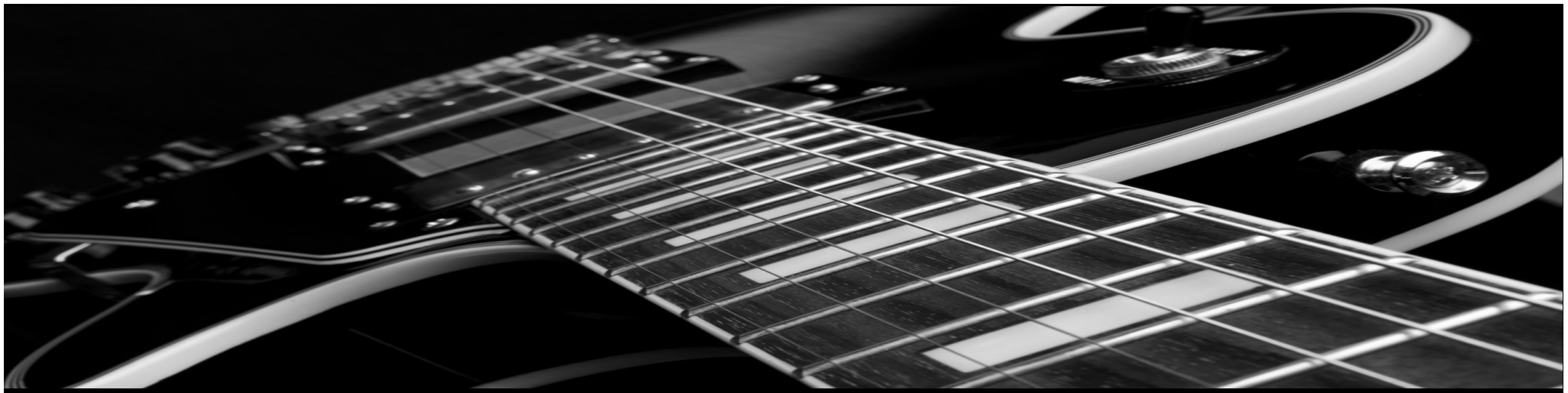
FRET Requirements?



Dimitra Giannakopoulou ● NASA Ames

how developers write requirements

Lockheed Martin Cyber-Physical System Challenge, component FSM:

- Exceeding sensor limits shall latch an autopilot pullup when the pilot is not in control (not standby) and the system is supported without failures (not apfail).
- The autopilot shall change states from TRANSITION to STANDBY when the pilot is in control (standby)

every time these conditions hold or only when they **become** true?

system is supported and sensor data is good.

- The autopilot shall change states from NOMINAL to MANEUVER when the sensor data is not good.
- The autopilot shall change states from NOMINAL to STANDBY when the pilot is in control (standby).
- The autopilot shall change states from MANEUVER to STANDBY when the pilot is in control (standby) and sensor data is good.
- …

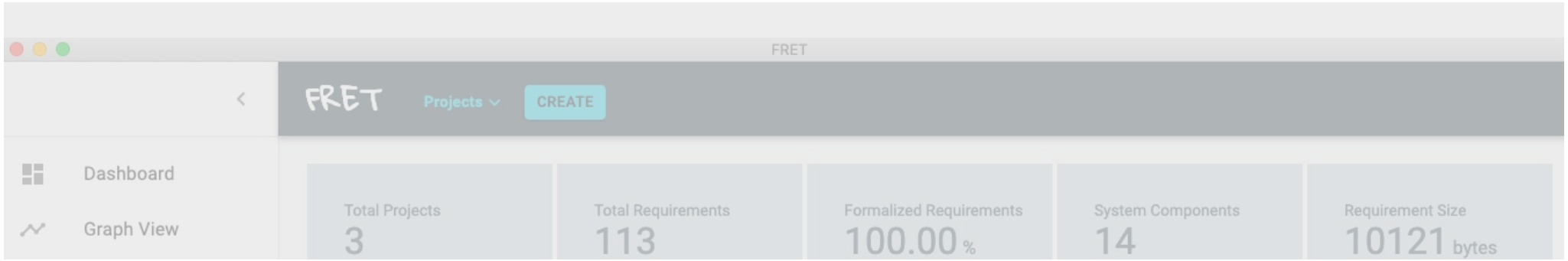
are these requirements consistent? does my model/code satisfy them?

languages formal analysis tools understand

```
var autopilot: bool = (not standby) and supported and (not
    apfail);
var pre_autopilot: bool = false -> pre autopilot;
var pre_limits: bool = = false -> pre limits;
guarantee "FSM-001v2" S((((((autopilot and pre_autopilot and
    pre_limits) and (pre ( not (autopilot and pre_autopilot and
    pre_limits)))) or ((autopilot and pre_autopilot and
    pre_limits) and FTP)) => (pullup)) and FTP), ((((autopilot
    and pre_autopilot and pre_limits) and (pre ( not (autopilot
    and pre_autopilot and pre_limits)))) or ((autopilot and
    pre_autopilot and pre_limits) and FTP)) => (pullup)));
```

FRET bridges the gap

- do you speak FRETish?: an extensible grammar defines a restricted natural language with unambiguous semantics
- explanations of the formal semantics in various forms: natural language, diagrams, interactive simulation
- compositional (hence maintainable and extensible) generation of formulas from requirement fields for analysis tools
- checks consistency of requirements and provides feedback
- exports verification code
  - for model checking of Simulink models with Cocosim
  - for runtime analysis of C programs with Copilot

