not?
- What if the deadlines were soft?

Reading assignment

- J. W. S. Liu, *Real-Time Systems*. Prentice-Hall, Englewood Cliffs, NJ, 2000
- Read Chapter 7