
TNO ESI
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TAKE THE NEXT STEP IN TEST AUTOMATION WITH MBT

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AGENDA

- Testing context and challenges in industry
  - Best practices in industry
  - Limitations of BDD test automation frameworks
- **Break + Reflections and Discussions**
- Take the next step in test automation with MBT
  - What do we mean by models and what is MBT
  - Collaborative specification of systems in context with BPMN4S
  - Automated Test Generation and Coverage
  - Live demo of a print shop
- How did we evaluate the methodology and show value, insights into adoption at ASML
- **Break + Reflections and Discussions**
- Research and Development Roadmap
- Can AI potentially help to improve systems testing?
- **Takeaways and Wrap-up**

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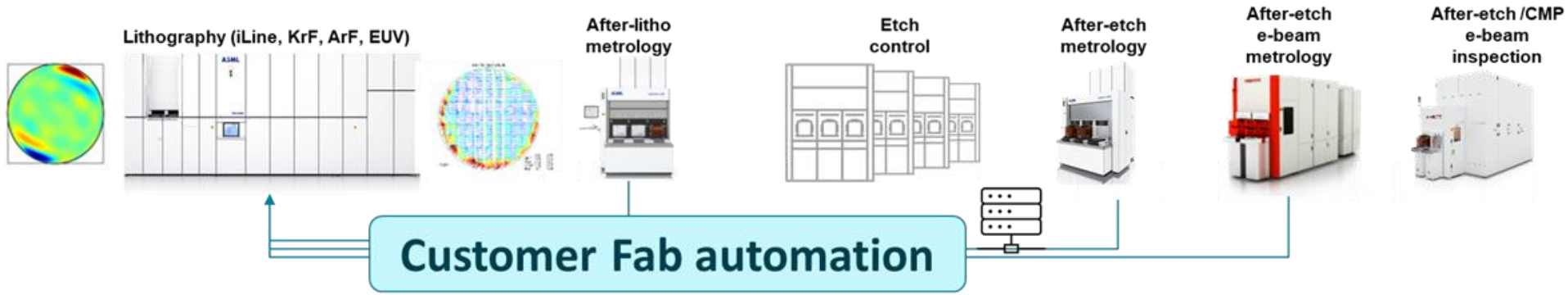
BACKGROUND OF THIS TALK

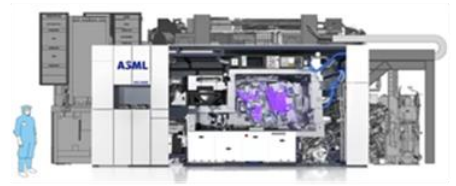
From 2023 to 2025, TNO-ESI and ASML *collaborated* in a **public-private partnership** to develop a **MBT** methodology to **improve efficiency and effectiveness** of **system**(-of-systems) **testing processes** in industry.

Open-source tooling offering a **collaborative modeling framework**, with capabilities for **simulation** and **automatic generation of test scripts** in various languages such as Cucumber, Robot, JUnit, and GTest.

Successful validation through several pilots, the methodology and tools are being **matured for adoption** into a new way of working.



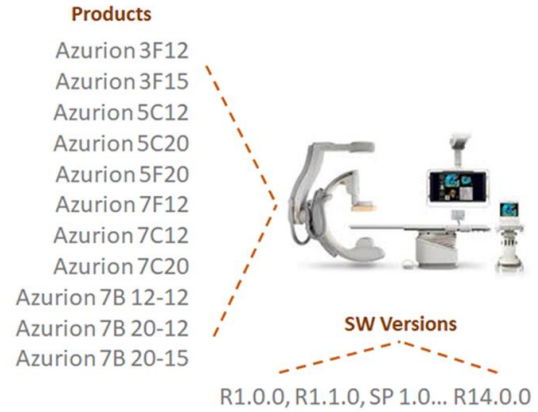
RISING COMPLEXITY OF CYBER-PHYSICAL SYSTEMS



Increasing role and complexity of software in cyber-physical systems

Ensuring promised system quality is a huge challenge

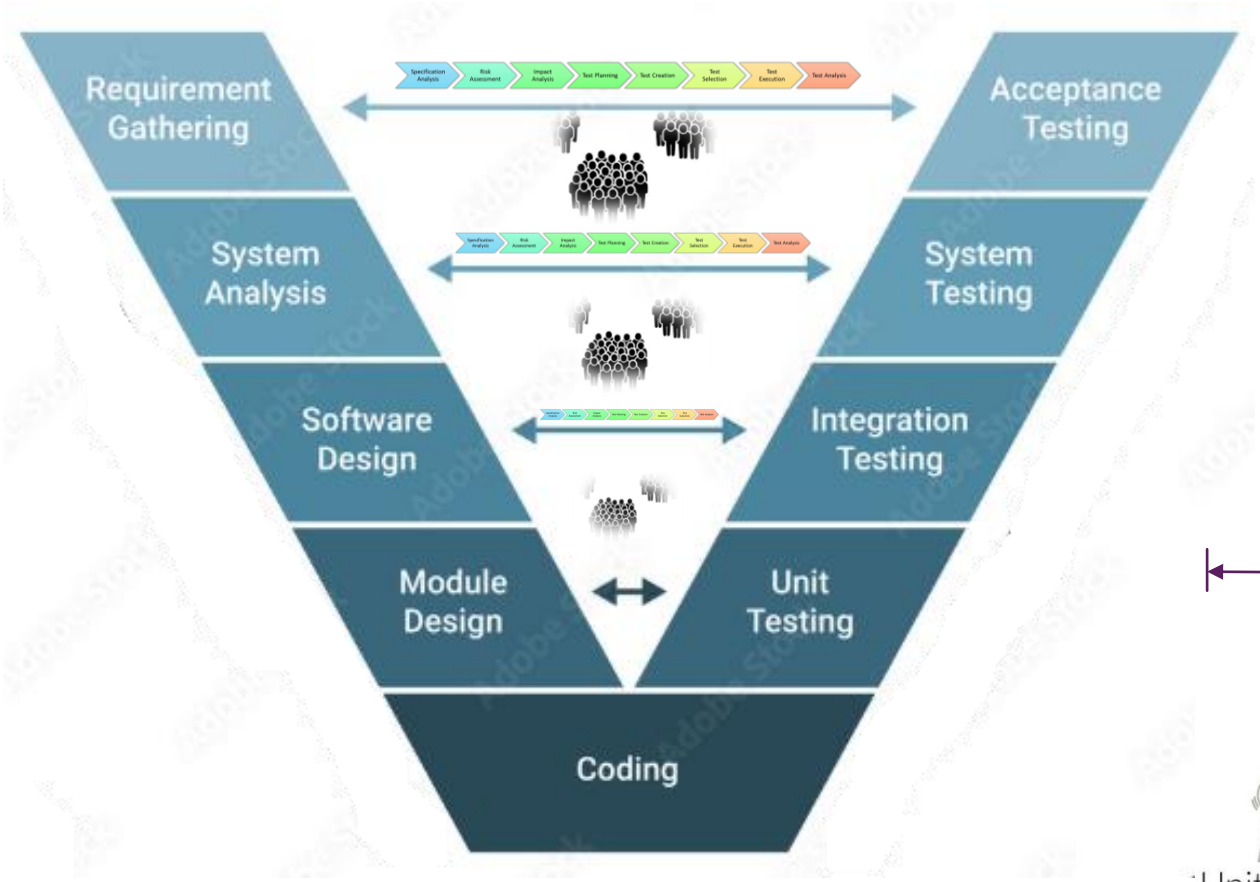
- Multi-disciplinary with intrinsic rising complexity
- Uncertainty in operational context (environment)
- Heterogeneity in systems, SW platforms and standards
- Product-line variability and long-lifetimes,
- Impact of updates and upgrades
- New trends such as AI, cloud deployments, IoT etc.

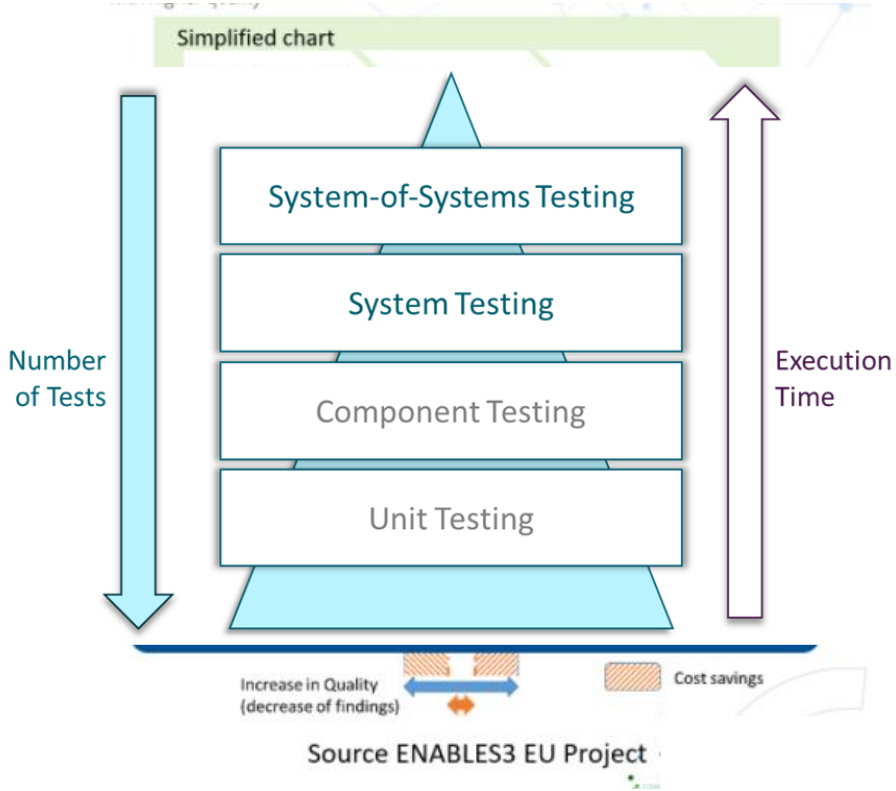


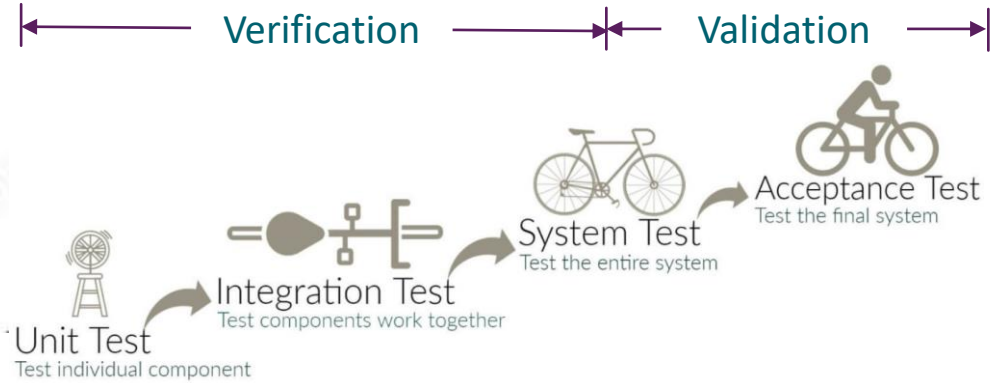
Testing is a key activity to assess and improve system quality but not much has changed in how we do it in the last 30 years…

SYSTEMS TESTING

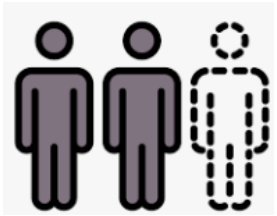
The cost of detecting software defects grows exponentially







TESTING CHALLENGES



How to enable faster time to market with promised quality and lower costs?

