TU Wien

Autonomous Emergency Braking: A System-of-Systems Perspective

H.Kopetz
S. Poledna
June2013

Outline

- Introduction
- Autonomous Emergency Braking
- Emergent Behavior
- Conflict Resolution
- Fault Mitigation
- Conclusion

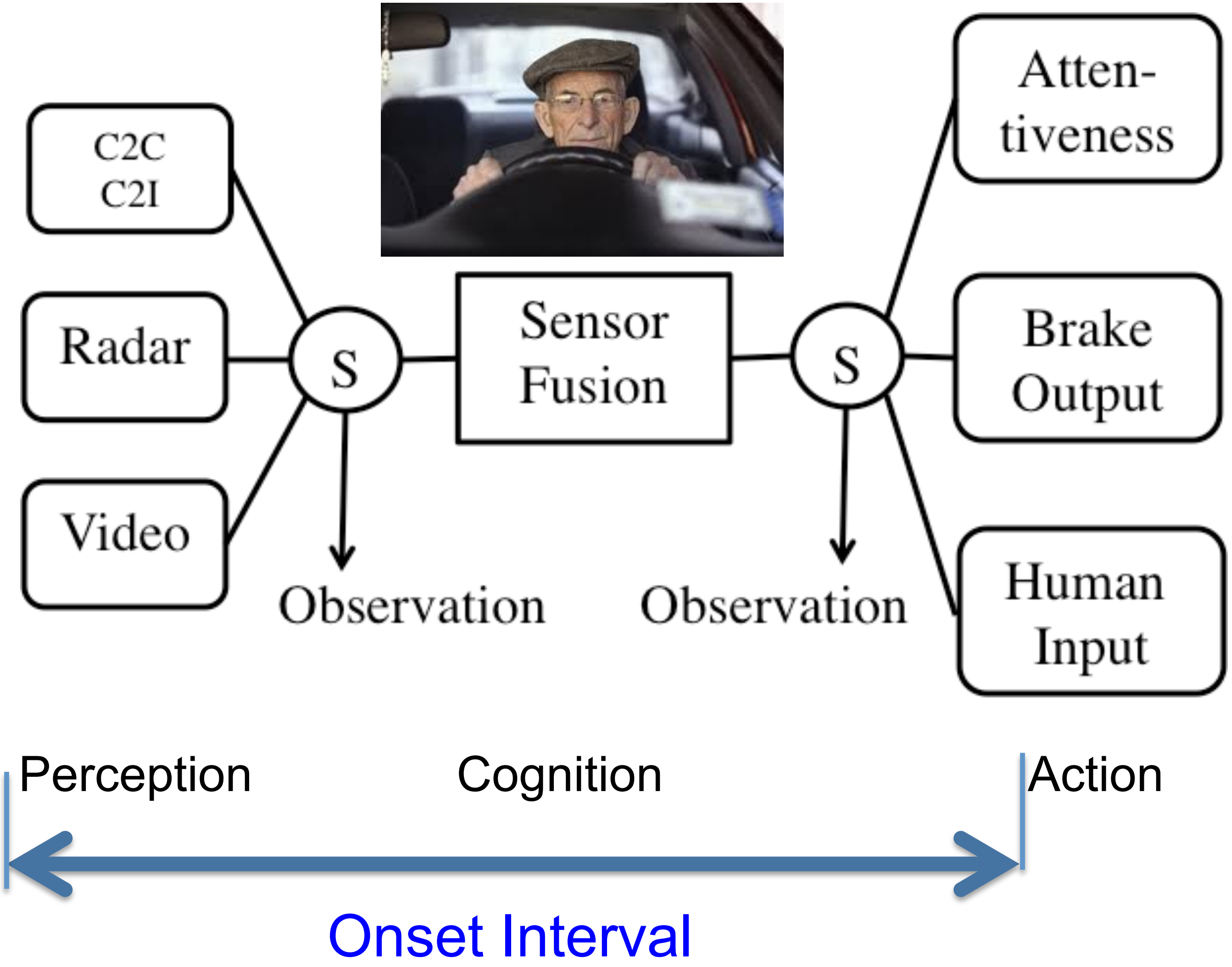
Introduction

- In June 2012 the Ratings Group of EURO-NCAP published a strategic roadmap of the NCAP organization about the required safety features of new cars up to the year 2016.
- According to this roadmap *Autonomous Emergency Braking Systems (AEBS)* to detect and protect pedestrians should be deployed on a wide scale in new cars by the year 2016.
- In a car equipped with an AEBS there are two autonomous systems that compete for the control over the car, *the human driver* and the *AEBS*. This is an example of a *System-of-Systems (SoS)*.

