Transparent Fault Tolerance Support in Model-Based Design

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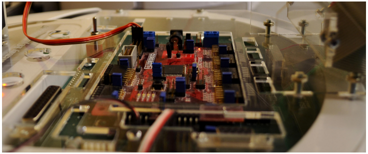

2nd Italian Workshop on Embedded Systems (IWES)
September 7 – 8, 2017, Rome, Italy

Outline

- Overview and Motivation
- Fault Tolerance Framework
- Fault Injection Capabilities
- Conclusion

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The CPAL Language

Cyber Physical Action Language

A high-level DSL to model, simulate, verify, and implement CPSs

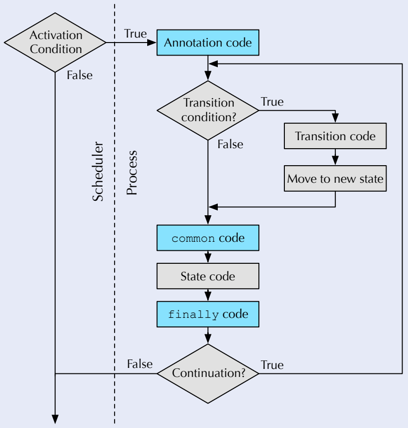
- It can express both functional and non-functional behaviors
- It can be executed in real time on an embedded platform, by means of an interpreter
- Simulation and execution are timing equivalent
- The language natively supports multiple periodic and/or event-driven processes, each modeled by means of a Mealy Finite State Machine (FSM)

The CPAL Language

Sample Process

```
processdef P(params) {
  common {
    code
  }

  state Warning {
    code
  }
  on (cond) {code} to Alarm_Mode;
  after (time) if (cond) to Normal_Mode;

  finally {
    code
  }
}

process P: inst[period,offset][cond](args);

@cpal:time:inst{
    annotation code
}
```

Elementary execution step



Using CPAL

A "Real-World" Modeling Language

- C-like syntax
- Suitable as an implementation language
- Schedulability analysis and timing-accurate simulation
- Run-time introspection (e.g. for overload detection)

Goals

- Use CPAL to model a communication protocol for fault tolerance (interactive consistency)
- Compare it with another prominent language (Promela)

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CPAL vs. Promela — Main Remarks

- Promela is meant for verification, rather than execution
  - Non-determinism is at the core of the language
  - No I/O support
  - No floating point data types
  - It can be translated to C and Java (with varying success)

- CPAL supports timing-accurate simulation and interpreted execution
  - Non-determinism must be avoided in most real systems
  - No formal proofs (except for schedulability analysis)
  - Executable model
  - The execution platform is decoupled from the application

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Fault-Tolerant CPSs

As CPSs become more and more software intensive, software defects tend to become the major source of faults

- Fault tolerance enables a system to tolerate software faults after its development
- Few work is done on automatic fault tolerance analysis and implementation at the system design phase

Goals

- Improve system dependability . . .
- . . . without affecting its functional behavior and timings
- Full integration with MBD workflow

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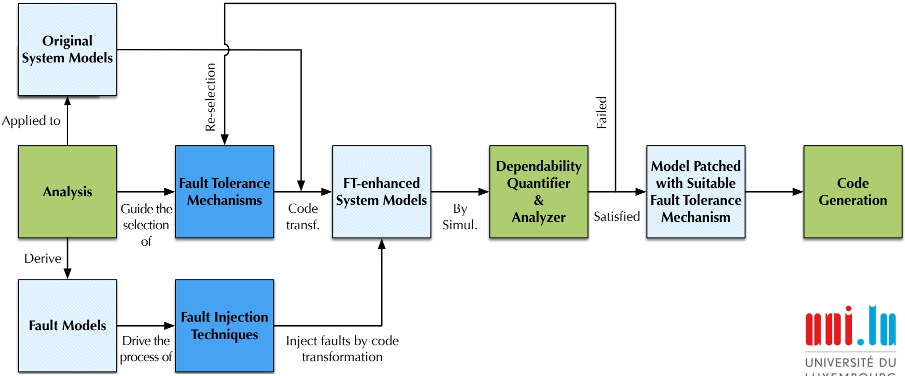
Model-Based FT System Design/Development