Automation of Manual Testing	Requirements Gathering and Stakeholder Management	Costs of Test Infrastructure	Lack of Available Hardware
Handcrafting of Test Suites	Traceability of Specifications and Tests	Maintenance of Test Suites	Test Execution Analysis
Dealing with Updates and Upgrades	Selection of Tests and Configurations	Coverage and Quality Metrics	Risk Management and Mitigation
Scarcity of People			

BEST PRACTICES IN INDUSTRY

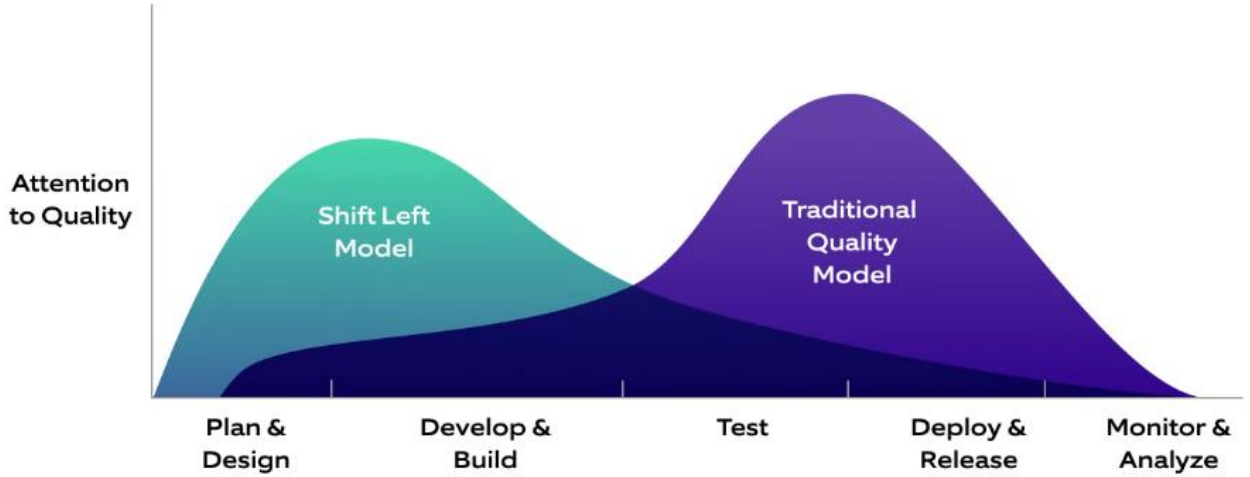
Shift-left strategy

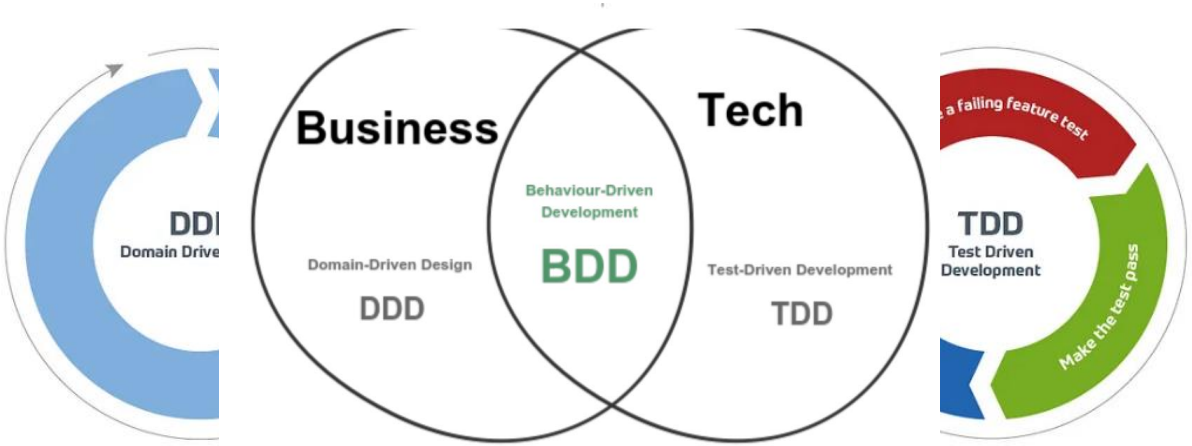
DDD: Create shared understanding and language between business and technical concepts (ubiquitous language in context)

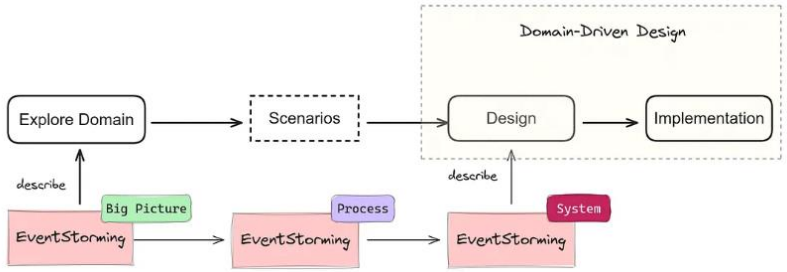
BDD: Focus on collaborative specification of *expected* system behavior as scenarios

TDD: Failing tests before systems development

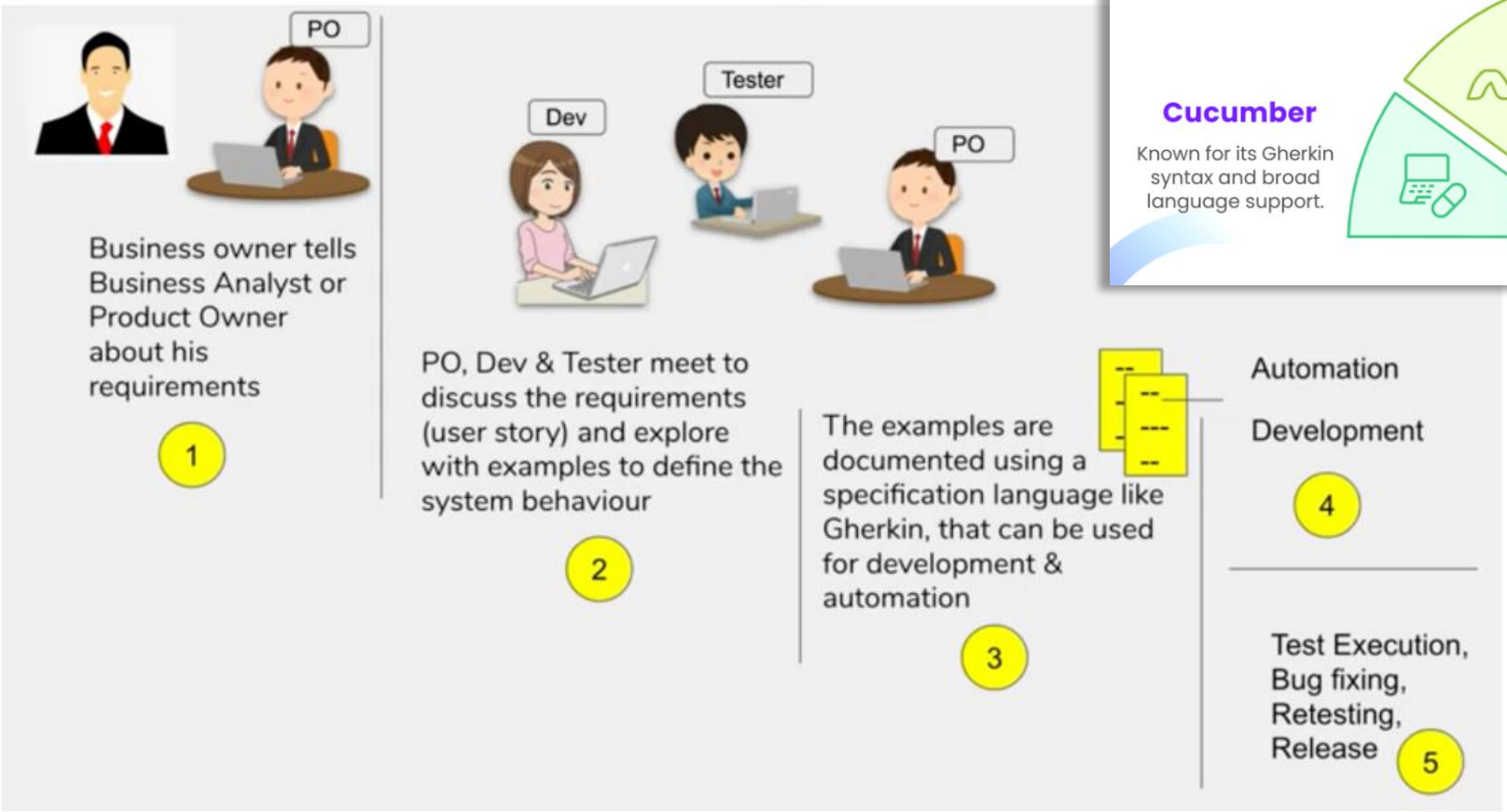
DDD + BDD + TDD (combinations of them) are widely used methodologies in industry

