Model-based Quality Assurance of Automotive Software

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The Problem (Meta-level M3)

- Research in Software Engineering is largely “hype-driven”.
- Research activities largely consist of solution development [cf Wieringa].
- Very little independent scientific validation, as would be expected from a scientific discipline (e.g. controlled and repeatable experiments, preferably independently from solution developers).
- This paper tries to contribute (a bit) towards improving this situation.

The Problem (Meta-level M2)

- Model-based development using UML is one of the current “hypes”: strongly promoted by “gurus” in industry, actively researched in academia [cf previous slide].
- But does it really pay ? When / under which conditions / to what degree / which techniques exactly … etc ?
- Very few independent, controlled and repeatable experiments regarding this question.
- This paper tries to contribute to improving this situation wrt. model-based quality assurance, with an emphasis on automotive / embedded software.

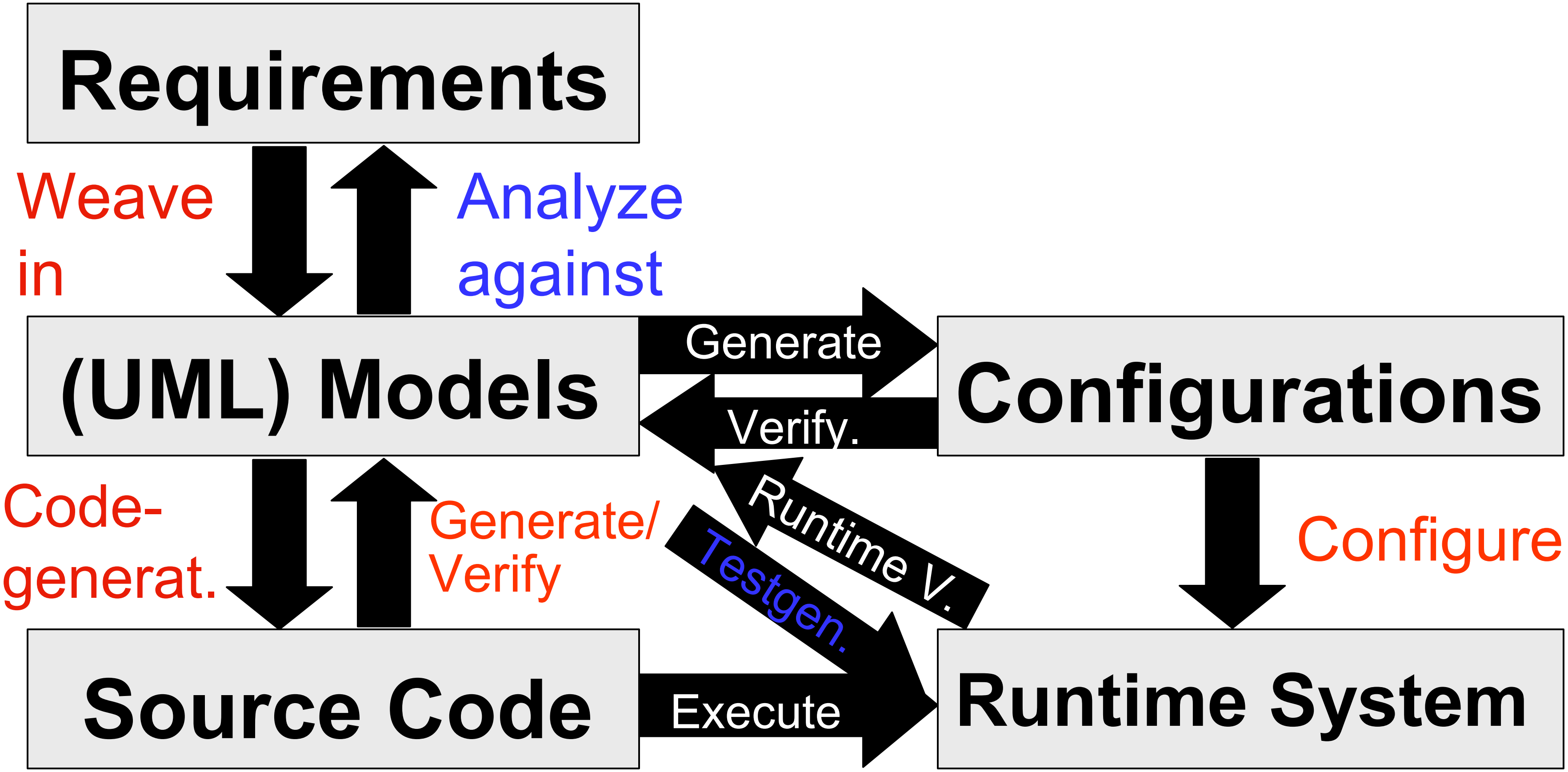
The Problem (Meta-level M1)

- Quality assurance of software consumes significant resources.
- There are high levels of assurance expected especially in safety-critical systems.
- The QA process should as far as possible controllable (to measure degree of assurance) and repeatable (also to account for software changes).
- Model-based quality assurance seems to offer the potential to address these requirements due to a high degree of automation.
- Investigate based on a practical experiment to which extent this may be true wrt. to different QA techniques in the context of model-based development, in a comparative approach.

Automotive Software

- High safety requirements for some of the embedded software.
- Increasing complexity of the software.
- High sales numbers (compared to e.g. airplanes).
- Incentive for quality assurance as opposed to fault-tolerance by replication of functions.
- Relatively high uptake of model-based development techniques and tools.

