## Homework index

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Goals for lecture

- Justify treating real-time design problem as optimization problem
- Example problem to illustrate specification and design
- Tractable algorithm design (NP-completeness in a nutshell)
- Detail on design representations
- Sensor network motivations
- NesC overview
The value of formality: Optimization and costs

• The design of a real-time system is fundamentally a cost optimization problem

• Minimize costs under constraints while meeting functionality requirements
  – Slight abuse of notation here, functionality requirements are actually just constraints

• Why view problem in this manner?

• Without having a concrete definition of the problem
  – How is one to know if an answer is correct?
  – More subtly, how is one to know if an answer is optimal?
Thinking of a design problem in terms of optimization gives design team members objective criterion by which to evaluate the impact of a design change on quality.

- Still need to do a lot of hacking
- Know whether its taking you in a good direction
Simple example

• Ensure that a wireless data display 300 m away from a temperature sensor always displays the correct temperature with a lag of, at most, 100 ms.

• Wireless broadcasts reach 100 m with high probability and 200 m with very low probability.

• There are two, evenly distributed, rebroadcast nodes between the sensor and the data display.

• Functional requirements?

• Constraints?

• Costs?
Example problem

- Richland, Washington’s Hanford Reservation plutonium finishing facility
- July 1988 facility’s last reactor, Reactor N, put into cold standby due the nation’s surplus of plutonium
- Was used for processing weapons-grade fissile material
Example problem

- Currently holds 11.0 metric tons of plutonium-239 and 0.6 metric tons of uranium-235
  - The two fissile materials most commonly used in nuclear weapons

- Even without refining, a small quantity of either would convert conventional explosives into weapons capable of causing long-term damage far beyond their blast radii

- Ongoing provisions for security required
Example problem

- Build perimeter security network
- Functional requirements?
- Constraints?
- Costs?
Example tasks

• Sense audio
• Compress it
• Determine whether it is unusual
• Sense, compress, and stream video
• Analyze information from region to determine most promising messages to forward, given network contention
Example constraints

- Data rate
- Dependencies between tasks
- Price
- Lifetime of battery-powered devices
- Etc.
Hanford security network design

• By 18 January, working with your lab partner, provide
  – A paragraph formalizing the real-time system design goals
  – A paragraph giving an overview of the design you propose

• Keep it within a page. We want you thinking about this and learning but you should focus on the lab assignment.

• Have questions? Do research. The Hanford Reservation is real.
  – Post to the newsgroup if you get stuck.
Lab one

- Subversion working for everybody?
- Access to mailing list?
- Anybody stuck on development?
NP-completeness

• Scheduling is central to real-time systems design and research
• Tractable algorithm design is central to scheduling
• Many (but not all) interesting and useful scheduling problems are NP-complete
• We need to understand what this means, at least at a high level
Recall that sorting may be done in $\Theta(n \lg n)$ time.

$\text{DFS} \in \Theta(|V| + |E|)$, $\text{BFS} \in \Theta(|V|)$, $\text{Topological sort} \in \Theta(|V| + |E|)$

[Graph showing functions $f(n) = n$, $f(n) = n \lg n$, and $f(n) = n^2$.]

NP-completeness
NP-completeness

There also exist exponential-time algorithms: $O(2^{\lg n}), O(2^n), O(3^n)$
NP-completeness

For $t(n) = 2^n$ seconds

- $t(1) = 2$ seconds
- $t(10) = 17$ minutes
- $t(20) = 12$ days
- $t(50) = 35,702,052$ years
- $t(100) = 40,196,936,841,331,500,000,000$ years
NP-completeness

- There is a class of problems, NP-complete, for which nobody has found polynomial time solutions.
- It is possible to convert between these problems in polynomial time.
- Thus, if it is possible to solve any problem in NP-complete in polynomial time, all can be solved in polynomial time.
- Unproven conjecture: $\text{NP } \nRightarrow \text{P}$
NP-completeness

• What is \( \text{NP} \)? Nondeterministic polynomial time.

• A computer that can simultaneously follow multiple paths in a solution space exploration tree is nondeterministic. Such a computer can solve \( \text{NP} \) problems in polynomial time.