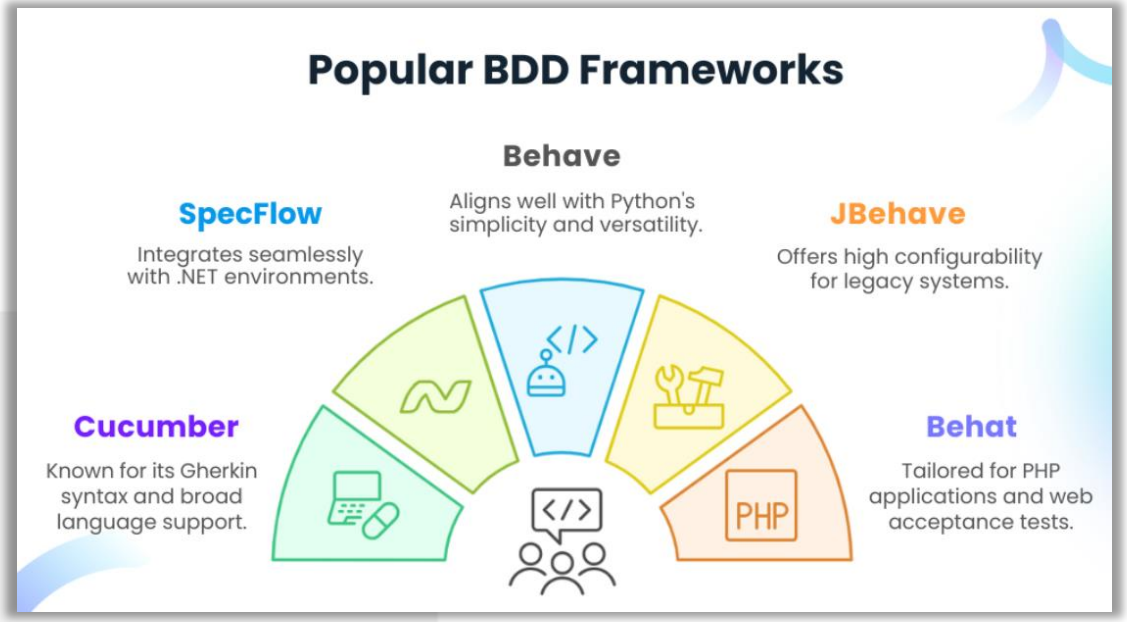




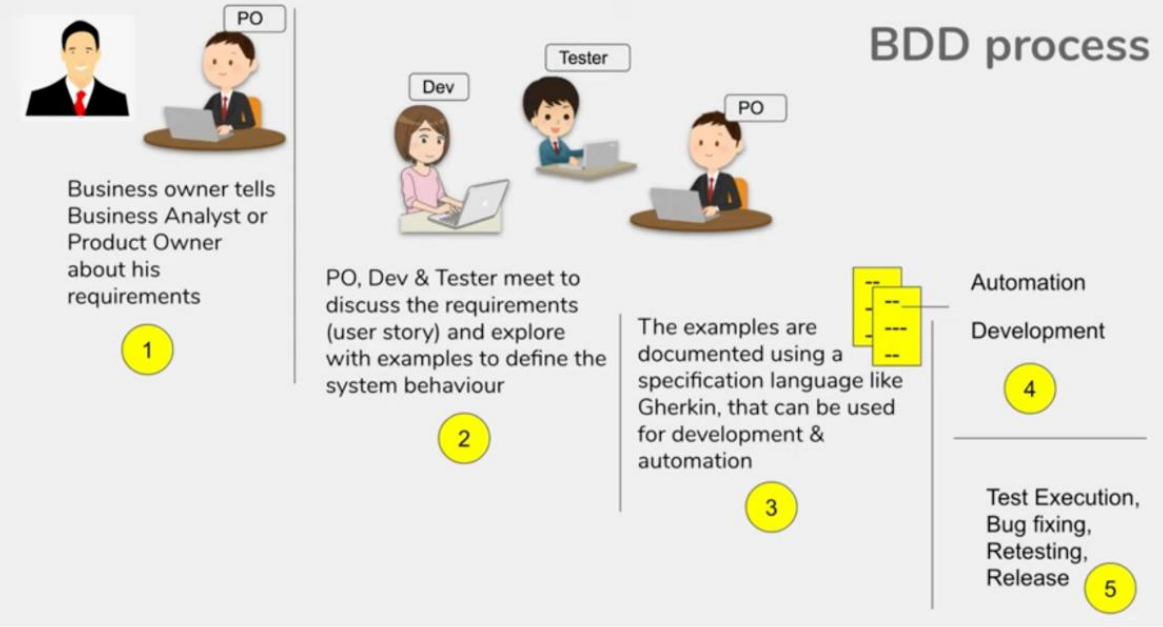


BEHAVIOR-DRIVEN DEVELOPMENT



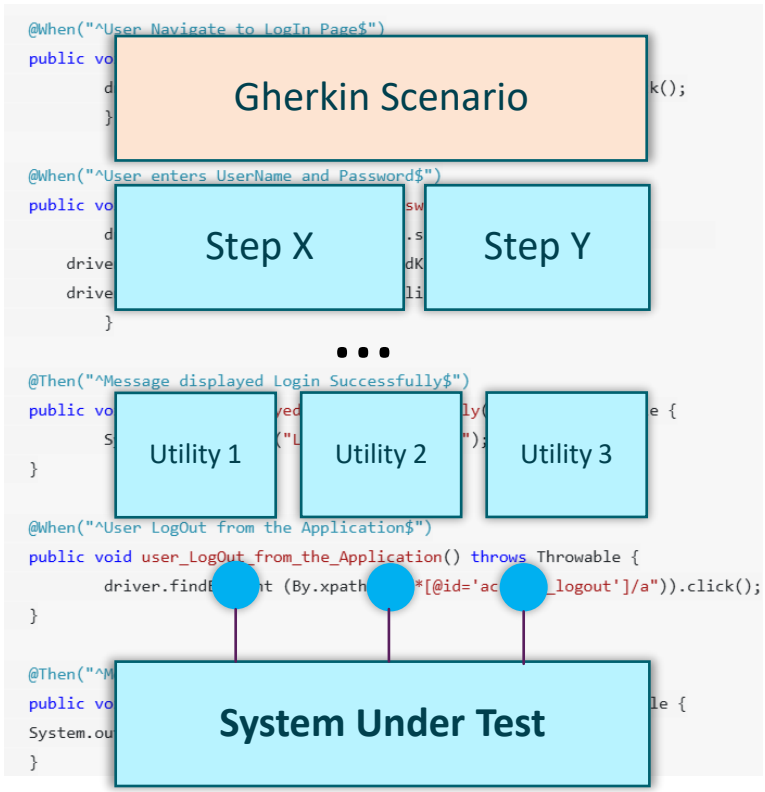


COLLABORATIVE SPECIFICATION WITH GHERKIN




```
Feature: Login
  As a user
  I want to be able to log in to the application
  So that I can access my account information

  Scenario: Successful login
    Given I am on the login page
    When I enter my username and password
    And I click the login button
    Then I should be taken to the dashboard page
```



BDD CHALLENGES

What can we really say about coverage of specification and risks?

What does a keyword really do?

```
Feature: Login
  As a user
  I want to be able to log in to the application
  So that I can access my account information

  Scenario: Successful login
    Given I am on the login page
    When I enter my username and password
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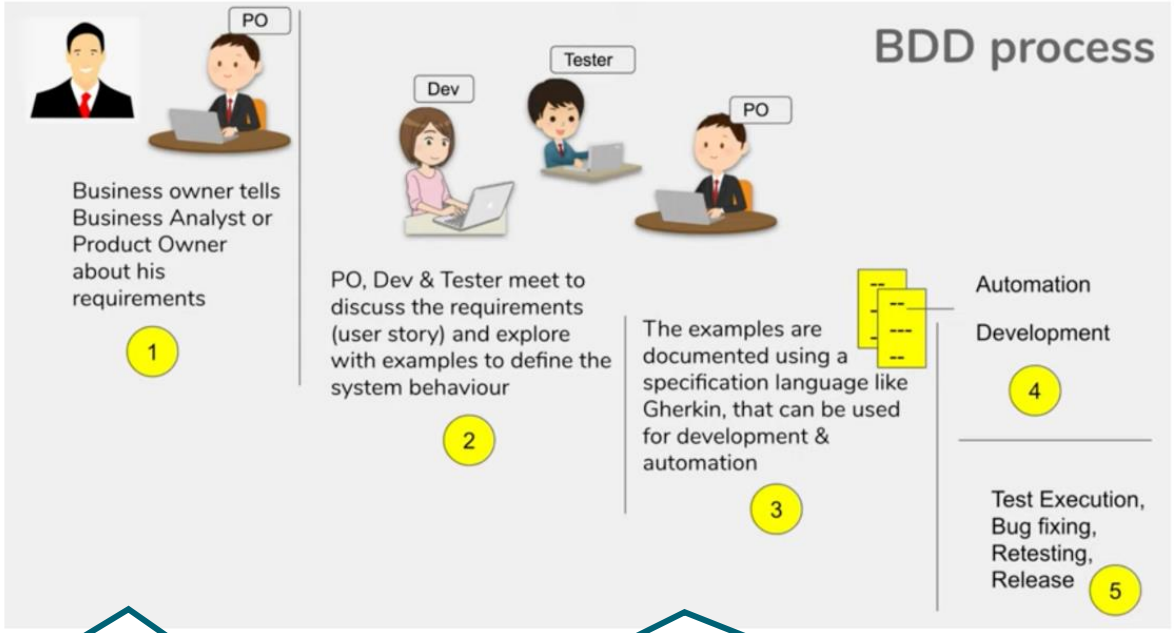



```
@When("^User Navigate to LogIn Page$")
public void user_Navigate_to_LogIn_Page() throws Throwable {
        driver.findElement(By.xpath(".//*[@id='account']/a")).click();
        }

@When("^User enters UserName and Password$")
public void user_enters_UserName_and_Password() throws Throwable {
        driver.findElement(By.id("log")).sendKeys("testuser_1");
    driver.findElement(By.id("pwd")).sendKeys("Test@123");
    driver.findElement(By.id("login")).click();
        }

@Then("^Message displayed Login Successfully$")
public void message_displayed_Login_Successfully() throws Throwable {
        System.out.println("Login Successfully");
}

@When("^User LogOut from the Application$")
public void user_LogOut_from_the_Application() throws Throwable {
        driver.findElement (By.xpath(".//*[@id='account_logout']/a")).click();
}

