Level Up Your Embedded Testing Game

FRETish, Robot, and Twister: A Dream Team

Christian Schlotter, Carl Zeiss Meditec AG

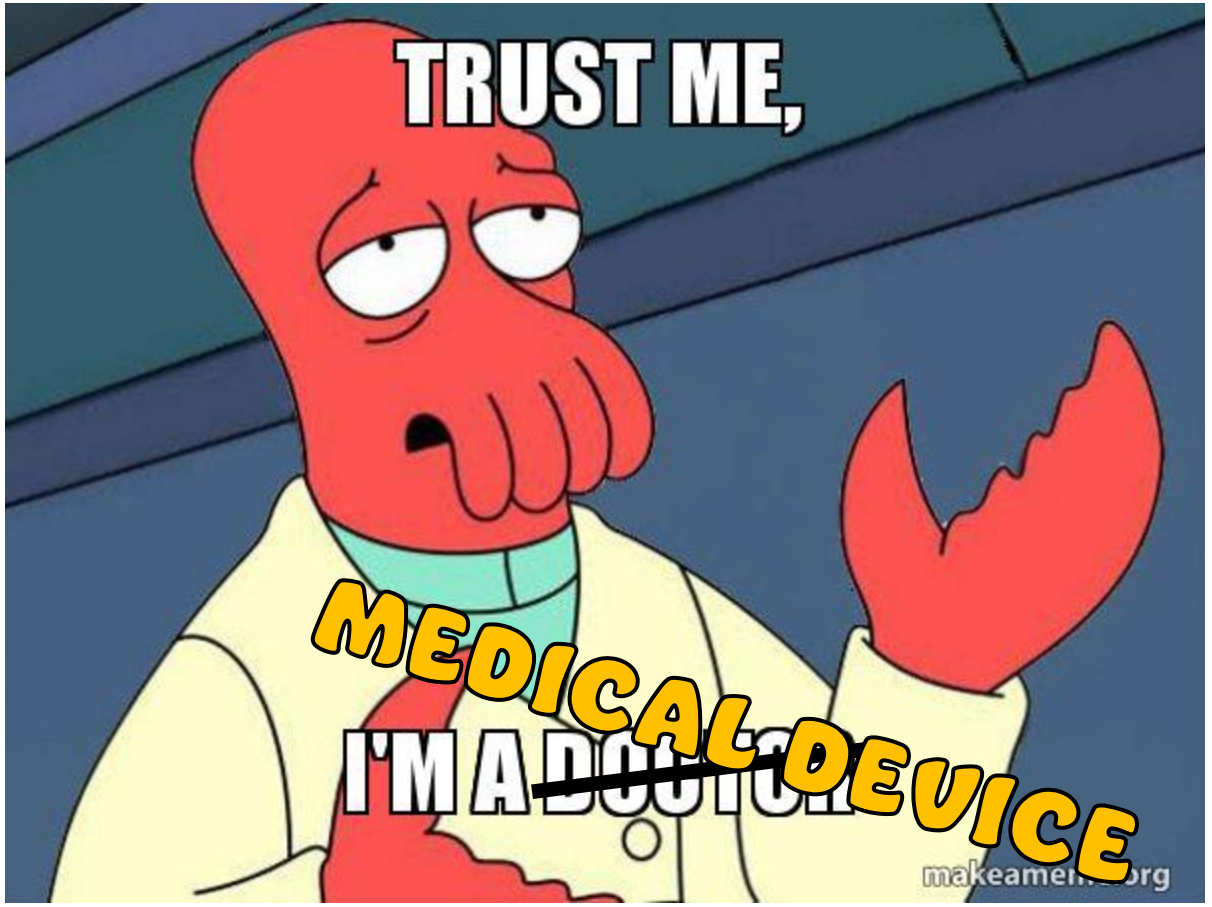
Stefan Kraus, UL Solutions SIS

Tobias Kästner, inovex GmbH

Open Source Summit Europe, Vienna
September 17, 2024

Medical is all about Trust

Supporting patients when they‘re most vulnerable



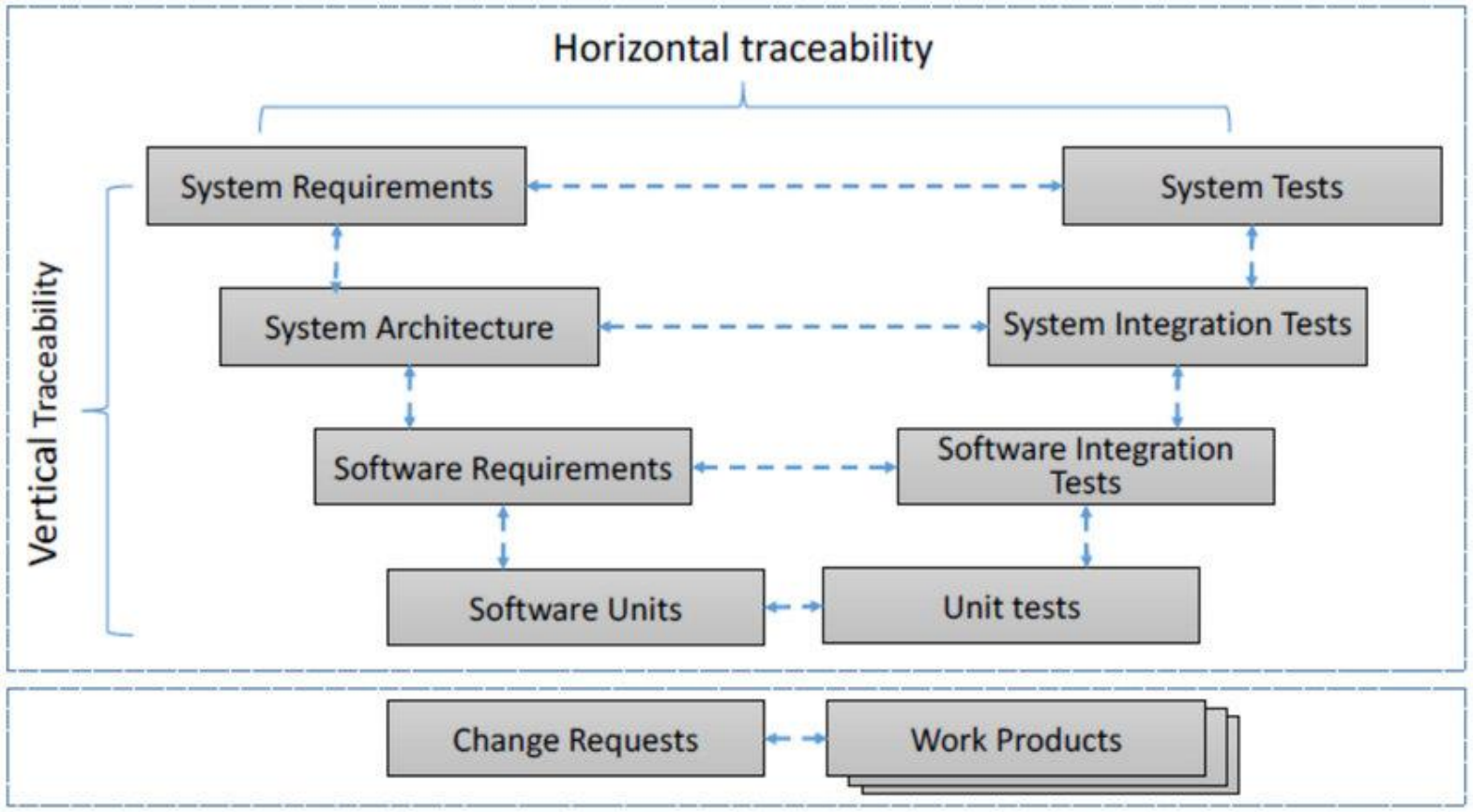
It’s not only what we care about

Regulators want us to take care of some things, too

- Requirements Management ✅
- Traceability of
  - Requirements ✅
  - Tests ✅

BUT:

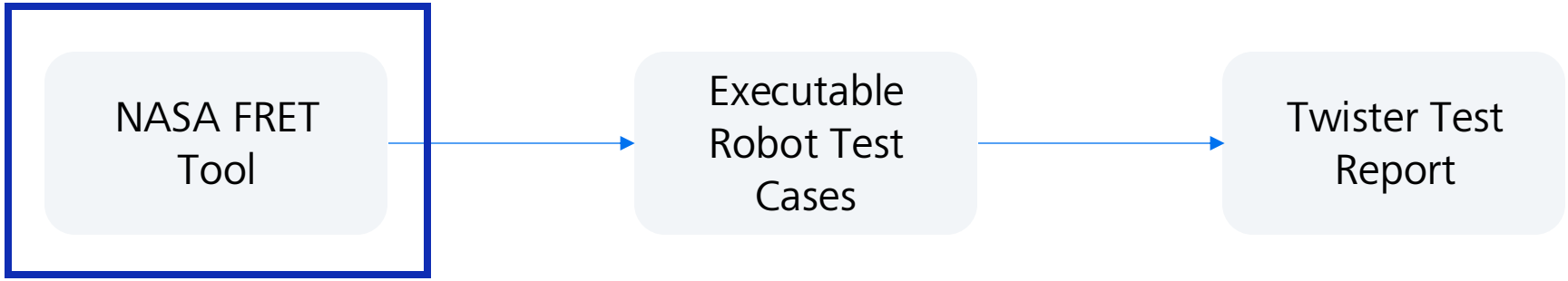
- How to check requirements for consistency?
- How to derive tests from requirements?
- How to update tests for changed requirements?



V-model

Raheem, Ahmed & Rashid, Yaseen. (2021). Tracking Software in the Automotive Field: Challenges and Solutions. Journal of Physics: Conference Series. 1804. 012064. 10.1088/1742-6596/1804/1/012064. CC BY 3.0

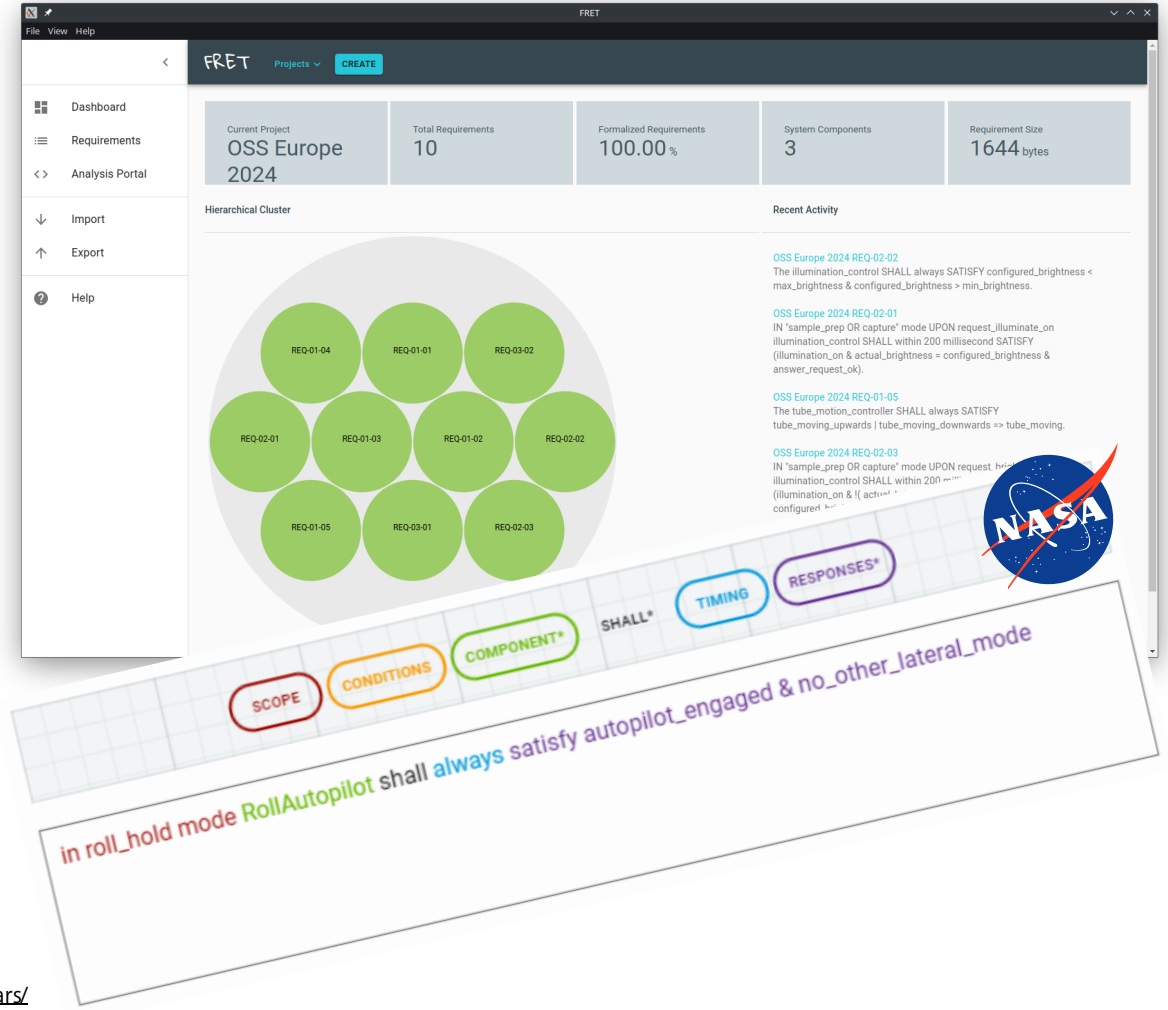
Our plan for today



Requirements Engineering

"It's not exactly rocket science, is it?"[4)]

- Many approaches for writing "better" requirements described in the literature
  - Easy Approach for Requirements Syntax (E.A.R.S) by Alistair Mavin[1)]
  - INCOSE Guide to Writing Requirements[2)]
  - **Functional Requirements Elicitation Tool (FRET)**[3)]
- FRET: New semi-formal approach to requirements pioneered by Anastasia Mavridou et al. @ Robust Software Engineering Group at NASA
  - FRETish Requirements are written in controlled natural language
- Requirements are machine-parsable and can be transformed to (temporal) logic formulas
  - Automated consistency & realizability checking
  - Simulation, ...



(1) https://alistairmavin.com/ears/

(2) https://www.incose.org/docs/default-source/working-groups/requirements-wg/rwg_products/incose_rwg_gtwr_summary_sheet_2022.pdf

(3) https://github.com/NASA-SW-VnV/fret

(4) https://www.youtube.com/watch?v=THNPmhBl-8I

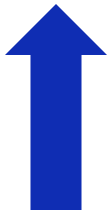
FRETish Requirements

A very basic "101" in 5 mins or less

General structure of a FRETish Requirement:

Scope | Conditions | Component* | SHALL* | Timing | Response*.

* = mandatory



What part of the system has to fulfill this requirement?

Examples

- The "Flight Controller"
- The "Lighting Subsystem"

Learn more at https://github.com/NASA-SW-VnV/fret and

in the excellent tutorial https://ntrs.nasa.gov/api/citations/20220007610/downloads/NFM22Tutorialv5.pdf

FRETish Requirements

A very basic "101" in 5 mins or less

General structure of a FRETish Requirement:

Scope | Conditions | Component* | SHALL* | Timing | Response*.

* = mandatory

What is the system supposed to do?

