Application of Model-Based Testing to validation of new nuclear I&C architectures

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Context – The Connexion Project

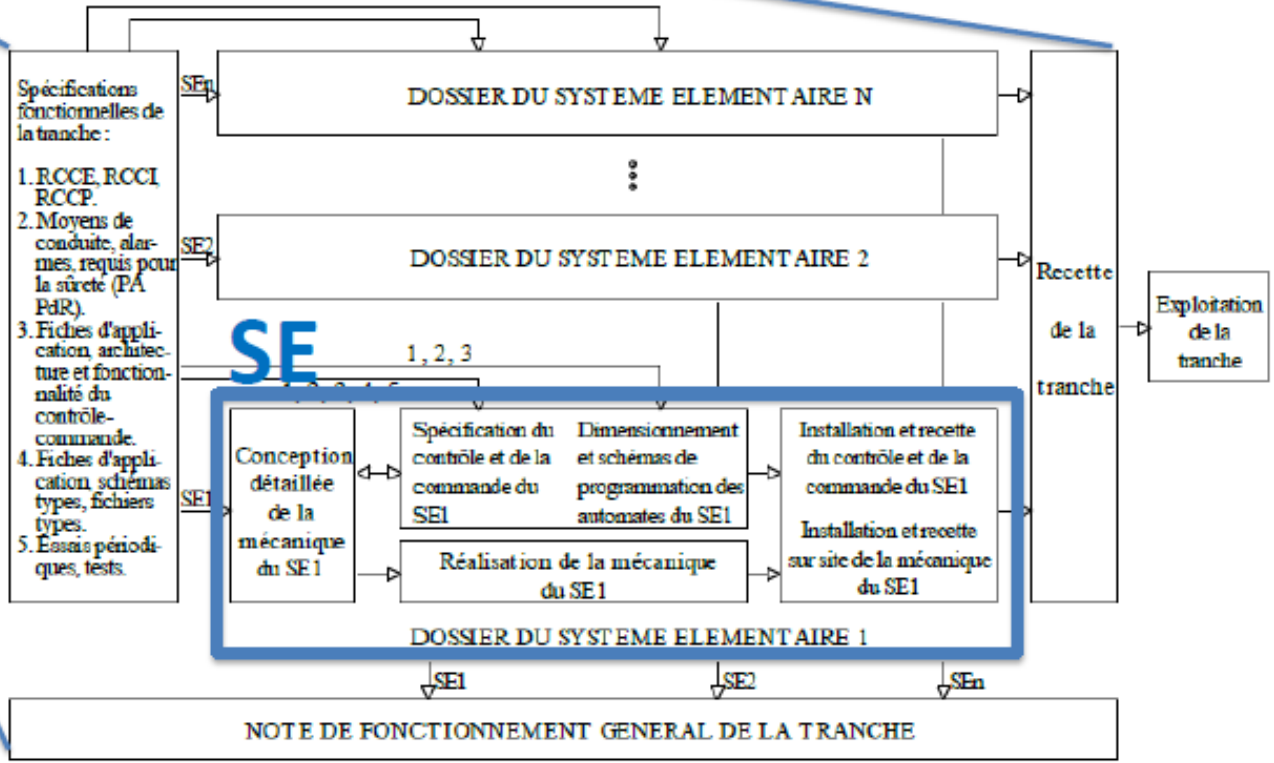
Connexion
Contrôle-commande numérique pour le nucléaire

- **A large cooperative R&D project**
  - ⇨ **Goal: a modular workbench for functional engineering activities in nuclear I&C (Instrumentation and Control) systems**
  - ⇨ **Includes all major French players in the nuclear I&C field**
    - Operator + architect/engineer (EDF), I&C systems providers (AREVA, Rolls-Royce, Alstom, Atos), technology suppliers (Esterel Technologies, CORYS, All4tec, Predict), research labs (CEA, ENS Cachan, CRAN, Telecom Paris Tech, INRIA, INP Grenoble)
  - ⇨ **Targets improvement of tools**
    - SCADE, MaTeLo, Safety Architect, CORYS ALICES, etc.
- **This presentation covers only one sub-project**
  - ⇨ **Early functional validation (i.e. validation of requirements before implementation)**
    - Tests should be reusable throughout the system development lifecycle
  - ⇨ **Scope: one I&C function**
    - I.e. the result of upstream analysis

