

Object Fusion for an Advanced Emergency Braking System (AEBS)



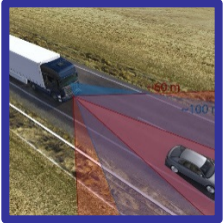
Agenda



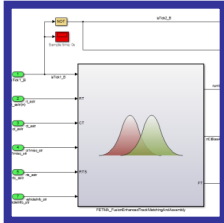
1. Rear-end collisions & EU legislation



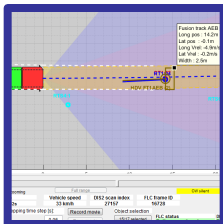
2. How the AEB system works



3. Object fusion methods



4. Simulink implementation



5. Sensor visualisation and testing tools

Rear-end collisions & Legislation

- Rear-end collisions most common accident types for heavy vehicles
- AEB regulated on heavy trucks and buses in the EU from:
 - Nov. 2013 – for new types
 - Nov. 2015 – for new vehicles



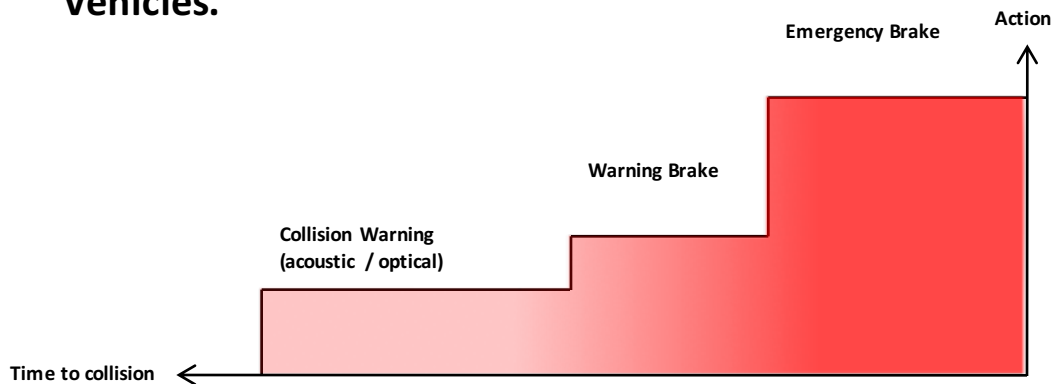
The result of a "trailerback" accident

How AEB works (Advanced Emergency Brake)

At risk of collision:

- **Collision warning**
→ If no driver reaction:
- **Warning brake** (- 3 m/s²)
→ If no driver reaction:
- **Emergency brake** (full brake ~6-7m/s²)

- Avoidance for moving target vehicles
- Attempting avoidance also for stationary vehicles.



How AEB works

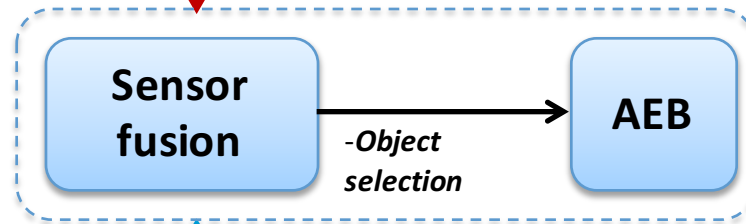
(Advanced Emergency Brake)



Camera
- Object detection
- Road marking detection



Radar
- Object detection



Instrument cluster

Collision warning

Brake request



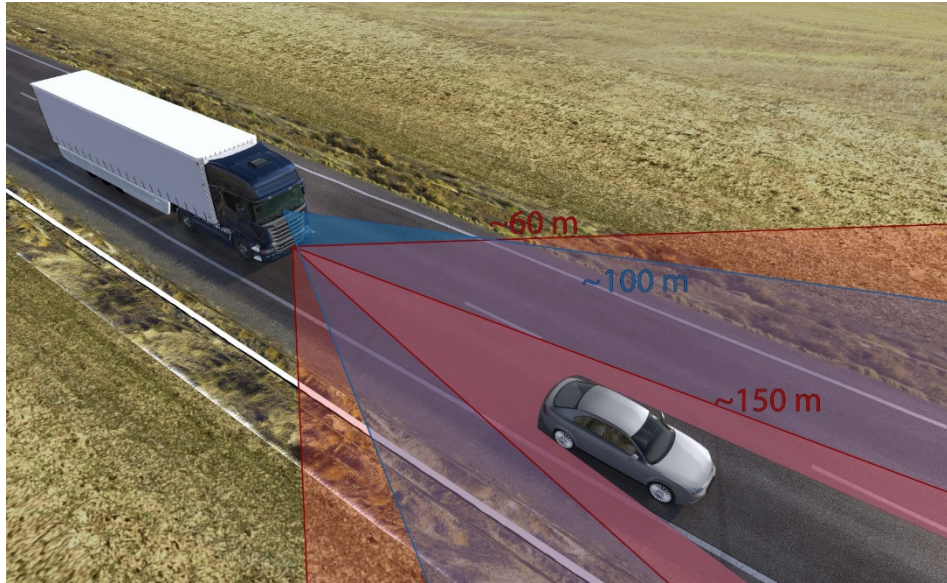
Brake system

AEB (Advanced Emergency Brake)



Sensor fusion

Two sensors -> One "truth"

