Implicit Testing

Rethinking Embedded Software Validation

Milan LECHNER – AGSOTEC
Dr. Emmanuel ARRAS - BMW

MATLAB EXPO Munich
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BMW GROUP

- In-House Embedded Software Development
- ECUs :
  - Fuel-Tank ICE and PHEV
  - Fuel-Cell and Tank for FCEV

//AGSOTEC

- Tailor-made Test Environment Setup
- Level 3 ECU Virtualization
- Scalable CI\CD Infrastructure Deployment

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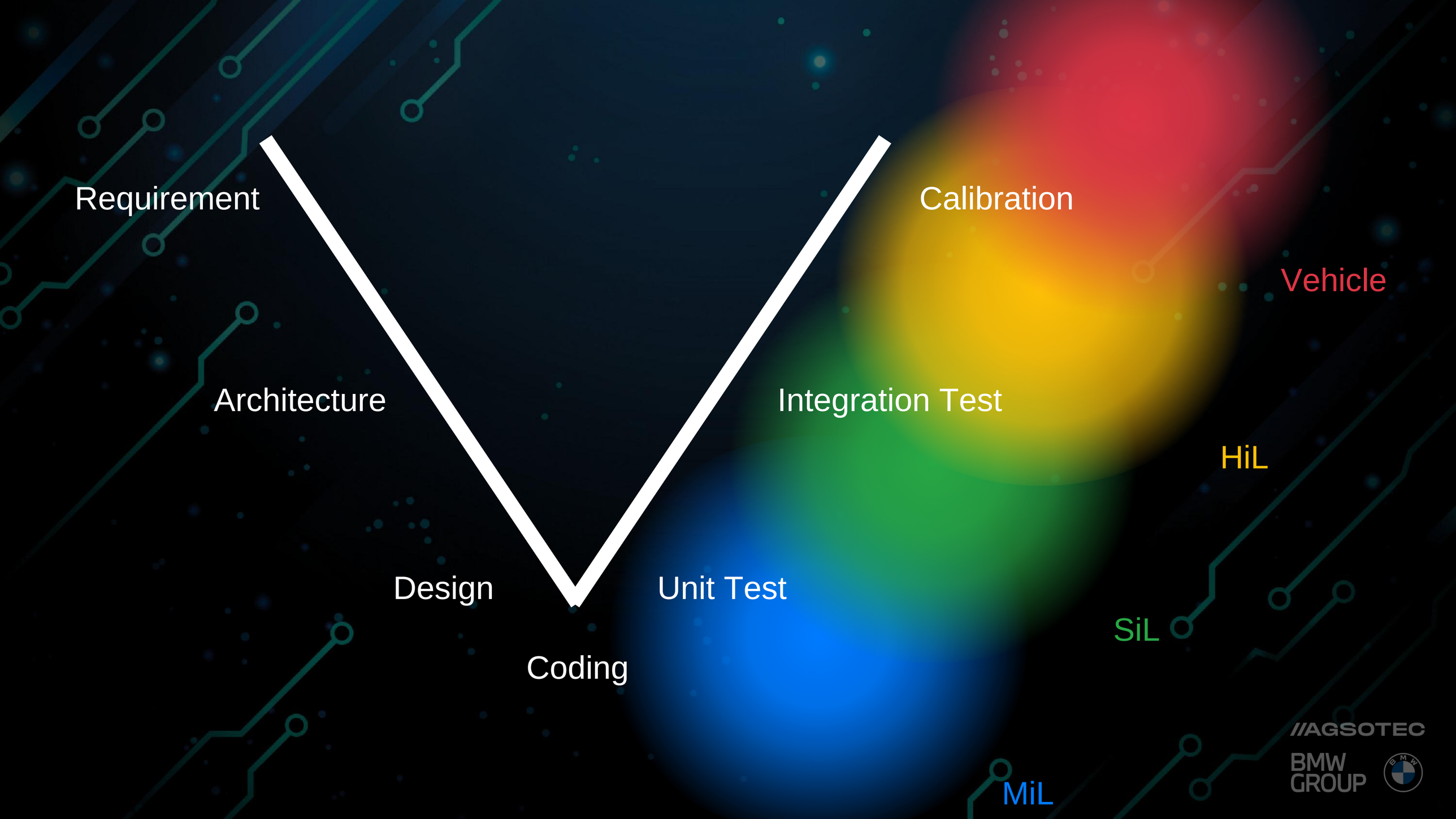
Requirement
Architecture
Design
Coding
Unit Test
Integration Test
Calibration
MiL
SiL
HiL
Vehicle

Vehicle

Field Testing
& Calibration

HiL

Release Validation Test

MiL / SiL

Unit Test

Coding

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BMW GROUP

- Reduce Manpower
- Split Dev-teams
- Reduce Dev-time
- Reduce Hardware

Quality drops !
Everyone is unhappy

Vehicle

Field Testing
& Calibration

HiL

Release Validation Test

MiL / SiL

Unit Test

Coding

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BMW GROUP

Our goal :
Devise a new way to find the bugs

- No Hardware
- Little ressources

Vehicle

Field Testing
& Calibration

HiL

Release Validation Test

?

MiL / SiL

Unit Test

Coding

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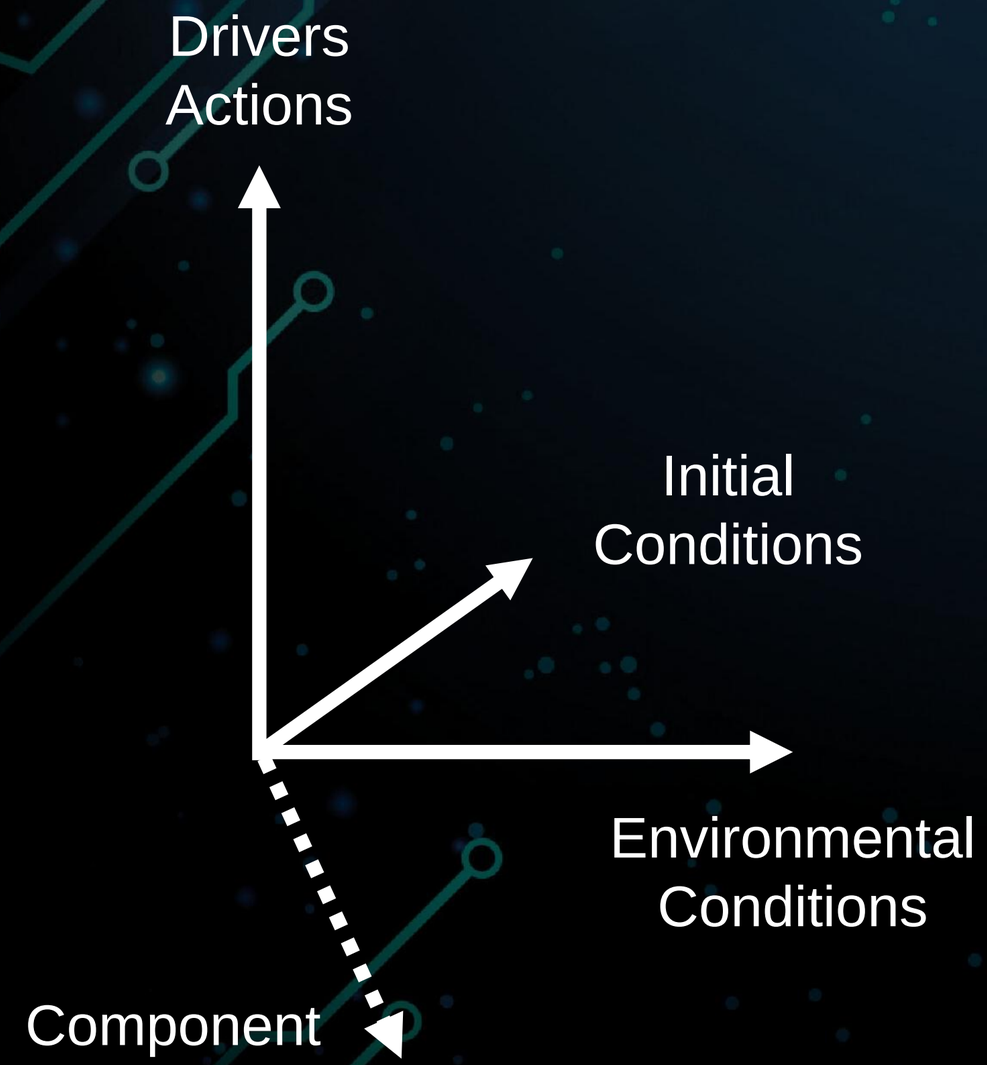