Context – Lifecycle Overview – 1 / 2

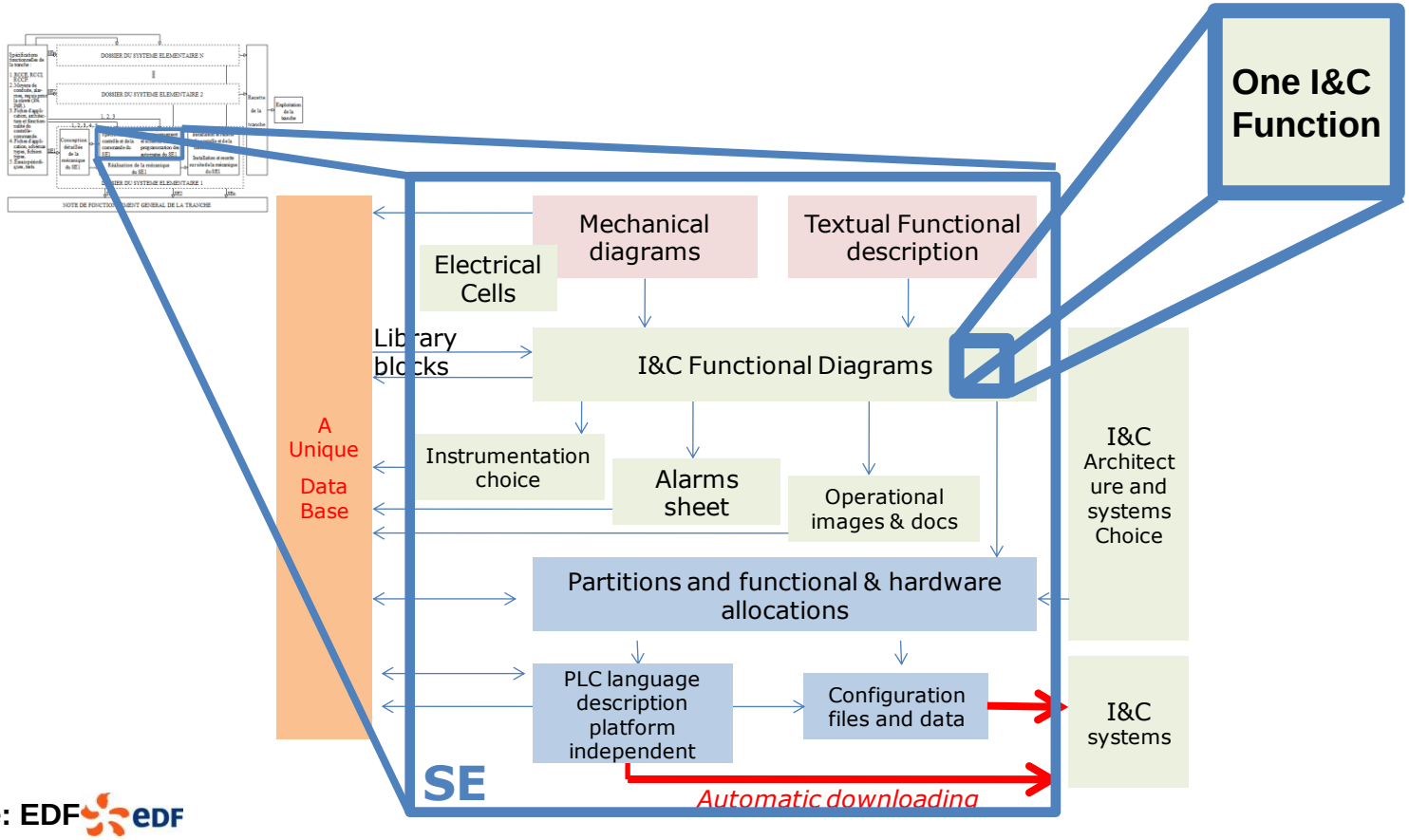
250 Elementary Systems (SE's)