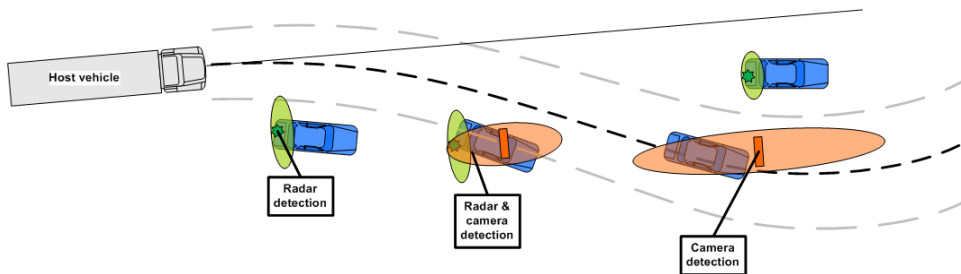


Sensors have different advantages

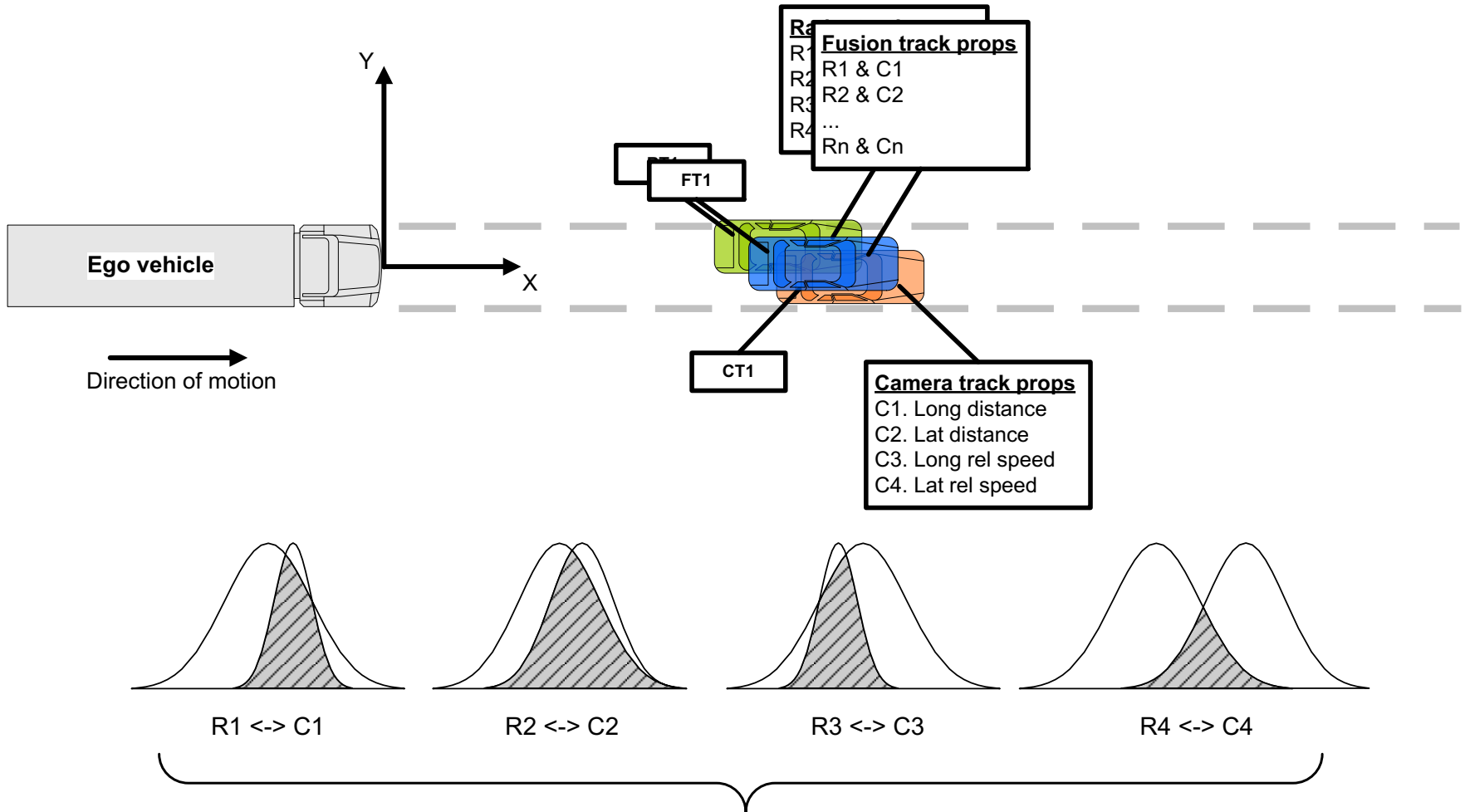
- Radar
 - + Range (longitudinal)
 - + Relative velocity
 - + Solid object reflection
 - No shapes
 - Lateral position

- Camera
 - + Object type
 - + Object width
 - + Lateral position
 - Range
 - Optical illusions