• Nobody has been able to prove either

\[
P \neq \text{NP}
\]

or

\[
P = \text{NP}
\]
NP-completeness

If we define NP-complete to be a set of problems in NP for which any problem’s instance may be converted to an instance of another problem in NP-complete in polynomial time, then

\[ P \subsetneq NP \Rightarrow \text{NP-complete} \cap P = \emptyset \]
Basic complexity classes

- \( \mathbf{P} \) solvable in polynomial time by a computer (Turing Machine)
- \( \mathbf{NP} \) solvable in polynomial time by a nondeterministic computer
- \( \mathbf{NP} \)-complete converted to other \( \mathbf{NP} \)-complete problems in polynomial time
Hard (NP-complete) scheduling problems

- Uniprocessor scheduling with hard deadlines and release times
- Uniprocessor scheduling to minimize tardy tasks
- Multiprocessor scheduling
  - Easy if all tasks are identical
- Multiprocessor precedence constrained scheduling
- Multiprocessor preemptive scheduling
- etc.
How to deal with hard problems

• What should you do when you encounter an apparently hard problem?

• Is it in NP-complete?

• If not, solve it

• If so, then what?
How to deal with hard problems

• What should you do when you encounter an apparently hard problem?

• Is it in \text{NP-complete}?

• If not, solve it

• If so, then what?

  Despair.
How to deal with hard problems

• What should you do when you encounter an apparently hard problem?

• Is it in NP-complete?

• If not, solve it

• If so, then what?

Solve it!
How to deal with hard problems

• What should you do when you encounter an apparently hard problem?

• Is it in NP-complete?

• If not, solve it

• If so, then what?

    Resort to a suboptimal heuristic.

    Bad, but sometimes the only choice.
How to deal with hard problems

• What should you do when you encounter an apparently hard problem?

• Is it in NP-complete?

• If not, solve it

• If so, then what?

Develop an approximation algorithm.
Better.
How to deal with hard problems

• What should you do when you encounter an apparently hard problem?

• Is it in NP-complete?

• If not, solve it

• If so, then what?

Determine whether all encountered problem instances are constrained.

Wonderful when it works.
One example

Terminology

• Book’s terminology fine, others also exist

• Different groups → different terminology

• Not confusing, terse definitions provided

• Book on jobs, tasks: Jobs discrete, tasks groups of related jobs

• Other sources: Tasks discrete, hierarchical
Additional terminology

- Or vs. And data dependencies

- Conditionals
  - Doesn’t help hard real-time unless perfect path correlation
  - Can help soft real-time
Terminology

- Scheduling, allocation, and assignment
- Scheduling central but not only thing
- Book treats scheduling as combination of scheduling and assignment
- More fine-grained definitions exist
Substantial quirks

1. Every processor is assigned to at most one job at any time
   • O.K.

2. Every job is assigned at most one processor at any time
   • Broken

3. No job scheduled before its release time
   • O.K., but the whole notion of absolute release times is broken for some useful classes of real-time systems.

4. Etc.
Design representations

- Introduction
- Software oriented
- Hardware oriented
- Graph based
- Resource description
Design representations

- Introduction
- Software oriented
- Hardware oriented
- Graph based
- Resource description
Specification language requirements

• Specify constraints on design

• Indicate system-level building blocks

• To allow flexibility in compilation/synthesis, must be abstract
  – Specify implementation details only when necessary (e.g., HW/SW)
  – Concentrate on requirements, not implementation
  – Make few assumptions about platform
Design representations

• Introduction
• Software oriented
• Hardware oriented
• Graph based
• Resource description
Design representations

- Introduction
- **Software oriented**
  - ANSI-C
  - SystemC
  - Other SW language-based, e.g., Ada
- **Hardware oriented**
- Graph based
- Resource description
ANSI-C advantages

• Huge code base
• Many experienced programmers
• Efficient means of SW implementation
• Good compilers for many SW processors
ANSI-C disadvantages

• Little implementation flexibility
  – Strongly SW oriented
  – Makes many assumptions about platform

• Little (volatile)/no built-in support for synchronization
  – Especially fine-scale HW synchronization

• Doesn’t directly support specification of timing constraints
SystemC

Advantages

• Support from big players
  – Synopsys, Cadence, ARM, Red Hat, Ericsson, Fujitsu, Infineon Technologies AG, Sony Corp., STMicroelectronics, and Texas Instruments

• Familiar for SW engineers

Disadvantages

• Extension of SW language
  – Not designed for HW from the start

• Compiler available for limited number of SW processors
  – New
Other SW language-based

• Numerous competitors

• Numerous languages
  – ANSI-C, C++, and Java are most popular starting points

• In the end, few can survive

• SystemC has broad support
Design representations

• Software oriented
• Hardware oriented
• Graph based
• Resource description
Design representations