@Then("^Message displayed Logout Successfully$")
public void message_displayed_Logout_Successfully() throws Throwable {
System.out.println("LogOut Successfully");
}
```

High effort, cost and lead time

Lack support for dealing with changes (updates/upgrades)

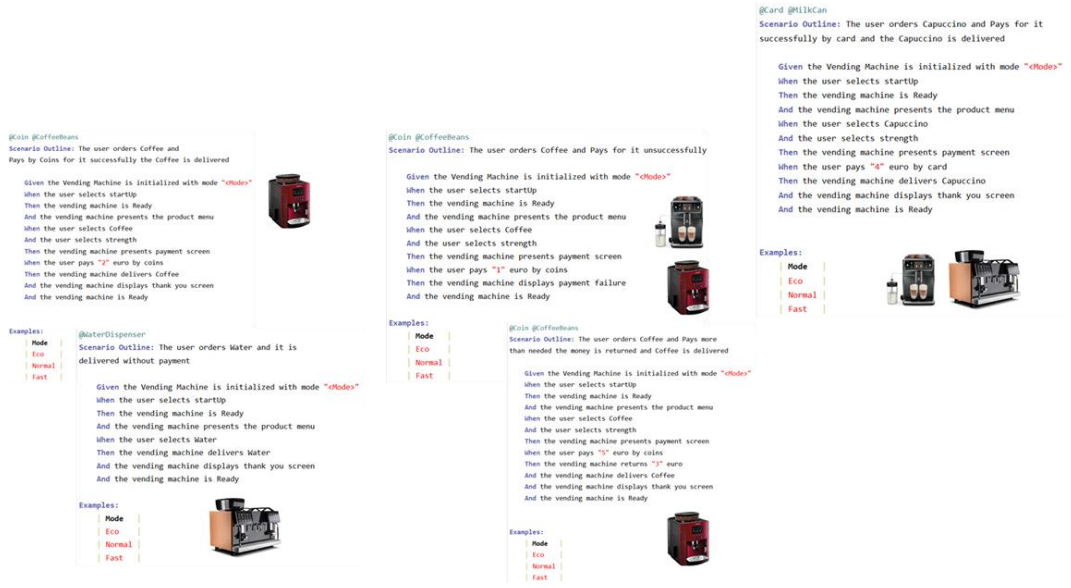
High maintenance effort

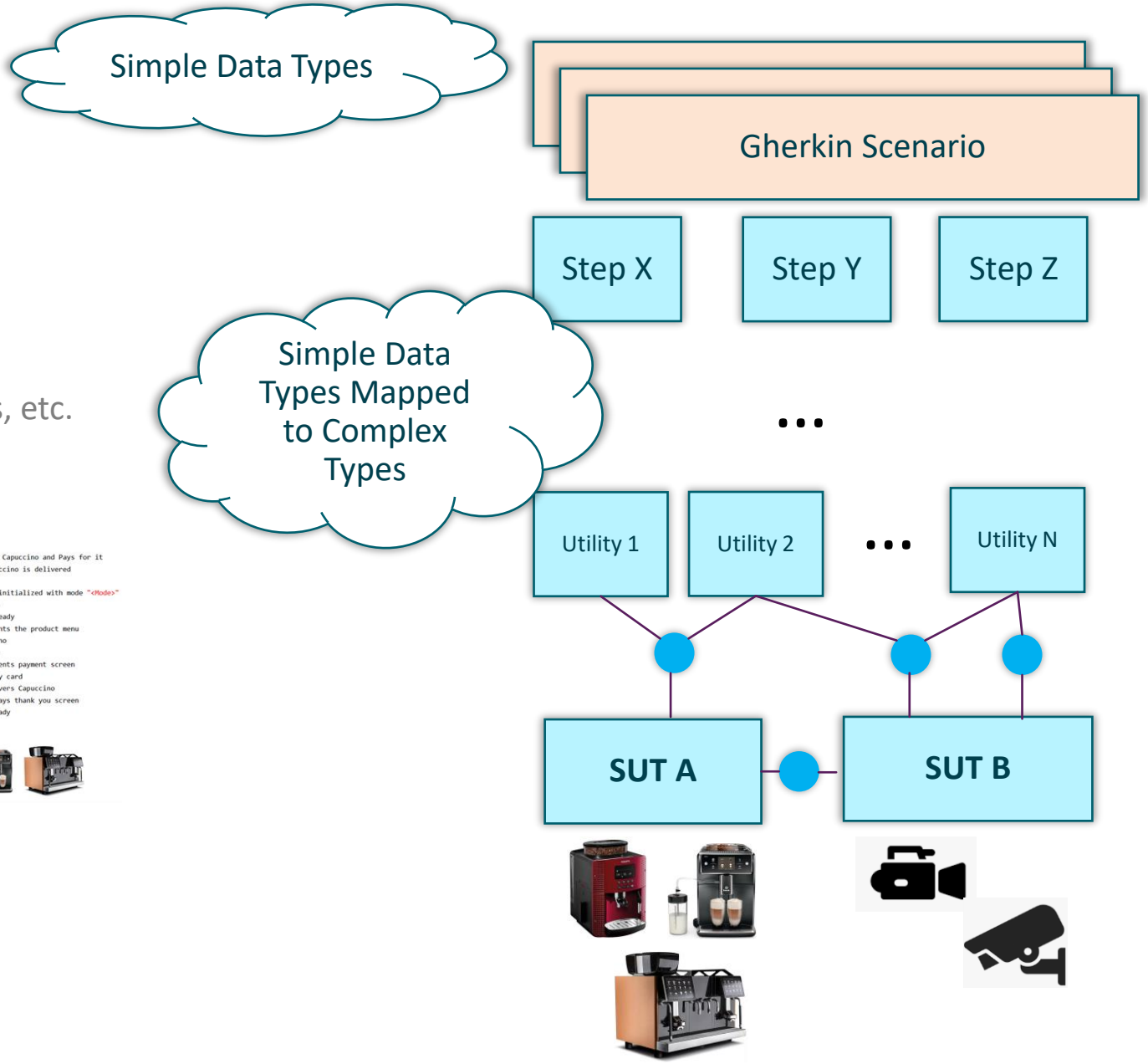
How to answer these questions: What is the coverage of my test suite? How much of each risk do each of my test cover? What does it mean to cover? etc…

LIMITATIONS OF GHERKIN

Limited Language Expressivity

- Limited data types (int, real, bool and string)
- Deterministic, i.e. no branching, e.g., if-else, loops, etc.
- No support for configuration variability





LIMITATIONS OF GHERKIN

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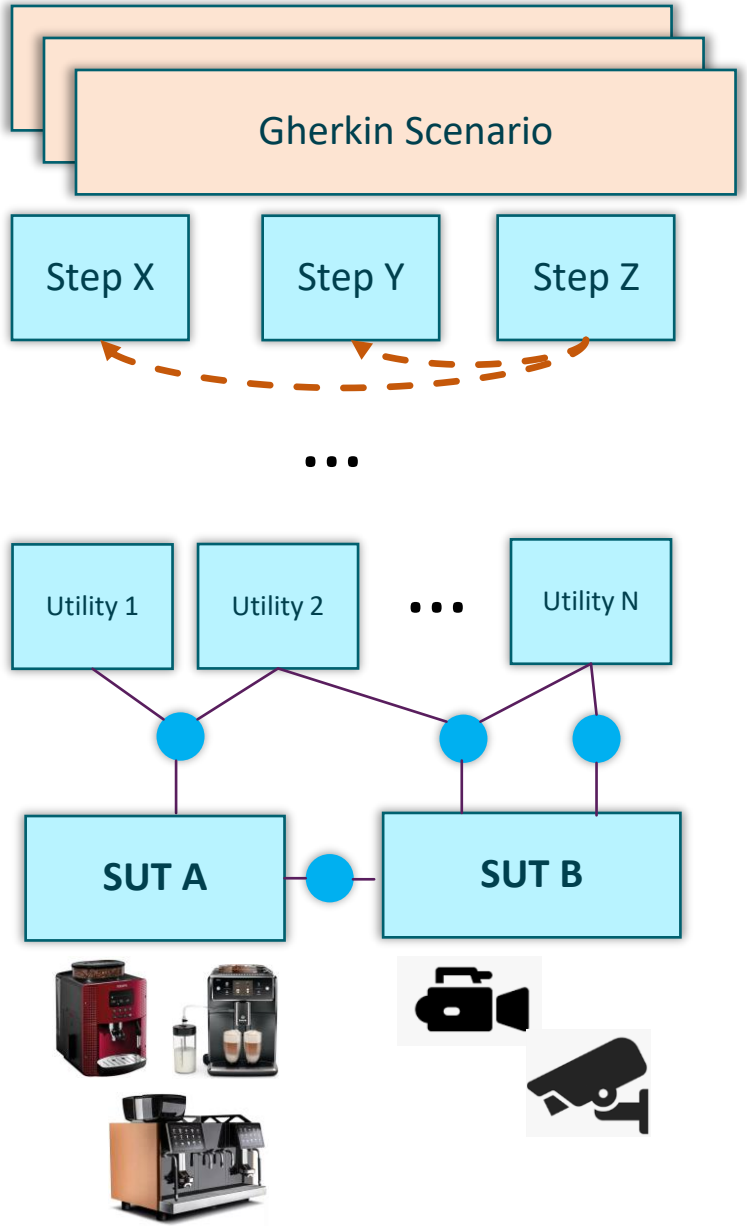
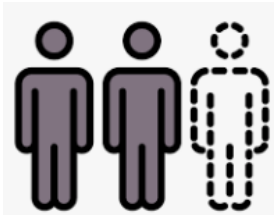
- Limited data types (int, real, bool and string)
- No branching, e.g., if-else, loops, etc.
- No support for configuration variability
- No support for references to step outputs

Leads-to

- Maintenance burden over time
  - Exploding number of test cases times system variants
  - Growing burden of keyword governance
  - How to prevent clones?
- High complexity, lead time and missing overview
  - Do all stakeholders have the same interpretation of steps?
  - Long scenarios with data relations between steps, implicit in their implementations
  - Multiple abstraction layers, written in different languages makes it difficult to get a global view



INNOVATIONS ARE NOT KEEPING UP