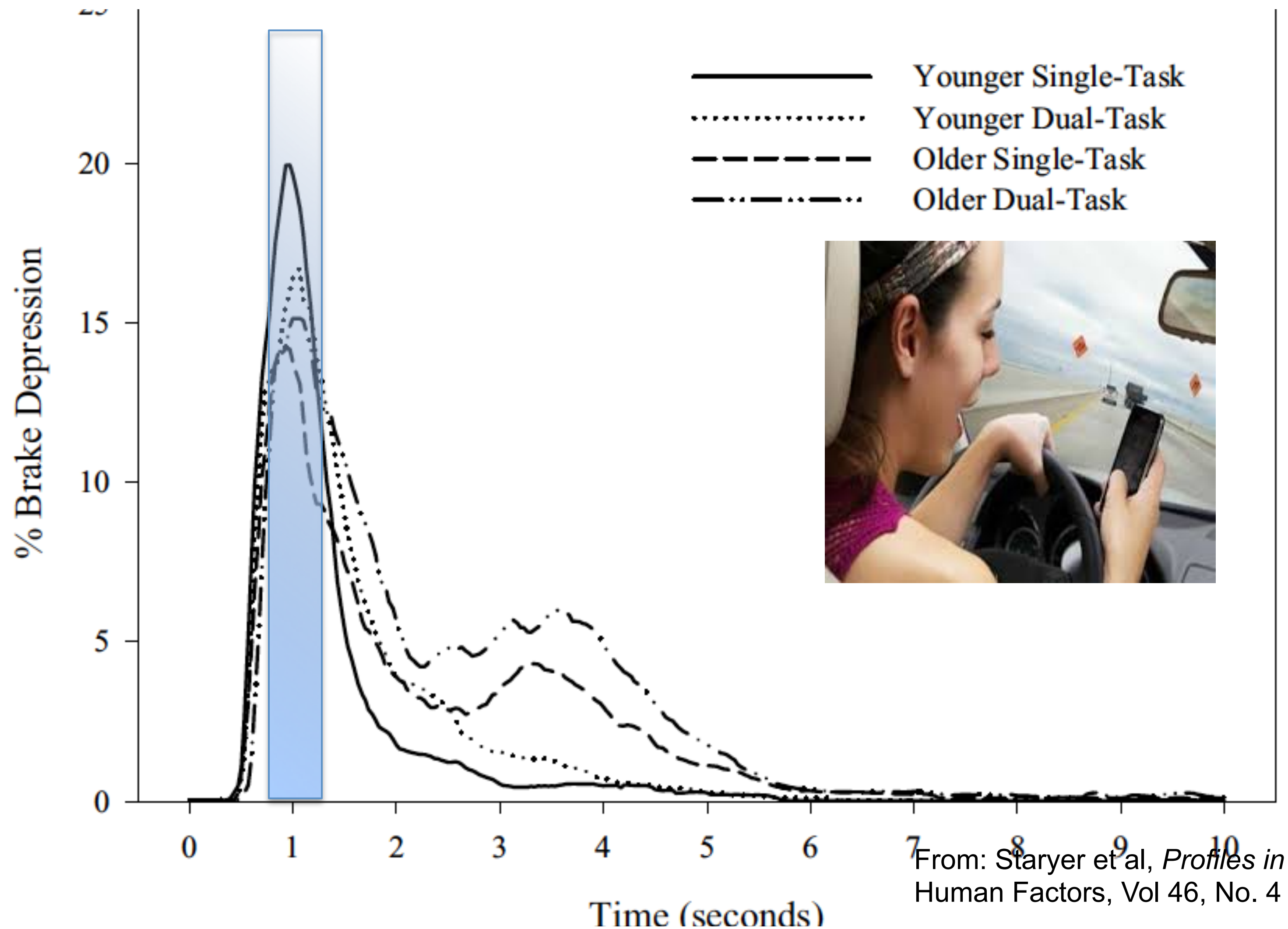
Properties of an *SoS*

Characteristic	Old-Classic	New-SoS
Scope of System	Fixed (known)	Not known
Structure	Hierarchical	Networked
Requirements and Spec.	Fixed	Changing
Control	Central	Autonomous
Evolution	Version control	Uncoordinated
Testing	Test phases	Continuous
Implement. Technology	Given and fixed	Unknown
Faults (Phys., Design)	Exceptional	Normal
Emergent Behavior	Insignificant	Important
System development	Process model	???

