WS72 Systems Architecture

Standards and Technical Processes II: Architecture Definition

Lecture 12

Loughborough University

1

The Essential Idea
A definition process is based on a definition.

- The essential technical definition processes use precise definitions to model and reason about concepts:[1]
    - Models are interpretation of language into a structure, e.g.
        - Sentences can be interpreted into structured language, or
        - Interpreted into the graphical structure of a UML diagram
    - A class diagram can be used to model a definition
- Precise definitions must be used for Architecture Definition [2]
    - A precise but practical definition of *architecture* is needed
    - A logical model will be the basis of the *definition process*
    - Concepts are interpreted from a *domain of discourse*

[1] This idea was introduced in lecture [2] and used for system specification.
S&TP I used the ISO definition of *system*.
[2] S&TP II will use the essential definitions of *system* and *architecture*.
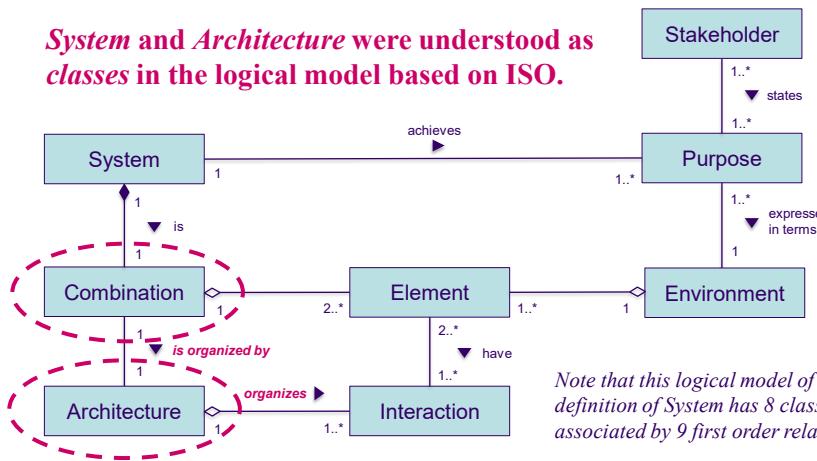
Loughborough University

2

2

Architectue Definition: Logical Model of *System*
Relationships of architecture in the ISO definition

System and *Architecture* were understood as *classes* in the logical model based on ISO.

Stakeholder

1..*
▼ states
1..*

System ——— achieves ▶ ——— Purpose
1   1..*

1
▼ is
1

1..*
▼ expressed
in terms of
1

Combination ◇——— Element ———◇ Environment
1   2..*   1..*   1

1
▼ *is organized by*
1

2..*
▼ have
1..*

Architecture ◇— *organizes* ▶ — Interaction
1   1..*

Note that this logical model of the ISO definition of System has 8 classes that are associated by 9 first order relationships.

*Associating '**organize**' with 'combination' and with 'interaction' shows the holistic role of architecture in the concept of system.*

Loughborough University

3

3

Standards and Organisations

Relevant standards managed by OMG include:
- SysML – a general-purpose graphical modelling language for specifying, analysing, designing systems.
  SysML v1.0 (2007), SysML 2.0 (2023)
- MDA – a modelling approach to software development:
  MDA 1.0 (2001), MDA 2.0 (2014)

Relevant standards managed by ISO include:
- 15288 – System and software life cycle processes
- 24641 – Methods and tools for MBSE
- 24707 – Logic based languages

MDA   Model Driven Architecture

SysML Systems Modeling Language

MBSE Model Based Systems Engineering

Loughborough University

4

4

Structure of Processes

Key Concepts

Models of Definitions

Interpretation of Concepts

Second Order Relations

Key Topics

Context and Critical Analysis

Definition Processes

Specification of Structures
and Integrated Processes

Definitions of Terminology

Loughborough University

Historical Summary of Architecture & MBSE
Refer to Essential Architecture and Principles, Chpt 1

1.1 Brief History of Architecture
- OMG Model Driven Architecture (MDA)   Adopted by OMG

1.2.1 Early History of MBSE
- Tarski   Adopted in ISO/IEC 24707
- Yourdon   Commercialised (for example, in OMG MDA)
- Wymore   Influential (especially on OMG SysML)
- Lin and Ma   Important (as a mathematical basis for MBSE)

