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Interoperability Network for the Energy Transition

Int:net Final Conference

Making it happen

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18 September 2025

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Understanding potentials and hurdles of interoperability in practice

Introduction to the newly developed ontology constraints tester

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The interoperability challenge

"Smart appliances are key to the energy transition —

but what happens if a dishwasher from brand A can't 'talk' properly with a home energy manager from brand B?"

Objective: Support engineers to verify/ensure/validate the interoperability compliance of data exchange for various systems with ontologies (e.g., SAREF).

Context:

- Started in INT:NET project to be continued in Hedge-IoT project.
- Based on the JRC for ESA CoC methodology interoperability test method and needs
- Built on **SAREF ontology** (ETSI SAREF) but extensible to any ontology

Why this tool matters now

Ontology = Single Source Of Trust (SSOT)

"Without a neutral, ontology-driven tester, each company reinvents its own method, slowing down adoption and increasing costs"

Motivation drivers

- **Energy transition** → more renewables, need for flexibility
- **Rapid digitalization** → more machine-to-machine data exchange
- **Cost optimization** → testing interoperability early saves money for manufacturers
- **Regulatory push** → GDPR, AI Act (GDPR, AI Act)

1st identified: verify compliance with the Code of Conduct for Smart Home Appliances (CoC-ESA) established by the European Commission's JRC and DG ENER.

Challenges we target

- How to verify semantic + behavioural (next) interoperability in practice?
- How to help engineers integrate ontologies without reinventing the wheel?

Use cases – Making it concrete

- **Energy Smart Appliances (ESA)** defined in CoC:
  - “Products that provide energy flexibility through machine-to-machine communication.”
- **Domains**:
  - Home appliances (washing machines, dryers, dishwashers)
  - HVAC + water heating
- **5 key use cases defined by JRC CoC**:
  - **Flexible start:** → **Verifying the order of messages between Customer Energy Manager ↔ Appliance** 
  - Limitation of power consumption
  - Manual operation
  - Monitoring of power consumption
  - Incentive-based consumption management
- **Manufacturers who sign CoC commit to**:
  - Launch at least one ESA model per year
  - Ensure interoperability via SAREF & SAREF4ENERInform consumers about available use cases

What we've built so far

"Until now, standards stayed on paper. With ODC-Tester, they become testable, verifiable, and actionable"

During int:net lifetime

Peer Reviewed Publication

- Full paper accepted at the 6th **K**nowledge **G**raphs & **S**emantic **W**eb **C**onference 2024
- Methodology, dataset design & validation results publicly documented

Synthetic-Dataset

- Generated from the JRC CoC "Flexible Start" use case
- Four JSON/RDF packs (1 fully compliant + 3 seeded-error variants)
- 100% detection (accuracy & robustness) in compliance tests

Working Prototype

- Django-based web UI for dataset upload & SHACL validation
- Automated PDF report generator using ReportLab
- rdflib + pySHACL Library fully integrated with Ontology Engine

Open Research Artifacts

- Datasets, SHACL shapes & validation outputs available on Zenodo

Int:net → **Semantic testing** (1st proof of concept achieved);

ODCT tool presented at the JRC CoC ESA plenary (18 Sept 2024);

Int:net (Deliverable D3.1)

TRL 3


Design of an Ontology-Driven Constraint Tester (ODCT) and Application to SAREF & Smart Energy Appliances

Next steps: From int:net and beyond

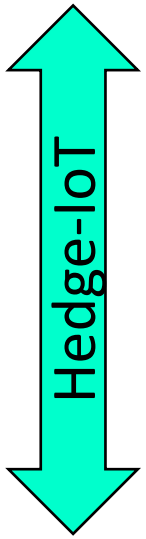
"Next version = not just checking messages, but verifying full conversations between systems"

- Current situation:
  - JRC's **Code of Conduct (CoC ESA)** already defines use cases and requires compliance.
  - BUT: It mainly checks **semantic correctness** (the data format), not **behavior** (the sequence of actions).
  - Result: integration delays, hidden costs, and missed energy flexibility opportunities.