Examples

- Satisfy "maintain speed & maintain altitude"
- Satisfy Illumination_ON

Boolean & Arithmetic expressions:

- !, & , | , =>, …
- =, !=, <, >, +, *, -, …

Learn more at https://github.com/NASA-SW-VnV/fret and

in the excellent tutorial https://ntrs.nasa.gov/api/citations/20220007610/downloads/NFM22Tutorialv5.pdf

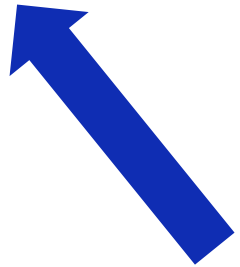
FRETish Requirements

A very basic "101" in 5 mins or less

General structure of a FRETish Requirement:

Scope | Conditions | Component* | SHALL* | Timing | Response*.

* = mandatory



During what portion of the execution is the requirement supposed to hold?

Examples:

- "During landing_operation"
- "In factory mode"

Keywords:

- In, before, after, notin, onlyin, ...

Learn more at https://github.com/NASA-SW-VnV/fret and

in the excellent tutorial https://ntrs.nasa.gov/api/citations/20220007610/downloads/NFM22Tutorialv5.pdf

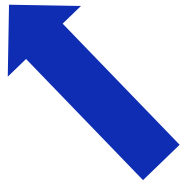
FRETish Requirements

A very basic "101" in 5 mins or less

General structure of a FRETish Requirement:

Scope | Conditions | Component* | SHALL* | Timing | Response*.

* = mandatory



What condition triggers the response?

Examples:

- "Upon auto_pilot_enable"
- "Upon request_dim_lighting"

Keywords:

- Upon, if, where, when, unless, …

Boolean & arithmetic expressions:

- !, & , | , =>, =, !=, <, >, +, *, -, …

Learn more at https://github.com/NASA-SW-VnV/fret and

in the excellent tutorial https://ntrs.nasa.gov/api/citations/20220007610/downloads/NFM22Tutorialv5.pdf

FRETish Requirements

A very basic "101" in 5 mins or less

General structure of a FRETish Requirement:

Scope | Conditions | Component* | SHALL* | Timing | Response*.

* = mandatory

When is the response due relative to scope and condition?

Examples:

- "always"
- "within 1 second"
- "after 200 ticks"

Keywords:

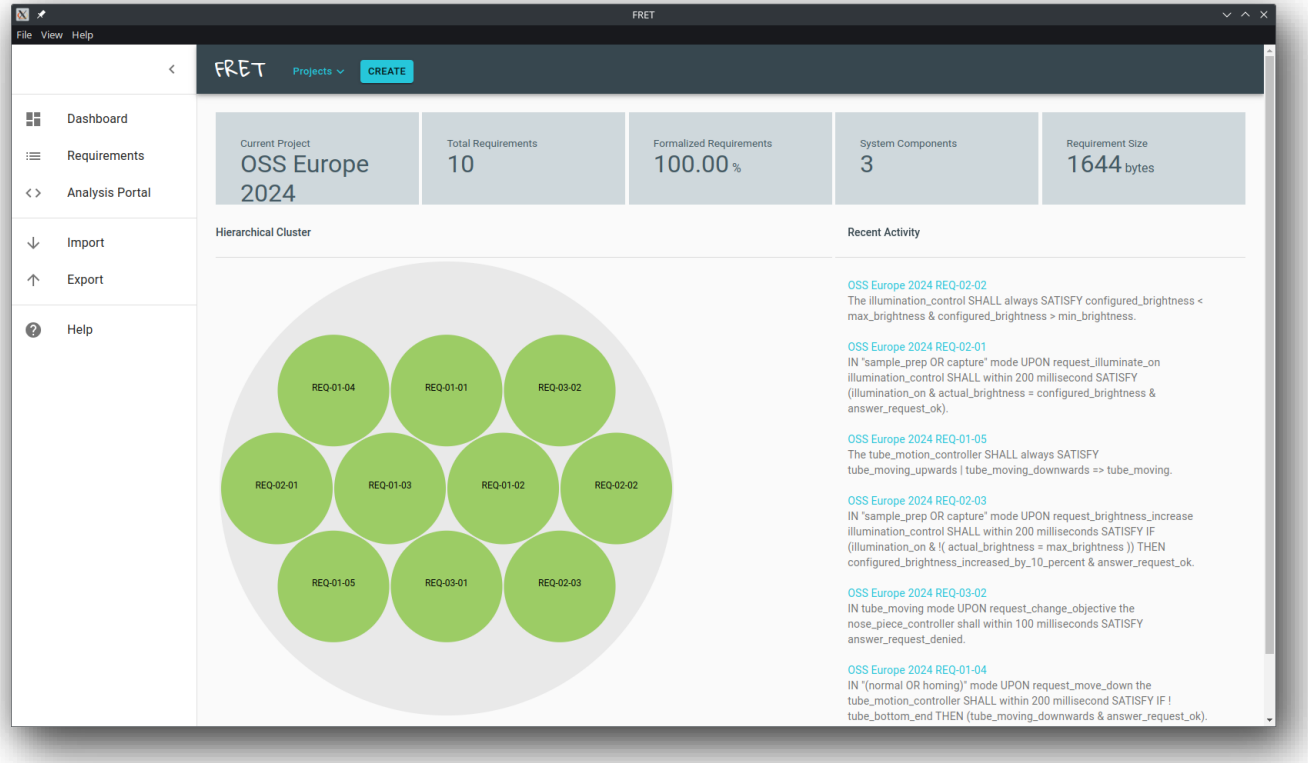
- Always, never, eventually, until, within, before, after

Learn more at https://github.com/NASA-SW-VnV/fret and

in the excellent tutorial https://ntrs.nasa.gov/api/citations/20220007610/downloads/NFM22Tutorialv5.pdf

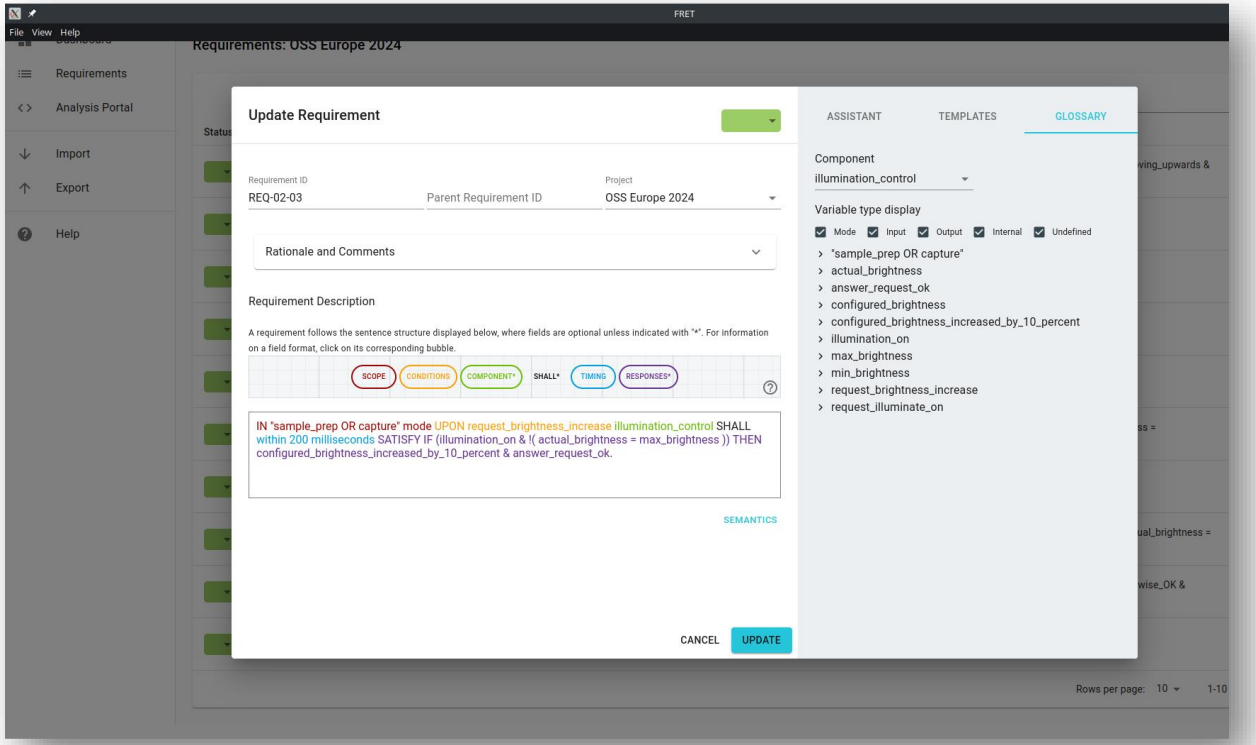
Tools for FRETish Requirements
The templates and the editor