Design phase



Source: EDF

Context – Lifecycle Overview – 2 / 2



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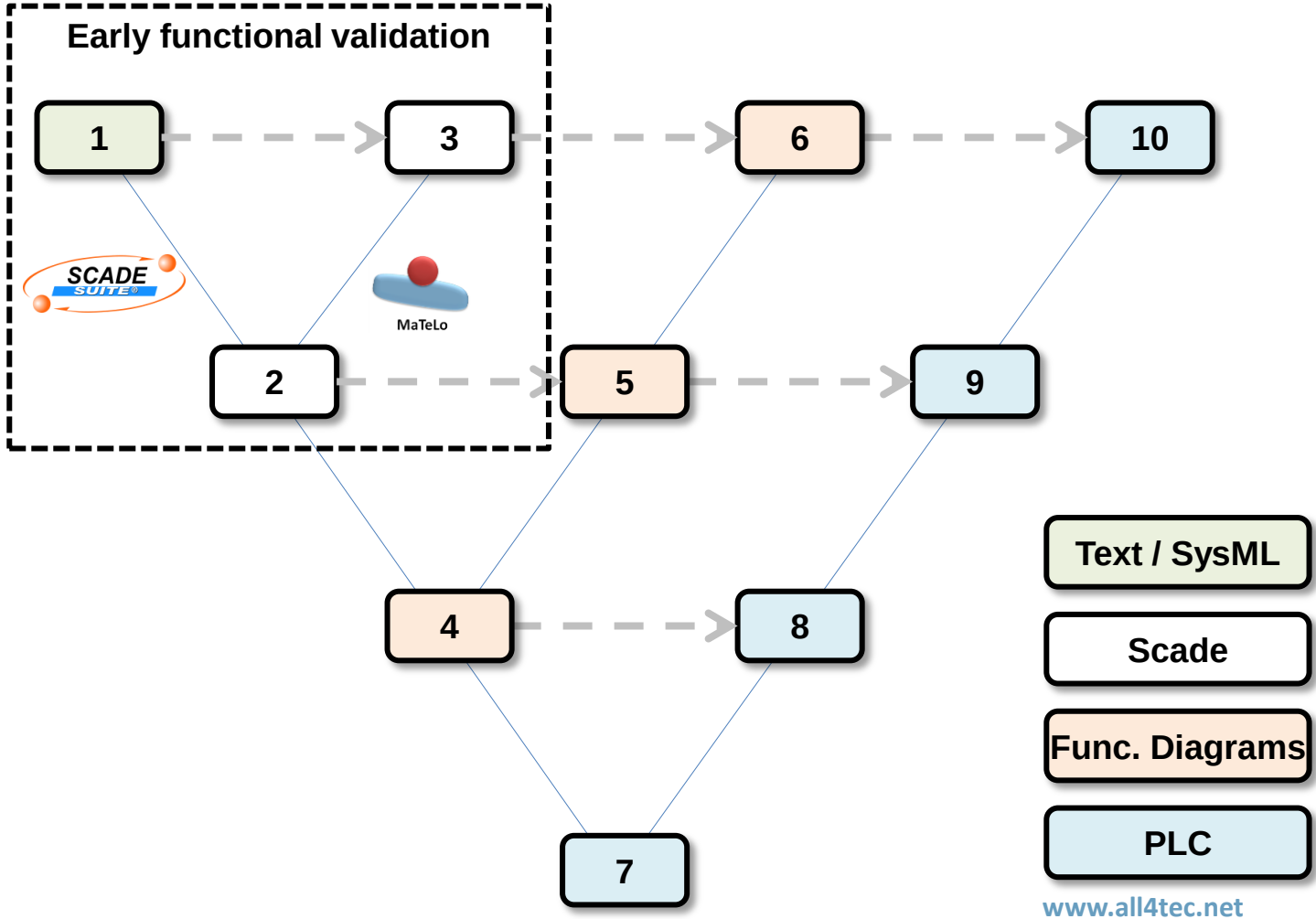
Context – Lifecycle of an I&C Function