Basic Structure of an AEBS

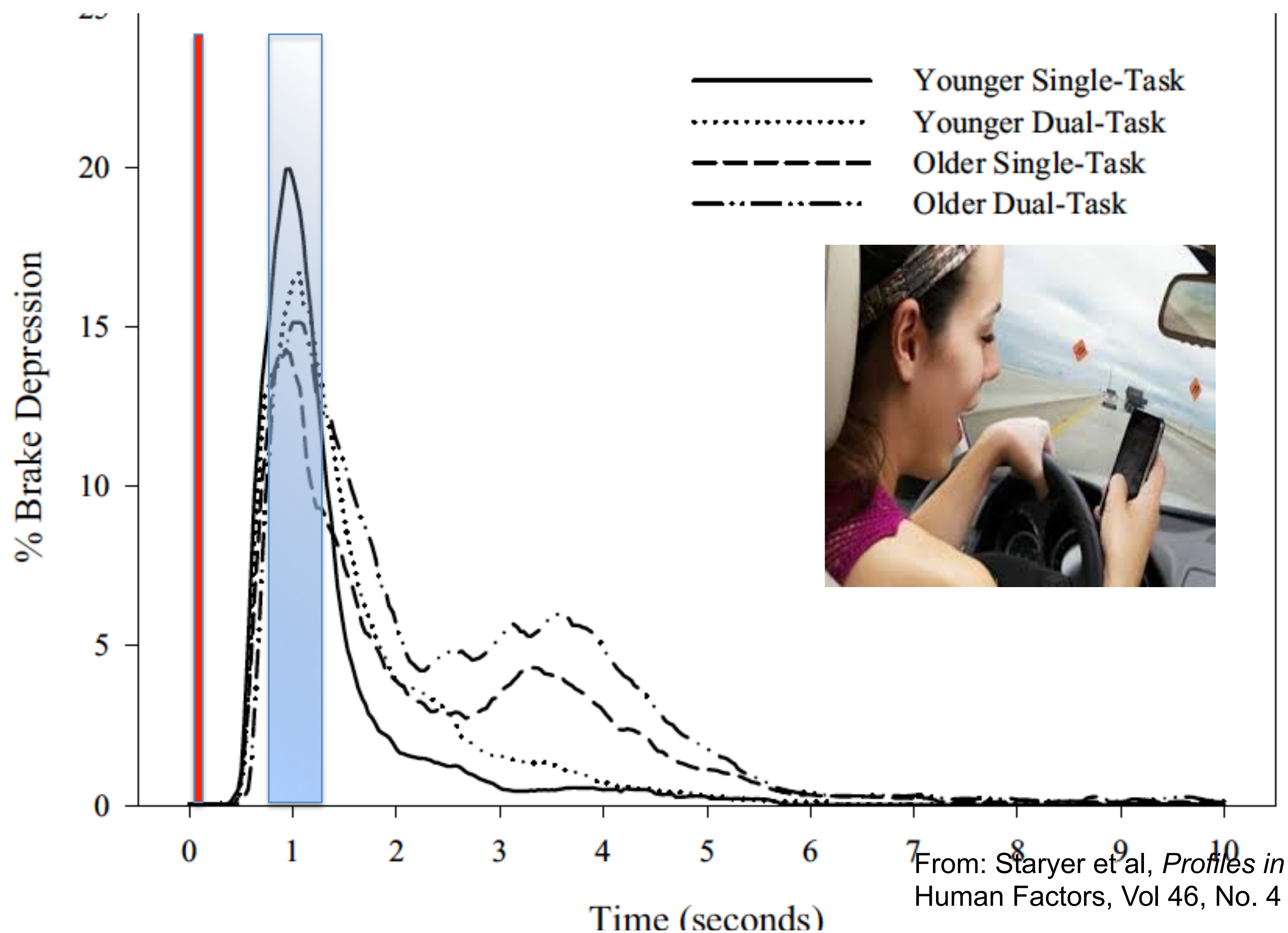


Human *Onset Interval*



From: Staryer et al, *Profiles in Driver Distraction*
Human Factors, Vol 46, No. 4 pp. 640-649, 2004