Off-the-shelf test automation frameworks **have not kept pace** with the **needs** to improve *efficiency* and *effectiveness* of testing complex systems.

Automation of Manual Testing	Requirements Capturing and Stakeholder Alignment	Costs of Test Infrastructure	Lack of Available Hardware
Handcrafting of Test Suites	Traceability of Specifications and Tests	Maintenance of Test Suites	Test Execution Analysis
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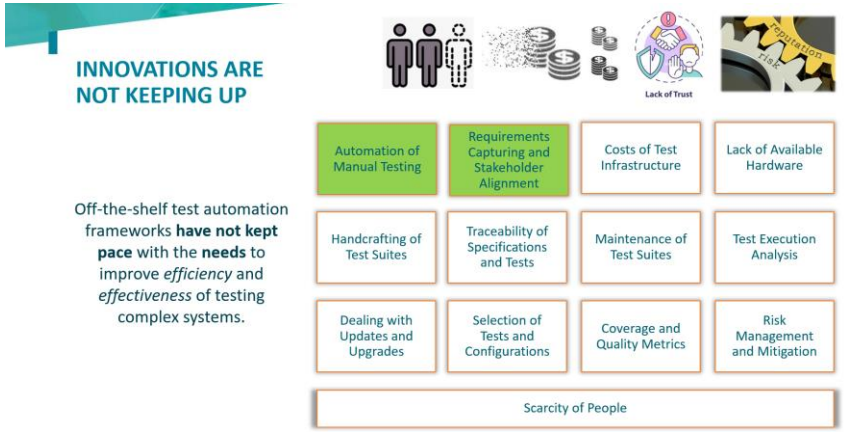
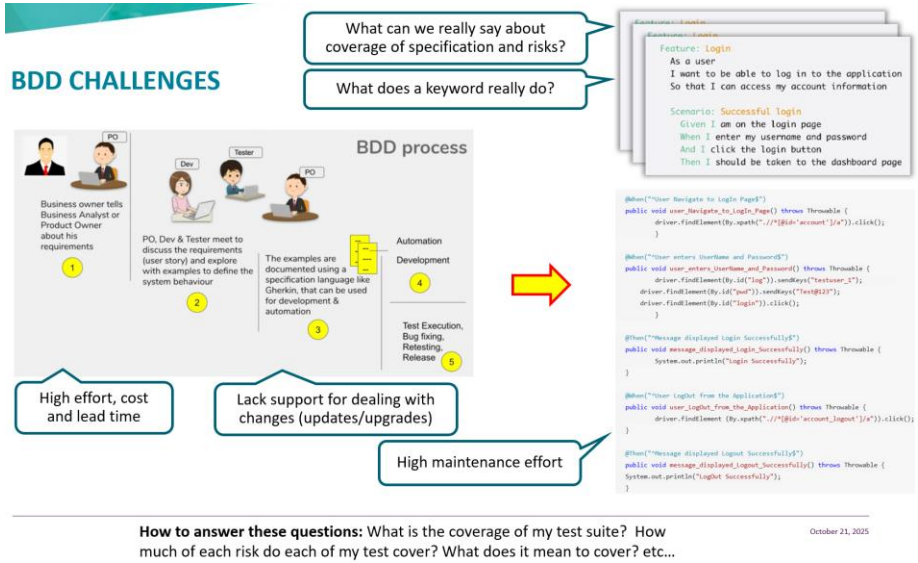
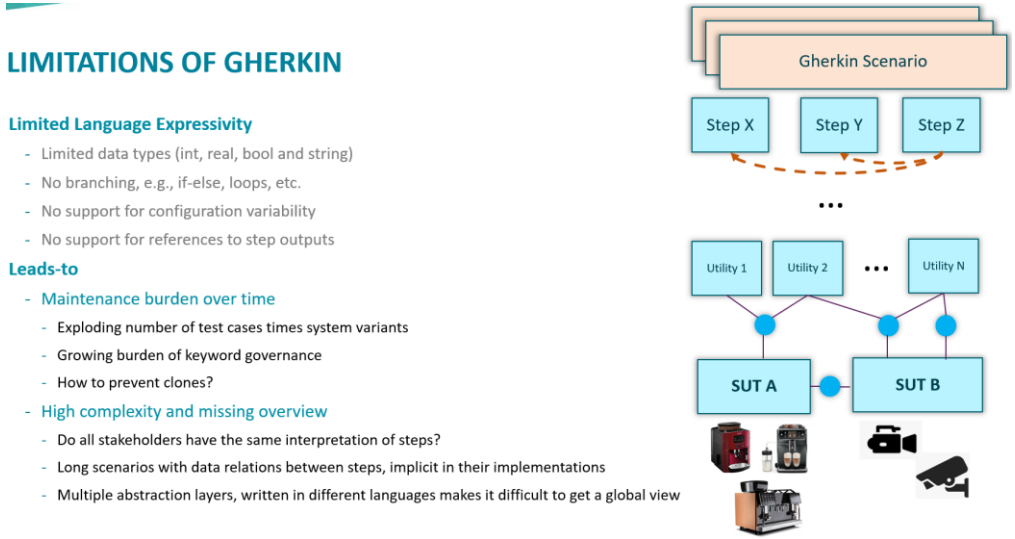
REFLECTIONS





We would love to hear your thoughts on

- How do you experience BDD in practice?
- Do you recognize these challenges?
- Do you think there are more, or less?
- Where do you feel the biggest need for innovation?



BREAK

AGENDA

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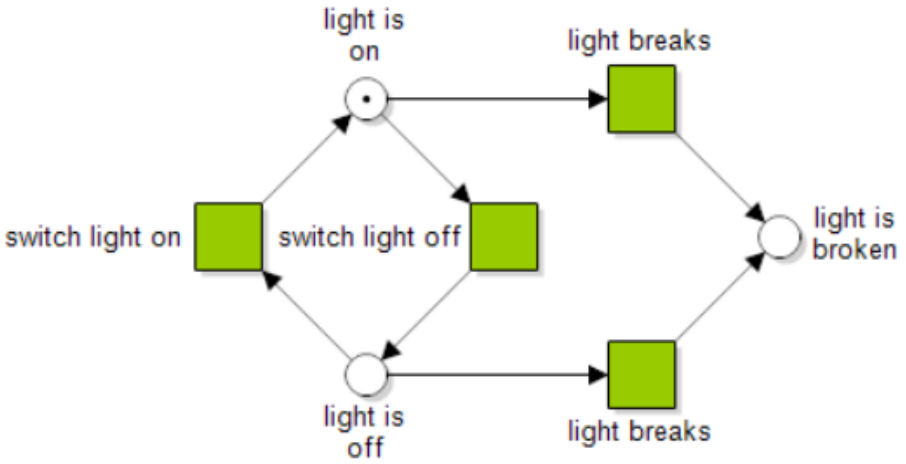
NON-DETERMINISTIC MODELS VERSUS SCENARIOS

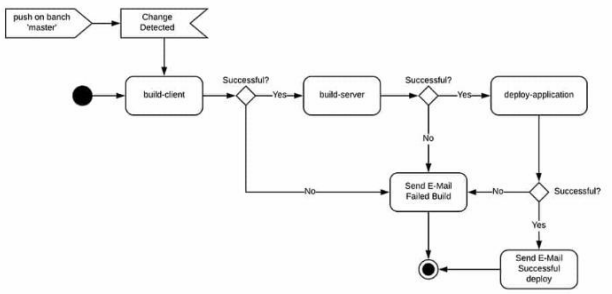
A Model of a Switch and Light Bulb



Represents an Infinite Number of Scenarios

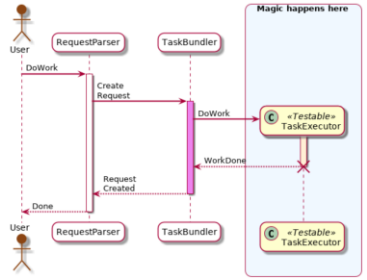
Switch Light On; Switch Light Off;
Switch Light On; Light Breaks
Switch Light On; Switch Light Off; Light Breaks
Switch Light On; Switch Light Off; Switch Light On; Switch Light Off; ….
Switch Light On; Switch Light Off; Switch Light On; Switch Light Off; Light Breaks …
…

TYPES OF MODELS



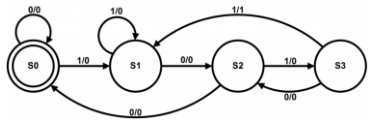
Control-Flow View

Activity Diagram
Event-driven Process Chain
BPML



Scenario View

Sequence Diagram, MSC
Communication Diagram



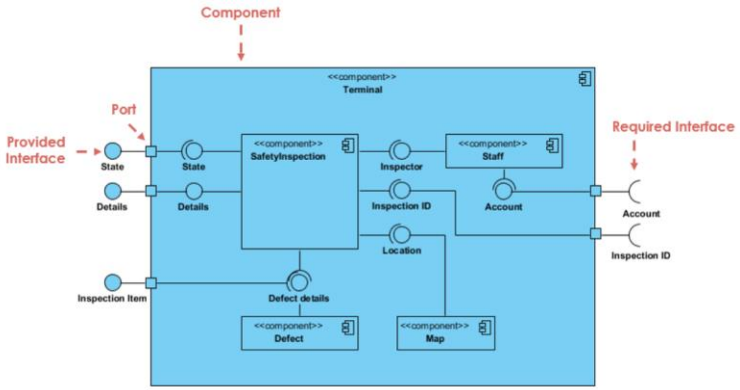
State View

State machine diagram
Finite Automaton
Statecharts