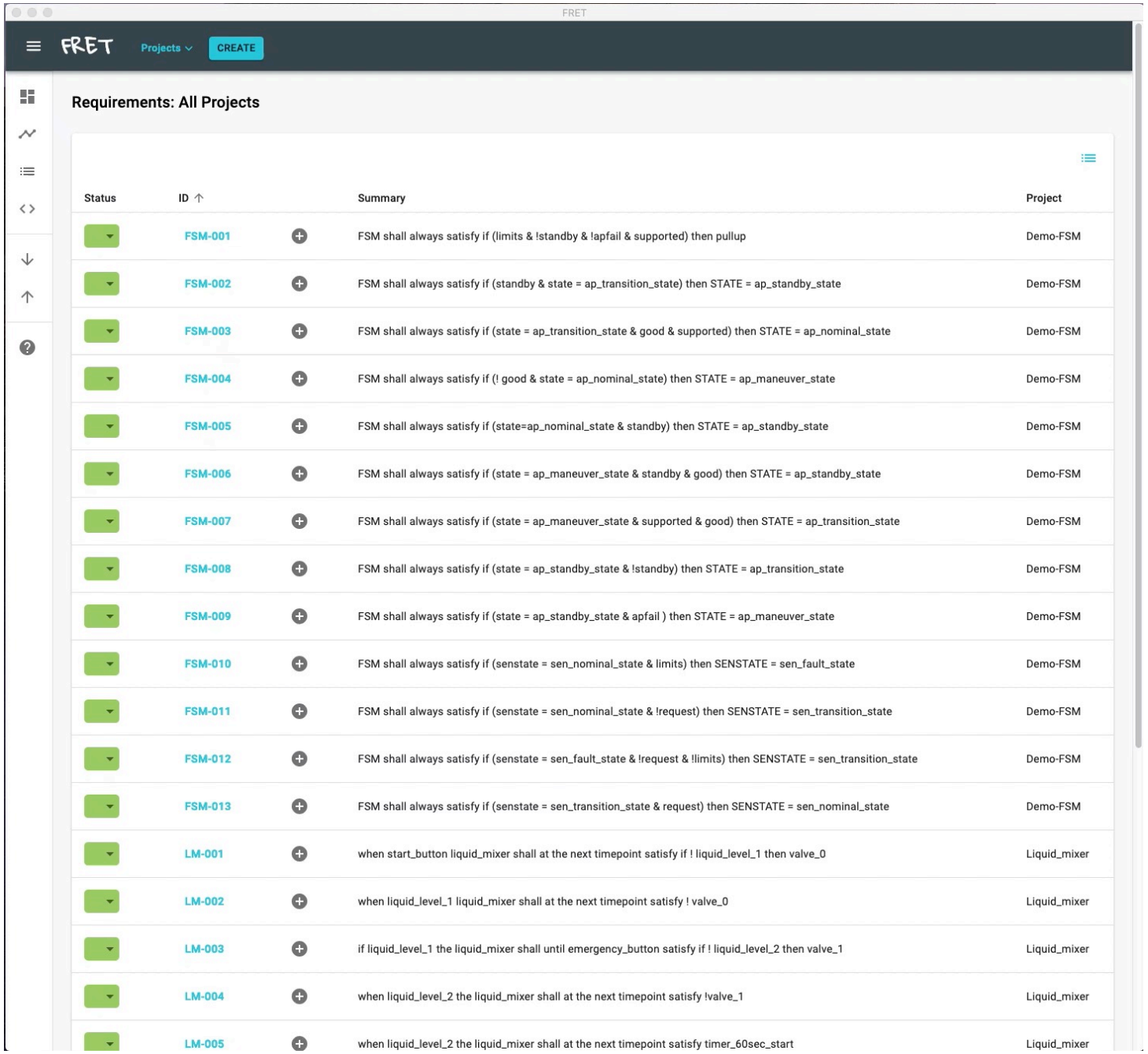


welcome to FRET!

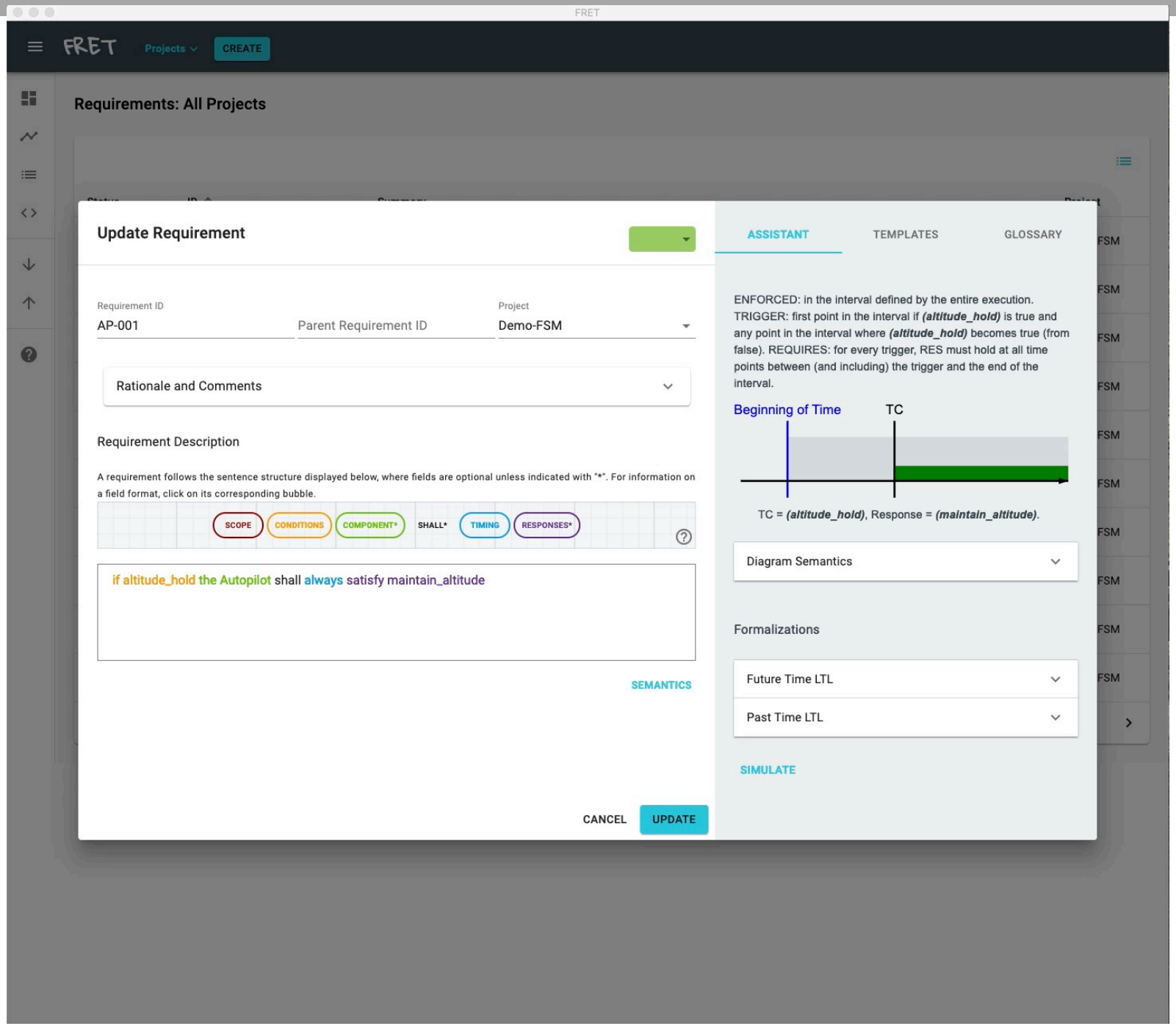
`https://github.com/NASA-SW-VnV/fret`

Team: Andreas Katis, Anastasia Mavridou, Tom Pressburger, Johann Schumann, Khanh Trinh
Alumni: David Bushnell, Tanja DeJong, George Karamanolis, David Kooi, Julian Rhein, Nija Shi

creating requirements



is this what I meant?



but it’s all FRETish to me!