Model-based System Assurance

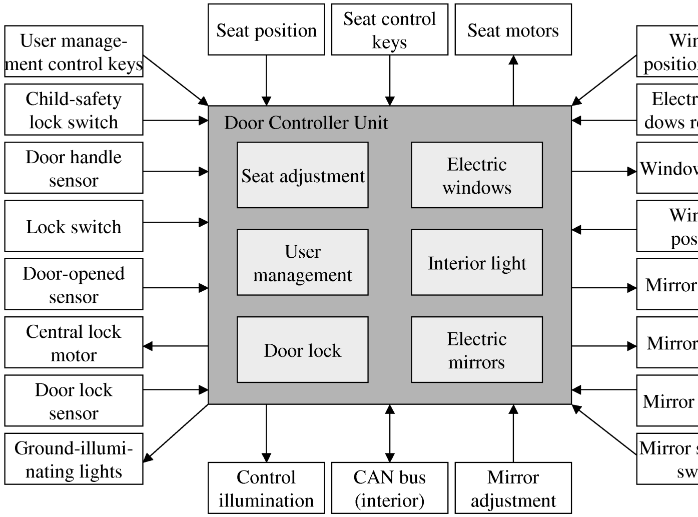


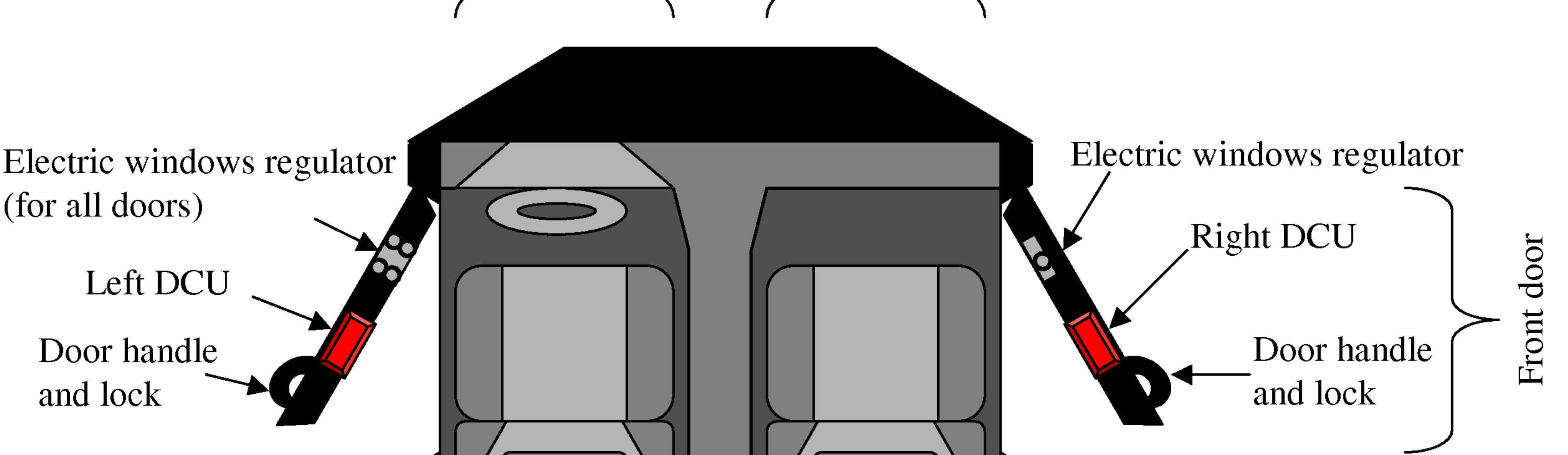
Case study: Door controller (M0)

Industrial specification [Paech et al, Fraunhofer 2002]. Here:

- Window lifter (including crush guard)
- Door locking/unlocking

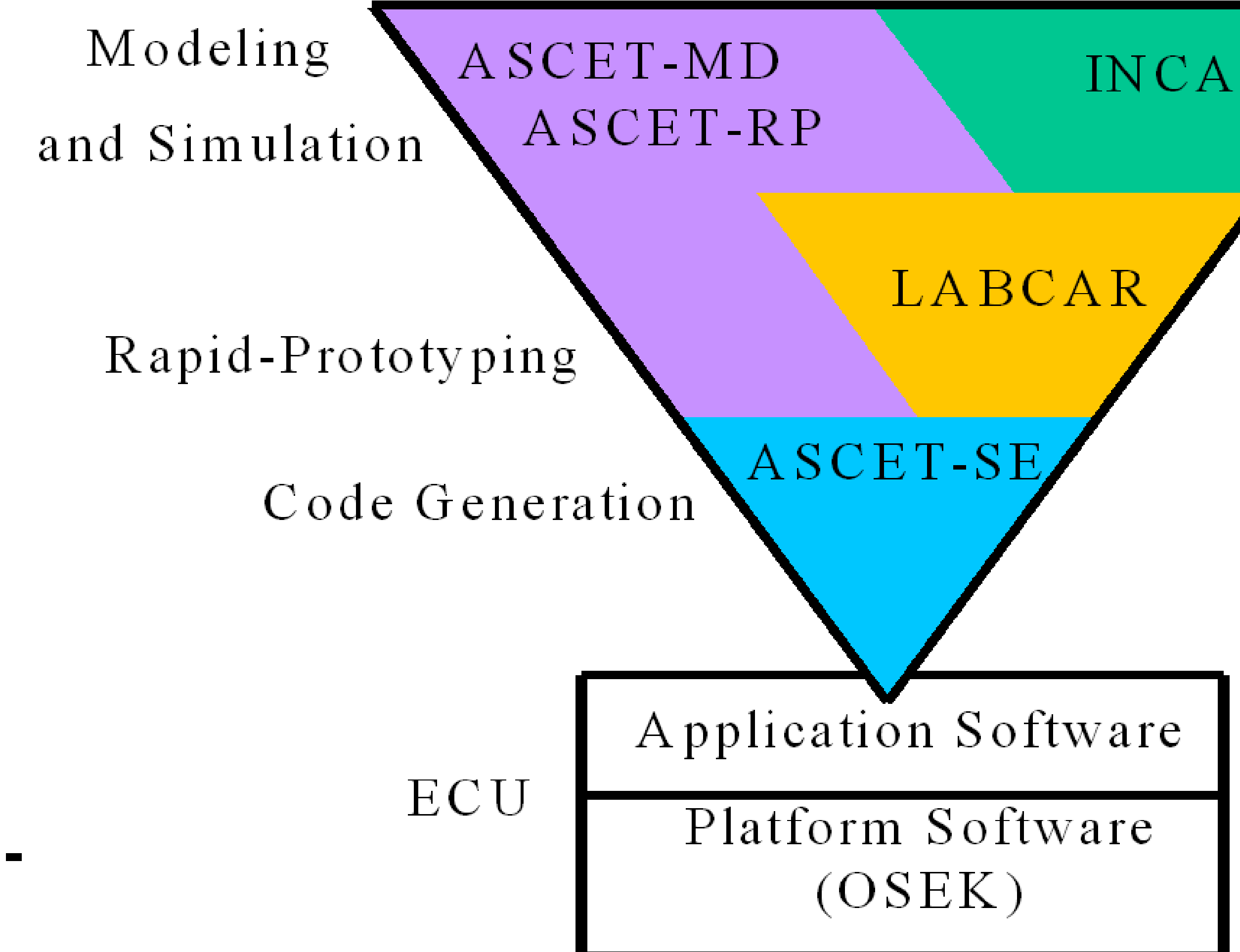
Two door controllers communicating via CAN bus

