Active Safety Control in Automotive Cyber-Physical Systems

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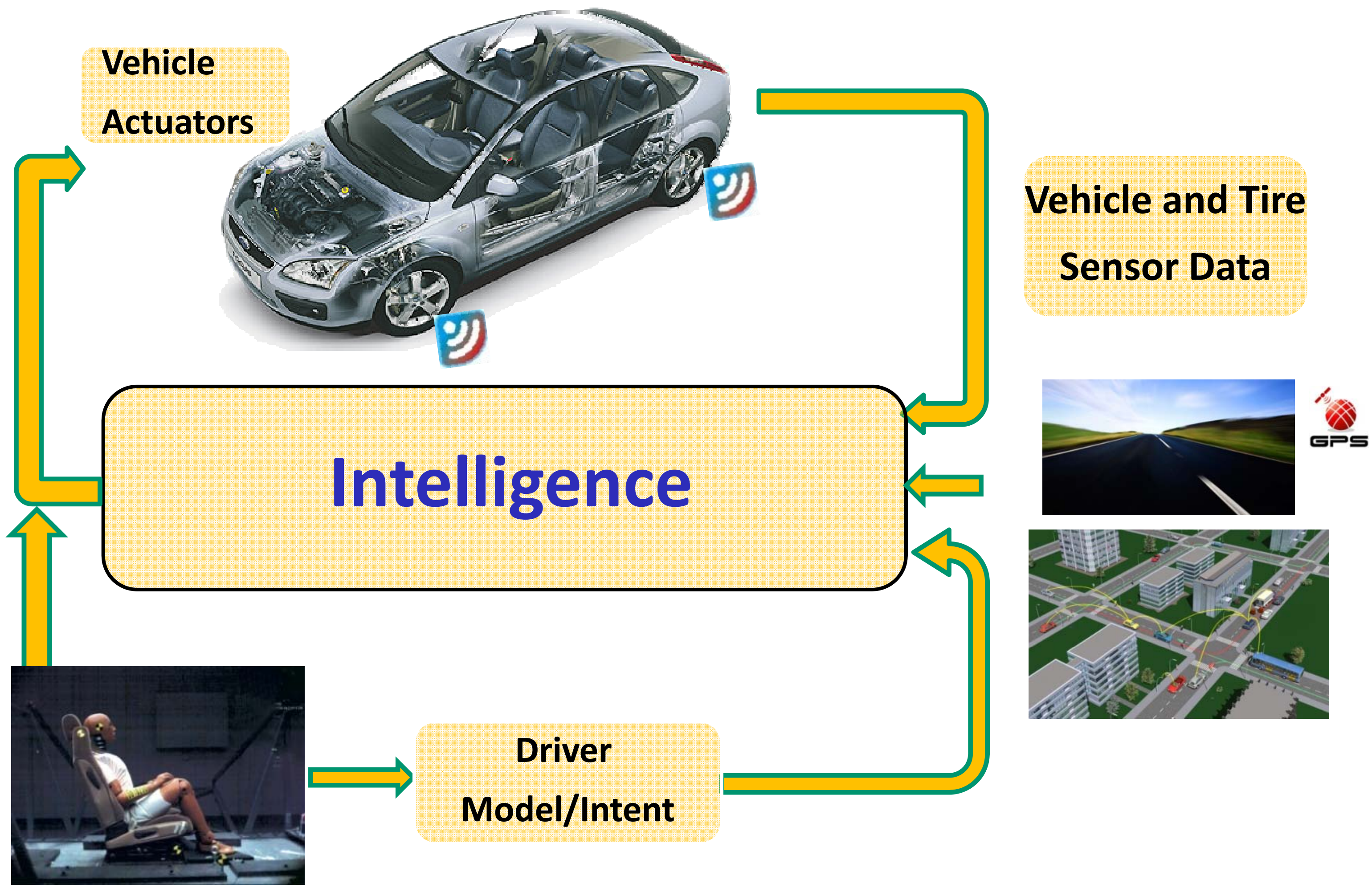
Automotive Cyber-Physical System



Safety | Comfort | Efficiency

Lane Departure A14 Highway – June 2009

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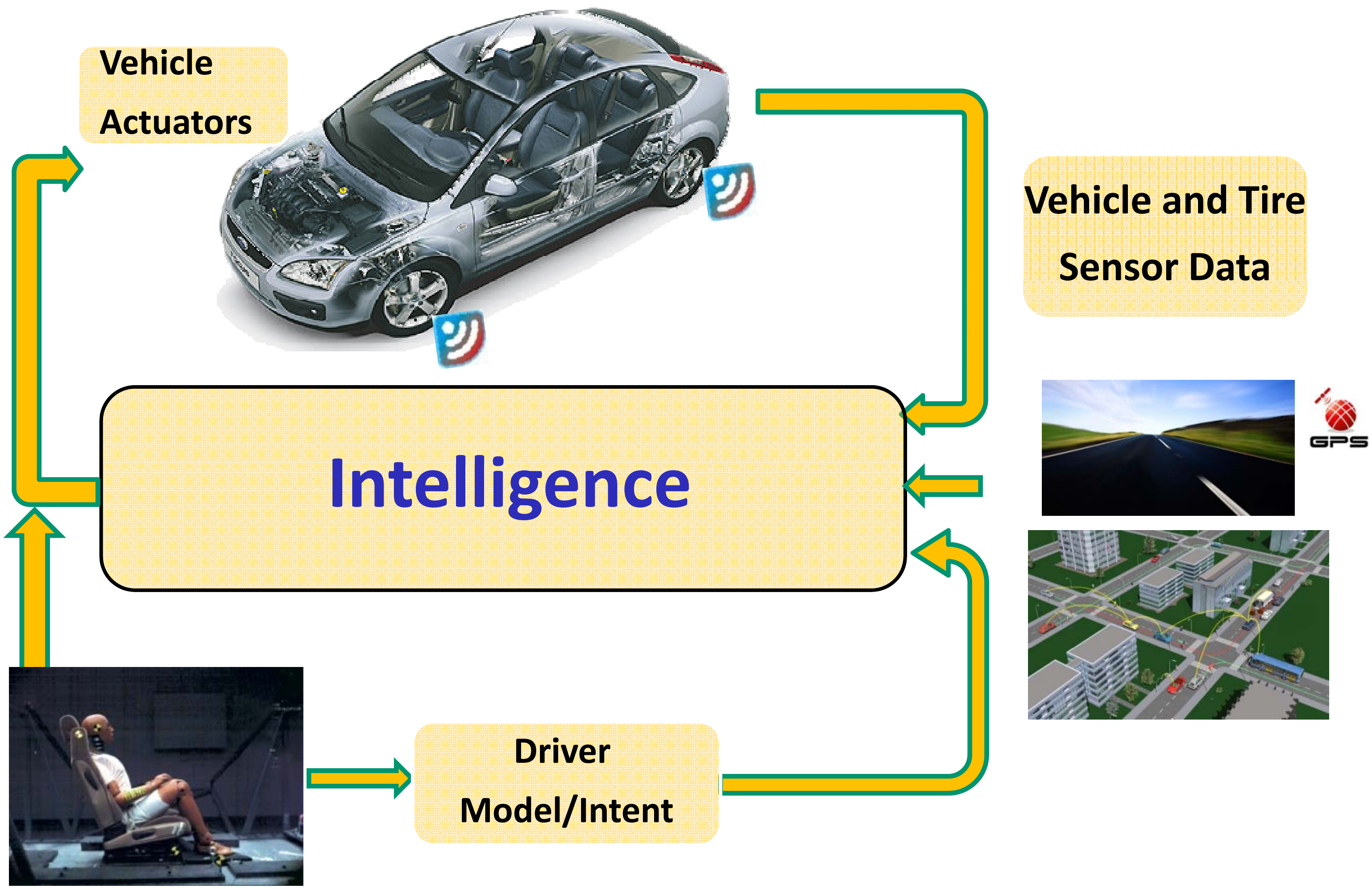
2008 US Statistics

Table 1: Occupants and Nonoccupants Killed and Injured in Traffic Crashes

Description	Killed				Injured			
	2007	2008	Change	% Change	2007	2008	Change	% Change
Total*	41,259	37,261	-3,998	-9.7%	**2,491,000**	**2,346,000**	**-145,000**	**-5.8%**
Occupants								
Passenger Vehicles	29,072	25,351	-3,721	-13%	**2,221,000**	**2,072,000**	**-149,000**	**-6.7%**
Passenger Cars	16,614	14,587	-2,027	-12%	**1,379,000**	**1,304,000**	**-75,000**	**-5.4%**
Light Trucks	12,458	10,764	-1,694	-14%	**841,000**	**768,000**	**-73,000**	**-8.7%**
Large Trucks	805	677	-128	-16%	23,000	23,000	0	0.0%
Motorcycles	5,174	5,290	+116	+2.2%	103,000	96,000	-7,000	-6.8%
Nonoccupants								
Pedestrians	4,699	4,378	-321	-6.8%	70,000	69,000	-1,000	-1.4%
Pedalcyclists	701	716	+15	+2.1%	**43,000**	**52,000**	**+9,000**	**+21%**
Other/Unknown	158	188	+30	---	10,000	9,000	-1,000	---

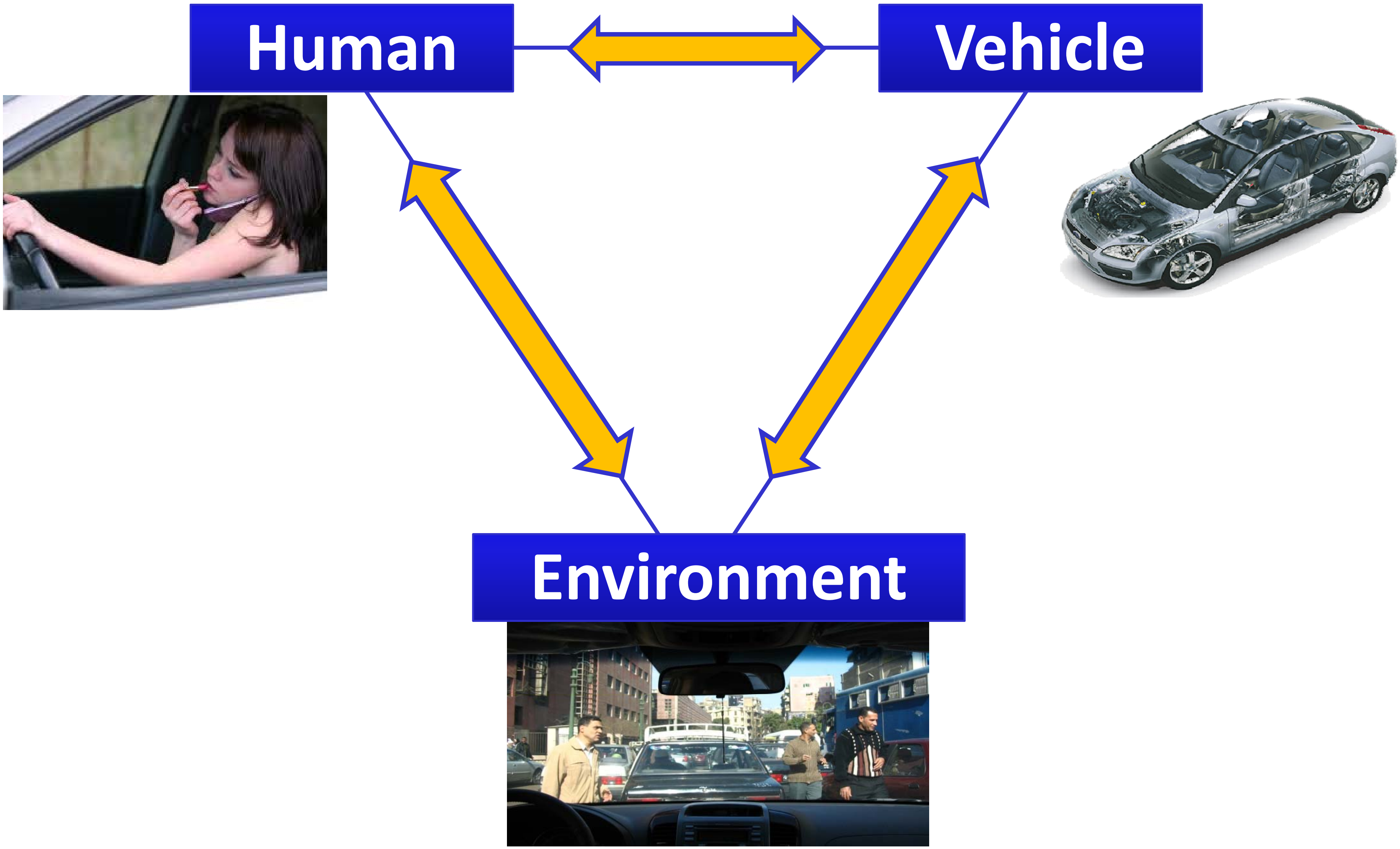
Source: Fatalities - FARS 2007 (Final), 2008 (ARF), Injured - NASS GES 2007, 2008 Annual Files
* Total includes occupants of buses and other/unknown occupants not shown in table.

