Essential Technical Processes and Methods for Systems Architecture

Lecture 19

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Summary of Processes and Methods

System Definition is concerned with how elements associated with a system can be defined in terms of functionality (purpose), behaviour, . These can be specified in terms of properties of and relations between the elements.

Architecture Definition is concerned with defining the structures associated with a system and its properties; relations amongst the structures, synthesis and normalisation; and interfaces between the system elements.

Architecture Implementation is concerned with (i) how the structures associated with a system respond under intended and alternative conditions, (ii) how control structures can be used for precise implementation of responses.

The output of the processes is a robust architecture specification that enables system design[1]: a software architecture that can be deployed to software developers; component specifications and interface definitions for system developers; and an implementation model for deployment to state machines (which will define how structures associated with the system change state in response to the occurrences of events).

[1] Recall that Steve Jobs recommended that [architecture and] design should engineer software and hardware concurrently.

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Mapping the 7 Principles[1] to Key Lectures

Conceptual Integrity	→ ***Starting in Lecture 24-00 (ToR)***
Role of the Architect	→ ***Starting in Lecture 24-00 (ToR)***
Principle of Definition	→ ***Lectures 24-02,-07 (S&TP I, II)***
Structured Analysis	→ ***Lecture 24-03 (Methods I)***
Structured Design	→ ***Lecture 24-08 (Methods II)***
Reflection of Structure	→ ***Lecture 24-13a (ROSETTA)***
Model Transformation	→ ***Lectures 24-03,-08 (Methods I, II)*** ***Lecture 24-13b (Maths DSIG)***

[1] Refer to p.*xxi* of *Essential Architecture and Principles of Systems Engineering*

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The Role of a System Architect

The role is succinctly expressed by Brooks*:

"The architect should be responsible for the conceptual integrity of all aspects of the product perceivable by the user."

"Conceptual integrity is the most important consideration in system design."

The System Architect's role complements engineering.

*Frederick Brooks, *The Mythical Man Month 1995*

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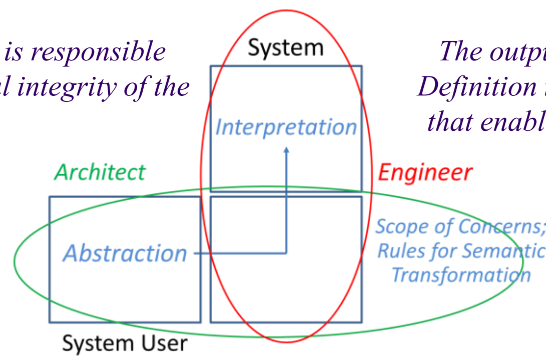
Thinking like a System Architect
The Role of Architecture in System Design

The Architect Interprets Concepts into System Structures.

The Architect is responsible for conceptual integrity of the system. [1]

*The output of Architecture Definition is a **specification** that enables system design.*



The specification must include system requirements that meet customer and user needs.

[1] *Conceptual integrity is accomplished by model specification and transformation .*

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Model Specification and Transformation for System Architecture and Design

Key Concepts

Models of Definitions

Relational Structures

Interpretation of Concepts

Transformation of Models

Processes & Methods

Definition Processes

Structured Methods

Wrap Up

Precise yet intuitive definitions and language are required for the successful engineering of systems.

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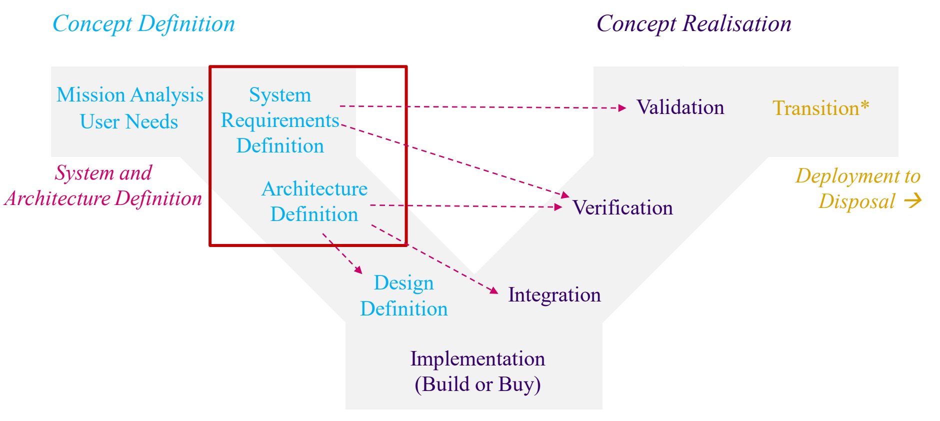
Definition Process Alignment to ISO/IEEE/IEC Technical Process and the Vee



