Introduction

EECS4315 Z:
Mission-Critical Systems
Winter 2025

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Learning Outcomes

This module is designed to help you understand:

- ***Mission***-Critical Systems vs. ***Safety***-Critical Systems
- **Code of Ethics** for Professional Engineers
- What a ***Formal Method*** Is
- ***Verification*** vs. ***Validation***
- Catching **Defects**: When?
- ***Model***-Based Development: EECS3342 vs. EECS4315

What is a Safety-Critical System (SCS)?

- A *safety-critical system (**SCS**)* is a system whose ***failure*** or ***malfunction*** has one (or more) of the following consequences:
  - death or serious injury to **people**
  - loss or severe damage to **equipment/property**
  - harm to the **environment**
- Based on the above definition, do you know of any systems that are ***safety-critical***?

Professional Engineers: Code of Ethics

- *Code of Ethics* is a basic guide for ***professional conduct*** and imposes duties on practitioners, with respect to **society**, **employers**, **clients**, **colleagues** (including employees and subordinates), the **engineering profession** and him or herself.
- It is the duty of a practitioner to act at all times with,
  1. ***fairness*** and ***loyalty*** to the practitioner's associates, employers, clients, subordinates and employees;
  2. ***fidelity*** (i.e., dedication, faithfulness) to public needs;
  3. devotion to ***high ideals*** of personal honour and professional integrity;
  4. ***knowledge*** of developments in the area of professional engineering relevant to any services that are undertaken; and
  5. ***competence*** in the performance of any professional engineering services that are undertaken.
- Consequence of misconduct?
  - ***suspension*** or ***termination*** of professional licenses
  - civil ***law suits***

Source: PEO's Code of Ethics

Developing Safety-Critical Systems

Industrial standards in various domains list *acceptance criteria* for **mission**- or **safety**-critical systems that practitioners need to comply with: e.g.,

- ***Aviation*** Domain: ***RTCA DO-178C*** "*Software Considerations in Airborne Systems and Equipment Certification*"
- ***Nuclear*** Domain: ***IEEE 7-4.3.2*** "*Criteria for Digital Computers in Safety Systems of Nuclear Power Generating Stations*"

Two important criteria are:

1. System ***requirements*** are precise and complete
2. System ***implementation*** conforms to the requirements

But how do we accomplish these criteria?

Safety-Critical vs. Mission-Critical?

- ***Critical***:

  A task whose successful completion ensures the success of a larger, more complex operation.

  e.g., Success of a pacemaker $\Rightarrow$ Regulated heartbeats of a patient
- ***Safety***:

  Being free from danger/injury to or loss of human lives.
- ***Mission***:

  An operation or task assigned by a higher authority.

  Q. Formally relate being ***safety***-critical and ***mission***-critical.

  A.
  - ***safety***-critical $\Rightarrow$ ***mission***-critical
  - ***mission***-critical $\not\Rightarrow$ ***safety***-critical
- Relevant industrial standard: ***RTCA DO-178C*** (replacing RTCA DO-178B in 2012) "*Software Considerations in Airborne Systems and Equipment Certification*"

Source: Article from OpenSystems

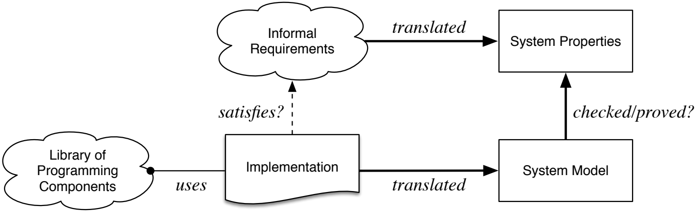
Using Formal Methods for Certification

- A ***formal method (FM)*** is a ***mathematically rigorous*** technique for the specification, development, and verification of software and hardware systems.
- ***DO-333*** "*Formal methods supplement to DO-178C and DO-278A*" advocates the use of formal methods:

  *The use of **formal methods** is motivated by the expectation that, as in other engineering disciplines, performing appropriate **mathematical analyses** can contribute to establishing the **correctness** and **robustness** of a design.*

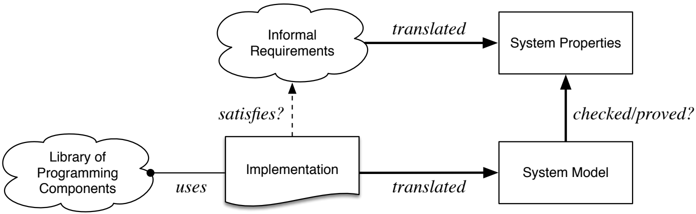
- FMs, because of their mathematical basis, are capable of:
  - *Unambiguously* describing software system requirements.
  - Enabling *precise* communication between engineers.
  - Providing ***verification (towards certification) evidence*** of:
    - A ***formal*** representation of the system being *healthy*.
    - A ***formal*** representation of the system *satisfying* *safety properties*.