- FRET tool can be downloaded from https://github.com/NASA-SW-VnV/fret (Win/Mac/Linux)
  - Need to build from source
- Simple Project Management
  - JSON-based Import & Export functionality



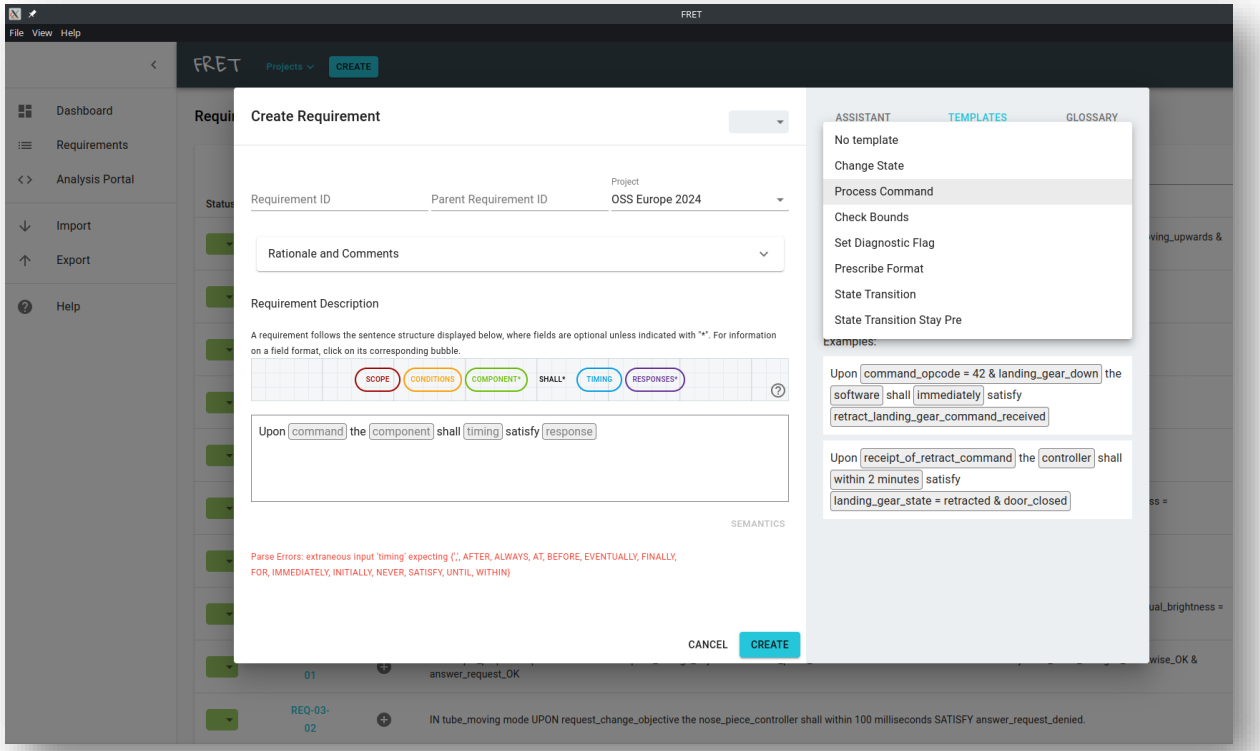
Tools for FRETish Requirements
The templates and the editor

- FRET tool can be downloaded from https://github.com/NASA-SW-VnV/fret (Win/Mac/Linux)
  - Need to build from source
- Simple Project Management
  - JSON-based Import & Export functionality
- Syntax Highlighting
- Automatic Glossary
  - Useful to keep terminology consistent across RQTs
- Also captures meta-data
  - ID, Comments, …
  - Parent/Child Relationships



Tools for FRETish Requirements
The templates and the editor

- FRET tool can be downloaded from https://github.com/NASA-SW-VnV/fret (Win/Mac/Linux)
  - Need to build from source
- Simple Project Management
  - JSON-based Import & Export functionality
- Syntax Highlighting
- Automatic Glossary
  - Useful to keep terminology consistent across RQTs
- Also captures meta-data
  - ID, Comments, …
  - Parent/Child Relationships
- Pre-defined templates for common scenarios
  - Very convenient for FRETish starters
- Many more features related to model checking and extracting formal expressions from the requirements
  - Not yet relevant for us

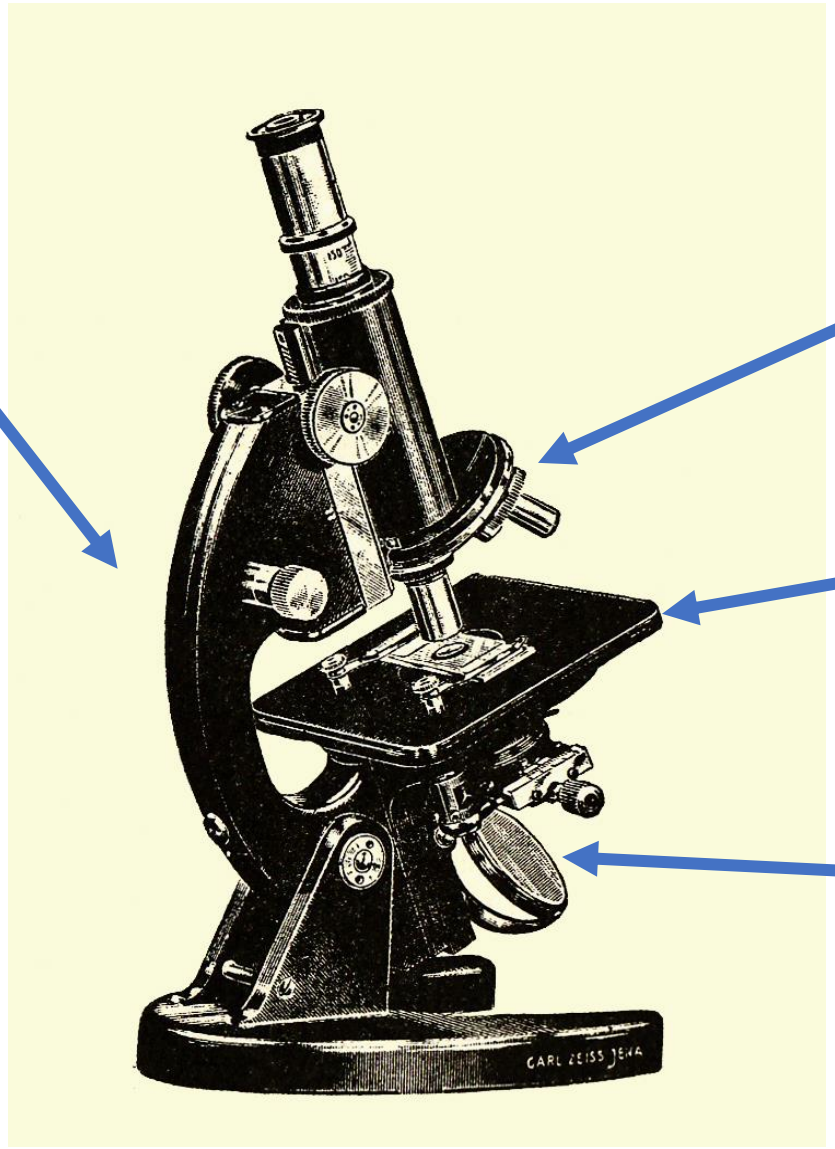


The digitally controlled microscope

An example is worth a thousand theories

Tube w/

Tube Motion Controller



Nose Piece w/

Nose Piece Controller

Stage w/

Stage Controller

Illuminator w/

Illumination Controller

Even microscopes need digital controls these days ;-)

- Precise focus control
- Precise illumination control
- Automated positioning of sample
- Automated change of objective

https://github.com/ZEISS/fretish_robot/tree/main/examples/digital_microscope

The digitally controlled microscope

FRETish Requirements for non-rocket things

Scope | Conditions | Component* | SHALL* | Timing | Response*.