Lockheed Martin Cyber-Physical System Challenge, component FSM:

- The autopilot shall change states from TRANSITION to STANDBY when the pilot is in control (standby).
- The autopilot shall change states from TRANSITION to NOMINAL when the system is supported and sensor data is good.
- The autopilot shall change states from NOMINAL to MANEUVER when the sensor data is not good.
- The autopilot shall change states from NOMINAL to STANDBY when the pilot is in control (standby).
- The autopilot shall change states from MANEUVER to STANDBY when the pilot is in control (standby) and sensor data is good.

Create Requirement

Requirement ID | Parent Requirement ID | Project: Demo-FSM

Rationale and Comments

Rationale

The autopilot shall change states from TRANSITION to NOMINAL when the system is supported and sensor data is good.

Comments

Requirement Description

A requirement follows the sentence structure displayed below, where fields are optional unless indicated with "*". For information on a field format, click on its corresponding bubble.

SCOPE | CONDITIONS | COMPONENT* | SHALL* | TIMING | RESPONSES*

SEMANTICS

CANCEL | CREATE

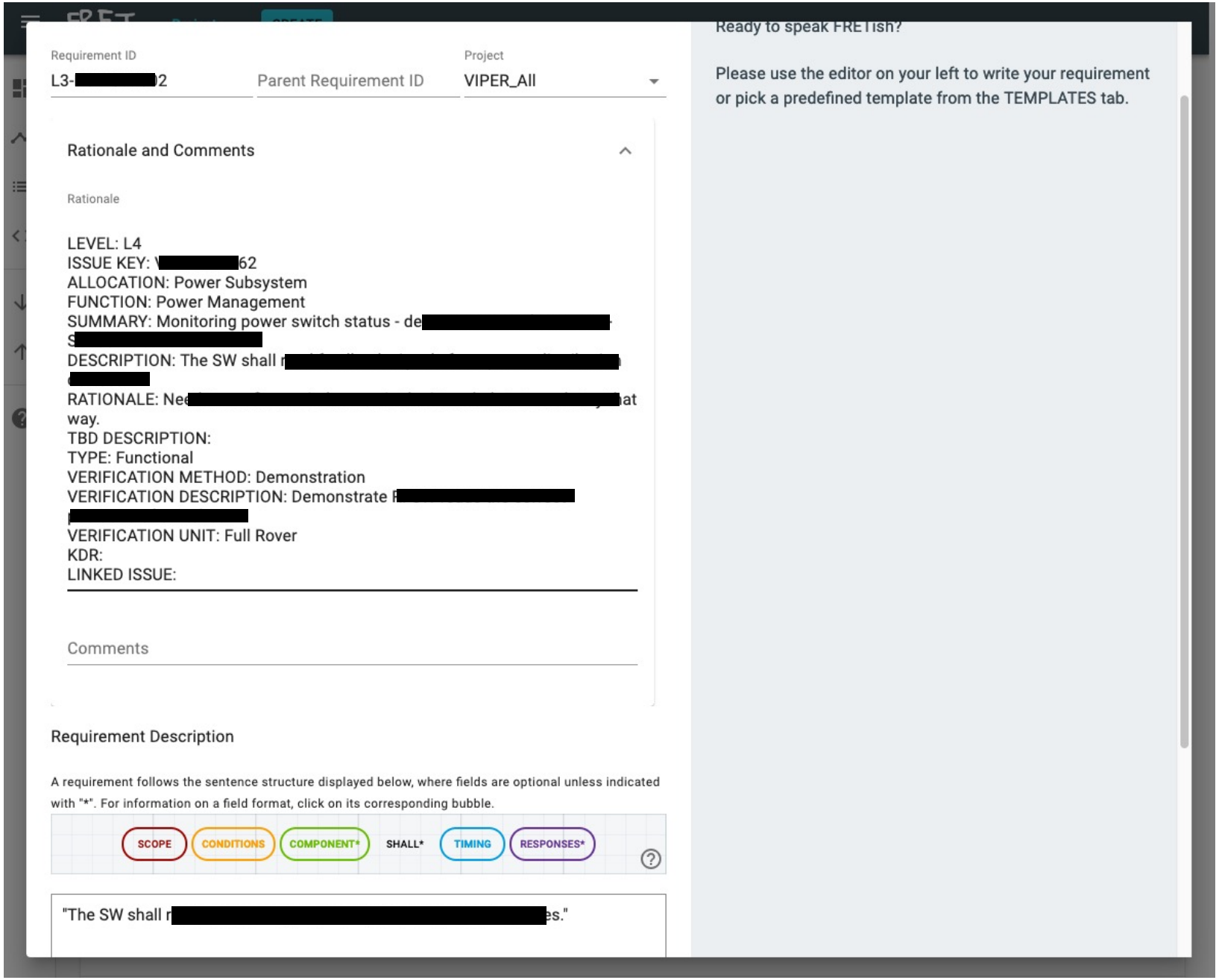
ASSISTANT | TEMPLATES | GLOSSARY

Template: No template

Choose a predefined template

You currently have not selected predefined template.

importing requirements



behind the scenes

semantic templates

while cruising, the Autopilot shall always satisfy if altitude_hold then maintain_altitude

scope — timing — response

SCOPE in, before, after, notin, onlyIn, onlyBefore, onlyAfter, null

CONDITION null, regular

TIMING immediately, next, always, never, eventually, until, before, for, within, after

RESPONSE satisfaction

160 semantic templates / template keys!

