Science of Cyber-Physical System Integration

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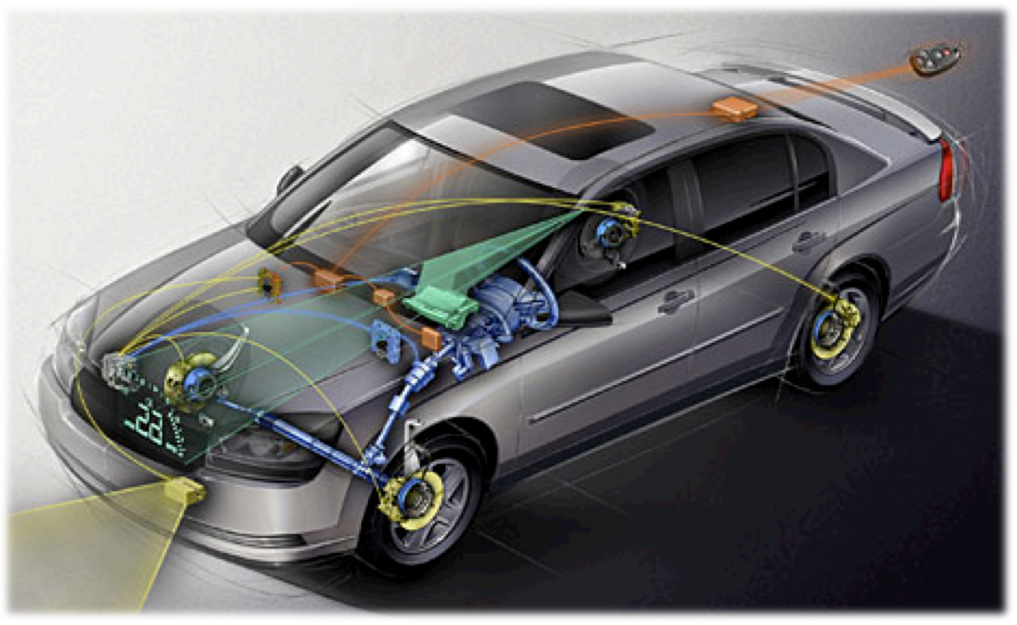
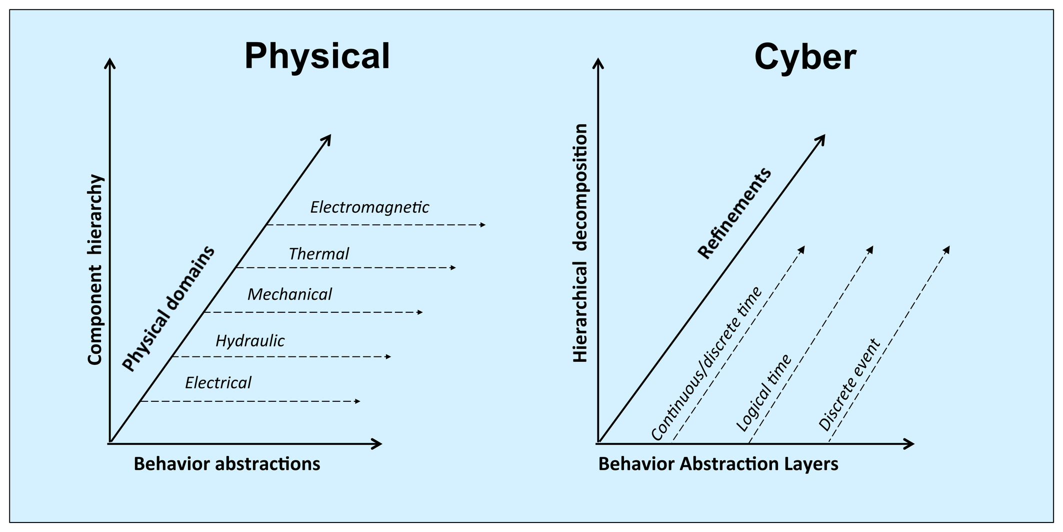
Next generation vehicles