Onset Interval—Machine versus Human



From: Staryer et al, *Profiles in Driver Distraction*
Human Factors, Vol 46, No. 4 pp. 640-649, 2004

Performance of an AEBS

Speed km/h	OD in m Manual	OD in m Auto	BD in m Manual	BD in m Auto	Time in s Auto
30	8.3	.83	12.1	4.7	1.0
50	**14**	1.4	24.6	**12**	1.6
80	22.2	2.2	49.6	29.6	2.6
100	27.8	2.8	70.7	45.6	3.2
130	36.1	3.6	108.6	76	4.1
160	44.4	4.4	154 l	114	5

OD: Onset Distance; BD Brake Distance; auto: autonomous

Assumptions: Onset time: manual 1 sec, autonomous 0.1 sec.

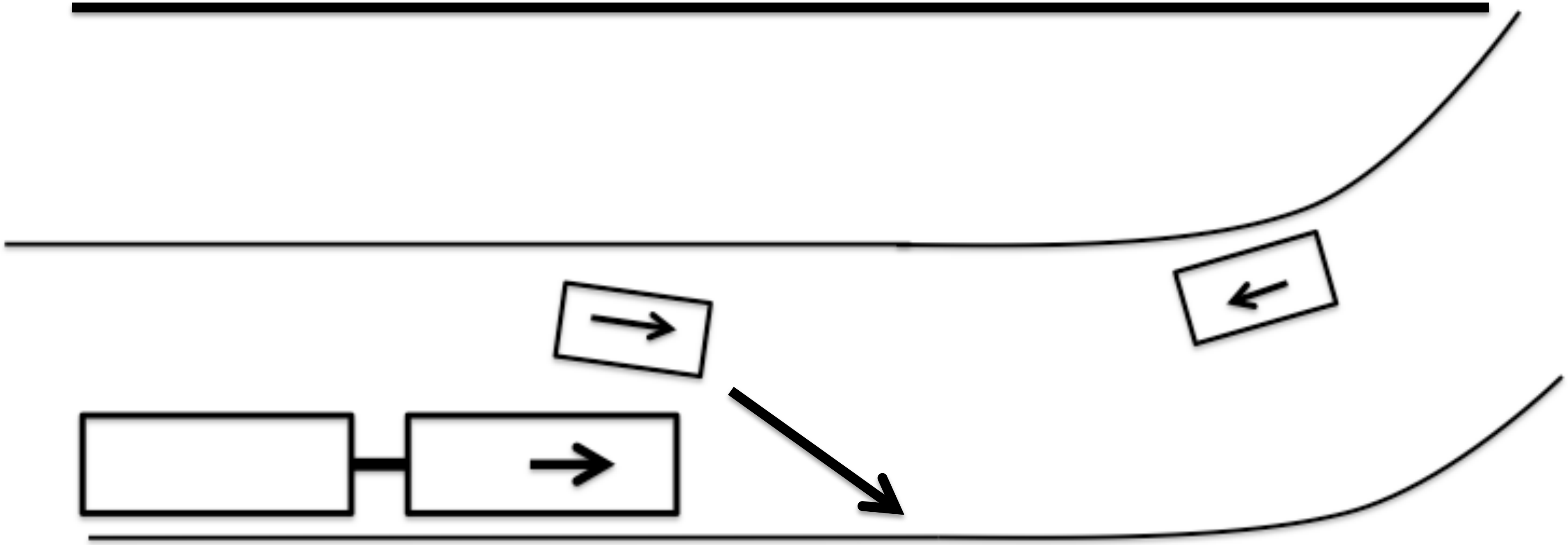
Legal Constraints of an AEBS

- Even if a car is equipped with a fully autonomic electronic control system that could, in principle, maneuver the car autonomously from start to finish, the traffic laws require that on public roads *a human driver must always be present in a car and the human driver must be able to take complete control over the car whenever desired*.
- *Perrow* in his analysis of accidents points out that the high risk of accidents in complex systems is caused by unforeseen interactions among subsystems. The detrimental consequences of unpremeditated interactions increase if the coupling of the CSs is increased.

