Model-Based Development of an Adaptive Vehicle Stability Control System

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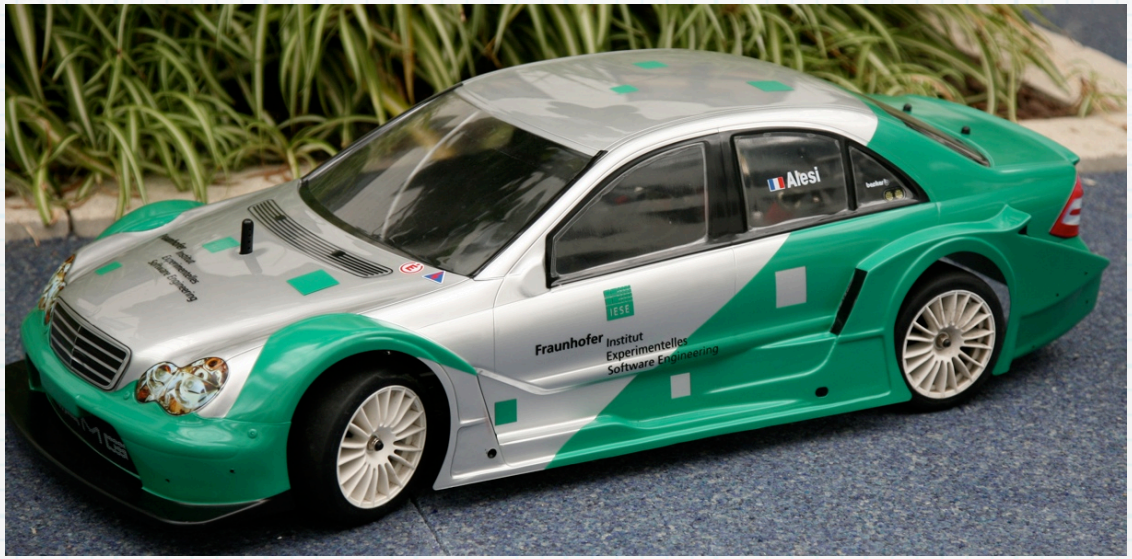
Technische Universität Kaiserslautern

SoFTeX Arbeitsgruppe Softwaretechnik

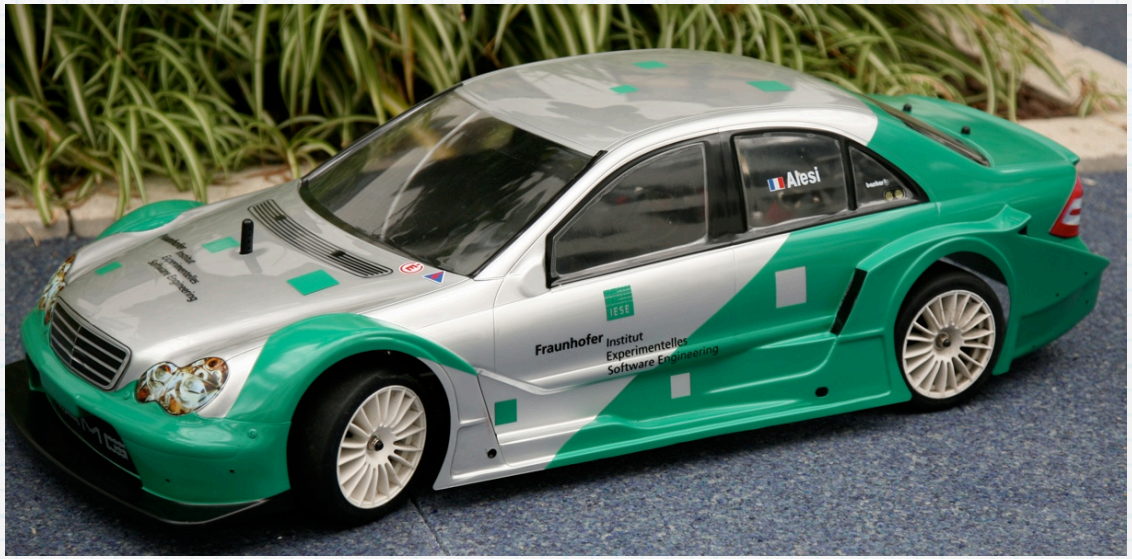
DASMOD Dependable Adaptive Systems and Mathematical Modeling