pre-processed cache

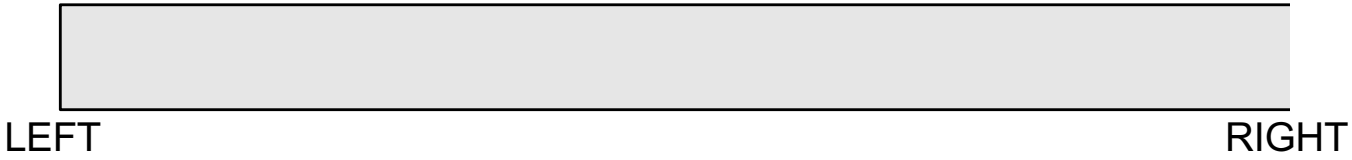

```
},
"in,null,always,satisfaction": {
  "ft": "(LAST V ($scope_mode$ -> $post_condition$))",
  "ftExpanded": "(LAST V ($scope_mode$ -> $post_condition$))",
  "pt": "(H ($scope_mode$ -> $post_condition$))",
  "ptExpanded": "(H ($scope_mode$ -> $post_condition$))",
  "CoCoSpecCode": "(H($scope_mode$ => $post_condition$))",
  "R2U2Code": "Under construction.",
  "ftInfAU": "(G ($scope_mode$ -> $post_condition$))",
  "ftInfAUExpanded": "(G ($scope_mode$ -> $post_condition$))",
  "ftInfBtw": "((G ((! Fin_$scope_mode$) | (X ((F Lin_$scope_mode$) -> (Lin_$scope_mode$ V $post_condition$))))) & ($scope_mode$ -> ((F Lin_$s
  "ftInfBtwExpanded": "((G ((! ((( $scope_mode$) & (! LAST)) & (X $scope_mode$))) | (X ((F (($scope_mode$ & (! LAST)) & (X (! $scope_mode$)))
  "ftFinBtw": "((LAST V ((! (Fin_$scope_mode$ & (! LAST))) | (X (((! LAST) U Lin_$scope_mode$) -> (Lin_$scope_mode$ V $post_condition$))))) &
  "ftFinBtwExpanded": "((LAST V ((! ((((! $scope_mode$) & (! LAST)) & (X $scope_mode$)) & (! LAST))) | (X (((! LAST) U (($scope_mode$ & (! LAS
  "ptFinBtw": "(H ((Lin_$scope_mode$ & (! FTP)) -> (Y ($post_condition$ S ($post_condition$ & Fin_$scope_mode$)))))",
  "ptFinBtwExpanded": "(H ((((! $scope_mode$) & (Y $scope_mode$)) & (Y TRUE)) -> (Y ($post_condition$ S ($post_condition$ & ($scope_mode$ & ((
  "CoCoSpecCodeFinBtw": "(H(((( not $scope_mode$) and (pre ($scope_mode$))) and ( not FTP)) => (pre (SI( ($scope_mode$ and (FTP or (pre ( not
  "description": "ENFORCED: in every interval where $scope_mode$ holds.\nTRIGGER: first point in the interval.\nREQUIRES: for every trigger, R
  "diagram": "_media/user-interface/examples/svgDiagrams/in_null_always_satisfaction.svg"
},
```


- semantic templates have RTGIL semantics
- **ALL** aspects of our approach are compositional therefore extensible

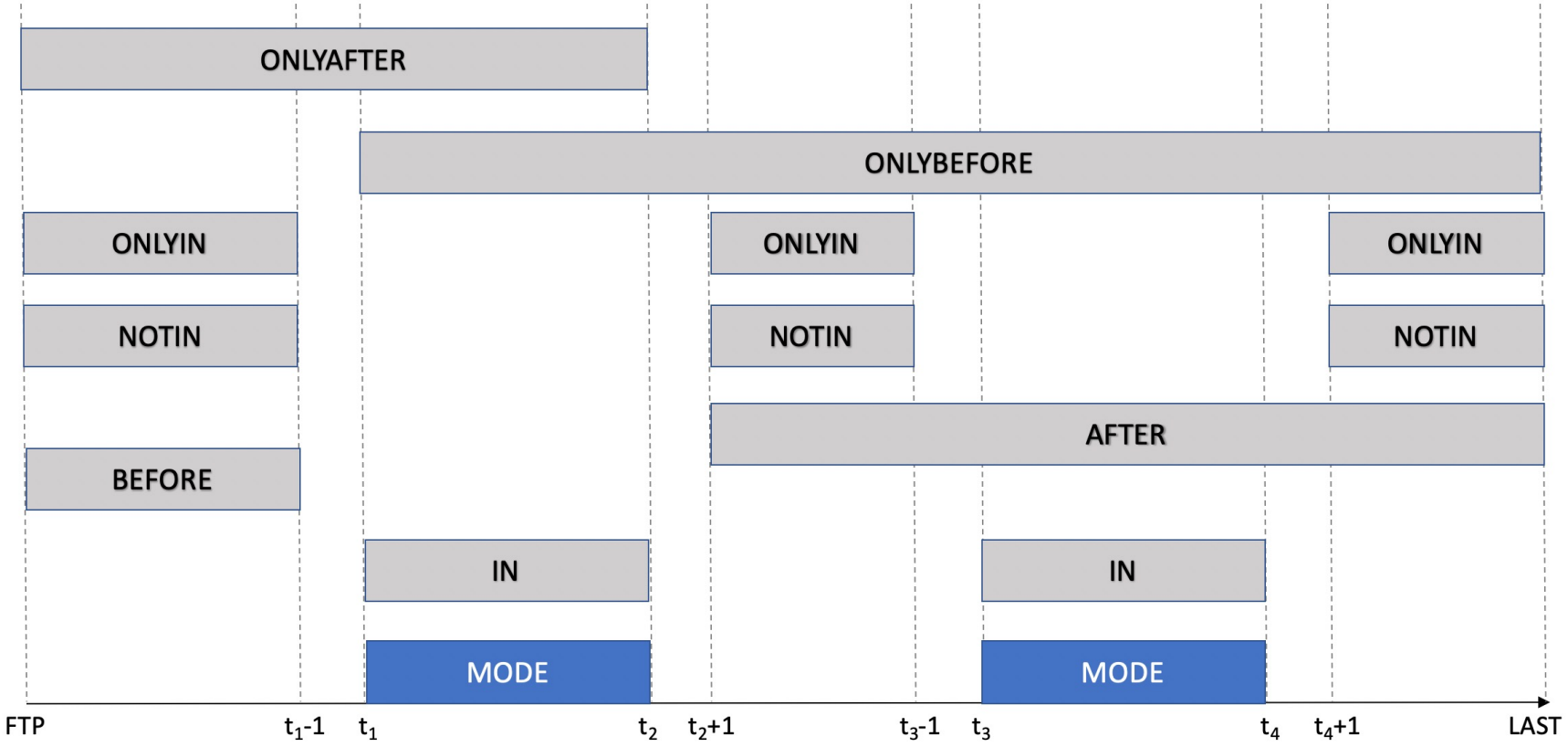
- Dimitra Giannakopoulou, Thomas Pressburger, Anastasia Mavridou, Johann Schumann: **Generation of Formal Requirements from Structured Natural Language.** REFSQ 2020
- Dimitra Giannakopoulou, Thomas Pressburger, Anastasia Mavridou, Johann Schumann: **Automated Formalization of Structured Natural Language Requirements.** IST Journal, 2021

past-time formulas

[LEFT, RIGHT):




```
historically (RIGHT implies previous
                                (FORMULA since inclusive required LEFT))
```