Emergent Behavior

- In a car equipped with an AEBS both systems, the *human driver* and the *AEBS* have a common goal—to avoid an accident.
- Whenever two or more autonomous CSs interact, there is the possibility of emergent properties or emergent behavior, i.e., behavior that comes about by the interactions of the CS and cannot be reduced to any single CS.
- Emergent properties can appear unexpectedly or they can be planned. They can be *beneficial* or *detrimental*.
- Emergent behavior disappears when the SoS is decomposed into its CSs.

Example: Passing on a Two-Lane Road



Strategy (a): accelerate further to finish the passing maneuver quickly and aligns the car ahead of the truck.
Strategy (b): perform an emergency braking action and align the car behind the truck.

Conflict Resolution

- We conjecture that it is infeasible to analyze the complete set of possible scenarios of concurrently operating subsystems (the human driver and the AEBS) in order to detect and avoid all detrimental emergent effects.
- The more tightly that components are coupled and their actions and interactions constrained, the more likely failures will occur and the less likely that intended global properties will emerge (Fisher 2006).
- **We propose that at any instant, the vehicle is under the control of a single autonomous system only and that oscillations of control transfer between the AEBS and driver must be avoided.**

Allocation of Control

The allocation of control to one of the two autonomous systems (the human driver or the AEBS) is determined by the following rules:

- If a critical traffic scenario evolves when the human driver is paying little attention to this critical scenario, then the AEBS takes over the control of the vehicle.
- If the *attentiveness of the human driver* is increased beyond the *criticality of the situation*, then the human driver gets control over the vehicle.
- If the human driver has acquired the control of the vehicle in a critical situation, she/he will remain in control until the critical situation has been resolved.

Criticality vs. Attentiveness

- In every frame the AEBS estimates the criticality of the current traffic situation and the attentiveness of the driver and records these estimates in two variables, the *criticality index (CI)* and the *attentiveness index (AI).*
- IF (in a frame) AI $\geq$ CI THEN the control over the car is delegated to the human driver ELSE the control is delegated to the AEBS .
- Once a control transfer from the AEBS to the human driver has taken place in a critical scenario, the human driver stays in control of the vehicle at least until the CI has decreased.
- In a scenario where maximum attentiveness meets maximum criticality, the driver always wins.

Criticality Index CI of the Scenario

- An *emergency action* is the most dramatic control action (e.g., application of the maximum brake force) that can be taken by the AEBS. We call the latest point in time when an emergency action has to be taken by the AEBS in order to avoid an imminent future accident the *Instant of Commitment (IoC)*.
- A soft control action is a control action that is taken before the IoC—a soft control action is less dramatic then an emergency action.
- We consider the *time interval* between the instant now and the IoC the most important indicator for estimating the criticality of the current scenario .