Self-Adaptive Systems

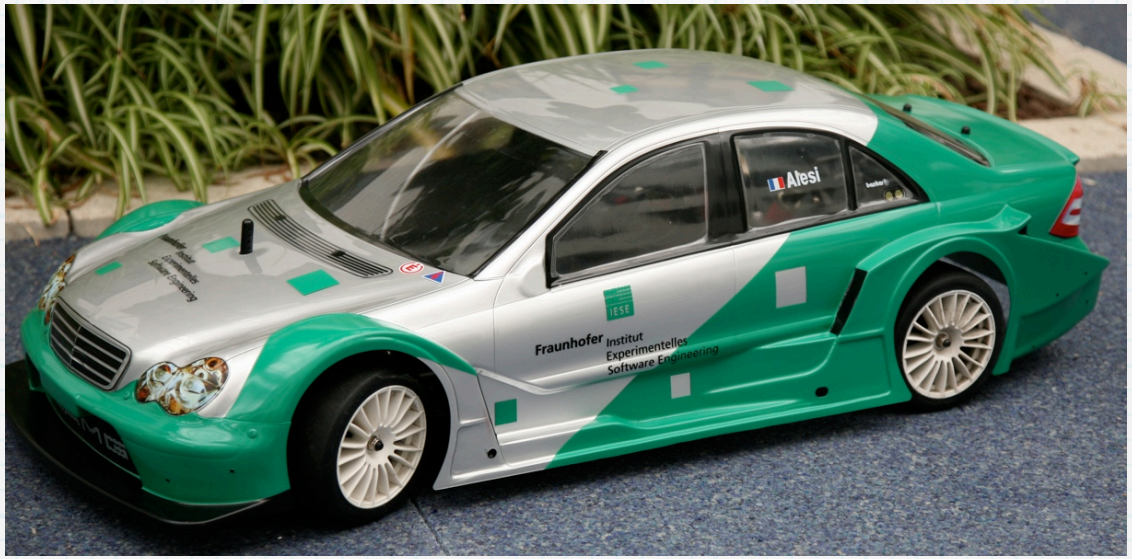


Self-Adaptive Systems

Faults and Environment Changes



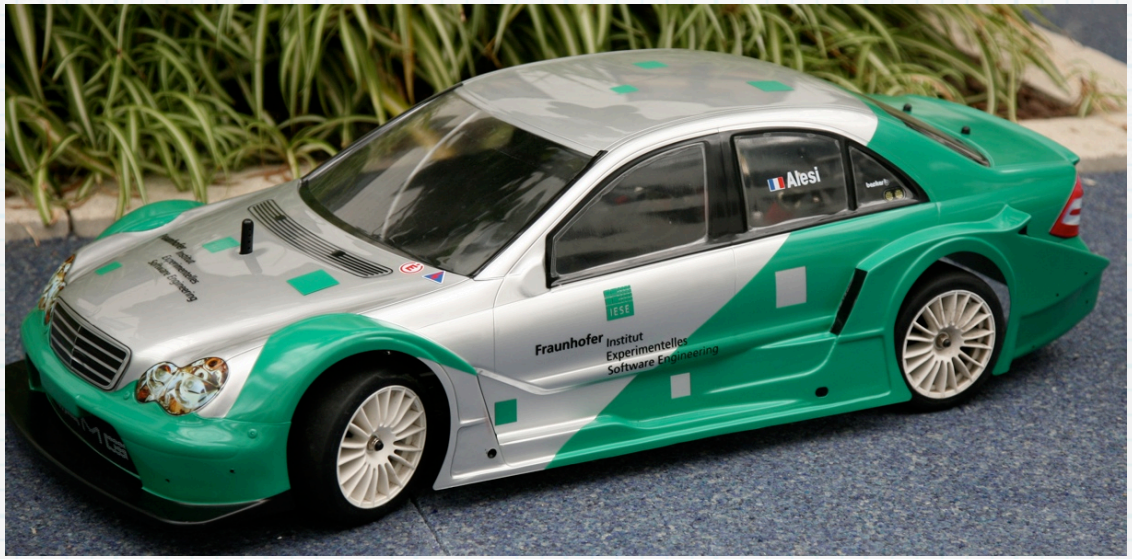
Self-Adaptive Systems



Faults and Environment Changes

Runtime adaptation

Self-Adaptive Systems

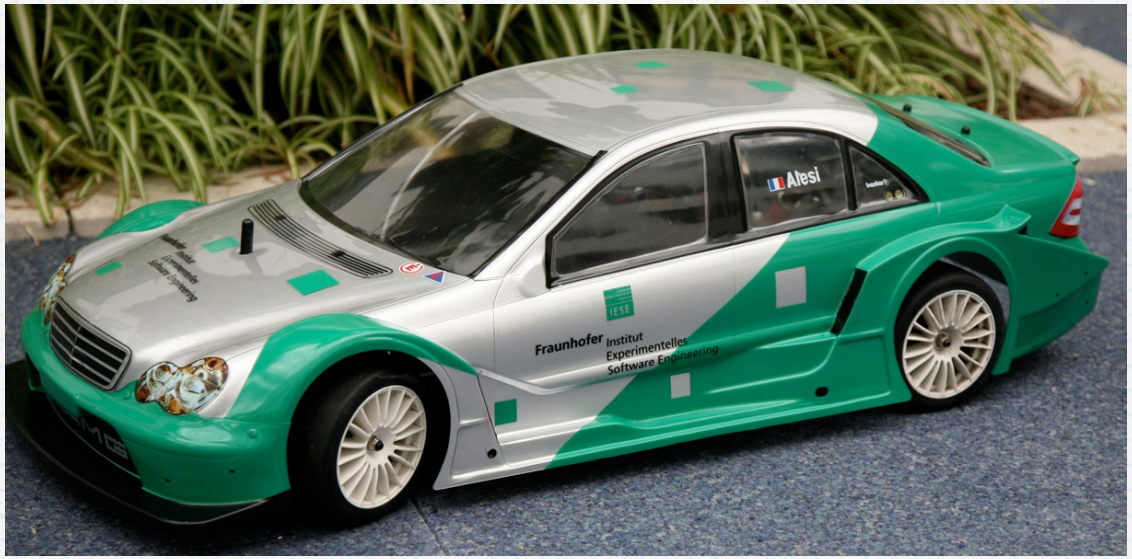


Faults and Environment Changes

Runtime adaptation

Degrade functionality to remain operational by switching to different predetermined configuration

Self-Adaptive Systems



Faults and Environment Changes

Safety Survivability

Runtime adaptation

Degrade functionality to remain operational by switching to different predetermined configuration

Adaptive Systems Development

Adaptation increases design complexity, since

- **decentralized adaptation mechanism**
- **reconfiguration triggers reconfiguration**
- **complex interdependencies**

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Solution:

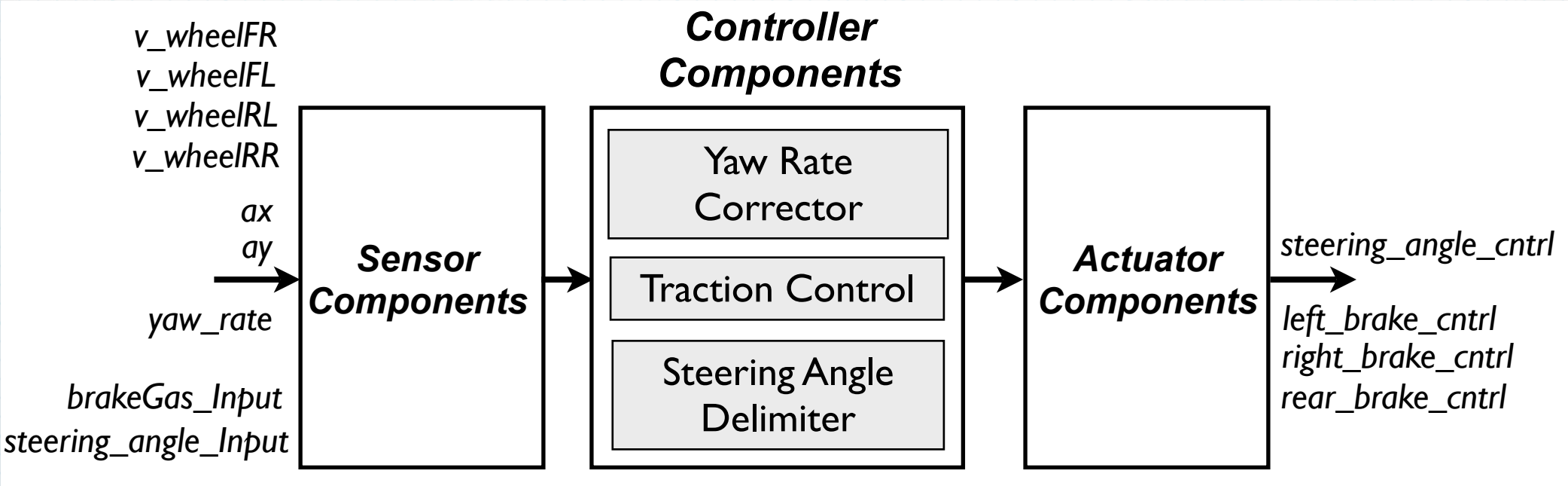
- **Model-Based Design of Adaptive Systems**
- **Integrated with Formal Verification of Adaptation Behaviour**

Outline

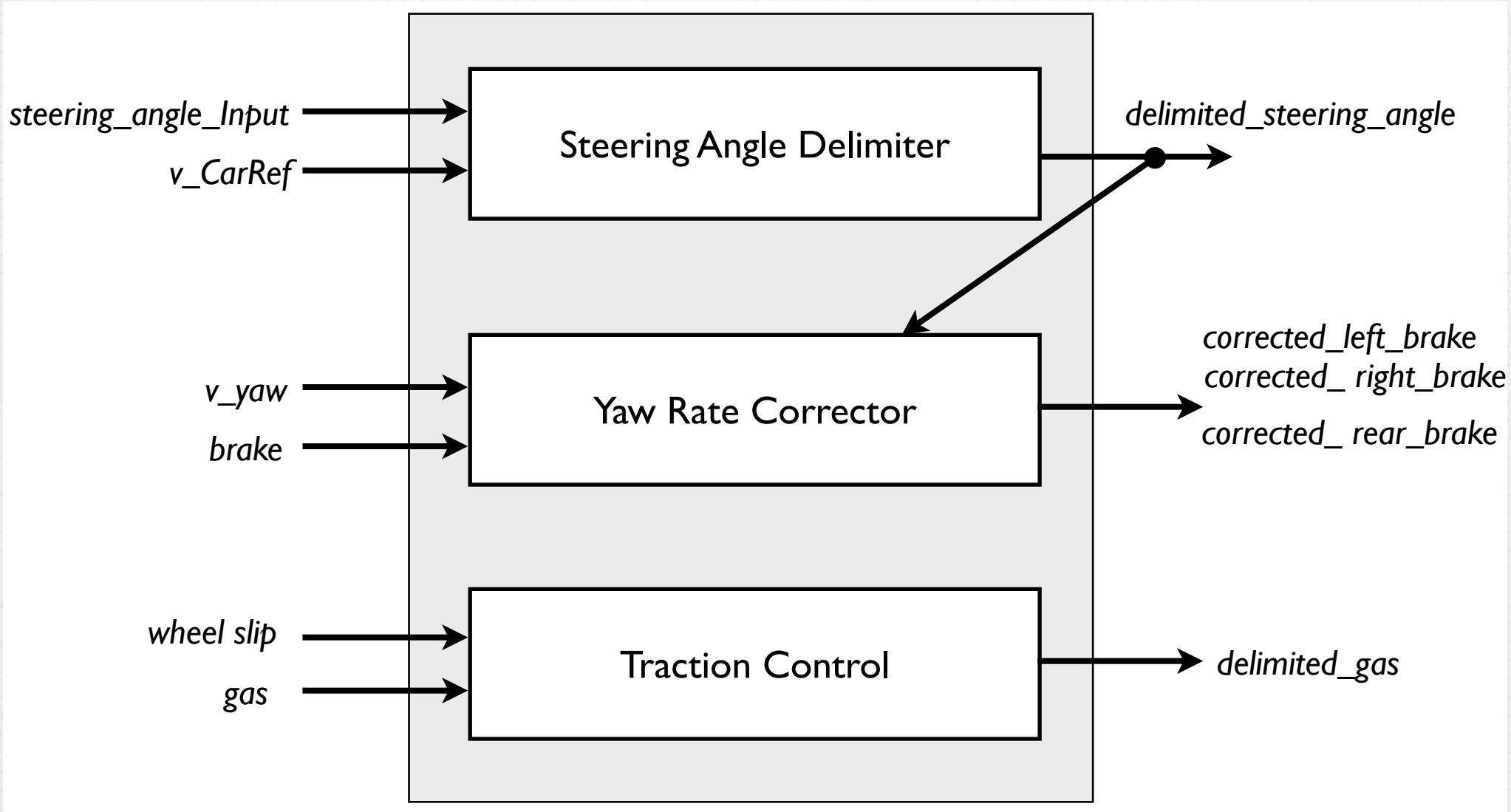
- Case Study: An Adaptive Vehicle Stability Control System
- MARS Modelling Concepts
- Development Process and Verification
- Conclusion and Future Work