```
if the customer does act-seq turn on then act-seq ready
should be shown by the coffeeMachine immediately-after
```

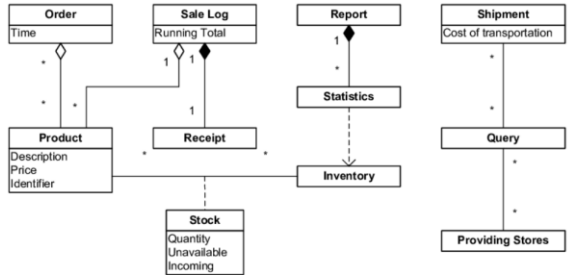
Constraint View

SCL, FRET, etc.



Structural View

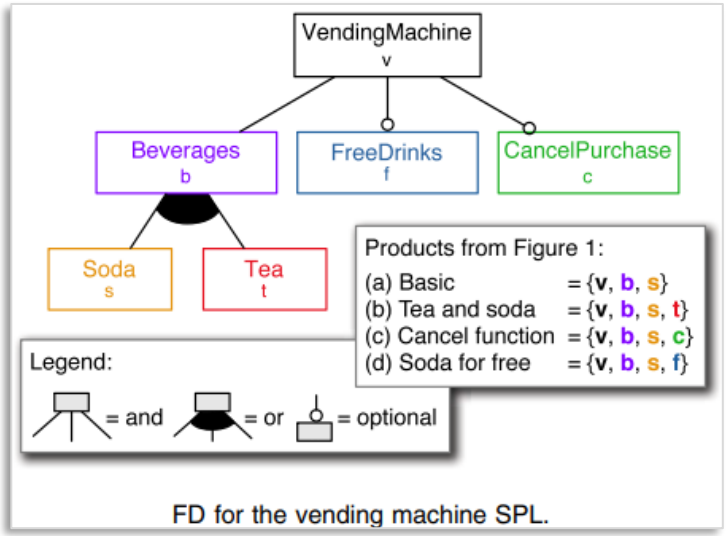
Component Diagram



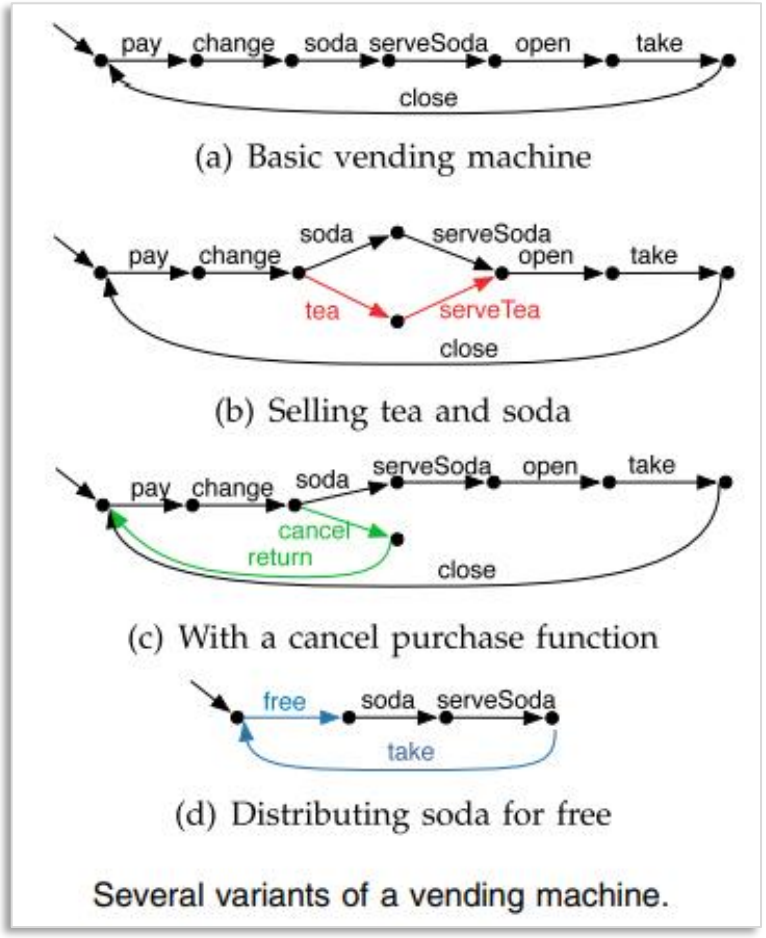
Data View

ER/Class Diagram

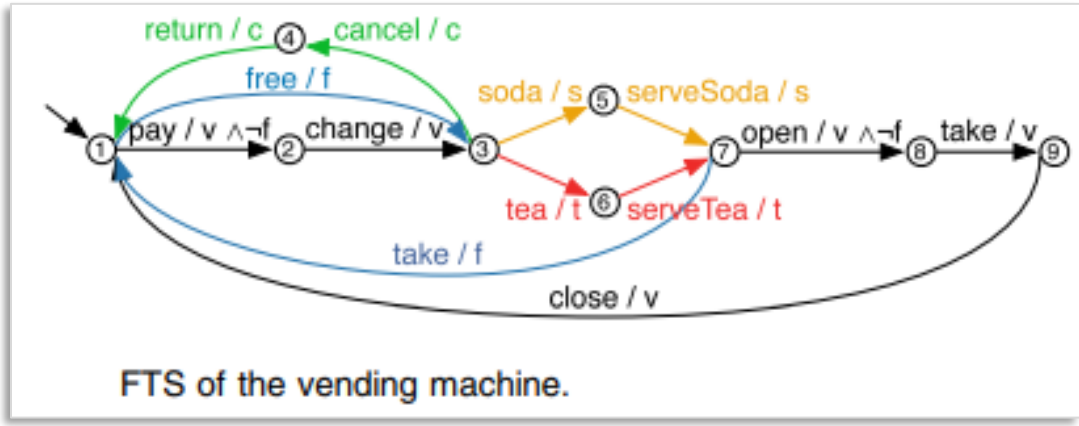
TYPES OF MODELS: VARIABILITY MODELING



FD for the vending machine SPL.



Several variants of a vending machine.



FTS of the vending machine.

WHAT IS MODEL-BASED TESTING

Offline MBT

Risks, Priorities, Test Goals

Test Purpose

Requirements and Design Specification

Specification Models

Model-based Test Selection and Generation

Abstract Test Suite

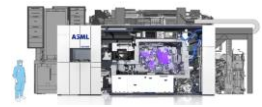
Verdict

Concrete Test Suite

Test Runner

Conformance?

System Under Test



WHAT IS MODEL-BASED TESTING

Online MBT

Risks,
Priorities,
Test Goals

Test Purpose

Requirements
and Design
Specification

Specification Models

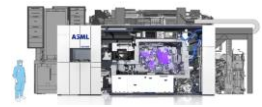
Model-based Test
Selection and
Generation

Verdict

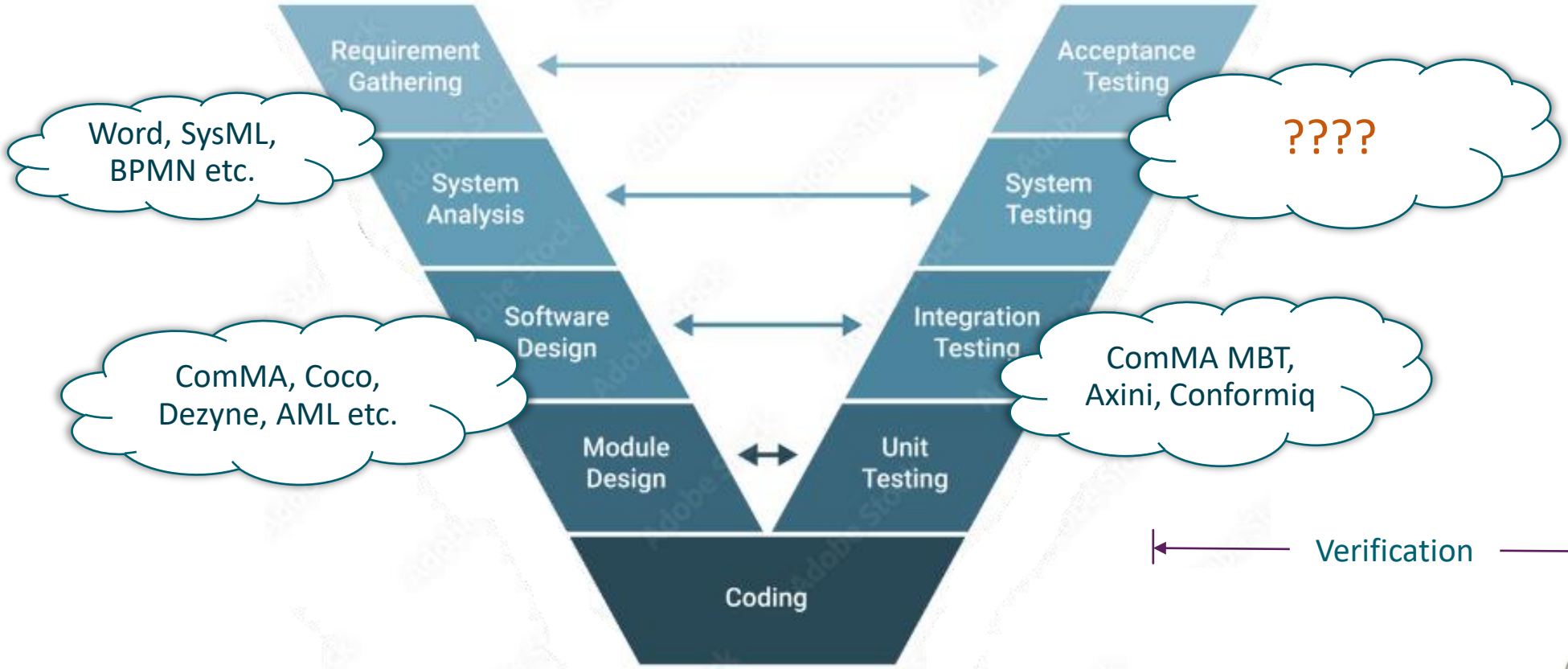
Test Adapter

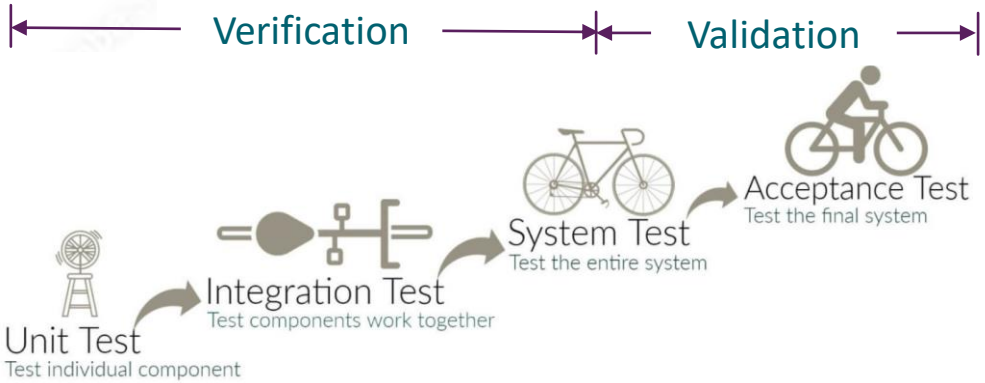
Conformance?

System Under Test



WHAT IS OUT THERE AND WHAT DO WE MISS?





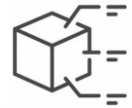
VALIDATION OF SYSTEMS IN CONTEXT

User

User Needs

System

Classical MBT approaches focus on modeling the system



Environment

Requirements

Module/Unit

For validation testing, the environment must be explicitly modeled!

Factory Automation

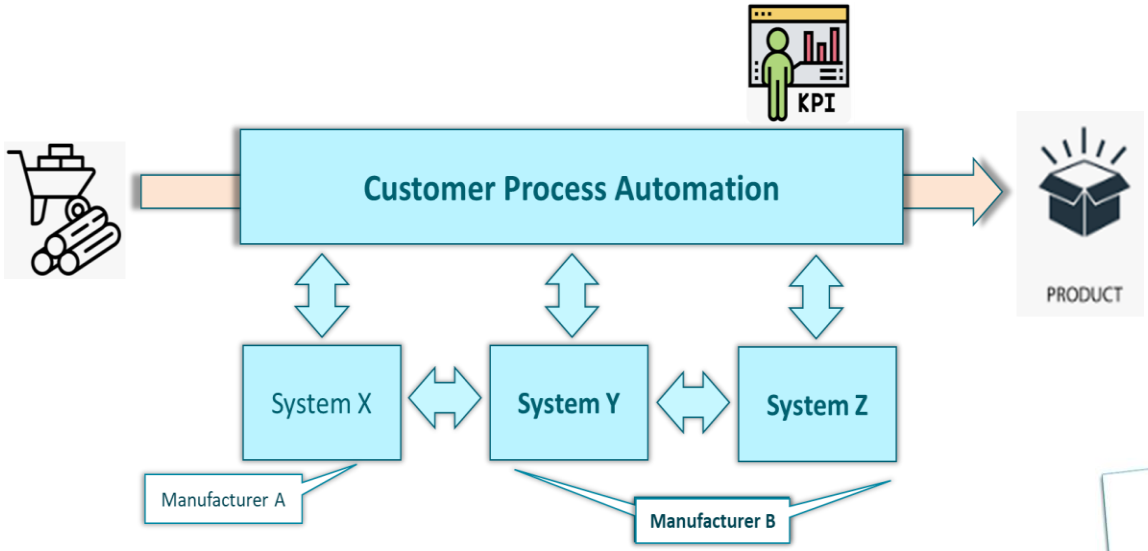
Value/KPIs

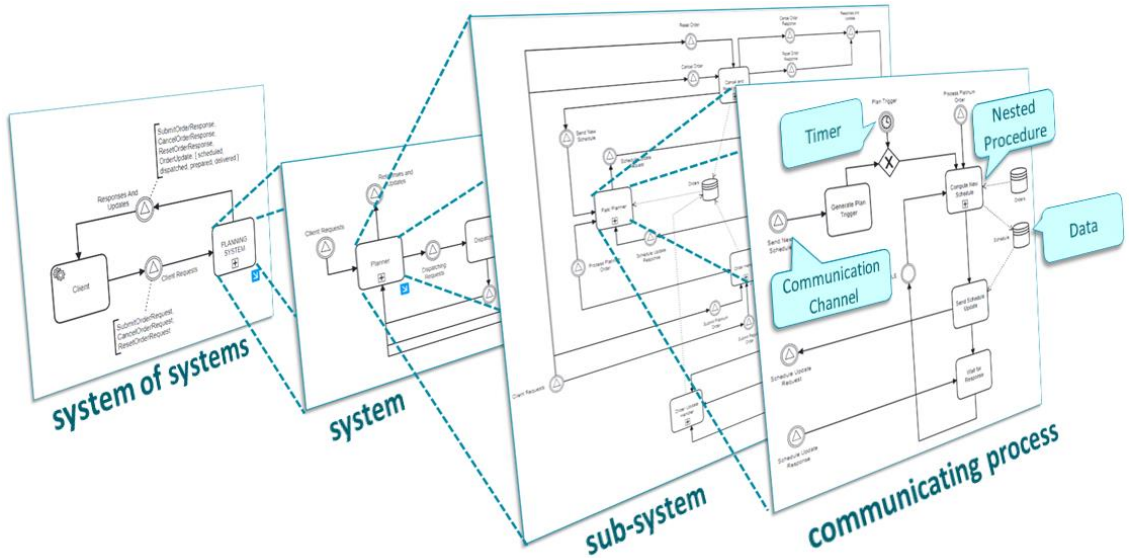
System X

System Y

Outside-In Perspective

SYSTEM OF SYSTEMS MODELING WITH BPMN4S





Methodology to Improve efficiency and effectiveness of system(-of-systems) testing processes by leveraging MBT technology

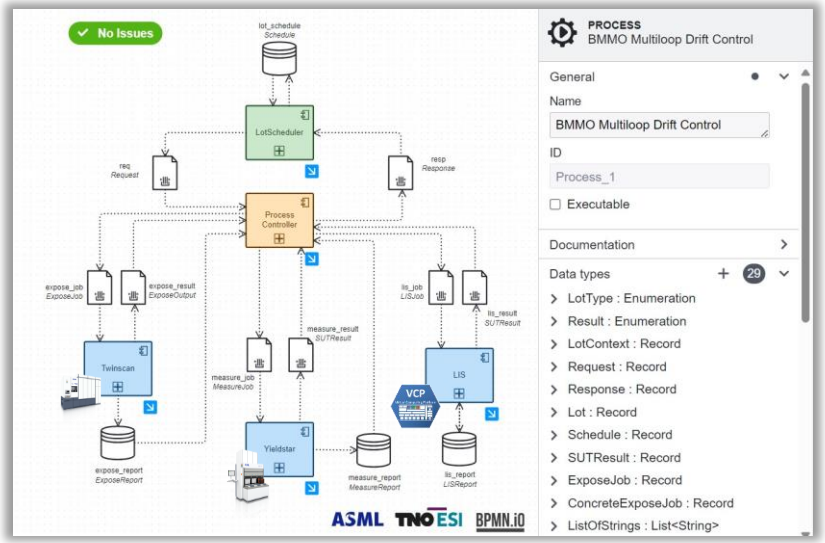
OFFLINE MBT FOR SOS IN CONTEXT

The BPMN4S Modeling Framework

