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IAF0530/IAF9530

Süsteemide usaldusväärsus ja veakindlus
Dependability and fault tolerance

Loeng 5
Testing Real-Time Systems

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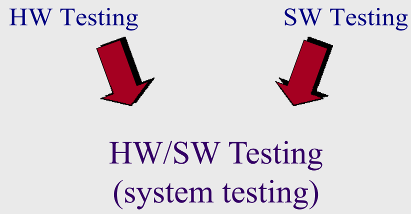
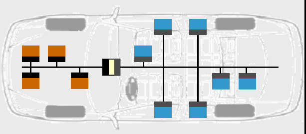
System Testing



Real-Time Systems

- *Real-Time System* – system, which is required to adhere not only functional but also tempoal requirements ("timing constraints" or "deadlines")
- RT-systems:
  - Hard RT-systems
  - Soft RT-systems



Real-Time Systems Testing

- Inherits issues from concurrent systems
  - Problems becomes harder due to time-constraints
    - More sensitive to probe-effects
    - Timing/order of inputs become more significant
- Adds new potential problems
  - New failure types
    - E.g. Missed deadlines, Too early responses…
  - Test inputs → Execution times
  - Faults in real-time scheduling
    - Algorithm implementation errors
    - Assumption about system wrong

Real-Time Systems Testing

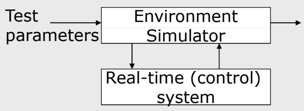
- Pure time-triggered systems
  - Deterministic
  - Test-methods for sequential software usually apply
- Fixed priority scheduling
  - Non-deterministic
    - Limited set of possible execution orders
  - Worst-case w.r.t timeliness can be found from analysis
- Dynamic (online) scheduled systems
  - Non-deterministic
    - Large set of possible execution orders
  - Timeliness needs to be tested

Testing Timeliness

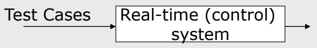
- Aim : Verification of specified deadlines for individual tasks
  - Test if assumptions about system hold
    - E.g. worst-case execution time estimates, overheads, context switch times, hardware acceleration efficency, I/O latency, blocking times, dependency-assumptions
  - Test system temporal behavior under stress
    - E.g. Unexpected job requests, overload management, component failure, admission control scheme
- Identification of potential worst-case execution orders
- Controllability needed to test worst-case situations efficiently

Testing Embedded Systems

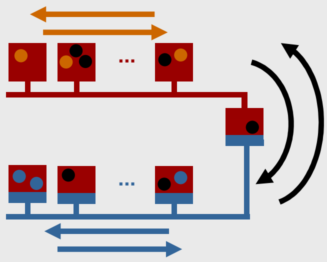
- System-level testing differs
  - Performed on target platform to keep timing
- Closed-loop testing
  - Test-cases consist of parameters sent to the environment simulator



- Open-loop testing
  - Test-cases contain sequences of events that the system should be able to handle



Distributed Real-Time Systems



- Distributed applications
  - On a single cluster
  - On several clusters
- Motivation
  - Reduce costs: use resources efficiently
  - Requirements: close to sensors/ actuators
- Distributed applications are difficult to...
  - Analyze (e.g., guaranteeing timing constraints)
  - Design (e.g., efficient implementation)

Testing Distributed RT-Systems

- Problems with distributed systems:
  - Increased complexity
  - The difficulties of observing and monitoring
  - Non-reproducible behaviour of the system
  - The lack of synchronized global clock and, consequently, the difficulties of unambiguously defining a "global state"

Testing Distributed RT-Systems

- Observability
  - What?
  - How?
  - When?
- Controllability
- Auxiliary outputs, interactive debuggers

Observability Issues

- Probe effect (Gait,1985)
  - "Heisenbergs's principle" - for computer systems
  - Common "solutions"
    - Compensate
    - Leave probes in system
    - Ignore
- Must observe execution orders
  - Gain coverage

Controllability Issues

- To be able to test correctness of a particular execution order we need control
  - Input data to all tasks
    - Initial state of shared data/buffers
  - Scheduling decisions
    - Order synchronization/communication between tasks

Testing Distributed RT-Systems

- **Reproducibility**
  - *Regression testing* – retesting after errors have been corrected
    - errors truely corrected
    - no new errors
  - A distributed system may be non-reproducible due to nondeteminism in it's hardware, software or operating system

Testing Distributed RT-Systems

- **Obtaining reproducibility**
  - Language-based approach
    - Enforcing the identified scenarios during execution
    - All solutions rely on source code transformations
  - Implementation based approach
    - Collecting all missing information during an execution of the system
    - Event histories or traces

Testing Distributed RT-Systems

- Disadvantages of implementation based approach:
  - Special dedicated HW (to monitor)
  - Large amount of information
  - Can we guarantee the correctnes of reply?
  - Modified programs. What happens with event histories. Are they still valid?
  - Event histories can be used only on target systems

Testing Distributed RT-Systems

- Interdependence of Obsevability and Reproducibility
  - Not independent!
  - Probe effect

Testing Distributed RT-Systems

- **The host/target approach**
  - Host - development
  - Target - execution
- Testing on the host system is used for (functional) unit testing and preliminary integration testing (as much as possible)
- Testing on the target system involves completing the integration test and performing the system test. Also performance, timing, etc.