*Transition to the customer is followed by Operation, Maintenance, and Disposal

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A Fundamental Principle

- **Principle of Definition**
  - ***One needs both a formal definition of a design for precision, and a prose definition for comprehensibility.****
- Levels of Precision
  - Formalisms (e.g. the Predicate Calculus) are the most precise.
  - Graphical languages can be more intuitive but may not be formal.
- Models
  - In software and systems engineering practices, a model is generally considered to be an abstraction that represents a system.
  - But the term *model* can also be given formal definitions.

*Brooks, *Mythical Man-Month*, p.234, 6.3

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Models in Science and Logic

Conceptual Integrity has Consistency and Completeness

- Stephen Hawking attributed a good model to be
  - Simple
  - Mathematically correct
  - Experimentally verifiable
- By analogy a model of a concept that has been expressed in language (e.g. a sentence*) must be
  - Simple
  - Logically well-formed and consistent
  - Verifiable through interpretation

The System Architect expresses concepts in models.

*Modelling as presented here is motivated by the meaning of models in the predicate calculus [see, e.g. J. L. Bell, *Models and Ultraproducts*].

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What is Engineering?

A Model Based Viewpoint

Engineering is a practice of concept realization in which relations between *structure* and *functionality* are *modelled* using the laws of science for the purpose of solving a problem or exploiting an opportunity.

Science and scientific methods bring models and repeatability to the development and production of marketable items.

Models are interpretation of language into structures.

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What is System Architecture?

- Essential Definition of a System*:

  A system is a set of interrelated elements that comprise [form] a whole, together with an environment.

- Essential Definition of Architecture*:

  Architecture is structural type in conjunction with consistent properties that can be implemented in a class of structure of that type.

A *System* is a pairing of two sets of elements (*S, E*) that are coupled.

***Architecture* is a pairing (*Structural Type, Properties*) that is coupled. For example, a system boundary partitions elements of interest into two distinct sets of elements (*S, E*). 'Partition' is a *structural type*.**

*Refer to *EA&PSE* Chapter 3 and to Bertalanffy, *General Systems Theory* 1969; and the IEEE paper, 'Architecture Definition in Complex System Design Using Model Theory', 2021.

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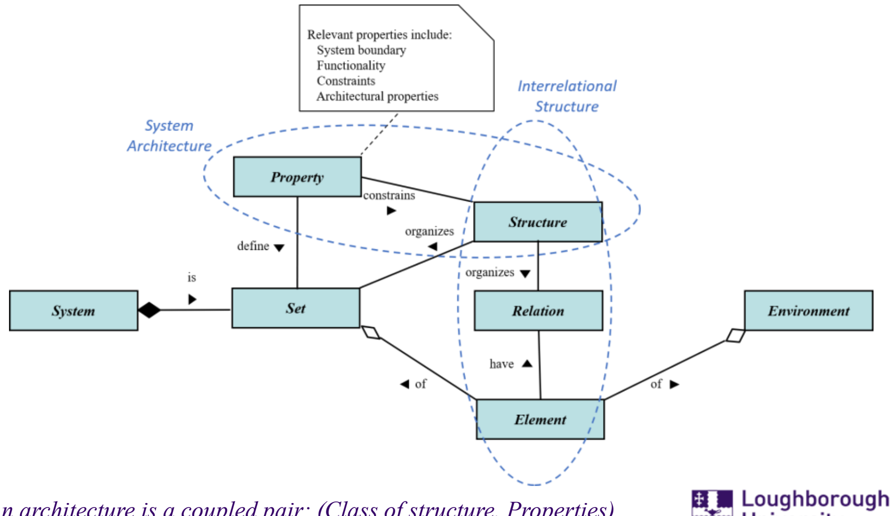
Logical Model: *Second order Nature of System Architecture*



An architecture is a coupled pair: (Class of structure, Properties).
A system is coupled pair of sets: (S, E).

