Safety evaluation and reliability analysis of nuclear automation

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Starting point

- Digitalization of nuclear Instrumentation&Control (I&C) systems
- Challenges in Verification&Validation (V&V)
- Relies heavily on subjective evaluation

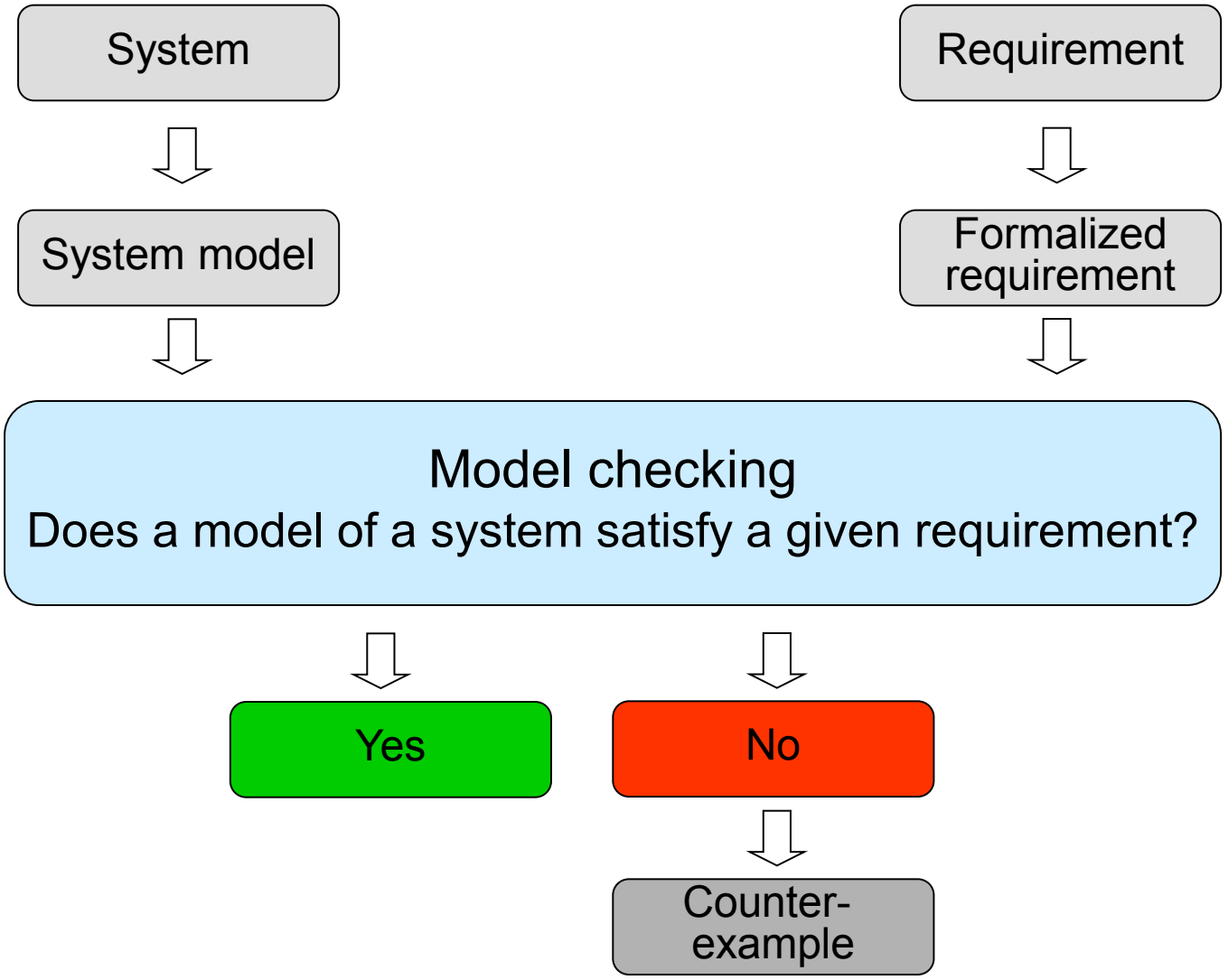
- Traditional methods such as testing and simulation:
  - Used late in the development cycle
  - Cover only a limited part of the possible system behaviour
  - Defining test scenarios and implementing them is challenging