constructing formulas from fields

while cruising, the Autopilot shall always satisfy if altitude_hold then maintain_altitude

scope in: [LEFT, RIGHT) → [FiM, LiM)

```
FiM = MODE and (FTP or previous (not MODE))
```

```
LiM = not MODE and previous MODE
```

timing always: `FORMULA → RES`

```
historically (RIGHT implies previous
                                (FORMULA since inclusive required LEFT))
```

scope: in, condition: null, timing: always, response: satisfaction

```
historically (LiM implies previous (RES since inclusive required FiM))
```

optimize

```
historically (MODE implies RES)
```

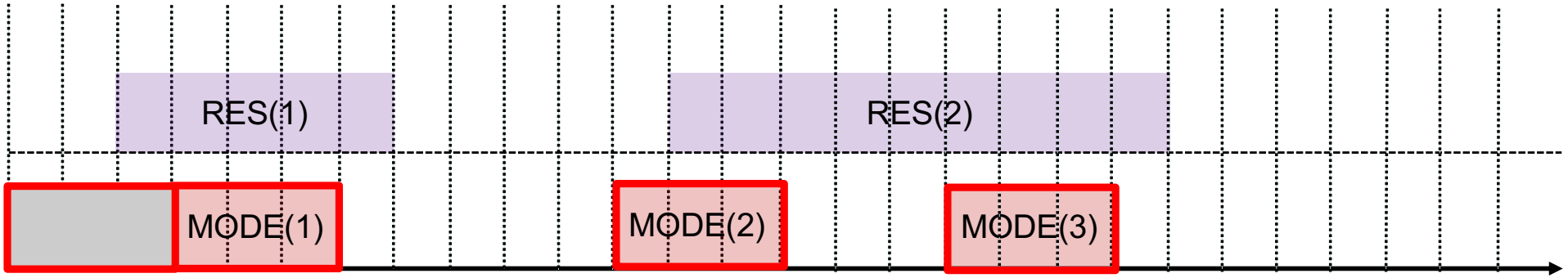
translate to SMV

```
(H (MODE → RES))
```

instantiate

```
(H (cruising → (altitude_hold → maintain_altitude)))
```

oracles



Oracle for scope: in, condition: null, timing: always, response: satisfaction

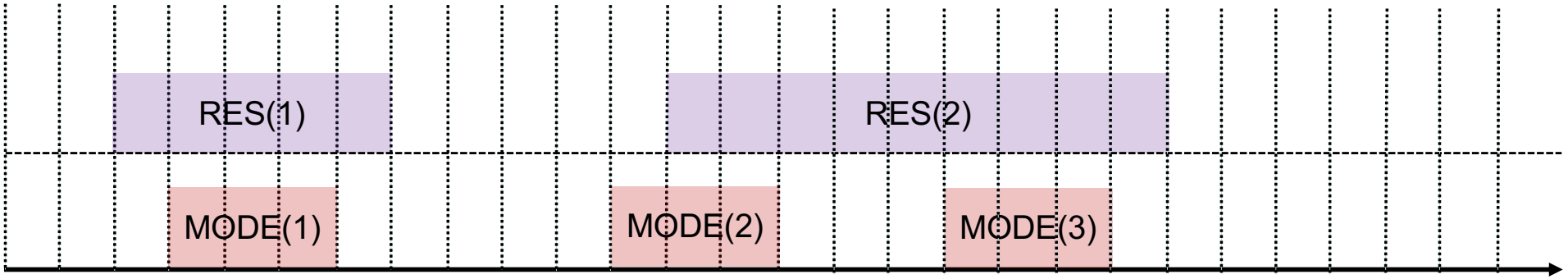
responseIntervals = {RES(1), RES(2)}

step1: determine scope intervals
result: scopeIntervals = {MODE(1), MODE(2), MODE(3)}

step 2: apply timing always
for each scopeInterval in scopeIntervals
there exists a responseInterval in responseIntervals such that:
responseInterval contains scopeInterval

Expected value: false (MODE(2) not contained in RES(1) or RES(2))

verification [in, null, always, satisfaction]



trace in SMV

```
DEFINE
   LAST := (t = 27);
   RES := case
            t < 2 : FALSE ;
            t <= 7 : TRUE ;
            t < 12 : FALSE ;
            t <= 21 : TRUE ;
            TRUE : FALSE ; esac ;
   COND := case
            TRUE : FALSE ; esac ;
   MODE := case
            t < 3 : FALSE ;
            t <= 6 : TRUE ;
            t < 11 : FALSE ;
            t <= 14 : TRUE ;
            t < 17 : FALSE ;
            t <= 20 : TRUE ;
            TRUE : FALSE ; esac ;
```

→ `(H (MODE → RES))` holds at timepoint LAST?