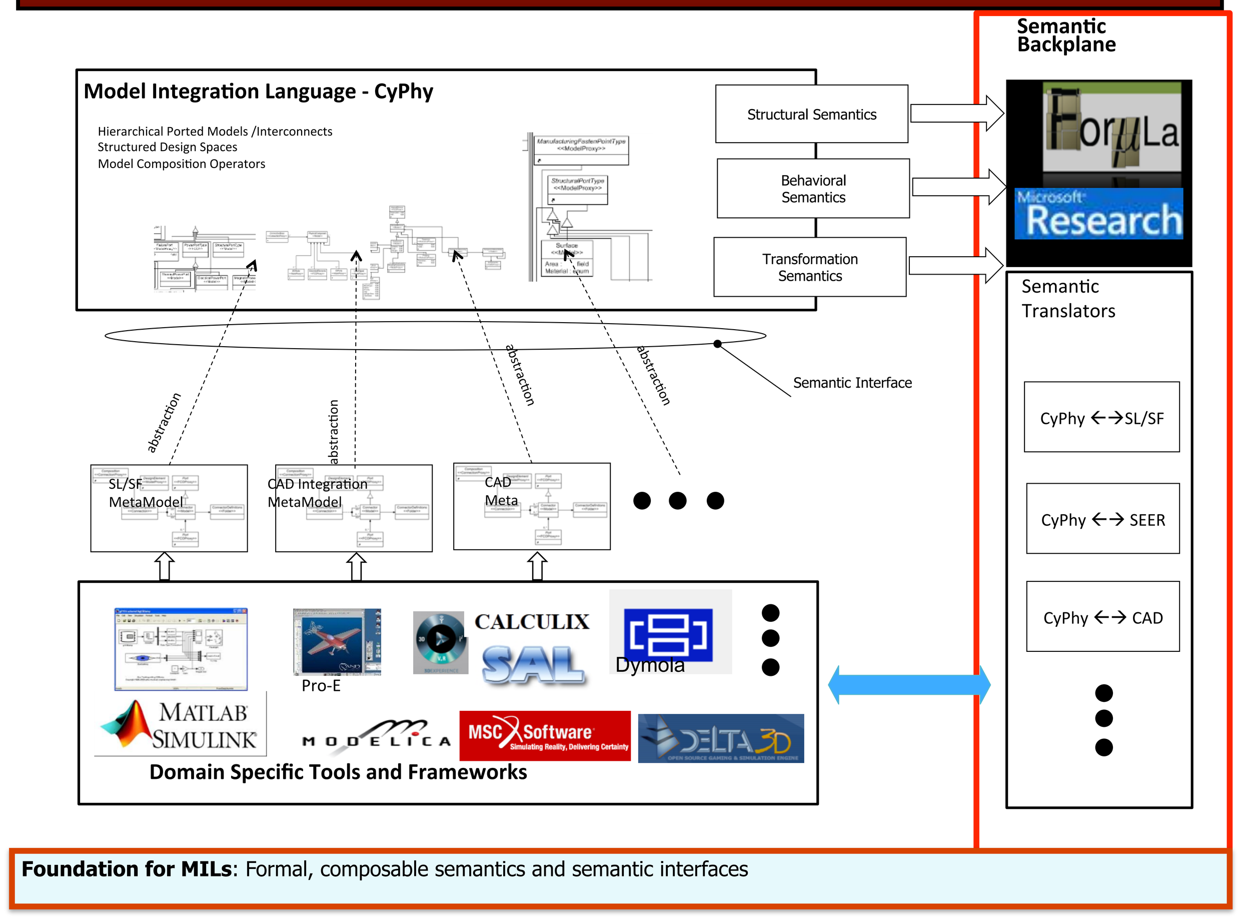
System Integration

- Next generation vehicles will include active safety, autonomous driving, and diverse energy conversion systems
- Design and engineering such vehicles requires a new synthesis-based paradigm
- The new design approach should facilitate integration and quick adoption of new technology
- The project objective is to develop the scientific foundations and a new systems engineering approach for CPS integration