1.2.2 Recent History of MBSE
- INCOSE OOSEM   Influential (as a method for using SysML)
- JPL State Analysis   Practiced (e.g., by NASA)
- IBM RUP   Commercialised
- OPM   Adopted in ISO/PAS 19450

SysML Systems Modeling Language   OOSEM Object Oriented SE Methodology
RUP Rational Unified Process
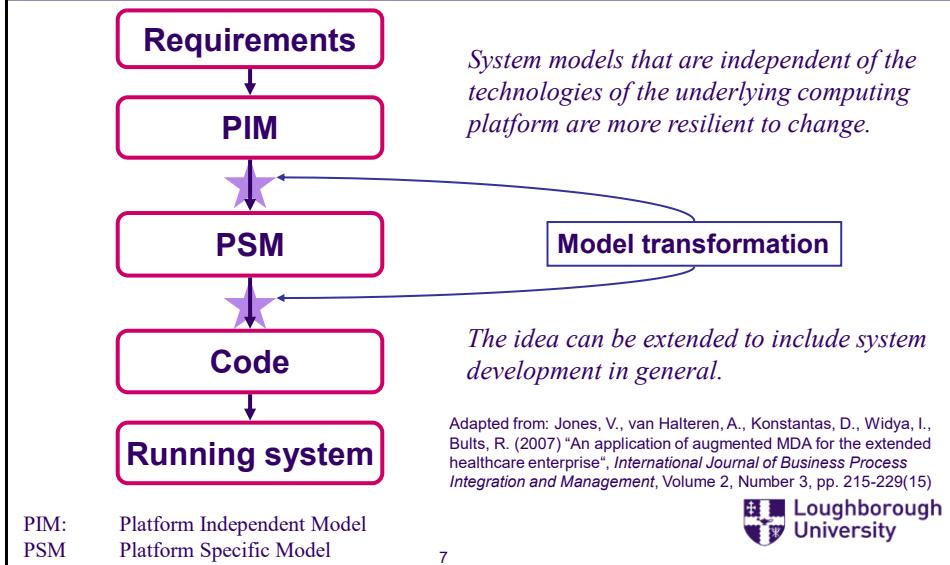
Loughborough University

OMG Model Driven Architecture (MDA)
Original Idea: an architecture for software development

Requirements

↓

PIM

★

PSM ← **Model transformation**

★

Code

↓

Running system

System models that are independent of the technologies of the underlying computing platform are more resilient to change.

The idea can be extended to include system development in general.

Adapted from: Jones, V., van Halteren, A., Konstantas, D., Widya, I., Bults, R. (2007) "An application of augmented MDA for the extended healthcare enterprise", *International Journal of Business Process Integration and Management*, Volume 2, Number 3, pp. 215-229(15)

PIM: Platform Independent Model
PSM   Platform Specific Model

Loughborough University

7

7

Business Benefits and Contentions about MDA and MBSE

- In addition to resilience of the PIM, MDA claims include
  - Improvements to design quality and configuration control
  - Life cycle cost savings for software development
- Both MDA and MBSE claim improvements over legacy document-based approaches* to development.
- But a survey of MIT post-graduate online students has indicated document-based approaches* are more popular
  - The survey indirectly implies the need for both approaches
  - The students were mostly mechanical engineers whose companies did not have an MBSE process in place