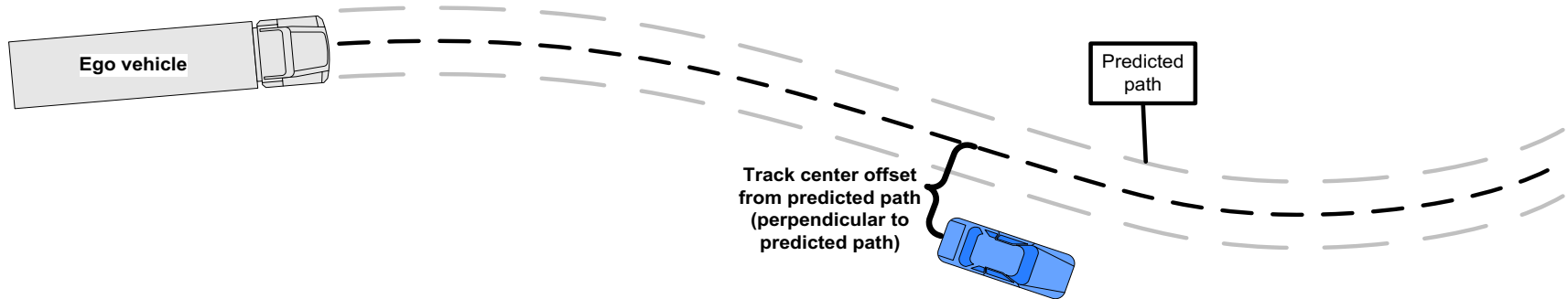
Redundance
required for
stationary
objects



Matching and merging



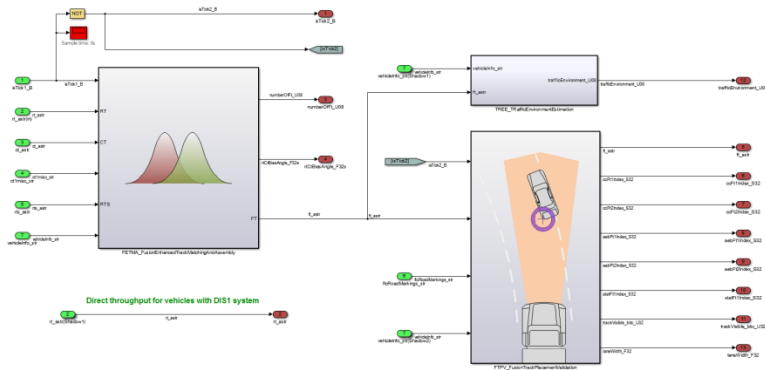
Object selection



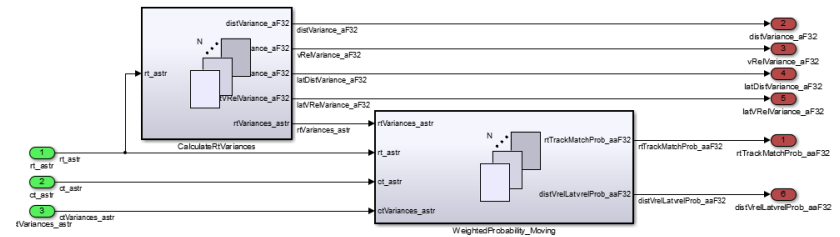
- Object position compared to a "predicted path"
- Relative speeds from/away from predicted path for cut-in/cut-out
- Different selection zones for AEB and ACC
 - ⇒ AEB has narrower field of interest than ACC
 - ⇒ The selection criteria of objects reported to AEB and ACC differ

Model Based Design for fusion

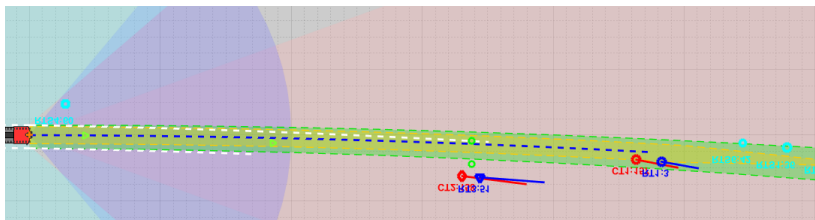
Easy to get nice and readable architecture



For-each systems and Matlab Function blocks, suitable for loops and similar calculations.



MATLAB is a suitable platform for debugging and visualization.



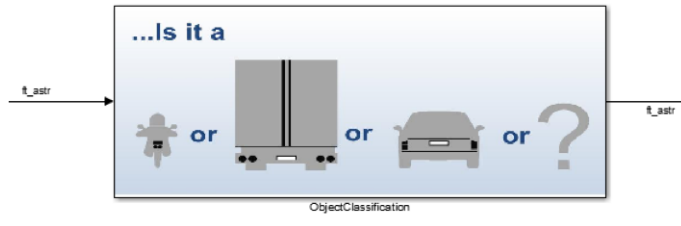
Easy debugging in Matlab Function Block

```

130 %% 3. Calculate zone-placement (candidates for validation)
131 % Proceed if the track is a single DIS track or "better". Single camera tracks are not let through here.
132
133 % Track valid, get its path offset and movement status.
134 offsetPredPathSquared_F32 = ft_ast(track_S32).instOffsetPredPathSquared_F32;
135 predOffsetPredPathSquared_F32 = ft_ast(track_S32).predOffsetPredPathSquared_F32;
136
137 mainZoneLeftSquared_F32 = mainTrackZone_aF32(track_S32)*mainTrackZone_aF32(track_S32);
138 mainZoneRightSquared_F32 = -mainZoneLeftSquared_F32;
139

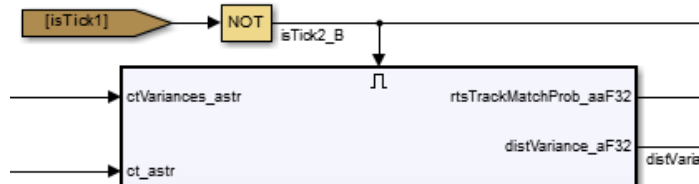
```