Modeling Heterogeneous Domains

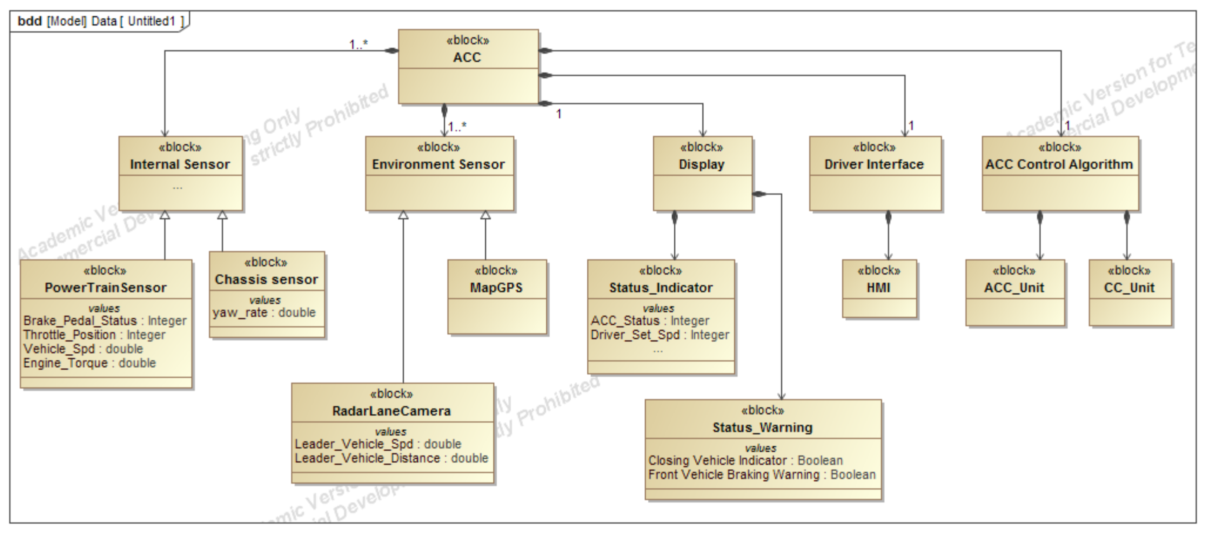


Model Integration Language

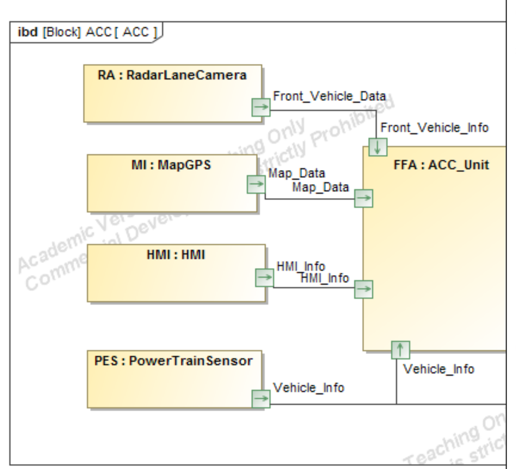


Model-Based Controller Design

- Model based system design approach for an embedded controller unit for Adaptive Cruise Control (ACC)
- Verify that ACC is able to maintain desired separation from the lead vehicle
- Analyze controller real-time perfomance



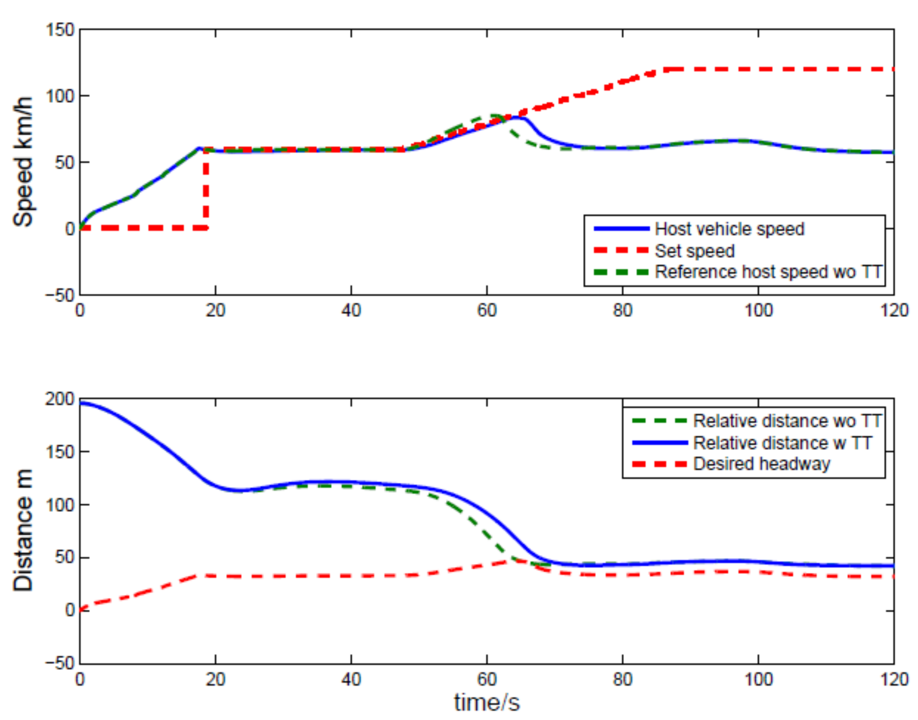
- Model transformation from block diagram to AADL



```
system ACC
 features
  Map_info: feature group ACC_Map_socket;
  ACC_state: out data port;
end ACC;

system implementation ACC.impl
 subcomponents
  FFA: system ACCUnit;
  PFA: system CCUnit;
  FLC: system LKI;
  RA: device RadarLaneCamera;
  MI: device MapGPS;
  PES: device PowerTrainSensor;
  HMI: device HMI;
 connections
  C1: port FFA.ACC_state -> ACC_state;
  C2: port FFA.CC_Engage_Flag -> PFA.CC_Engage_Flag;
  C3: port PFA.CC_state -> FFA.CC_state;
  C4: feature group MI.Map_info -> Map_info;
  ...
  C20: feature group PES.VehicleInfo -> FLC.Vehicle_info;
end ACC.impl;
```

