# Towards Refactoring FRETish Requirements\*

Marie Farrell Matt Luckcuck Oisín Sheridan Rosemary Monahan

Department of Computer Science, Maynooth University, Ireland valu3s@mu.ie

#### Abstract

Like software, requirements evolve and change frequently during the development process. Refactoring is the process of reorganising software without changing its behaviour, to make it easier to understand and modify. We propose refactoring for formalised requirements to reduce repetition in the requirement set so that they are easier to maintain as the system and requirements evolve. This work-in-progress paper describes our motivation for and initial approach to refactoring requirements in NASA's Formal Requirements Elicitation Tool (FRET). This work was directly triggered by our experience with an industrial aircraft engine software controller use case. In this paper, we reflect on the requirements that were obtained and, with a view to their maintainability, propose and outline functionality for refactoring FRETISH requirements.

## 1 Introduction and Background

Detailed requirements elicitation is an important step in the software development process. This often begins with a set of natural-language requirements, which then evolve as the project progresses, as additional functionality is added, and as bugs reveal unintended or unsafe system behaviour. For safety-critical systems, requirements can often be drawn from standards or regulator guidance, and verifying that the system's design and implementation preserve these requirements can be an integral part of securing approval to use the system.

Formal methods can provide robust verification that gives developers and regulators the confidence that the system functions correctly and safely. However, natural-language requirements can be difficult to express in the logical formalisms that formal methods use. Tools such as NASA's Formal Requirements Elicitation Tool (FRET) plug this gap by providing a structured natural requirements language (called FRETISH) that has an underlying temporal logic semantics, which can be used directly as input to formal methods tools [7].

Through examining recent work [3], we see that sets of natural-language requirements can contain many similar requirements, as well as dependencies between requirements. This makes the necessary task of maintaining the requirements tedious and error-prone, as the system and its requirements evolve.

In software engineering, refactoring is the process of improving the structure of the software without altering its functionality [6]. An example is using the EXTRACT METHOD refactoring, which extracts a large piece of code into a method, to simplify and modularise the program. This is often used when the same functionality is repeated throughout the program. Here we investigate how to use refactoring to simplify and modularise requirements.

We view the maintenance of a requirements set to have similar benefits to the maintenance of software, namely that the requirements can be modified more easily with a reduced potential for human error. The notion of refactoring requirements is not new and has been previously explored in [12]. Here, we introduce the idea for FRET through examining how refactoring can be applied to the FRETISH requirements for an aircraft engine controller system.

<sup>\*</sup>The authors thank Georgios Giantamidis, Stylianos Basagiannis, and Vassilios A. Tsachouridis (United Technologies Research Center, Ireland) for their collaboration in the requirements elicitation process; and Anastasia Mavridou (NASA Ames Research Center, USA) for her help with FRET. This research was financially supported by the European Union's Horizon 2020 research and innovation programme under the VALU3S project (grant No 876852). This project is also funded by Enterprise Ireland (grant No IR20200054). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

ID	Description
UC5_R_1	Under sensor faults, while tracking pilot commands, control objectives shall be satisfied (e.g.,
	settling time, overshoot, and steady state error will be within predefined, acceptable limits)
$UC5_R_2$	Under sensor faults, during regulation of nominal system operation (no change in pilot input),
	control objectives shall be satisfied (e.g., settling time, overshoot, and steady state error will be
	within predefined, acceptable limits)
$UC5_R_3$	Under sensor faults, while tracking pilot commands, operating limit objectives shall be satisfied
	(e.g., respecting upper limit in shaft speed)
$UC5_R_4$	Under sensor faults, during regulation of nominal system operation (no change in pilot input),
	operating limit objectives shall be satisfied (e.g., respecting upper limit in shaft speed)

Table 1: UC5\_R\_1–UC5\_R\_4 of the natural-language requirements for the aircraft engine controller. These 4 requirements are mainly concerned with continued operation of the controller in the presence of sensor faults [4].

Within the VALU3S project<sup>1</sup>, we elicited and formalised requirements for an aircraft engine software controller use case with our industrial partner [8, 4]. We are now constructing formal models of the system to verify the requirements against, and generating verification conditions from the requirements. At this stage, it is important that our FRETISH requirements are easy to maintain and update, should new or modified functionality be developed. As a result, we are devising an approach to refactoring these requirements to reduce repetition and aid the maintainability of the requirements set. We take inspiration from prior work on refactoring natural-language requirements [12] and apply it to formal requirements with an additional step to check that the refactored requirement preserves the meaning of its unrefactored counterpart.