SMV returns: false expected: false ✓

example traces are generated automatically:
targeted scenarios; random scenarios

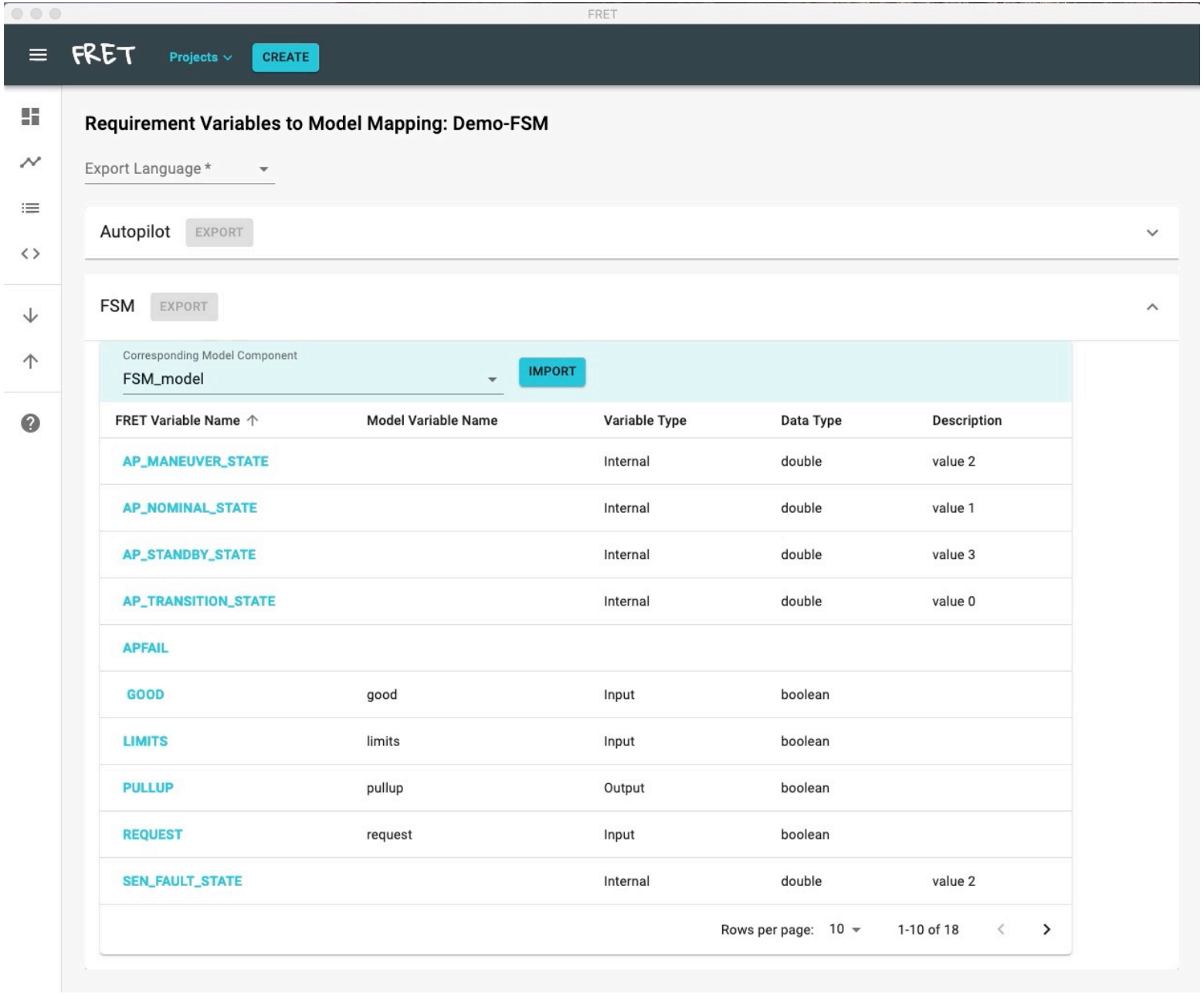
we also use SMV to check equivalence between:

- past and future time properties for each template key
- optimized and non-optimized formulas

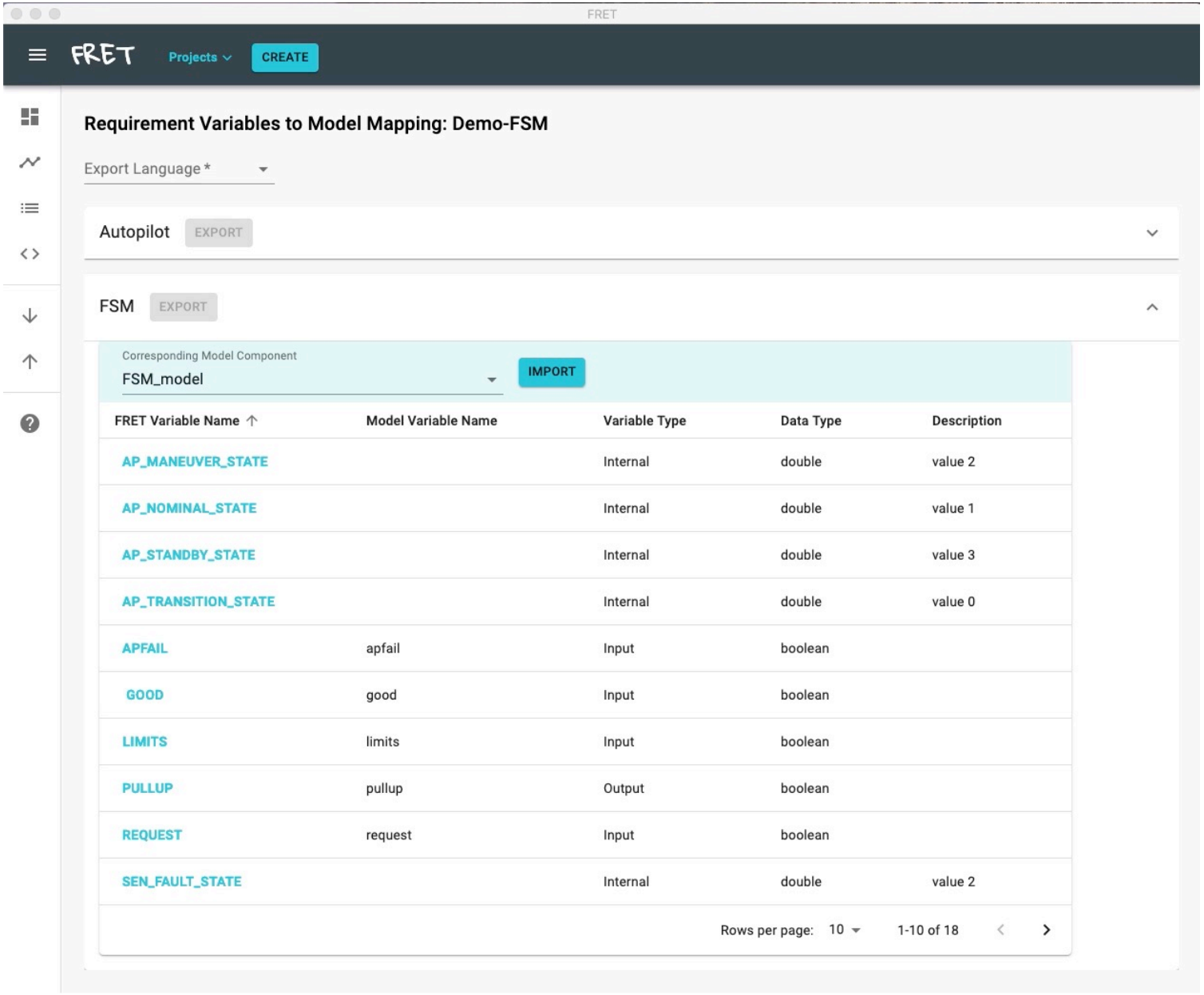
constructing proofs in PVS with NASA Langley