Automotive Cyber-Physical System



Safety | Comfort | Efficiency

CPS-Synoptic Scheme



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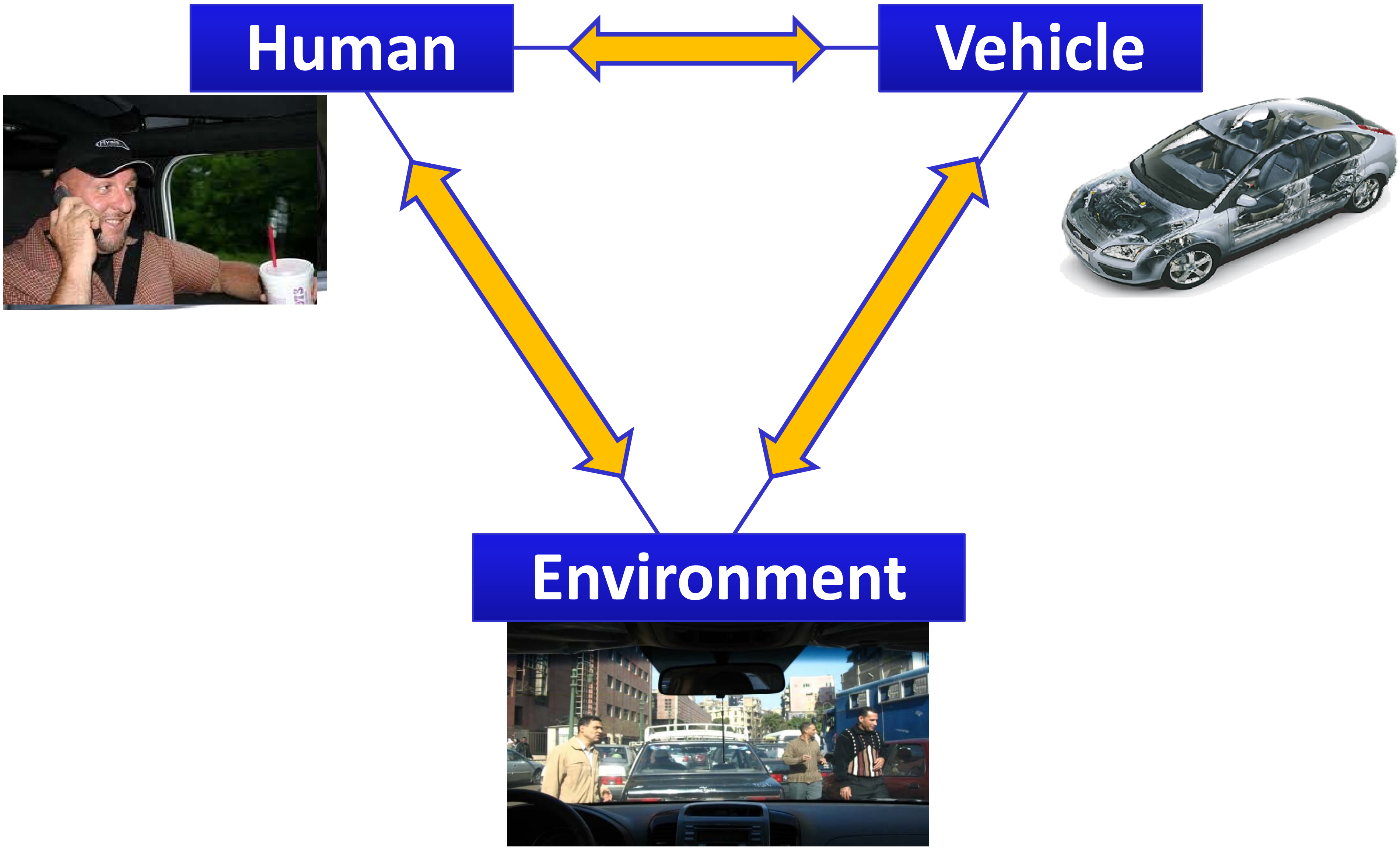

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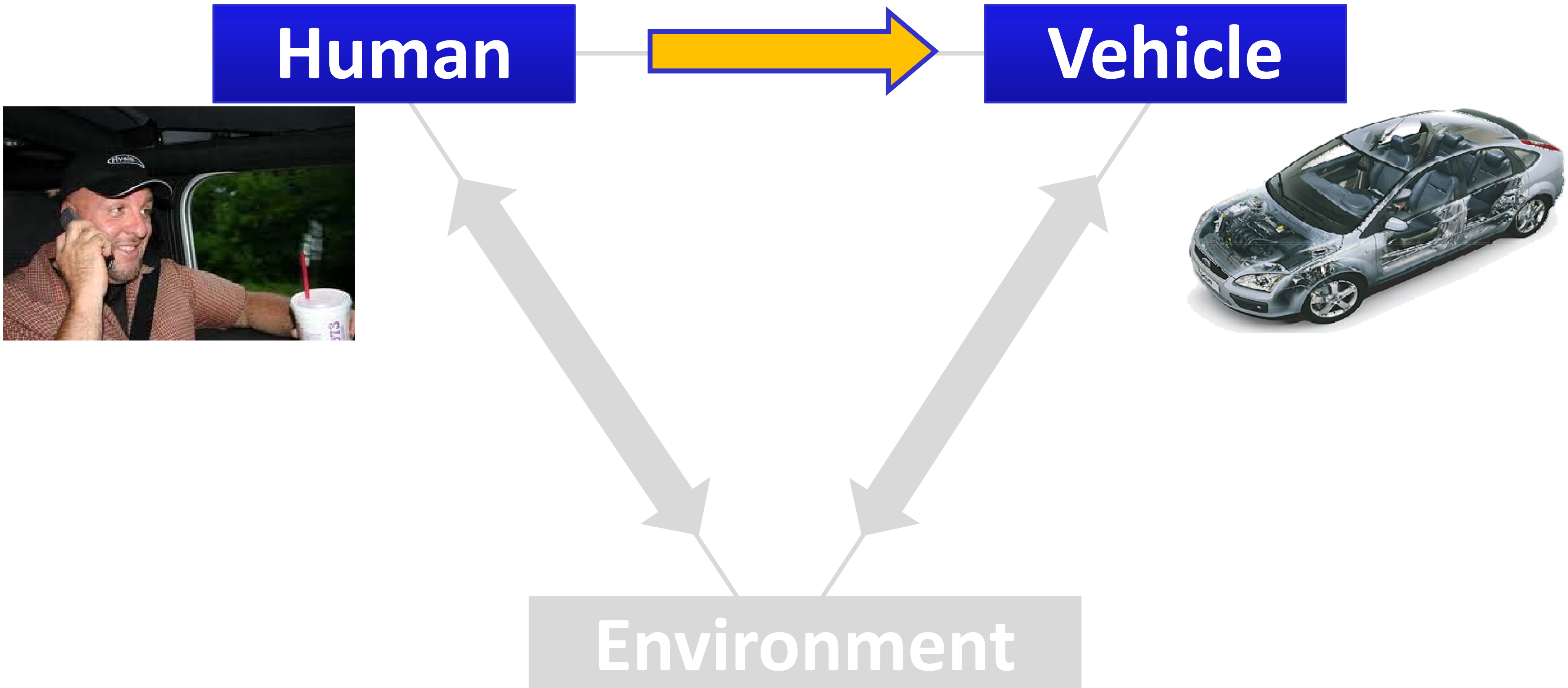
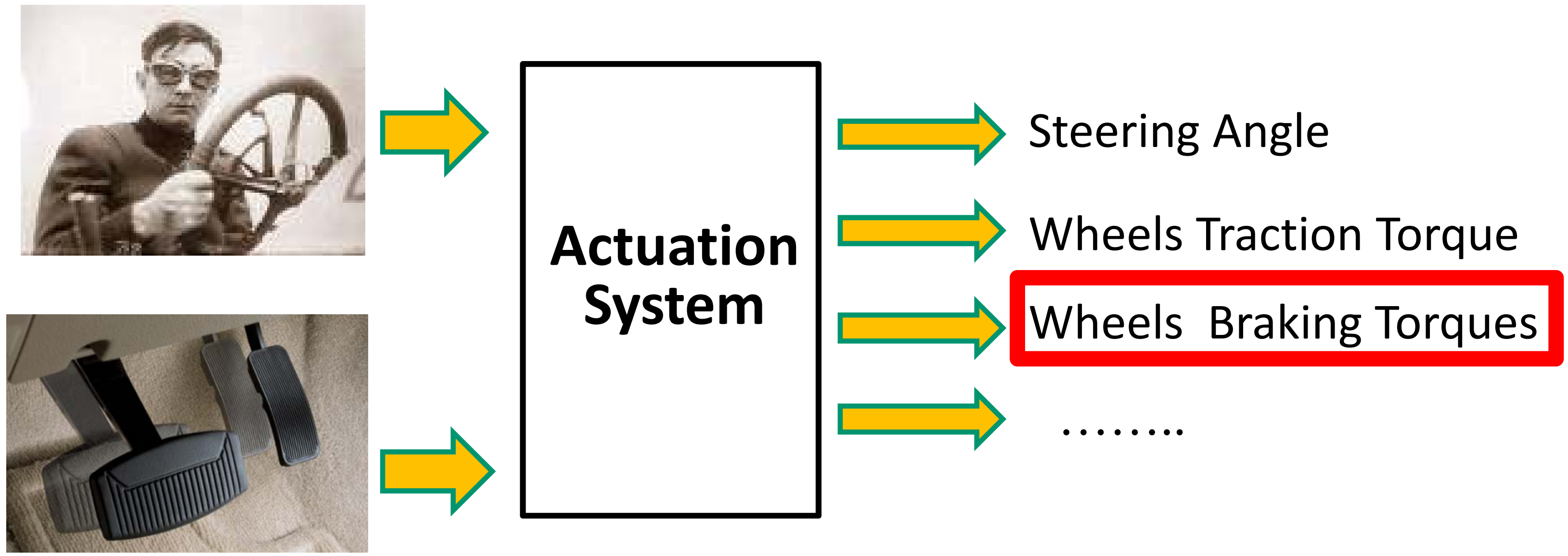


Human-Vehicle Interaction

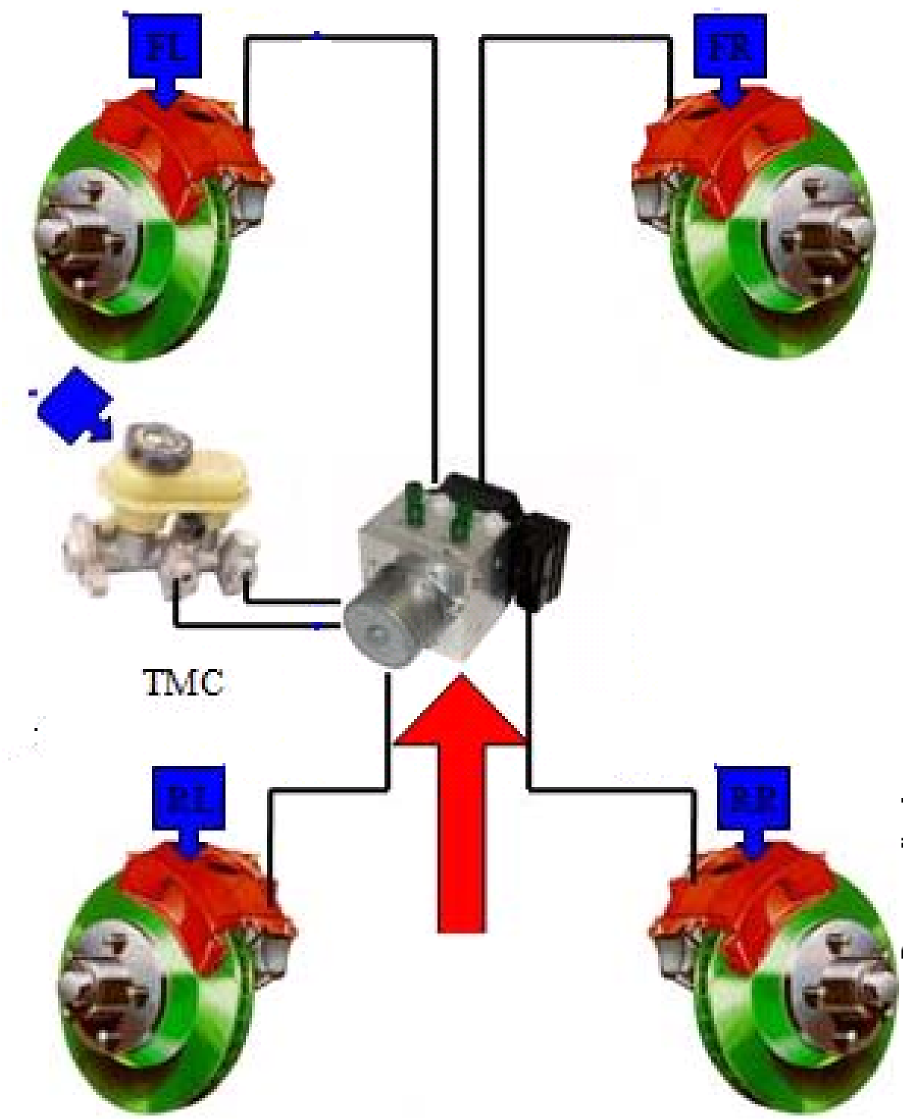
Actuation System

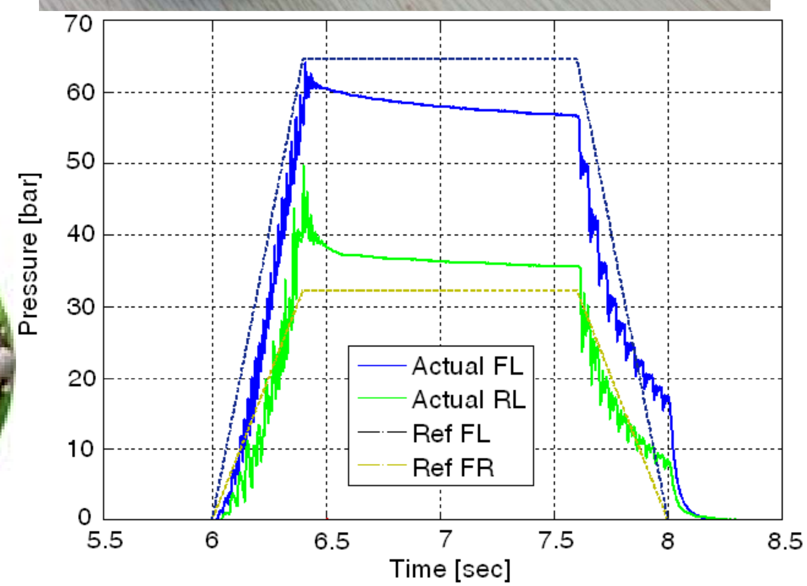
- Steering Angle
- Wheels Traction Torque
- Wheels Braking Torques
- ....