Adaptive Vehicle Stability Control

System Architecture



Controller Components

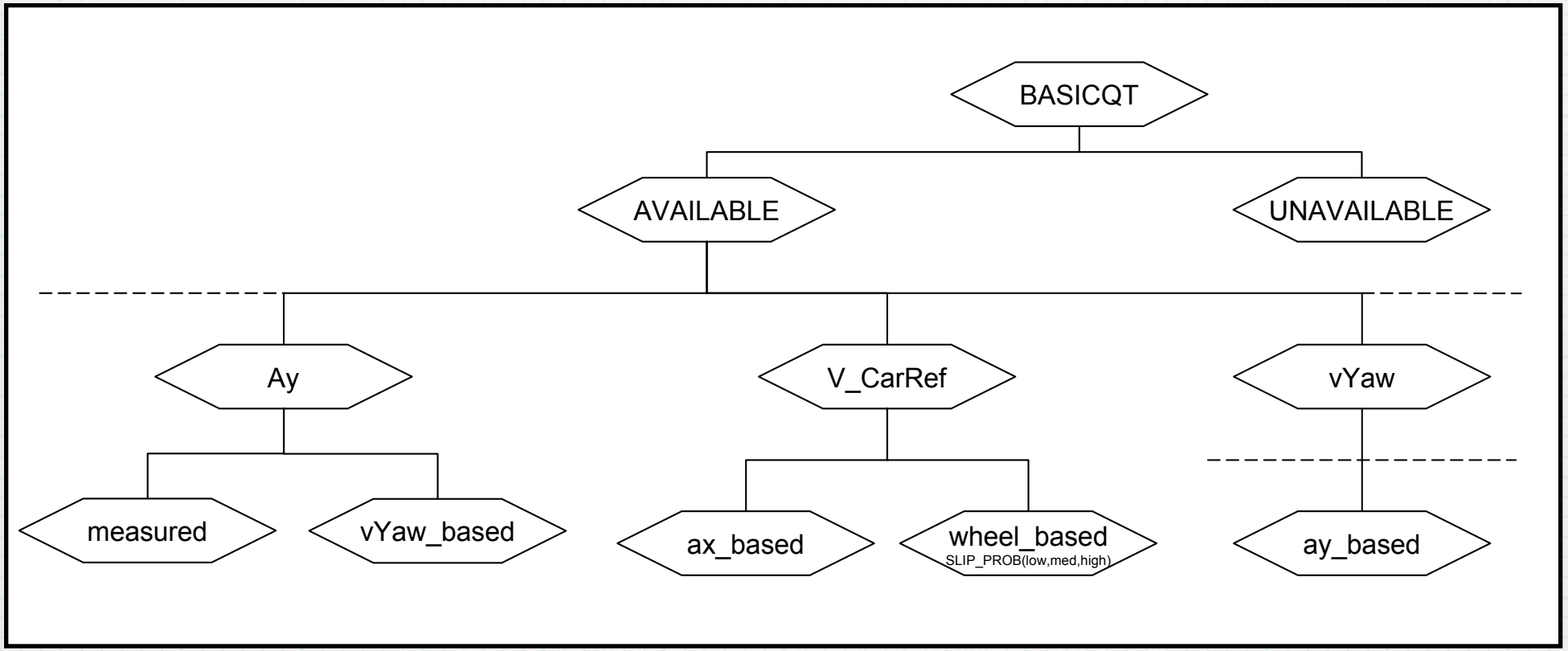


Adaptive System Modelling (MARS)

Main Concepts reducing Design Complexity:

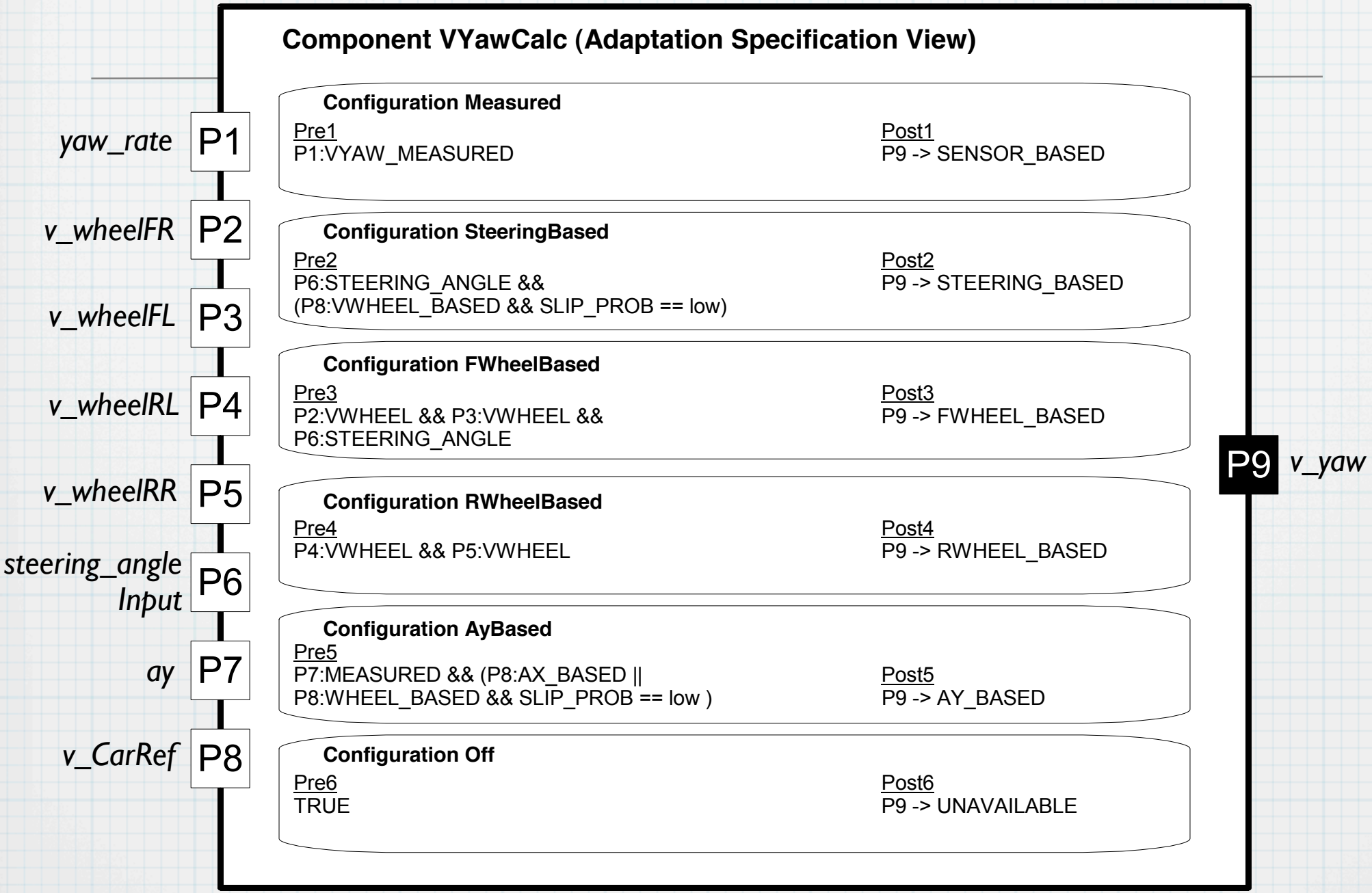
- **Modular System Structure**
- **Propagation of Adaptation by Quality extended Data Types (Datives)**
- **Separation of Adaptation and Functionality in Components**