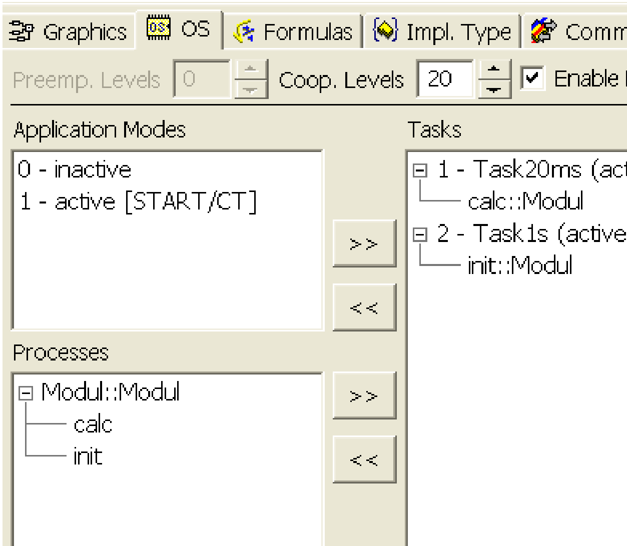




ASCET

- Commercial CASE tool by ETAS
- Used in automotive industry
- Event-driven operational model





Preemp. Levels 0
Coop. Levels 20
☑ Enable

Application Modes

0 - inactive
1 - active [START/CT]

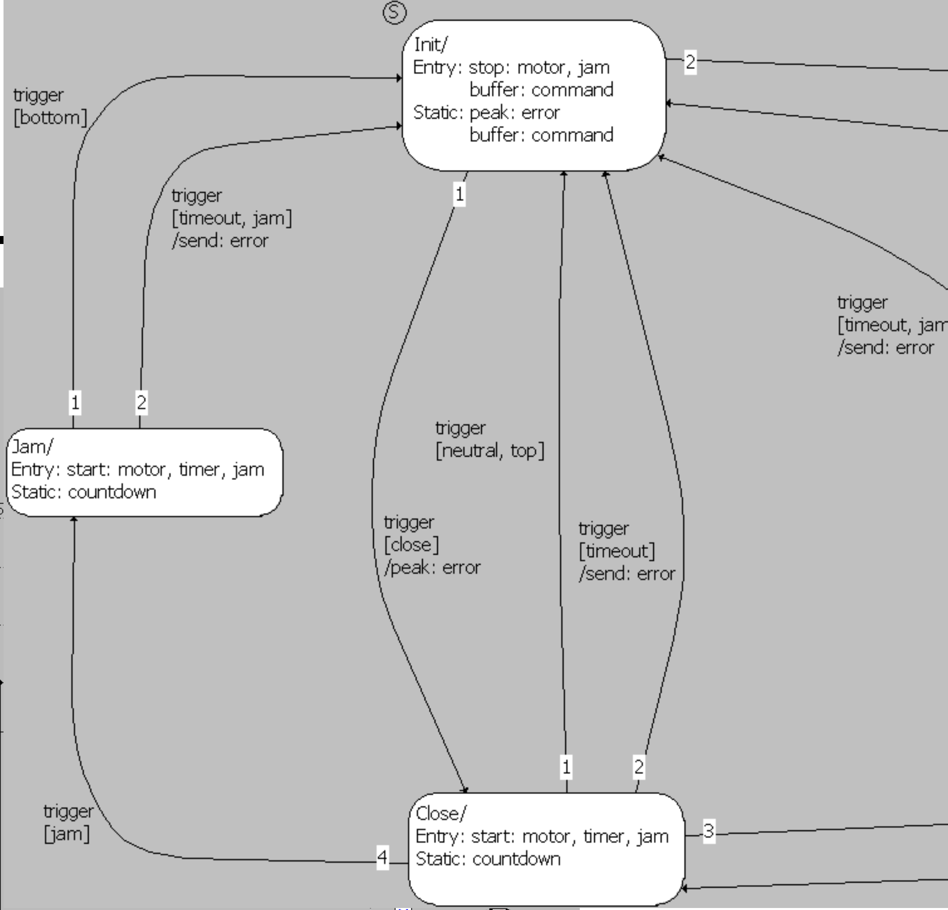
Tasks

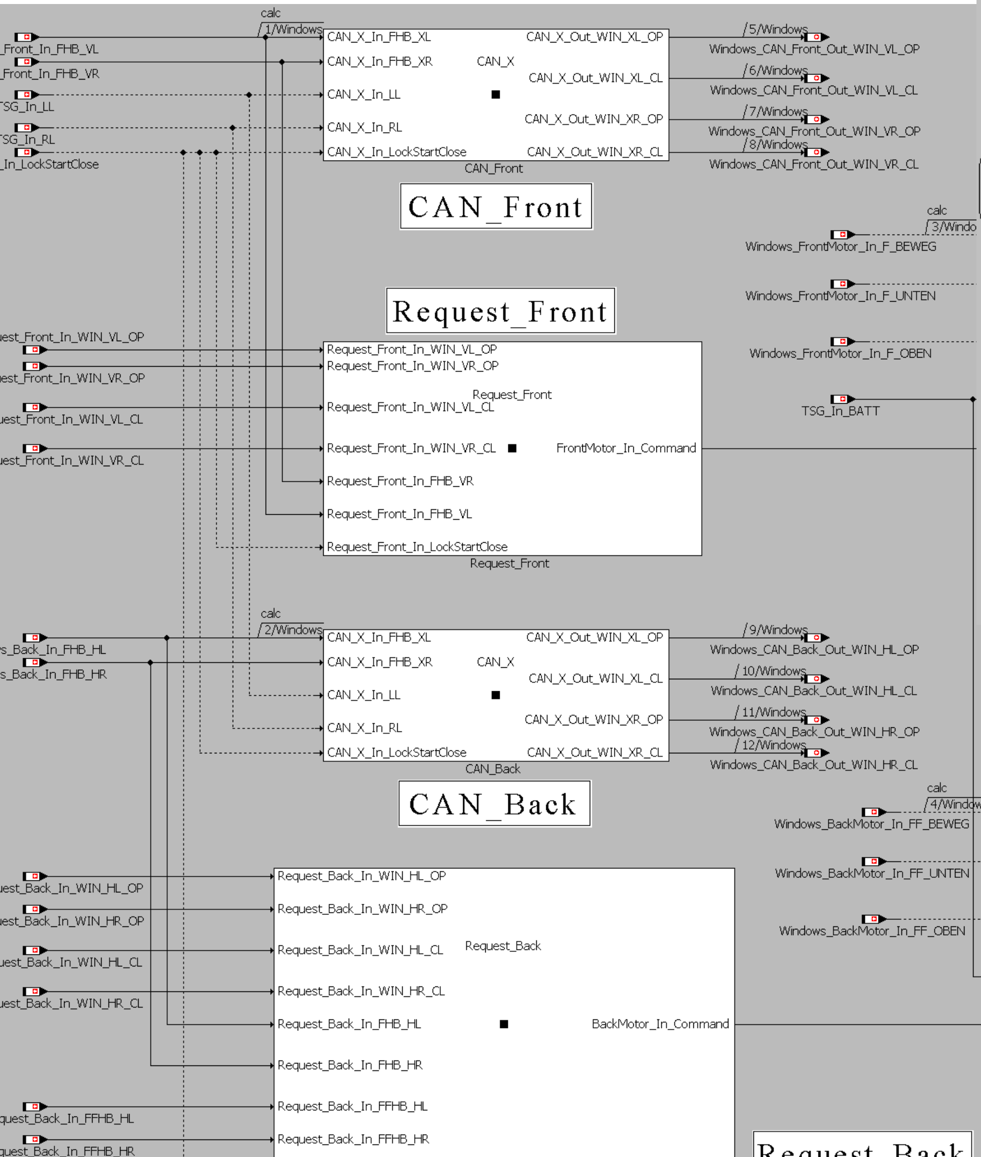
1 - Task20ms (ac
calc::Modul
2 - Task1s (active
init::Modul