MDA   Model Driven Architecture

MBSE Model Based Systems Engineering
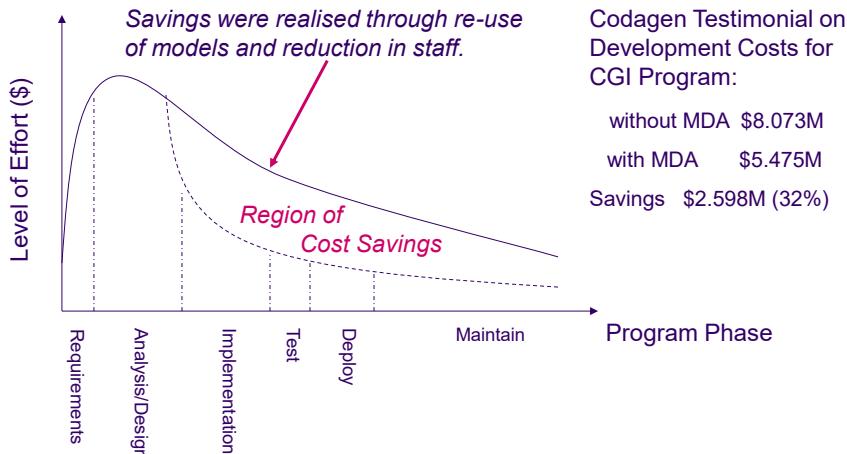
PIM   Platform Independent Model

*Such as textual documents and spreadsheets. Refer to the Counterpoint graph, Slide 10.

Loughborough University

8

8

MDA Cost Savings over Program Life
Legacy Codagen Testimonial to OMG

Savings were realised through re-use of models and reduction in staff.

Level of Effort ($)

Region of Cost Savings

Requirements

Analysis/Design

Implementation

Test

Deploy

Maintain

Program Phase

Codagen Testimonial on Development Costs for CGI Program:

without MDA $8.073M

with MDA $5.475M

Savings $2.598M (32%)
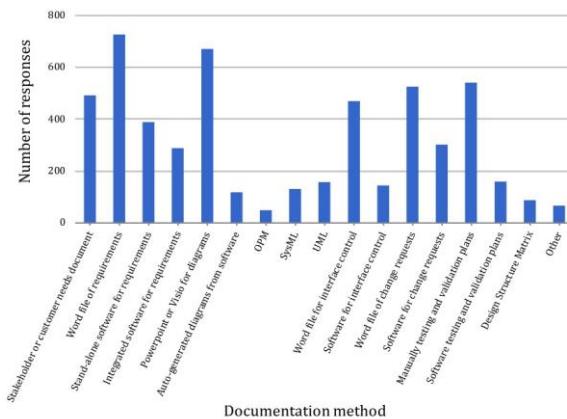
The benefits of MBSE should include similar savings in the tail of the spend profile i.e., implementation through maintenance.

Loughborough University

9

Counterpoint to Argument of Benefits
Commercial usage in companies of post-graduate students

Number of responses

800

600

400

200

0

Stakeholder or customer needs document

Word file of requirements

Stand-alone software for requirements

Integrated software for requirements

Powerpoint or Visio for diagrams

Auto-generated diagrams from software

OPM

SysML

UML

Word file for interface control

Software for interface control

Word file of change requests

Software for change requests

Manually testing and validation plans

Software testing and validation plans

Design Structure Matrix

Other

Documentation method

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

Reasons for usage were not analysed.

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

Loughborough University

10

Structure of Processes

Key Concepts

Models of Definitions

Interpretation of Concepts

Second Order Relations

Key Topics

Context and Critical Analysis

Definition Processes

Specification of Structures
and Integrated Processes

Definitions of Terminology

Loughborough University

11

Key ISO 15288 Technical Processes
Architecture and Design Definition

- *System Requirements Definition**
  Transforms stakeholder and user requirements into a technical view of the system.

- *Architecture Definition**
  Defines architecture alternatives and final selection. Architecture must be defined at a sufficient level of detail to enable Design.

- *Design Definition*
  Defines system elements in sufficient detail to enable implementation.

- *System Analysis*
  Supports the technical processes with mathematical analysis, modelling and simulation to analyse performance, behaviour, etc.

*Parts of the system requirements process and parts of the architecture definition process have been referred to collectively as *System Definition*.

ISO: The International Organisation of Standards

Loughborough University

12

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 [2]
  - System decomposition

- Architecture Definition:[1]
  - Concept definition: theories about and properties of the system
  - Specification of structures into which concepts are realised [3]
  - Synthesis and normalisation of relations and interrelations

[1] These features have been distilled from ISO/IEC/IEEE 15288 and the essential definitions.
[2] The terminology of requirements provides descriptions but not precise definitions of any of the terms.
[3] i.e., interpreted into the structures

Loughborough University

13

13

Definition of Terms*

- Essential definition of System:

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

  A system is a pair of sets: (S, E) coupled by interrelations.