Latest achievements connection with Next Steps:

- Now aligned with **ISO/IEC 21823-5** (link) and **EEBUS Spine WG** (EEBUS)

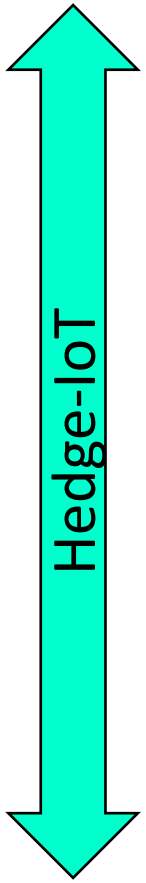
TRL 2



Next steps: Behavioural testing

"Semantic validation is like checking if two people speak the same language. Behavioral testing is making sure they can actually have a meaningful conversation"

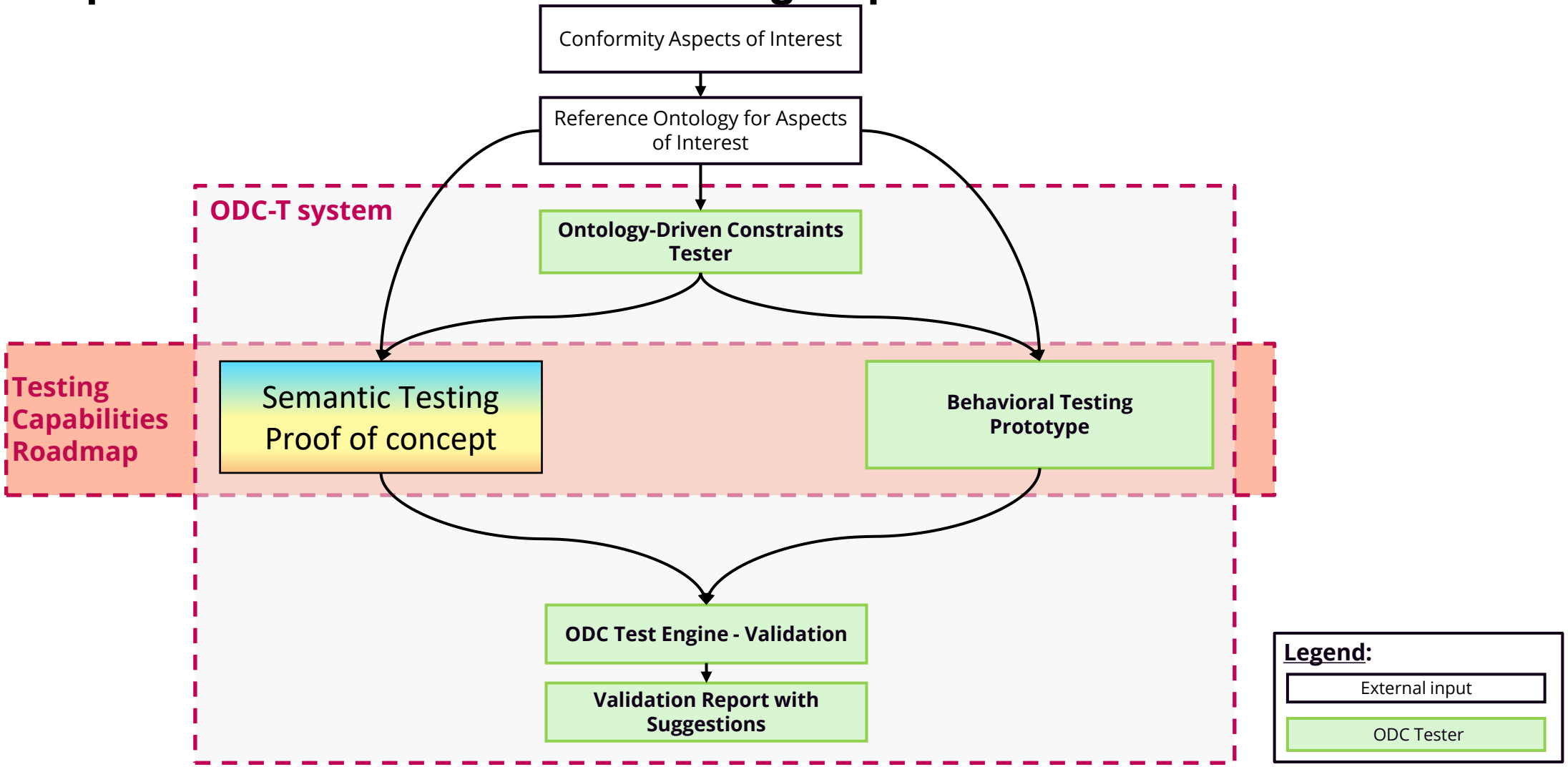
- Transition from prototype → production-ready tool
- Roadmap:
  - Select methodology for behavioural testing
  - Prototype & test behavioural architecture
  - Extend validation with real manufacturer data (as soon as available)
  - Continue contributions: JRC CoC Phase 2, ISO/IEC 21823-5, EEBUS Spine WG
  - Internal validation with project partners