This work-in-progress paper explores how formalised FRET requirements can be refactored, and illustrates our refactoring process via our industrial, aerospace use case.

### 2 Refactoring Requirements

This section provides an overview and brief analysis of the requirements that we elicited for the aircraft engine software controller use case (originally presented in [4]) and describes our approach to refactoring them.

### 2.1 Analysis: Aircraft Engine Controller Requirements

Previously, we presented 14 natural-language requirements for an industrial aircraft engine controller which we formalised using FRET [4]. Table 1 contains the first 4 of these requirements, which were constructed independently by our industrial partner. It was clear to us from the outset that these requirements were repetitive, for example the phrase 'Under sensor faults' appears in several requirements (4/14 in total).

To preserve traceability between the natural language requirements and their corresponding FRETISH encodings we opted for a one-to-one mapping, where each natural-language requirement corresponds to one (parent) requirement in FRETISH. FRETISH requirements have the following structure and fields:

scope condition component shall timing response Here, scope and timing are optional. Users specify a condition under which a component shall satisfy a response. For example the FRETISH encoding of UC5\_R\_1 is: if((sensorFaults)&(trackingPilotCommands)) Controller shall satisfy (controlObjectives). 'Under sensor faults' maps to the boolean sensorFaults, and the other requirements (Table 1) follow a similar structure.

Since we adopted a one-to-one mapping, the repetition of 'Under sensor faults' is mirrored by the repetition of sensorFaults in the FRETISH requirements. We refer to these repeated pieces as requirement fragments. We identified 7 fragments in our 14 abstract requirements, and each fragment was repeated in between 4 and 7 of the 14 requirements. Fig. 1 shows the dependencies between the requirements and specific fragments.

Once the high-level requirements were encoded in FRETISH, we elicited 28 detailed child requirements that expanded the definitions of the abstract terms in the 14 parent requirements [4]. UC5\_R\_1

<sup>&</sup>lt;sup>1</sup>https://valu3s.eu/

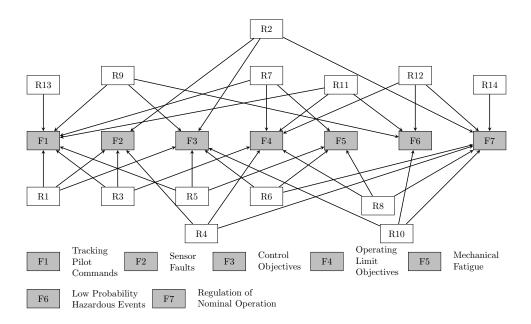


Figure 1: Dependency graph: arrows indicate a 'depends on' relationship between requirements (white boxes) and fragments (grey boxes).

ID	FRETISH
UC5_R_1.1	when $(diff(r(i), y(i)) > E) if((sensorValue(S) > nominalValue + R)   (sensorValue(S))$
	<pre>&lt; nominalValue - R)   (sensorValue(S) = null) &amp; (pilotInput =&gt; setThrust = V2) &amp;</pre>
	(observedThrust = V1)) Controller shall until $(diff(r(i), y(i)) < e)$ satisfy (settlingTime
	>= 0) & (settlingTime $<=$ settlingTimeMax) & (observedThrust = V2)
UC5_R_1.2	when $(diff(r(i), y(i)) > E) if((sensorValue(S) > nominalValue + R)   (sensorValue(S))$
	< nominalValue - R)   (sensorValue(S) = null)& (pilotInput => setThrust = V2) &
	(observedThrust = V1)) Controller shall until (diff(r(i),y(i)) < e) satisfy (overshoot
	>= 0) & (overshoot <= overshootMax) & (observedThrust = V2)
UC5_R_1.3	when $(diff(r(i), y(i)) > E) if((sensorValue(S) > nominalValue + R)   (sensorValue(S))$
	<pre>&lt; nominalValue - R)   (sensorValue(S) = null)&amp; (pilotInput =&gt; setThrust = V2)&amp;</pre>
	(observedThrust = V1)) Controller shall until $(diff(r(i), y(i)) < e)$ satisfy (steadyStateError
	>= 0) & (steadyStateError $<=$ steadyStateErrorMax) & (observedThrust = V2)

Table 2: Three distinct child requirements for UC5\_R\_1 capture the correct behaviour with respect to each of settling time, overshoot and steady state error.