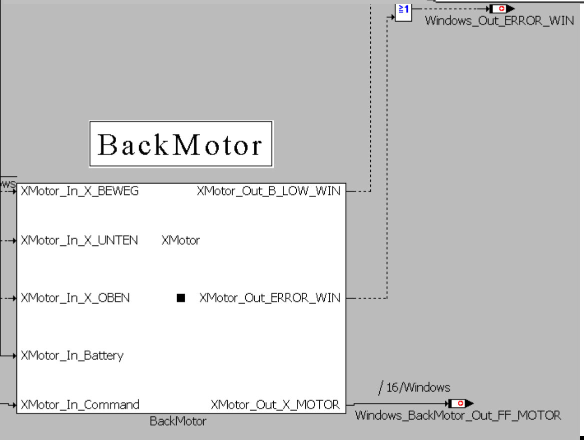
Processes

Modul::Modul
calc
init

ASCET Modeling





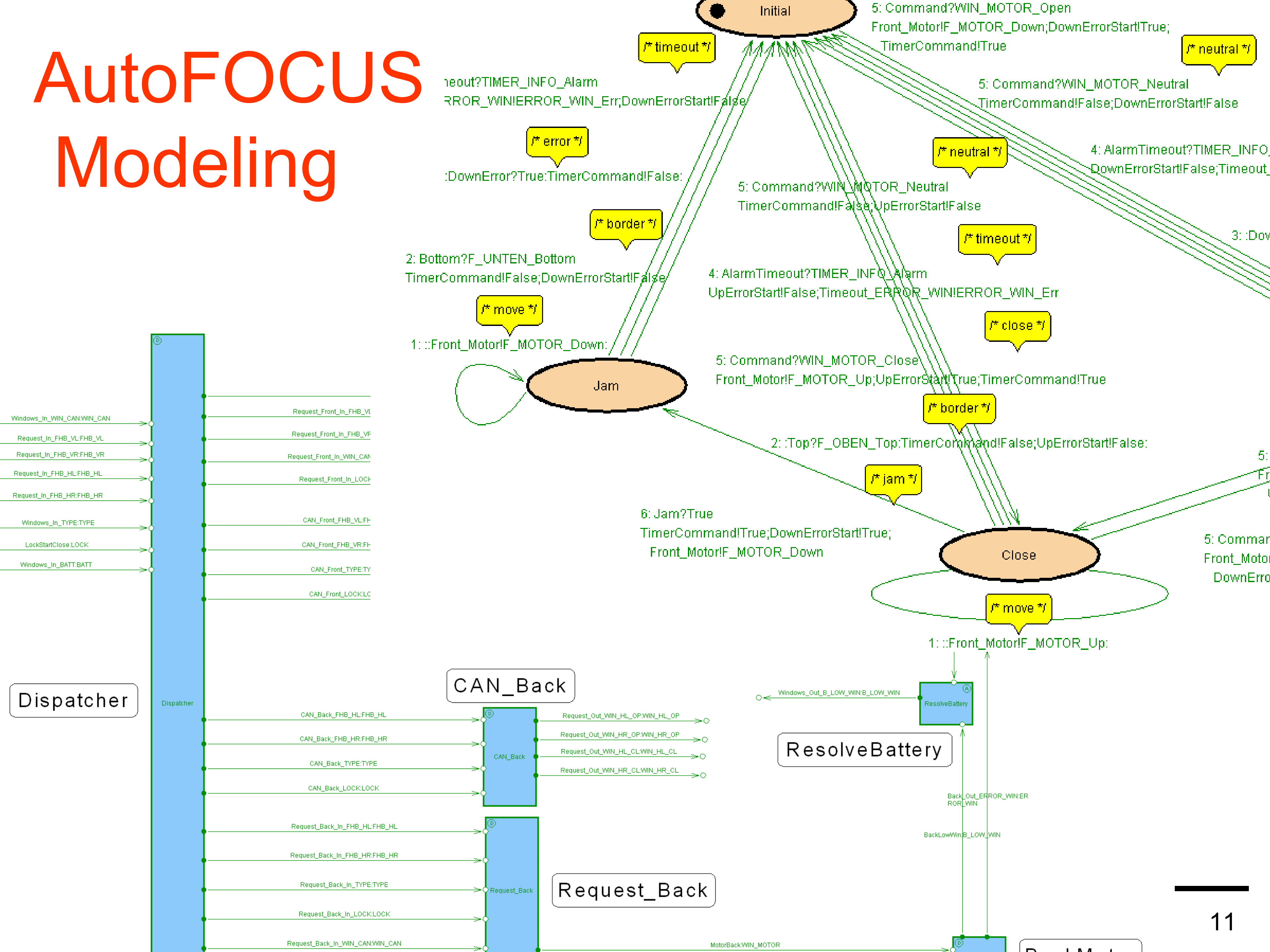


AutoFOCUS

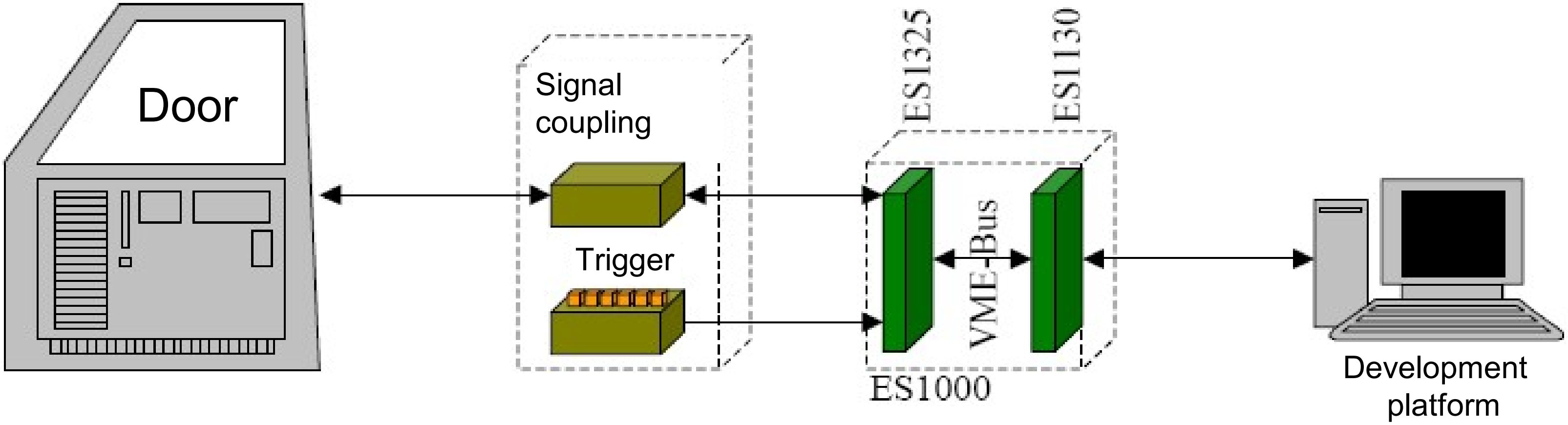
Academic CASE tool for model-based development with UML-like notation (http://autofocus.informatik.tu-muenchen.de)

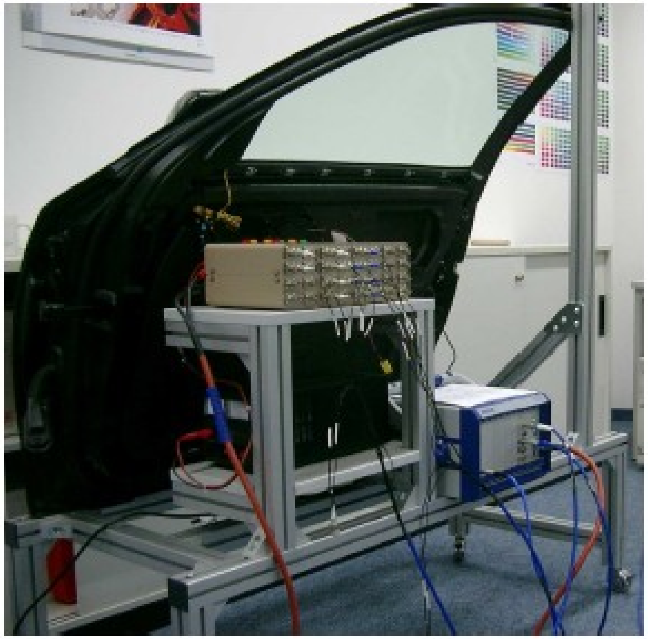
- Discrete-time operational semantics
- Simulation
- Validation (Consistency, Testing, Model Checking)
- Code Generation (e.g. Java, C, Ada)
- Connection to Matlab

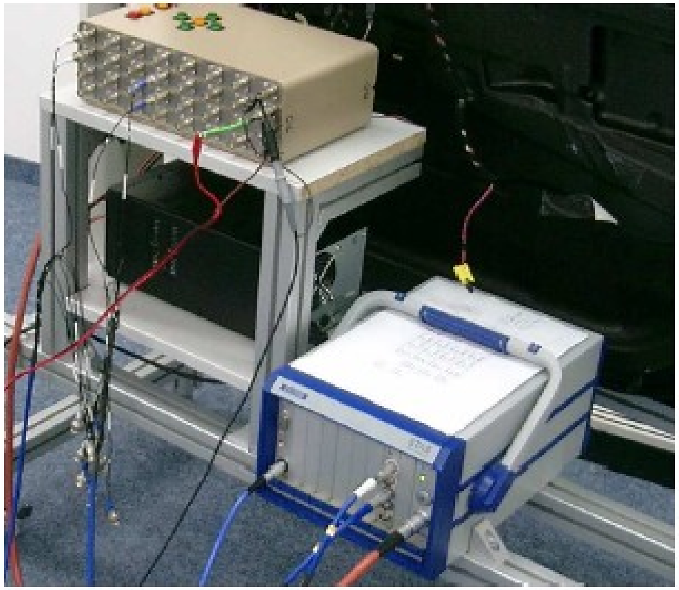
AutoFOCUS Modeling


Initial
5: Command?WIN_MOTOR_Open
Front_Motor!F_MOTOR_Down;DownErrorStart!True;
TimerCommand!True
/* timeout */
/* neutral */
ieout?TIMER_INFO_Alarm
RROR_WIN!ERROR_WIN_Err;DownErrorStart!False
5: Command?WIN_MOTOR_Neutral
TimerCommand!False;DownErrorStart!False
/* error */
:DownError?True:TimerCommand!False:
/* neutral */
4: AlarmTimeout?TIMER_INFO_
DownErrorStart!False;Timeout_
5: Command?WIN_MOTOR_Neutral
TimerCommand!False;UpErrorStart!False
/* border */
/* timeout */
3: :Dow
2: Bottom?F_UNTEN_Bottom
TimerCommand!False;DownErrorStart!False
4: AlarmTimeout?TIMER_INFO_Alarm
UpErrorStart!False;Timeout_ERROR_WIN!ERROR_WIN_Err
/* move */
/* close */
1: ::Front_Motor!F_MOTOR_Down:
Jam
5: Command?WIN_MOTOR_Close
Front_Motor!F_MOTOR_Up;UpErrorStart!True;TimerCommand!True
/* border */
2: :Top?F_OBEN_Top:TimerCommand!False;UpErrorStart!False:
5:
Fr
/* jam */
6: Jam?True
TimerCommand!True;DownErrorStart!True;
Front_Motor!F_MOTOR_Down
Close
5: Comman
Front_Moto
DownErro
/* move */
1: ::Front_Motor!F_MOTOR_Up:
Windows_In_WIN_CAN:WIN_CAN
Request_In_FHB_VL:FHB_VL
Request_In_FHB_VR:FHB_VR
Request_In_FHB_HL:FHB_HL
Request_In_FHB_HR:FHB_HR
Windows_In_TYPE:TYPE
LockStartClose:LOCK
Windows_In_BATT:BATT
Request_Front_In_FHB_VL
Request_Front_In_FHB_VF
Request_Front_In_WIN_CAN
Request_Front_In_LOCK
CAN_Front_FHB_VL:FH
CAN_Front_FHB_VR:FH
CAN_Front_TYPE:TY
CAN_Front_LOCK:LC
D
Dispatcher
Dispatcher
CAN_Back
CAN_Back_FHB_HL:FHB_HL
CAN_Back_FHB_HR:FHB_HR
CAN_Back_TYPE:TYPE
CAN_Back_LOCK:LOCK
D
CAN_Back
Request_Out_WIN_HL_OP:WIN_HL_OP
Request_Out_WIN_HR_OP:WIN_HR_OP
Request_Out_WIN_HL_CL:WIN_HL_CL
Request_Out_WIN_HR_CL:WIN_HR_CL
Request_Back_In_FHB_HL:FHB_HL
Request_Back_In_FHB_HR:FHB_HR
Request_Back_In_TYPE:TYPE
Request_Back_In_LOCK:LOCK
Request_Back_In_WIN_CAN:WIN_CAN
D
Request_Back
Request_Back
MotorBack:WIN_MOTOR
Windows_Out_B_LOW_WIN:B_LOW_WIN
A
ResolveBattery
ResolveBattery
Back_Out_ERROR_WIN:ERROR_WIN
BackLowWin:B_LOW_WIN
D
Back_Mot