Human-Vehicle Interaction



Hydraulic Brake Unit





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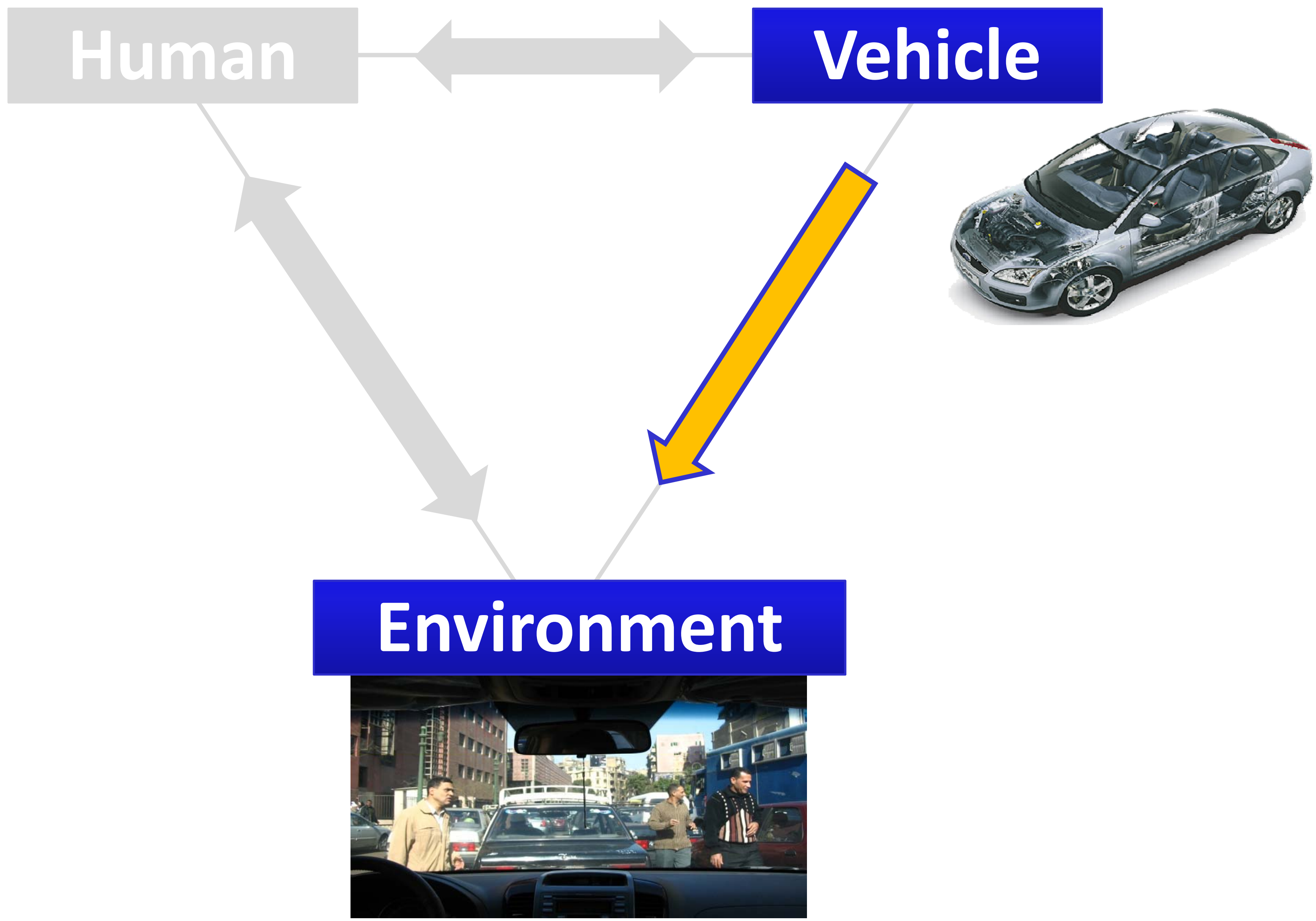
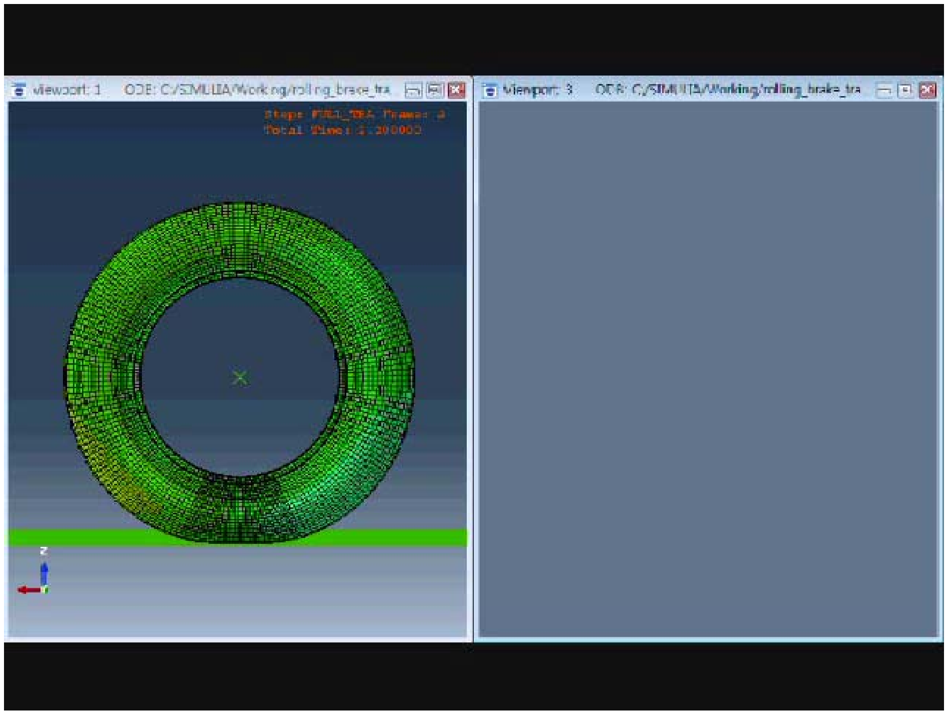
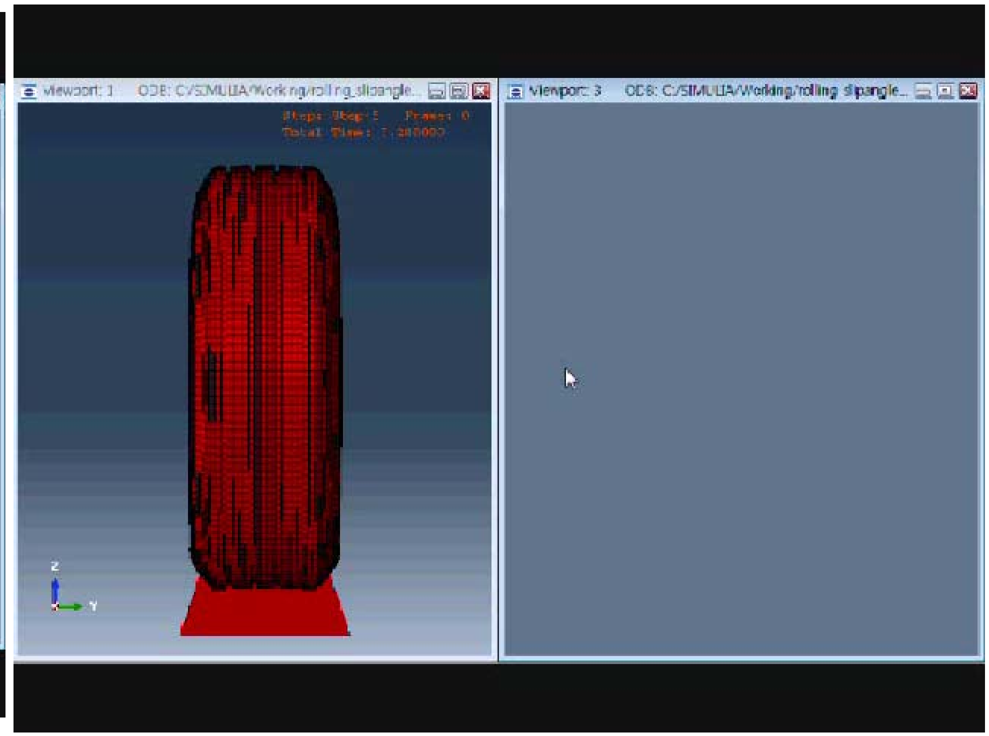


Vehicle-Road Interaction
FEM Simulation





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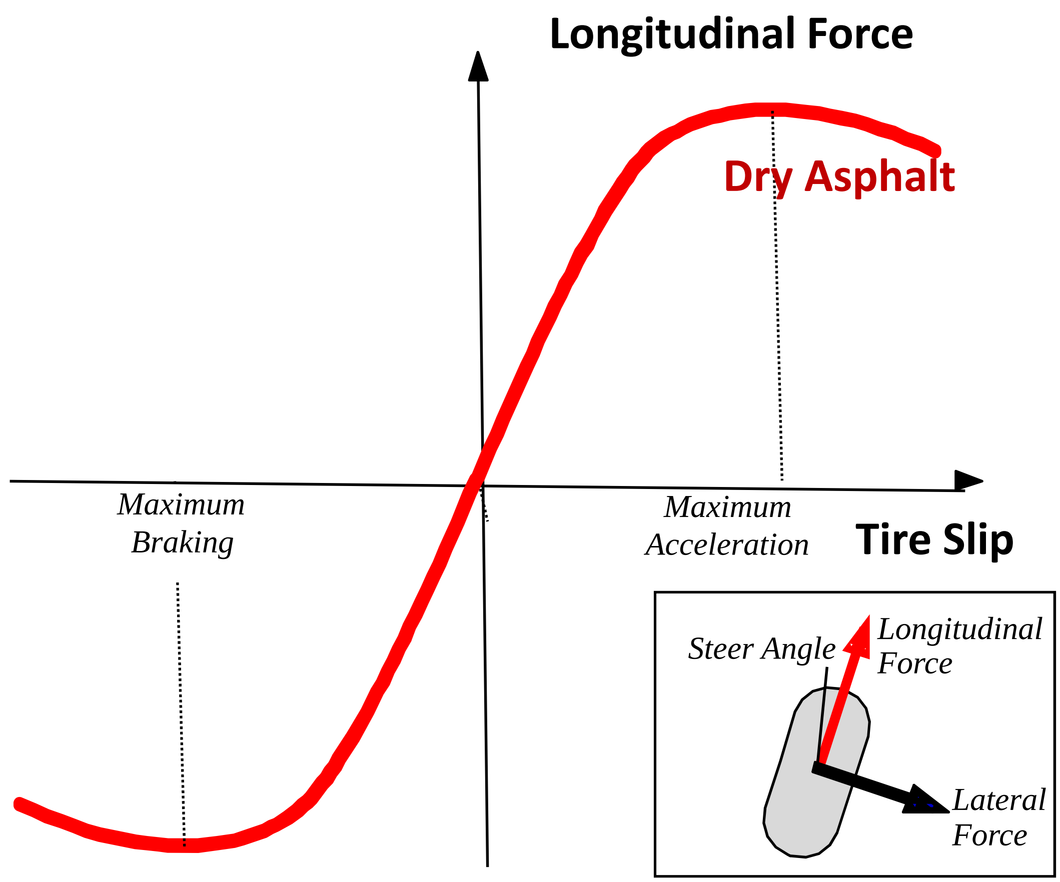
Vehicle-Road Interaction
Simplified Models



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Vehicle-Road Interaction
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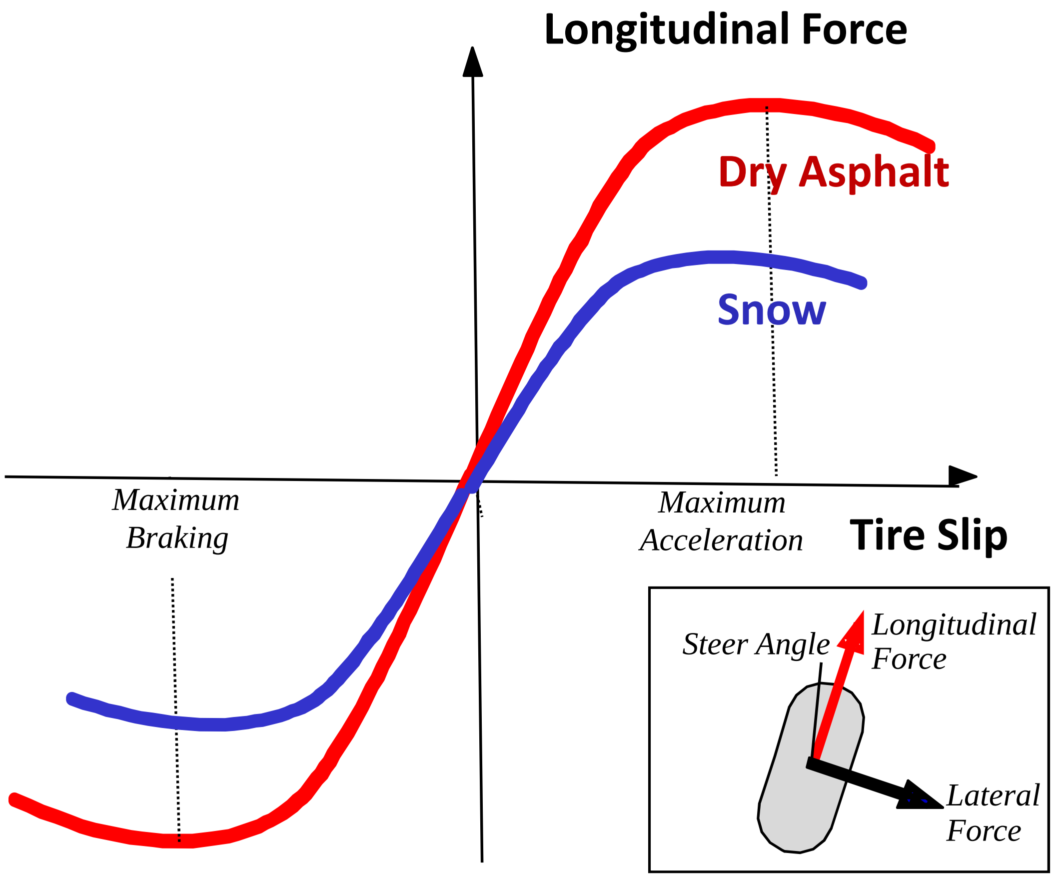

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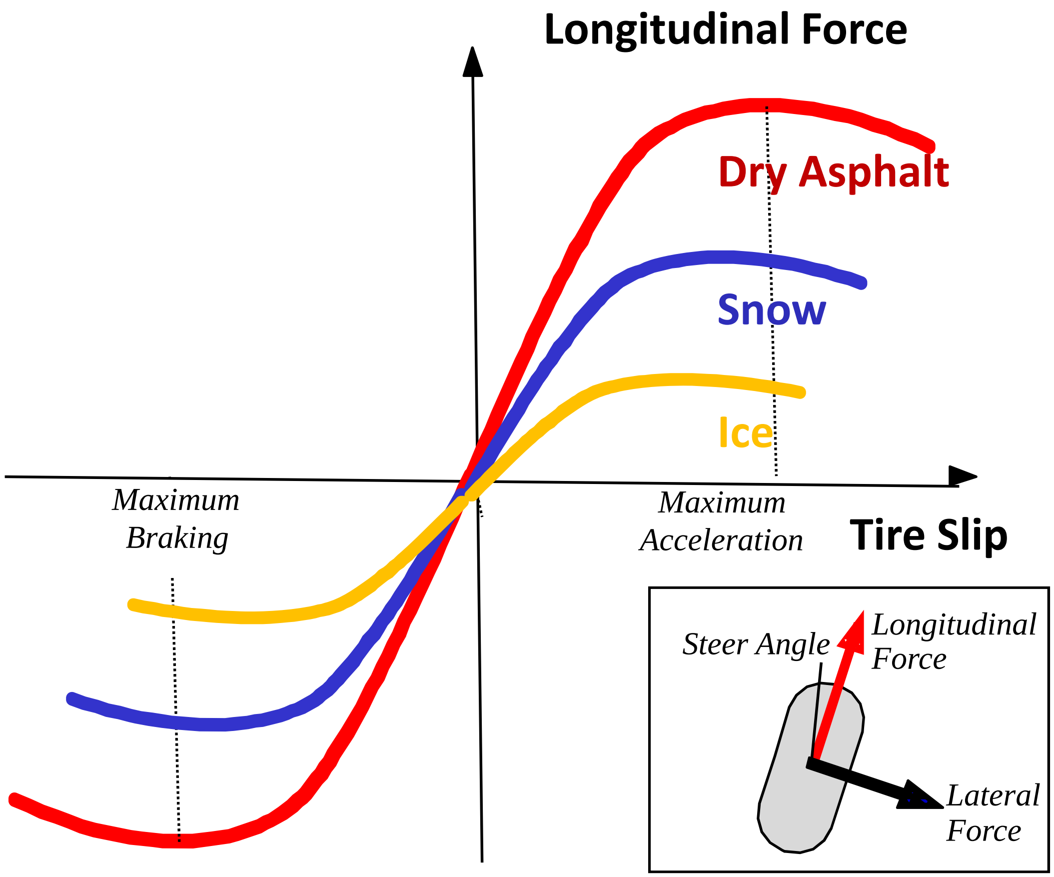