Qualities

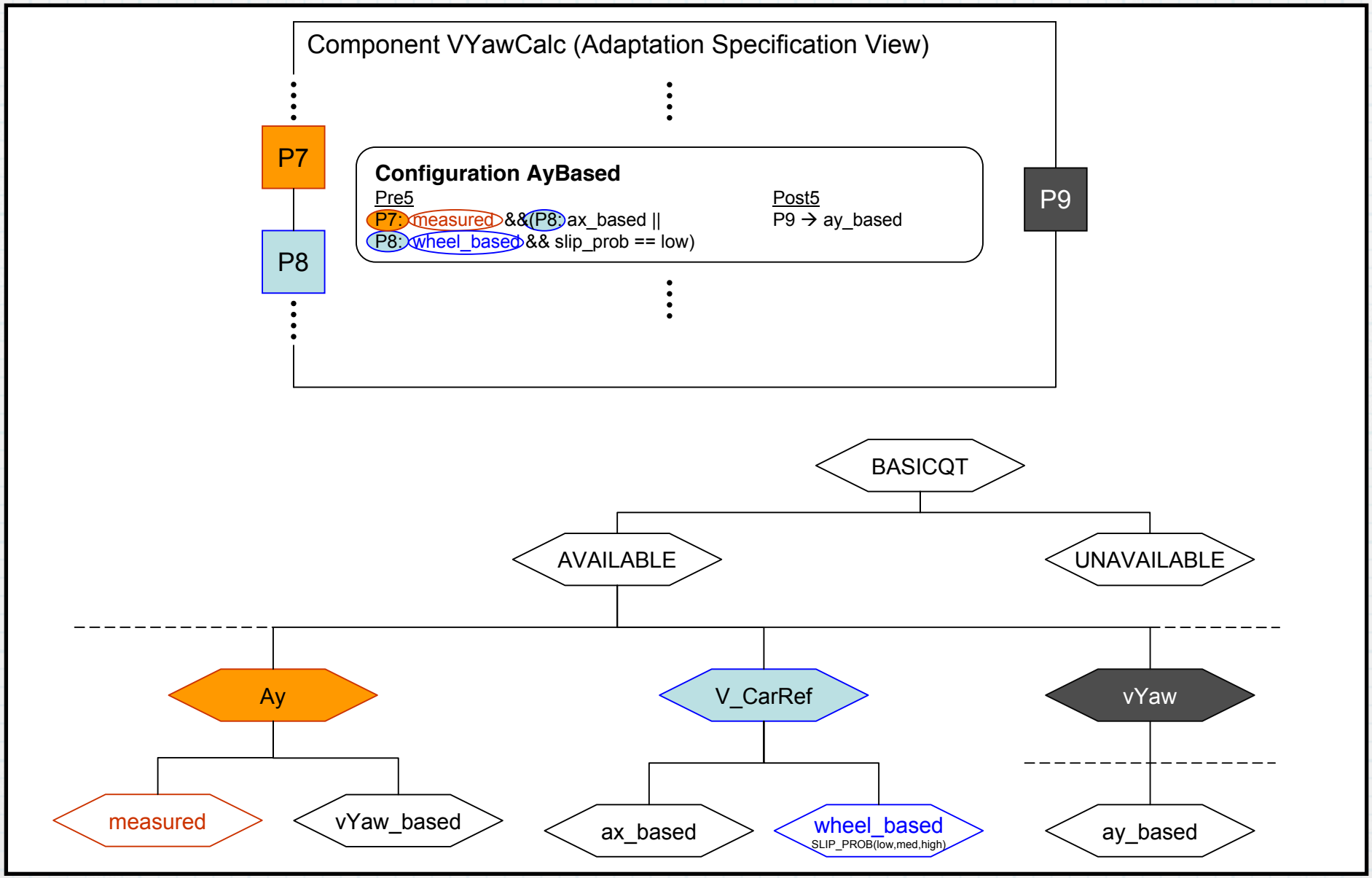

BASICQT
AVAILABLE
UNAVAILABLE
Ay
V_CarRef
vYaw
measured
vYaw_based
ax_based
wheel_based
SLIP_PROB(low,med,high)
ay_based

Adaptive Components

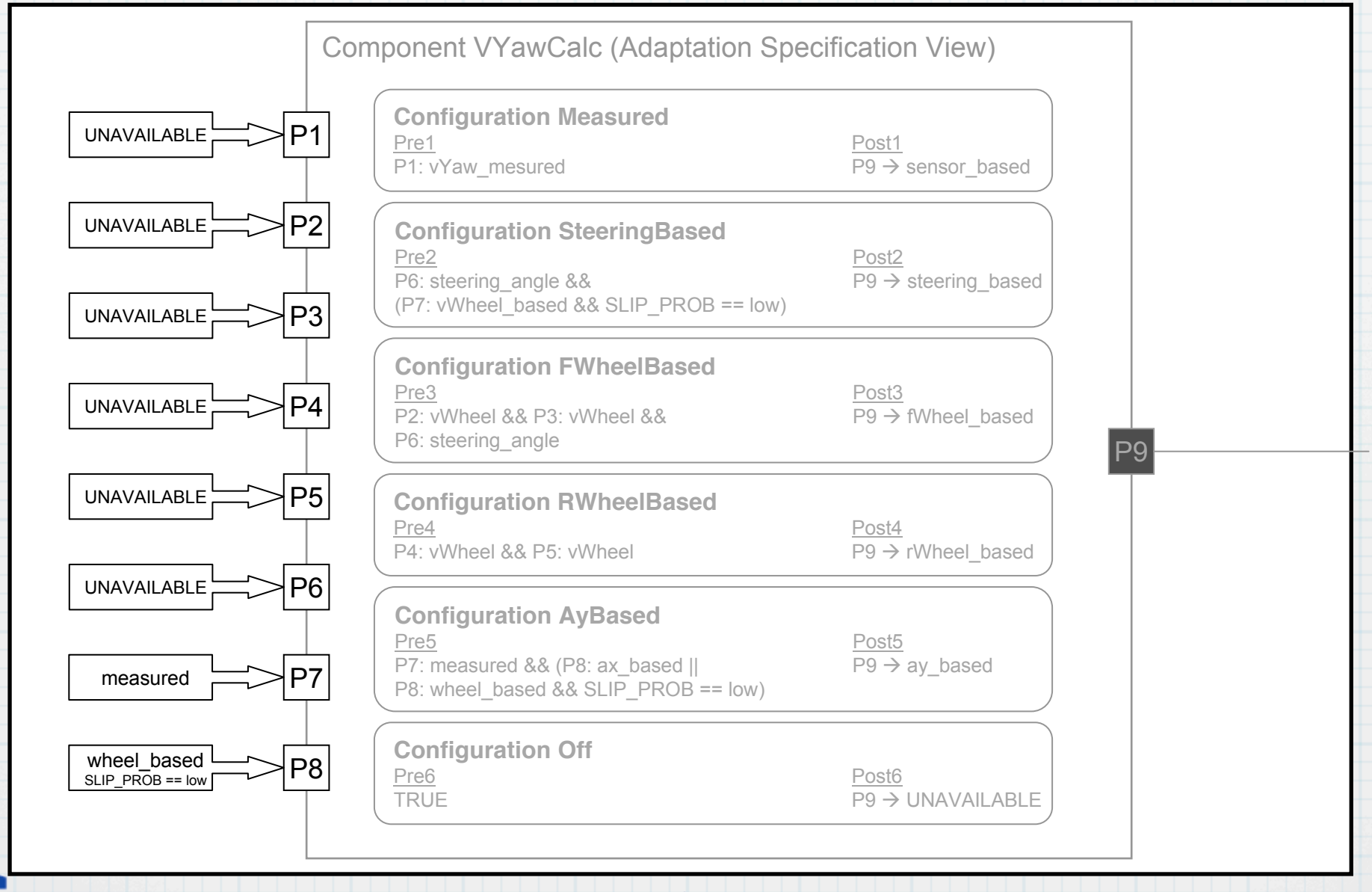
- Input and Output Ports for Functional Data
- Required and Provided Ports for Qualities
- Set of Predetermined Configurations with Pre- and Postconditions on Input and Output Qualities


Component VYawCalc (Adaptation Specification View)
yaw_rate
P1
v_wheelFR
P2
v_wheelFL
P3
v_wheelRL
P4
v_wheelRR
P5
steering_angle Input
P6
ay
P7
v_CarRef
P8
Configuration Measured
Pre1
P1:VYAW_MEASURED
Post1
P9 -> SENSOR_BASED
Configuration SteeringBased
Pre2
P6:STEERING_ANGLE &&
(P8:VWHEEL_BASED && SLIP_PROB == low)
Post2
P9 -> STEERING_BASED
Configuration FWheelBased
Pre3
P2:VWHEEL && P3:VWHEEL &&
P6:STEERING_ANGLE
Post3
P9 -> FWHEEL_BASED
Configuration RWheelBased
Pre4
P4:VWHEEL && P5:VWHEEL
Post4
P9 -> RWHEEL_BASED
Configuration AyBased
Pre5
P7:MEASURED && (P8:AX_BASED ||
P8:WHEEL_BASED && SLIP_PROB == low)
Post5
P9 -> AY_BASED
Configuration Off
Pre6
TRUE
Post6
P9 -> UNAVAILABLE
P9
v_yaw