System Configurations

Concrete Test Data

Job Recipes Test Purposes



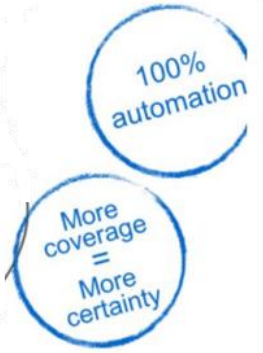
Collaborative specification and simulation of *expected* system behavior in context

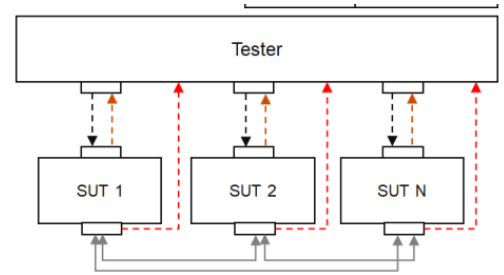
Offline MBT

BDD Test Suite

Gherkin Scenario

C# Step Definitions



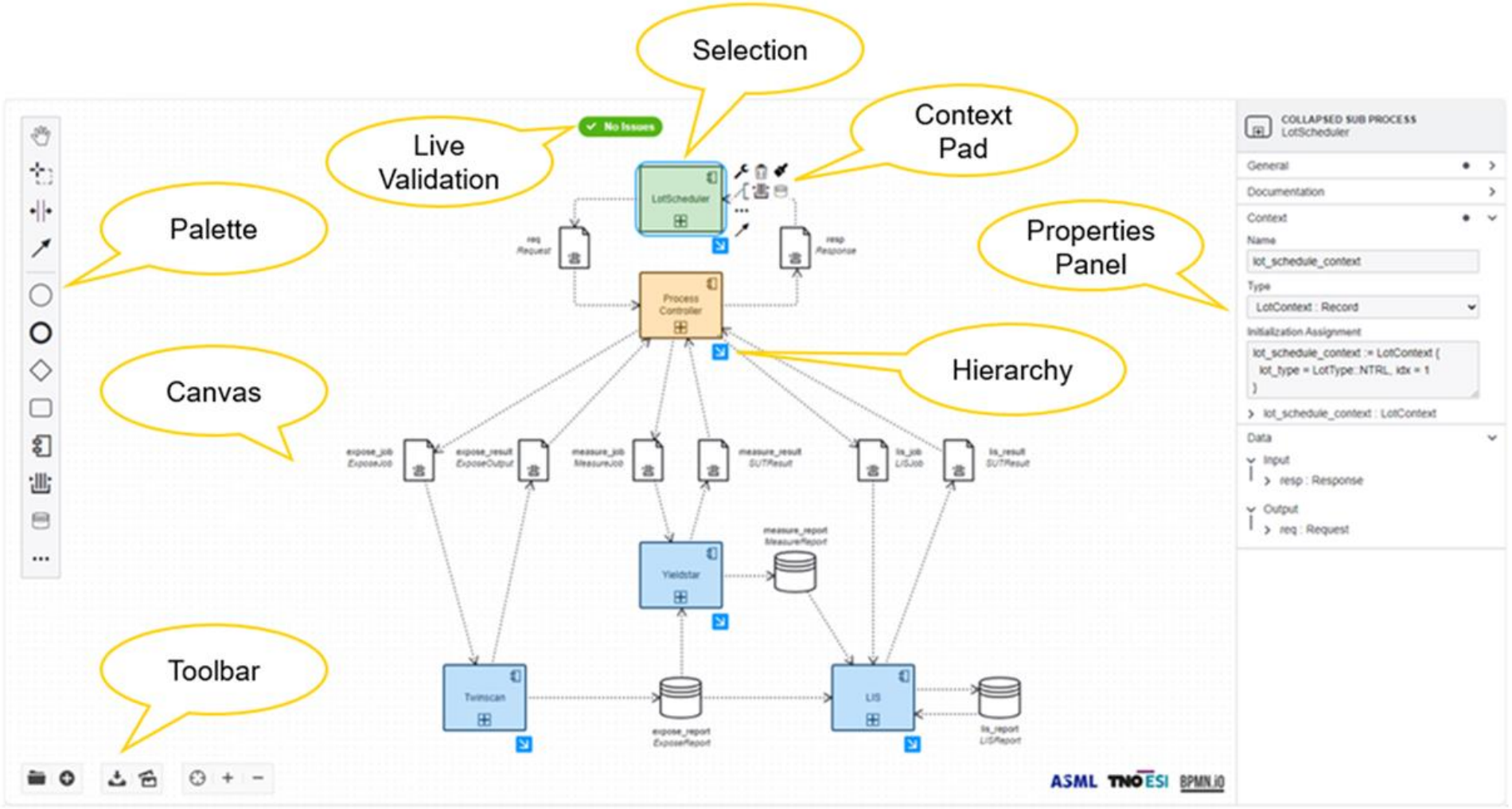


- Automation *reduces lead time* by *eliminating* the need to hand-craft tests
- Models grow *linearly* as compared to test scenarios (easy maintenance)
- Provides sound basis to reason about *coverage*
- Intrinsic *traceability* between specifications and tests
- Sound basis for *automated impact analysis and regression test selection*

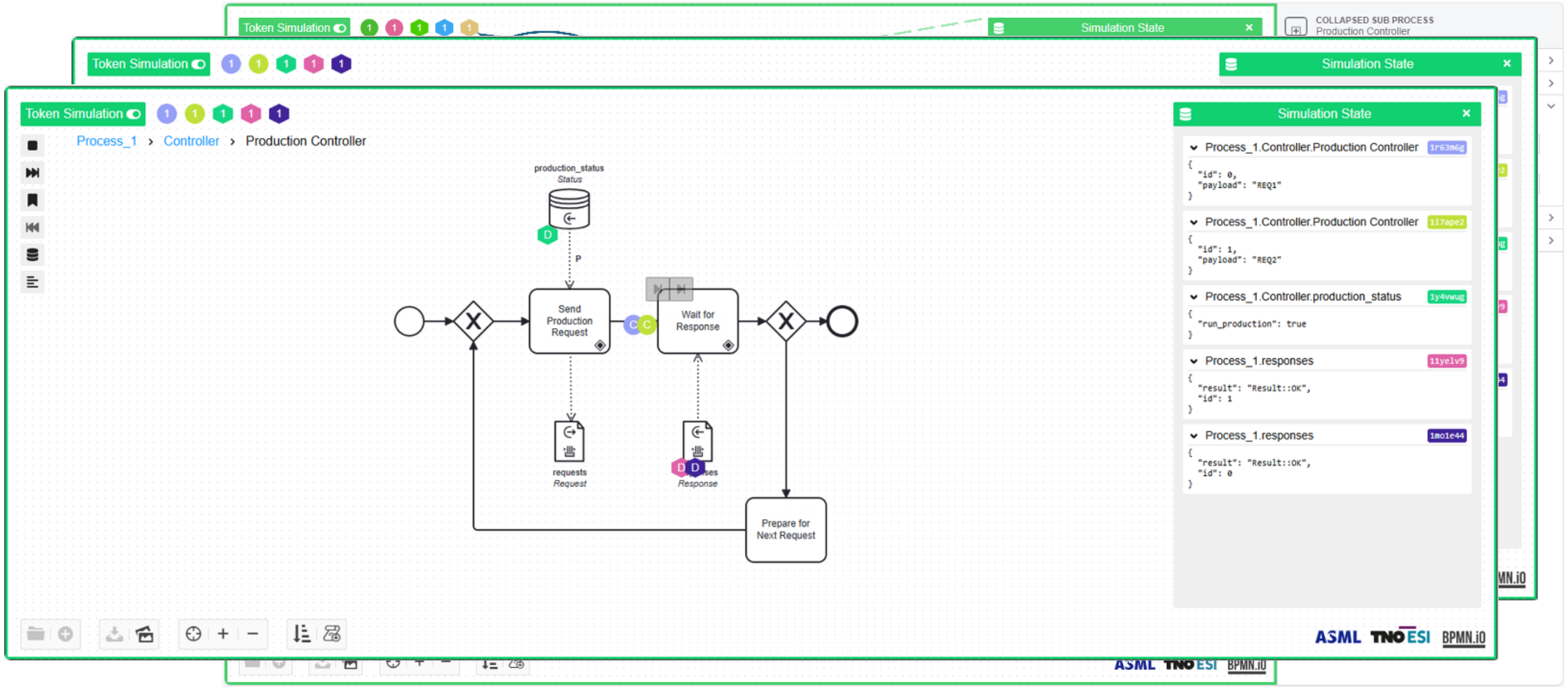
THE BPMN4S EDITOR

Extends the OMG standard for **BPMN 2.0**

Builds on the open source **bpmn.io** editor

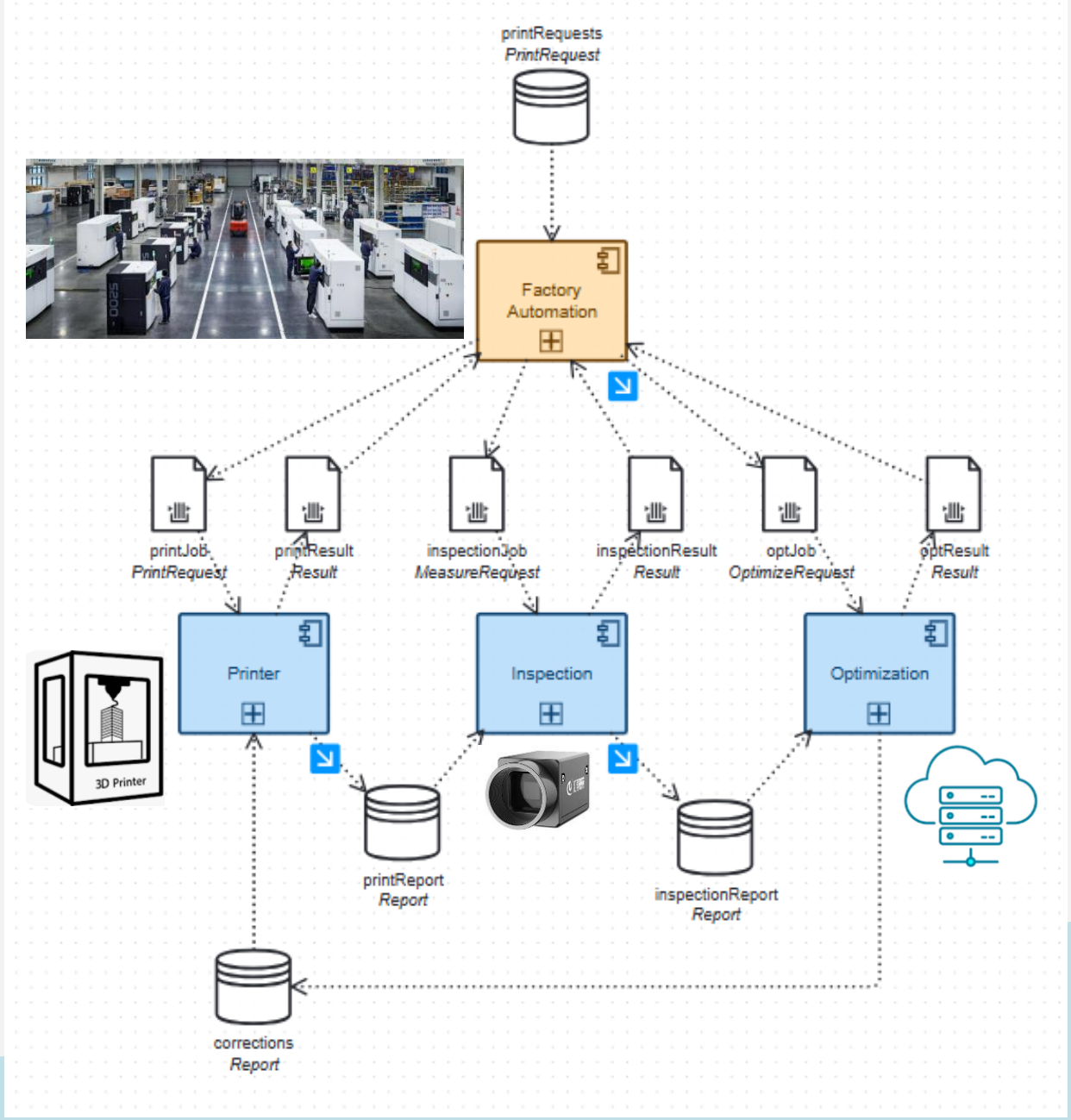


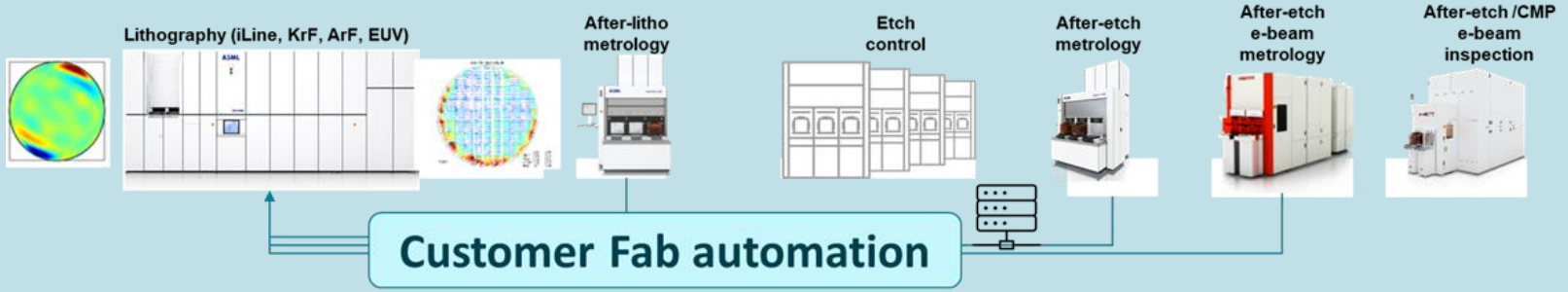
SIMULATION OF BPMN4S MODELS



DEMO

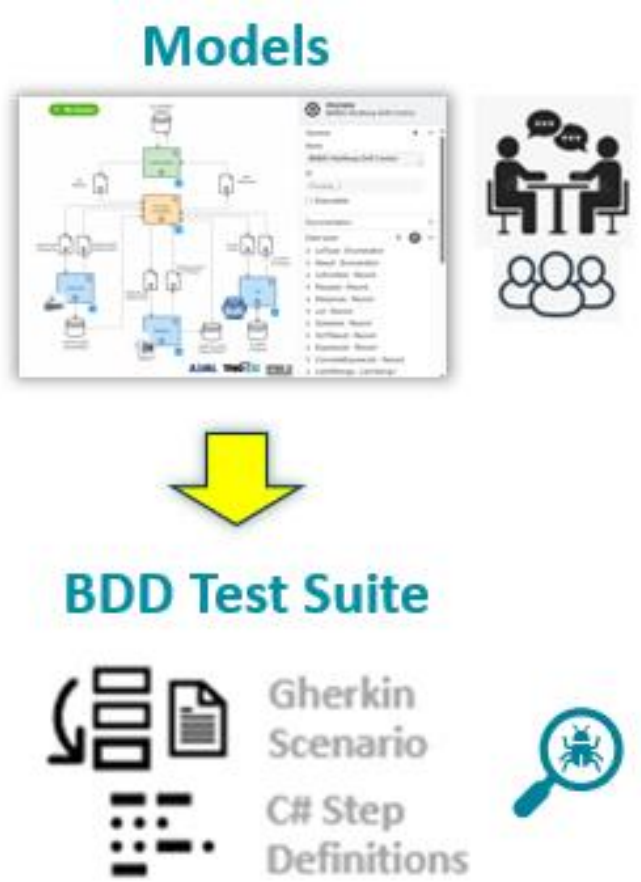
Simple 3D Printshop Model and Simulation





HOW DID WE EVALUATE THE METHODOLOGY AND SHOW VALUE AT ASML

REFLECTIONS



We would love to hear your thoughts on

- What did you think about the BPMN4S language and its simulation features? Is this a step up in fostering collaboration and creating shared understanding?
- Do you agree that with such an approach the focus will towards more on understanding and capturing the domain and risks?
- Do you see such an approach resulting in higher efficiency and effectiveness? If not, what concerns you the most?

BREAK

AGENDA

- Testing context and challenges in industry
  - Best practices in industry
  - Limitations of BDD test automation frameworks
- Break + Reflections and Discussions
- Take the next step in test automation with MBT
  - What do we mean by models and what is MBT
  - Collaborative specification of systems in context with BPMN4S
  - Automated Test Generation and Coverage
  - Live demo of a print shop