Test-space is IMMENSE

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Requirements
Test-Set
Known Problems
Test-Set
?
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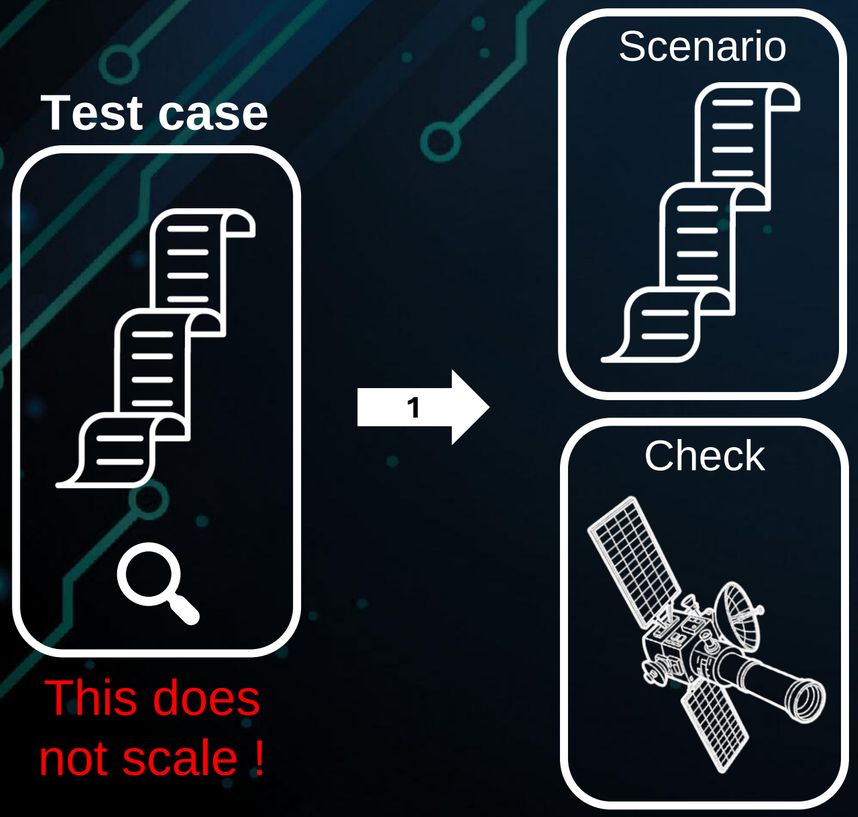
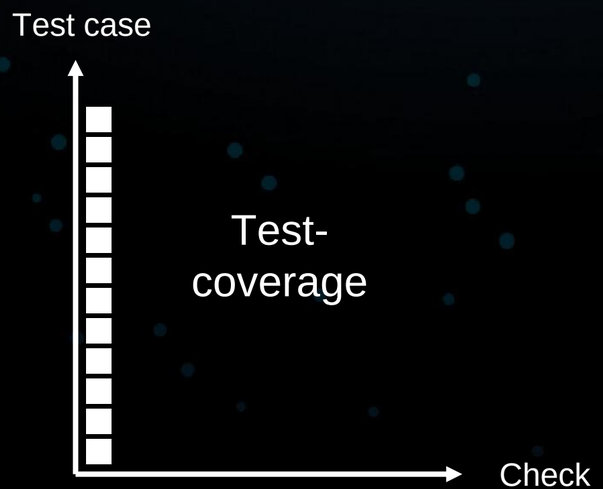


1. Split Scenario and Check(s)



Explicit Testing

Test case

This does not scale !

1

Scenario

Checks

2

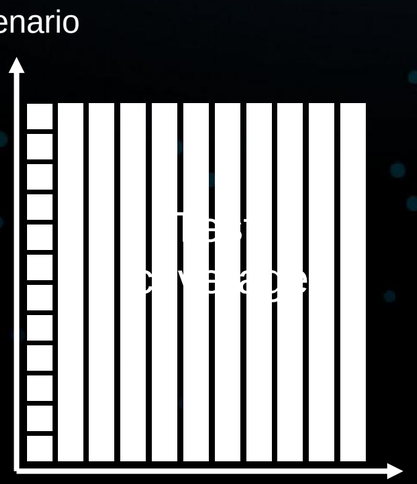
Implicit Testing

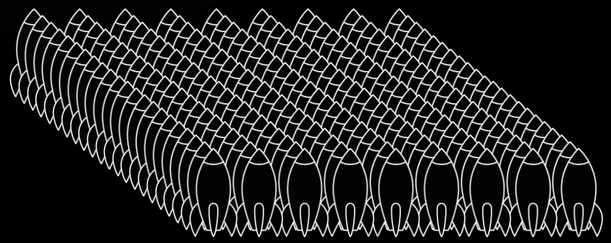
Scenario

Checks

This scales !

1. Split Scenario and Check(s)
2. Industrialize Scenario creation





- **High level**
- **Transferable**
- **Modular**

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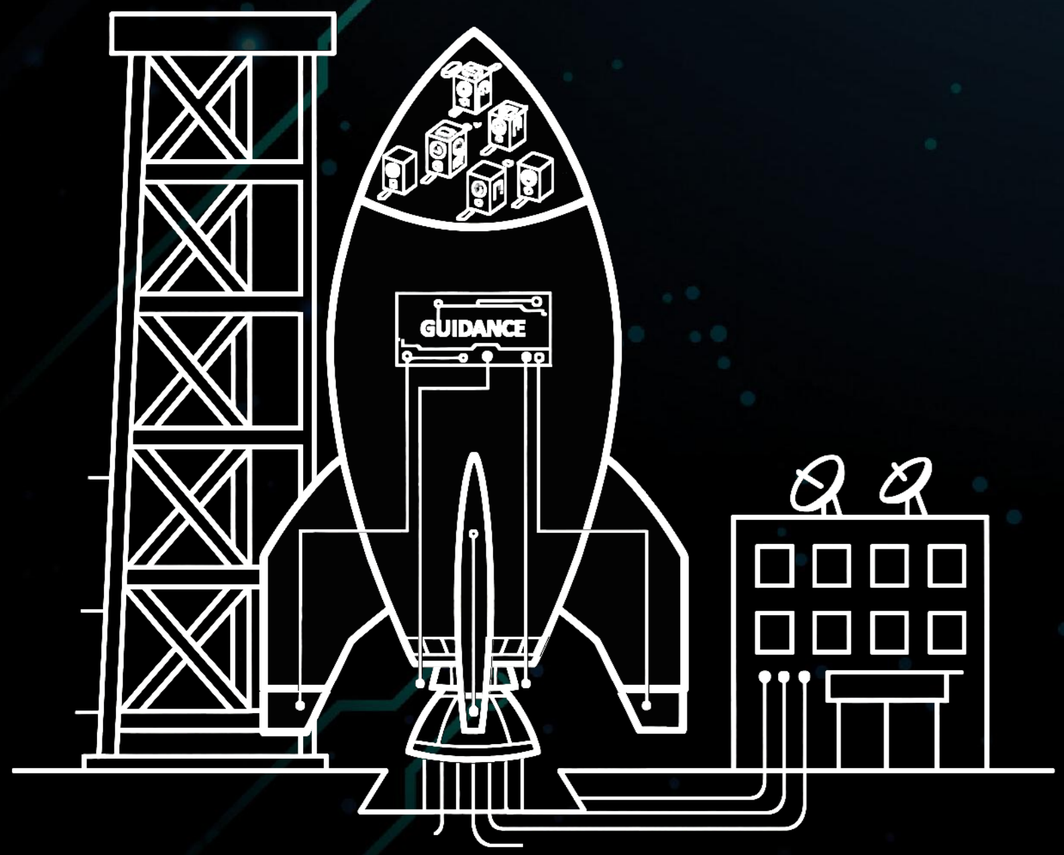
Implicit Testing