• Software oriented

• Hardware oriented
  – VHDL
  – Verilog
  – Esterel

• Graph based

• Resource description
VHDL

Advantages

• Supports abstract data types
• System-level modeling supported
• Better support for test harness design

Disadvantages

• Requires extensions to easily operate at the gate-level
• Difficult to learn
• Slow to code
Verilog

Advantages

• Easy to learn
• Easy for small designs

Disadvantages

• Not designed to handle large designs
• Not designed for system-level
Verilog vs. VHDL

• March 1995, Synopsys Users Group meeting

• Create a gate netlist for the fastest fully synchronous loadable 9-bit increment-by-3 decrement-by-5 up/down counter that generated even parity, carry and borrow

• 5 / 9 Verilog users completed

• 0 / 5 VHDL users competed
Verilog vs. VHDL

- March 1995, Synopsys Users Group meeting
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Does this mean that Verilog is better?

Maybe, but maybe it only means that Verilog is easier to use for simple designs.
Esterel

• Easily allows synchronization among parallel tasks

• Works at a high level of abstraction
  – Doesn’t require explicit enumeration of all states and transitions

• Recently extended for specifying datapaths and flexible clocking schemes

• Amenable to theorem proving

• Translation to RTL or C possible

• Commercialized by Esterel Technologies
Design representations

- Software oriented
- Hardware oriented
- Graph based
- Resource description
Design representations

• Software oriented
• Hardware oriented
• Graph based
  - Dataflow graph (DFG)
  - Synchronous dataflow graph (SDFG)
  - Control flow graph (CFG)
  - Control dataflow graph (CDFG)
  - Finite state machine (FSM)
  - Petri net
  - Periodic vs. aperiodic
  - Real-time vs. best effort
  - Discrete vs. continuous timing
  - Example from research
• Resource description
Dataflow graph (DFG)

- Nodes are tasks
- Edges are data dependencies
- Edges have communication quantities
- Used for digital signal processing (DSP)
- Often acyclic when real-time
Dataflow graph (DFG)

- Nodes are tasks
- Edges are data dependencies
- Edges have communication quantities
- Used for digital signal processing (DSP)
- Often acyclic when real-time
- Can be cyclic when best-effort
Synchronous dataflow graph (SDFG)
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Synchronous dataflow graph (SDFG)
Control flow graph (CFG)

- Nodes are tasks
- Supports conditionals, loops
- No communication quantities
- SW background
- Often cyclic
Control dataflow graph (CDFG)

- Supports conditionals, loops
- Supports communication quantities
- Used by some high-level synthesis algorithms
Finite state machine (FSM)
Finite state machine (FSM)
Finite state machine (FSM)
Finite state machine (FSM)

- Normally used at lower levels
- Difficult to represent independent behavior
  - State explosion
- No built-in representation for data flow
  - Extensions have been proposed
- Extensions represent SW, e.g., co-design finite state machines (CFSMs)
Petri net

- Graph composed of places, transitions, and arcs
- Tokens are produced and consumed
- Useful model for asynchronous and stochastic processes
- Places can have priorities
- Not well-suited for representing dataflow systems
- Timing analysis quite difficult
- Large flat graphs difficult to understand
- Real-time use: Specification and formal timing verification
Petri net

M/D/3/2: Markov arrival, deterministic service delay,

From A. Zimmermann’s token game demonstration.
Petri net

thinking processes

think

waiting processes

enter service

busy servers

serve

available servers

M/D/3/2: Markov arrival, deterministic service delay,

From A. Zimmermann’s token game demonstration.
Petrinet

thinking processes → think → waiting processes → enter service → busy servers → serve → available servers

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NesC

- View as a ANSI C with additional layer
- Specify interfaces between components
- Centers on *commands* and *events*
- Commands
  - Provided by interface, do things
  - Non-blocking, split-phase (response from events)
  - Call down
  - E.g., transmit data
NesC

Events

• Provided by interface
• Used to signal command completion
• Interrupt tasks
• Require concurrency control (*atomic* blocks)
NesC

- Tasks: Interrupted only by events, no normal preemption
- Asynchronous code: can be reached by interrupt handlers
- Synchronous code: can be reached only from tasks
- Not the only option
Summary

• Justify treating real-time design problem as optimization problem
• Example problem to illustrate specification and design
• Tractable algorithm design (NP-completeness in a nutshell)
• Detail on design representations
• Sensor network motivations
• NesC overview
Reading assignment (18 January)

  - Chapter 1
  - Chapter A5: Sequencing and scheduling

  - Chapter 3
  - Chapter 4