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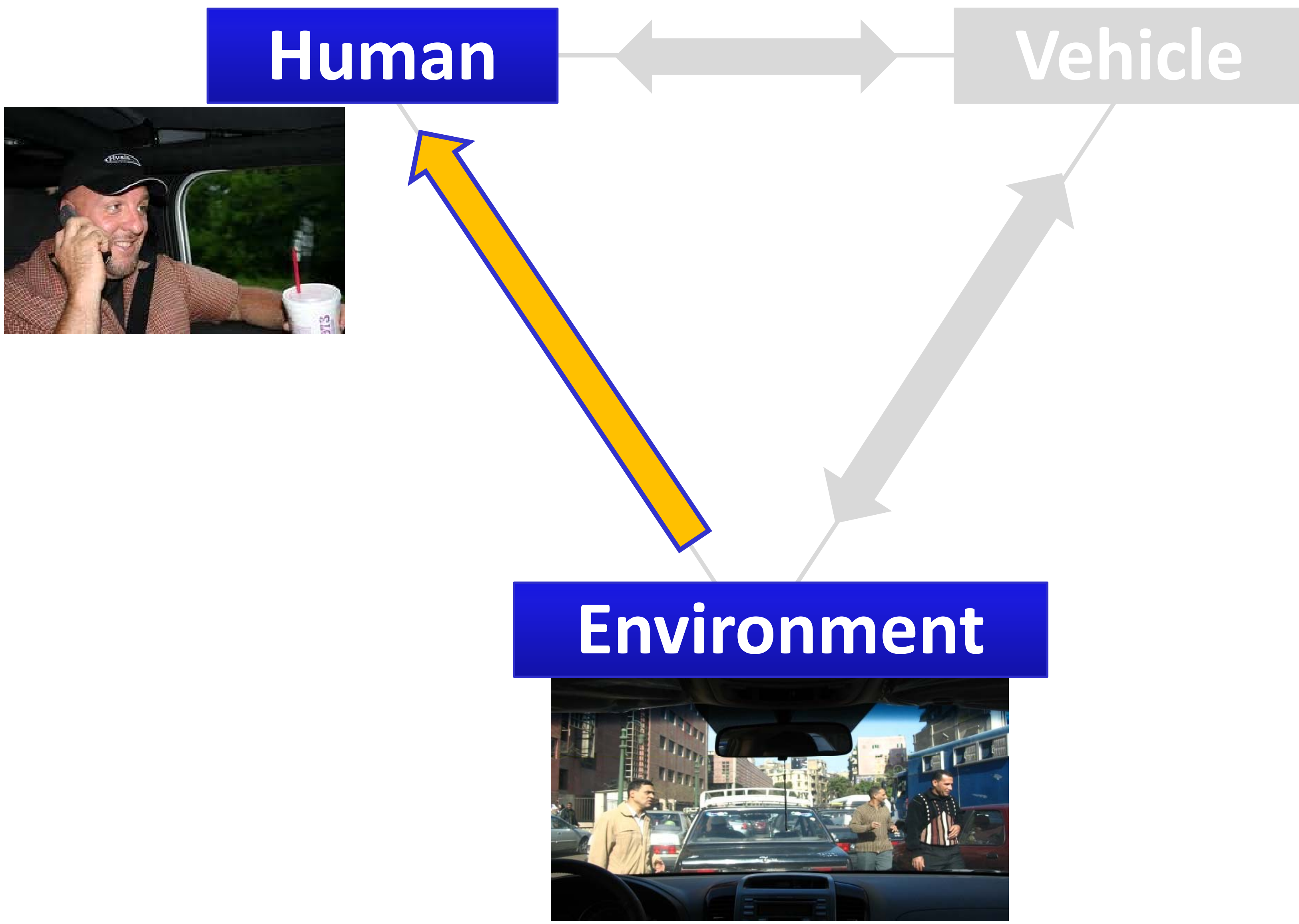
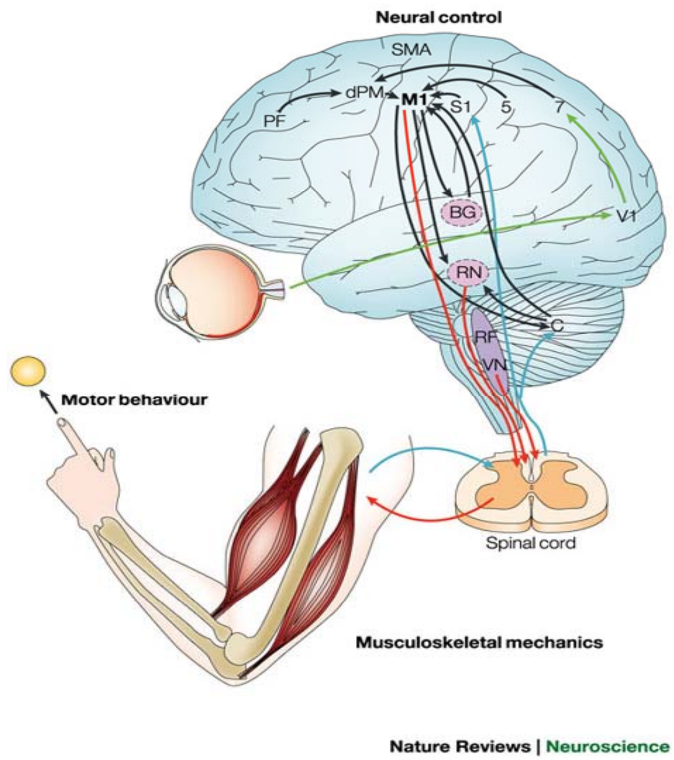
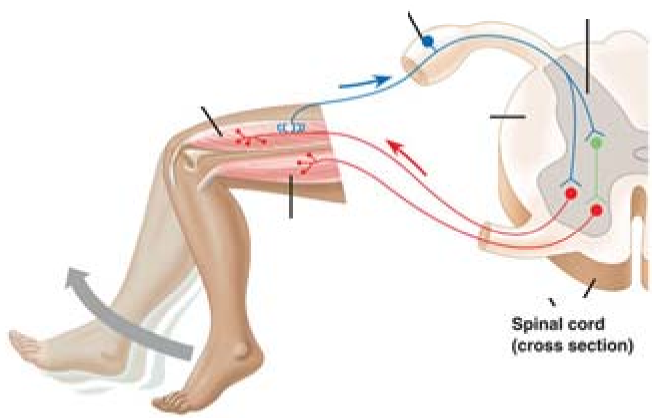


Environment-Human Interaction





Sensory Inputs

Brain

Spinal Cord

Muscles

http://www.nature.com/nrn/journal/v5/

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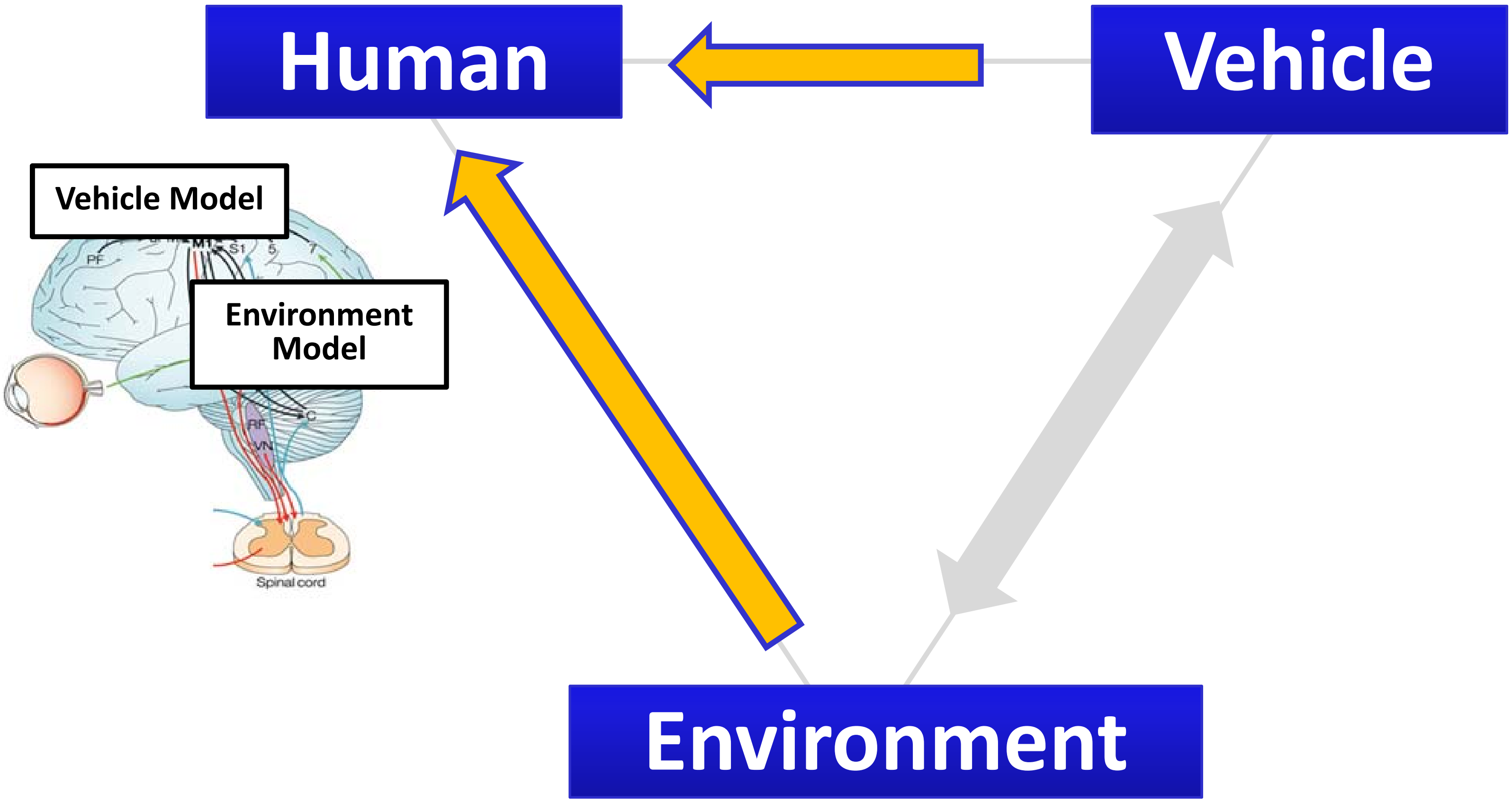
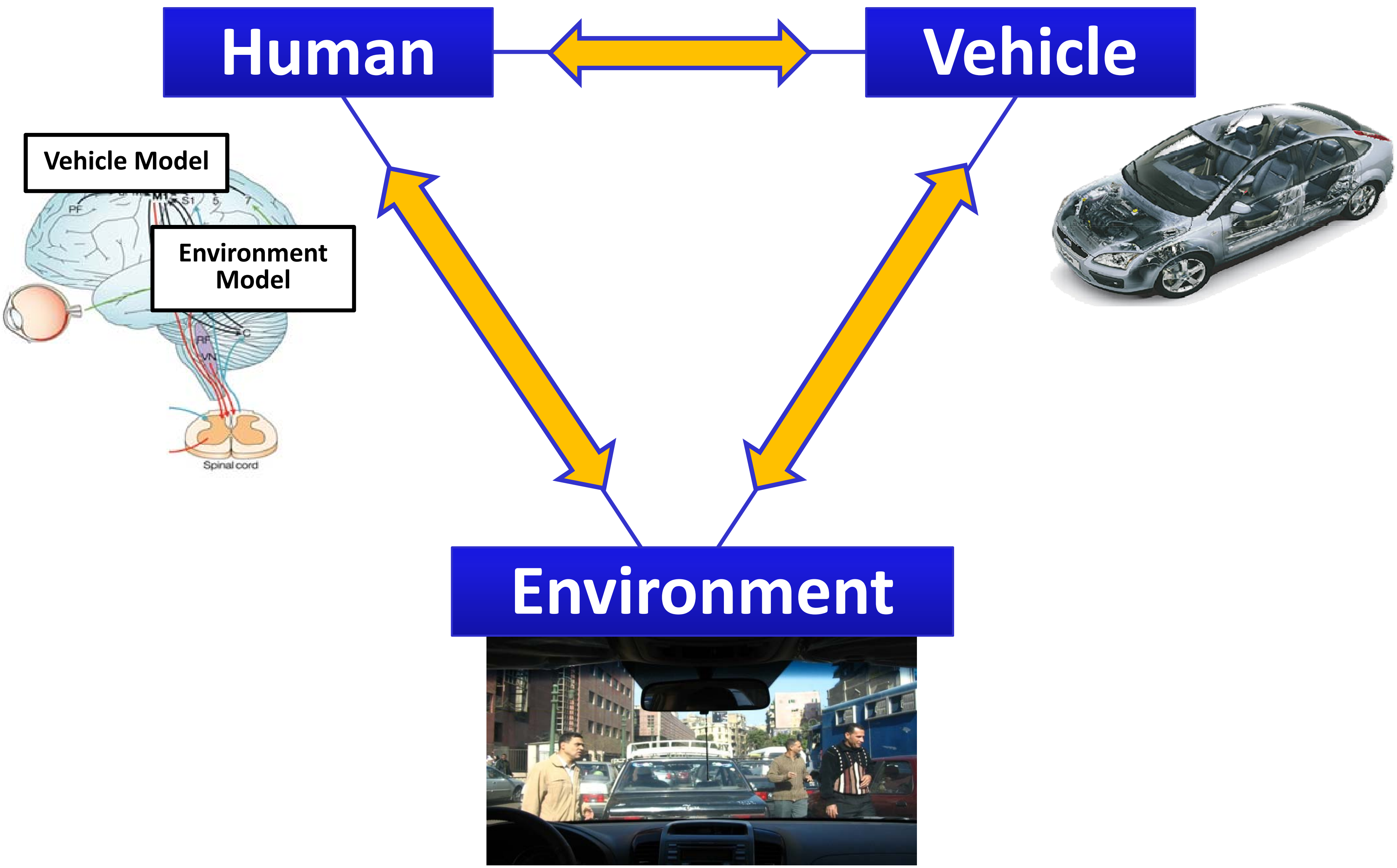