N-Version Programming (NVP)

N-fold replication of the same computation, carried out by means of N software modules, called member versions (software diversity)

- Member versions run in parallel, operating on the same inputs
- Result reached by consensus (e.g. majority voting)
- Requires member versions to generate comparison vectors at predefined cross-check points
- Feedback to the member versions depending on the result (terminate/continue, recovery)

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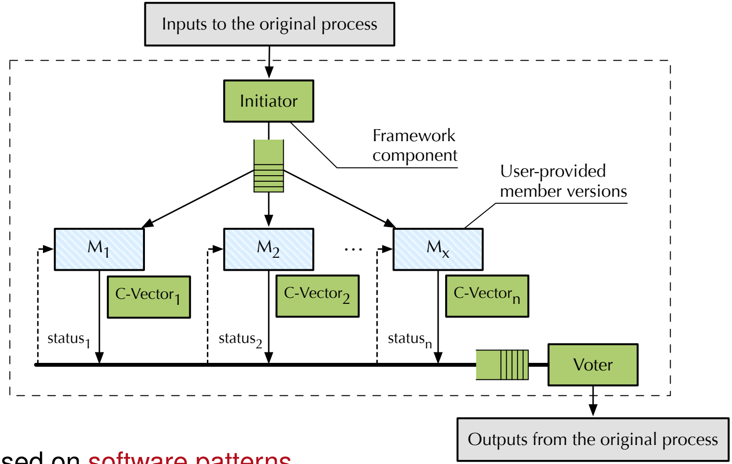
NVP Framework



Based on software patterns,
automatic code-generation friendly,
cross-check points set at execution step boundaries

Main Achievements

- Fault-tolerant mechanisms are kept independent from the logic of the application
- System designers may explore their use early in the design phase, focusing only on the application-dependent functional logic
- Minimal or no user involvement in low-level implementation details
- A C-language implementation derived from the model is also available (when direct model execution is impractical)

The same methodology can be applied to other fault tolerant mechanisms

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Software Fault Injection

Motivation

No fault tolerance framework can be considered complete without the ability of injecting faults into the model

- Very powerful, well-understood assessment technique
- Time consuming, requires extensive know-how

Goals

- Automate software fault injection
- Integrate it with the design flow ...
- ... by means of software patterns

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What Can We Model? — Fault Categories

- Global State: State information resides in a pool of RAM statically allocated at link time $\rightarrow$ Its corruption can model various kinds of memory corruption
- Activation Arguments: Processes access state information through arguments, passed by value or by reference $\rightarrow$ Better granularity (down to the process activation level)
- Instance Variables: Local (stack-based) process storage is often implemented differently than global storage $\rightarrow$ Support the distinction between how different kinds of memory fail
- Control Flow Disruption: Most details of control flow are hidden in the model $\rightarrow$ Tampering with state transition conditions provides a useful surrogate

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How? — Injection Mechanisms and Patterns

- External Injector: One or more processes are dedicated to fault injection → Keeps a clean boundary between the normal behavior of a system and its fault profile, centralized approach
- Common/Finally Blocks: They are executed before and after state-specific code upon process activation → They can also access activation arguments and local variables, per-instance behaviors are possible
- Annotation-Based Injector: CPAL supports annotations to express non-functional properties of a program and isolate them from functional properties → With respect to common/finally, they can also affect state transitions

Summary Table

Mechanism	Fault category: Global state	Activation arguments	Local variables	Control flow
External process(es)	✓			✓
Pre/post conditions	✓	✓	✓	
Annotation-based	✓			✓

Results

- Software fault injection of data errors can be effectively performed at the DSL level
- More limited modeling of code changes is possible, too
- All patterns can be fully automated

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Ongoing Work

Automatic code generation and instrumentation

- Complete the implementation of the fault tolerance and fault injection framework
- Operate only at the DSL level, for modularity and applicability to other languages
- Design an appropriate annotation-based language extension to this purpose
- Consider further fault tolerance and injection mechanisms

Further Reading

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CPAL: High-level abstractions for safe embedded systems.
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THANK YOU FOR YOUR ATTENTION