➔ Testing and simulation alone are inadequate to produce sufficient evidence of correct functioning of safety critical systems in all possible scenarios

Objectives

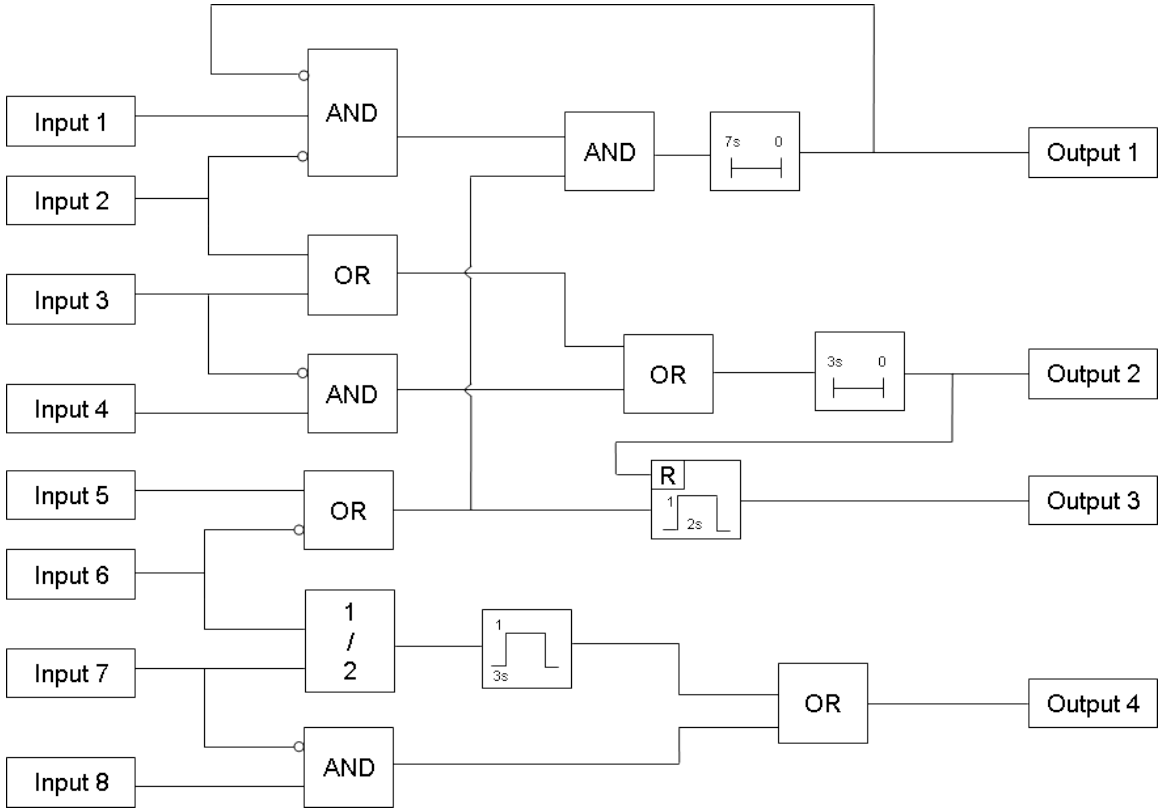
- Develop methods and procedures for model-based safety evaluation and reliability assessment of NPP automation.
- Apply the methods in selected case studies
- Evaluate the suitability of the methods for critical NPP automation analysis
- Practical utilization

What is model checking?