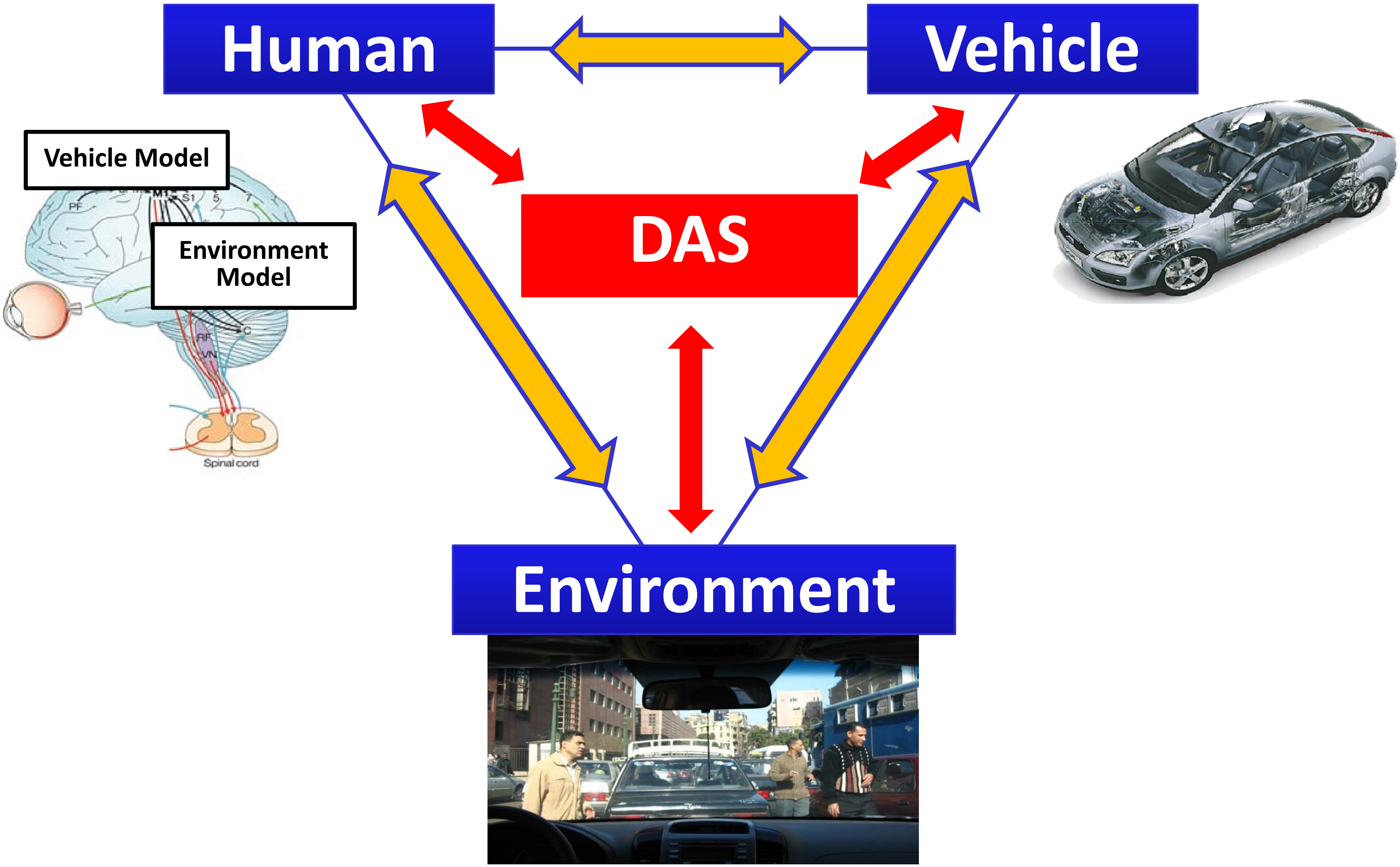
``We know that a lot of the brain has an internal neural simulator"… "to anticipate or predict the future for a given a input"

Eric Kandel (Charlie Rose interview, 2008)

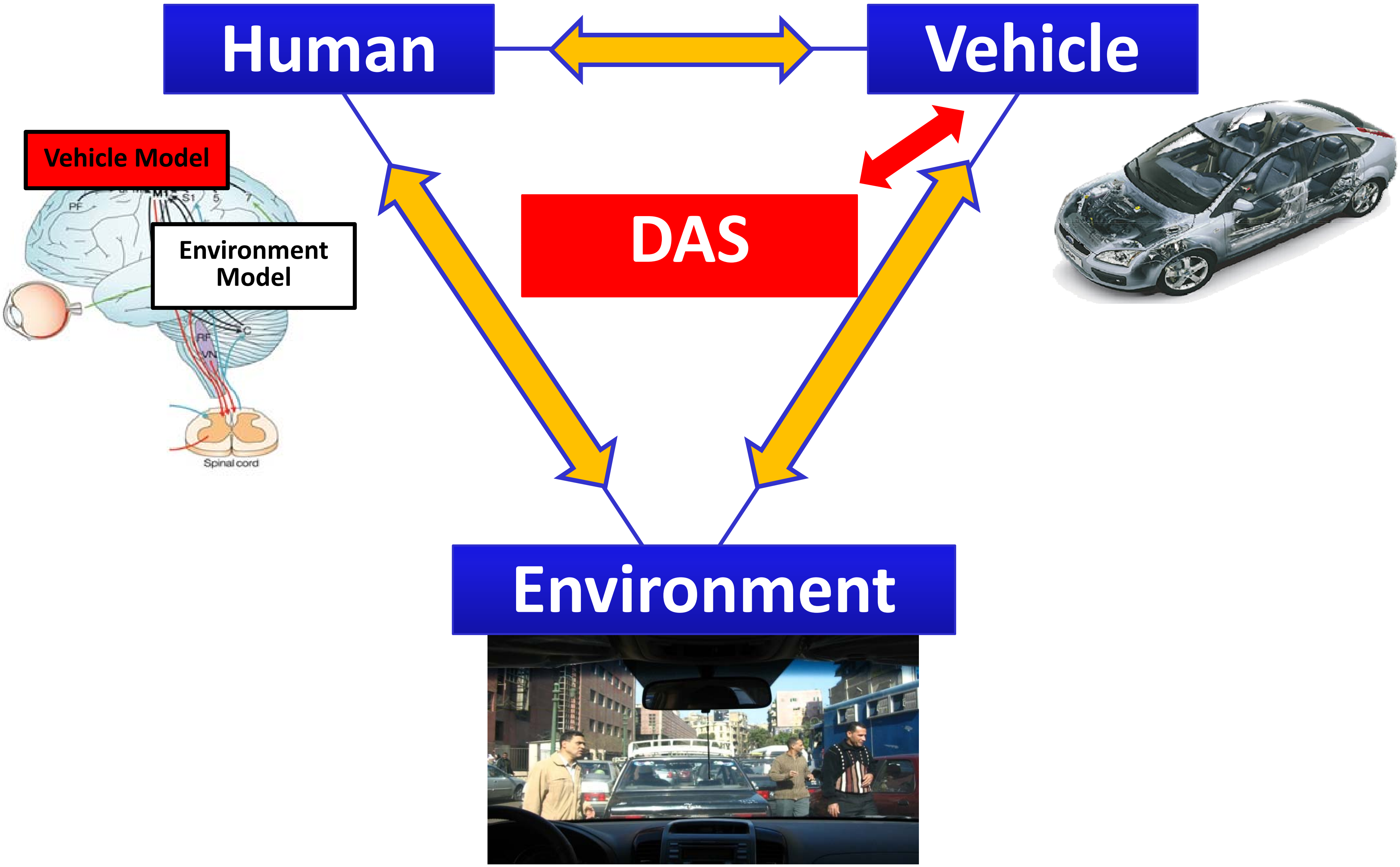
CPS-Synoptic Scheme



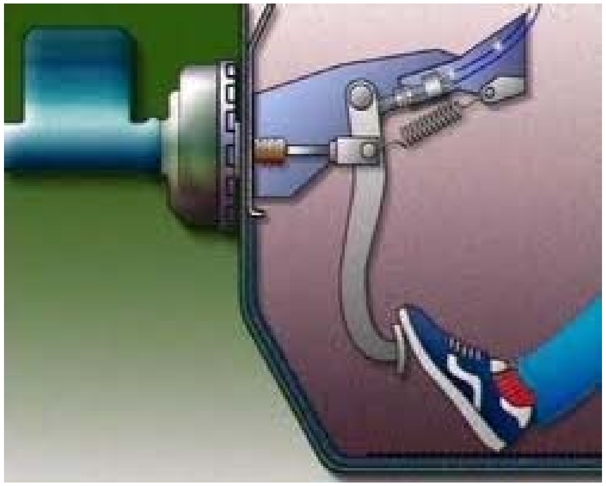
CPS with Driver Assistance System (DAS)