has 3 child requirements (Table 2). Each of these contains the expanded, more detailed definition of sensorFaults:

```
(sensorValue(S) > nominalValue + R) | (sensorValue(S) < nominalValue - R) |
(sensorValue(S) = null)</pre>
```

As expected, this repetition of definitions in the child requirements makes the requirements set more difficult to maintain, because changes to the definition of one fragment cause updates in multiple places. For example, if the definition of sensorFaults were to change, as it did during the elicitation process, then 8 of the 28 child requirements would require updating. This process is time-consuming, tedious, and error prone. A better approach would be to update the definition of sensorFaults in one place and avoid this duplication of effort.

sensorFaults corresponds to one detailed clause in each child requirement, but this was not the case for all fragments. For example, trackingPilotCommands corresponds to a condition (when (diff(r(i), y(i)) > E)) and a timing constraint (until (diff(r(i), y(i)) < e)). An automatic approach to refactoring FRETISH requirements would be even more helpful in similar situations where an abstract requirement corresponds to multiple detailed clauses.

Next, we outline our approach to refactoring FRETISH requirements, taking inspiration from prior work on refactoring natural-language requirements.

#### 2.2 Refactoring Requirements

We briefly show how we specialise the classical refactoring, EXTRACT METHOD [6], to requirements. EXTRACT METHOD extracts code into a method, so that it can be called rather than copying code snippets. Our specialisation is based on the EXTRACT REQUIREMENT refactoring in [12]; but with an extra step, facilitated by FRET's automatic translation of requirements to temporal logic.

We begin by creating a new requirement to contain the behaviour that we wish to extract. We then replace the extracted behaviour in the original requirement with a reference to the new one. Finally, we check that the restructuring has not altered the behaviour of the original requirement, and we propagate this change throughout the requirements set.

EXTRACT REQUIREMENT allows us to define the sensorFaults fragment in one place. Then, individual requirements essentially 'call' the fragment in a similar way to method calls in object oriented programming languages. Supporting this 'calling' capability in FRET is part of our current work.

We chose FRET because it facilitates the formal verification that an implementation obeys its requirements. We intend to translate FRETISH requirements into other formalisms for verification [8]; so it is important that they are easy to maintain, if and when formal methods tools find problems in the system.

When refactoring the FRETISH encodings of requirements we can formally verify that the refactoring preserves the semantics of the original requirements. The Linear-time Temporal Logic (LTL) representation FRET generates enables us to perform the 'compile and test' step that is included in software refactoring [6] but not previously addressed for refactoring natural-language requirements [12].

### 3 Towards FRET-Supported Refactoring

FRET does not currently support refactoring. This section outlines our initial investigations into how automatic refactoring functionality could be included.

FRET requirements are not aware of one another. For example, although a requirement might depend on another it cannot *call the* other requirement in the way that a program can call a method. Requirements can be linked by a parent-child relationship but this is superficial at present, although it is useful from a user-perspective for maintaining traceability as requirements evolve.

We propose an additional requirement type, called FRAGMENT, that can be called from other requirements. This will involve updating the FRET interface and will lead to minor modifications to the generation of LTL specifications. FRET uses an in-built bank of templates to generate the LTL semantics for each requirement [7]. Templates take the form: [<scope-option>, <condition-option>, <timing-option>]. Since each FRAGMENT will be a specialised requirement, each will produce a template. When generating the LTL semantics for a requirement that references a FRAGMENT, it will be necessary to combine the templates of the FRAGMENT and the requirement to produce a complete template.

In general we think that combining templates can be achieved by taking the union of the *scope*, *condition*, and *timing* fields (respectively). However, we can also see specific situations where this simple approach might fail; e.g., if we combine two distinct timing options, should they be summed or should one take precedence (if so, which one)? We leave this investigation as future work.

Users should be able to refactor existing requirements *and* create fragments from scratch. Refactoring existing requirements could be realised, similarly to refactoring code in Eclipse<sup>2</sup>, by selecting the part of a requirement to become a FRAGMENT and selecting (from a context-menu) that it should be extracted. The FRET interface should also provide the option to 'create FRAGMENT'.

When refactoring existing requirements, FRET should check that the original and refactored requirements (including the extracted FRAGMENT(s)) are equivalent. FRET already checks the equivalence of the past- and future-time LTL for each requirement, this step performs a similar check between requirements.