IN "(sample_prep|capture)" mode UPON request_illuminate_on the illumination_controller **SHALL** within 200 milliseconds
SATISFY (illumination_on & actual_brightness = configured_brightness & answer_request_ok).

IN "(sample_prep|capture)" mode UPON request_brightness_increase the illumination_controller **SHALL** within 200 milliseconds
SATISFY IF (illumination_on & !(actual_brightness = max_brightness))
THEN configured_brightness_increased_by_10_percent & answer_request_ok.

The illumination_controller **SHALL** always
SATISFY configured_brightness <= max_brightness & configured_brightness >= min_brightness.

The digitally controlled microscope

FRETish Requirements for non-rocket things

Scope | Conditions | Component* | SHALL* | Timing | Response*.

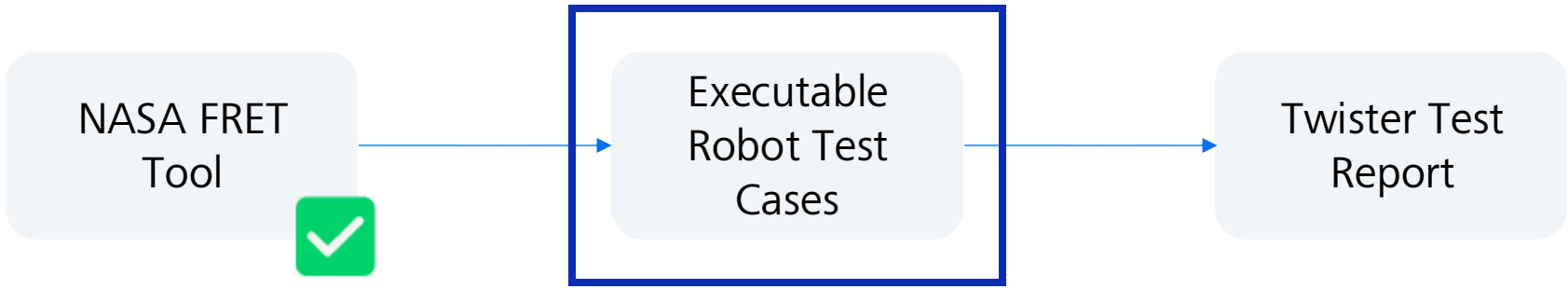
IN "(sample_prep|capture)" mode UPON request_change_objective the nose_piece_controller **SHALL** within 1 second SATISFY objective_lens_changed_clockwise_ok & answer_request_ok.

IN tube_moving mode UPON request_change_objective the nose_piece_controller **SHALL** within 100 milliseconds SATISFY answer_request_denied.

IN "(normal|homing)" mode UPON request_move_up the tube_motion_controller **SHALL** within 200 milliseconds SATISFY IF !tube_upper_end THEN (tube_moving_upwards & answer_request_ok).

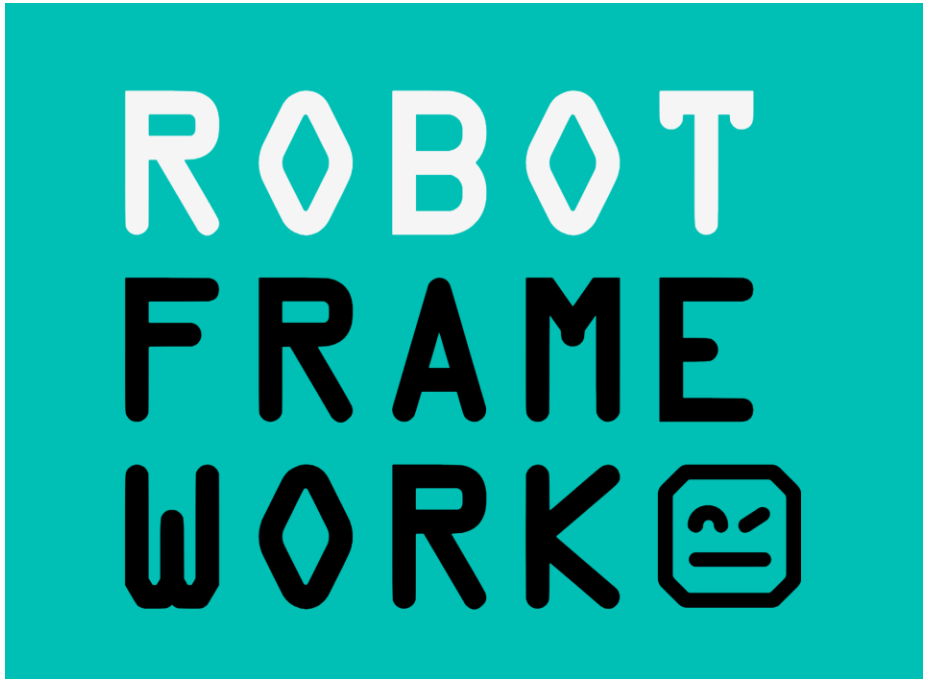
Upon request_move_up the tube_motion_controller **SHALL** always SATISFY IF tube_at_upper_end THEN tube_position_hold.

Our plan for today



Robot Framework
Human-readable, yet machine-executable

- Open-Source Automation Framework
  - Very mature, development started in 2005
  - Keyword-driven
  - Supports several testing methodologies like Behavior Driven Development (BDD)
  - Also used for Robotic Process Automation (RPA)
  - Very popular for end-to-end testing in web technologies
- Funded by non-profit Robot Framework Foundation
- Supported by Zephyr's Test Runner Twister
- Allows to write human-readable test specifications that can be executed automatically

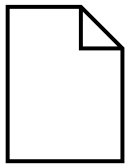


https://robotframework.org/

Robot Framework
Let's look at a simple example

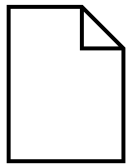
TestSuite.robot

```
*** Test Cases ***
Login with Password
    Connect to Server
    Login User              ironman    1234567890
    Verify Valid Login      Tony Stark
    Close Server Connection
```



keywords.resource

```
*** Keywords ***
Login User
    [Arguments]    ${login}    ${password}
    Set Login Name    ${login}
    Set Password    ${password}
    Execute Login
```

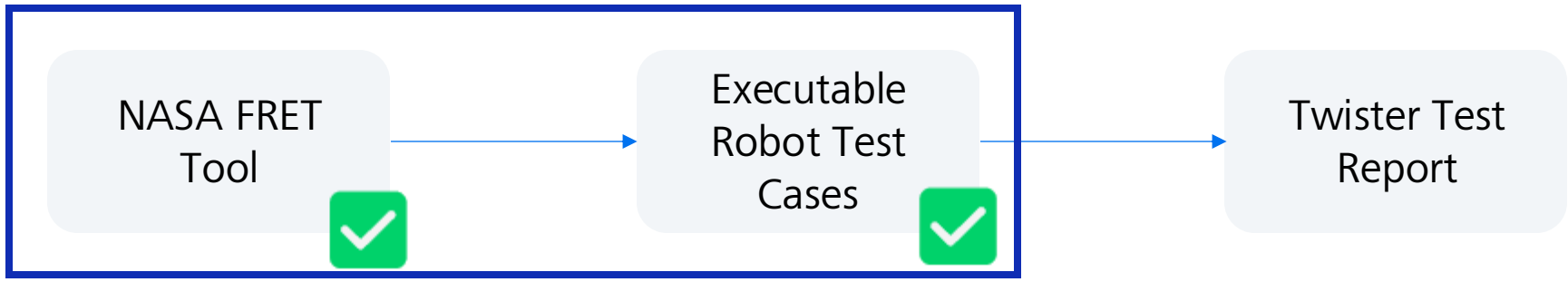


CustomLibrary.py

```
def set_login_name(self, login):
    '''Sets the users login name and stores it for authentication.'''
    self.login = login
    info(f'User login set to: {login}')
```

https://robotframework.org/robotframework/latest/RobotFrameworkUserGuide.html#creating-keywords