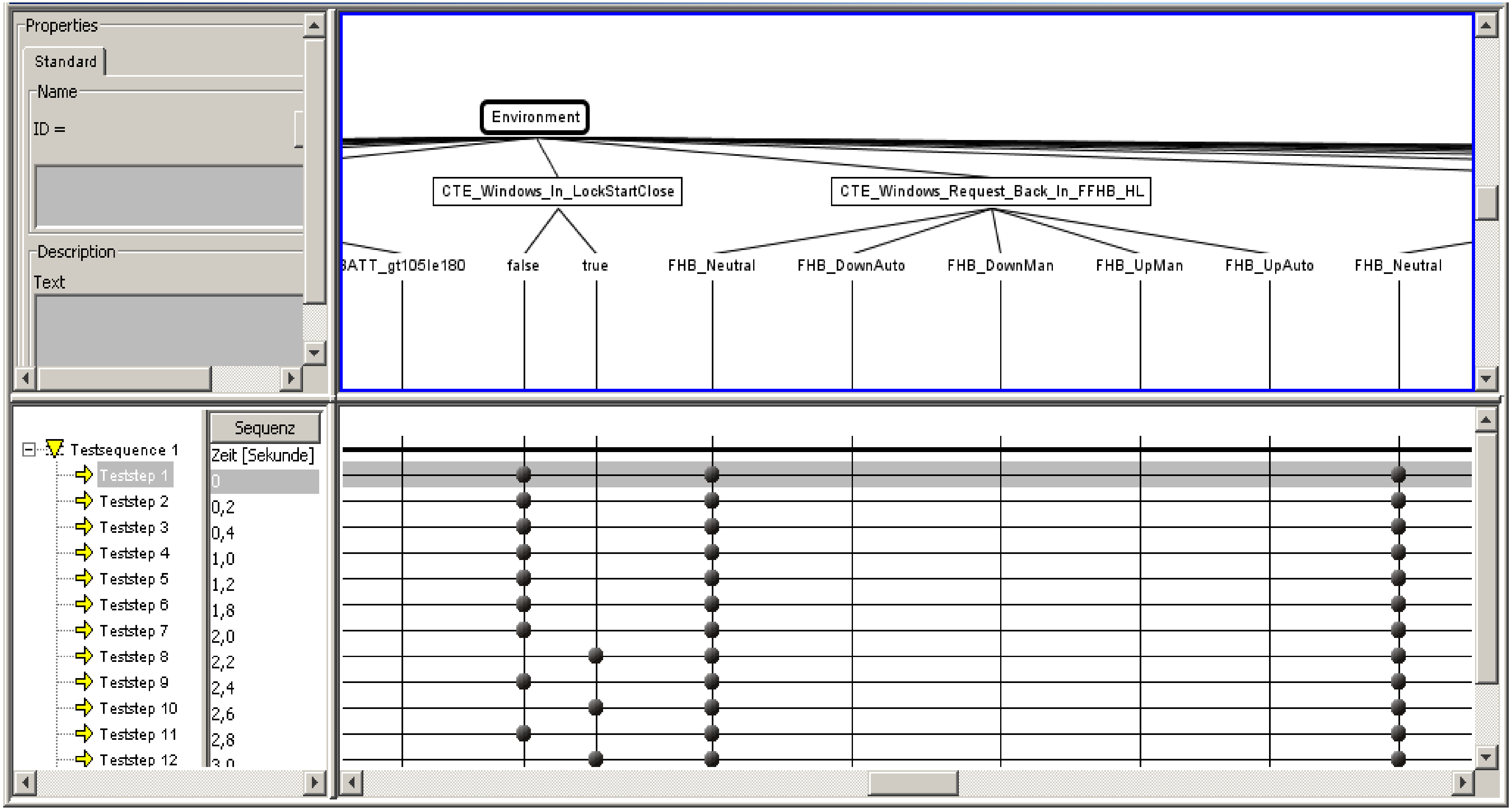
ASCET: Rapid Prototyping / Simulation





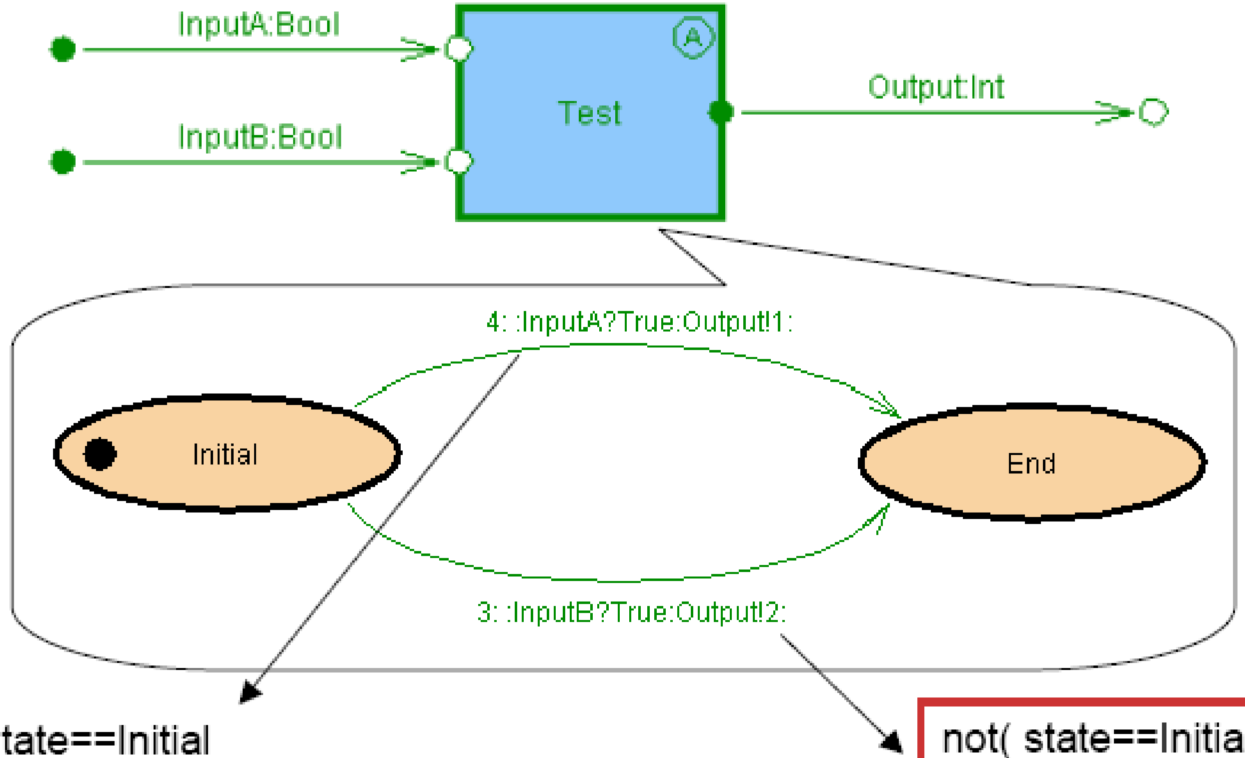


Testing in ASCET



	Zeit [Sekunde]
Teststep 1	0
Teststep 2	0,2
Teststep 3	0,4
Teststep 4	1,0
Teststep 5	1,2
Teststep 6	1,8
Teststep 7	2,0
Teststep 8	2,2
Teststep 9	2,4
Teststep 10	2,6
Teststep 11	2,8
Teststep 12	3,0

Model Checking (AutoFOCUS)



```
state==Initial
&& next(state)==End
&& is_Msg(InputA)
&& getVal(InputA)==True
&& getVal(next(Ouput))==1
```

```
not( state==Initial
        && is_Msg(InputA)
        && getVal(InputA)==True )
&& state==Initial
&& next(state)==End
&& is_Msg(InputB)
&& getVal(InputB)==True
&& getVal(next(Ouput))==2
```

Evaluation: Modeling Effort

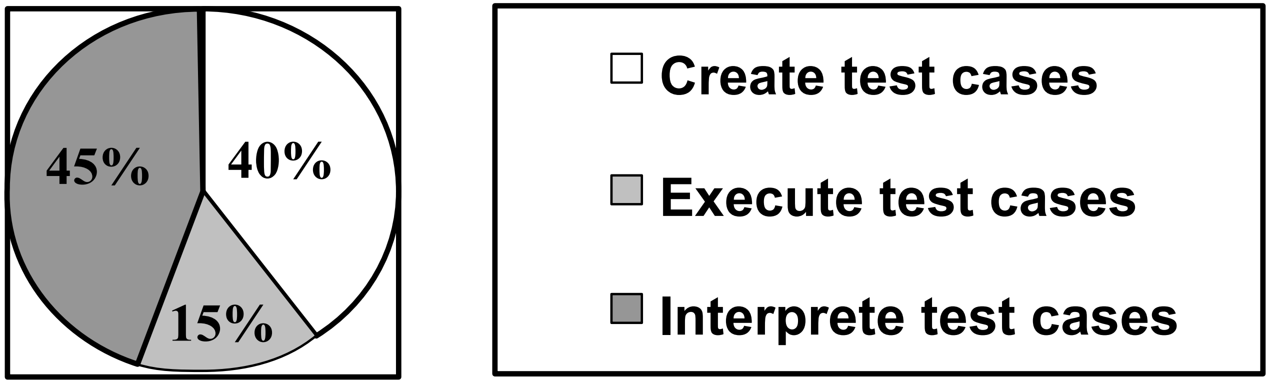
Modeling	ASCET	AutoFocus (Including Specification)
Training	1 week	1 day
Door lock	1.5 weeks	3 weeks
Window lifter	1.5 weeks	3 weeks