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Essential System and Architecture Definition

- System (including Requirements) Definition:[1]
  - Boundary definition: system and environment elements
  - Functional definition
    - Functional, performance, and non-functional requirements
    - Traceability of system to stakeholder requirements
  - System decomposition
- Architecture Definition:[1]
  - Concept definition: theories about and properties of the system
  - Specification of structures in which concepts are realised [2]
  - Synthesis and normalisation of relations and interrelations
  - Define interactions and interfaces between elements

[1] These features have been distilled from ISO/IEC/IEEE 15288 and the essential definitions.
[2] i.e., interpreted into the structures

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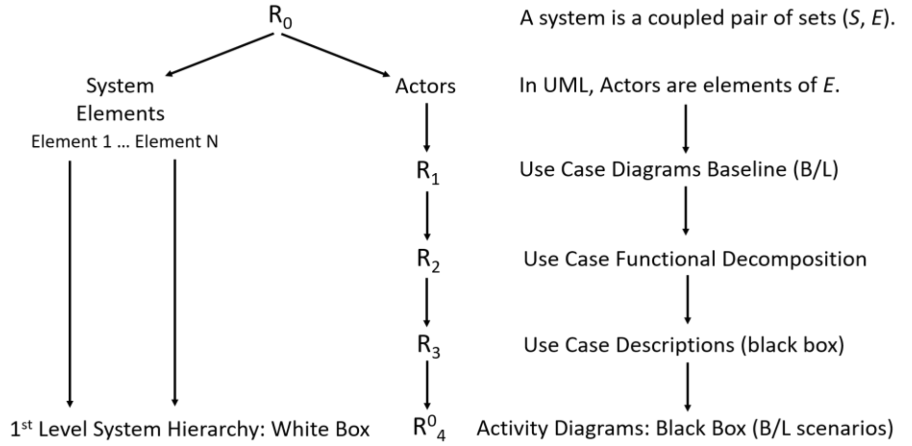
Structures for System Definition (S&TP I)

*One iteration through the definition process**



**As presented in S&TP I, a second iteration is applied to system elements. In Tutorial I this resulted in both system and system element level activity diagrams that were normalised.*

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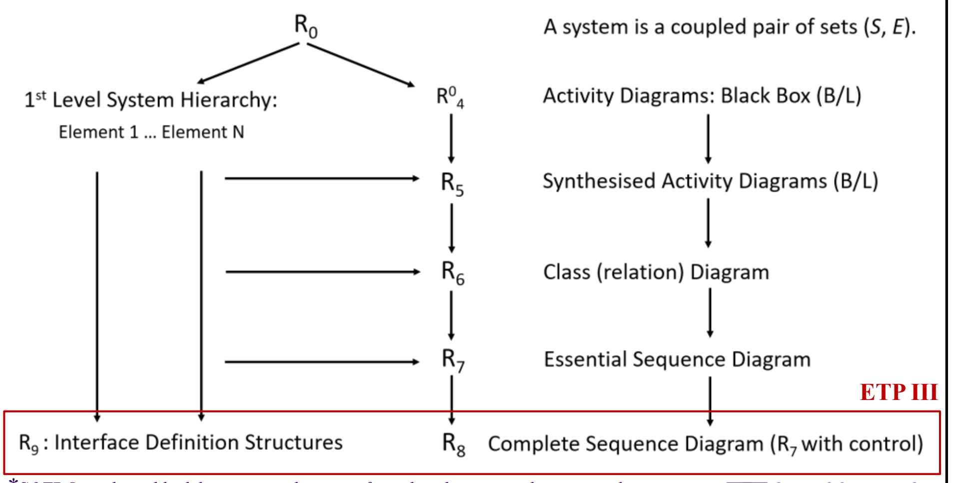
Essential Technical Processes (S&TP) II, III