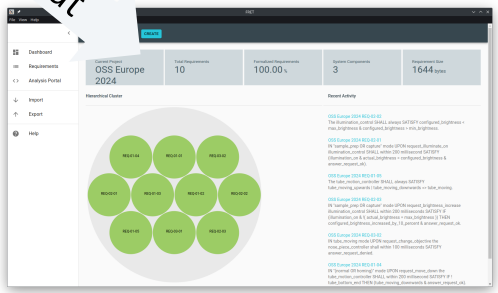
Our plan for today



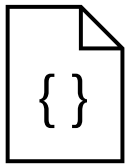
From FRET to Robot

On the shoulders of giants

input

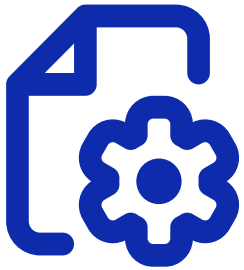


export



`fretish_reqs.json`

`fret-to-robot CLI`[1)]



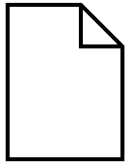
translate

`fret_test.robot`

execute

ROBOT FRAME WORK

generate



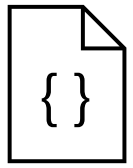
`Test Report`

(1) https://github.com/ZEISS/fretish_robot

Generated Robot testcase

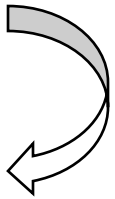
Shown for simple example requirement

```
{
    "scope_mode": "\"(sample_prep|capture)\"",
    "regular_condition_unexp_pt": "request_illuminate_on",
    "component_name": "illumination_control",
    "timingTextRange": [ 86, 107 ],
    "post_condition_unexp_ft": "((illumination_on & (actual_brightness = configured_brightness)) & answer_request_ok)",
}
```



fretish_reqs.json

```
$>fret-to-robot fretish_reqs.json --out fret_test.robot
```



```
*** Test Cases ***
TEST_REQ-02-01-1
    [Tags]    REQID=REQ-02-01    SCOPE=sample_prep    TRIGGER=request_illuminate_on
    In sample_prep mode
    Upon    request_illuminate_on
    Within    200 millisecond    Satisfy    (($illumination_on and
            ($actual_brightness == $configured_brightness)) and $answer_request_ok)
```

fret_test.robot

Keyword implementation
Teaching FRETish to a robot

```
Upon    request_illuminate_on
```

FRETish keywords

- Keywords in FRETish syntax to express FRET semantics
- Examples: `Upon`, `Within X (milli)seconds`
- Implementation:
  - Done in library `fretish_robot.FRETlib`
  - Reduction to built-in keywords

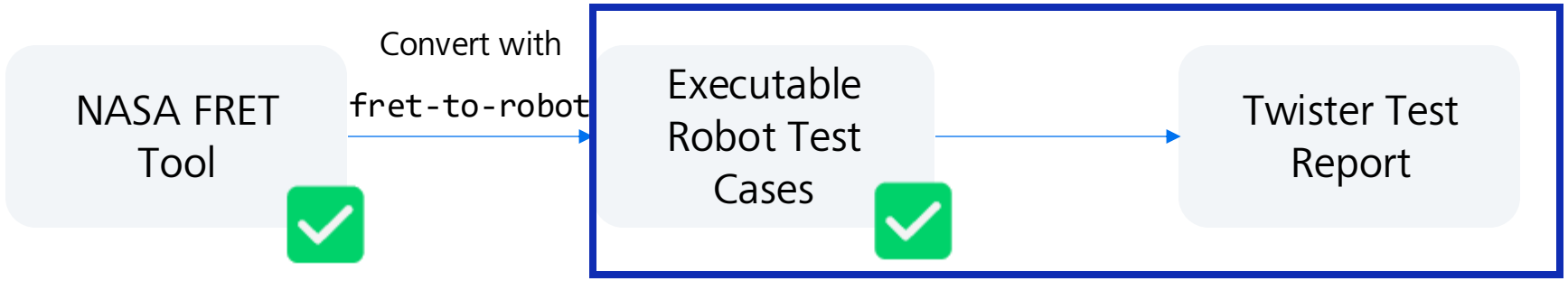
Functional keywords

- Keywords that implement functional behavior
- Example: `request_illuminate_on`
- Implementation:
  - Specific to application logic → additional custom library

```python
# FRETLib.py
def upon(self, event_name):
    """Runs the `event_name` keyword.
    Like `Run Keyword` but for FRET read"""
    self.built_in.run_keyword(event_name)
```

```python
# CustomLib.py
def request_illuminate_on(self):
    """Turns illumination on.
    Done by sending command via shell fixture"""
    self.shell.exec_command("illuminate set on")
```

Our plan for today



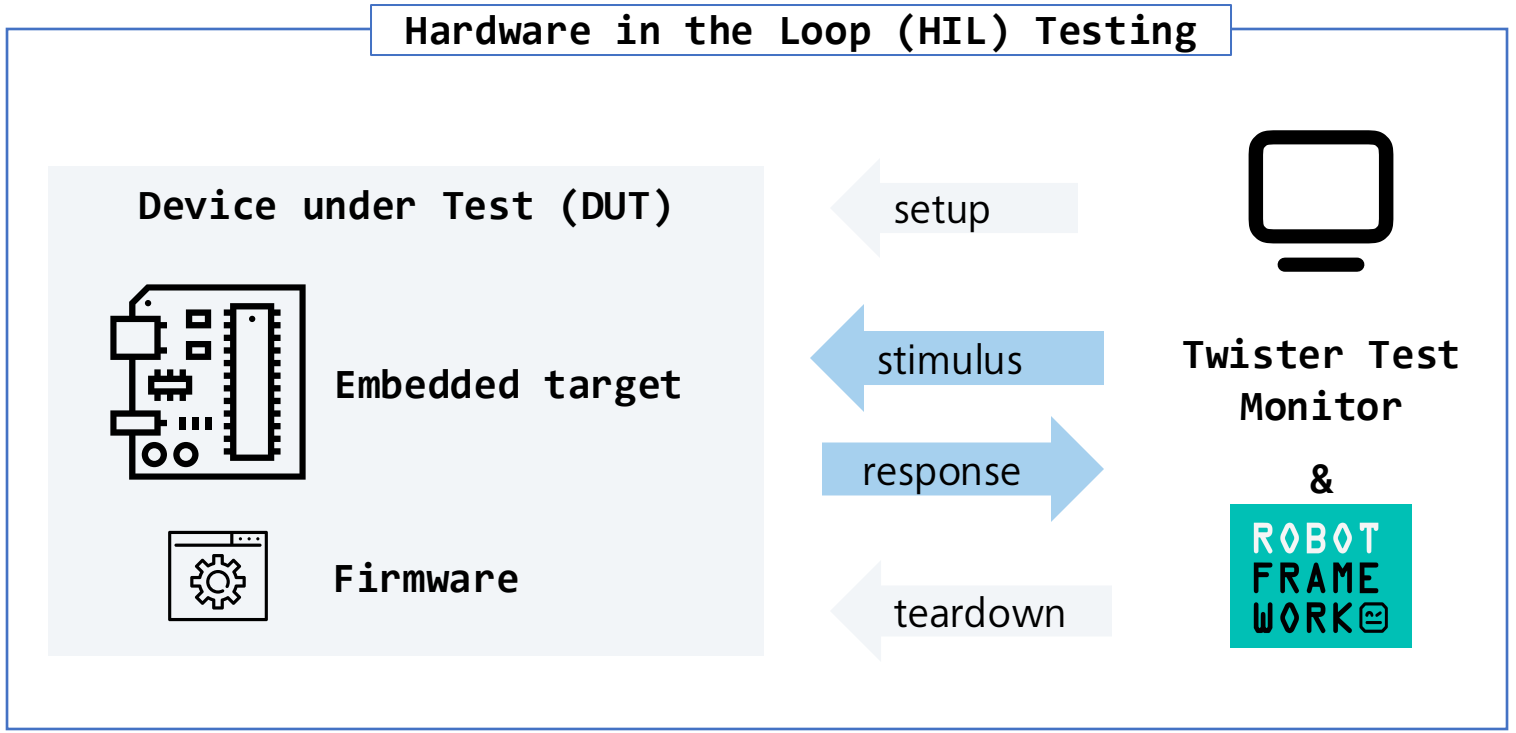
Zephyr, Twister and Test Harnesses
All batteries included, yes, or no?