Code generation optimization: Solutions



Problem: Data copies of bus-arrays are extremely expensive

Solution: *Signal objects used to force reuse the data*



Problem: Execution time too long for ECU

Solution: *Model divided into two ticks – probabilities calculated only every 2 ticks.*

```
coder.ceval('Mbd_approxSqrt_F32', x_F32);
```

$$\sqrt{x} \sim f(x)$$

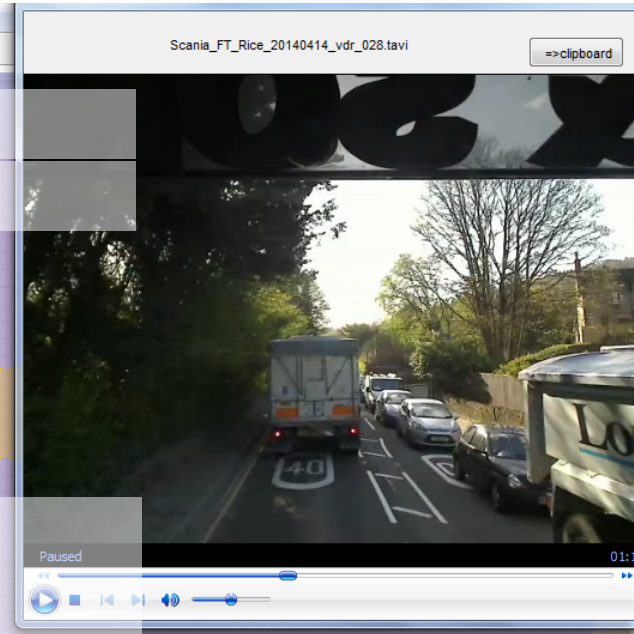
Problem: Trigonometric functions are expensive on target HW

Solution: *Trigonometric approximations. coder.ceval used for hand-coded functions.*

Sensor Visualization

- Sensor visualization tool developed with MATLAB/GUIDE
- Synchronize sensor/fusion data with web camera

- Matlab class used to represent each object
- Tool used offline or online (connected to vehicle network)



Fusion track AEB [1]
Long pos : 14.4m
Lat pos : -0.0m
Long Vrel: -5.0m/s
Lat Vrel : -0.2m/s
Width : 2.5m

HDV FT1AEB (2)

RT184-1

RT86-50

Tools

Rotate view Proportional zooming Full range

Online Always print IDs

Play Video Refresh data

Plaving speed: x1

Time: 148.12s

Vehicle speed: 33 km/h

DIS2 scan index: 27157

FLC frame ID: 16728

Stepping time step [s]: 0.05

Record movie Save movie

Object selection: 15/17 selected

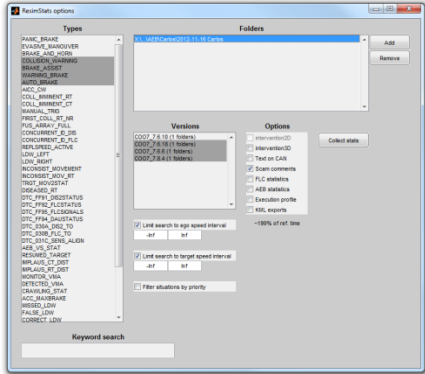
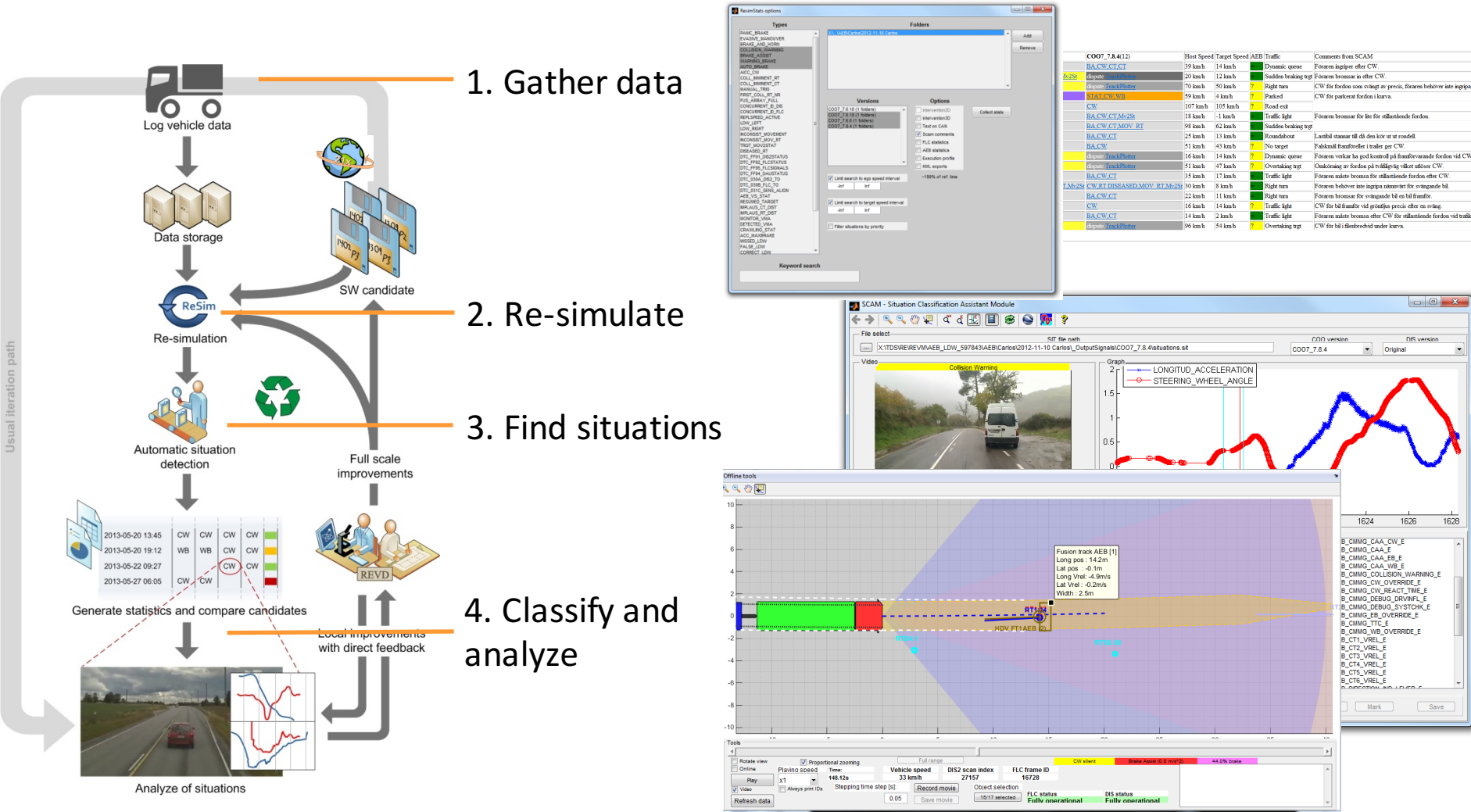
FLC status: Fully operational