- Outlook:

Potential beyond energy: IoT ecosystems, mobility, healthcare devices

Next steps: ODC-Tester – Overall Testing Capabilities



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Q&A: Understanding potentials and hurdles of interoperability in practice

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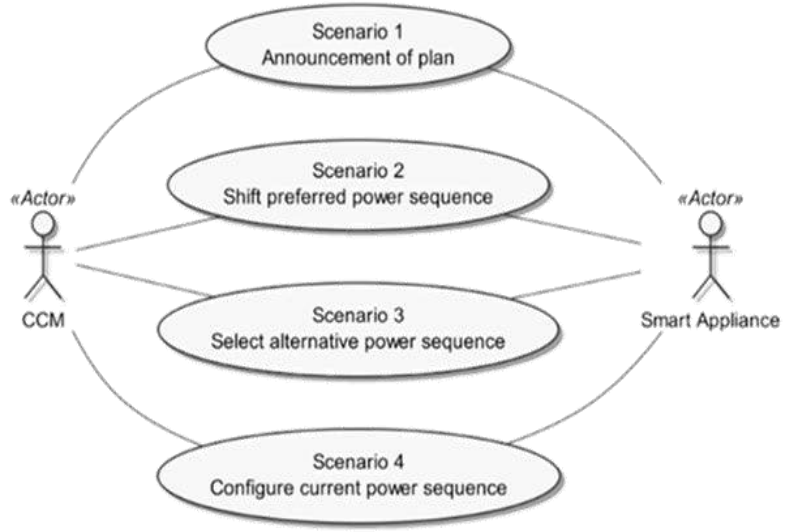
What is behavioral testing?

- ISO/IEC 21823-5 definition:
  - "**Interoperability so that the actual result achieves the expected outcome**."
- Focus on dynamic behaviour:
  - State transitions
  - Timing/synchronization
  - Policy rules
- Technique: Given–When–Then + state machines



View of the different scenarios for the Flexible Start use case of the JRC's CoC

Actions

- **Target use case:** CoC-ESA - **"Flexible Start" (Scenario 3)**
- **Standards & ecosystem:** participation in **EEBUS SPINE IoT WG**; alignment with **JRC CoC**,
- **ISO/IEC 21823-5** and **EN 50631-3-1**
- **Expected deliverables:** conformance reports and **reusable test templates** for manufacturers

What is behavioural testing?

Behavioral Testing (definition)

- From ISO/IEC 21823-5: *"Interoperability so that the actual result achieves the expected outcome."*
- Focuses on **dynamic behavior** → state transitions, timing, and policy rules over time.
- Validates *how* a system behaves during operation, not just *what* data it provides.

