

Introduction



EECS4315 Z:
Mission-Critical Systems
Winter 2023

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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

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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**?

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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**

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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?

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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**.

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Safety-Critical vs. Mission-Critical?

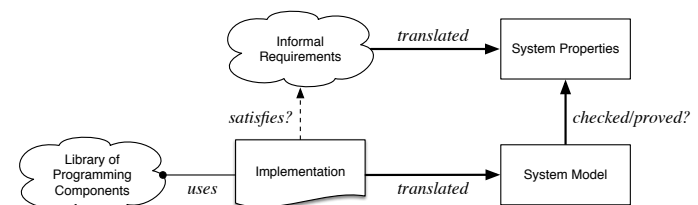


- **Critical:**
A task whose successful completion ensures the success of a larger, more complex operation.
e.g., Success of a pacemaker \Rightarrow Regulated heartbeats of a patient
- **Safety:**
Being free from danger/injury to or loss of human lives.
- **Mission:**
An operation or task assigned by a higher authority.
Q. Formally relate being **safety-**critical and **mission-**critical.
A.
 - **safety-**critical \Rightarrow **mission-**critical
 - **mission-**critical \nRightarrow **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](#)

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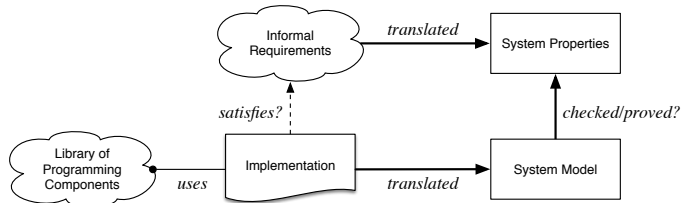
Verification: Building the Product Right?



- **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...**

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Validation: Building the Right Product?



- o Successful checks/proofs \nRightarrow We **built the right product**.
- o The target of our checks/proofs may not be valid:
The requirements may be **ambiguous**, **incomplete**, or **contradictory**.
- o Solution: **Precise Documentation** [EECS4312]

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Model-Based Development in EECS3342



- **Modelling** and **formal reasoning** should be performed **before** implementing/coding a system.
 - o 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.
 - o A system may have a list of **models**, "sorted" by **accuracy**:

$$\langle m_0, m_1, \dots, m_i, m_j, \dots, m_n \rangle$$
 - The list starts by the most **abstract** model with least details.
 - A more **abstract** model m_i is said to be **refined by** its subsequent, more **concrete** model m_j .
 - The list ends with the most **concrete/refined** model with most details.
 - o 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**.

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Catching Defects – When?



- To minimize **development costs**, minimize **software defects**.
- Software Development Cycle:
Requirements \rightarrow **Design** \rightarrow **Implementation** \rightarrow 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

- \therefore 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

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Model-Based Development in EECS4315



- **Modelling** and **formal reasoning** should be performed **before** implementing/coding a system.
 - o 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**.
 - o m is checked against **invariant** and **temporal** properties.
 - o m may be added with more details (e.g., variables) to result in a more "refined" model m' .
 - o 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' .

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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+.

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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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TLA+: An Industrial Strength Toolbox

Beyond this lecture ...

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