Supervisory control synthesis

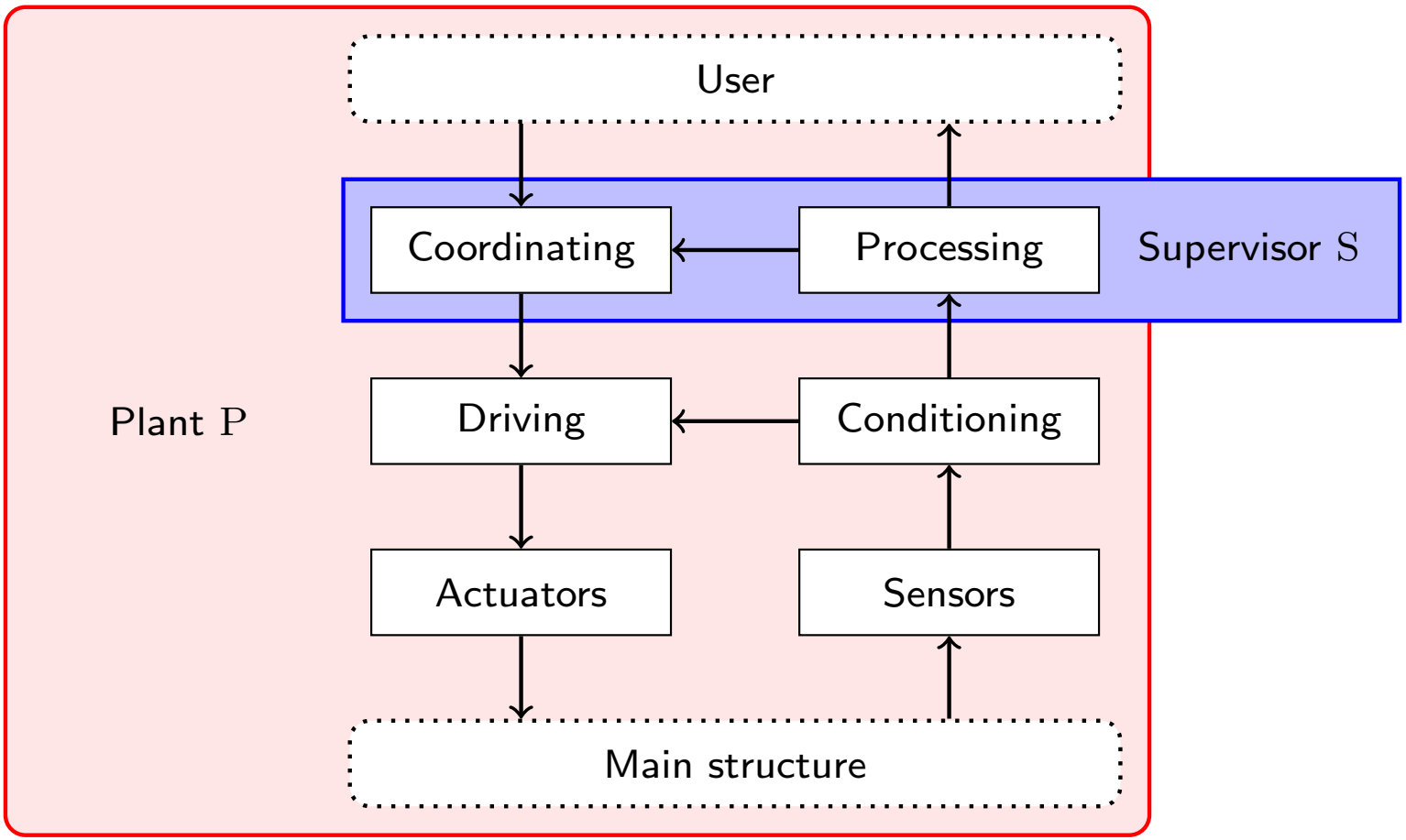
Bert van Beek

Systems Engineering Group
Dept. of Mechanical Engineering

5 November 2009

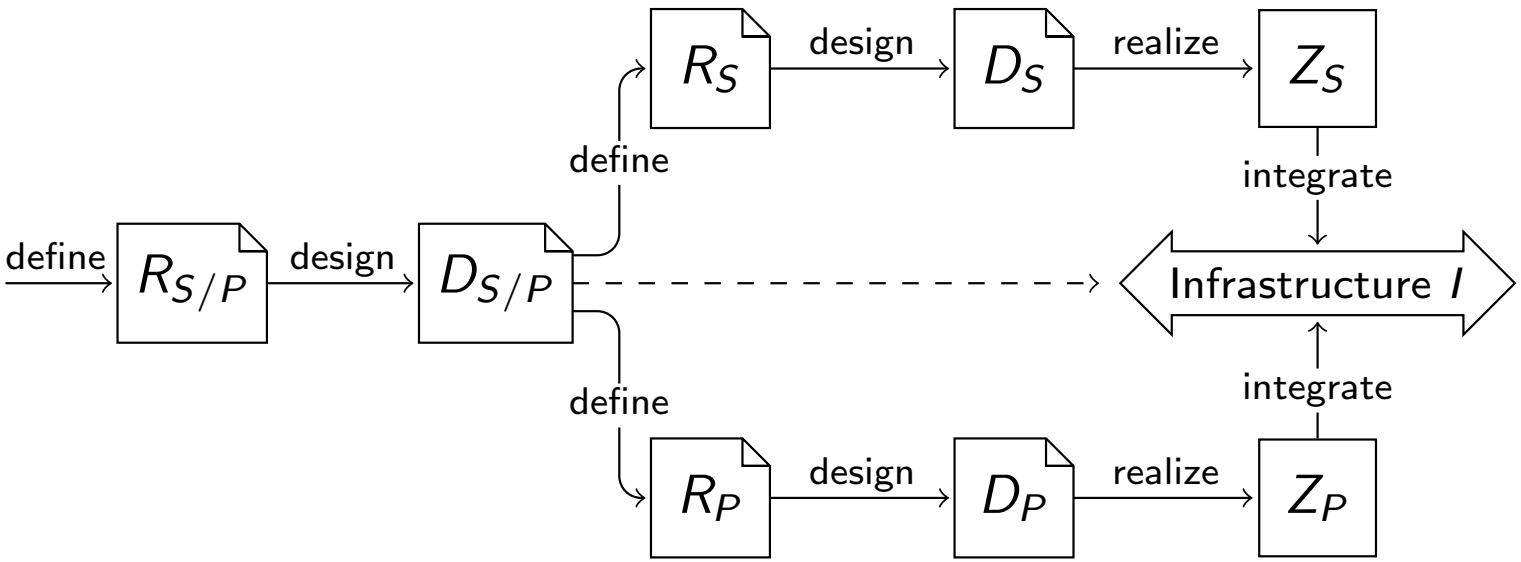
System view

A system can be divided in (uncontrolled) plant P and supervisor (controller) S:

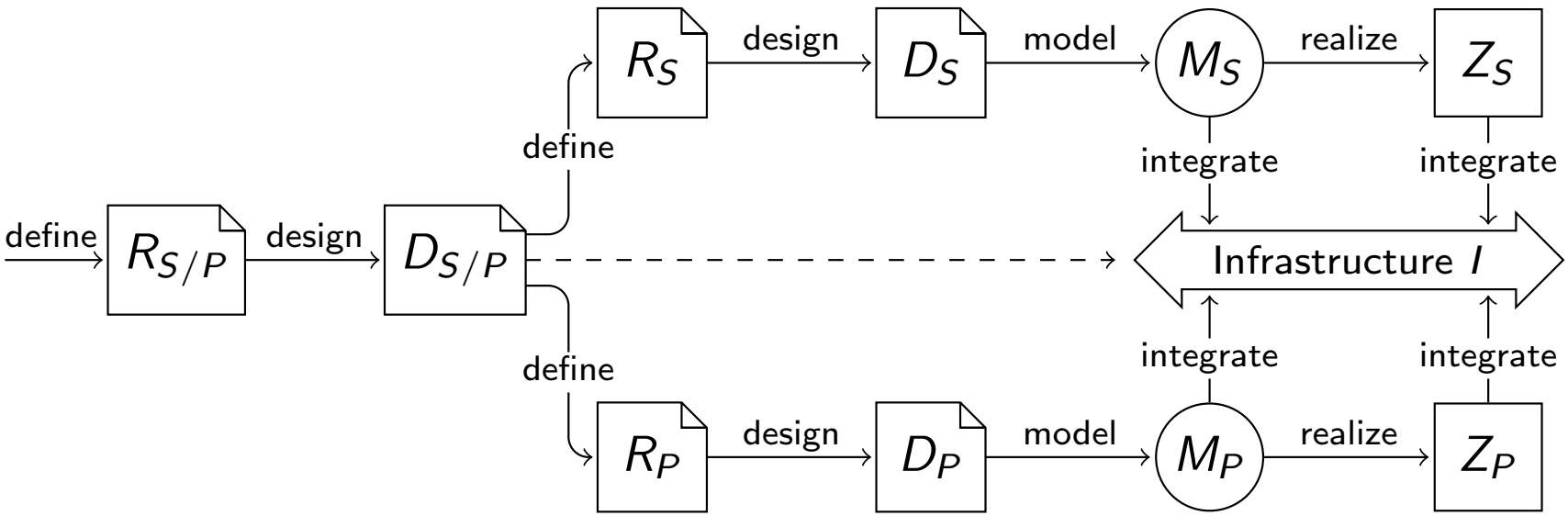


S ensures that P satisfies its control requirements R_{S}.