Scenario : **User-friendly**
- Modular
- High level

Test Harness : **Realistic**



Check : **Scalable**
- High level
- Transferable

Toolchain : **Flexible**

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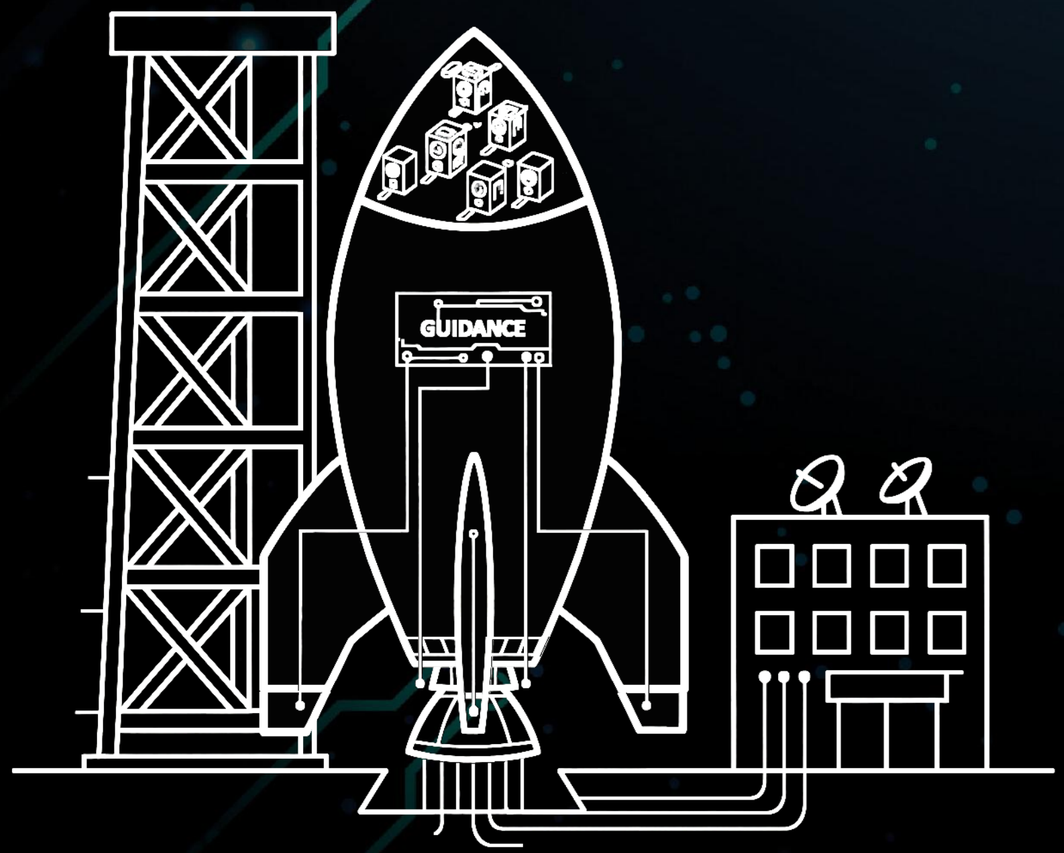
Implicit Testing

Scenario : **User-friendly**
- Modular
- High level
- Intuitive

Test Harness : **Realistic**
- Comprehensive
- Physical
- Configurable



Check : **Scalable**
- High level
- Transferable
- Plug-and-play
- Robust
- Self-Explanatory

Toolchain : **Flexible**
- Standardized
- Evolutive
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- Comprehensive
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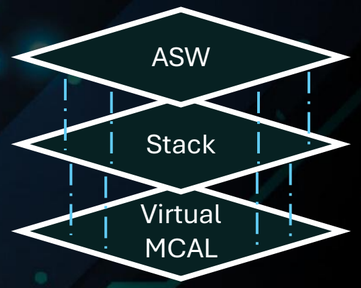
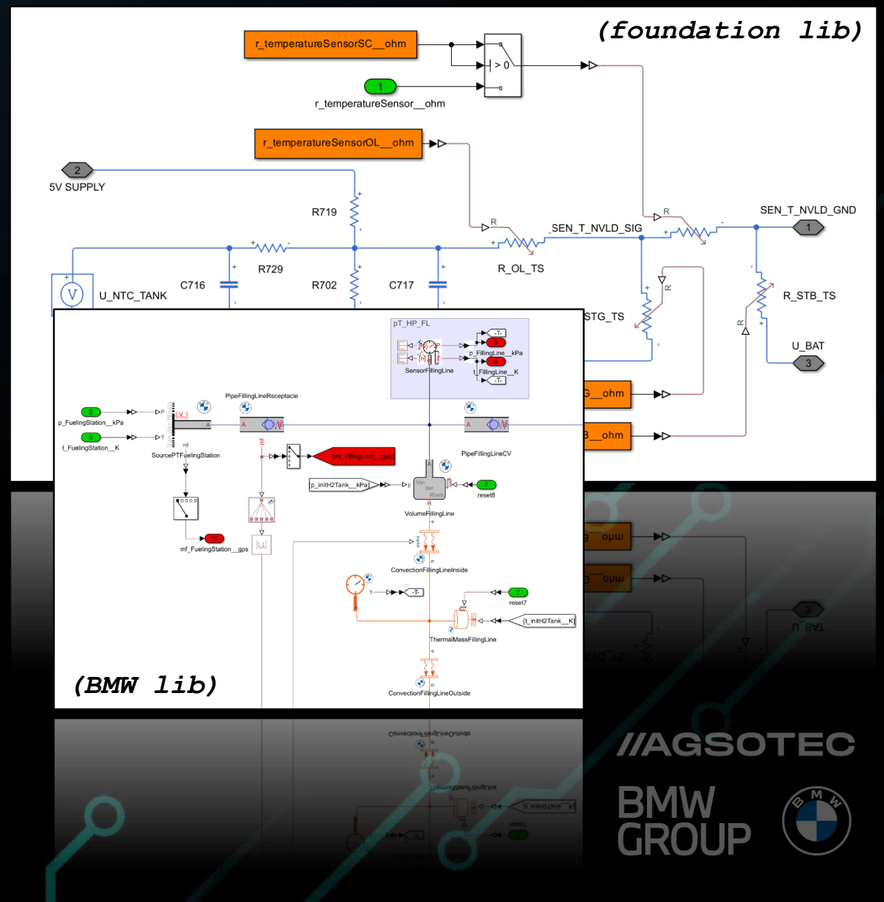
SiL level 3