DIS status: Fully operational

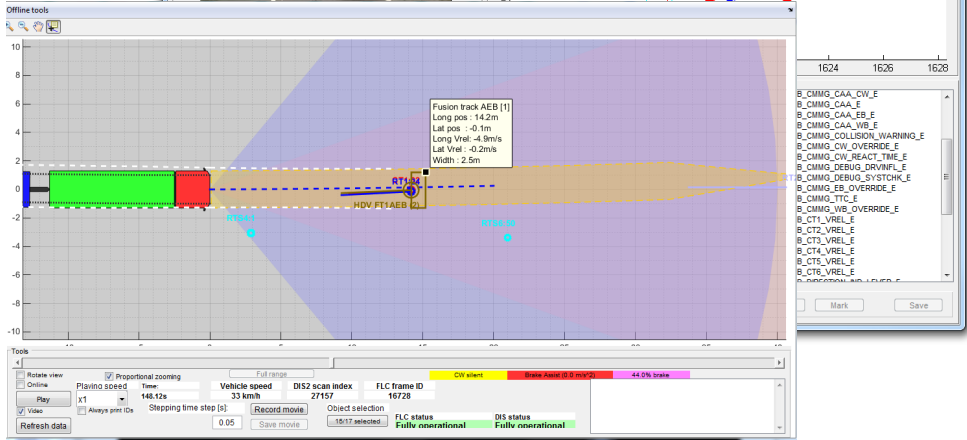
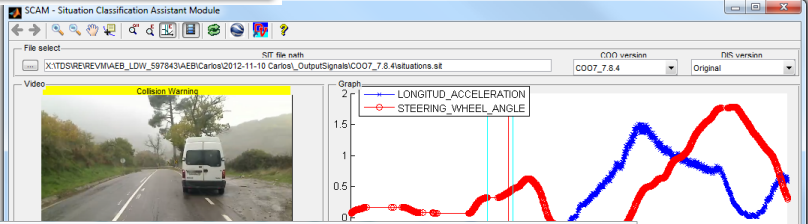
CW silent | Brake Assist (0.0 m/s²) | 44.0% brake



Development workflow



COO7_7.4.1.D	Hot Speed	Target Speed	AEB	Traffic	Comments from SCAM
BAC.W.CT.CT	39 km/h	14 km/h	Dynamic queue	Foramen register efter CW	
6.2.9.1 Bispate TrackPlayer	20 km/h	12 km/h	Sudden braking tpt	Foramen bromsar efter CW	
Bispate TrackPlayer	70 km/h	50 km/h	Right turn	CW för fordon som svägar av precis. Foramen behövs inte aggrä.	
BAC.W.CW	59 km/h	4 km/h	Parked	CW för parkerat fordon i kurva.	
CW	107 km/h	105 km/h	Road end		
BAC.W.CT.M29	18 km/h	-1 km/h	Traffic light	Foramen bromsar för för tillståndet fordon.	
BAC.W.CT.MOV_RT	98 km/h	62 km/h	Sudden braking tpt		
BAC.W.CT	25 km/h	13 km/h	Roundabout	Lastbil stannar till då den kör ut ur rondell.	
BAC.W.CT	51 km/h	43 km/h	No target	Falskäm Ramföret i trailer per CW.	
BAC.W.CT	16 km/h	14 km/h	Dynamic queue	Foramen väntar på god kontroll på framförande fordon vid CW.	
Bispate TrackPlayer	51 km/h	47 km/h	Oversteering tpt	Oversteering av fordon på tilläpning vilket utlöser CW.	
BAC.W.CT	35 km/h	17 km/h	Traffic light	Foramen måste bromsa för tillståndet fordon efter CW.	
CW.RT.DISASSED.MOV_RT.M29	30 km/h	8 km/h	Right turn	Foramen behövs inte aggrä omanövr för svängande bil	
BAC.W.CT	22 km/h	11 km/h	Right turn	Foramen bromsar för svängande bil en bil framför	
CW	16 km/h	14 km/h	Traffic light	CW för bil framför vid grönljus precis efter en sväng	
BAC.W.CT	14 km/h	2 km/h	Traffic light	Foramen måste bromsa efter CW för tillståndet fordon vid trafikljus.	
Bispate TrackPlayer	96 km/h	54 km/h	Oversteering tpt	CW för bil i Bimbech vid under kurva.	