Attentiveness Index AI of the Driver

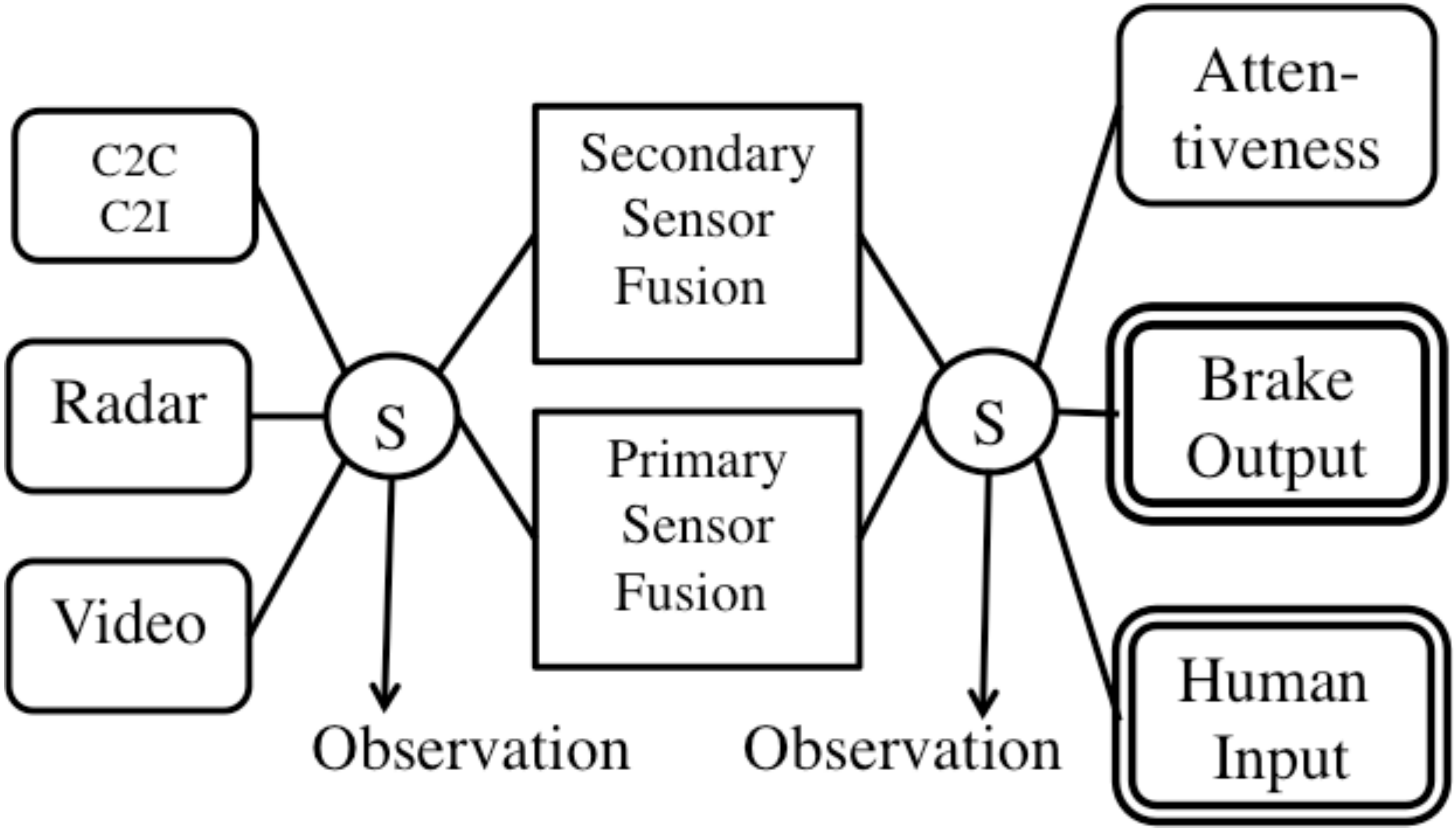
- *Passive Technique:* Observing the driver and monitoring her/his line of sight, i.e., the gaze. The AEBS continuously constructs a model of the traffic situation and determines if there are any Points of Critical Action (PCA) in the three dimensional space. If the driver's gaze is not focusing on this PCA it is fair to assume that the driver is not aware of the imminent danger of this situation (with a high CI)
- *Active Technique*: Measures the force which the driver exerts on the steering (measured by a steering wheel sensor). If the force is increased beyond a preset value, then the attentiveness index AI is raised to the highest level and control over the vehicle is transferred to the driver.

Faults are Normal in an SoS.

The following requirements must be satisfied, even if a fault occurs:

- If an obstacle is detected in the current path of the vehicle, the AEBS must slow down the vehicle before it hits the object.
- Any unnecessary emergency braking action must be avoided, since an emergency-braking action increases the risk of a *rear-end collision*.
- Any unrecoverable error (caused by a *physical or design fault*) within the AEBS must be detected within a frame duration and the driver must be alerted about the immediate control transfer to the driver.