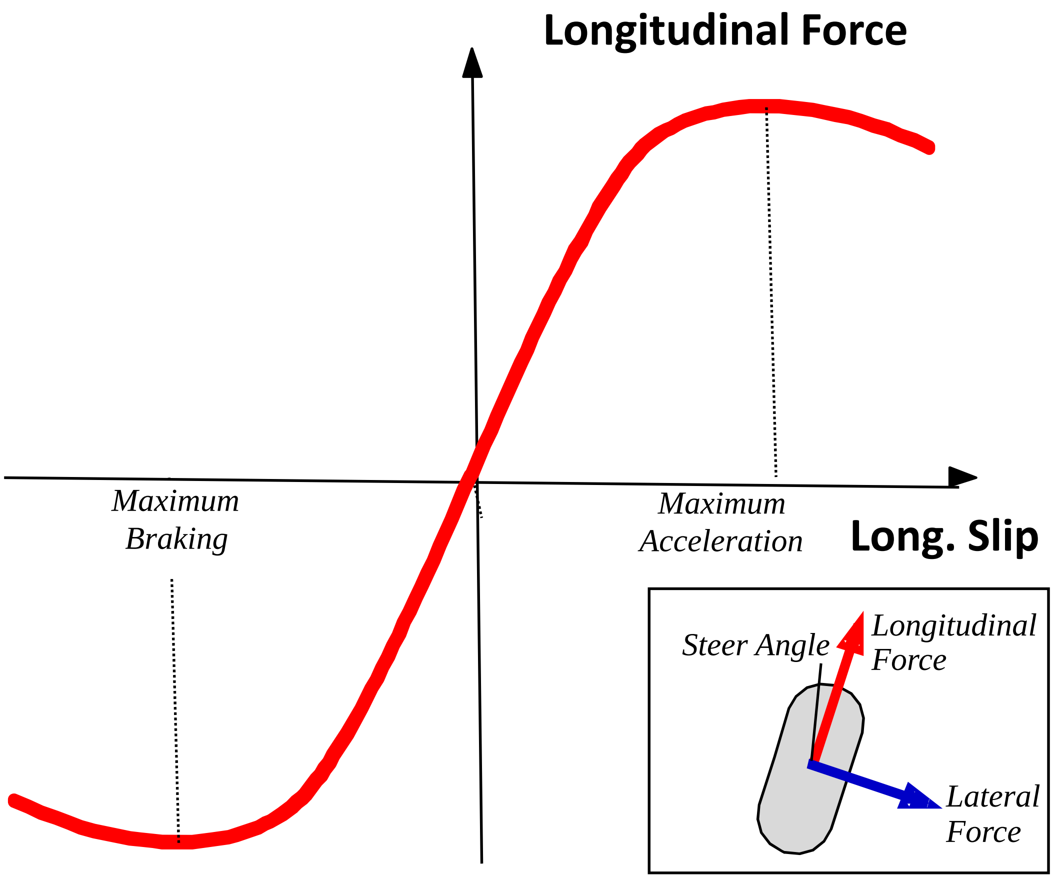


Vast Majority of DAS systems



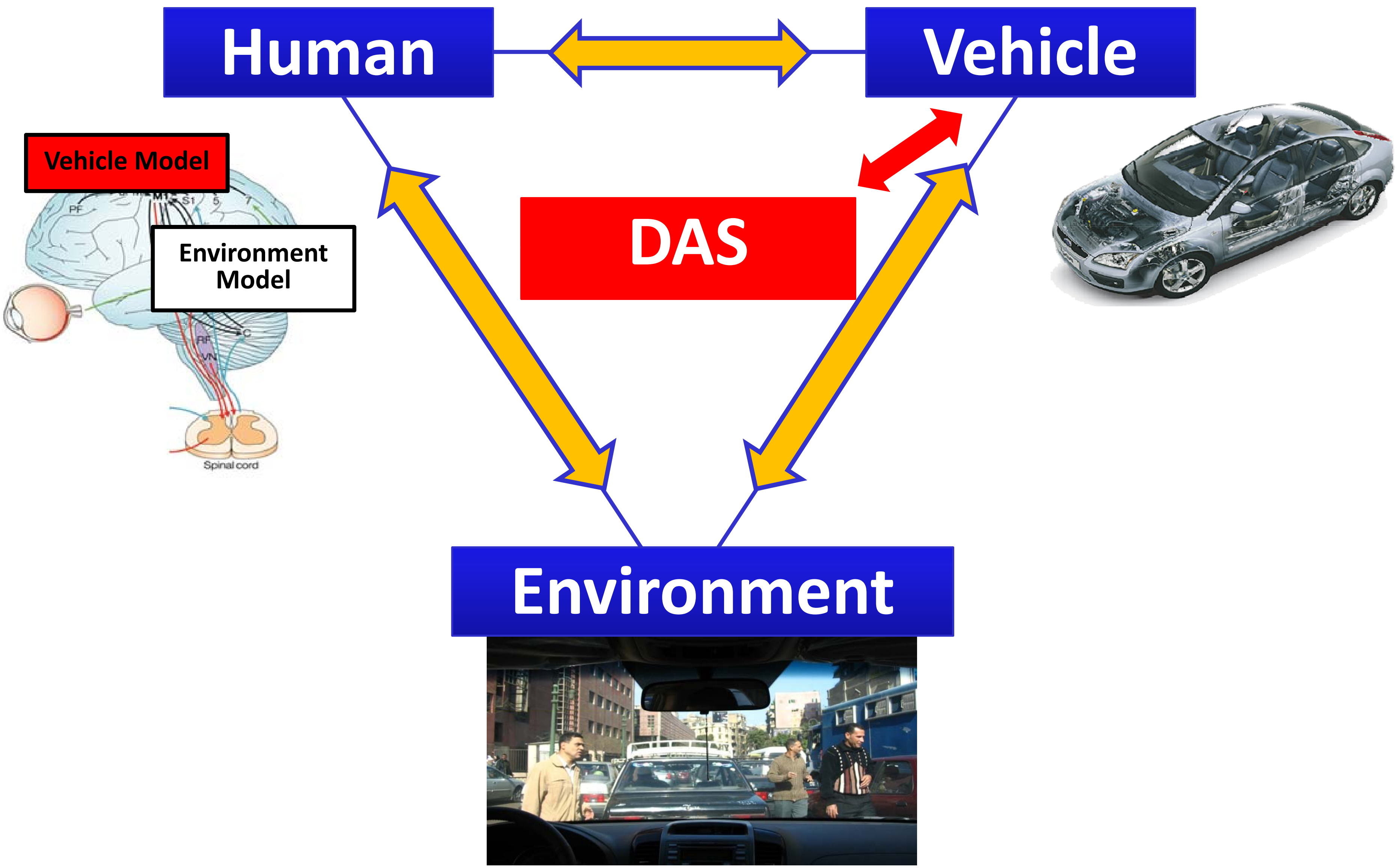
Anti-lock Braking Systems





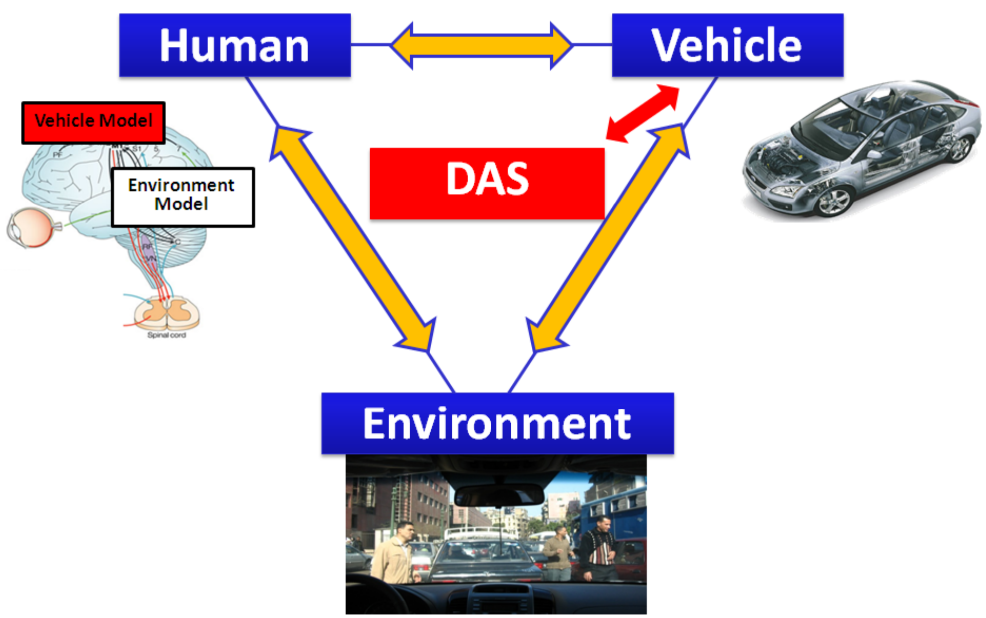
Counter-Steering and Over-Steering

Vast Majority of DAS systems



Vehicle CPS Main Issues

- Complexity/Compositionality…
- "Shy" Autonomy
- No Guarantees/Heuristic Tunings
- Human MotionPerception/Cognition Ignored



CPS Main Issues

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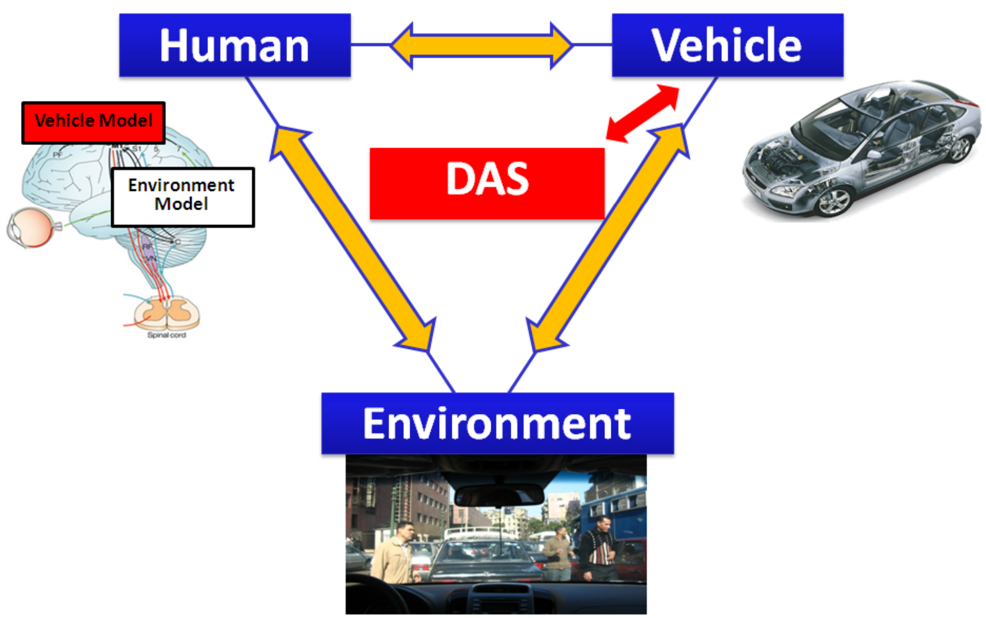
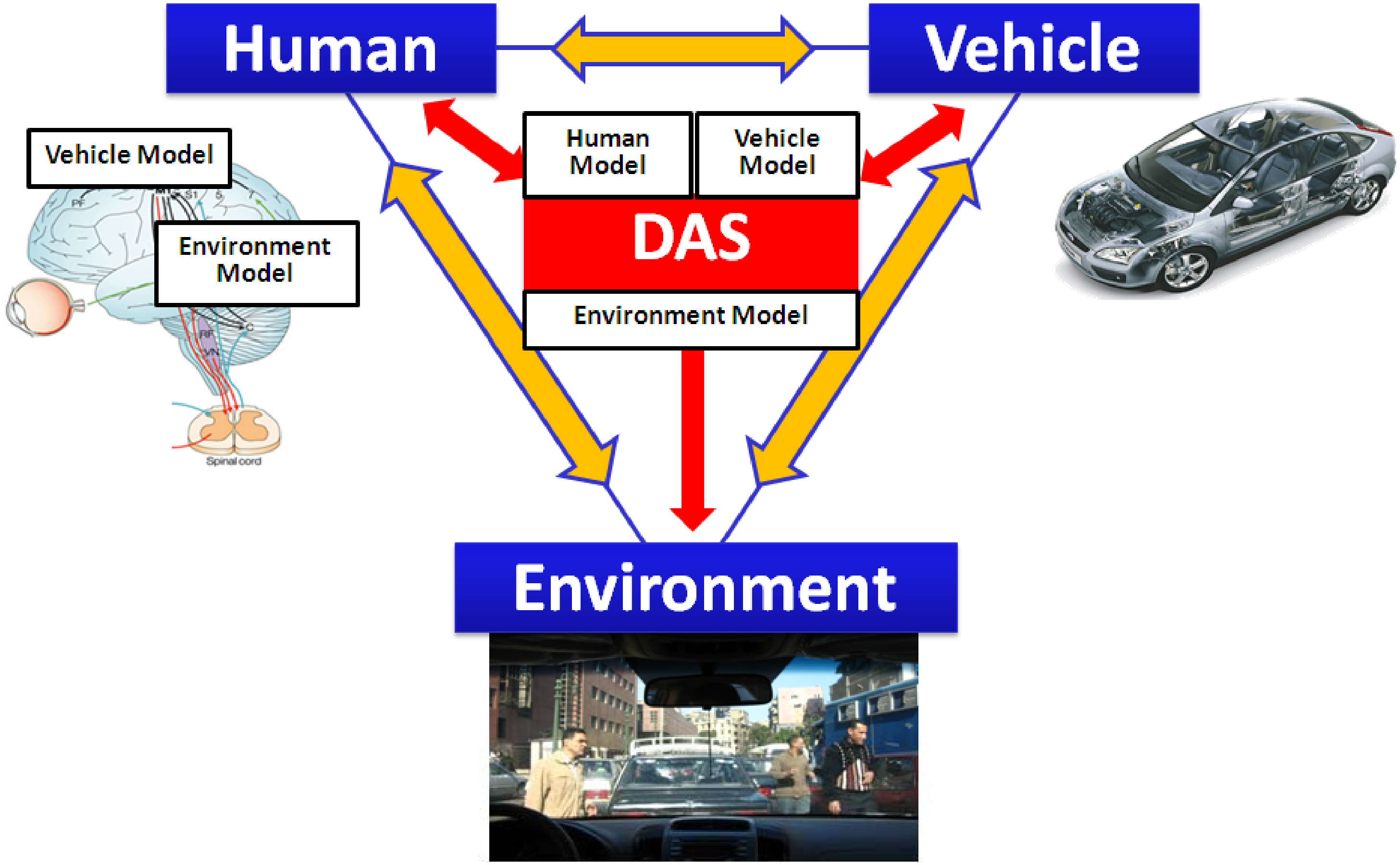


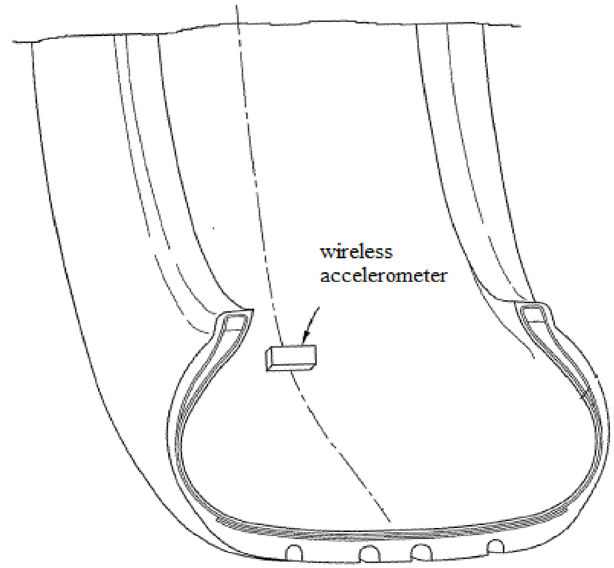
Research Goals

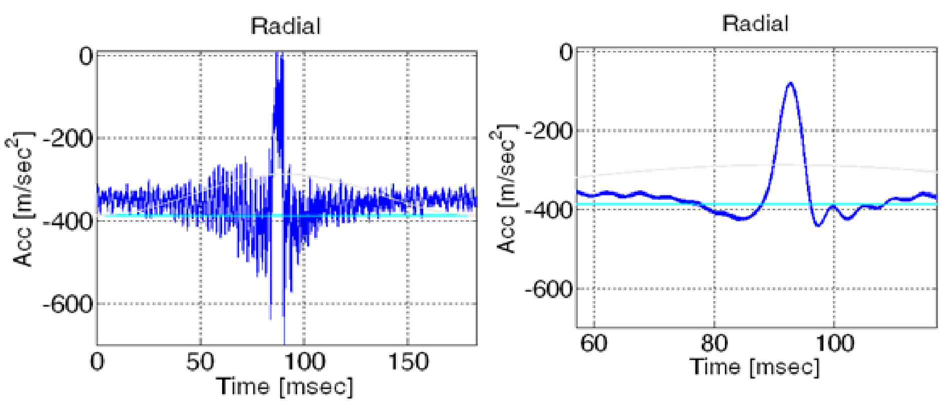
Provably Safe and Adaptive Autonomy

Quantifying Uncertainties (Human and Environment)