SYNOPSYS® Silver



Simscape + MATLAB® & SIMULINK®



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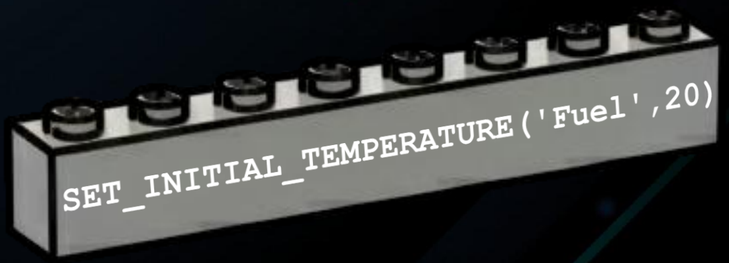
Scenario

```
FUNCTION1(arguments)
FUNCTION2(arguments)
FUNCTION3(arguments)
...
```



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BMW GROUP

Scenario : **User-friendly**

- Modular
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- Intuitive

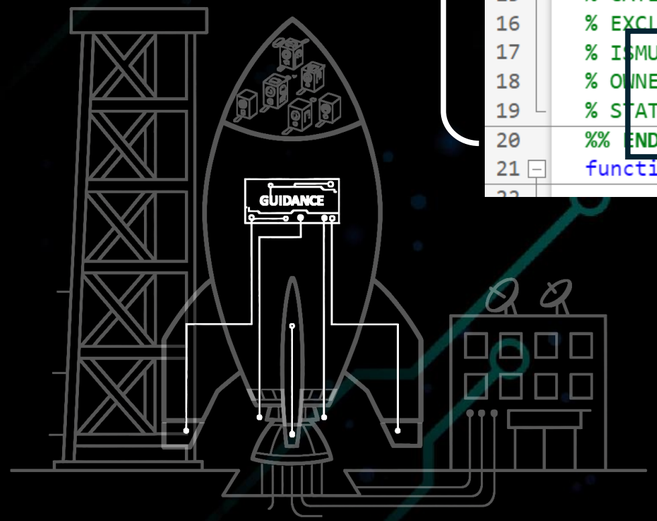
Header for Test-Case Database

```
1   %% START HEADER TESTDATABASE SCENARIOELEMENT
2   %% CAN NOT BE MODIFIED
3   % NAME: SET_ROAD_PROFILE
4   %% CAN BE MODIFIED
5   % TESTHARNESS: H2CU_A2 H2CU_B IFM_basis
6   % DESCRIPTION:
7   % Set the road profile with the following arguments:
8   % SET_ROAD_PROFILE(ENUM_roadProfile, initialAltitude). initialAltitude is the initial
9   % altitude (optional argument). ENUM_roadProfile can be one of the following
10  % Example: SET_ROAD_PROFILE("DownTownLosAngeles")
11  % Example: SET_ROAD_PROFILE("DownTownLosAngeles", 100)
12  % ARGUMENTS:
13  % Enum ENUM_roadProfile DownTownMunich DownTownMunich ['SeeLevel','DownTownMunich', 'DownTownLosAngeles', 'DownTownMexicoCity', 'PassBrennerDownTop', 'PassBrer
14  % Value al_initAltitude__m m 520 520 -1000 8000 500 True
15  % CATEGORY: conditions.environment
16  % EXCLUDES:
17  % ISMULTIUSABLE: False
18  % OWNER: QXZ46D7
19  % STATUS: ACTIVE
20  %% END HEADER TESTDATABASE
21  function testSpecObj = SET_ROAD_PROFILE(testSpecObj, ENUM_roadProfile, al_initAltitude__m)
```

→ Set Plant parameter

→ Define Argument properties

(for web-based Test-Case generator)



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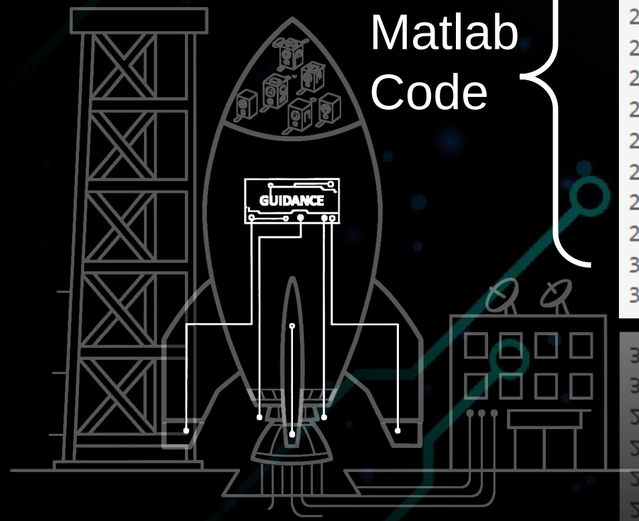
Header for Test-Case Database

Matlab Code




```
1   %% START HEADER TESTDATABASE SCENARIOELEMENT
2   %% CAN NOT BE MODIFIED
3   % NAME: SET_INITIAL_H2_DENSITY
4   %% CAN BE MODIFIED
5   % TESTHARNESS: H2CU_A2 H2CU_B
6   % DESCRIPTION:
7   % SET_INITIAL_H2_DENSITY(30) sets the initial density in the H2 Tank to 30 g/l.
8   % Sets initial PlantModel value as well as VECU-NvM.
9   % ARGUMENTS:
10  % Value rho_init g/l 31.2 31.2 0.08 57 5 False
11  % CATEGORY: conditions.initial
12  % EXCLUDES: SET_INITIAL_H2_LEVEL SET_INITIAL_H2_PRESSURE SET_INITIAL_H2_MASS
13  % ISMULTIUSABLE: False
14  % OWNER: q335505
15  % STATUS: ACTIVE
16  % USEBEFORE: SET_PLANT_PARAMETER SET_NVM_VALUE
17  %% END HEADER TESTDATABASE
18  function testObj = SET_INITIAL_H2_DENSITY(testObj,rhoInit__gpl)
19
20      % Check ScenarioElement order
21      Common.checkUseBeforeInTestSpecElements(testObj, {'SET_PLANT_PARAMETER' 'SET_NVM_VALUE'})
22      % end Check
23
24      % set VECU init (nvm)
25      testObj = ScenarioElement.SET_NVM_VALUE(testObj,'BMW_SWC_HtsNvBlock_snSAVED_ZONE_NV.ppBMW_dens_H2TankNv',rhoInit__gpl);
26
27      % set plant Model init
28      pInit__kPa = 100*Physics.computeH2Pressure(rhoInit__gpl,testObj.input_plantParameters.plantParam_FuelCell_Gen3.tInitH2Tank__K);
29      testObj = ScenarioElement.SET_PLANT_PARAMETER(testObj,'plantParam_FuelCell_Gen3.p_initH2Tank__kPa',pInit__kPa);
30  end
31
```

→ Define Argument properties

(for web-based Test-Case generator)

→ Set Non-Volatile-Memory

→ Set Plant parameter

Scenario : **User-friendly**

- Modular
- High level
- Intuitive

SWITCH_CAR_USAGE('Parked_locked',30)