Verification: Building the Product Right?



- ***Implementation*** built via ***reusable programming components***.
- *Goal* : *Implementation Satisfies Intended Requirements*
- To verify this, we ***formalize*** them as a ***system model*** and a set of (e.g., safety) ***properties***, using the specification language of a theorem prover (EECS3342) or a model checker (EECS4315).
- Two Verification Issues:
  1. Library components may ***not behave as intended***.
  2. Successful checks/proofs ensure that we *built the product right*, with respect to the informal requirements. **But**...

Validation: Building the Right Product?



- Successful checks/proofs $\not\Rightarrow$ We ***built the right product***.
- The target of our checks/proofs may not be valid:

  The requirements may be ***ambiguous***, ***incomplete***, or ***contradictory***.
- Solution: ***Precise Documentation*** [EECS4312]

Catching Defects – When?

- To minimize *development costs*, minimize *software defects*.
- Software Development Cycle:

  Requirements → *Design* → *Implementation* → Release

  Q. Design or Implementation Phase?

  Catch defects *as early as possible*.

Design and architecture	Implementation	Integration testing	Customer beta test	Postproduct release
1X*	5X	10X	15X	30X

  ∵ The cost of fixing defects *increases exponentially* as software progresses through the development lifecycle.
- Discovering *defects* after **release** costs up to 30 times more than catching them in the **design** phase.
- Choice of a *design language*, amendable to ***formal verification***, is therefore critical for your project.

Source: IBM Report

Model-Based Development in EECS3342

- ***Modelling*** and ***formal reasoning*** should be performed **before** implementing/coding a system.
  - A system's ***model*** is its ***abstraction***, filtering irrelevant details.

    A system ***model*** means as much to a software engineer as a ***blueprint*** means to an architect.
  - A system may have a list of ***models***, "sorted" by **accuracy**:

    $$\langle m_0, m_1, \ldots, \boxed{m_i}, \boxed{m_j}, \ldots, m_n \rangle$$

    - The list starts by the most ***abstract*** model with least details.
    - A more ***abstract*** model $\boxed{m_i}$ is said to be ***refined by*** its subsequent, more ***concrete*** model $\boxed{m_j}$.
    - The list ends with the most ***concrete/refined*** model with most details.
  - It is far easier to reason about:
    - a system's ***abstract*** models (rather than its full ***implementation***)
    - ***refinement steps*** between subsequent models
- The final product is ***correct by construction***.

Model-Based Development in EECS4315

- ***Modelling*** and ***formal reasoning*** should be performed **before** implementing/coding a system.
  - A system's ***model*** is its ***abstraction***, filtering irrelevant details.

    A system ***model*** means as much to a software engineer as a ***blueprint*** means to an architect.
- A design ***model*** m specified at the "right" level of ***abstraction***:

  State space **not** causing a ***state explosion***.
  - m is checked against ***invariant*** and ***temporal*** properties.
  - m may be added with more details (e.g., variables) to result in a more "refined" model m'.
  - m' is consistent with (or "refines") m as long as:
    - **No** ***combinatorial explosion*** from variable ranges
    - **All** properties that m passes also pass in m'.

TLA+: An Industrial Strength Toolbox

From `https://lamport.azurewebsites.net/tla/tla.html`:

> *TLA+ (**Temporal Logic of Actions**) is a **high-level language** for modeling programs and systems–especially concurrent and distributed ones.*
> *It's based on the idea that the best way to describe things precisely is with **simple mathematics**.*
> *TLA+ and its tools are useful for eliminating fundamental **design errors**, which are hard to find and expensive to correct in code.*

> TLA+ is a language for modeling ***software*** above the code level and ***hardware*** above the circuit level.
> It has an ***IDE*** (Integrated Development Environment) for writing models and running tools to check them. The tool most commonly used by engineers is the ***TLC model checker***, but there is also a proof checker.
> TLA+ is based on mathematics and does not resemble any programming language. Most engineers will find *PlusCal*, described below, to be the easiest way to start using TLA+.

Beyond this lecture . . .

- The ***TLA+ toolbox*** has been report about its use in industry: `https://lamport.azurewebsites.net/tla/industrial-use.html`
- Two papers have been made available on eClass:
  - Newcombe, C. ***Why Amazon Chose TLA+***. In *Abstract State Machines, Alloy, B, TLA, VDM, and Z*, pp 25 – 39. Springer (2014).
  - Newcombe, C., Rath, T., Zhang, F., Munteanu, B., Brooker, M., Deardeuff, M. ***How Amazon Web Services Uses Formal Methods***. In *Communications of the ACM*, 58(4), pp 66 – 73. ACM (2015).
- You're encouraged to read them first: we will guide you through some highlights later in the course (after you've gained experience on the TLA+ toolbox).

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