User Story: Dishwasher Schedule Management
Narrative: As a user I want to be able to set a preferred dishwasher cycle schedule. So that I can have the dishwasher run when it's most convenient for me, taking into account electricity tariffs or personal preference.

Scenario 1: Dishwasher Accepts Preferred Schedule
Given the dishwasher has an initial preferred sequence P1 (21:00-22:30) and a pre-condition for requests to be sent before 21:00,
When I send a request to start the dishwasher cycle,
Then the dishwasher accepts the request, transitions to State P2 (waiting), starts the cycle at 23:00 (±1 min), and ensures the dishwasher cycle finishes by 00:30.

Scenario 2: Dishwasher Rejects Out-of-Window Request
Given the dishwasher has an initial preferred sequence P1 (21:00-22:30) and a pre-condition for requests to be sent before 21:00,
When I send a request that does not meet the pre-condition (e.g., after 21:00),
Then the dishwasher rejects the request.

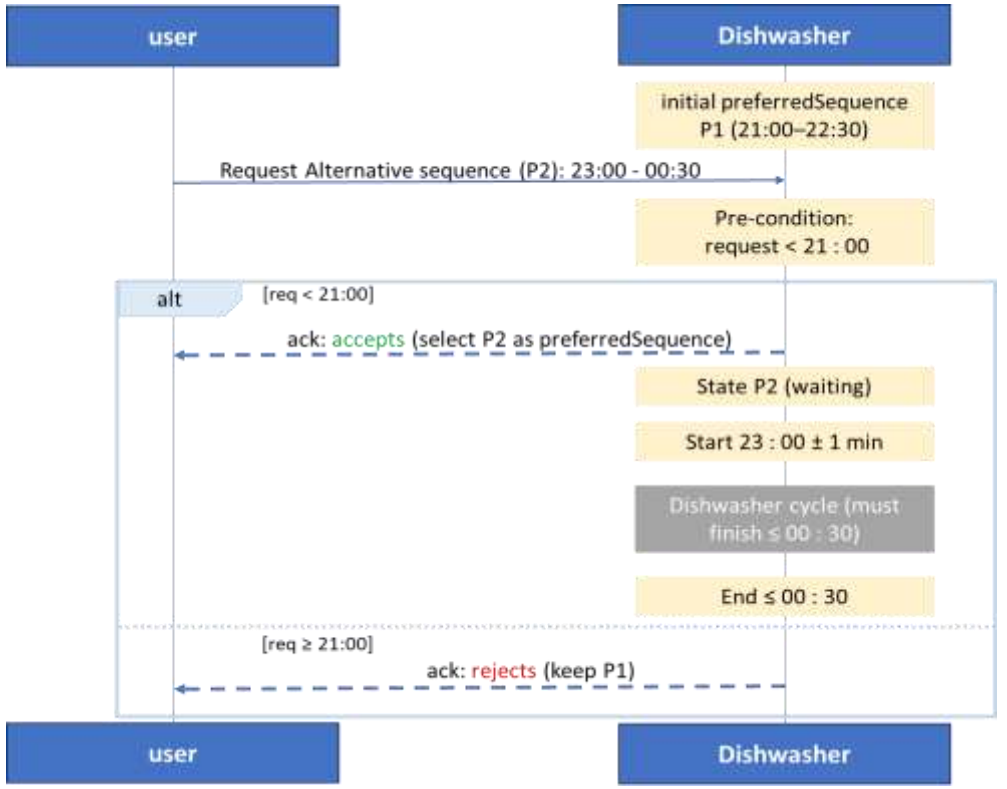


Figure: Dishwasher (Select Alternative Power Sequence) Sequence diagram

Disclaimer: This example scenario is a simplified example used for demonstration purposes. Actual appliance behavior, requirements, or timing constraints may vary.

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Thank you for your attention.

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