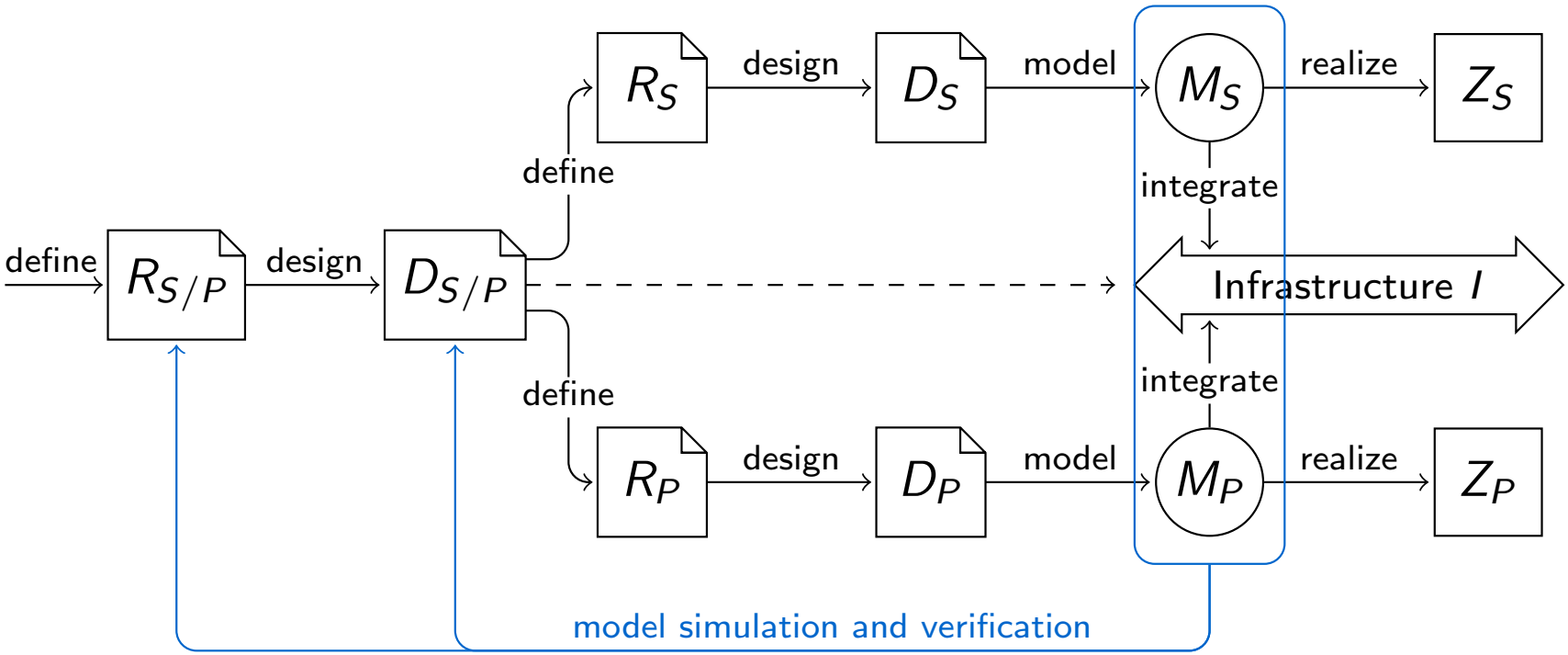
Traditional engineering



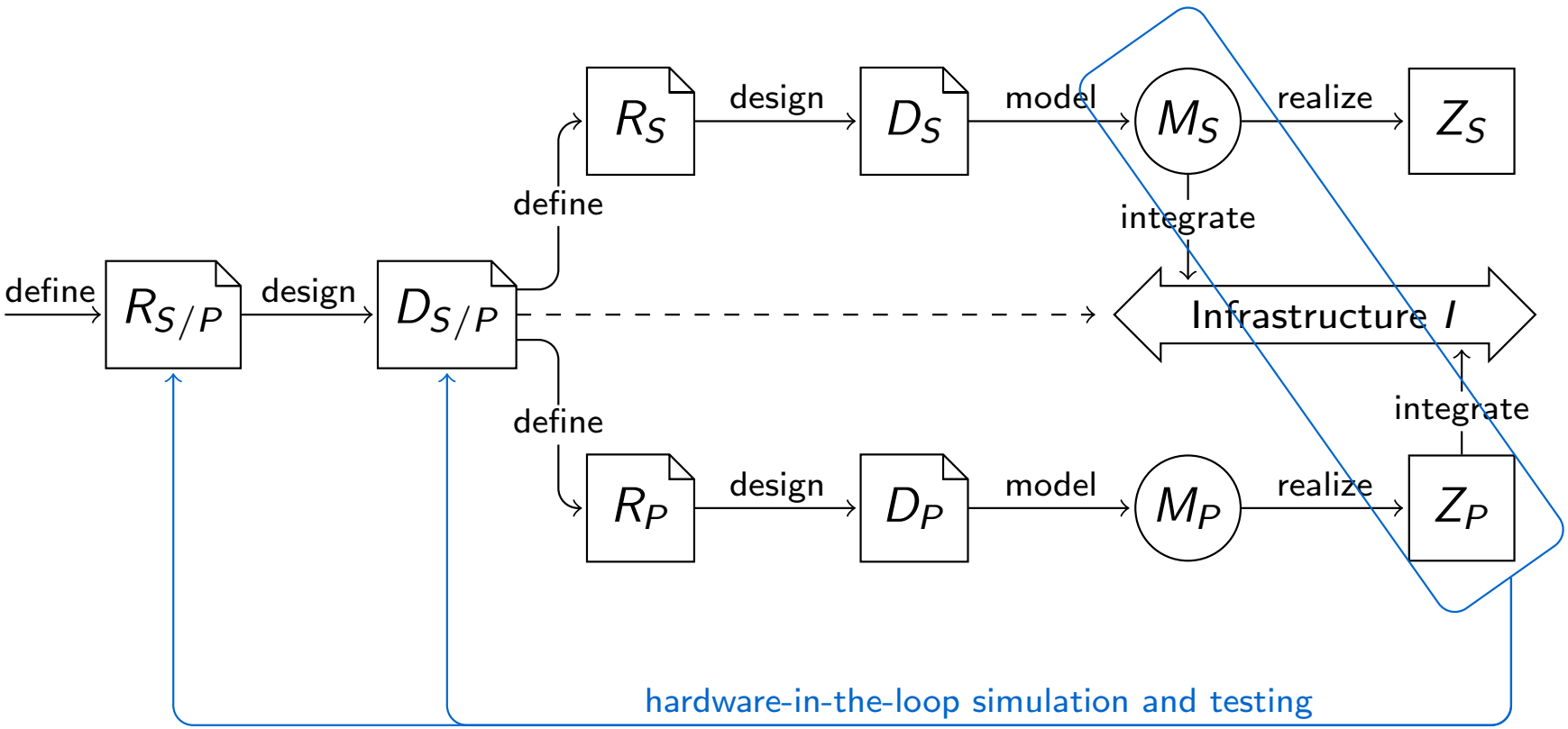
Model based engineering



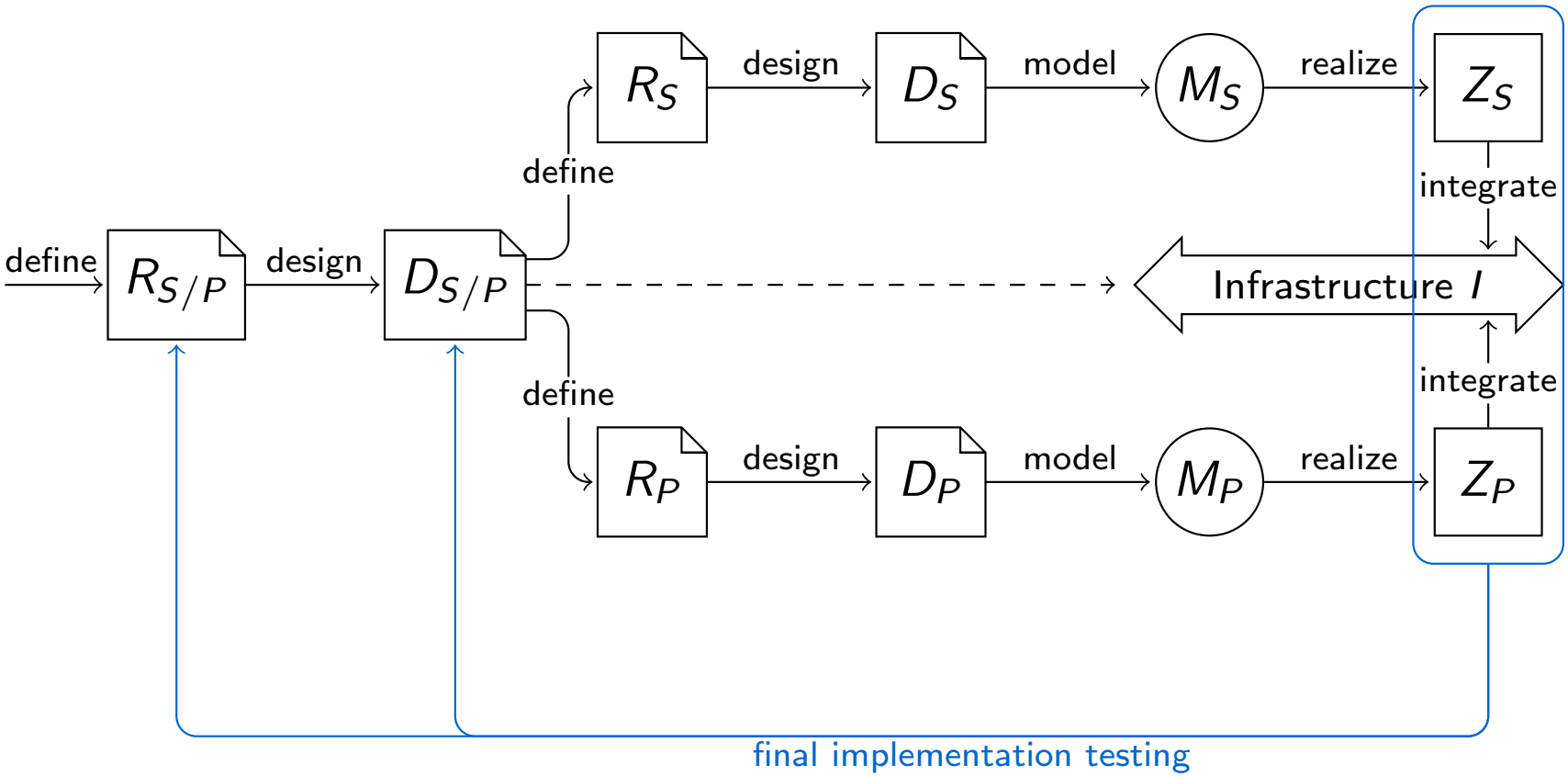
Model based engineering



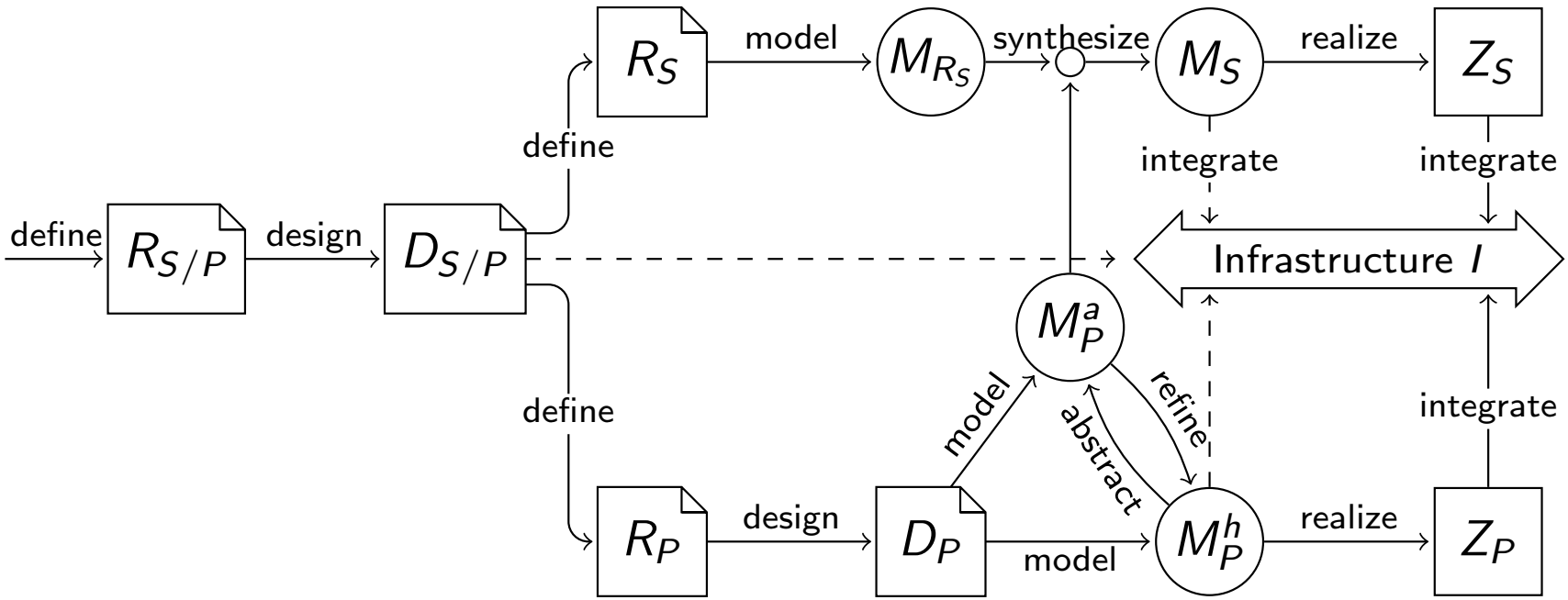
Model based engineering



Model based engineering



Synthesis based engineering



Supervisory control synthesis

The resulting supervisor is:

- by construction mathematically correct w.r.t. M_{R_S}
- controllable (allows uncontrollable events)
- non-blocking (deadlock free and livelock free)
- maximally permissive allowing selection of 'optimal' sequence of events

Supervisory synthesis flavors

Event-based:

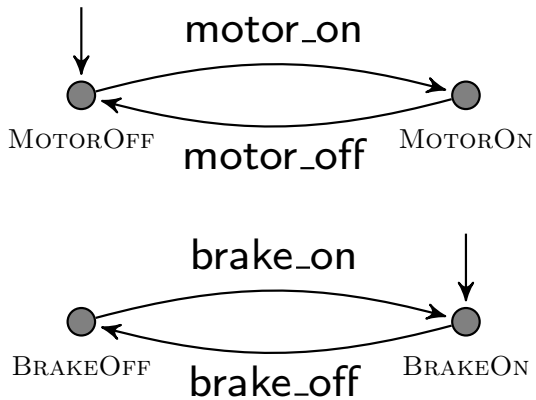
- Plant and control requirements modeled by means of automata
- Monolithic SCS: synthesis of one (big) monolitic supervisor in the form of an automaton
- Modular SCS: control requirements partitioned into groups; synthesis of a supervisor for each group
- Can deal with unobservable events

State-based (state tree structures):

- Plant modeled by means of automata
- Control requirements modeled by means of automata, by means of predicates over states (state exclusion), and by means of state transition exclusion
- Monolithic SCS: synthesis of a BDD (Binary Decision Diagram) for each event (very efficient algorithm)
- No unobservable events

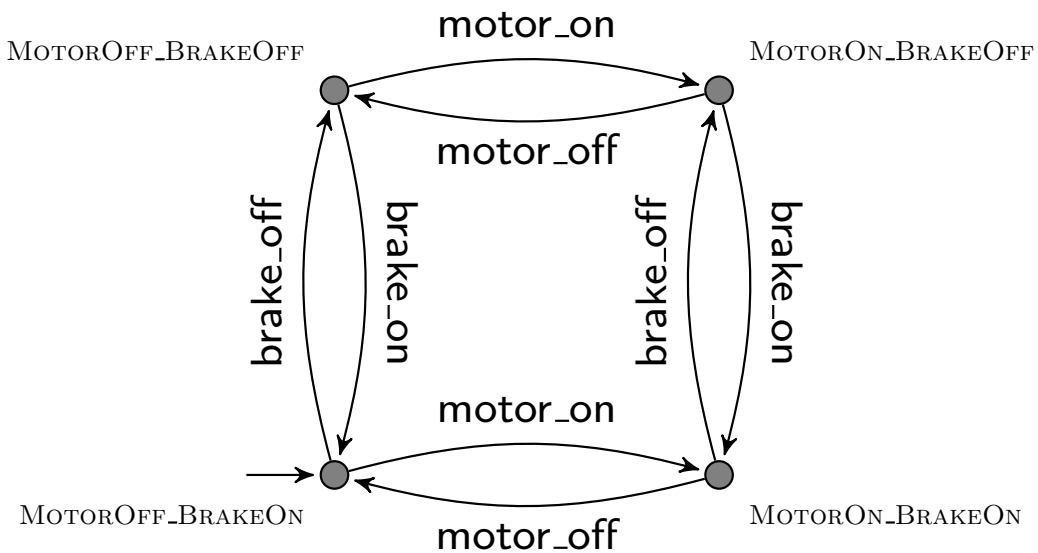
Motor and brake

Plant model:



Motor and brake

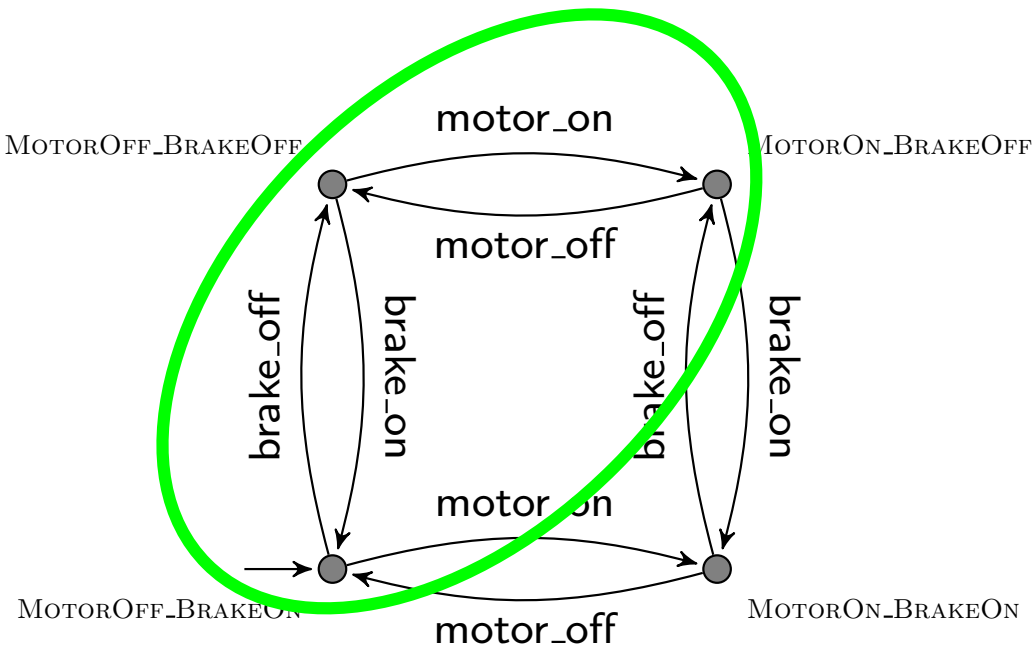
Equivalent plant model:



Motor and brake event-based

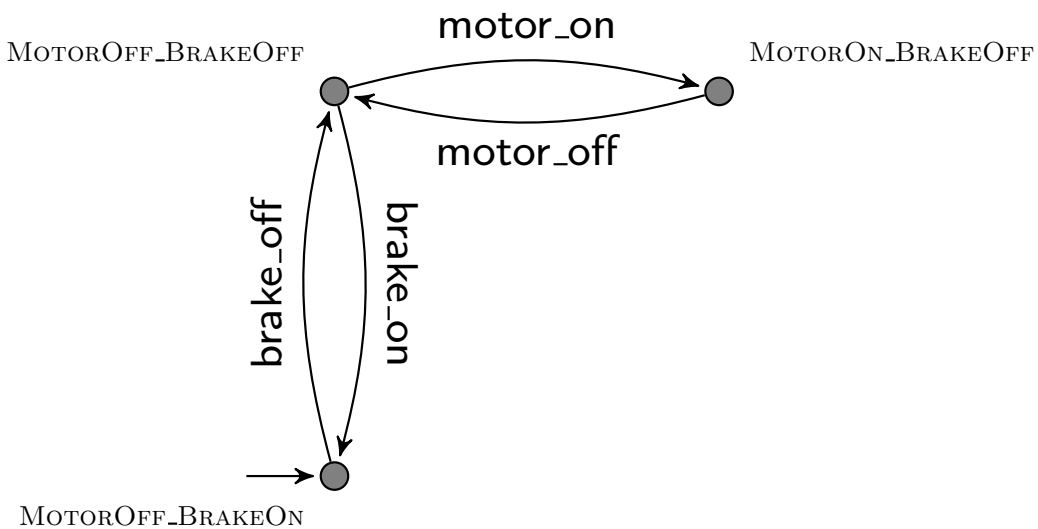
The brake may not be on when the motor is on.

Green area represents safe behavior in plant model:



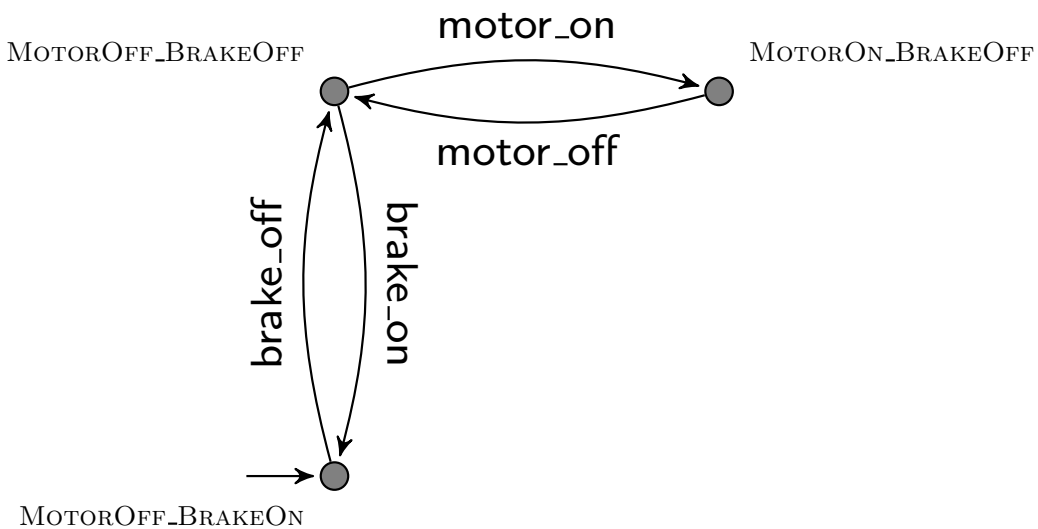
Motor and brake event-based

Event-based control requirement:



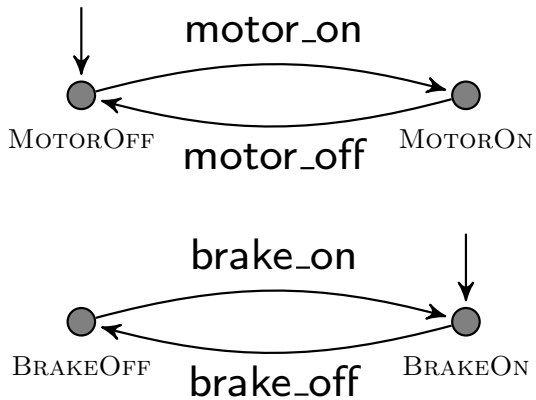
Motor and brake event-based

In this case, supervisor equals control requirement:



Motor and brake state-based

Plant model:

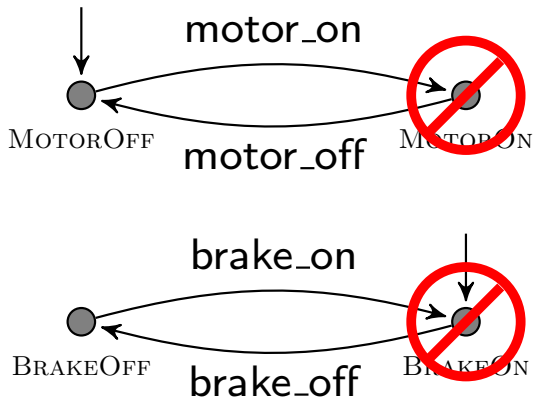


State-based control requirement:

$$\neg\,(\textsc{BrakeOn} \wedge \textsc{MotorOn})$$

Motor and brake state-based

Plant model:

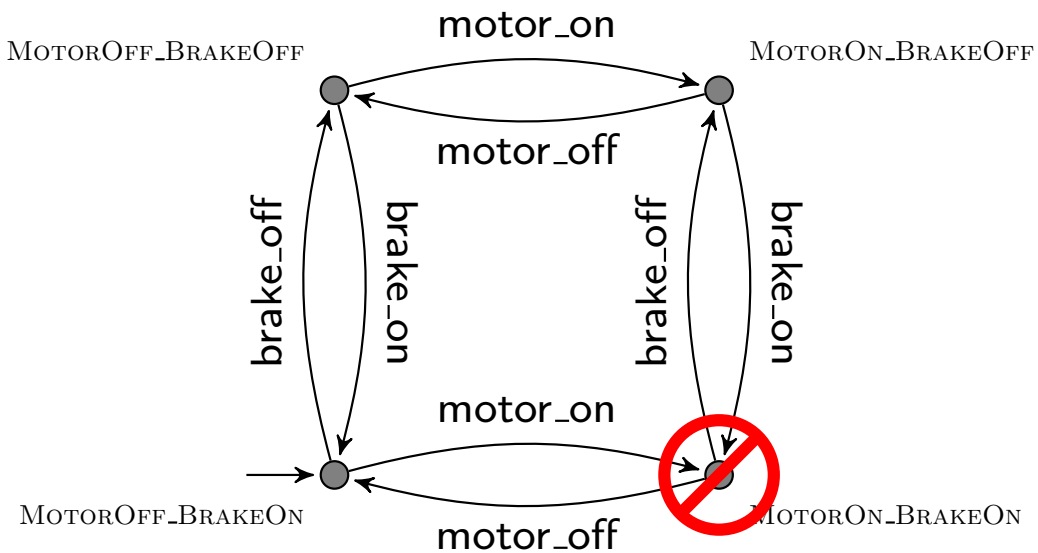


State-based control requirement:

$$\neg\,(\textsc{BrakeOn} \wedge \textsc{MotorOn})$$

Motor and brake state-based

Synthesis of supervisor, forbidden state:

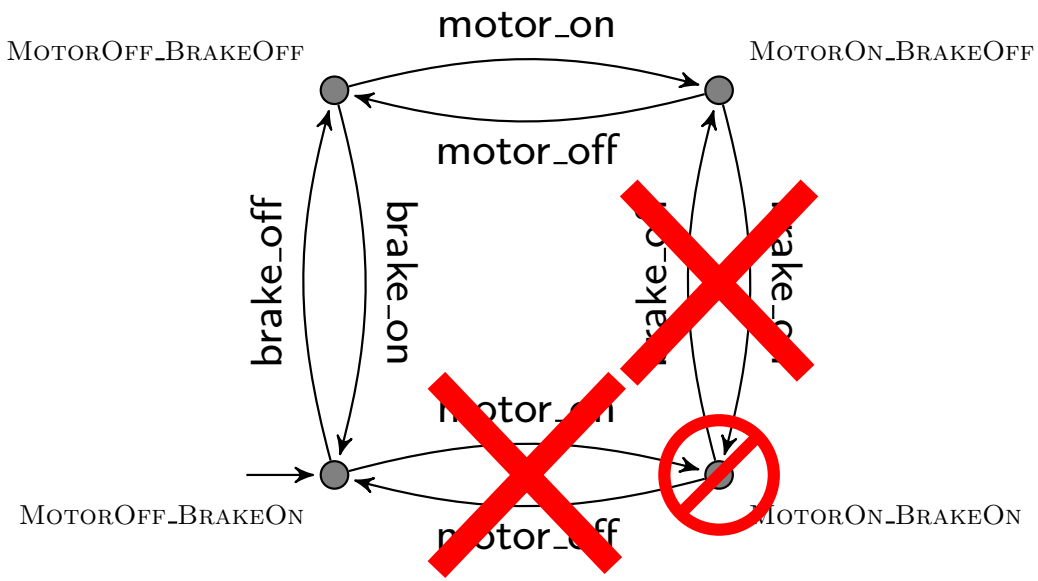


State-based control requirement:

$$\neg\,(\textsc{BrakeOn} \wedge \textsc{MotorOn})$$

Motor and brake state-based

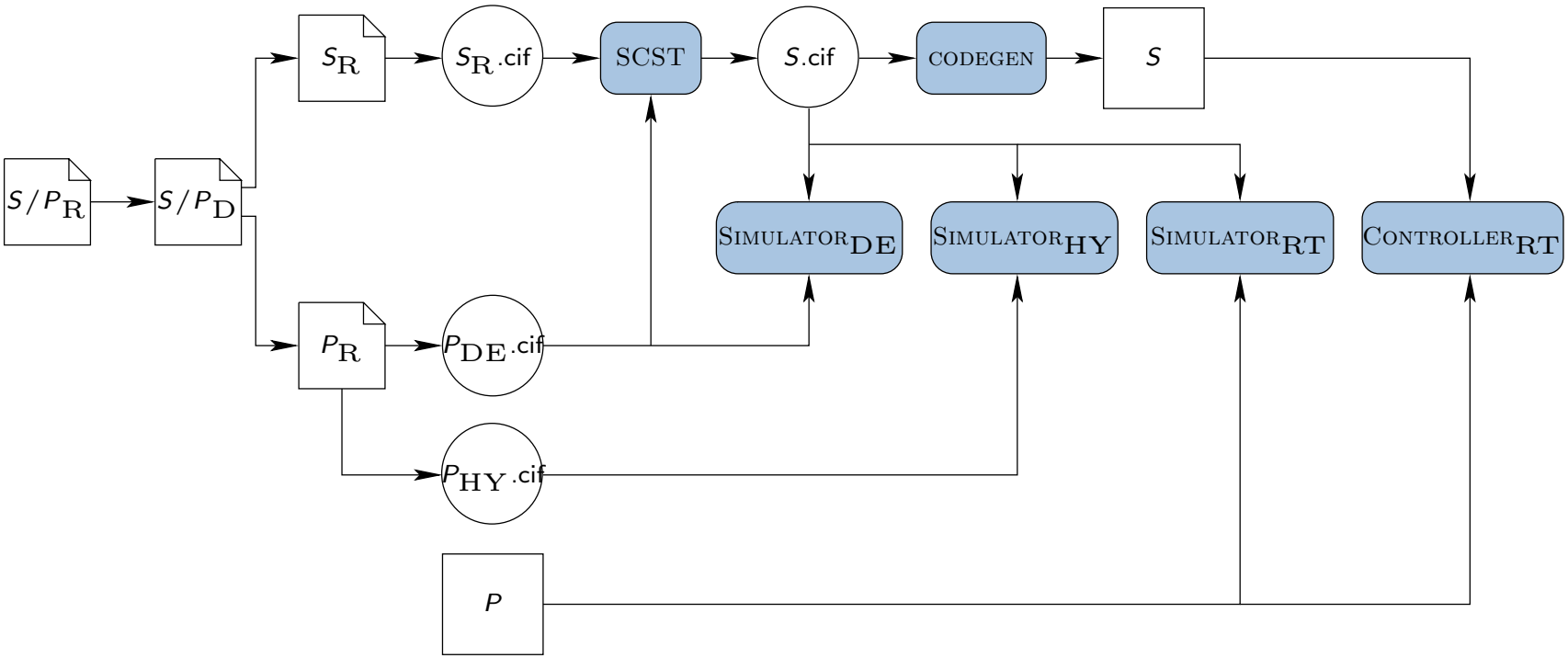
Synthesis of supervisor, disable events:



State-based control requirement:

$$\neg\,(\textsc{BrakeOn} \wedge \textsc{MotorOn})$$

Tool chain


S_R
S_R.cif
SCST
S.cif
CODEGEN
S
S/P_R
S/P_D
SIMULATOR$_{DE}$
SIMULATOR$_{HY}$
SIMULATOR$_{RT}$
CONTROLLER$_{RT}$
P_R
P_{DE}.cif
P_{HY}.cif
P

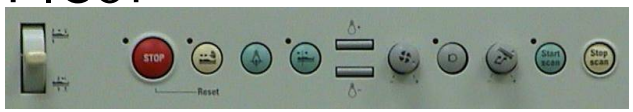
Real-time control of a patient support system

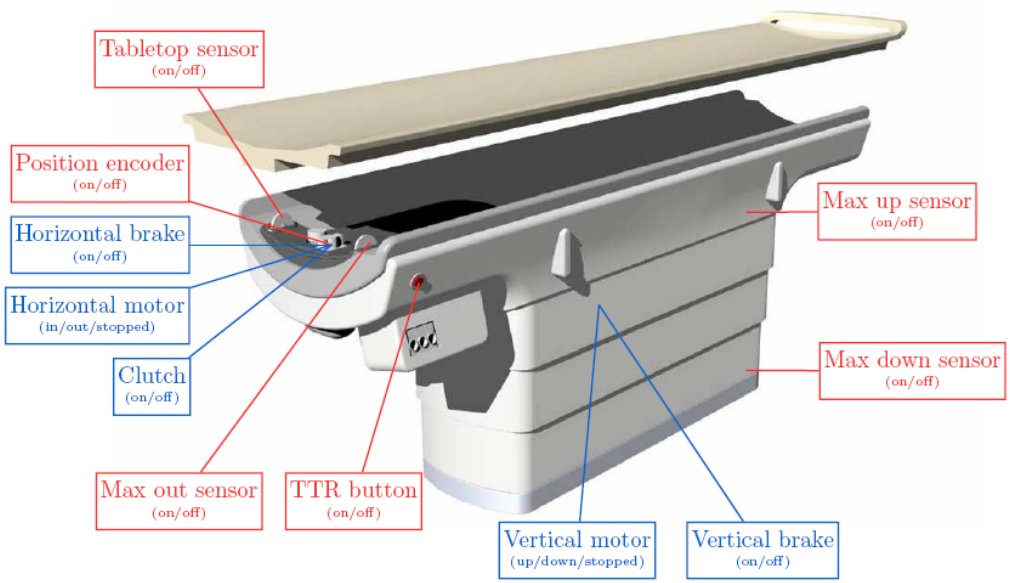
Supervisory control synthesis using:

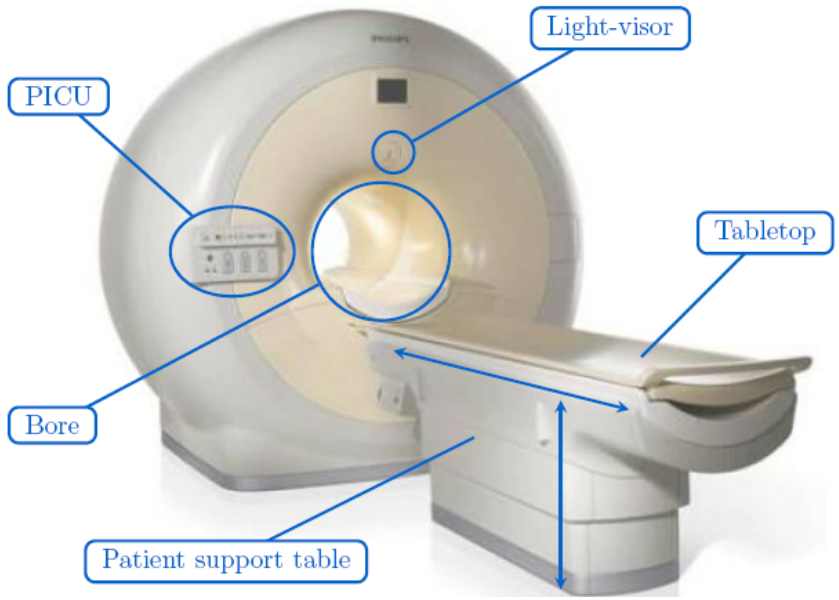
- modular supervisory control
- state-based supervisory control

Uncontrolled system: 6.3 billion states

PICU:







Plant model

Patient support table modeled by

- 19 automata

User interface modeled by

- 8 automata

Total uncontrolled systems

- 6.3 billion states

Control requirements

Event-based:

- 57 automata

State-based:

- 4 automata
- 50 logical expressions

Examples of requirements:

- Do not move beyond end sensors
- Only motorized movement if clutch is active
- Only move vertically if horizontally in maximal out position
- Tumble switch moves table up and down, or in and out

Synthesized supervisor

Supervisor event-based

- The model of the supervisor consists of 14 modular supervisors
- The size of each supervisor is in the range of 20 – 2.000 states

Supervisor state-based

- One BDD for each action

Validation:

- The synthesized supervisor has been simulated in parallel with a (hybrid) model of the plant
- A real-time supervisory controller execution environment has been implemented
- The synthesized supervisor has been executed in this environment to control the actual patient support system

Conclusions

- Supervisory control synthesis focusses on designing control requirements instead of designing controllers
- Control requirements can be read and understood by domain experts and software experts
- Debugging and improving control requirements instead of debugging and improving control code
- Prove of concepts in several industrial cases

Acknowledgements

- Dennis Hendriks, programmer SE
- Albert T. Hofkamp, scientific programmer SE
- Jason Markovski, postdoc SE
- Asia van de Mortel-Fronczak, UD SE
- Damian Nadalus, PhD student SE
- Jacobus (Koos) E. Rooda, group leader SE
- Ramon R.H. Schiffelers, postdoc SE
- Rong Su, postdoc SE
- Rolf Teunissen, PhD student SE
- Peter Thijs, programmer SE