Case study – Diesel Load Sequencer

- One particular I&C function
  - ⇨ **One of the components of a larger plant function: back-up power supply (BPS)**
  - ⇨ **Is the control system for the Emergency Diesel Generator (EDG)**
- Purpose: if Main Power Supply is lost, start the Diesel generators, then reconnect the major components of the plant
  - ⇨ **Provide an orderly load sequence to prevent heavy transients on the emergency diesel generator solicitation**
- Features
  - ⇨ **Many Boolean inputs (24)**
    - Input redundancy (AND / OR) is defined by Quality of Service requirements allocated to this function
  - ⇨ **Boolean outputs (12)**
  - ⇨ **Complex timing constraints (orderly reload sequence: 7 or 9 scheduled actions at timed intervals)**

I&C Specification – 1 / 2

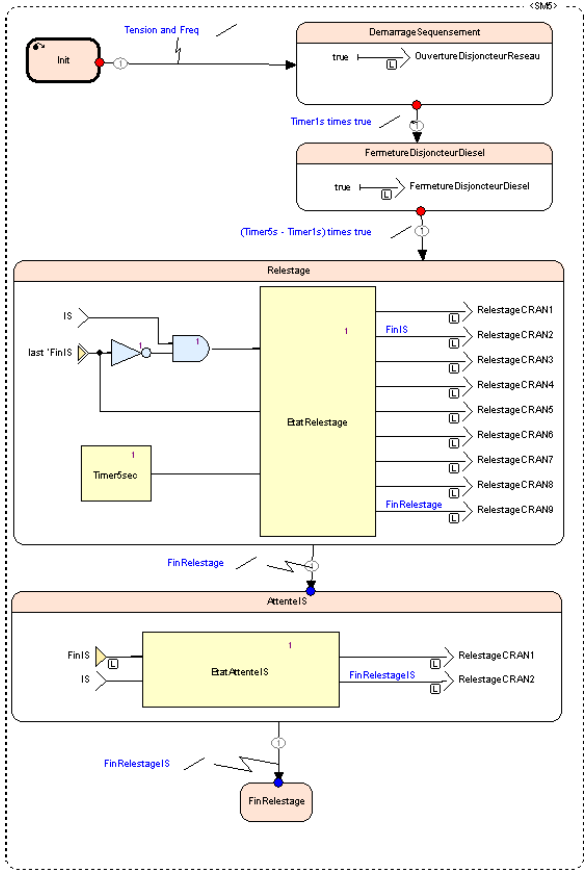
Goal: Early validation of functional requirements

- Combination of Model Based Design and Model Based Testing
- Models developed by independent teams from same requirements

Model Based Design (MBD)

- Graphical model to describe a system from textual requirements
- Executable model allowing clarification of the early set of requirements and early testing (before writing any code)
- Full traceability to textual requirements
- All verifications performed at model level