Quantifying Uncertainties: Tire/Road Interaction

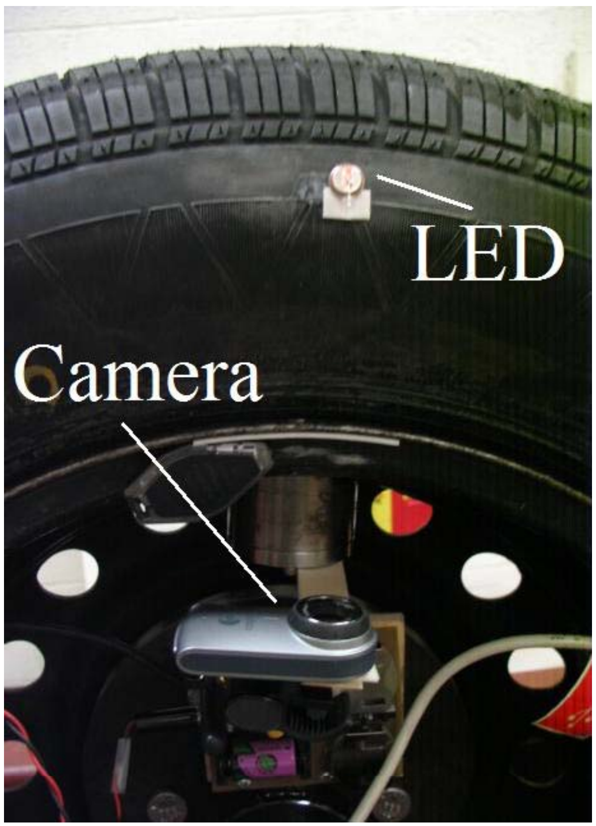


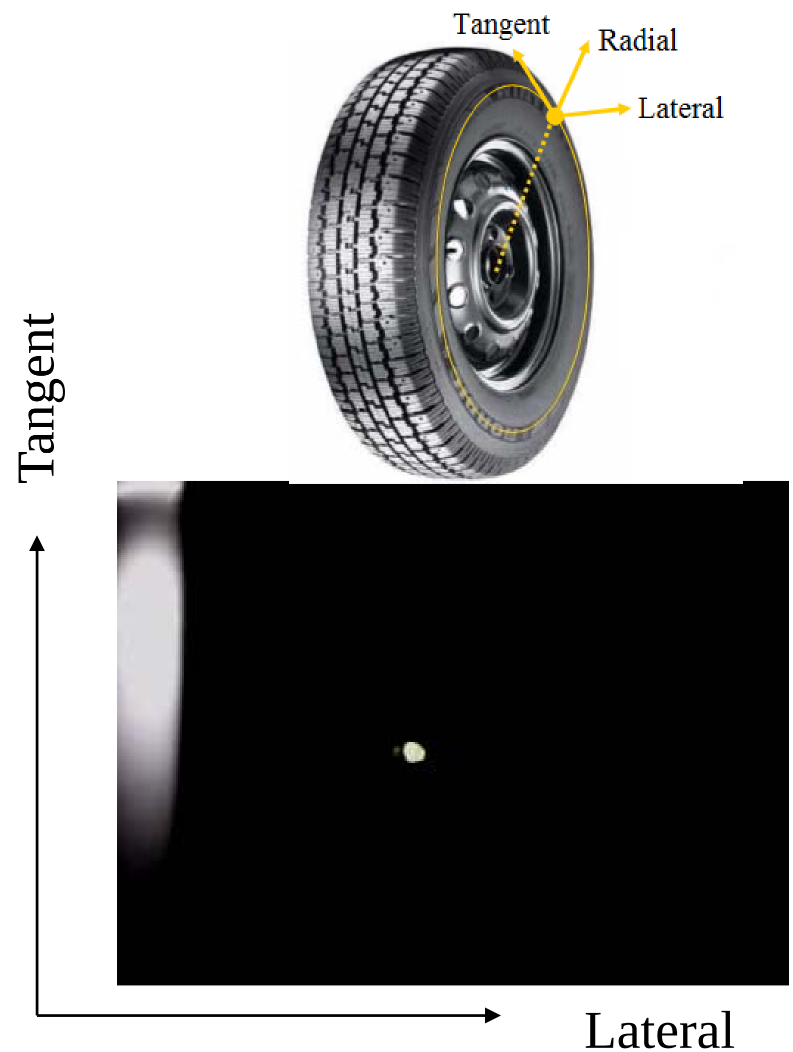


CYBER™TYRE

Quantifying Uncertainties: Tire/Road Interaction

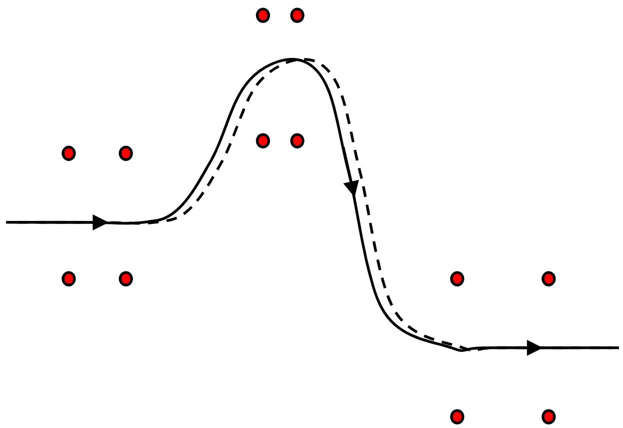
Tangential and Lateral Sidewall

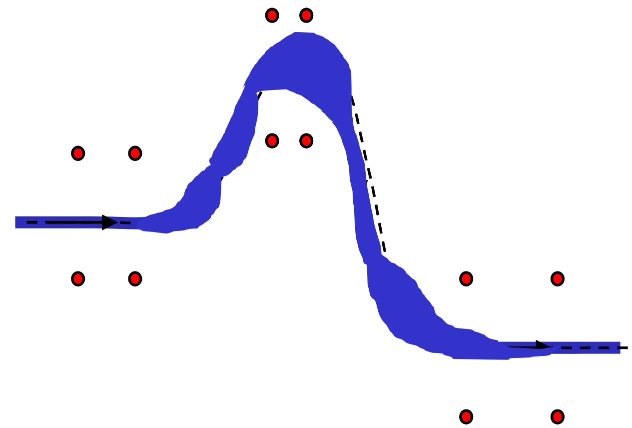




Quantifying Uncertainties: Driver Models

Objective: Exploit real-time driver state (joint angles) detection to extract compatible set of trajectories



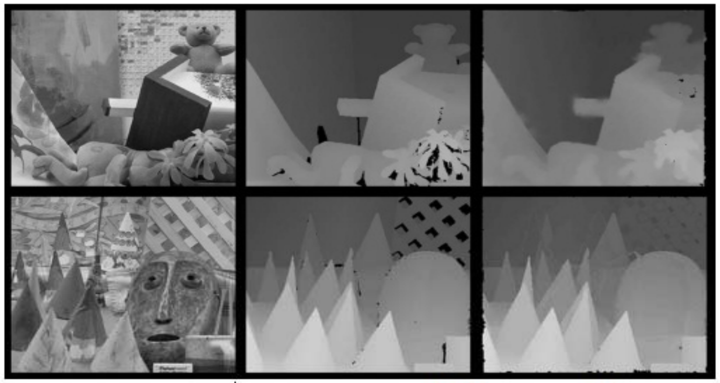


Methodology:

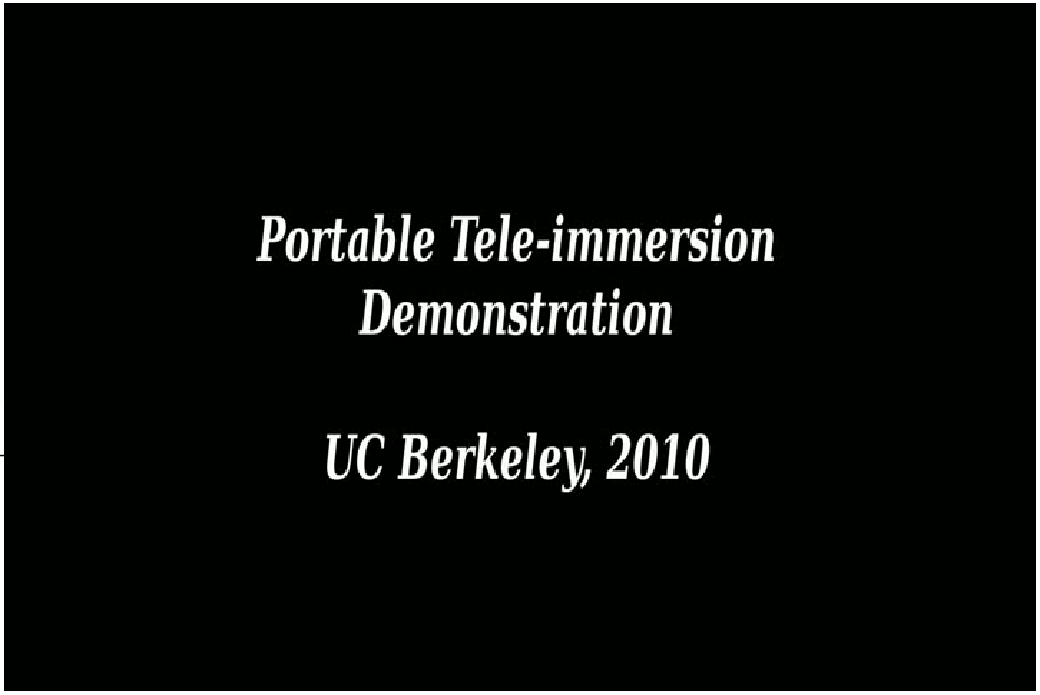
1-Stereo cameras for 3D reconstruction of the scene

2- Articulated tracking, use body sensor network for validation

Real-Time 3D Reconstruction and the Middlebury Stereovision Dataset

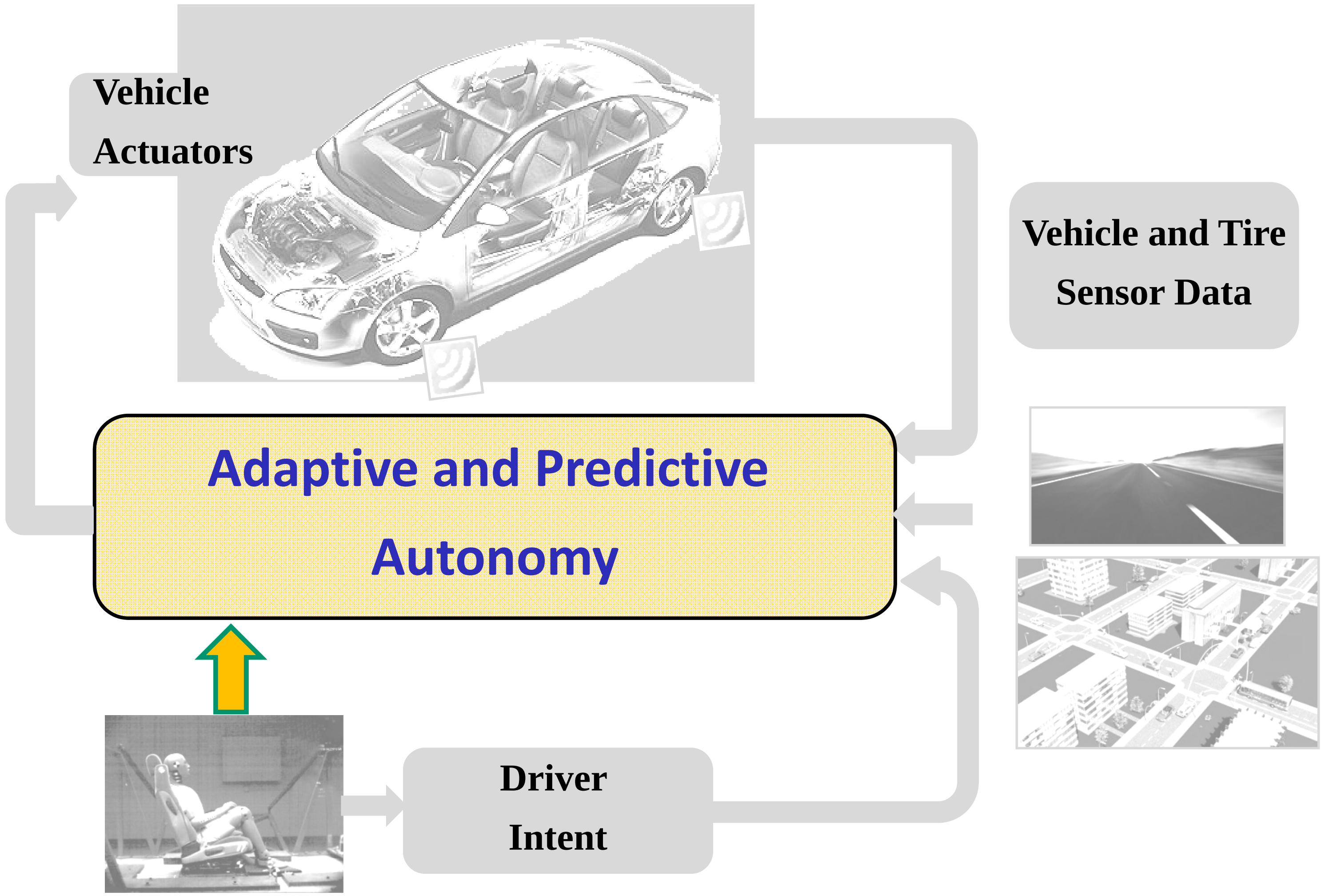


Process	Our's	Wang	Bleyer
Teddy 1-Pixel Error	7.15%	8.31%	6.54%
Teddy Speed	42.1ms	20s	100s
Cone 1-Pixel Error	7.56%	7.18%	8.62%
Cone Speed	53.8ms	20s	100s



Real-Time 3d Reconstruction Driver

Provably Safe Adaptive Autonomy



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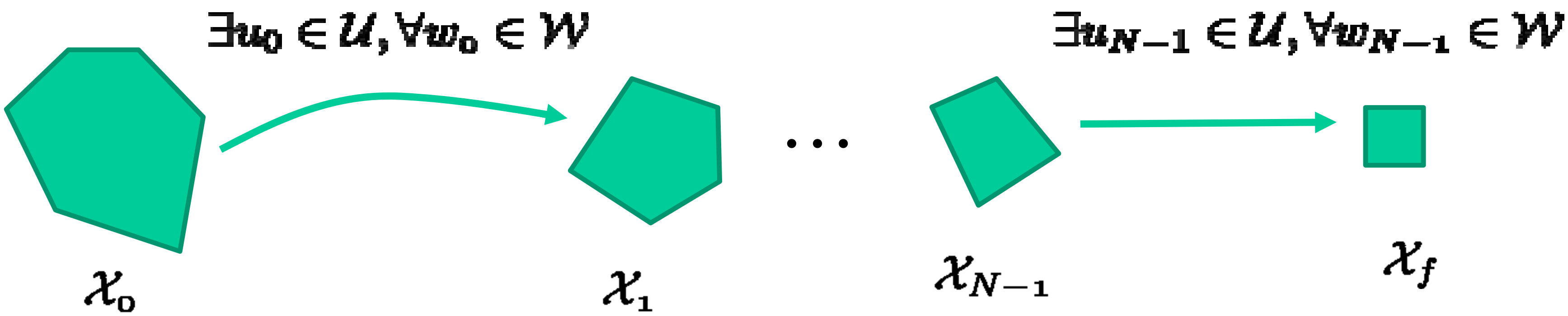
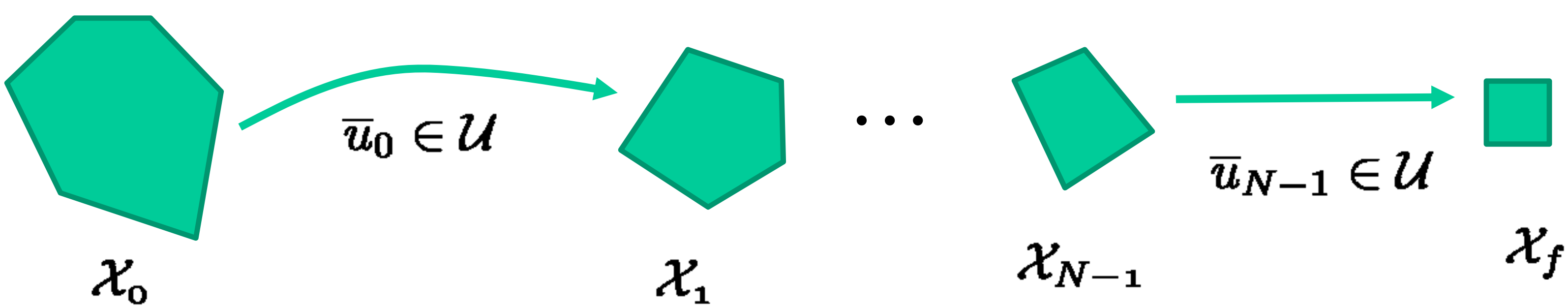
Set-Based Control Design

$$x_{k+1} = f(x_k, u_k, w_k), x_k \in \mathcal{X}, u_k \in \mathcal{U}, w_k \in \mathcal{W}$$

- **Compute N-steps controllable set**



- **Given x_j compute $\overline{u}_j$ such that** $x_{j+1} \in \mathcal{K}_{j+1}, \forall w_j \in \mathcal{W}$



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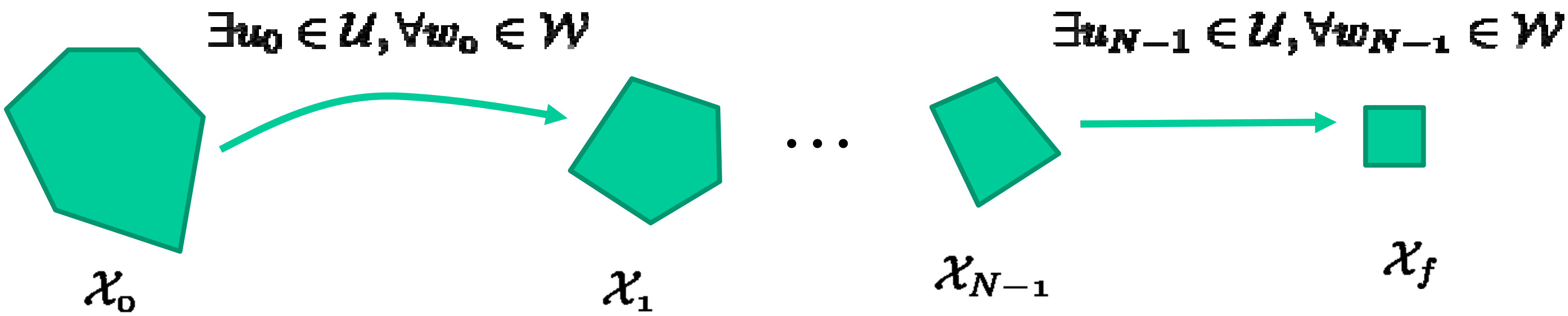