- Simulink + Truetime + CarSim

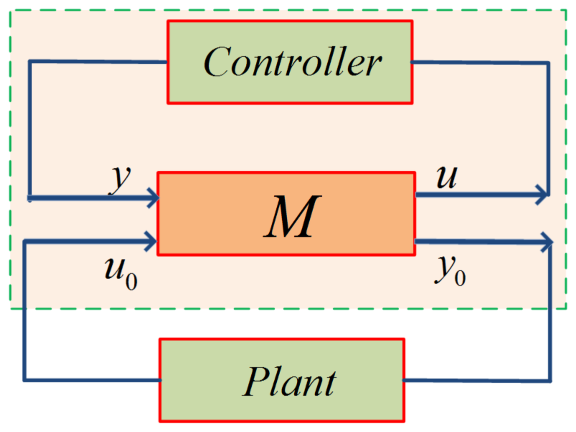


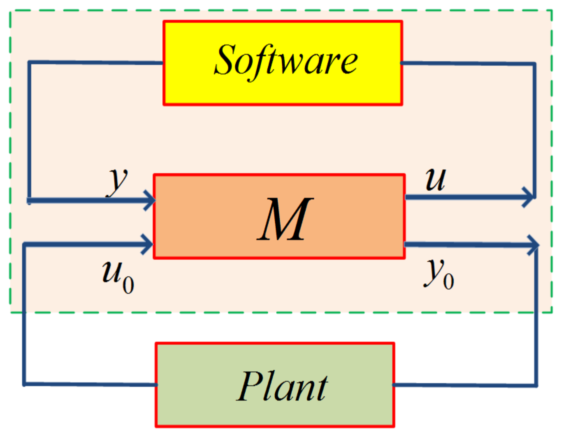
Passivation: From Control to Software

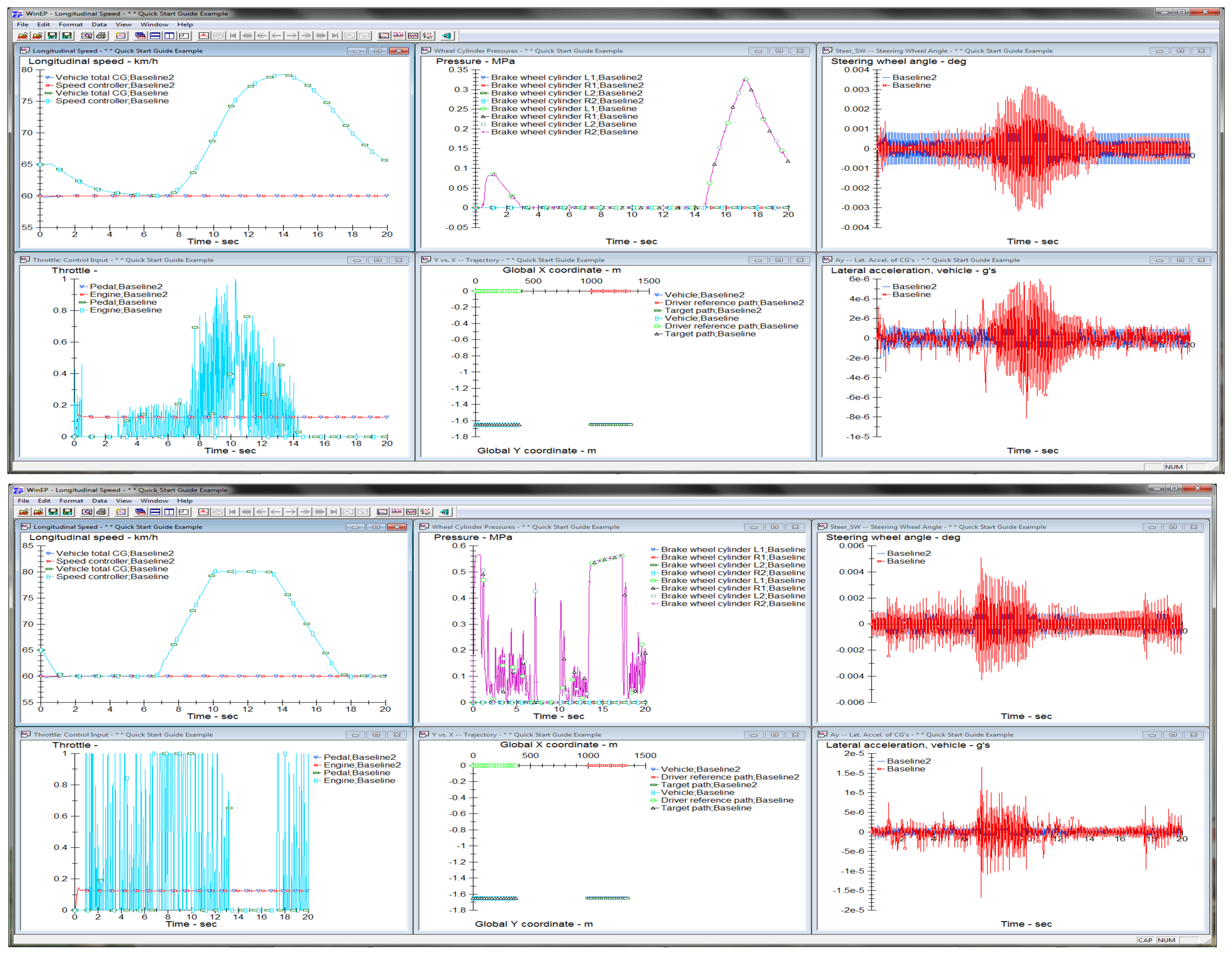
- Consider a passivation method given by an input/output transformation matrix M

$$\begin{bmatrix}u_0\\ y_0\end{bmatrix} = M\begin{bmatrix}u\\ y\end{bmatrix} \qquad M = \begin{bmatrix}m_{11}I & m_{12}I\\ m_{21}I & m_{22}I\end{bmatrix}$$

- By appropriate choices of the matrix M, desired passivity indices for the closed-loop system can be guaranteed
- When the control algorithm is implemented in software, time-varying delays may not be avoided
- The transformation matrix M can be used to reduce the delay effects and improve the closed-loop system performance
- M can be computed by minimizing the tracking error using non-gradient optimization (Hookes and Jeeves, extrenum seeking
- Simulink + CarSim