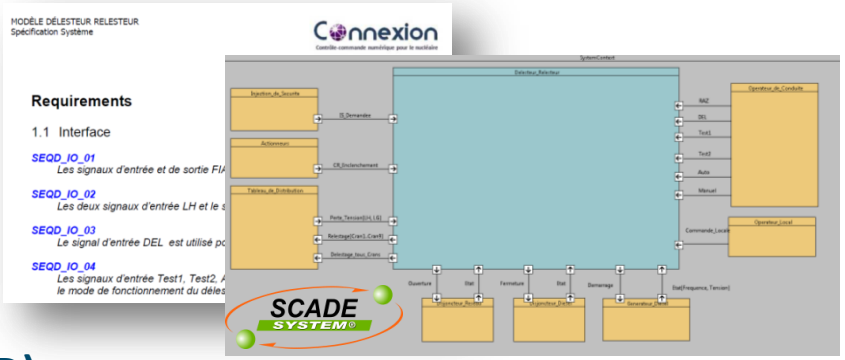
The SCADE formal notation



I&C Specification – 2 / 2

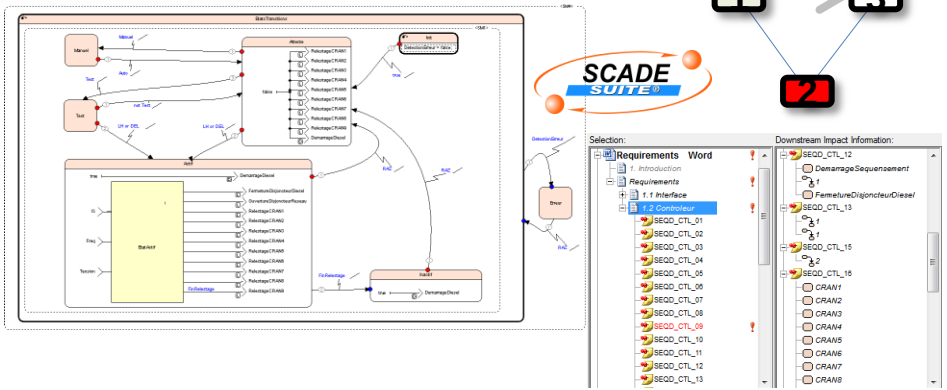
❑ Functional requirements

- ⇨ Textual description
- ⇨ System in its environment



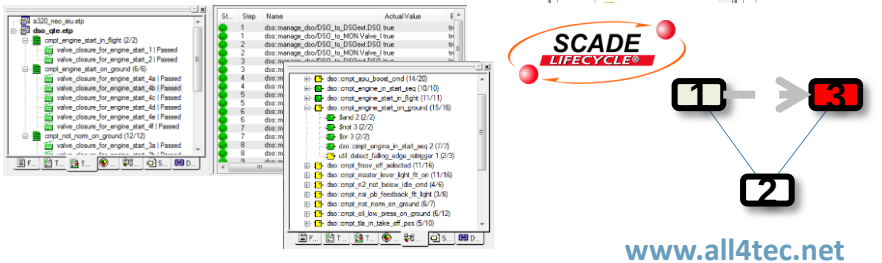
❑ Functional specification (MBD)

- ⇨ Detailed description of dynamic behaviour and algorithms
- ⇨ Traceability to functional requirements



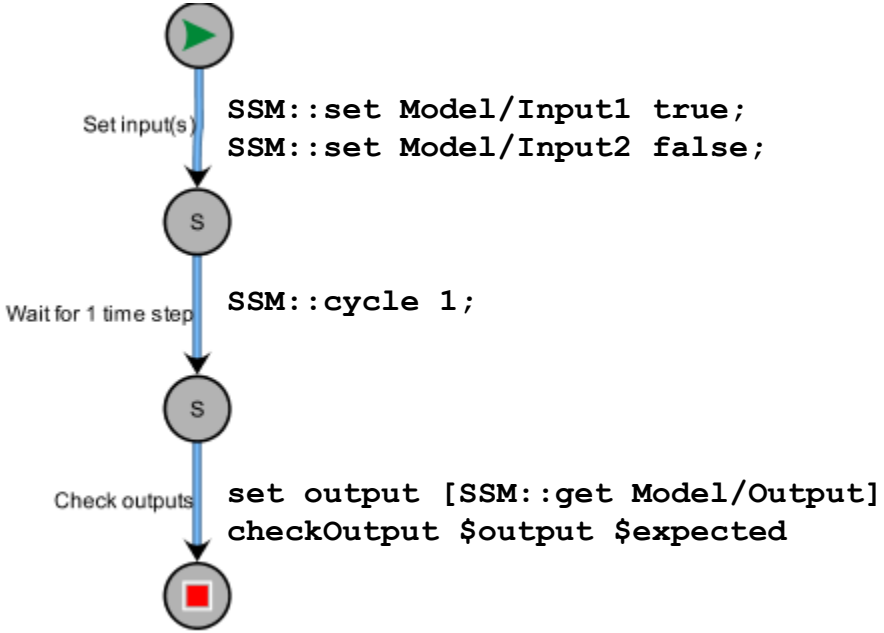
❑ Functional validation (MBT)