Structures for the Implementation Model: R_6, R_8, R_9



**S&TP I results in black box activity diagrams for either the system elements or the system as a whole. These must be synthesised into the R_5 structure. S&TP II then synthesises these with R_6 to form R_7. Semantic transformation admit a bottom-up process via inverses.*

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Specifying Structures for Technical Processes:

*Model-based Essential Architecture Definition**

- Architecture Definition based on model theory defines:
  - A sequence of concepts (statements), T = (T_0, T_1, T_2, …, T_n)
  - A sequence of structures, A_R = (R_0, R_1, R_2, …, R_n)
  - The concepts are theories about the system (e.g. properties)
  - Each concept T_i is a theory relevant to the structure R_i
  - The result of interpreting a concept into a structure is *a model*
- Transformations are then needed to join the structures
  - *Semantic transformation* defines relations between structures
  - In this pairing of structures, i.e. (R_{i-1}, R_i), the sequence A_R becomes an interrelational structure on the elements in *S, E*.
  - UML graphical models can serve as the relevant structures

*Refer to Dickerson, Wilkinson et al., "Architecture Definition in Complex System Design Using Model Theory," in the *IEEE Systems Journal*, 2021.

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Model Specification and Transformation for System Architecture and Design

Key Concepts

Models of Definitions

Relational Structures

Interpretation of Concepts

Transformation of Models

Processes & Methods

Definition Processes

Structured Methods

Wrap Up

System and Architecture Definition can be implemented by a sequence of transformations of models.

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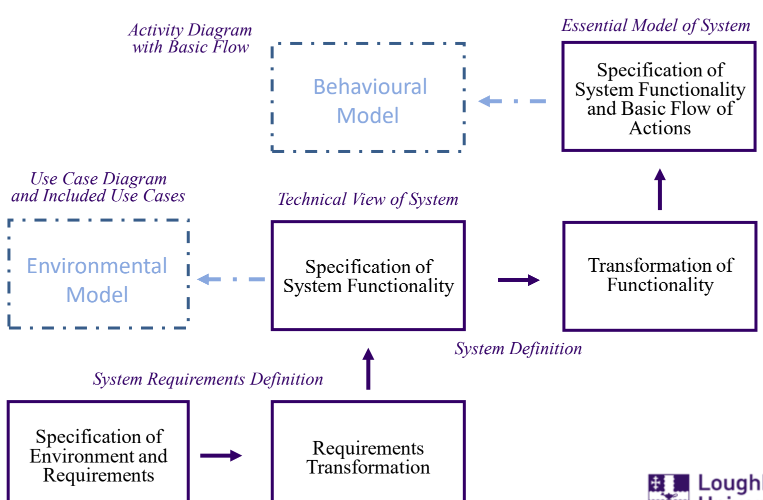
A Framework for Structured Analysis



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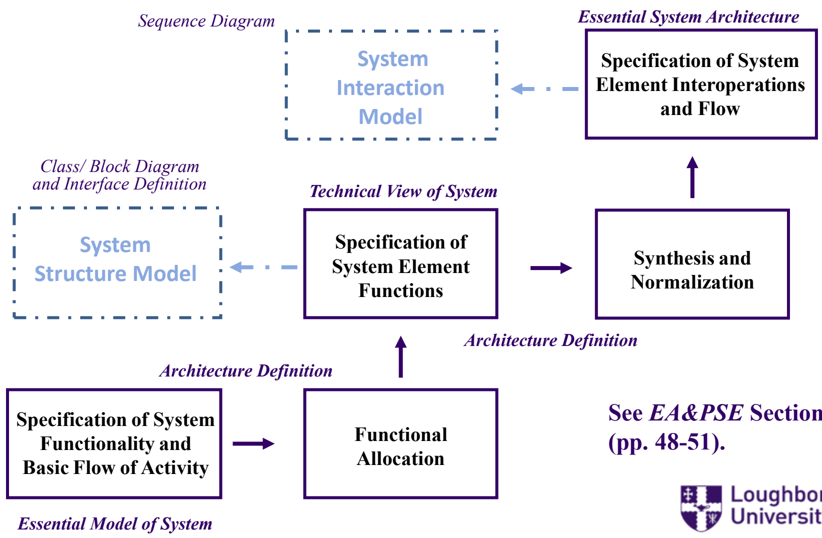
A Framework for Structured Design



See *EA&PSE* Section 4.3 (pp. 48-51).