- Break + Reflections and Discussions
- How did we evaluate the methodology and show value, insights into adoption at ASML
- Research and Development Roadmap
- Can AI potentially help to improve systems testing?
- Takeaways and Wrap-up

RESEARCH AND DEVELOPMENT ROADMAP

Further enhance collaborative specification

- Version management, reviewing, model comparisons, replay of test cases in simulation

Focus testing efforts where it matters

- Reason about product risks and priorities
- Exploit usage profiles, test execution logs and defects

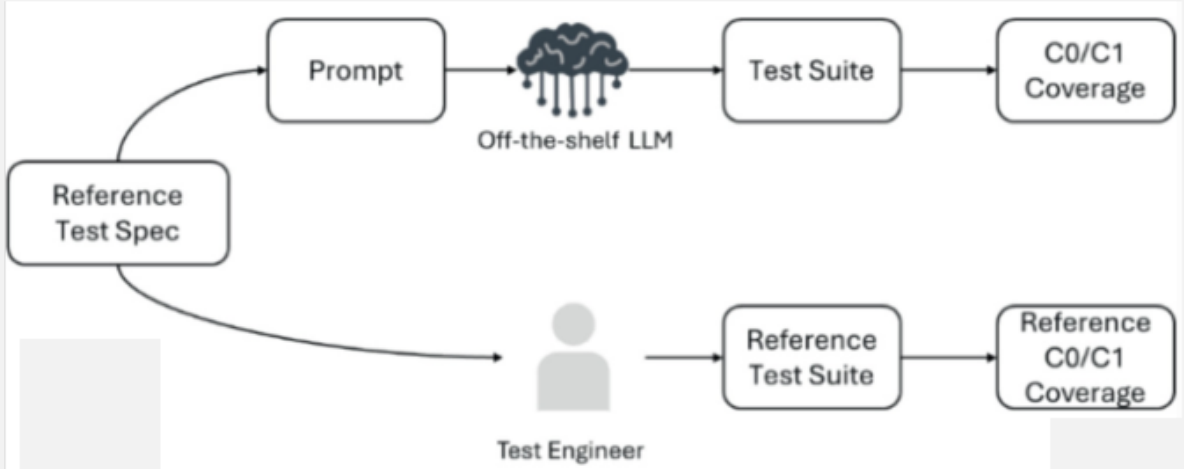
Faster root-cause analysis

- Model-assisted root-cause analysis of failing tests
- Coverage analysis and test reporting

Higher coverage with online model-based testing

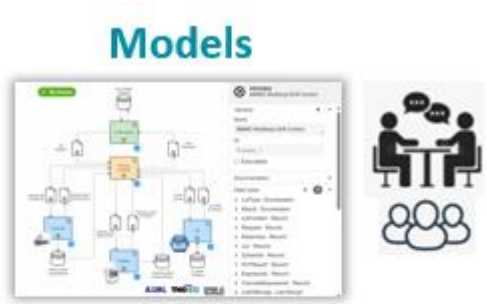
- On-the-fly test generation and execution
- More representative testing of real-world dynamics

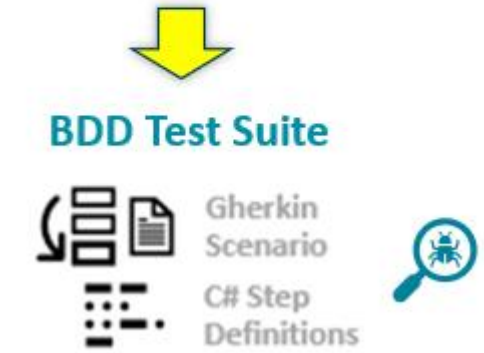
CAN AI AUGMENT BDD + MBT?



TAKE AWAYS

- Systems are getting more complex
- Current approach to testing is not scaling
- BDD truly triggered the shift-left movement
- But there is an urgent need for innovation in technologies supporting BDD
- Model-based testing can augment BDD by taking collaboration to the next level and improve test coverage
- LLMs may hold the answer to the modeling hurdle in MBT
- Finding the right application of AI and embedding in existing tech/WoW is not trivial





How to enable faster time to market with promised quality and lower costs?

Automation of Manual Testing	Risk Management and Mitigation	Costs of Test Infrastructure	Lack of Available Hardware
Handcrafting of Test Suites	Traceability of Specifications and Tests	Maintenance of Test Suites	Test Execution Analysis
Dealing with Updates and Upgrades	Selection of Tests and Configurations	Coverage and Quality Metrics	Defect Leakage and Exploiting Usage Profiles
Scarcity of People			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