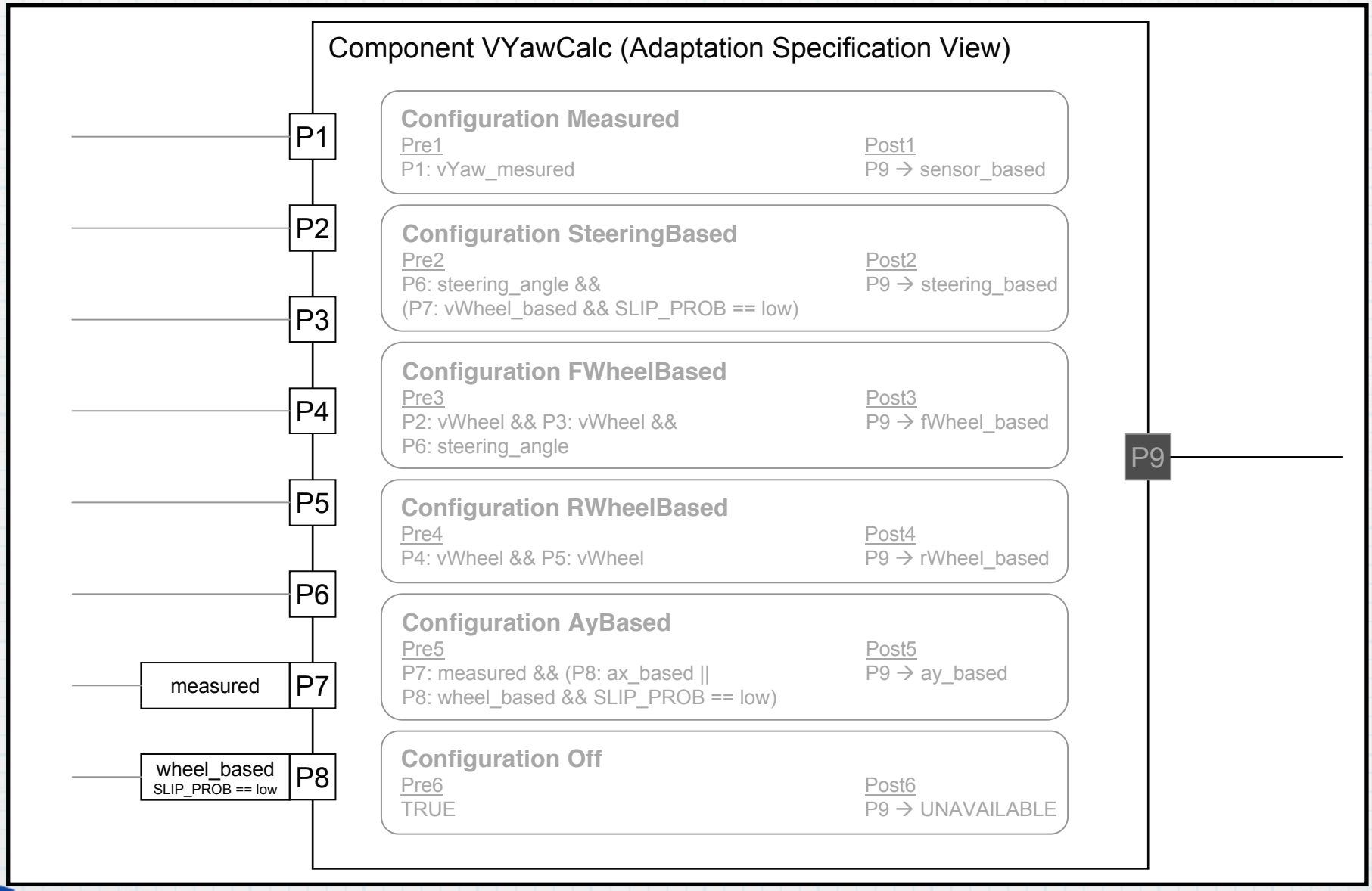
Adaptive Components (3)