- 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.

  Architecture is a coupled pair: (Class of Structure, Properties).
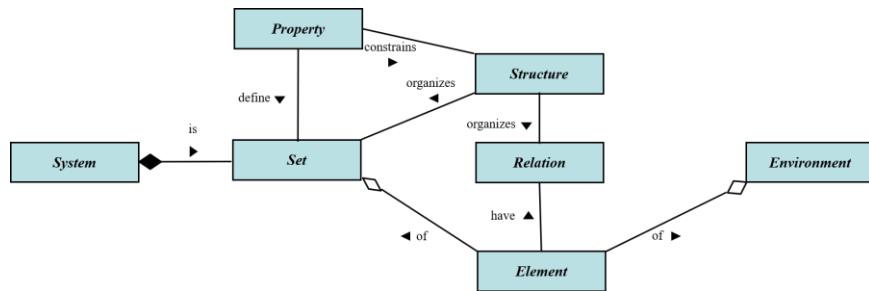
  These two definitions are mathematically based and have been normalized against each other.

*See *EA&PSE* Chpt 3 Sections 3.2.2 and 3.2.5 (pp. 27-28) for further details. The essential definitions will be used in this and subsequent lectures.

Loughborough University

14

14

Logical Model: *Essential Definitions of System and Architecture (integrated)*
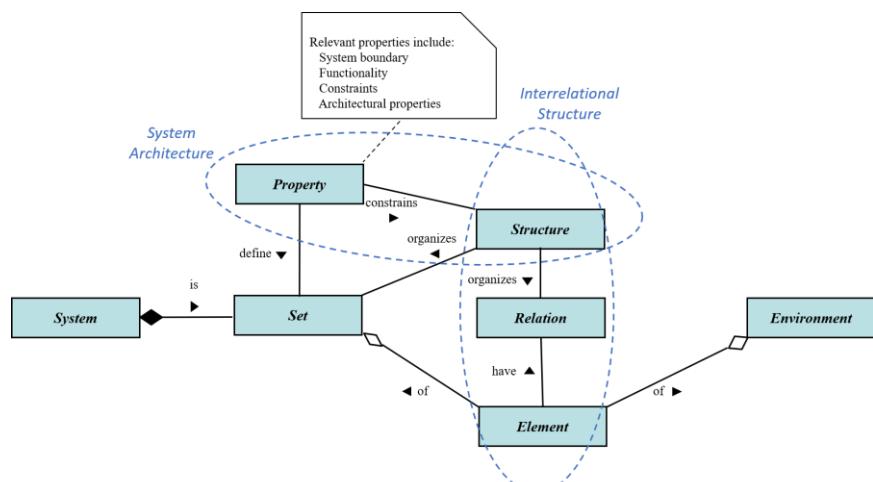
Refer to Figure 4.11, p.56 of EA&PSE.

Loughborough University

15

Logical Model: *Second order Nature of System and Architecture*

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

Loughborough University
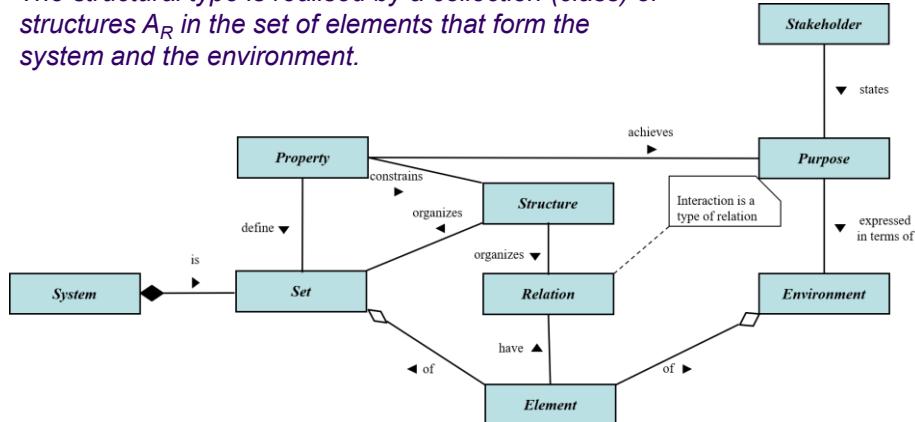
16

Logical Model of *System*
*Integrating ISO concepts with essential definitions**

The structural type is realised by a collection (class) of structures A_R in the set of elements that form the system and the environment.