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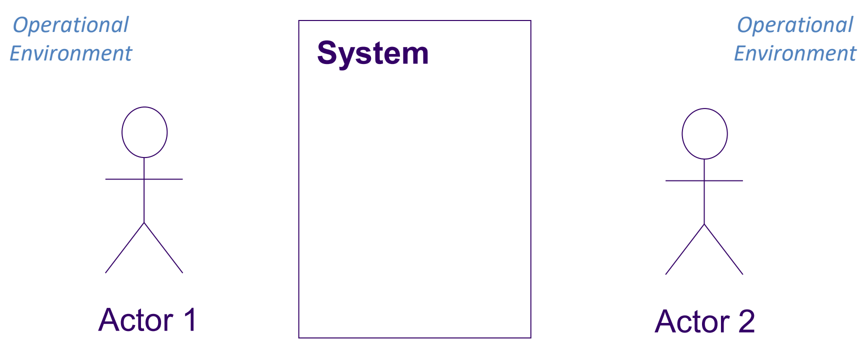
Use Case Diagram: System Boundary
Syntax and Semantics of Partition Structure



Elements of the environment are separated from those of the system. The diagram defines those elements that <u>are in</u> the environment but <u>are not in</u> the system.

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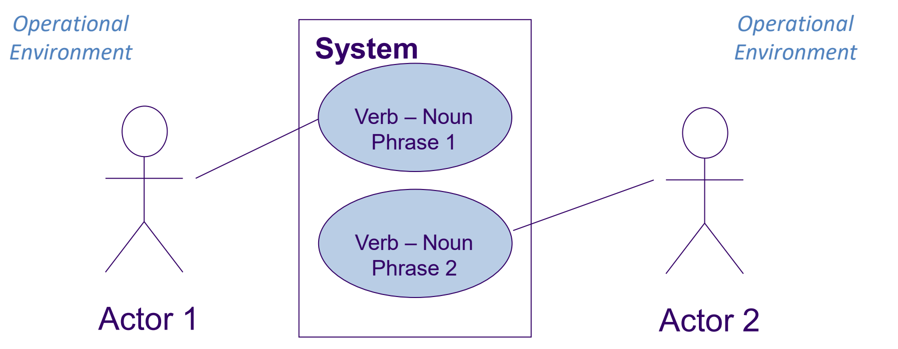
Base Use Cases: System Functionality
Syntax and Semantics of Interaction Model



(e.g. subject of verb)

(e.g. object of verb for service)

System Functionality is determined by what the system <u>does</u> ('verb').

Association lines identify interactions between the System and Actors.

[1] **Each use case is a relation that conforms to the interaction type. It is the collection of use cases that forms a structure.**

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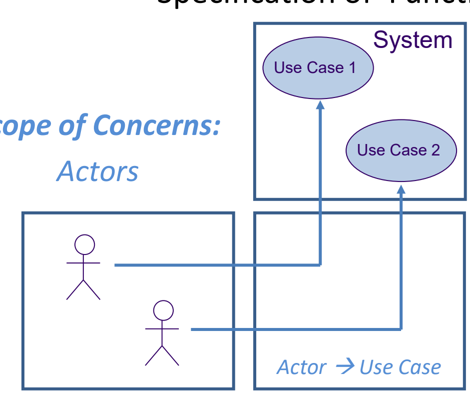
Application to System Definition:
System Interactions with its Environment

Specification of Functionality



Scope of Concerns:

System boundary
Use Cases

Scope of Concerns:

Actors

Transformation Rules:

Association based on Interactions

User Needs

In the Tutorial, the actors were the Aircraft and Airport.

Semantic transformation is the basis of a Use Case Diagram that is a graphical model of functionality.