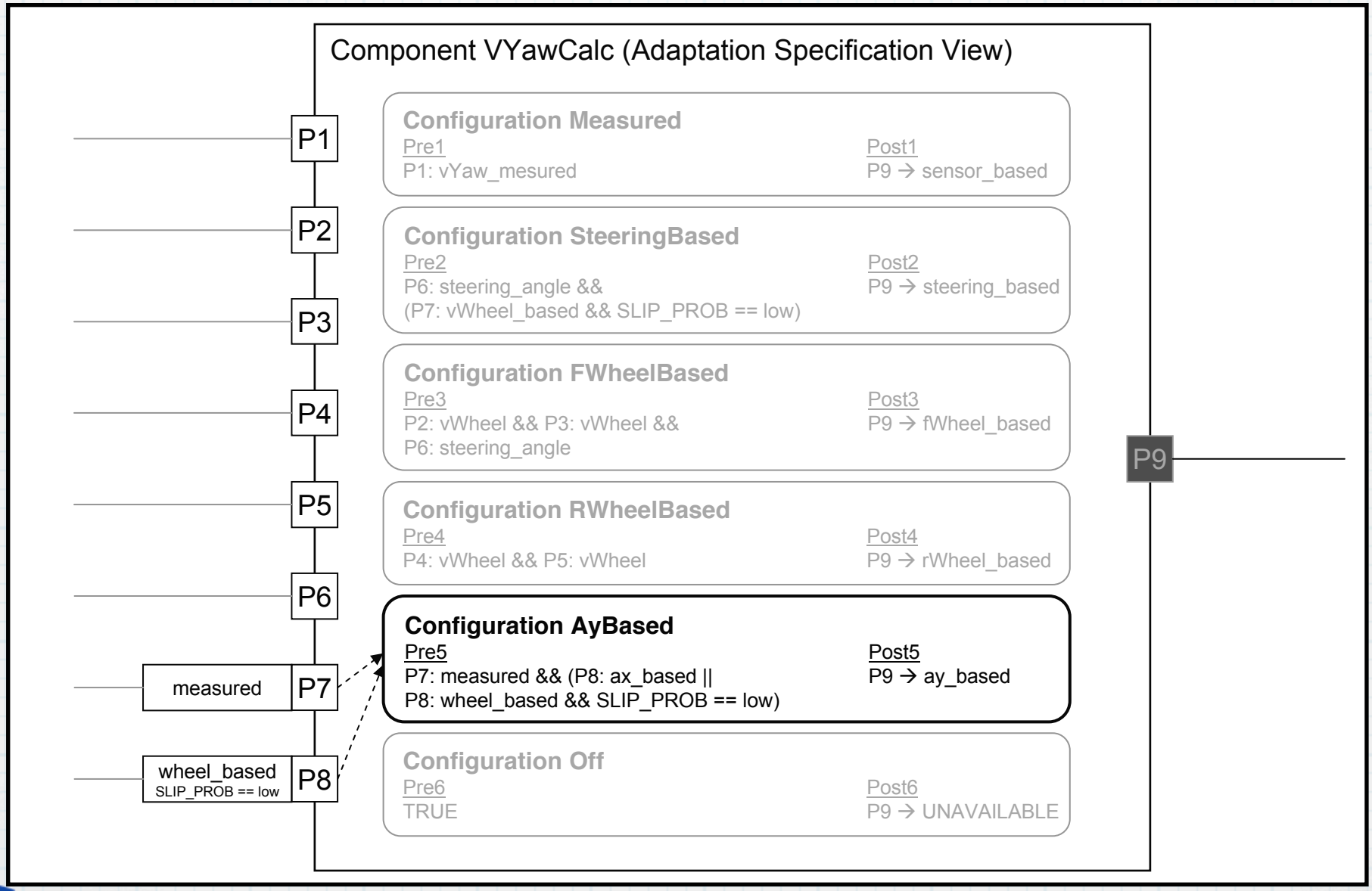
Modelling Adaptation



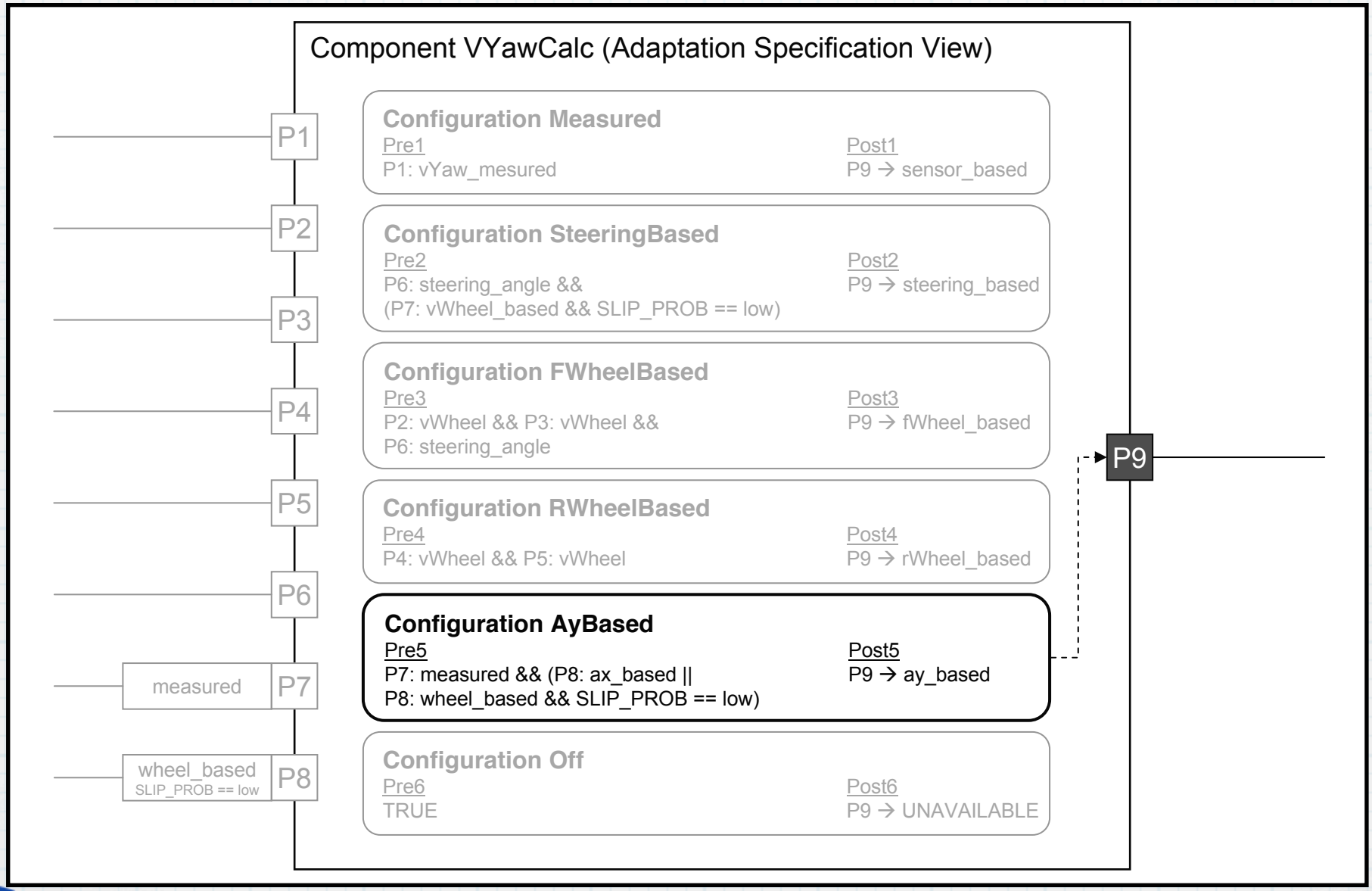
Modelling Adaptation



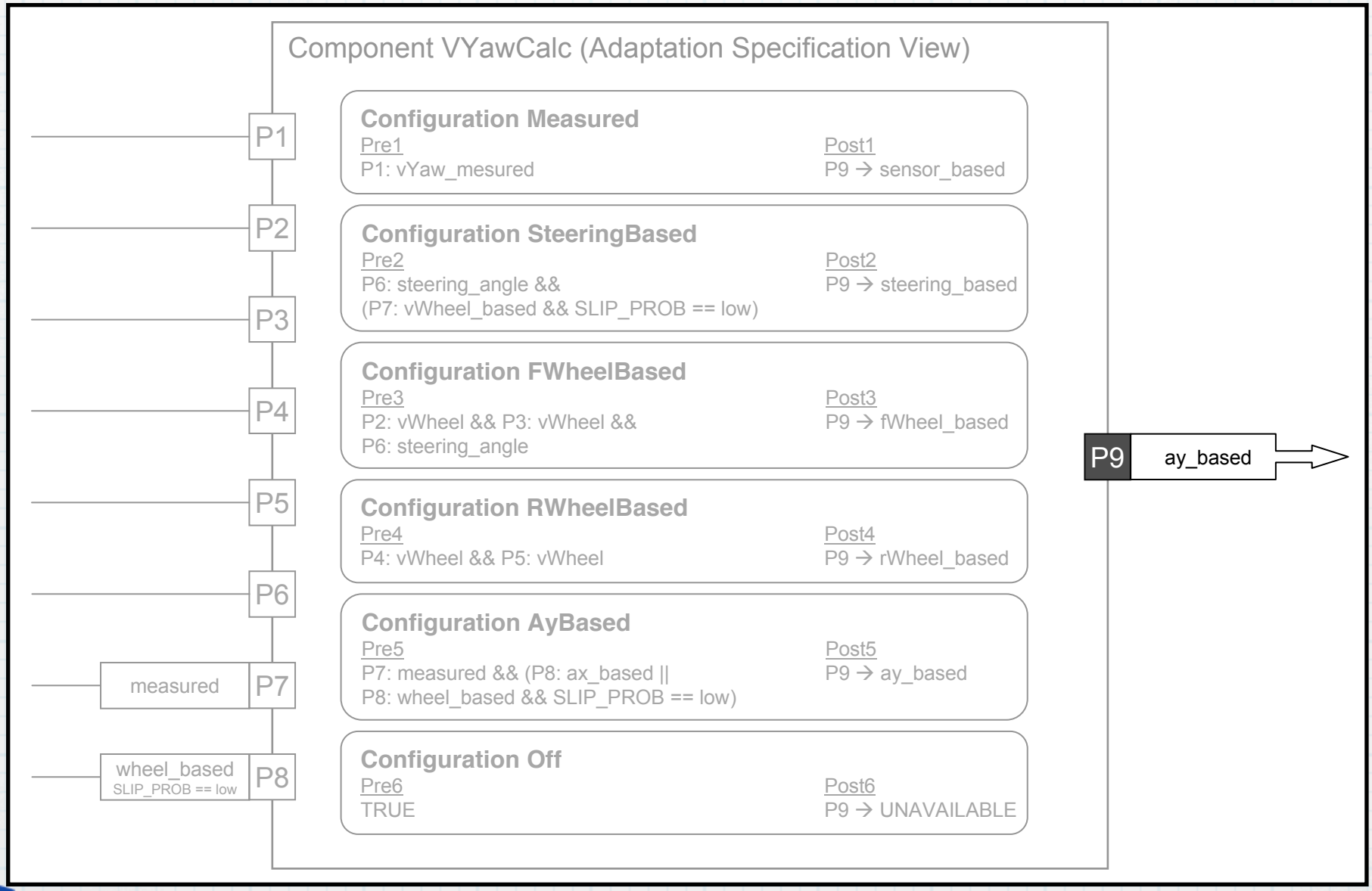
Modelling Adaptation



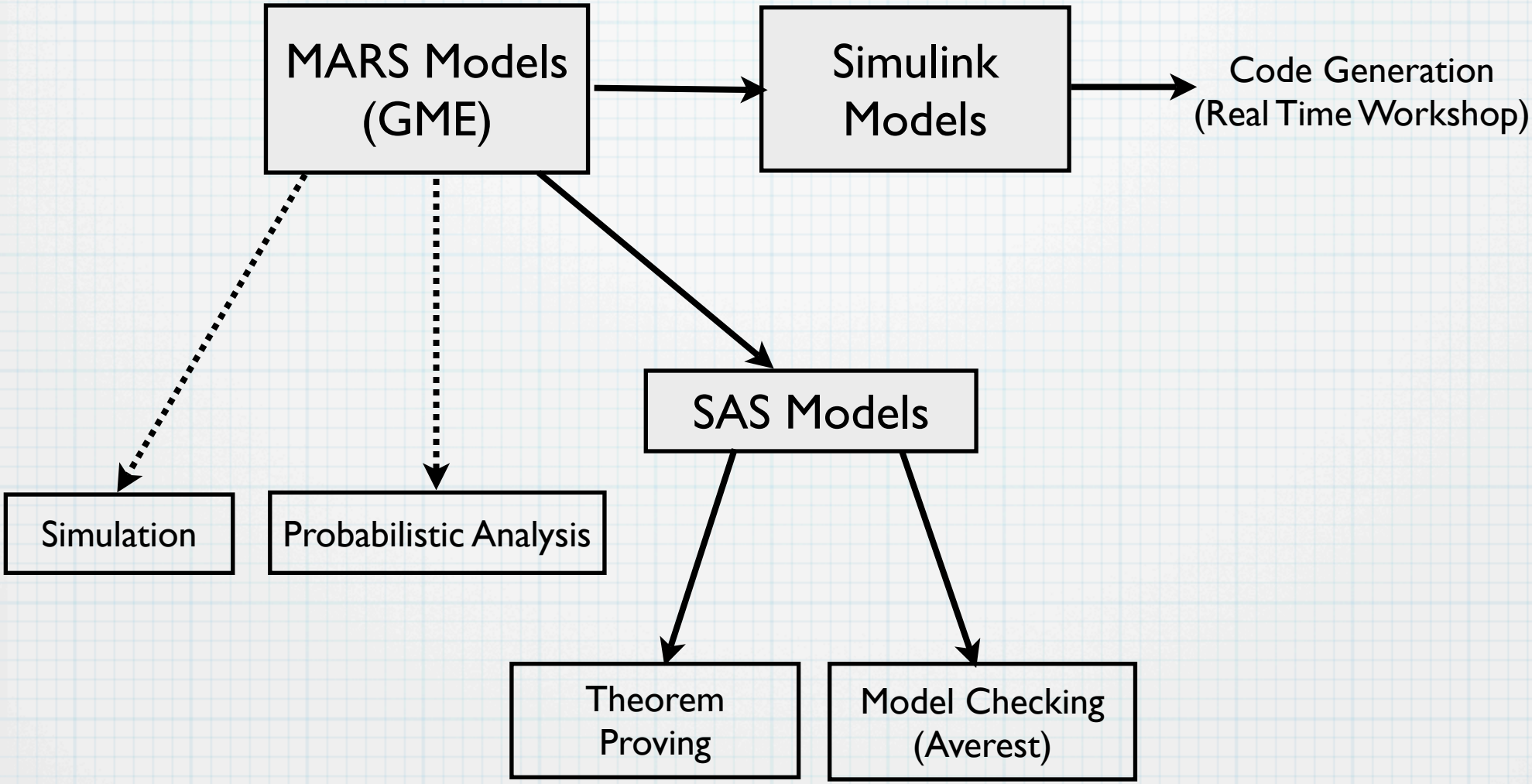
Modelling Adaptation



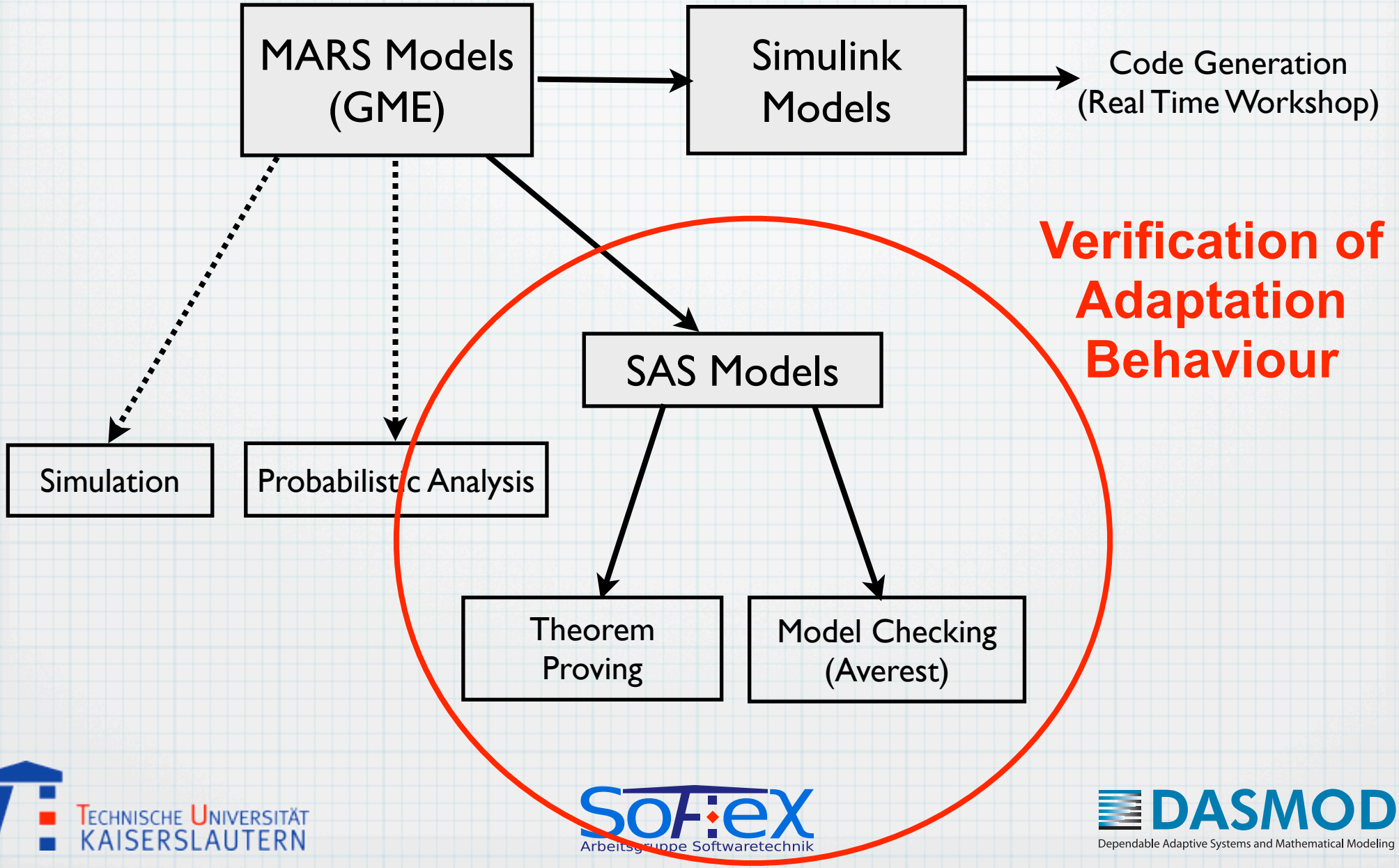
Modelling Adaptation



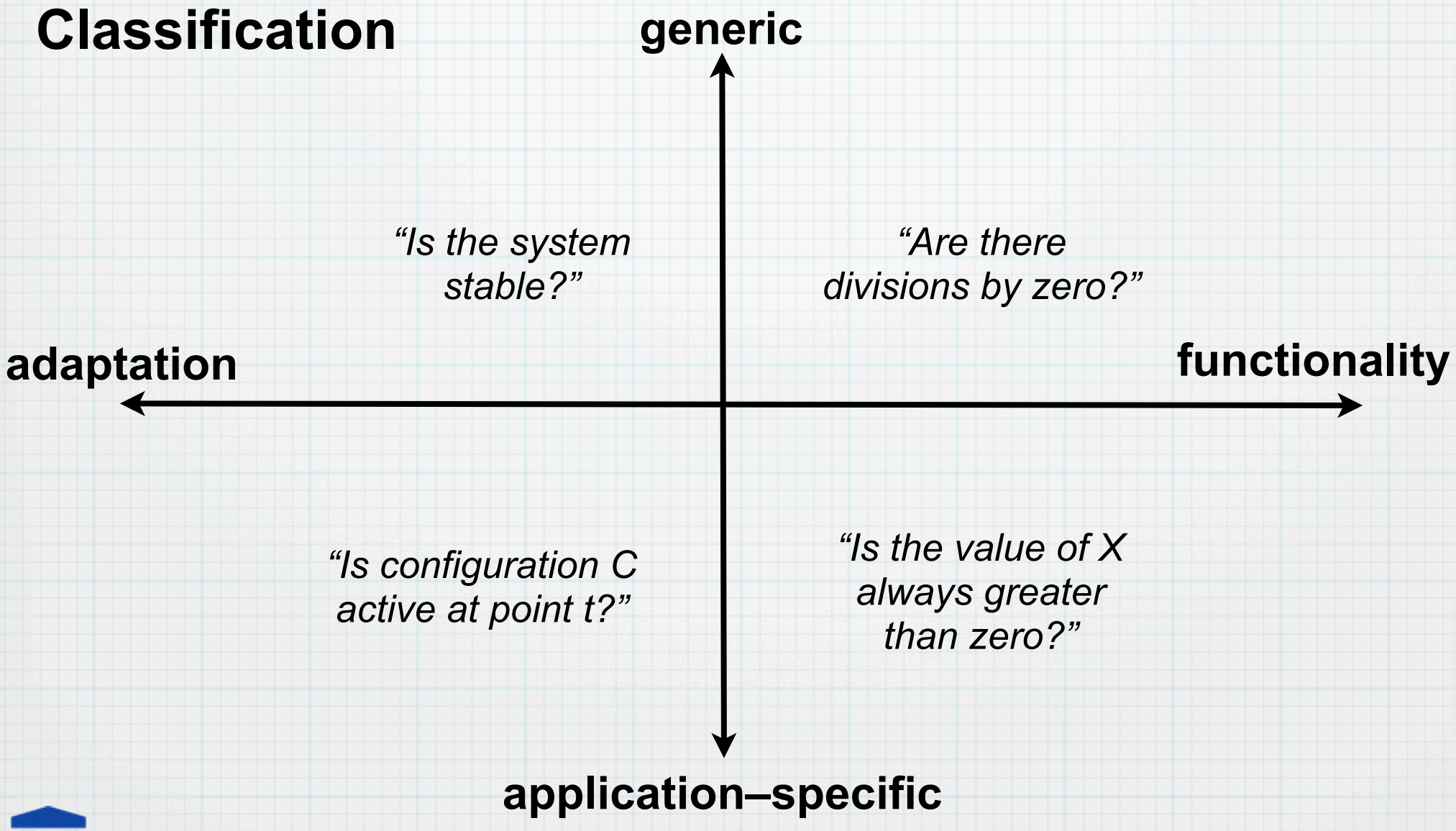
Development Process



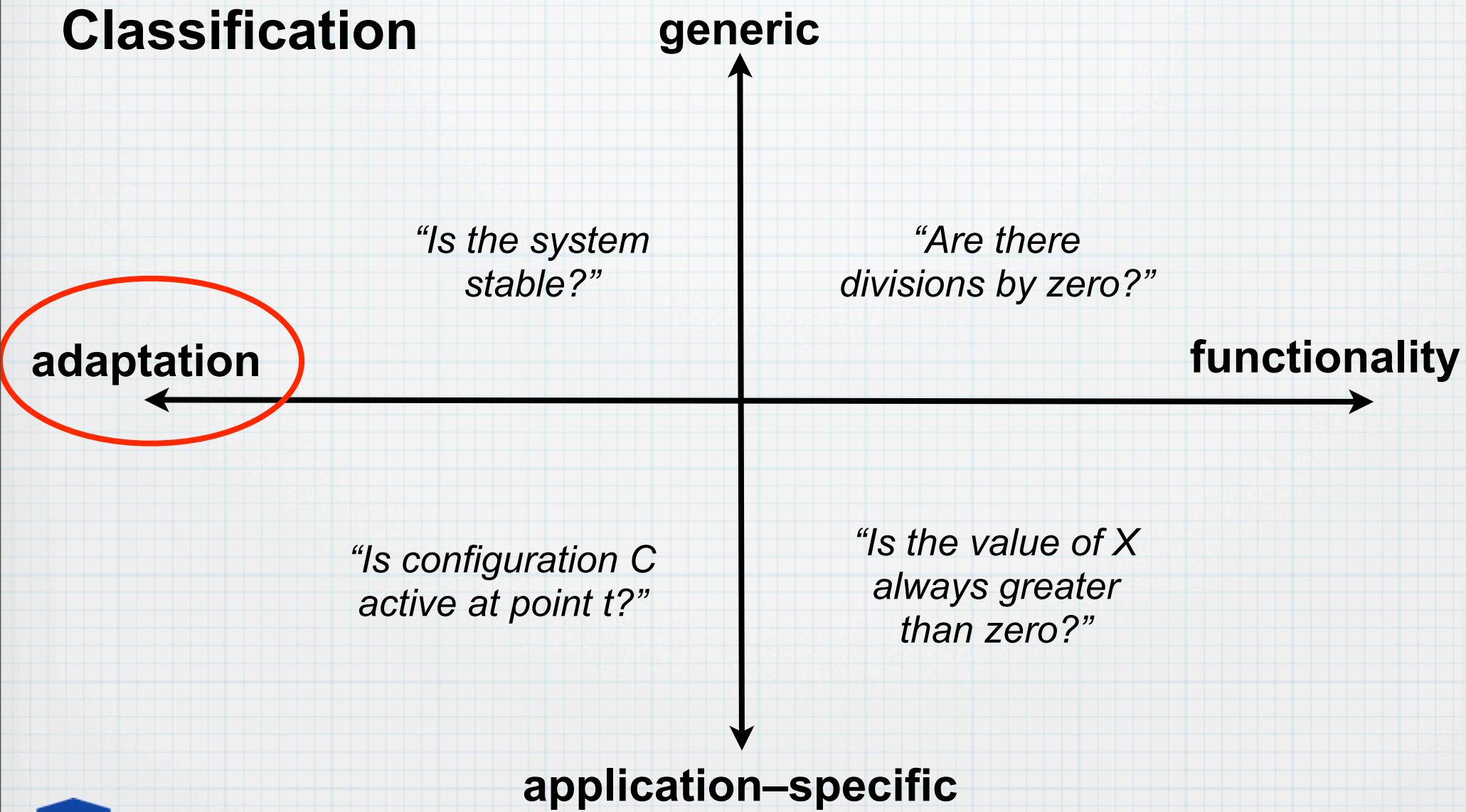
Development Process



System Properties



System Properties



Adaptive Generic Properties

- **No module gets stuck in the default configuration ‘off ’:**

$$\mathsf{AG}(c = \text{off} \rightarrow \mathsf{EF} c \neq \text{off})$$

- **Every module can reach all configurations at all times:**

$$\mathsf{AG}(\bigwedge_{i=1}^{n} \mathsf{EF}\ c = \text{config}_i)$$

- **No inconsistent states can be reached:**

$$\mathsf{AG}(\bigvee_{i=1}^{n} c = \text{config}_i)$$

- **No configuration is always only transient:**