< > analysis portal

mapping requirement variables



exporting verification code



exporting verification code

FSMSpec.lus

```
--Historically node H(X:bool) returns (Y:bool); let Y = X -> (X and (pre Y));
--tel

--Y since inclusive X node SI(X,Y: bool) returns (Z:bool); let Z = Y and (X or
--(false -> pre Z)); tel

--Y since X node S(X,Y: bool) returns (Z:bool); let Z = X or (Y and (false ->
--pre Z)); tel

--Once node O(X:bool) returns (Y:bool); let Y = X or (false -> pre Y); tel

--Timed Once: less than or equal to N node OTlore(const N: int; X: bool;)
--returns (Y: bool); var C:int; let C = if X then 0 else (-1 -> pre C + (if pre
--C <0 then 0 else 1));

    Y = 0 <= C and C <= N; tel

--Timed Once: general case node OT(const L: int; const R: int; X: bool;) returns
--(Y: bool); var  D:bool; let D=delay(X, R); Y=OTlore(L-R, D); tel

-- Timed Historically: general case node HT(const L: int; const R: int; X:
-- bool;) returns (Y: bool); let Y = not OT(L, R, not X); tel

-- Timed Since: general case node ST(const L: int; const R: int; X: bool; Y:
-- bool;)  returns (Z: bool); let Z = S(X, Y) and OT(L, R, X); tel

-- Timed Since: general case node SIT(const L: int; const R: int; X: bool; Y:
-- bool;) returns (Z: bool); let Z = SI(X, Y) and OT(L, R, X); tel
```

A. Mavridou, H. Bourbouh, P.L. Garoche, D. Giannakopoulou, T. Pressburger, J. Schumann: **Bridging the Gap Between Requirements and Simulink Model Analysis.** REFSQ 2020

are my requirements consistent?

$$\text{Realizable}_{AG} \stackrel{\text{def}}{=} \exists s.\, G_I(s) \wedge \text{Viable}_{AG}(s)$$

there exists an initial state that is viable,

$$\text{Viable}_{AG}(s) \stackrel{\text{def}}{=} \forall a.\ (A(s,a) \Rightarrow \exists s'.\ G_T(s,a,s') \wedge \text{Viable}_{AG}(s'))$$

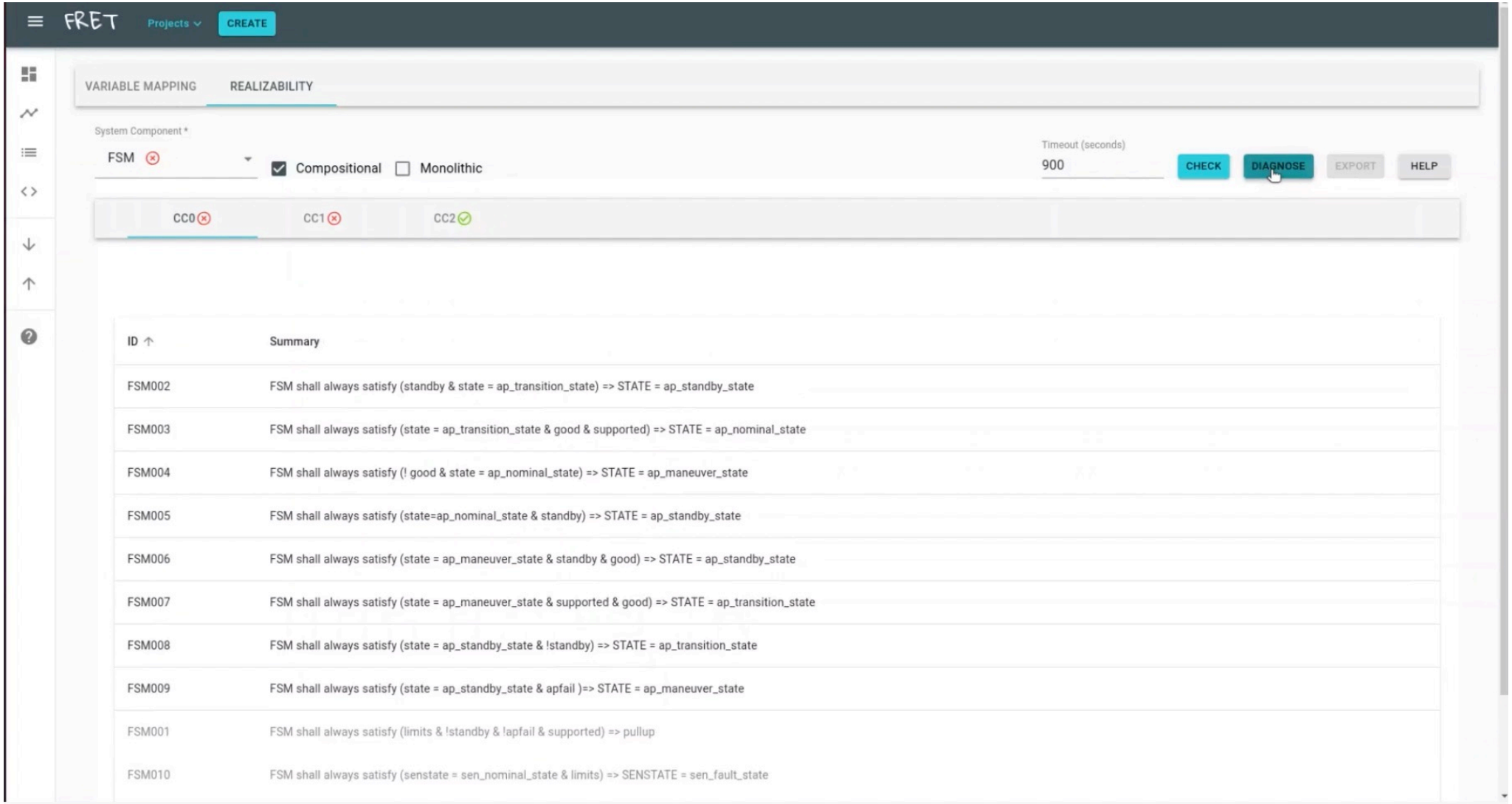
meaning that for each input that satisfies the assumptions of the contract, it is possible to transition to a viable state, without violating the contract

Andrew Gacek, Andreas Katis, Michael W. Whalen, John Backes, Darren D. Cofer:
Towards Realizability Checking of Contracts Using Theories. NFM 2015