Interior light	0.5 weeks	1 week

Evaluation: QA Effort and Results

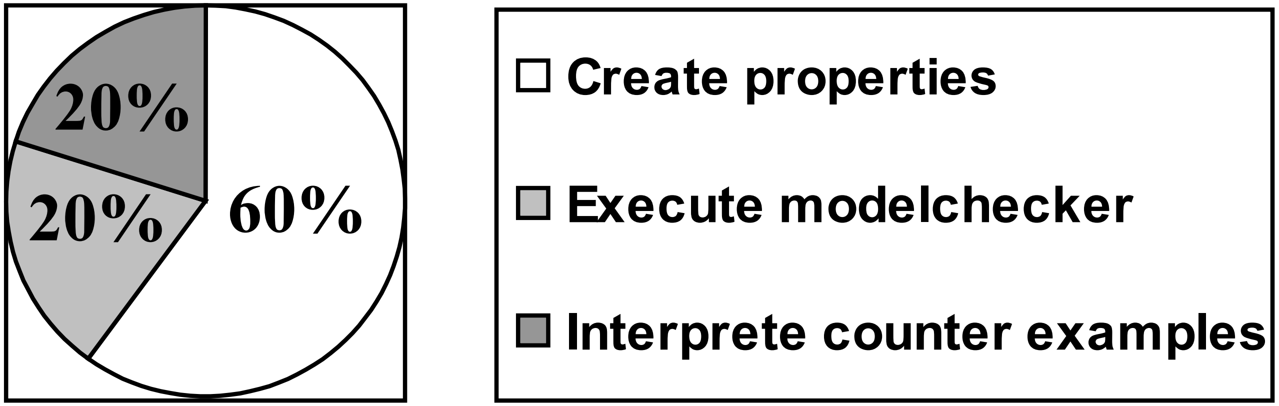
Method	Time effort (days)	Error count
Simulation (ASCET)	3	10
White box testing (ASCET)	7	5
Simulation (AutoFocus)	3	5
Model Checking (AutoFocus)	10	5

Evaluation: Effort Distribution

- Testing



- Model Checking



Modelchecking: Experiences

State explosion problem

- compositional modelchecking

Modelling abstractions:

- execution timer
- equivalence classes for values

➔ compromise between abstraction and verification efficiency

Classes of Bugs

Simulation (ASCET [10] / AutoFOCUS [5]):

- wrong priority definition
- wrong value communicated
- logical error at branchings
- wrong execution sequence (ASCET)

Coverage analysis / rapid prototyping (ASCET [7])

- same bugs as in simulation
- unreachable code
- wrong assumptions on hardware

Modelchecking (AutoFOCUS [5])