*See *EA&PSE* Chpt 4 Section 4.5 (pp. 54-57), especially Figure 4.11.

**Loughborough University**

17

17
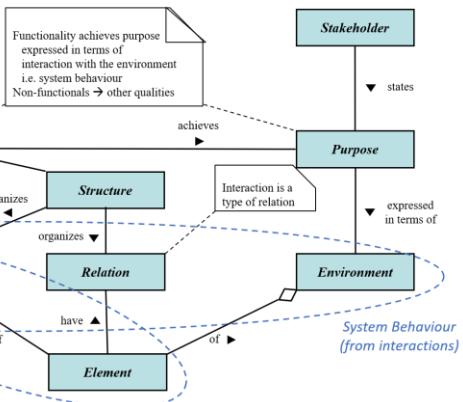
Using the Logical Model of *System*
Definition Processes in ETP I

The coupled pair of sets (S, E) establishes the system boundary.

Functional definition is based on interactions with environment.

System decomposition is based on 1st level system hierarchy.

ETP: Essential Technical Processes

Loughborough University

18

18

Structure of Processes

Key Concepts

Models of Definitions

Interpretation of Concepts

Second Order Relations

Key Topics

Context and Critical Analysis

Definition Processes

Specification of Structures and Integrated Processes

Definitions of Terminology

Loughborough University

Specifying Structures for Technical Processes:
*Model-based Architecture Definition process**

- Architecture Definition based on model theory defines:
  - A sequence of concepts (statements), $T = (T_0, T_1, T_2, \ldots, T_n)$
  - A sequence of structures, $A_R = (R_0, R_1, R_2, \ldots, R_n)$
  - 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.
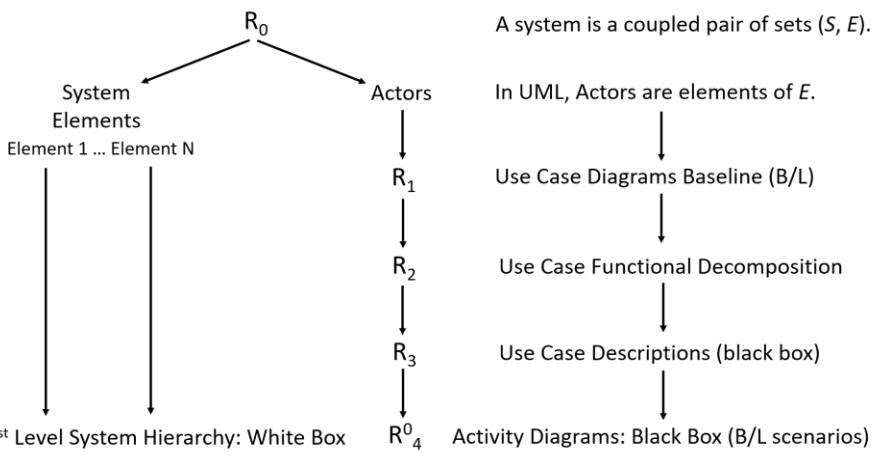
*Refer to Dickerson, Wilkinson et al., "Architecture Definition in Complex System Design Using Model Theory," in the *IEEE Systems Journal*, 2021.

Loughborough University

Structures for System Definition (S&TP I)
*One iteration through the definition process**

S&TP: Standards & Technical Processes

R_0

System Elements
Element 1 … Element N

Actors

A system is a coupled pair of sets (S, E).

In UML, Actors are elements of E.

R_1 — Use Case Diagrams Baseline (B/L)

R_2 — Use Case Functional Decomposition

R_3 — Use Case Descriptions (black box)

1st Level System Hierarchy: White Box R^0_4 Activity Diagrams: Black Box (B/L scenarios)

*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.