Testing Distributed RT-Systems

- Environment simulation (for target system test)
  - Simulated v. real environment:
    - Safety and/or cost considerations.
    - "rare event" situations
    - More control over simulated environment
    - Easier to obtain responses and test results
  - On-line v. off-line test data generation:
    - Need to generate large amounts of input data
    - Runs cost-effectively

Testing Distributed RT-Systems

- Representativity
  - Only small number of real-world scenarios can be anticipated and taken into account.
  - Only a fraction of those anticipated real-world scenarios can be tested due to the combinatorial explosion of possible event and input combinations.
- Test coverage - how many of the anticipated real-time scenarios can be or have been covered by corresponding test scenarios.

Self-checking distributed systems

- Run-time checking of the effects of faults on system behaviors needs to be carried out continuously.
- Reliability – the key to distributed SW quality

Self-checking distributed systems

- Aspects to design correct SW:
  - Reliability with which the SW specifications are adequately described and correctly implemented in the actual implementation.
  - Run-time checking

Self-checking distributed systems

- Fault-secure systems are systems, where faults may be enforced not to propagate.
  - Faults are not visible or have no effect
  - Faults are visible, but it's easy to notice that an error exists
- Self-testing – System is self testing when there exists testing behavior, occurring during the run-time behavior of the system, such that this fault will be propagated to the output and it's easy to notice, that there is a fault (out of predefined set of values)
- System is self-checking for a set of faults, if whatever a fault belonging to this set, it is fault-secure and self-testing.

Self-checking distributed systems

- Worker-observer
  - the *worker* is a classical implementation of the system behavior
  - the observer is a given redundant implementation whose outputs are comparable with the outputs of the worker.
- To obtain observing behavior:
  - Redundancy
  - Reference
  - Visibility
    - Worker cooperates with the observer
    - Worker behavior can be spied by the observer

Self-checking distributed systems

- A *formal observer* is a subsystem designed to check distributed behaviors where:
  - Its sw is independent of the specific protocols to be checked in the considered system;
  - Its data are defined by the protocols to be checked and this data can be formally specified and verified.

Self-checking distributed systems

- Design of the system
  - write a description of the beavior of the system to be implemented;
  - Implement the system itself, i.e., the worker;
  - From the description of the worker, select (based on experience) that part of the behavior which should be observed and write a formal model of it.

Self-checking distributed systems

- The system is *quasi self-checking* if
  - It is an observer-worker system
  - The observer is a formal observer.
- For "real-life" only part of the system will be modelled.
- Formal model must be able to
  - Express simplified specifications of distributed systems
  - Support verification procedures
  - Be able to act as a basis for implementing the observer.

Few testing criteria exists for concurrent systems

- Number of execution orders grow exponentially with # synchronization primitives in tasks
  - Testing criteria needed to bound and selecting subset of execution orders for testing
- E.g. Branch / Statement coverage not sufficient for concurrent software
  - Still useful on serializations
  - Execution paths may require specific behavior from other tasks
- Data-flow based testing criteria has been adapted
  - E.g. define-use pairs

Determinism vs. Non-Determinism

- Deterministic systems
  - Controllability is high
    - input (sequence) suffice
  - Coverage can be claimed after single test execution with inputs
  - E.g. Filters, Pure "table-driven" real-time systems
- Non-Deterministic systems
  - Controllability is generally low
  - Statistical methods needed in combination with input coverage
  - E.g.
    - Systems that use random heuristics
    - Behavior depends on execution times / race conditions

Test execution in concurrent systems

- Non-deterministic testing
  - "Run, Run, Run and Pray"
- Deterministic testing
  - Select a particular execution order and force it
  - E.g. Instrument with extra synchronizations primitives
    - (No timing constraints make this possible)
- Prefix-based Testing (and Replay)
  - Deterministically run system to a specific (prefix) point
  - Start non-deterministic testing at that specific point

Important

- No lecture on March 14
- March 21: Draft of the report + introductory presentation of the topic (3-5 min.).

Participation mandatory!!

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Questions?