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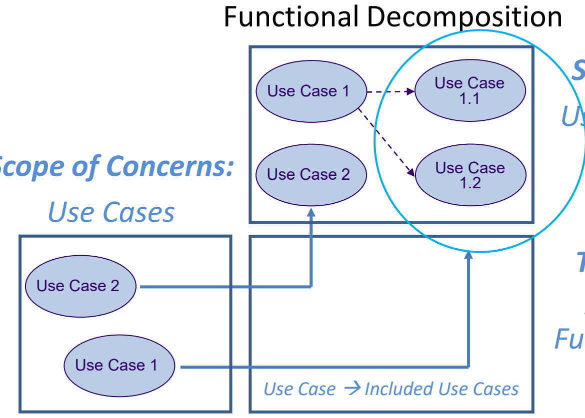
Application to System Definition:
Decomposition of Use Cases (1st level Hierarchy)

Functional Decomposition

Scope of Concerns:

Use Cases



Functionality

Scope of Concerns:

Use Cases, Inclusions

Transformation Rules:

Association based on Functional Decomposition (use case inclusion)

In the Tutorial, the ATC Use Cases were Provide ATC Service and Control Air Traffic.

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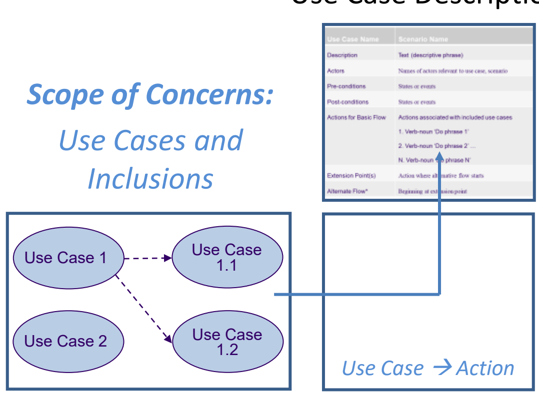
Application to System Definition:
This completes the sequence of transformations.

Use Case Description

Scope of Concerns:

Use Cases and Inclusions



Functional Decomposition

Scope of Concerns:

Actors, Conditions, Actions, Basic Flow; Extension Points, Alternative Flows

Transformation Rules:

Association of Actions, Basic Flow with Use Cases

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Activity Diagram: System Behaviour*

Syntax and Semantics of Activity Flow and Partition

Name (use case; scenario)

Actor(s) (relevant to scenario)

Pre-conditions

Actions (basic)

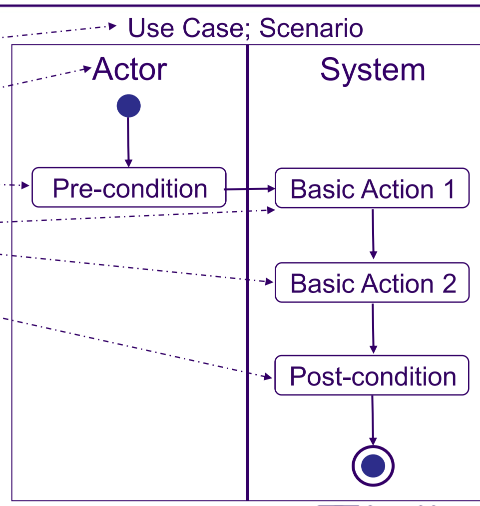
Post-conditions

Based on analysis, the need can be determined for:

Extension Points

Alternative Flow

The descriptive text can also be included.



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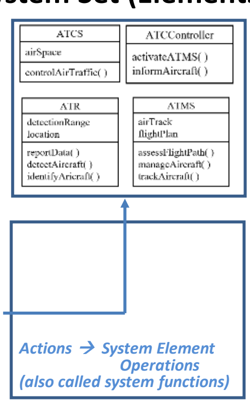
*This interpretation of the table realises an *Essential Model* of the System.