Extended AEBS Architecture



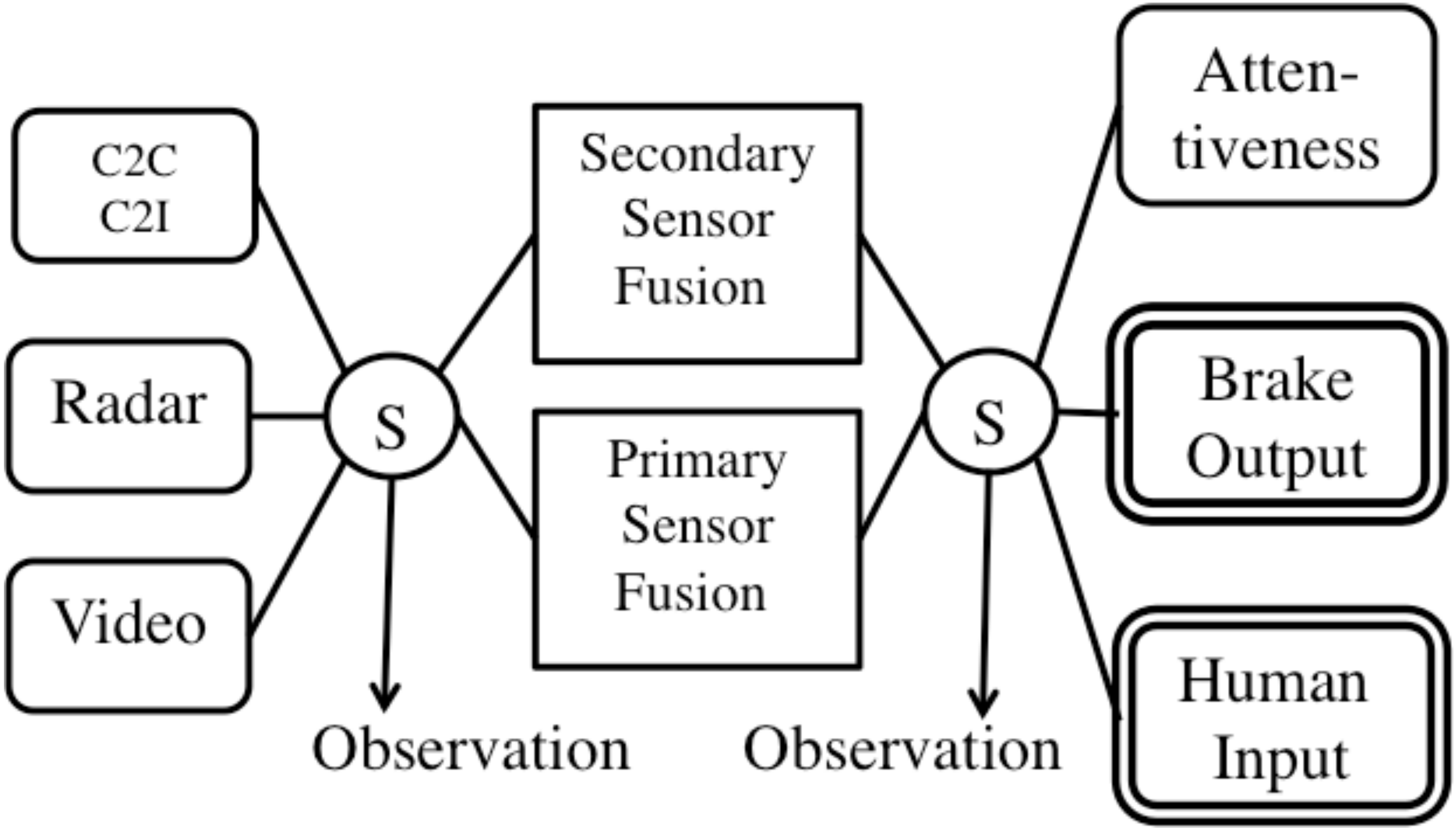
Brake Output

The Brake Output is calculated by the Brake Output Component according to the following Table:

PSF Component \ SSF Component	Emergency Brake	Brake	No Brake
Emergency Brake	**EB**	EB	B
Brake	B	**B**	B
No Brake	B	N	**N**

If there is no fault, the Primary Sensor Fusion Component And the Secondary Sensor Fusion Component arrive at the same result.

Fault Analysis



Conclusion

- It is well known from the study of systems-of-systems that the interactions of two autonomously operating control systems that try to reach the same goal by employing different strategies can result in detrimental emergent behavior.
- We have analyzed these conflicts and proposed a detailed plan for control allocation in an AEBS equipped car.
- In the final section a strategy for the mitigation of the consequences of residual design errors or transient hardware faults in the complex sensor fusion software has been presented.