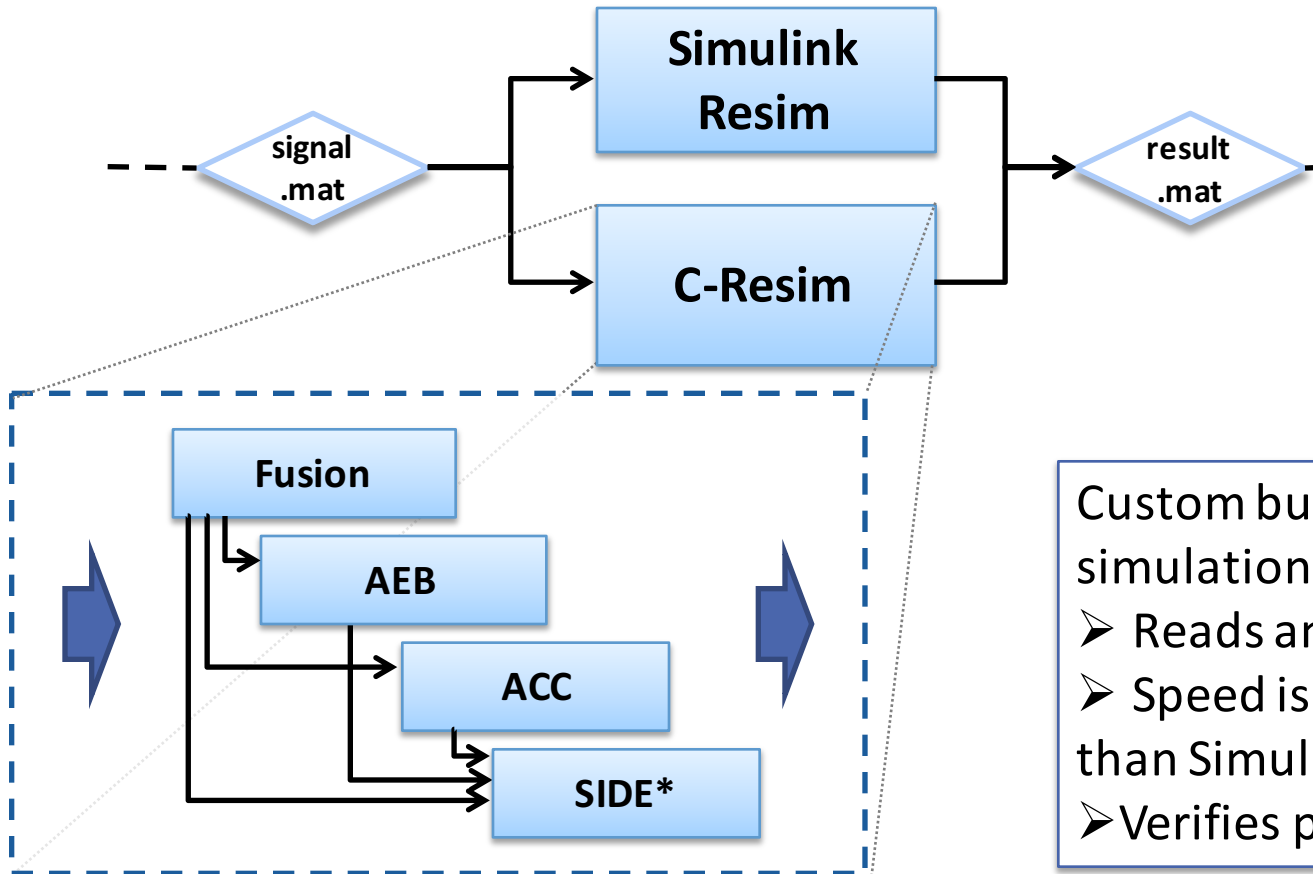


Data gathering



- Record ALL required data for the system to work continuously together with a reference camera.
- Need for real traffic data for negative testing is **massive**.

Re-simulation (1)



*SIDE = Situation Identification

Custom built emulator for the simulation need.