TRIGGER_FUELING_REQUEST(10)

SET_TARGET_CAR_SPEED(80,10)

SET_TARGET_CAR_SPEED(80,10)

river

MALFUNCTION_LEAK('Tank',0.5,20)

MALFUNCTION_SENSOR_STUCK('PT_T',115)

modifications.malfunction

SET_INITIAL_STATE_OF_CHARGE(30)

SET_INITIAL_TEMPERATURE('Fuel',20)

SET_NVM_VALUE('bmw_pct_fuLvl',67)

SET_INITIAL_TEMPERATURE('Fuel',20)

actions.driver

actions.mechanic

conditions.initial

conditions.envir

SET_ROAD_PROFILE("DownTownMunich")

.fuelingStation

config.simulation

vehicle

…

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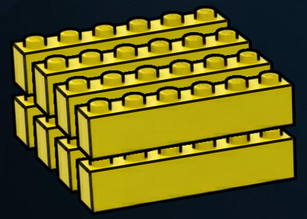
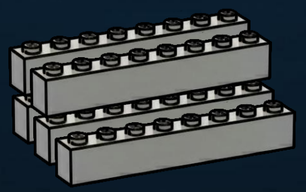


actions-SET

City / Highway
Refueling
Workshop



conditions-SET

Winter/Summer
Sea Level/Mountain
Cold/Warm-Start

vehicle-SET

7er/X5/Mini
“Integration-Level” (calib.)

Scenario 1

Scenario 2

Scenario 3

Scenario 4

Ultra-Fast
Scenario Generation
through combinations !

modifications

Min/Nom/Max Components
Malfunctions

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Implicit Testing

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Test Harness : **Realistic**
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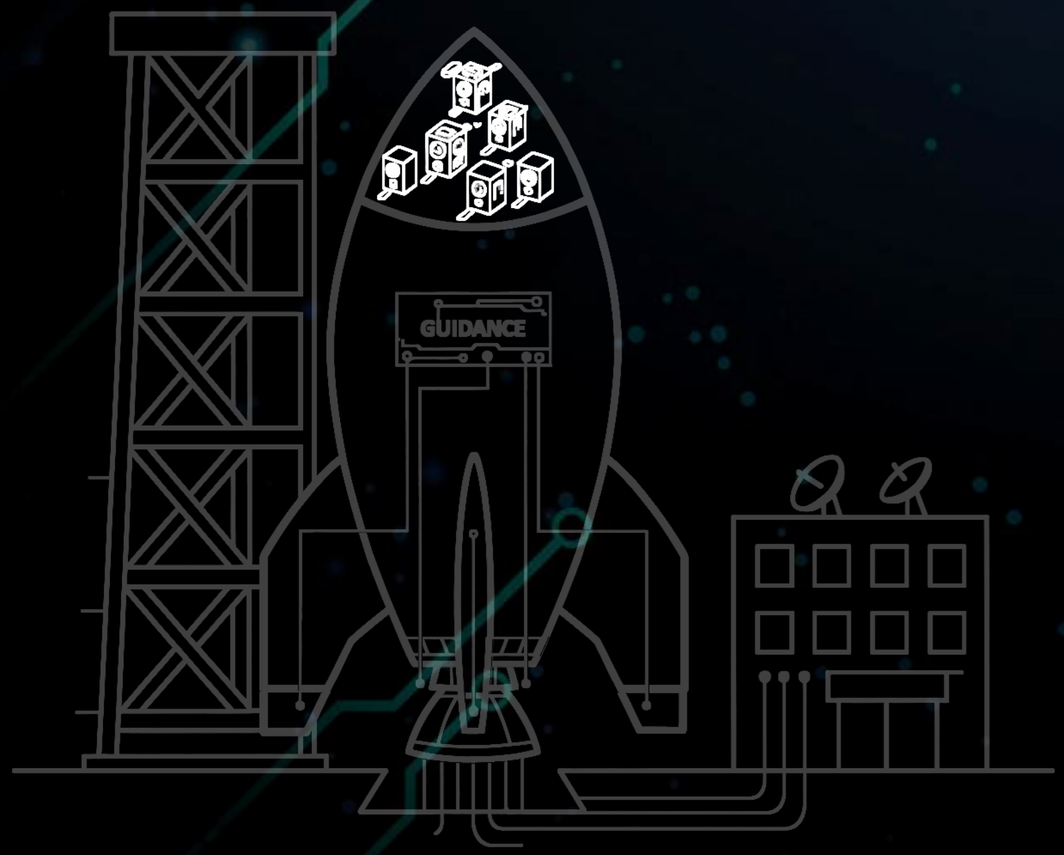

Check : **Scalable**
- High level
- Transferable
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Toolchain : **Flexible**
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BMW GROUP

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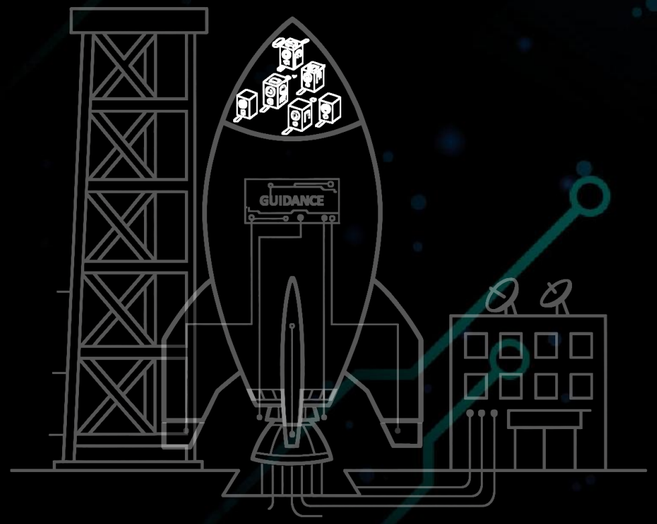