System Structure Model (1 of 2)

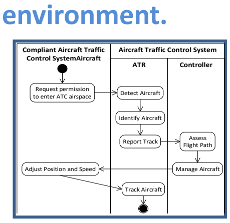
System Elements (White Box)

System Set (Elements)

A system **is a set of interrelated elements that comprise a whole, together with an environment.**



Scope of Concerns: System Elements and their Operations



Activity Model

Transformation Rules: Functional Allocation

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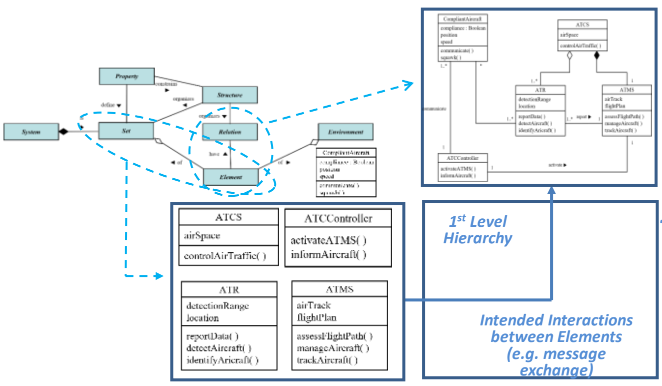
System Structure Model (2 of 2)
Interactions of the System Elements

Class Diagram



System Set (Elements)

Scope of Concerns: System Elements and Interactions

Transformation Rules:

System Hierarchy
Message Exchange

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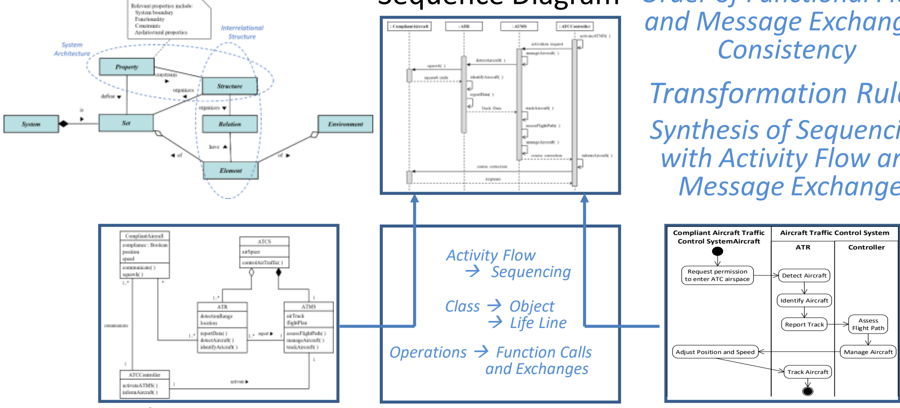
The Essential System Architecture
(Implemented in an Interrelational Structure)

Essential Sequence Diagram



Class Diagram

Activity Diagram

Scope of Concerns: Order of Functional Flow and Message Exchange, Consistency

Transformation Rules: Synthesis of Sequencing with Activity Flow and Message Exchange

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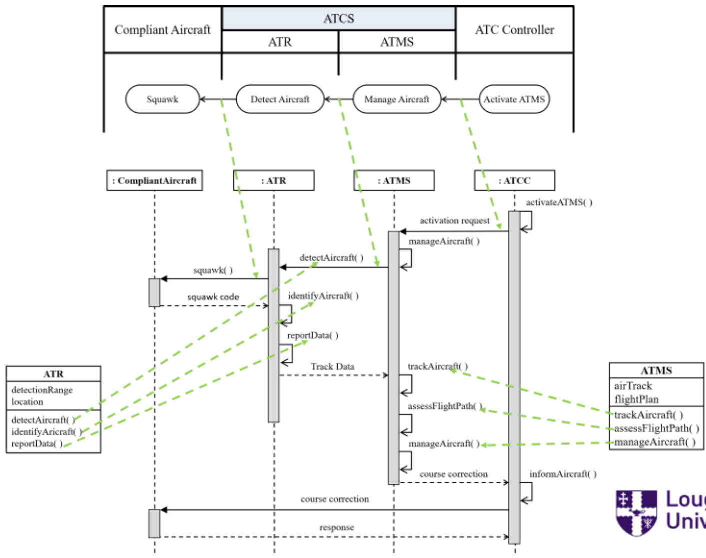
Example of Synthesis from Tutorial II



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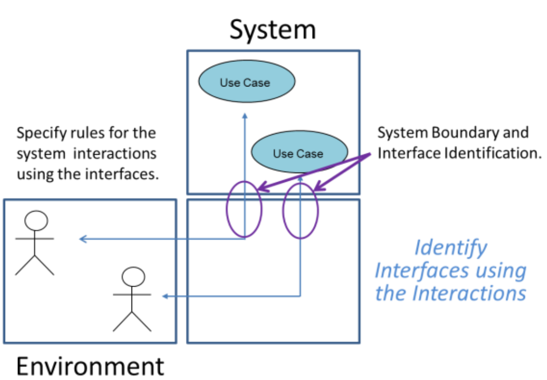
Interface Definition Based on *System Interactions with its Environment**



Define interfaces for using the exchanges between the system elements (objects) in the sequence diagram.