- To this point FRETish & Robot independent of application domain
- Our domain is embedded computing, and our Firmware runs on Zephyr :-)
- Better still, Zephyr has built-in support for HIL testing called **Twister**

Our Question then became:

How can we

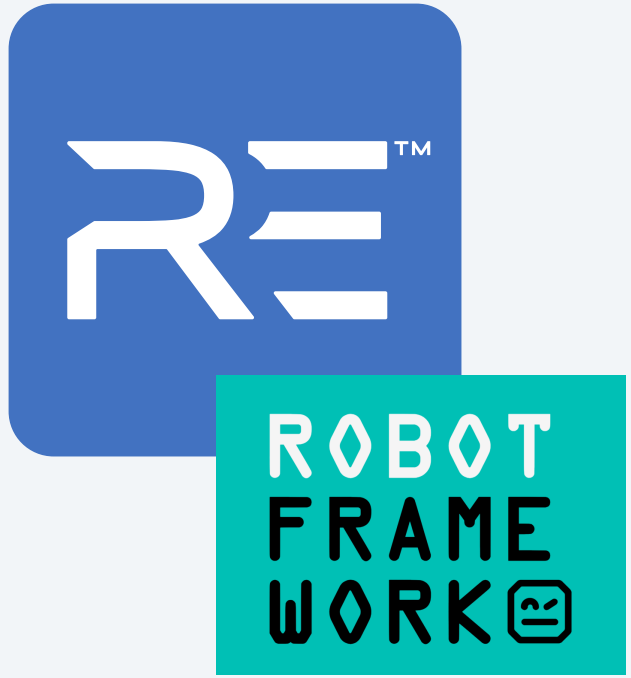
- make Twister run our Robot files and
- give us back the Robot test results?



Current State of Robot integration into Twister

The good, the not-so-good, the missing

- Twister supports different test frameworks called harnesses
  - Console, Ztest, GoogleTest but also pytest and **Robot**
- Twister also supports different test monitors called handlers
  - Simulation (native), QEMU, Device
- However, not all harnesses can be used with all handlers
  - Robot harness tightly coupled to Renode simulator
  - Renode simulator configured only for a small list of (in-tree) boards
- Robot Framework integration provides special keywords
  - `Start Emulation, Send Key to Uart, Wait For Outgoing Packet`
- But currently usable with Renode simulator only



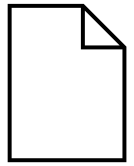
Introducing the `robotframework` **Twister harness**
Our changes and why they were necessary

Goals of the `robotframework` harness:

- Run Robot Test Suites
- Execute on `native_sim`, QEMU and **real hardware**
- Provide Zephyr-specific Robot keywords
  - `Run Device`: Flash application and run
  - `Run Command`: Send commands via any transport (UART, MQTT, CAN)

Our strategy:

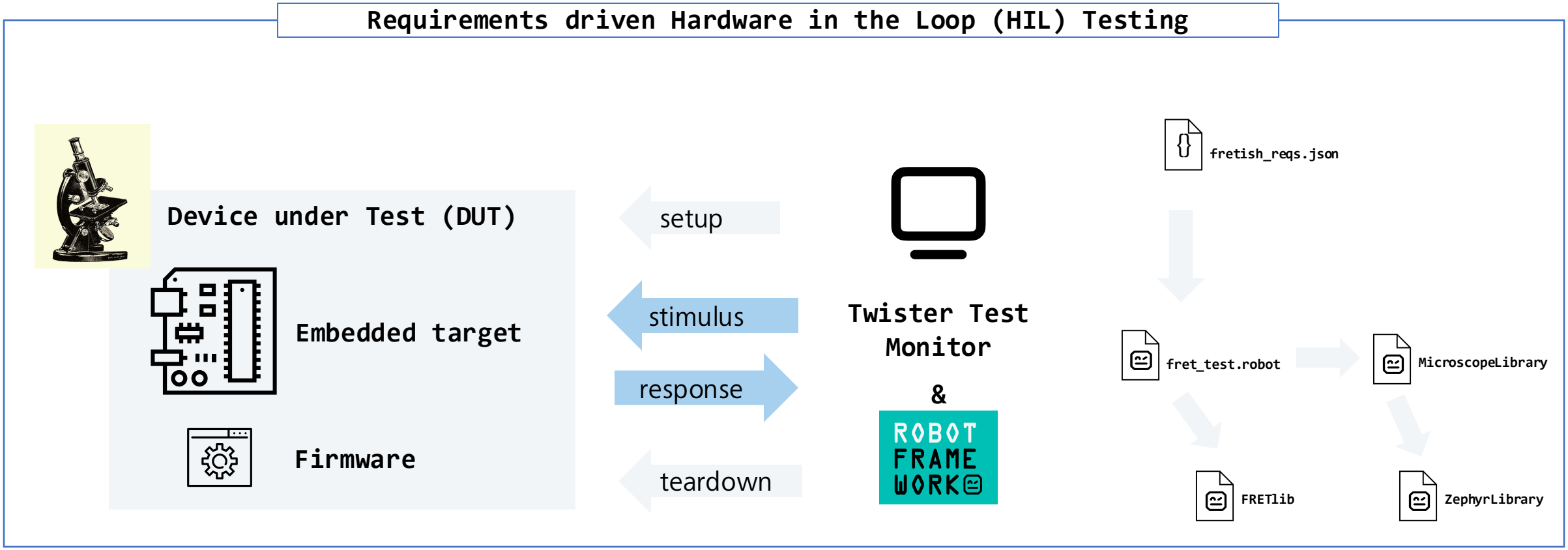
- Leverage existing pytest integration and code from (in-tree) `pytest_twister_harness` plugin
  - Invoke the `robot` CLI the same way as it is done for `pytest`
  - Figure out a way to pass relevant information from `twister` to `robot`
  - Implement required keywords using `XYZAdapter` classes from `pytest_twister_harness`
- Code available on https://github.com/ZEISS/zephyr/tree/zeiss/fretish_robot



`testcase.yaml`

```yaml
tests:
  sample.robot.shell_1:
    harness: robotframework
    platform_allow:
      - native_sim
      - mimxrt1020_evk
    tags:
      - test_framework
      - robot
```

Our current setup
All together now ...



- Reminder: Robot tests contain general FRETish as well as domain-specific keywords
- Domain specific keywords still need to implemented by hand, yet making use of generic `TwisterLibrary` for interacting with DUT

Our plan for today
All done!