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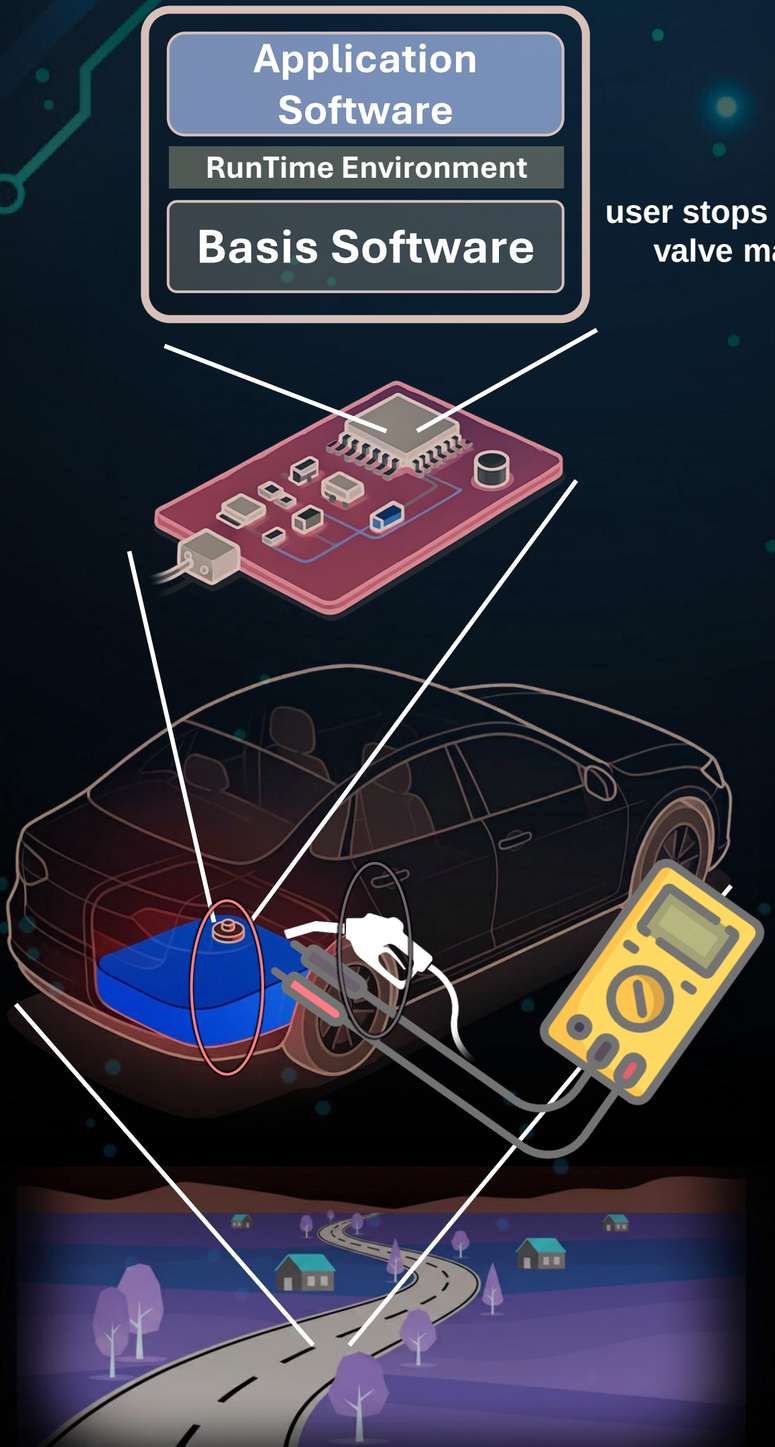
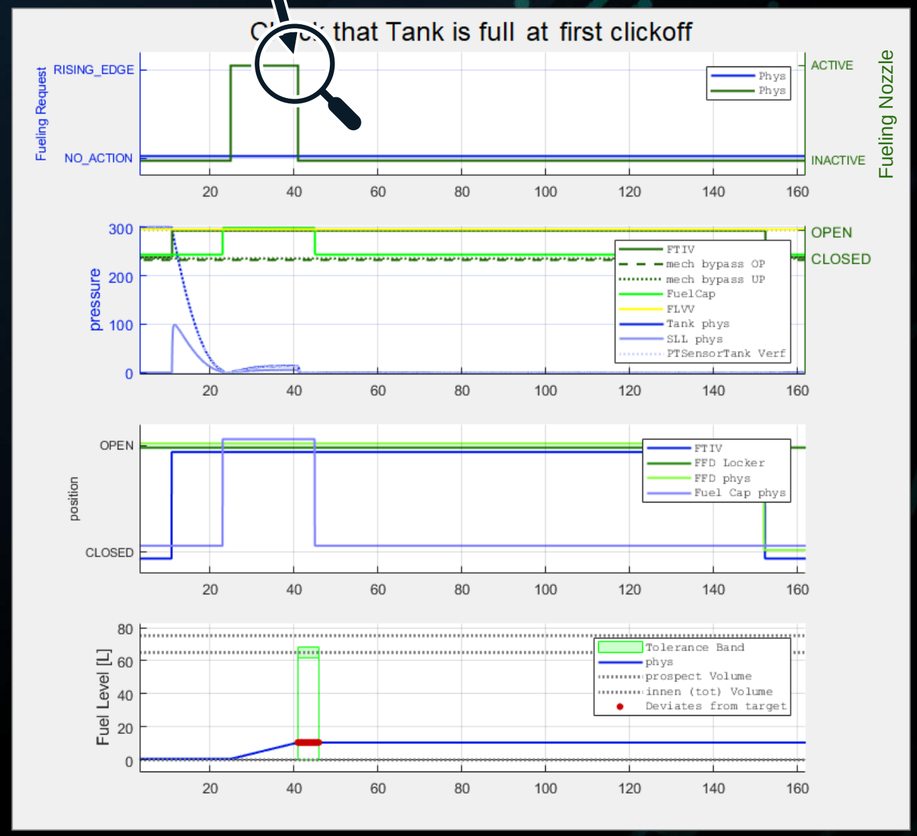
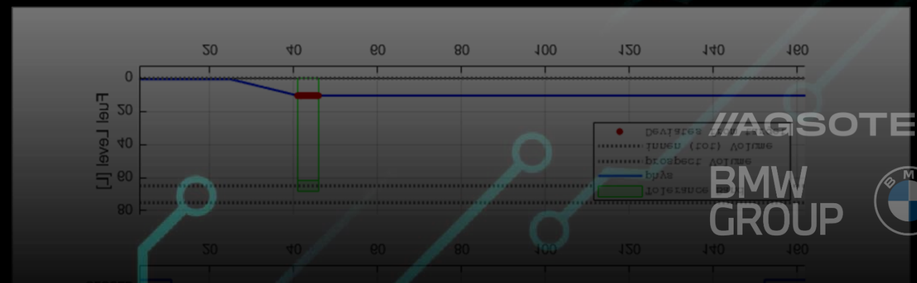


Result = **PASSED**
FAILED

no fueling
user stops fueling before end
valve malfunction injected
} **CONDITION-NOT-FULFILLED**





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Toolchain : **Flexible**

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Pre-Processing

- Different Input Formats (excel, mdf, dcm, json)