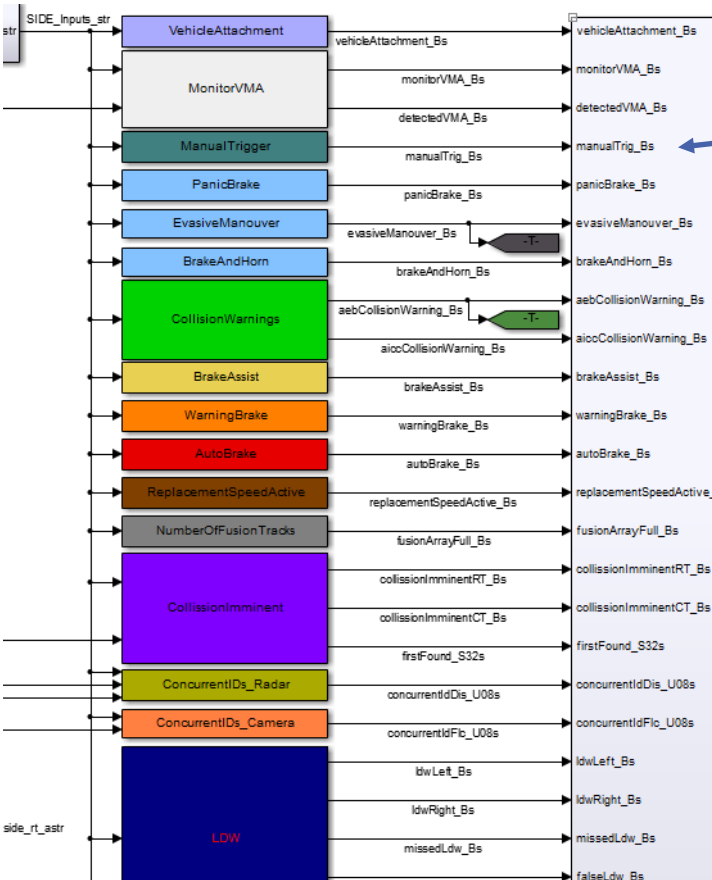
- Reads and writes mat-files
- Speed is ~150 times faster than Simulink.
- Verifies production code

Situation detection

Finding situations in the data

- Events from simulation
- Interesting situations
- Problems with sensors
- ...

Compare SW versions



Scan	COO7_7.6.18(17)	COO7_7.8.4(12)	Host Speed	Target Speed	AEB	Traffic	Comments from SCAM
55346	BA,CW,CT,CT	BA,CW,CT,CT	39 km/h	14 km/h	Green	Dynamic queue	Föraren ingriper efter CW.
47603	BA,CW,CT,RT DISEASED,Mv2St	dispute TrackPlotter	20 km/h	12 km/h	Green	Sudden braking trgt	Föraren bromsar in efter CW.
61868	CW	dispute TrackPlotter	70 km/h	50 km/h	Yellow	Right turn	CW för fordon som svängt av precis, föraren behöver in
3312	STAT,CW	STAT,CW,WB	59 km/h	4 km/h	Yellow	Parkeed	CW för parkerat fordon i kurva.
62236	CW	CW	107 km/h	105 km/h	Yellow	Road exit	
30755	BA,CW,CT,Mv2St	BA,CW,CT,Mv2St	18 km/h	-1 km/h	Green	Traffic light	Föraren bromsar för lite för stillastående fordon.
5608	BA,CW,CT,MOV RT	BA,CW,CT,MOV RT	98 km/h	62 km/h	Green	Sudden braking trgt	
34994	BA,CW,CT	BA,CW,CT	25 km/h	13 km/h	Green	Roundabout	Lastbil stannar till då den kör ut i rondell.
9209	BA,CW	BA,CW	51 km/h	43 km/h	Yellow	No target	Falskmal framförelser i trailer ger CW.
33362	CW,Mv2St	dispute TrackPlotter	16 km/h	14 km/h	Yellow	Dynamic queue	Föraren verkar ha god kontroll på framförvarande fordo
36343	CW	dispute TrackPlotter	51 km/h	47 km/h	Yellow	Overtaking trgt	Onkörning av fordon på tvärliggväg vilket utlöser CW.
34524	BA,CW,CT	BA,CW,CT	35 km/h	17 km/h	Green	Traffic light	Föraren måste bromsa för stillastående fordon efter CW
30535	CW,RT DISEASED,MOV RT,Mv2St	CW,RT DISEASED,MOV RT,Mv2St	30 km/h	8 km/h	Green	Right turn	Föraren behöver inte ingripa nämnvärt för svängande bil
39796	BA,CW,CT	BA,CW,CT	22 km/h	11 km/h	Green	Right turn	Föraren bromsar för svängande bil en bil framför.

Regression testing

➤ Test scenario creation tool suitable to design test cases visually.

➤ Can run same test cases in

➤ Simulink

➤ C-Resim

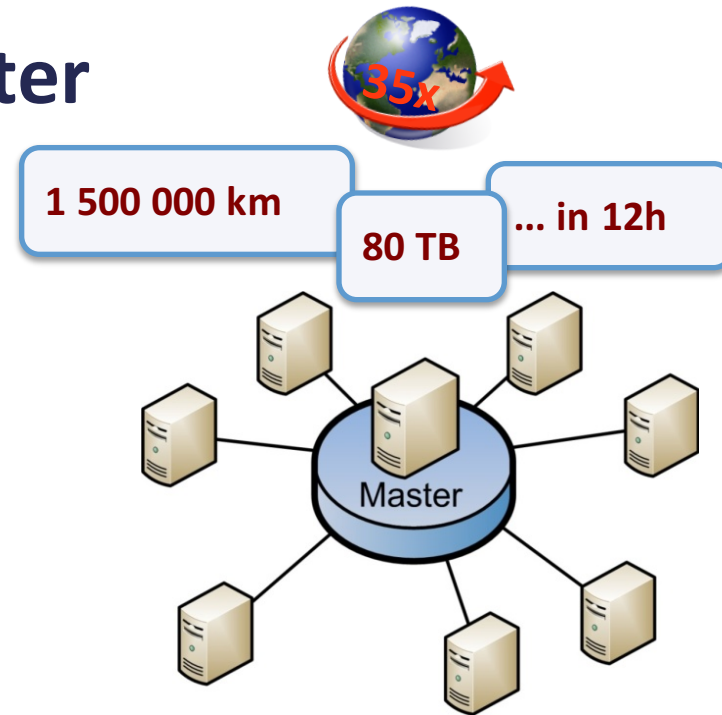
➤ HIL

The screenshot displays a software interface for creating test scenarios. The top part features a plot titled 'Vehicles' with a coordinate system (m) showing a blue vehicle moving along a path. The bottom part is an 'Action table' with the following content:

Line	Time	Action
1	0s	HOST vehicle (speed=30) [reset position and heading to zero]
2	0s	SET RTDB_FRONT_AXLE_SPEED_E = 30
3	0s	*Spawn a car*
4	0s	New RADAR vehicle [1] (speed=5, longDist=75, latDist=0.0, id=3)
5	0s	RADAR vehicle [1] (visible=1, longAcc=0, latAcc=0)
6	0s	SET DISMDEL_COUNTERS_ENABLE = 1
7	0s	SET FLICMDEL_COUNTERS_ENABLE = 1
8	0s	SET FLICMDEL_TRACKS_STATUS = 255
9	0s	SET DISMDEL_TRACKS_STATUS = 255
10	0s	*Testcase*
11	2s	WAIT 2000 ms
12	2s	TEST RTDB_FT1AEB_DISID_E > 250 *Not valid*
13	4s	WAIT 2000 ms
14	4s	RADAR vehicle [1] (visible=1, longAcc=2, latAcc=0)
15	4s	TEST RTDB_FT1AEB_DISID_E > 250 *Still not valid*
16	6s	WAIT 2000 ms
17	6s	TEST RTDB_FT1AEB_VREL_E > (10-30)/3.6
18	6s	TEST RTDB_FT1AEB_DISID_E == 3 *Above (abs) speed limit*
19	6s	TEST RTDB_FT1AEB_FLICID_E > 250 *No CT*
20	6s	RADAR vehicle [1] (visible=1, longAcc=-2, latAcc=0)
21	9s	WAIT 3000 ms
22	9s	TEST RTDB_FT1AEB_VREL_E == [-30/3.6 1]
23	9s	TEST RTDB_FT1AEB_DISID_E == 3 *Stopped but still valid*
24	10s	WAIT 1000 ms
25	10s	*Clear targets*
26	10s	RADAR vehicle [1] (visible=0, longAcc=0, latAcc=0)
27	11s	WAIT 1000 ms

Simulation cluster

- Speed is increased by separating the job into **parallel tasks** and distribute them **over the network** with the help of **MATLAB**
- A master node coordinates the job while client nodes offer their computational capacity. New nodes can join in during



<u>Simulation method</u>	<u>Relative simulation speed</u>
Simulink-simulation (AEB)	0.25 x real-time
C-resim (AEB)	40 x real-time
Distributed C-resim (AEB)	N x 40 x real-time

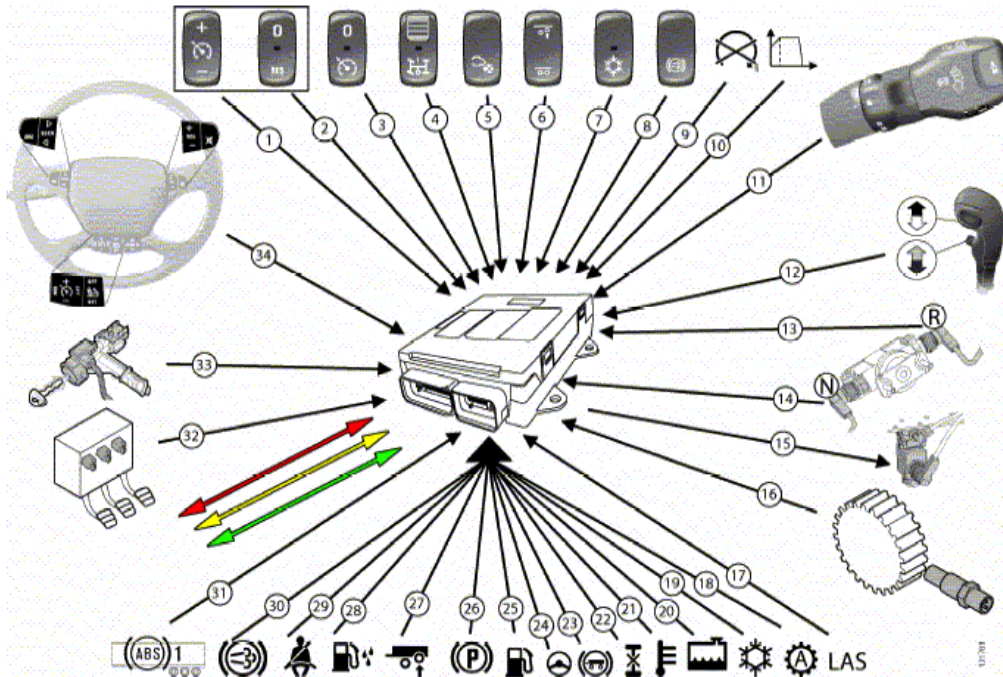
Thank you!



Summary

- Visualization of sensor data – key to understanding any scenario.
- Development by “Massive simulation” - enhances quality and confidence of active safety functionality.
- (Fast simulations are necessary to achieve the above)
- Mathworks tools have successfully supported this workflow

Target ECU Hardware (2013)



ECU Hardware

CPU	132MHz (floating point support)
RAM	64kByte + 512kByte (external)
Flash	1Mb
E2	64kByte
CPU load	~60% before introduction of AEB and fusion

ECU designed for I/O, gateway and simple functions.

Not optimized for massive calculations!