- ⇨ Tests scenarios generated by MaTeLo are executed under QTE



Test Model – Time Management

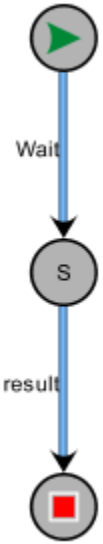
❑ Discrete time



❑ Timed events

```
set cycles [seconds * $tick]
SSM::wait $cycles
```

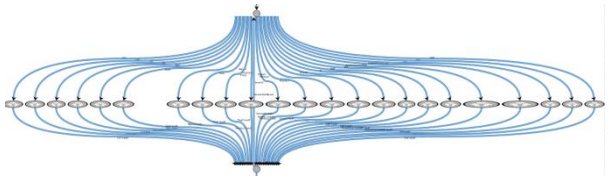
```
set output [SSM::get Model/Output]
checkOutput $output $expected
```



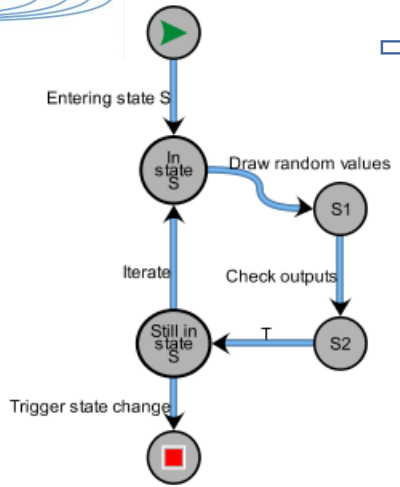
Test Model – Advanced Features

❑ Ignored inputs

- ⇨ **Requirement: in state S (…), all other inputs are ignored**
- ⇨ **Exhaustive approach**
  - Set “other” inputs one at a time

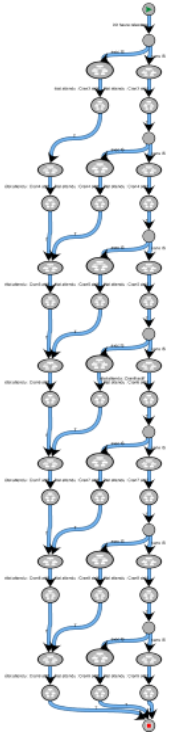


- ⇨ **Stochastic approach**
  - Draw random values for “other” inputs



❑ Random interrupts in a sequence of timed actions

- ⇨ **Requirement : if signal S becomes active during the reloading sequence, perform steps 1 and 2, then continue sequence where it was interrupted**
- ⇨ **Stochastic approach ruled out (MaTeLo arcs coverage mandatory)**