MATLAB

Run

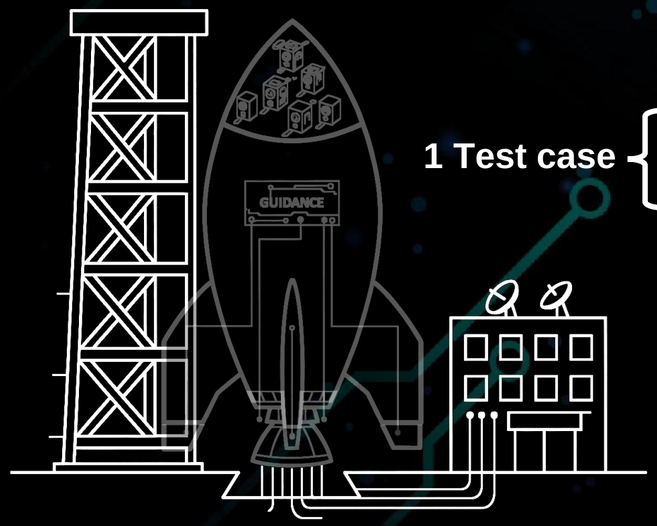
- Interoperability with Silver

SYNOPSYS® Silver

Post-Processing

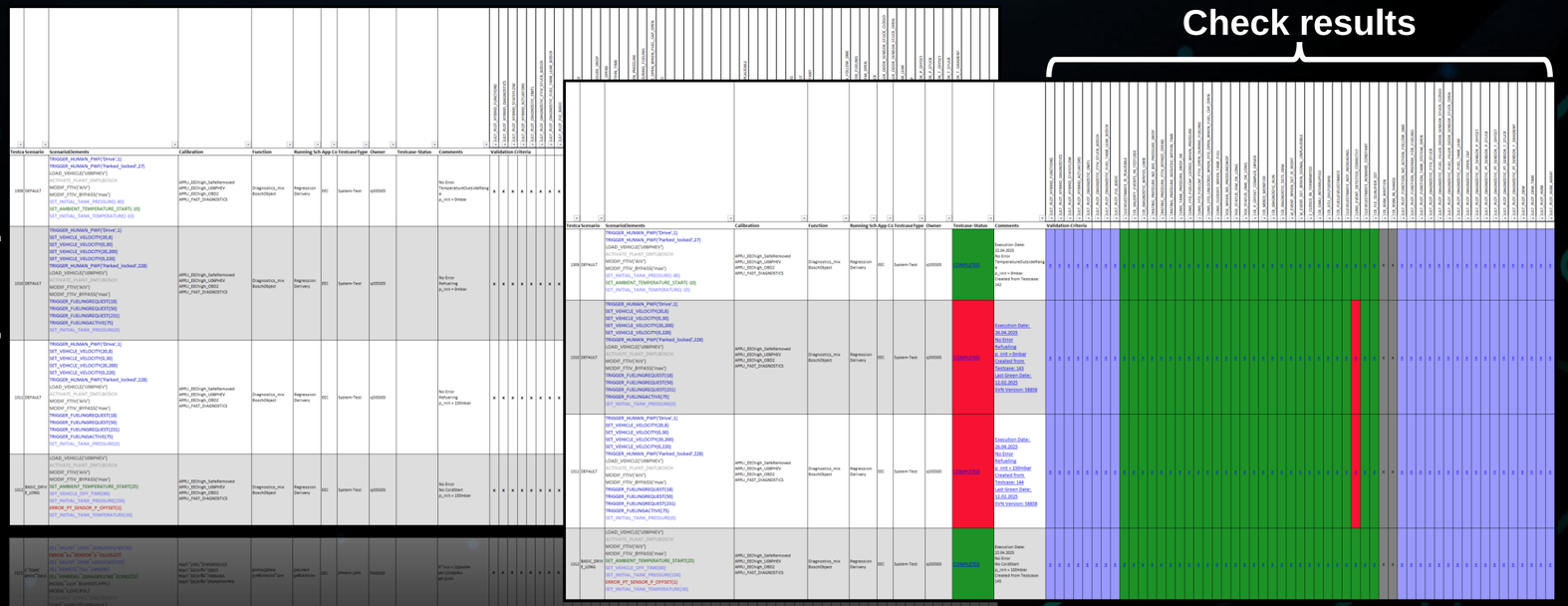
- Different Output Formats (excel, mdf, json)

MATLAB



1 Test case

Check results



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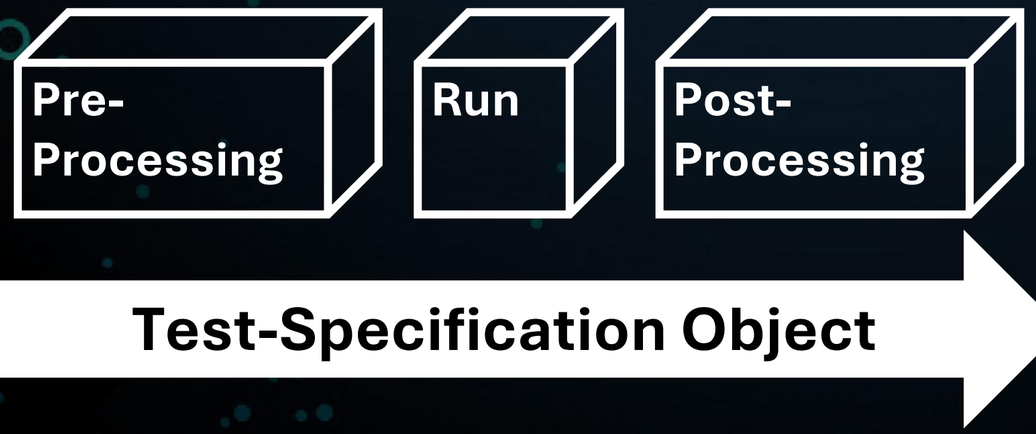

Header

header_preProcessDate	'20250926_1338'
header_gitInfo	*1x1 struct*
header_gitInfoSmvEcu	*1x1 struct*
header_gitInfoSmTh	*1x1 struct*
header_project	'FCEV'
header_testHarness	'H2CU_B'
header_simulinkConfig	''
header_fileName	'20250926_1338_TestRunData_01002'
header_testCaseNumber	1002
header_ecuSwVersion	*1x1 struct*
header_thVersion	'250926.0'
header_owner	'QQH2CU0'
header_calibrationBaseDST	'31A430792BHGXAB'

Testharness config

thConfig_silverModuleConfig	*1x1 struct*
thConfig_signalsToBeLogged	*1x1 struct*
thConfig_modeSignals	*1x1 struct*
thConfig_NvM	*1x1 struct*
thConfig_sensorMapping	*73x24 table*
thConfig_actuatorMapping	*13x33 table*
thConfig_boardnetRoutingList	*427x19 cell*
thConfig_overwriteFirstDataPoint	*0x0 cell*
thConfig_remotePath	'\\Europe.bmw.corp\WINFS\Panama\PLW_EA_e4\...
thConfig_enumNamesMapping	*dictionary (string --> string) with 1738 entries*
thConfig_enumStateMapping	*31x13 table*
thConfig_canPduMapping	*71x8 table*
thConfig_ignoreListDtc	*3x2 table*
thConfig_DEM	*1x1 struct*
thConfig_inputSignalMapping	*0x2 table*
thConfig_labelConfig	*1x1 struct*
thConfig_errorSignals	*1x1 struct*
thConfig_demStimulation	*0x9 table*
thConfig_demFimMapping	*0x5 table*
thConfig_sensorMalfunction	*[ ]*
thConfig_iniFiles	*1x1 struct*
input_testSpecification	*1x1 struct*

Input data

input_signals	*dictionary with unset key and value types*
input_NVM	*1x1 struct*
input_hash	*1x1 struct*
input_loadedScenarioElement	*1x1 struct*
input_loadedCalibration	*1x1 struct*
input_initialAccessPointParameters	*15835x1 table*
input_plantParameters	*1x1 struct*
input_calibrationParametersInfo	*45x1 cell*
input_calibrationParameters	*dictionary (string --> struct) with 31216 entries*
input_calibrationParameterNotFound	*dictionary (string --> struct) with no entries*
input_scenarioElementParameters	*1x1 struct*
input_validationCriteriaParameters	*1x1 struct*
input_signalsToBeLogged	*1x1 struct*
input_simulationTiming	*1x1 struct*

Execution data

exec_processStep	10
exec_testHarnessVersionIsHeadRevision	*[ ]*
exec_type	-1
exec_measurementRaster	1.0000e-03
exec_computationRun	*1x1 struct*
exec_logging	*1x1 struct*

Output data

output_signals	*dictionary (string --> timeseries) with 3799 entries*
output_NVM	*1x1 struct*
output_DEM	*dictionary (string --> timeseries) with 1362 entries*
output_Malfunction	*19x13 table*