**This also applies to every system element; in which case the environment can include other system elements.*

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Model Specification and Transformation for System Architecture and Design

Key Concepts

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Definition Processes

Structured Methods

Wrap up

Essential System and Architecture Definition are an Implementation Structured Analysis and Design.

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Critical Analysis of Model Driven and Model Based Systems Engineering

INCOSE[1] regards MBSE as formalised application of modelling to
- System Requirements
- Analysis and Design
- Verification & Validation

At the end of the twentieth century [2] the uptake of …
- Formal and mathematical expressions of systems was limited
- Less formal more intuitive graphical languages was beginning.

Now, after more than two decades of commercial development,
- Graphical languages and tools are entering a second generation
- Methods have not been broadly adopted; specialised scripts are used.
- Authoritative demonstrations of the business case are lacking.

[1] *This has been the INCOSE position for a number of years.*

[2] *EA&PSE Chpt 1.2.1, 1.2.2*

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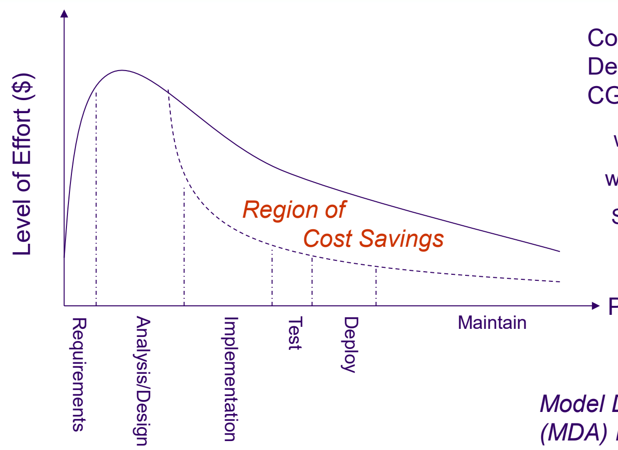
MDA Cost Savings over Program Life

Codagen Testimonial to OMG



Codagen Testimonial on Development Costs for CGI Program:

w/o MDA $8.073M

with MDA $5.475M

Savings $2.598M (32%)

Model Driven Architecture (MDA) is an implementation of Structured Analysis and Design.

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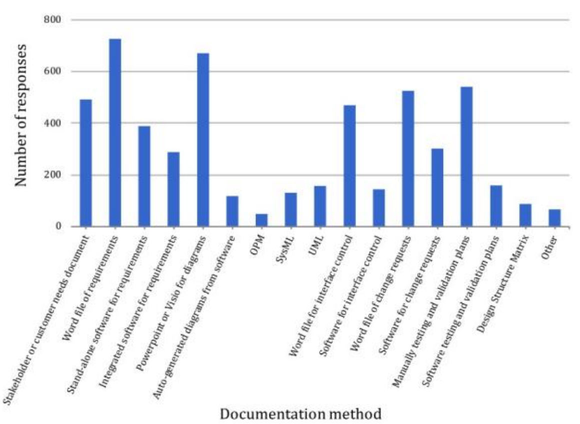
Counterpoint to Argument of Benefits

Commercial usage in companies of post-graduate students



Note that the survey only reflects usage of method at the student's company.

Reasons for usage and attendance of postgrad study were not analysed.

Source: Cameron and Adsit, MBSE Uptake in Engineering Practice, *IEEE Transactions on Business Management*, Feb 2020

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[1] Recall that Steve Jobs recommended that [architecture and] design should engineer software and hardware concurrently.

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This is the end of the beginning of your postgraduate study of Model Based Systems Engineering

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