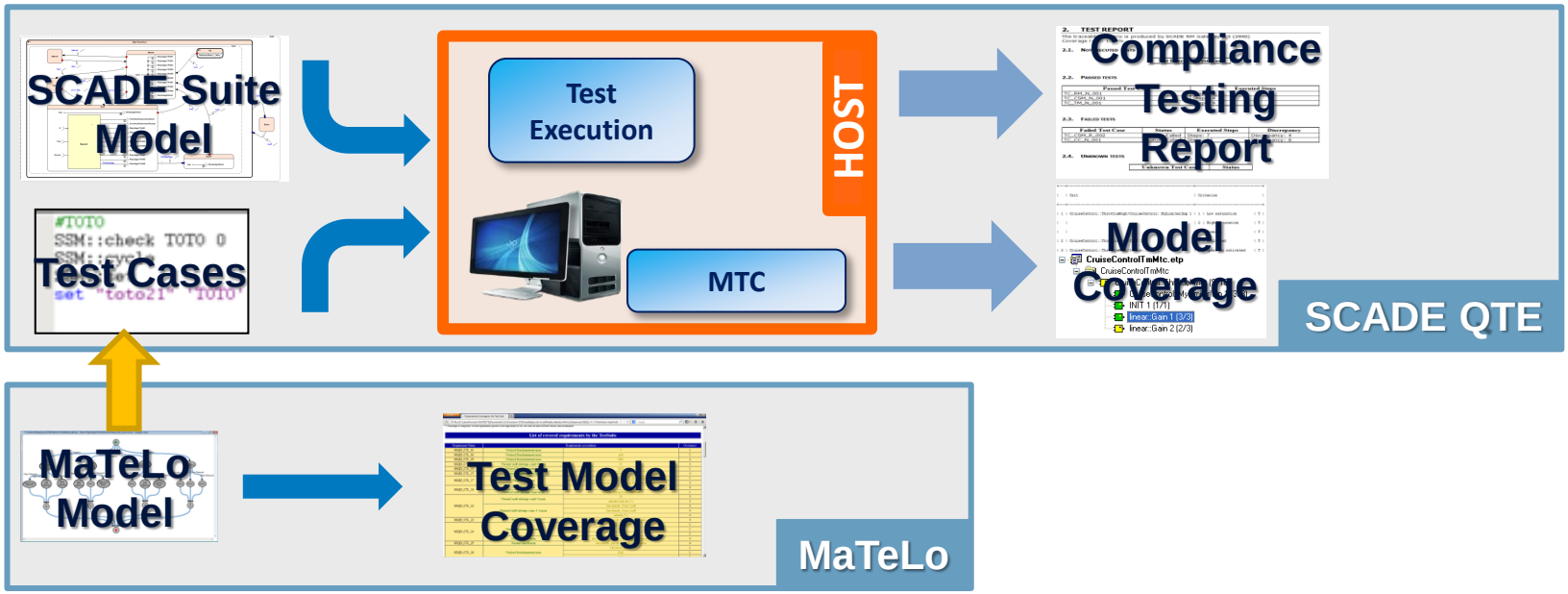
Tools Integration

- Test scripts are generated by MaTeLo in the TCL language
- MaTeLo uses SCADE QTE functions to set inputs, read outputs, handle time
- Requirement traceability is maintained
  - ⇨ Requirements ID's included in test scripts as comments
- Simple and powerful integration
  - ⇨ Automated execution of tests
  - ⇨ Seamless traceability of requirements

```
SSM::set Model/Input

SSM::get Model/Output

SSM::cycle or SSM::cycle $n


# Requirements: SEQD_CTL_08
```

MBT Preliminary Results

- Integrated execution chain



- Verification of requirements (Functional Validation)
  - ⇨ Errors in the (fake) requirements used for this project were indeed found
  - ⇨ Errors in both models were found as well
- 100% MC/DC coverage achieved for test model and design model

Conclusion

- Integration of Model-Based tools has significant added value
  - ⇨ … and is quite easy to achieve
- The combination of early prototyping with MBT makes it possible to verify requirements very early in the lifecycle
  - ⇨ Inconsistencies and lacks in the requirements were easily found
- The same test scripts can (and will) be reused later to validate successive implementation refinements of this function
  - ⇨ Thanks to a very elaborate integration environment
- The Connexion project goes on…