Toolchain : **Flexible**

- Standardized
- Traceable
- Automated
- Evolutive

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header_gitInfoSmvEcu	*1x1 struct*
header_gitInfoSmTh	*1x1 struct*
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header_testHarness	'H2CU_B'
header_simulinkConfig	''
header_fileName	'20250926_1338_TestRunData_01002'
header_testCaseNumber	1002
header_ecuSwVersion	*1x1 struct*
header_thVersion	'250926.0'
header_owner	'QQH2CU0'
header_calibrationBaseDST	'31A430792BHGXAB'
thConfig_silverModuleConfig	*1x1 struct*
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thConfig_demStimulation	*0x9 table*
thConfig_demFimMapping	*0x5 table*
thConfig_sensorMalfunction	*[ ]*
thConfig_iniFiles	*1x1 struct*
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input_calibrationParametersInfo	*45x1 cell*
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input_calibrationParameterNotFound	*dictionary (string --> struct) with no entries*
input_scenarioElementParameters	*1x1 struct*
input_validationCriteriaParameters	*1x1 struct*
input_signalsToBeLogged	*1x1 struct*
input_simulationTiming	*1x1 struct*
exec_processStep	10
exec_testHarnessVersionIsHeadRevision	*[ ]*
exec_type	-1
exec_measurementRaster	1.0000e-03
exec_computationRun	*1x1 struct*
exec_logging	*1x1 struct*
output_signals	*dictionary (string --> timeseries) with 3799 entries*
output_NVM	*1x1 struct*
output_DEM	*dictionary (string --> timeseries) with 1362 entries*
output_Malfunction	*19x13 table*

MATLAB® & SIMULINK®

.mdf / .mf4

//AGSOTEC

BMW GROUP

Vehicle
Field Testing
& Calibration

HiL
Release Validation Test

SiL lev3

Implicit Testing

MiL / SiL
Unit Test

Already a success story !

First Time Right

No major Bug found in car tests

Economical

50% cut on Hardware cost

Stable Quality

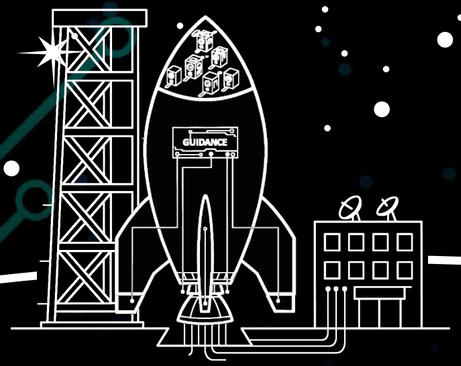
“build-in” regression Testing

//AGSOTEC

BMW GROUP

Thank you for your attention

We look forward to seeing you at the **AGSOTEC** booth



//AGSOTEC

BMW GROUP

BACKUP

Scenario : **User-friendly**

- Modular
- High level
- Intuitive

Generate with:
- Model-Based-Testing
- AI

actions-SET

City / Highway
Refueling
Workshop

Generate with:
- Deterministic Combinations

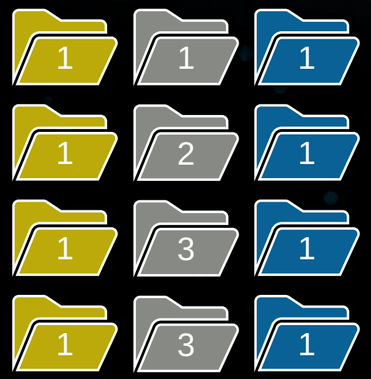
conditions-SET

Winter/Summer
Sea Level/Mountain
Cold/Warm-Start

Generate with:
- Standard BMW Development Process

vehicle-SET

7er/X5/Mini
“I-Stuffen” Calibrations



Scenario 1

Scenario 2

Scenario 3

Scenario 4

Ultra-Fast
Scenario Generation
through combinations !

modifications

Min/Nom/Max Components
Malfunctions

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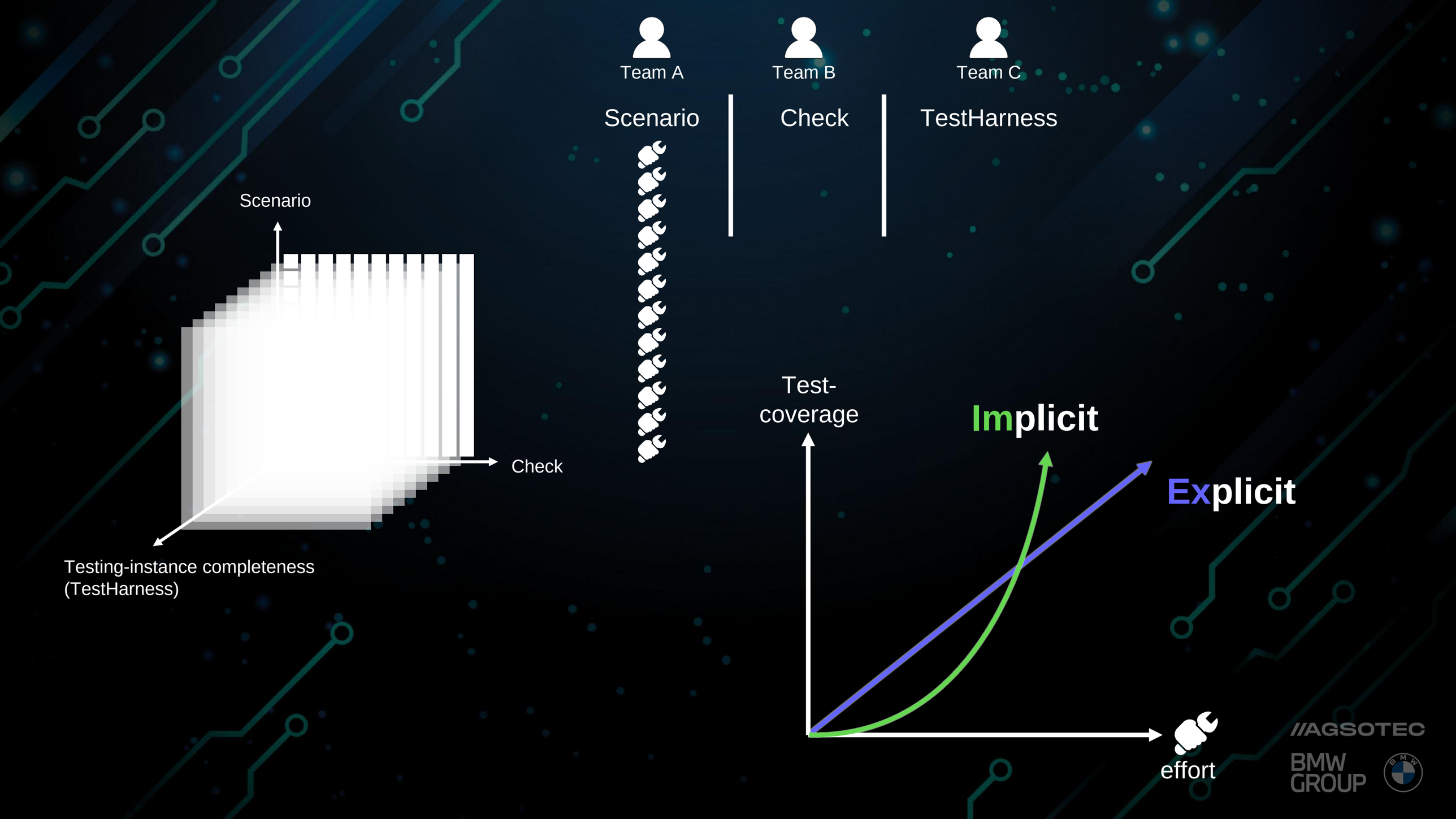
Team A
Team B
Team C
Scenario
Check
TestHarness
Scenario
Check
Testing-instance completeness
(TestHarness)
Test-
coverage
Implicit
Explicit
effort