Loughborough University

21

21

Essential Technical Processes (S&TP) II, III
Structures for the Implementation Model: R_6, R_8, R_9

S&TP: Standards & Technical Processes

R_0

1st Level System Hierarchy:
Element 1 … Element N

R^0_4

A system is a coupled pair of sets (S, E).

Activity Diagrams: Black Box (B/L)

R_5 — Synthesised Activity Diagrams (B/L)

R_6 — Class (relation) Diagram

R_7 — Essential Sequence Diagram

S&TP III

R_9 : Interface Definition Structures R_8 Complete Sequence Diagram (R_7 with control)

*The results of S&TP I are black box activity diagrams for either the system elements, the system as a whole, or both. These must be synthesised into the R_5 structure. S&TP II then synthesises these with R_6 to form R_7 . S&TP III integrates Interface Definition.

Loughborough University

22

Structure of Processes

Key Concepts

Models of Definitions

Interpretation of Concepts

Second Order Relations

Key Topics

Context and Critical Analysis

Definition Processes

Specification of Structures
and Integrated Processes

Definitions of Terminology

Loughborough
University

OMG MDA Terminology and Concepts

- View and Viewpoint
- Platform
- Independence
- System Specification
- Model Transformation

Loughborough
University

MDA Terminology: View and Viewpoint

- A *viewpoint* on a system is a technique for abstraction using a selected set of
  - Architectural concepts and structuring rules
  - To focus on particular concerns within that system.
- The term *abstraction* is used to mean the process of suppressing selected detail to establish a simplified model.
- A *viewpoint model* or *view** of a system is a representation of that system from the perspective of a particular viewpoint.

*The definition in the MDA Guide V1.0.1 is based on IEEE 1471.

Loughborough University

25

25

MDA Terminology: Platform, Independence

- The terminology and description of the MDA^{TM} that follow are from the MDA 1.0 Guide.

- A *platform* is a set of subsystems and technologies that provide a coherent set of functionality through interfaces and specified usage patterns*.
- *Platform independence* is a quality that a <u>model</u> may exhibit, where the model is independent of the features of the platform.

*The definition in the MDA Guide V1.0.1 goes on to require that any application supported by the program can use [the subsystems and technologies] without concern for the details of how the functionality provided by the platform is implemented .

Loughborough University

26

26

MDA Terminology: Viewpoints

- *Computational Independent Viewpoint*
    - Focuses on the environment of the system and requirements for the system
    - The details of the structure and processing of the system are hidden or as yet undetermined.
- *Platform Independent Viewpoint*
    - Focuses on the operation of a system while hiding the details necessary for a particular platform.
    - Shows that part of the complete specification that does not change from one platform to another.
- *Platform Specific Viewpoint*
    - Combines the platform independent viewpoint with an additional focus on the detail of the use of a specific platform.

Loughborough University

MDA Terminology: Views (Models)

- *Computational Independent Model (CIM)*
    - A view of the system from the computation independent viewpoint.
    - Does not show details of the structure of the system.
- *Platform Independent Model (PIM)*
    - A view of the system from the platform independent viewpoint.
    - Exhibits a specified degree of platform independence so as to be useful for use with a number of different platforms of similar type.
- *Platform Specific Model (PSM)*
    - A view of the system from the platform specific viewpoint.
    - Combines the specifications of the PIM with the details that specify how that system uses a particular type of platform.

Loughborough University

Terminology: System Specification

- Platform Model (PM)
    - A set of technical concepts, representing the different kinds of parts that make up a platform and the services provided by that platform.
    - Also specifies requirements on the connection and use of the parts of the platform, and the connections of an application to the platform.
    - A generic platform model can amount to the specification of a particular architectural style.
- Implementation
    - A specification which provides all the information needed to construct a system and to put in into operation.

Loughborough University

29

29

Model Transformation

- *Model transformation* is the process of converting one model to another model of the same system.
- An MDA *mapping* provides specifications for transformation of a PIM into a PSM for a particular platform.
    - The platform model will determine the nature of the mapping.
- Model transformation can be thought of as part of the design and development process.

*See for example *Model Driven Architecture with Executable UML*, Raistrick et al..

Loughborough University

30

30

Questions?

Loughborough University

31

Loughborough University

32