What we achieved so far

If it doesn't scale it ain't worth a penny

Our pilot project captured

743 FRETish requirements

↓

Presented tooling derived

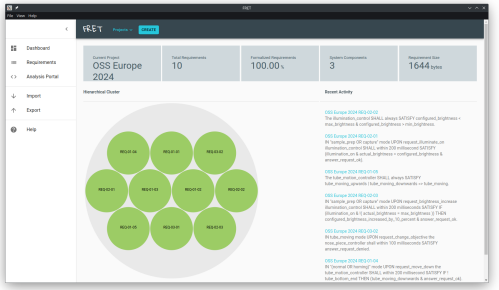
594 test cases

Benefits of FRETish Requirements & Test Automation

So why are we doing this?

FRETish Requirements

- Clear and unambiguous semantics
- Machine-parsable
- Additional use cases like model checking, simulation, …



Robot Framework

- Tests expressed in human-readable form and understandable for non-SW folks
- Derivable from FRETish requirements (traceability included)
- Obviously, not limited to automatically generated tests
- Keyword Libraries for re-use and separation of concerns

Zephyr

- Market-leading RTOS library and embedded firmware framework
- Built-in HIL-support
- Extensible and tunable to specific needs

Future Improvements for Robot Twister Integration

Let's work together!

Make general usage of Robot available upstream

- Allow robot scripts without renode · **Issue #64825** · zephyrproject-rtos/zephyr (github.com)[1)]
- Integrate Robot Framework without Renode into twister by MP-StefanKraus · **Pull Request #67607** · zephyrproject-rtos/zephyr (github.com)[2)]

Not mergeable as is since community should also address technical debts in `twister` codebase

- Pytest harness works quite different from other harnesses
- Redundant implementations between Twister handlers and `pytest_twister_harness` adapters – which to choose?
- Provide consistent extension API for handlers/harnesses

(1) https://github.com/zephyrproject-rtos/zephyr/issues/64825

(2) https://github.com/zephyrproject-rtos/zephyr/pull/67607

The End
Come talk to us

Christian Schlotter
Software Architect
Carl Zeiss Meditec AG

Security Committee, Zephyr Project

Dr. Tobias Kästner
Solution Architect Medical IoT
Inovex GmbH

Safety Working Group, Zephyr Project
Maintainer Bridle Project, Tiac-Systems

Stefan Kraus
Senior Software Engineer
UL Solutions

Working for a safer world

Seeing beyond

The digitally controlled microscope

FRETish Requirements for non-rocket things

IN "(sample_prep|capture)" mode UPON request_change_objective the nose_piece_controller **SHALL** within 1 second SATISFY objective_lens_changed_clockwise_ok & answer_request_ok.

IN tube_moving mode UPON request_change_objective the nose_piece_controller **SHALL** within 100 milliseconds SATISFY answer_request_denied.

Scope | Conditions | Component* | SHALL* | Timing | Response*.

The digitally controlled microscope

FRETish Requirements for non-rocket things

UPON (tube_moving_upwards & tube_at_upper_end) the tube_motion_controller
SHALL at the next timepoint SATISFY tube_position_hold.

UPON (tube_moving_downwards & tube_at_bottom_end) the tube_motion_controller
SHALL at the next timepoint SATISFY tube_position_hold.

IN "(normal|homing)" mode UPON request_move_up the tube_motion_controller **SHALL** within 200 milliseconds
SATISFY IF !tube_upper_end THEN (tube_moving_upwards & answer_request_ok).

IN "(normal|homing)" mode UPON request_move_down the tube_motion_controller **SHALL** within 200 milliseconds
SATISFY IF !tube_bottom_end THEN (tube_moving_downwards & answer_request_ok).

The tube_motion_controller **SHALL** always
SATISFY IF (tube_moving_upwards | tube_moving_downwards) THEN tube_moving.

Scope | Conditions | Component* | SHALL* | Timing | Response*.

FRET exported requirements

FRET tool exports to simple JSON

IN "(sample_prep|capture)" mode

UPON request_illuminate_on

the illumination_controller

SHALL

within 200 milliseconds

SATISFY (

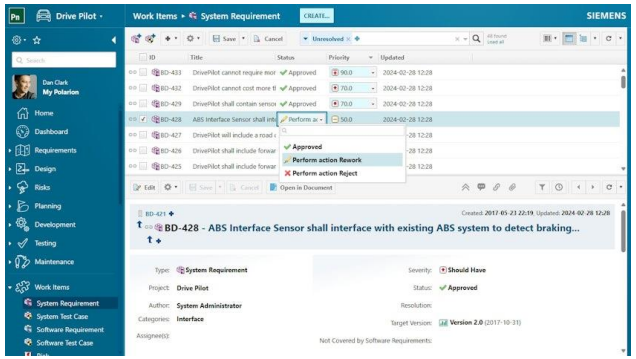
illumination_on &
actual_brightness = configured_brightness &
answer_request_ok

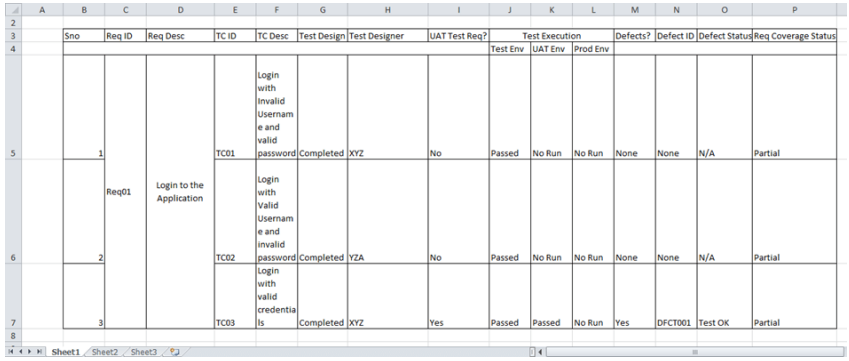
)


```
{
    "reqid": "REQ-02-01",
    "fulltext": "IN \"(sample_prep|capture)\" mode UPON
request_illuminate_on illumination_control SHALL within 200
millisecond SATISFY (illumination_on & actual_brightness =
configured_brightness & answer_request_ok)",
    "semantics": {
        "scope_mode": "\"(sample_prep|capture)\"",
        "regular_condition_unexp_pt": "request_illuminate_on",
        "component_name": "illumination_control",
        "timingTextRange": [ 86, 107 ],
        "post_condition_unexp_ft": "((illumination_on &
(actual_brightness = configured_brightness)) & answer_request_ok)",
        "variables": [ "request_illuminate_on", …]
    }
}
```

What we did not cover

There is only so much you can say in 30 mins





Sno	Req ID	Req Desc	TC ID	TC Desc	Test Design	Test Designer	UAT Test Req?	Test Execution			Defects?	Defect ID	Defect Status	Req Coverage Status
								Test Env	UAT Env	Prod Env				
1	Req01	Login to the Application	TC01	Login with Invalid Username and valid password	Completed	XYZ	No	Passed	No Run	No Run	None	None	N/A	Partial
2			TC02	Login with Valid Username and invalid password	Completed	YZA	No	Passed	No Run	No Run	None	None	N/A	Partial
3			TC03	Login with valid credentials	Completed	XYZ	Yes	Passed	Passed	No Run	Yes	DFCT001	Test OK	Partial

Requirements Management Tool

Convert to format that can be parsed by FRET

NASA FRET Tool

Convert with `fret-to-robot`

Executable Robot Test Cases

Execute with Twister

Twister Test Report

Generate document

Test Specification

Generate document

Test Report

Current State of Robot integration into Twister

- Upstream Zephyr supports running Robot Test Suites in Twister via `robot` harness
- Harness employs `renode-test` to run a Robot Test Suite in Renode
  - Starts Renode in the background
  - Configures it to allow Robot Framework to connect to Renode
- Robot Framework integration in Renode provides special keywords
  - `Start Emulation`
  - `Send Key to Uart`
  - `Wait For Outgoing Packet`
  - …