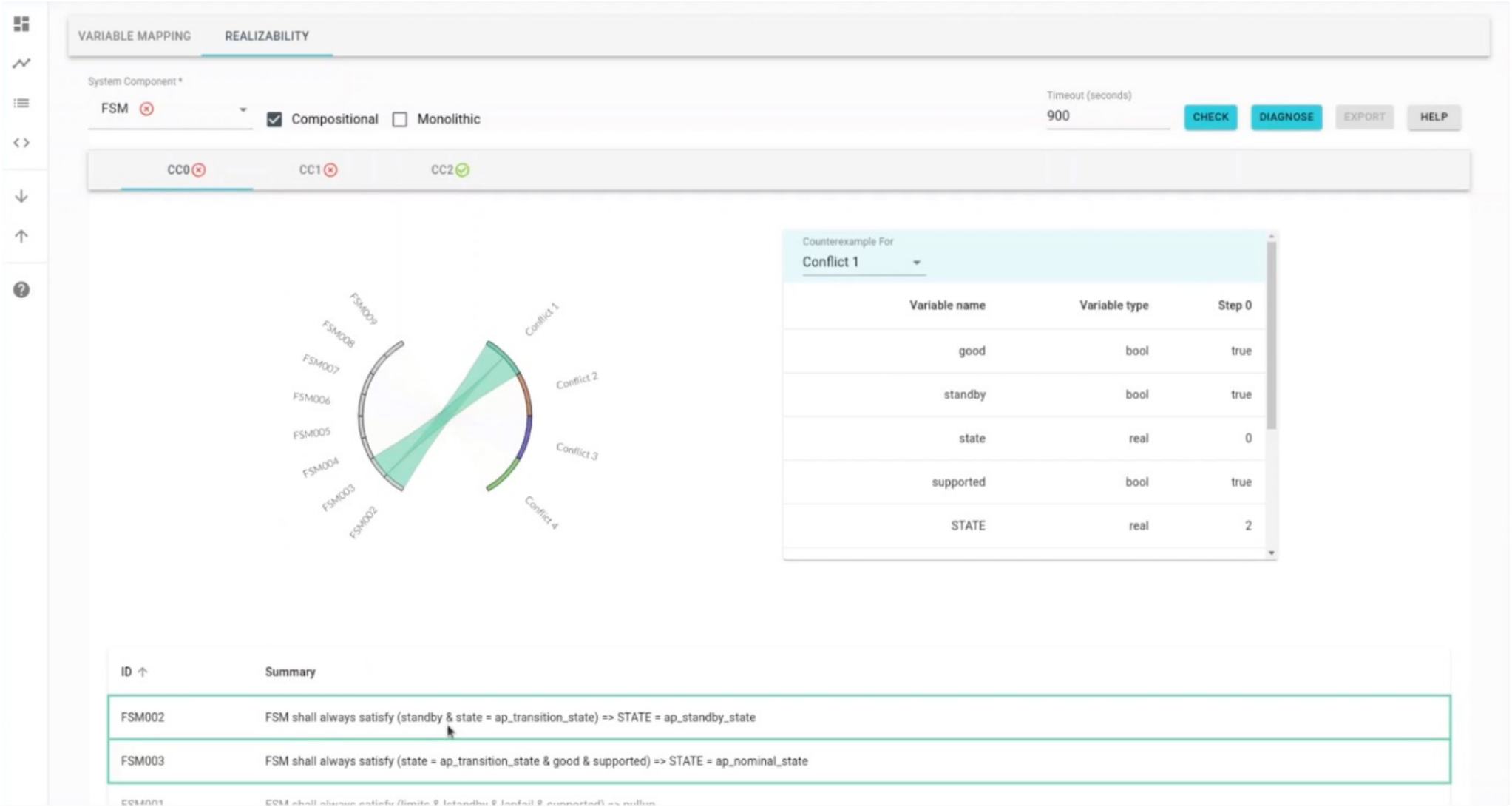
realizability in FRET

- uses variable mapping from analysis portal
- automatically decomposes realizability of a set of requirements into an equivalent set of smaller realizability problems
- computes “minimal conflicts”
- visualizes results

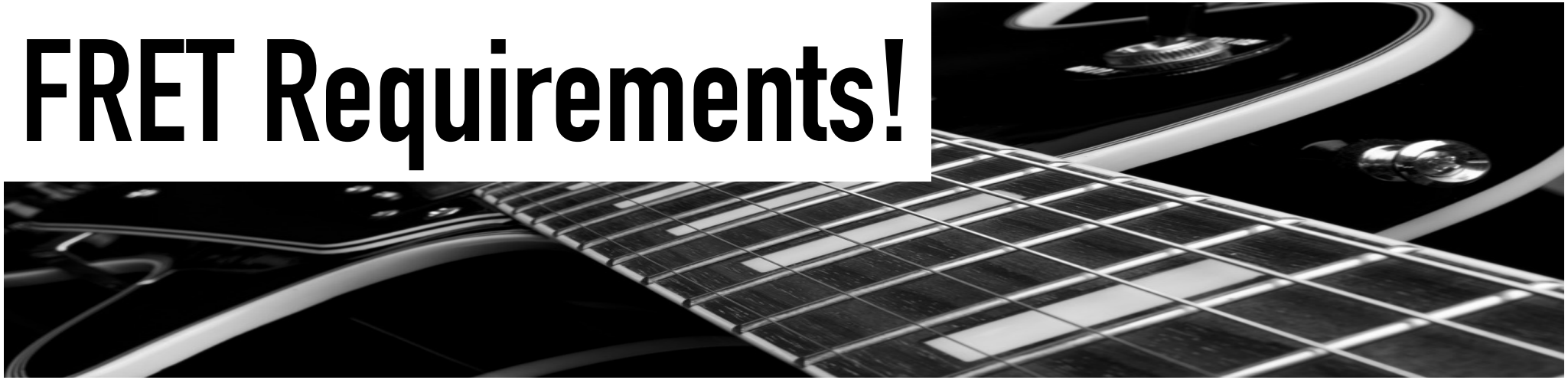
decompose / diagnose



understand conflicts



FRET Requirements!



solid foundations, extensible, sleek

focus on usability

FRET v2.0 coming soon

https://github.com/NASA-SW-VnV/fret

Dimitra Giannakopoulou, Thomas Pressburger, Anastasia Mavridou, Johann Schumann: *Automated Formalization of Structured Natural Language Requirements.* IST Journal, 2021

Aaron Dutle, César A. Muñoz, Esther Conrad, Alwyn Goodloe, Laura Titolo, Iván Pérez, Swee Balachandran, Dimitra Giannakopoulou, Anastasia Mavridou, Thomas Pressburger: *From Requirements to Autonomous Flight: An Overview of the Monitoring ICAROUS Project.* FMAS 2020

Anastasia Mavridou, Hamza Bourbouh, Dimitra Giannakopoulou, Thomas Pressburger, Mohammad Hejase, P-Loïc Garoche, Johann Schumann: *The Ten Lockheed Martin Cyber-Physical Challenges: Formalized, Analyzed, and Explained.* RE 2020

Dimitra Giannakopoulou, Thomas Pressburger, Anastasia Mavridou, Johann Schumann: *Generation of Formal Requirements from Structured Natural Language.* REFSQ 2020

Anastasia Mavridou, Hamza Bourbouh, Pierre-Loïc Garoche, Dimitra Giannakopoulou, Thomas Pressburger, Johann Schumann: *Bridging the Gap Between Requirements and Simulink Model Analysis.* REFSQ 2020