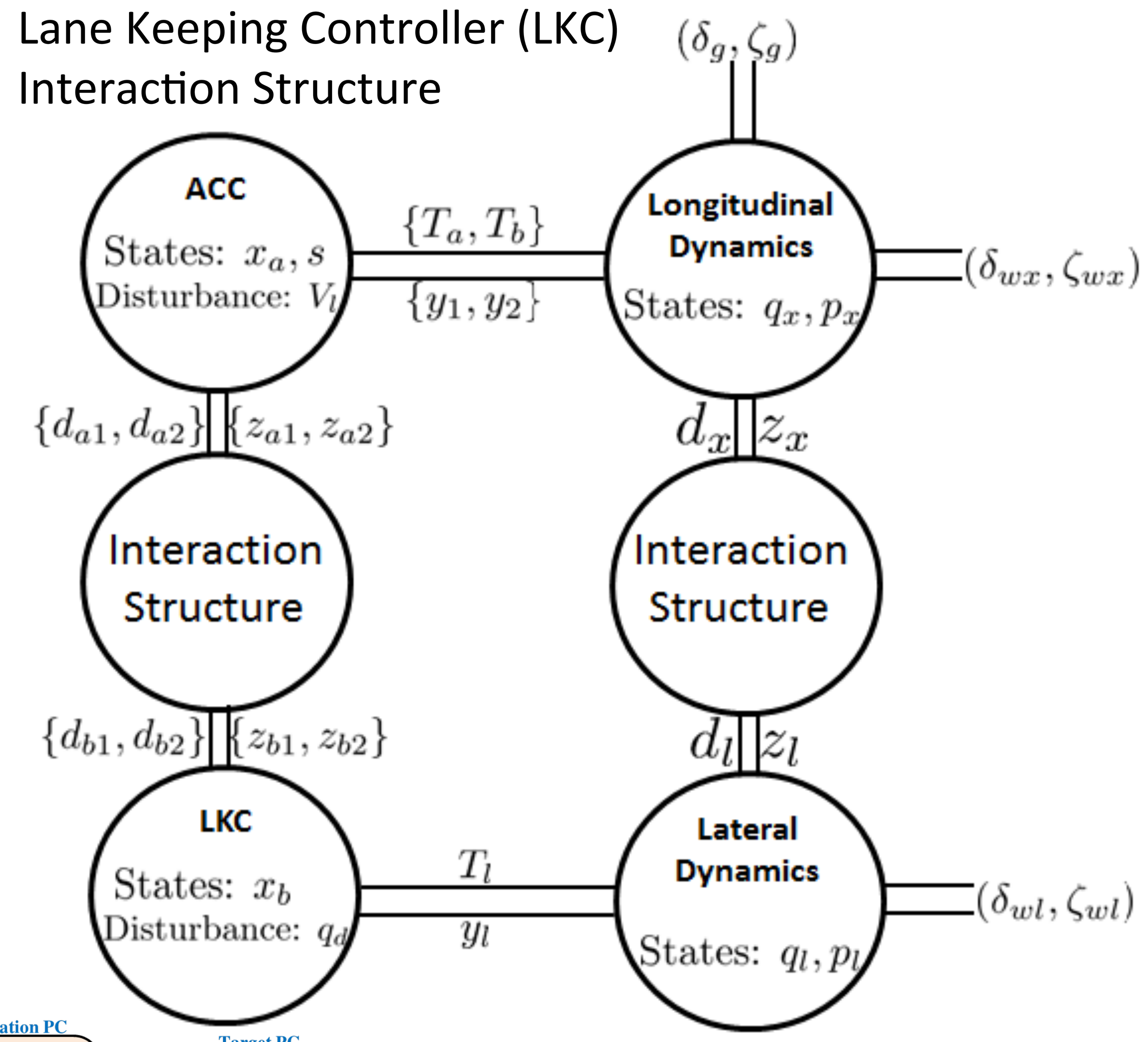


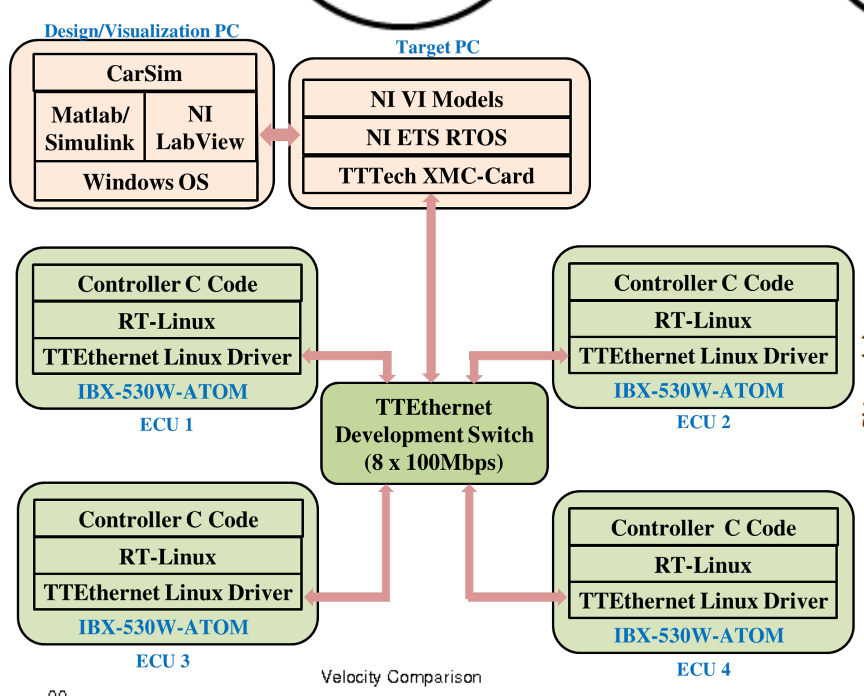


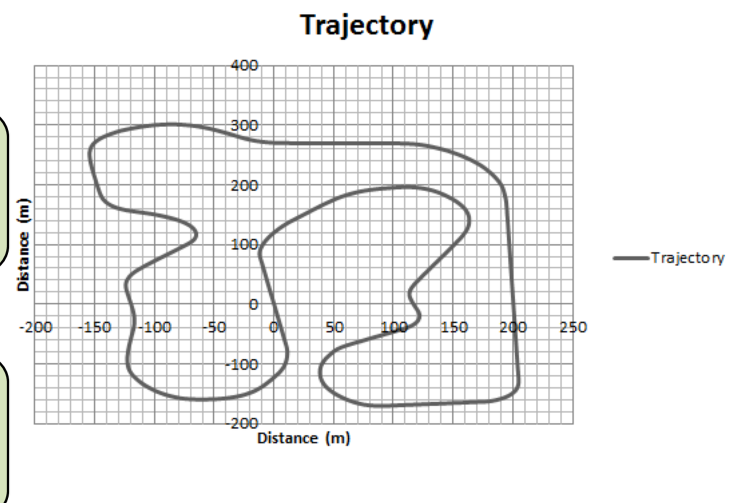


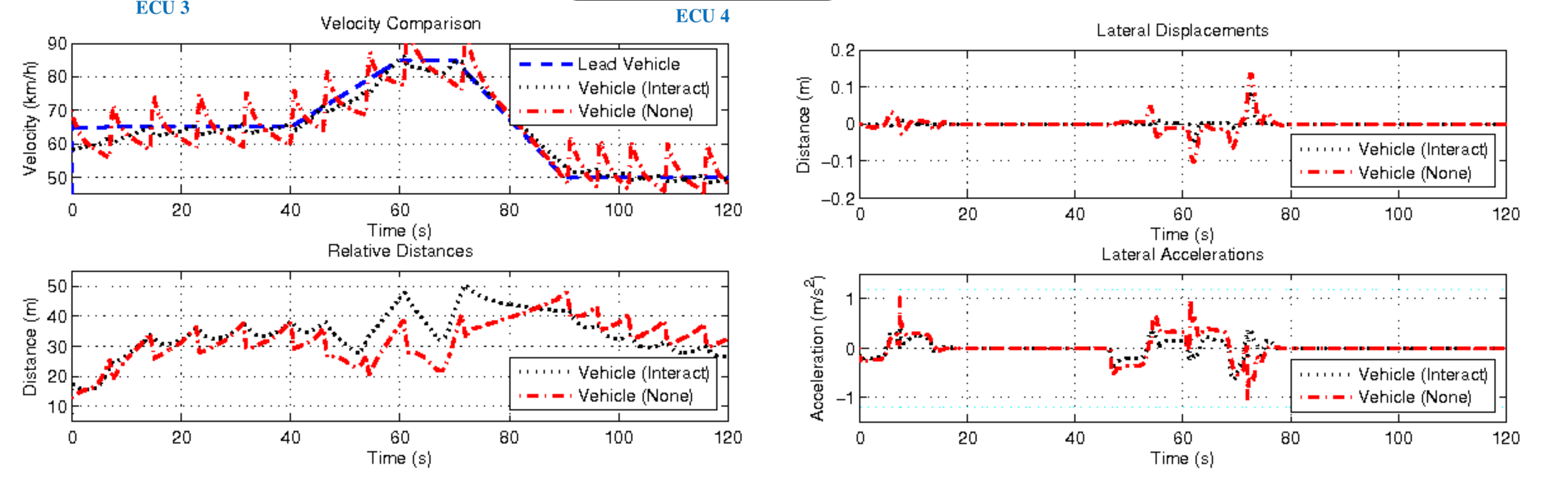
Passivity-Based Control Software Design

- Compositional control design using port-Hamiltonian systems
  - Adaptive Cruise Controlller (ACC)
  - Lane Keeping Controller (LKC)
  - Interaction Structure









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