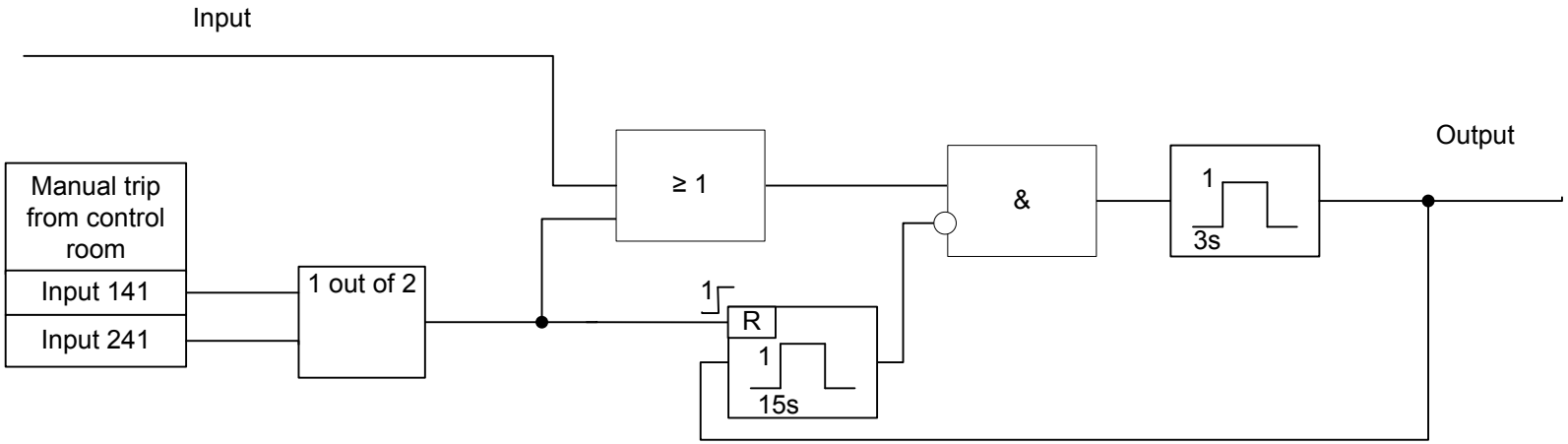
Large state spaces

- Typical logical circuits of safety critical automation systems contain delays, feedback loops and timers
- State spaces grow easily beyond 10^{10} even in designs that look rather simple



➔ Extensive verification manually or by testing and simulation becomes practically impossible

Formulation of properties



Test scenarios (are these sufficient ?):

- *Input = 1, but changes to 0 after 20 seconds*
- *Input = 1 and operator trips manually when the 15 second pulse has been running **6** seconds*
- *Input = 1 and operator trips manually when the 15 second pulse has been running **2** seconds*

Scenario for model checking

- *"In all possible cases when the Input = 1, Output finally gets value 1"*

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Typical types of design errors

- Normal mode of operation is usually well tested and working
- Errors are usually found in corner cases: Scenarios that are difficult to take into account in test planning
  - Errors after subsystem re-initializations
  - Timing scenarios where multiple events happen simultaneously
  - Several improbable events occur simultaneously
  - Unexpected operator or maintenance actions

Model Checking Achievements in SARANA

- Exhaustive analysis of system models containing large state spaces, over 10^{20} states
- Improving automated tools that check timing-related behaviors
- Using two independent model checker tool chains to get more confidence in the results from both
- Developing automated, compositional model checking methodology for analysing large designs
- A success in technology transfer in SAFIR: From a research project to practical utilization

Reliability analysis of digital systems

- General objective is to provide guidelines to analyse and model digital systems in Probabilistic Risk Analysis (PRA) context
- Finalization of the digital Instrumentation&Control (I&C) failure modes taxonomy (OECD/NEA WGRISK's task DIGREL), VTT is task leader
- Suitable level of detail for an I&C architecture model will be investigated
- Modelling and quantification of software faults

Dynamic flowgraph methodology

- DFM is an approach for reliability assessment of systems with time dependencies and feedback loops
- YADRAT tool developed at VTT for analysing DFM models
- YADRAT models can be translated into models for the NuSMV model checker
- Improved algorithms to solve DFM models
- Computing importance measures and modeling common cause failures

Remaining challenges

- Minimizing human effort in modelling and interpreting analysis results
- Scalability of the methods to larger real world systems
- Methodology for expressing requirements formally but still in a light weight fashion
- Software reliability analysis is still a challenge
- Integration of the methods with e.g., traditional testing and simulation based approaches

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