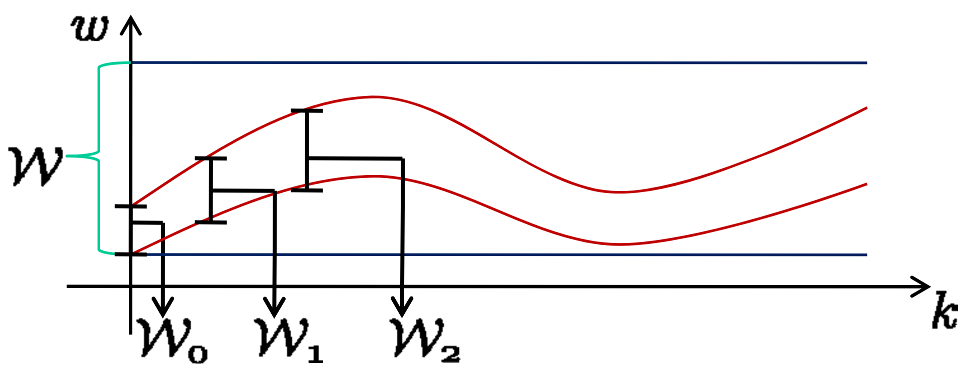

Benefit in Autonomy Concept

At time j

- Driver intent w_j
- Among all possible actuations $\overline{u}_j$ choose the one that solves

$$min_{u_j} \; \|u_j - w_j\| \; subj.to. \; x_{j+1} \in \mathcal{X}_{j+1}$$

Adaptive and Predictive Autonomy

Main Limitation: Real-Time Computation

``Predictive Control": Borrelli, Bemporad Morari

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- PWA Model

$$x_{k+1} = A^i x_k + B^i u_k + E^i w_k - C^i \quad if\,[x_k, u_k] \in \mathcal{P}^i$$

- One-step robust controllable set

$$\mathcal{X}_j(S) = \{x \in \mathcal{X} | \exists u \in \mathcal{U},\ s.t.\ f(x,u,w) \subseteq S, \forall w \in \mathcal{W}\}$$

-For linear (A,B) system: $\mathcal{X}_j(S) = (\mathcal{X} \ominus \mathcal{W} \oplus (-BU))A$

-For linear systems, result is polytope

-For PWA systems, result is union of polytopes

Process Industry

4Ghz, 1 Terabyte

Automotive

50Mhz, 2 Mbytes

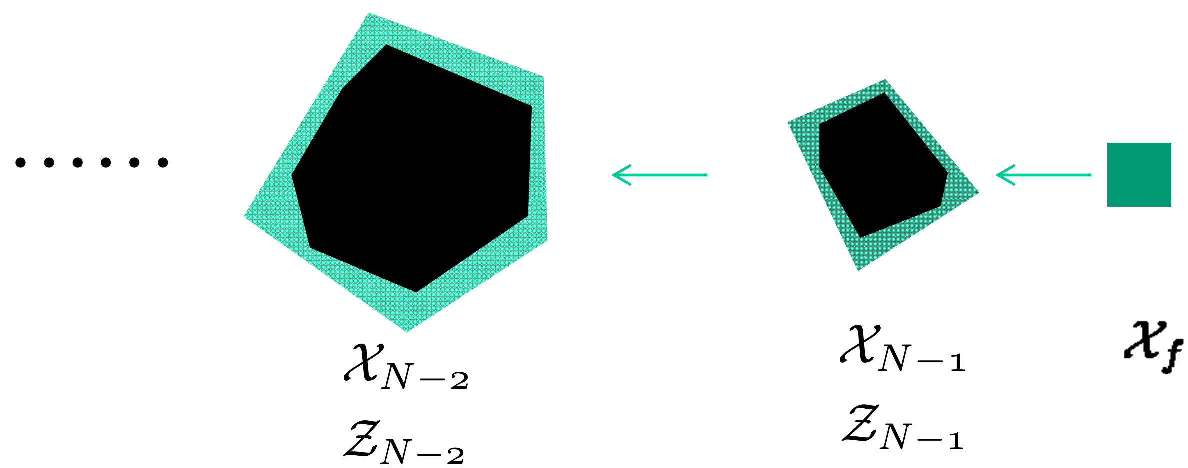
Safe Control Design Through Simplified Models

"True" System

$$x_{k+1} = f(x_k, u_k, w_k)$$
$$y_{k+1} = g(x_k)$$
$$x_k \in \mathcal{X}, u_k \in \mathcal{U}, w_k \in \mathcal{W}$$

Simplified System

$$z_{k+1} = h(z_k, u_k, w_k)$$
$$s_{k+1} = k(z_k)$$
$$z_k \in \mathcal{Z}, u_k \in \mathcal{U}, w_k \in \mathcal{W}$$



$\mathcal{Z}_k$: k-step controllable set for "True" System when control law designed for simplified system is applied.

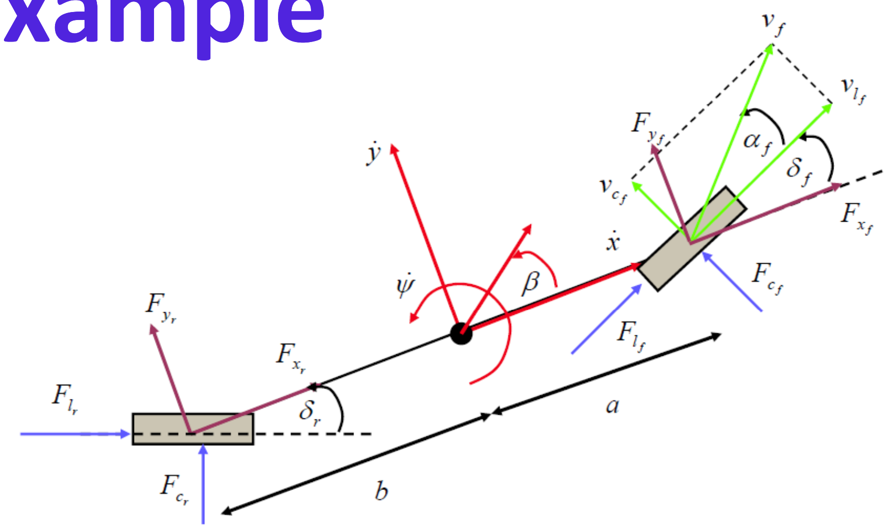
2D Example

States: $\dot{y}, \dot{\psi}$

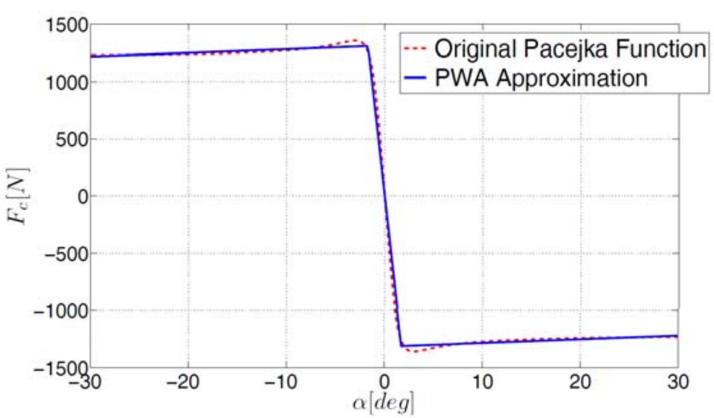
Inputs: M

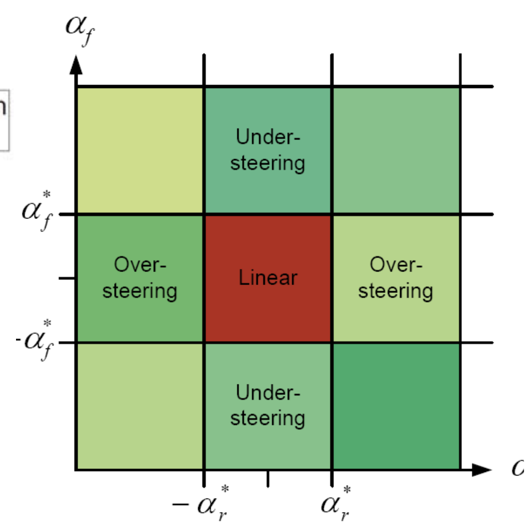
Disturbance: δ_f

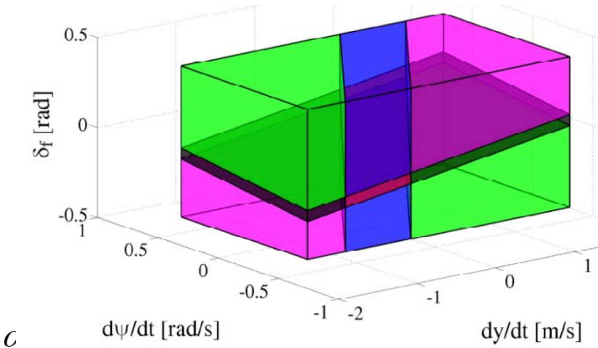
Assume constant: μ, V_x



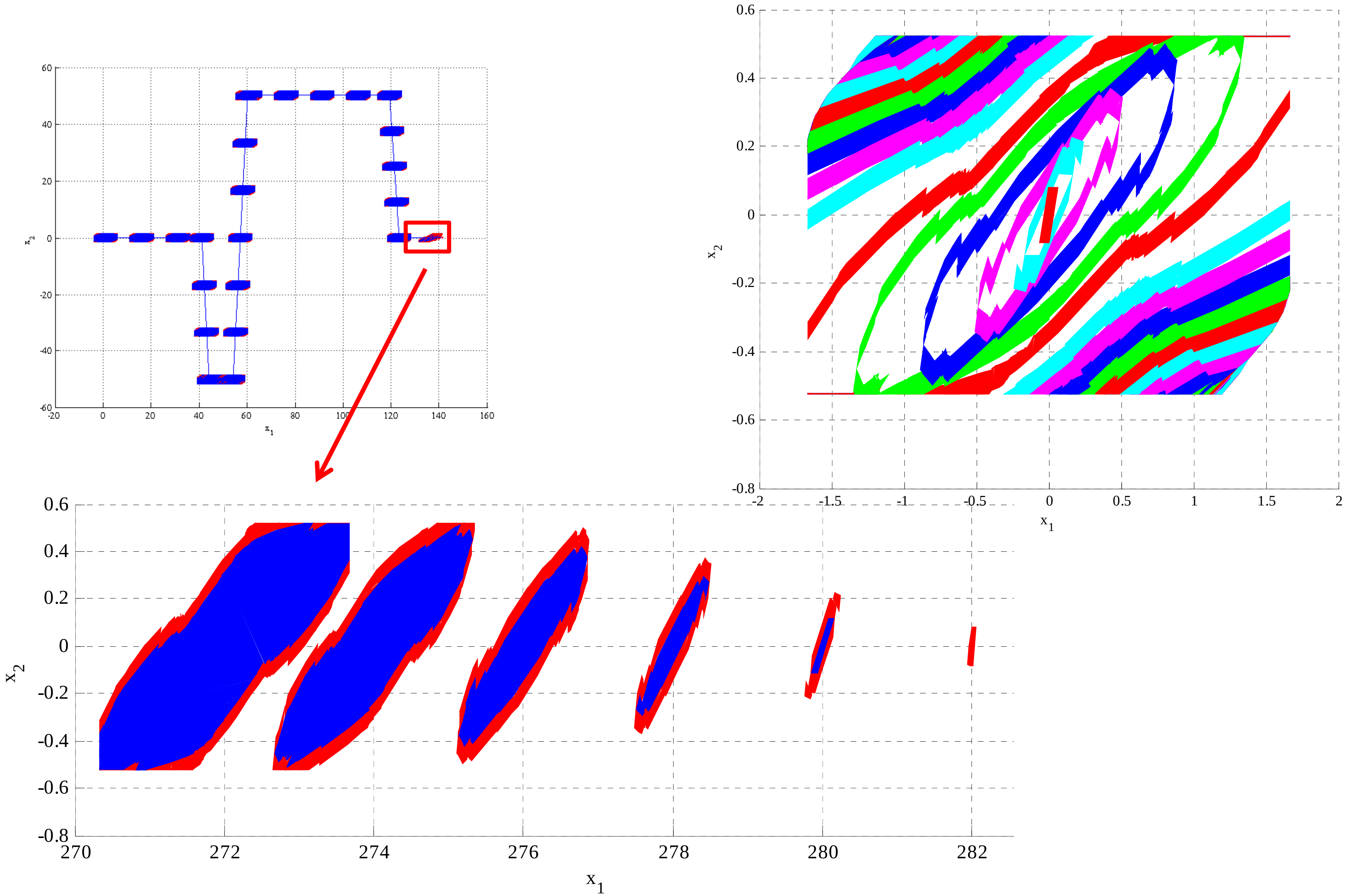
PWA approximation of Pacejka tire model







2D Example – Robust Set Computation



From 2-D to 12-D Example
Experimental results @ 72 Kph on Ice

LAPACK

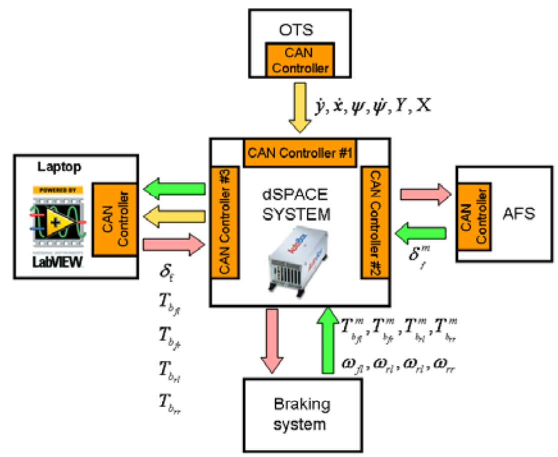
dSPACE

NAG

COIN OR

LabVIEW

Stanford Business Software Inc.
DISTRIBUTION OF SOL/UCSD OPTIMIZATION SOFTWARE



FORD RESEARCH LABORATORY

Ford

Conclusions/Outlook

- **Developing concept and methods for**
  Provably Safe Adaptive Autonomy
  – Quantifying uncertainties in
    - Vehicle/Road Interaction
    - Human/Car Interaction

  – Real-time Computation of Controllable Sets with different level of granularity

The Team

UC Berkeley

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- Yiqi Gao
- Ruzena Bajscy
- Karl Hedrick

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- Jahan Asgari, Eric Tseng, Davor Hrovat

Pirelli Research Labs (Milano,Italy)

- Federico Mancosu, Giorgio Audisio