- synchronization error for concurrent components
- wrong evaluation of logical expressions

➔ Testing takes real hardware into account;
modelchecking finds spurious / obscure bugs

➔ combination brings synergies

Evaluation: Model vs Code QA

Model:

+ earlier (less expensive to fix flaws)

+ more abstract → more efficient (→ higher coverage, but at higher abstraction level)

- more abstract → may miss flaws

- programmers may introduce flaws

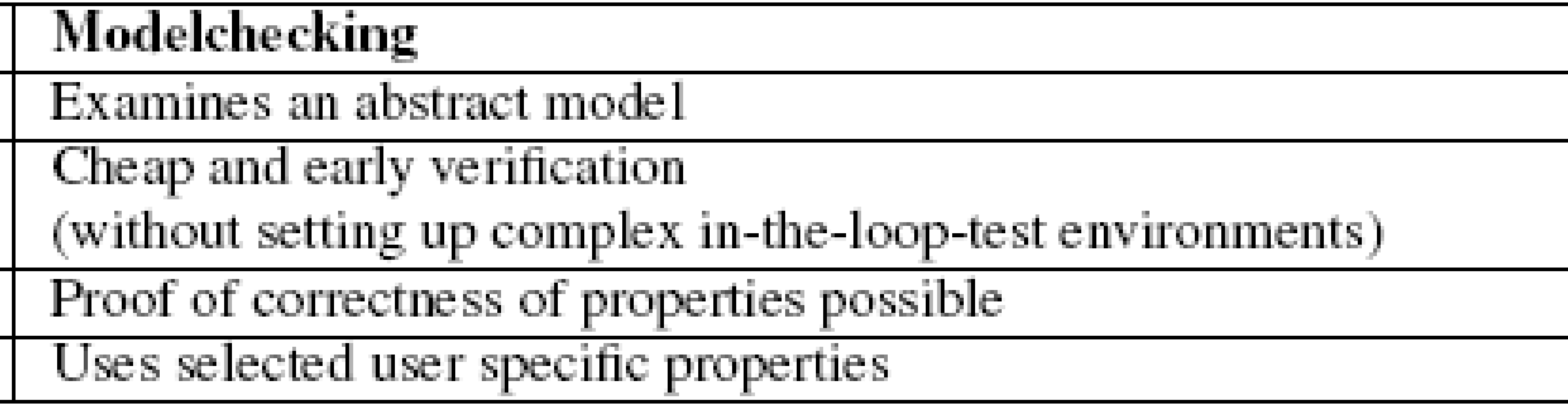
- even code generators, if not formally verified

Code:

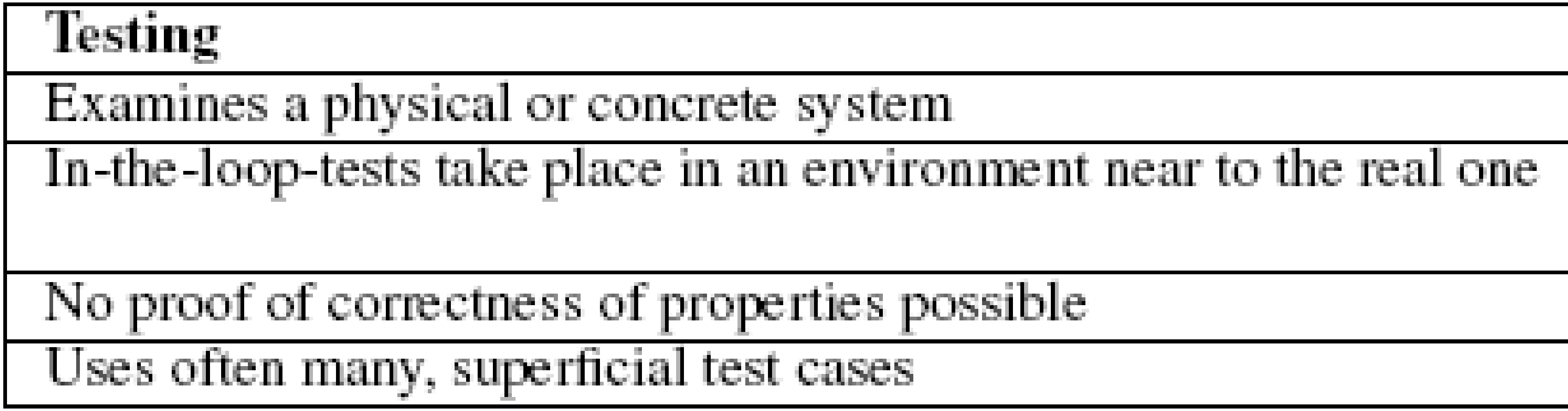
+ „the real thing“ (which is executed)

→ Do both where feasible.

Evaluation: General Comparison



Modelchecking
Examines an abstract model
Cheap and early verification (without setting up complex in-the-loop-test environments)
Proof of correctness of properties possible
Uses selected user specific properties



Testing
Examines a physical or concrete system
In-the-loop-tests take place in an environment near to the real one
No proof of correctness of properties possible
Uses often many, superficial test cases

Evaluation (M3)

- Semi-independent: researchers in model-based development, from AutoFocus group
- Repeatability: experimental data available from http://mcs.open.ac.uk/jj2924/publications/experiments/autoqa (ref 10 in paper)
- Comparative SE: use same or different developers ?
- Qualitative study, so no claim to statistical significance.

Related Work

Practical experiments on model-based QA in:

- automotive: Pretschner et al. (ICSE 2005: model-based testing with AutoFocus); Kropf (CAV 2007)
- security: Best, Jurjens, Nuseibeh (ICSE 2007; information systems); Jurjens Schreck, Bartmann (ICSE 2008; mobile systems); Jurjens, Rumm (M.Med.Inf 2008; e-health-card)
- general: Halling, Biffl, Grunbacher (METRICS 2003; requirements analysis); Brat, Drusinsky, Giannakopoulou et al. (FMSD 2004; Martian Rover); Cheng et al. (Models 2005; model analysis); Bradbury, Cordy, Dingel (PASTE 2005; testing vs formal analysis); Denney, Fischer, Schumann (IJAIT 2006; ATPs); Mouchawrab, Briand, Labiche (ESEM 2007; model-based testing)

Conclusions

Model-based QA of automotive software:

- Model-checking and model-based testing complementary.
- Model-based testing quickly excludes large classes of flaws.
- Model-checking exhaustively checks user-defined sophisticated property.

Ongoing work with Microsoft Research Cambridge: assurance for cryptoprotocol implementations.

ADVERTISEMENT: Postdoc / PhD positions in model-based security !

Questions?

More information
(papers, slides,
tool etc.):

http://www.jurjens.de/jan

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