$$\bigwedge_{i=1}^{n} \mathsf{EFEG}\ c = \text{config}_i$$

Properties of VSC System

Controller Modules correctly implement Fail-Safe Layer.

Traction Control:

$$\mathsf{AG}((gas\_output.quality = available \wedge gas\_input.quality = available) \rightarrow c_{traction\_control} \neq Off)$$

Steering Angle Delimiter:

$$\mathsf{AG}((steering\_angle\_input.quality = available \wedge steering\_angle\_servo.quality = available) \rightarrow c_{steering\_angle\_delimiter} \neq Off)$$

Yaw Rate Correction:

$$\mathsf{AG}((wheel\_brakeFL.quality = available \wedge wheel\_brakeFR.quality = available \wedge wheel\_rearBrake.quality = available \wedge brake\_input.quality = available \rightarrow c_{yaw\_rate\_corrector} \neq Off)$$

Experimental Results

Characteristics of Vehicle Stability Control System

Number of components	28
Number of configurations	70
Lines of code	≈ 2500
Number of reachable states	$\approx 5 \cdot 10^{18}$
Number of properties	151

Analysis Times for Generic Adaptive Properties

Property	**Time [seconds]**			
	Min.	**Avg.**	**Max.**	**Total**
P1 (liveness)	< 0.1	3.1	71.5	84.0
P2 (reachability)	< 0.1	2.4	52.1	63.8
P3 (safety)	< 0.1	0.1	0.2	0.7
P4 (persistence)	< 0.1	0.3	4.5	19.6

Related Work

Modelling and Verification of Adaptive Systems

- [Bradbury et al.; 2004]:
  Survey on Self-Managed Software Architectures

- [Zhang, Cheng; 2005/06]:
  Modelling and Verification of Adaptation Behaviour based on Petri Nets

- [Schneider, Schüle, Trapp; 2006]:
  Direct Translation of Modelling Concepts to Verification Tools

Conclusion

- Modelling Concepts for Adaptive Systems
- Integration of Model-based Development and Formal Verification

Future Work

- **Extension of Modelling Concepts with Intuitive Property Specification at Modelling Level**
- **Further Development of Verification Techniques**
- **Propagation of Verification Results back to Modelling Level**