FRET links to the CoCoSim [2] and Copilot [11] verification tools. The translations to these tools would now require an extra step to address refactored requirements. A naive approach would involve recombining the fragments, effectively 'unrefactoring' the requirement. This would be hidden from the user, with the fully expanded requirement only appearing in the generated verification conditions.

<sup>&</sup>lt;sup>2</sup>Eclipse: https://www.eclipse.org/ide/.

However, if the user wanted to edit the generated conditions, the original problems with repetition in the requirements would reappear.

A more sophisticated approach would carry the refactoring relationship through to the generated conditions. For example, in CoCoSim, guarantees would be generated corresponding to the fragments, but investigating how these guarantees are combined whilst preserving the semantics of the requirement is future work.

### 4 Conclusion

This paper presents our work-in-progress on refactoring FRET requirements, which is directly motivated by our specification of an industrial aircraft engine controller use case. We demonstrated that repetition in natural-language requirements can cause difficulty when maintaining a set of corresponding formalised requirements, and presented an approach to refactoring requirements that extends an existing approach in the literature. We have also outlined how we intend to implement this in FRET as future work.

Other FRET studies have not encountered such a strong need for refactoring [1, 9, 5]. However, these do not directly involve an industry partner throughout the requirements elicitation and formalisation process. Our study is unique, since it is the first published use of FRET in an industrial case study where development of the system is ongoing [4]. That said, recent FRETISH requirements for a liquid mixer [10] exhibit some repetition, so may benefit from our refactoring approach. Investigating refactoring for FRET in other use cases is an important avenue of future work.

### References

- Bourbouh, H., Farrell, M., Mavridou, A., Sljivo, I., Brat, G., Dennis, L.A., Fisher, M.: Integrating formal verification and assurance: An inspection rover case study. In: NASA Formal Methods Symposium. pp. 53–71. Springer (2021)
- [2] Bourbouh, H., Garoche, P.L., Loquen, T., Noulard, É., Pagetti, C.: CoCoSim, a code generation framework for control/command applications An overview of CoCoSim for multi-periodic discrete Simulink models. In: European Congress on Embedded Real Time Software and Systems (2020)
- [3] Deshpande, G., Arora, C., Ruhe, G.: Data-driven elicitation and optimization of dependencies between requirements. In: International Requirements Engineering Conference. pp. 416–421. IEEE (2019)
- [4] Farrell, M., Luckcuck, M., Sheridan, O., Monahan, R.: FRETting about Requirements: Formalised Requirements for an Aircraft Engine Controller. In: International Conference on Requirements Engineering: Foundation for Software Quality. To appear (2022)
- [5] Farrell, M., Mavrakis, N., Ferrando, A., Dixon, C., Gao, Y.: Formal Modelling and Runtime Verification of Autonomous Grasping for Active Debris Removal. Frontiers in Robotics and AI (2022)
- [6] Fowler, M., Beck, K.: Refactoring: improving the design of existing code. The Addison-Wesley object technology series, Addison-Wesley (1999)
- [7] Giannakopoulou, D., Pressburger, T., Mavridou, A., Schumann, J.: Automated formalization of structured natural language requirements. Information and Software Technology 137 (2021)
- [8] Luckcuck, M., Farrell, M., Sheridan, O., Monahan, R.: A Methodology for Developing a Verifiable Aircraft Engine Controller from Formal Requirements. In: IEEE Aerospace Conference. To appear (2022)
- [9] Mavridou, A., Bourbouh, H., Giannakopoulou, D., Pressburger, T., Hejase, M., Garoche, P.L., Schumann, J.: The ten lockheed martin cyber-physical challenges: formalized, analyzed, and explained. In: International Requirements Engineering Conference. pp. 300–310. IEEE (2020)

- [10] Mavridou, A., Katis, A., Giannakopoulou, D., Kooi, D., Pressburger, T., Whalen, M.W.: From partial to global assume-guarantee contracts: Compositional realizability analysis in fret. In: International Symposium on Formal Methods. pp. 503–523. Springer (2021)
- [11] Perez, I., Dedden, F., Goodloe, A.: Copilot 3. Tech. rep., NASA/TM-2020-220587, National Aeronautics and Space Administration (2020)
- [12] Ramos, R., Piveta, E.K., Castro, J., Araújo, J., Moreira, A., Guerreiro, P., Pimenta, M.S., Price, R.T.: Improving the Quality of Requirements with Refactoring. In: Simpósio Brasileiro de Qualidade de Software. pp. 141–155. Sociedade Brasileira de Computação (2007)